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Early detection and fighting of fires in belt conveyor

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E-mail: rtd-steel-coal@ec.europa.eu
RTD-PUBLICATIONS@ec.europa.eu

Contact: RFCS Publications

European Commission
B-1049 Brussels

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Ms Marta Fernández and Mr Ángel Rodríguez

Asociación para la Investigación y el Desarrollo Industrial de los Recursos Naturales

Margarita Salas 14, 28918 Leganés, SPAIN

Ms Joanna Pruchnicka

Centrum Badan i Dozoru Gornictwa Podziemnego SP Z.O.O. (CBiDGP)

Ul.Ledzinska 8, 43 143 Ledziny, POLAND

Mr Ulrich Hoischen

DMT Montan Technologie DMT GmbH & Co. KG

Am Technologiepark 1, 45307 Essen, GERMANY

Mr Piotr Wojtas

Centrum Elektryfikacji i Automatyzacji Gornictwa (EMAGPL)

ul. Leopolda 31, 40 189 Katowice, POLAND

Mr Jose Luis Peón González

Hulleras del Norte S.A. (HUNOSA)

Avenida de Galicia 44, 33005 Oviedo, SPAIN

Mr David Brenkley

Mines Rescue Service Ltd (MRSL)

Leeming Lane South, Mansfield Woodhouse, NG19 9AQ Mansfield, Nottinghamshire, UNITED KINGDOM

Mr Richard Cole

UK Coal Mining Ltd. (UKCOAL)

Blyth Road, Harworth Park, Harworth, UNITED KINGDOM

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1 FINAL SUMMARY

This chapter addresses the most significant aspects on a task by task basis addressing project objectives, results obtained and their usefulness, plus possible applications and patents.

1.1 WP1 – FUNDAMENTAL MECHANISMS OF CONVEYOR BELT FIRES

The objective of this work package was to establish the fundamental mechanisms behind the initiation and propagation of belt conveyor fires, as well as the characteristics and effects of the combustion products. The output of this WP formed the basis for the work developed within the remaining work packages. A specific goal was to identify the potential ignition sources in and around conveyors. This permitted the mechanisms behind fire propagation to be determined. This, in turn, led to a study of the influence on the above of other installations, materials and equipment present in the same roadway, to characterise the combustion process, including an estimation of fire load and characteristics of combustion products, and the effect of these combustion products on persons (including workers and local population) as well as on the environment.

1.1.1 Task 1.1 – Identification of ignition sources and their acting mechanisms

The focus of the work was on detailed and systematic investigations to identify as many ignition sources as possible for conveyor belt fires together with their acting mechanisms. The investigations were shared between the partners involved on a regional basis and information from outside Europe was also included.

Although the available data and time intervals under investigation were different, and the absolute values are therefore not comparable, the investigation still showed clearly showed that the main causes for conveyor belt fires are associated with failures in roller idler sets and bearings. A second big reason for fires is coal spillage.

Prevention of conveyor belt fires should therefore focus on this part of the installation. However, technical installations are never 100% safe. A certain failure risk will always remain. Investigations into fire prevention in conveyor installations need to address the whole system in order to guarantee maximum safety.

Apart from the ignition sources mentioned above, which are related to the conveyor belt installation itself, other flammable materials in the vicinity of conveyor belts can be found. Such materials, while being basically inert in terms of acting as a fire source, may under certain conditions, alone or in combination with other materials, act as sources of ignition for a conveyor belt fire.

In underground coal mining, flammable materials like wood, diesel fuel, mineral oil, hydraulic liquids, solid or liquid types of plastics, and plastic equipment can be found. Effects and incidents like smouldering coal dust, hot surfaces, burning liquids, electric arcs or welding beads and fire beads may qualify as sources of ignition.

In order to investigate the ignition behaviour of belts used in European underground mining, some tests have been carried out according to DIN EN 14973. This standard recommends tests representing different ignition energy levels. It was decided to make tests according to this standard in order to obtain comparable results.

The test showed that all test samples have the recommended properties for general application in underground mining. However, all samples can be ignited if they are exposed to high energy sources. The consequence of these test results is that high fire loads in the vicinity of conveyor belt installation should be avoided.

1.1.2 Task 1.2 – Mechanisms of conveyor fires propagation

The focus of the work was on identifying all materials in the vicinity of a conveyor system, by appraising the effect of their presence on the fire load and fire propagation and by carrying out tests to detect fire propagation behaviour in the presence of different materials and material combinations.

Fire tests according to standardised test procedures have been carried out in order to investigate the fire propagation behaviour of conveyor belt samples from three European countries. The different test procedures represent different fire loads simulating various additional fuel types in the vicinity of conveyor belt installations.

Possible causes of the varying intensity of fires in mine roadways have been highlighted. There are many and varied factors, indicating that there are many unanswered questions with regard to the causes. These factors need to be investigated and answers provided before possible solutions can be formulated to minimise the effect of these fires. There is therefore the need to carry out further investigation.

As to fire propagation, the Polish and German belt samples showed similar results considering the thickness of the cover plate respectively. Although we do not have any detailed information about the amount of flame-retardant included in the belt material, we assume that there are differences in the samples investigated. If this assumption is correct, the amount of flame-retardant is a factor influencing the fire propagation. It was also clear that rubber belts showed better characteristics than PVC belts when exposed to higher energy rates. Finally, the construction of the belt itself may also influence fire propagation.

As a consequence, it is not possible to characterise conveyor belts according to their fire propagation behaviour by carrying out only one of the test procedures outlined. Our investigations showed that a reliable characterization is only possible when results of tests according to all procedures (A, B, C and large scale) are available. Any future revision of DIN EN 14973 should take this result into account.

1.1.3 Task 1.3 – Investigations into combustion gases

This task aimed to identify and determine the concentration of the combustion gases produced by burning different types of conveyor belts used in underground mining. The tests were performed on rubber-fabric, polyvinyl chloride-rubber, and polyvinyl chloride belts. Studies were carried out in three types of research environment: micro-chamber (sample dimension: 8 x 8 cm), test chamber (sample dimension: 30 x 60 cm) and DMT gallery (sample dimension: 1.2 x 2.5 m). The tests were performed by the following methods: in–situ measurements, colorimetric, titrumetric, chromatographic, ICP and gravimetric analyses.

Polymers are used for the production of belt material. Included here are rubber, PVC, polyamide, and polyester separators. Therefore, the basic combustion products result from pyrolysis taking place in the process of thermal decomposition. In the case of the combustion of conveyor belts, oxygen plays an important role in the pyrolysis as it reacts with the group of lateral polymers that accelerates the formation of volatile products. Oxygen also influences the acceleration of the emission of HCl, the fluctuation of the type of pyrolysis products, and the increase in the level of their aroma.

The studies showed the differences between emissions of hazardous substances dependent on the belt composition. Obviously, it is necessary to generalize the results obtained and carry out modelling of the real conditions measured in a fire incident that will be the subject of further studies. Multiple results obtained in the studies carried out so far will allow an in-depth analysis and assessment of the materials used in belt production with the aim of reducing their health and environmental threat.

The magnitude of the emission of air pollutants is dependent on the fire characteristics (exposure to the air, type of burning material. i.e. the type of the belt) and the duration of the fire.

Taking into consideration all the observations and calculations, it is reasonable to conduct a proper fire prevention policy. In addition, in the case of a fire, fire fighting should be carried out without delay in order to eliminate the potential source of air pollution.

The analysis of the eluate related to the determination of content of such metals as: Ba, Cd, Cr, Cu, Hg, Mo, Ni, Pb, and Se indicate a very low content in the filtrate or even below the detection level. In the case of As, Sb, and Zn, indicated concentrations reached significant levels.

Due to the high concentration of heavy metals, the waste produced in the conveyor belt combustion threatens underground waters contributing significantly to their pollution.

1.1.4 Task 1.4 – Mathematical Modelling

At the start of the project, it was necessary to be able to predict the consequences of a conveyor fire and to assess the related risks before a fire is properly established. Therefore, mathematical modelling of conveyor fire was planned based on experiences obtained in previous projects and the results of the investigations carried out in this project. A model capable of predicting the situation in the case of a fire, under certain conditions, will significantly contribute to an improvement of safety of underground conveyor installations, as well as to underground safety in general.

If the material-specific parameters required for a fire simulation are available, then it is possible to use the Fire Dynamics Simulator (FDS) code as a method of determining the fire resistance of a conveyor belt during the development of a new conveyor belt. The required parameters can be determined, for example, by tests using a cone calorimeter. The big advantage of this method is the rather low amount of material required which helps the manufacturers of conveyor belts to reduce costs.

Knowing the material-specific parameters, large scale fire tests could be replaced by simulations prospectively. Ideally, manufacturers of conveyor belts could use the results of simulated fire tests to reduce development costs and the amount of time to develop a new conveyor belt. Furthermore, mining companies could evaluate their fire risks by using simulations. The influence of fire loads and ventilation could be ascertained numerically. Therefore, more fire tests have to be done to adjust the necessary parameters for FDS to the different conditions.

Test results showed that the influence of different ventilation conditions concerning the propagation of a fire should be analysed in more detail. Increasing the volume of the test facility showed more positive results for all conveyor belts whereas increasing the air velocity resulted in worse test results. The test results also showed the influence of the material from which the conveyor belt is made. The British conveyor belt was the only one made of PVC and showed a very different behaviour than the other conveyor belts.

Finally, it can be postulated that the results of the simulated fire tests reproduced the test results of the real fire test very well. With some further research, simulated fire tests may become an essential part for a prospective analysis of the properties of newly constructed conveyor belts even before testing them in real fire tests. However, simulated fire tests are not currently able to replace real fire tests for the certification of conveyor belts.

1.2 WP2 – PREVENTION: ASSESSMENT OF DEVELOPMENT POSSIBILITIES OF (AUTOMATED) CLEANING AND DUSTING EQUIPMENT

The objective of this work package was to develop cleaning equipment, possibly automated, to facilitate local removal of carbonaceous material build-up, as well as of the development of plant to rapidly and evenly deposit stone dust in roadways. Specific goals were to:

- Establish the mechanisms behind spillage and build up of coal-dust deposits.
- Prepare the functional specifications of an automated de-dusting and an automated inertization unit.
- Prepare the manufacturing drawings for small scale models of the above machinery.
- Build and test small scale functional models.

1.2.1 Task 2.1 – Spillage and coal-dust buildup mechanism

It is well known that is better to prevent fires than deal with them, therefore the main work in Task 2.1 was to establish the basis for prevention, focusing on the study of the structure of conveyor belts, the characteristics of the coal dust accumulation, and the maintenance of belt conveyors. Details of the work in this task can be found in the report related to Deliverable D2.1.

Spillage and coal-dust build up quite naturally in certain locations around belt conveyor, for reasons dependent intrinsically on the configuration and operating principles of the transport system. These layers are considered to be a source of hazard, which, under certain conditions, analysed in WP1, may be the cause of a fire. The main goal of this task was to understand the mechanisms behind the accumulation of coal dust and spillage (that is, how and where coal dust is accumulated) and what characteristics these accumulations have. This issue was tackled by analysing the design of the belt conveyor and specifically of its driving drums and transfer points, which are considered the points more prone to these accumulations.

The causes of spillage and coal dust accumulations, such as conveyor belt mistracking and transfer points, have been studied in more detail. Other activities carried out in this task were the study of cleaning conveyor belt devices, components that improve performance of the conveyor system and the maintenance of conveyor belts.

This first analysis was the basis for designing and implementing on-line dust-prevention characteristics in conveyors, as well as for the following tasks in this Work Package.

1.2.2 Task 2.2 – Automated de-dusting plant

The main goal of this task was to prepare the specification of a machine or device for de-dusting; that is, for the elimination or reduction of dust accumulations in the vicinity of belt conveyors, since the coal can spontaneously combust. When coal is discharged from the conveyor, usually small amounts of coal escape from the conveyor as spillage or airborne dust.

Several techniques have been studied and some of them are being implemented manually in some collieries at the UK. However, it was determined that de-dusting the material accumulated below a conveyor belts requires a capacity that can only be achieved using a back digger based articulated arm.

A more dynamic solution was the development of a mechanism that collects the material dislodged from the conveyor belts and returns it to the conveyor or deposits in another place for easy collection. Rather than just a de-dusting machine, it would be a cleaning/coal-recovering device. By minimizing or eliminating completely the accumulation of coal below conveyors, on conveyor belt parts, and along the conveyor line, the risk of fire hazard would be decreased.

After several analyses and concept prototypes, a scaled prototype was designed and built for laboratory tests. The three degrees-of-freedom arm has a cleaning tool that collects the coal dust below the conveyor belt.

1.2.3 Task 2.3 – Automated inertization plant

Initially, an examination of the current inertization techniques was studied. Manual spreading using a stone dust named Fosforin is the most commonly used inertization technique at the HUNOSA facilities. UK Coal Mining has a number of automatic/semi-automatic inertization systems/plants in use at its mines. These vary from very simple bin type blowers to large volume piped systems. Some mines have semi-automatic systems that are vehicle mounted with automatic spreaders. A brief description of the different techniques was presented.

The goal of this task was to produce the specification of a machine or device for coal inertization, by spreading inertization agents (or stone dust) along roadways where the belt conveyors are installed.

An inertization device was developed to eliminate the risk of combustion of the dust accumulated along the conveyor belts inside coal mines. A requirement was that, irrespective of what automated devices are used to spread the rockdust in coal accumulations, an operator should still be able to manipulate the hose manually. But given that this accumulation may be found all around conveyor belts, it was necessary to develop a device which could permit this task to be carried out periodically by the mining companies.

The inertization device is based on the same mobile platform as the de-dusting device, the back digger ZITRON PRZ-330. The concept design consists on a multi-joint mechanism that may give an operator the ability to reach dust accumulations under or over the conveyor belt or in any other parts of the mine where a railroad is available. A scaled prototype was implemented for lab testing purposes and its conclusions are described on T5.1.

1.3 WP3 – EARLY DETECTION: INVESTIGATION OF ADVANCED DISCRIMINATING FIRE DETECTORS AND THEIR APPLICATION

The objective of this work package was the investigation of early detection of fires on conveyor belts, through the study of fire detection technologies, and the development of measurement devices and methods for detecting incipient fires in underground coal mines. Specific goals of this WP were the following:

- measuring fire signatures and point detector responses with a view to developing an advanced discriminating fire detector capable of the early detection of fires on conveyors;
- analysis and tests of various types of sensors for detection of products of combustion emitted from a fire source;
- test characteristics of an integrated merged visual-IR image fire detector within visual and infrared radiation of an object to be monitored;
- development of wireless heat detectors for temperature monitoring of conveyor belt elements.
- high reliability signal processing in a multi-sensor device for early fire detection; structure, technical documentation and manufacturing of a multi-sensor device conformity with ATEX requirements.
- location of fire detector devices along conveyor routes to provide effective fire detection;

1.3.1 Task 3.1 – Measurement of fire signatures and point detector response

An appraisal of the state of the art in fire detection was carried out to identify technologies for the early detection of incipient fires on conveyors. MOS sensors were found to offer low cost and low maintenance overhead but have not been used extensively in the European mining industry.

An experimental evaluation was carried out with the result that MOS sensors are recommended for possible use in the multi-sensor device that was developed in T3.5.

1.3.2 Task 3.2 – Development of a merged visual-IR image fire detector

Activities carried out consisted of constructing a bespoke belt conveyor test frame and conducting a series of tests using merged visual-IR thermal imaging technology to detect heat from the rollers/idlers. The tests were carried out in a controlled environment, using different heat sources and lighting conditions. The main purpose of this work is to examine the feasibility of merged visual-IR technology as a means of early fire detection on belt conveyors in coal mining.

The tests confirmed good detection of heating points which may be a source of fires in belt conveyors. The tests showed that this equipment would be suitable for portable use as well as in a permanent installation.

1.3.3 Task 3.3 – Application of low cost wireless heat detectors

The goal of this task was the development of a communication infrastructure using wireless transmission technologies for the early detection of fires in conveyor belts as well as the temperature sensor elements needed for the monitoring of heat sources along conveyor belts.

Activities in this task were focused on the analysis of the key points in order to achieve a reliable monitoring method capable of detecting dangerous temperature increments along conveyor belt transportation systems, and consequently, possible fire sources. The monitoring system has always been based on using discrete temperature sensors, wireless as data transmission media and low cost devices.

One key in the integration of a communication infrastructure using wireless transmission is the number of temperature sensor elements needed for the monitoring of hot spots.

Even though heat sensors can be used for the early detection of fire, experience has shown that other types of sensors (CO and smoke detectors) could provide better results. Hence, temperature detectors should be treated as auxiliary devices that will control critical elements of the conveyor construction. Additionally, to work as a warning and signalling device, they would also serve as a method to help identify the cause and the location of a fire.

The placement of temperature sensors have to be close to the elements of belt conveyor construction which are especially a risk of damage. It was considered that critical elements which should especially be monitored using heat point detectors are (i) tail pulleys, (ii) head pulleys, (iii) bend and take-up pulleys, (iv) transfer points, (v) loading and discharge points and (vi) hydraulic and electrical devices. The ideal situation for the temperature heat point detectors would be to install them on each idler in both sides, but this would lead in a high cost system, even when the wireless heat point detectors are low cost itself. A lower cost solution would be to place the heat detector every 5-10 m, alternating the location of the detectors in both sides.

1.3.4 *Task 3.4 – Development of signal processing and guidelines (layouts) of a multi-sensor meter for fire detection in belt conveyors*

The task aimed at development of a method of signal processing and principles of location of multi-sensor devices along belt conveyor routes. Tests of temperature increments at selected constructional elements (potentially dangerous as a reason for fires) on belt conveyors were carried out. Using both flame resistant and non-flammable belts in mines, which produce various substances during their thermal decomposition, belts were heated to various temperatures to determine the products emitted. These tests and research work were the basis for the selection of the following detectors: carbon monoxide (CO), hydrogen cyanide (HCN), smoke and temperature increment.

The research work was used for the development of a method of fire detection by means of fire indexes: (i) index averaging measuring results from various sensors (physical method); (ii) "Fuzzy Logic" index; (iii) temperature increment at selected elements along a belt conveyor.

On the basis of the tests carried out in the laboratory and in the experimental adit, the time-spatial distributions of individual volatile fire products along conveyor routes were developed, thereby allowing the lay-out of sensors for the best fire protection to be determined.

1.3.5 *Task 3.5 – Development of a multi-sensor meter and its tests and trials*

The goal of this task was the development, construction, and testing of a multi-sensor device. The developed device consists of:

1. multi-parameter sensor DWP-1 (CO, HCN) – the main sensor;
2. temperature increment sensor CPT;
3. micro-processor smoke detector MCD-1.

Other types of sensors (e.g. Figaro) were also tested in the laboratory to determine their potential use in a multi-detector device. The following tests were carried out:

- measuring characteristics;
- accuracy and repeatability of measurements;
- response dynamics;
- operation within hazard monitoring systems;
- products of heating belt samples.

The approval tests were made by the notified certification body Barbara of the Central Mining Institute and ATEX No KDB 10ATEX142 was obtained.

The temperature increment sensors CPT and the micro-processor smoke detectors MCD-1 are connected to the inputs of the multi-parameter sensor DWP-1.

The multi-parameter sensor DWP-1 makes measurements of products (like carbon monoxide and hydrogen cyanide) emitted during heating flame resistant and non-flammable belts. The smoke detector MCD-1 is sensitive to volatile particles of thermal degradation of different types of belts. The temperature increment sensor CPT consists of several temperature detecting elements which control a temperature of belt construction. The increase in temperature of any detecting element over the set temperature increment in relation to ambient temperature will signal a fire hazard.

Software and control systems for multi-detector device were developed to realize the method of fire detection developed in the Task 3.4.

1.4 WP4 – FIRE FIGHTING AND MANAGEMENT: APPLICATION OF VENTILATION CONTROL AND INERTISATION TO MANAGE AND SUFFOCATING CONVEYOR BELT FIRES

The main goal of this work package was the development of specific methods and tactics for controlling, confining and fighting fires in conveyor belts, with a scope ranging from ventilation control to inertization and firemen protection. Specific task-related summaries follow.

- To determine the ways of application of ventilation for limiting gas and smoke expansion during fires in conveyor belts (especially in miners workplaces), developing new control algorithms.

- To establish the possibility of using inertization techniques for suffocating belt conveyor fires, and the plant and methods needed for carrying out this operation.
- To develop specific hardware and software for controlling the ventilation applying the above algorithms, including general connections to mine's SCADA and environmental control system.
- To develop local fire-fighter thermal environment management techniques based on water sprays or water mists to ensure that access roadways are available and protected from excessive heat build-up. These measures will enhance the personal safety of firefighters and possibly extend considerably their safe working time at the fire location.

1.4.1 Task 4.1 – Fire fighting and containing through ventilation control

This task was concerned with research into ventilation network structures in underground coal mines and the application of ventilation systems to determine the spread of gas and smoke during conveyor belt fires.

The development of new algorithms for ventilation control during a fire was assessed. First, the characterization of the early development of the fire (i.e. when a flame has not yet been produced) was analyzed. Emission of smoke, gases and heat does not change the density of the air flowing out from the centre of a fire, and therefore, the air distribution in a ventilation network can be calculated on the assumption of constant air density. If the location of the ignition is possible, the determination of the direct smoke zone and escape routes can be calculated. The opposite problem was considered as well: based on the data obtained from smoke detectors and by the use of pre-prepared accessibility matrixes, it is possible to determine the branch where the fire started.

The investigation continued with the development of the algorithm for the second stage of a fire (i.e. where the emission of smoke is intensive enough to change significantly the density of air flowing out from the centre of a fire), the final part of which was reported under task 4.3 and included in deliverable D4.3.

The definition of fire escape rules and emergency planning for safe evacuation of personnel during fire hazards were studied.

The influence of heat flow on ventilation, particularly the potential for air flow inversion, was also assessed.

1.4.2 Task 4.2 – Other firefighting methods

A test rig was developed to investigate the novel use of chemical agents in spray mist form to combat spontaneous combustion fires. The aim was to extinguish fires without the generation of water gas (hydrogen and carbon monoxide) which are potentially explosive and which can be generated when using pure water sprays. Although pure water was the most effective at extinguishing fires, hydrogen was given off. However, by using either a 100% sodium silicate solution or a 75%:25% mixture of sodium silicate and hydrochloric acid, no hydrogen was detected.

Other initiatives involved (1) the use of a synthetic foam concentrate to effectively and reliably extinguish fires in coal mine, (2) the use of waste to fill the voids around a fire area to totally prevent the fire continuing or spreading, and (3) the use of explosion-proof dams to isolate the region containing the fire. The conclusions of water mist tests obtained under the ECSC project Fire Fighting Systems were also reviewed.

Backfilling and grouting techniques for firefighting have been studied and described. The use of underground mining technologies, which allows the utilization of waste, offer additional advantages in the form of reduced environmental impacts of these industrial processes, where considerable waste has been generated.

In most fires and without any possibility of active suppression, there is a need for the insulation of a region (with the fire inside) though the application of fire dams (having explosion-proof construction). The damming of fire fields has been studied under this task.

1.4.3 *Task 4.3 – Implementation of control algorithm*

The continuation of the work started in Task 4.1 regarding the algorithm for the second stage of a fire was transferred to T4.3. The mathematical model of a fire in a mine gallery (especially one with longitudinal ventilation) is similar to that of tunnel ventilation during a fire or of a fire in any compartment with one horizontal dimension significantly larger than others and with one opening – i.e. a door. To be applicable to mining, though, several additional assumptions were included in the model.

This task also defined the functional specifications and the interaction between the applications involved in a mine ventilation management system. The system was designed according to open standards in order to facilitate its integration with any SCADA (Supervisory Control And Data Acquisition). For this purpose an OPC Server application for communication with ventilation network software and a SCADA system has been developed.

Simulations of smoke distribution in a ventilation network during a conveyor belt fire were carried out. Simulation of air distribution in the excavations of air under the influence of the main fans was performed for a given model. This was done using AERO software which is based on the cross iteration method. In the same way the working points of the main fans were obtained.

1.4.4 *Task 4.4 – Review of heat strain potential and mitigation options*

Issues of the exposure of personnel to radiative heat sources and the potential of personal cooling systems were studied. Excessive exposure to heat can inflict heat related illness (hyperthermia), skin burns and burns in the respiratory tract. Detrimental effects are exacerbated by increases in the moisture content of the air, of the clothing ensemble, and by high activity. Recommended maximum air temperatures and radiation levels, consistent with the safety of fire fighters in tunnels, were obtained. In studying options for personal cooling systems, it was concluded that the effect of cooling garments or other personal equipment was likely to be modest and, accordingly, the more substantial approach advocated in Task 4.5 was called for.

1.4.5 *Task 4.5 – Protection of fire fighters using water mist techniques*

The theoretical requirements of the water mist equipment were studied. It was recognised that the ideal droplet size would be a compromise in order both to penetrate a zone of high temperature gasses and to provide adequate cooling while minimising the volume of water.

A gallery was equipped with temperature and humidity sensors along its length. Gas burners simulated a fire and an air flow was established to simulate mine ventilation. The spray equipment was pressurised and was used with three different nozzles each of which was tested at three pressures. Significant temperature reductions – sufficient to maintain the body temperature of firefighters below that at which it becomes stressed or life-threatening – were demonstrated for a substantial period of time and the results allow the correct choice of nozzle type and pressure to be selected for a range of scenarios.

Favourable results led to the production of a prototype portable unit capable of providing an effective cooling mist for a period of around one hour.

1.5 WP5 – FIELD TESTS

WP5 comprises the activities related with the integration tests and trials under real or near real operating conditions of the systems, devices and software developed more or less independently in the previous Workpackages. These tests combine the efforts of coal producers and research institutes to trial the apparatus and systems developed in the project. Therefore the goals of this WP were:

- Appraise the performance of small scale prototypes.
- Perform the final integration of the systems developed in the project
- Carry out field tests of all systems and devices
- Health risk assessment in real conditions.
- Critically assess of the results obtained in the project and extract conclusions.

1.5.1 Task 5.1 – Test of small-scale machine prototypes

The goal of this task was the implementation and testing of small-scale machine prototypes for de-de-dusting and inertization, designed and developed within WP2. Additionally, a scaled conveyor belt was built in order to simulate the behaviour of the prototypes in real infrastructures.

According to the description made of the small scale de-dusting prototype and the scale inertization unit, these machines were tested through different experiments in lab conditions to verify the behaviour of the concepts and to test the dimensional functionality.

From the test performed with the de-dusting prototype, it was determined that the dust is collected better when using the vacuum device, which solves the problems encountered regarding to: (i) the pickup of the collected dust from the blades and (ii) the transportation of the material to a wagon or over the main conveyor belt again.

For the inertization device a couple of spraying techniques have been tested. The spraying disk has been designed to rotate using the reaction of the of the pressure of the sprayed liquid as the disk is attached to a rotating coupling and supported by bearing installed in the slider.

UK Coal presented a couple of inertization devices that are using in their coal mines where regular inert dusting is required and accessibility for larger devices is problematic: (1) termed dusty bins and (2) wheel borne inert duster.

1.5.2 Task 5.2 – Systems integration

The study of the integration of EMAG multisensor meter into current hazard monitoring systems used in coal mines was assessed, in order to carry out field test. In particular, this integration has been realized into RELIA environmental control system (Spain) and in the monitoring system SMP-NT/* (Poland). Next task presents the field trials carried out in underground mines.

Within Task 5.2 the ventilation management system developed under WP4 was tested and validated for different types of fire ignitions and locations. Considering the site of the coal mine where the fire is originated and based on the readings of the sensors placed in the fire source, the simulations were performed to study the gases movements through the ventilation network according to the air flows and characteristics of the branches. Based on the results obtained and with the help of the mine experts knowledge, in the event of a fire the definition of fire escape routes and emergency planning for safe evacuation of personnel under fire hazard can be performed.

1.5.3 Task 5.3 – Join Test of "Early Detection" and "Fire management and fighting" subsystems

Task 5.3 presents the tests related to early detection devices in underground coal mines. Firstly, the scenarios chosen for the trials and the field test are described.

The multisensor device designed for early detection of fires in conveyors belts was tested in two underground coal mines: (1) in the coal mine Area Sueros, in particular in San Nicolás (Spain) using the RELIA monitoring system and (2) experimental adit in the Central Mine Rescue Station in Bytom (Poland).

The tests in Spain were carried out in two places: the first ones aimed at the connection of the multisensor to the new RELIA system, which has the software implemented for the ventilation management. The second ones aimed at checking detection of products emitted at very early stage of fire development in a belt conveyor (this part of the mine was suitable for heating a conveyor belt, but the RELIA system in this area is not upgraded and it does not include the ventilation management).

The tests results from Poland allowed calculating the distributions of the emitted products along a working during development of a fire. The results of tests and research works allowed determining, within the WP3, the fire indexes that permit the detection of changes in signals that come from all detectors built in the multisensor device. The analysis of the measuring data was made with the aim of: (i) calculation of distribution of gas and smoke concentration along mine workings under ventilation conditions of tests; (ii) determination of temperature increments at various points of mechanical construction of a belt conveyor; (iii) calculation of a fire index and its distribution along mine workings for a multi-parameter sensor and for a detection monitoring system; (v) determination of principles of location of multisensor devices along belt conveyor transport lines. The fire indexes allow a quick and reliable (minimization of false alarms) detection of a fire at its early stage.

The test related to wireless heat point detectors were performed in Area Sueros coal mine as well. Test results showed a clear coherence with the events produced during the tests. The heat detection system is clearly capable of monitoring and recognizing anomalous situations that could involve fire generation from a temperature increment. It could also server as a method to help identify the cause and the location of the fire.

Finally, the estimation of the health risk related to chemicals emerged in the fire of conveyor belts was assessed. The first stage of the study aimed at the identification and qualitative and quantitative analyses of the chemicals emerged in the fires of conveyor belts. The assessment was made on the basis of the data obtained in experiments performed in three kinds of testing sites: micro-chamber, test chamber and DMT gallery. Final tests were performed in HUNOSA coal mine in Spain in order to confirm that the results of experimental test correspond to results obtained in real conditions. In general it was found that the concentrations of chemicals measured in experimental conditions should be applied for health risk assessment.

The tests performed in the real conditions allowed confirming the results of identification measurements of the substances emitted in the combustion process. It is not possible to compare quantitative results as the conditions of the testing performance were different: in the laboratory conditions the belts were combusted directly over the flame while in the coal mine due to the safety procedures and protection only the simulation of the friction was possible. It came out that it was reasonable to assess health risk on the basis on the average or highest concentrations of identified substances determined in laboratory experiments in order to be able to predict the highest risk and to undertake efforts to protect workers' health and life.

1.5.4 Task 5.4 – Overall assessment and conclusions. Final Report.

The goal of this task was to perform a detailed appraisal of the required dissemination activities and an assessment of the overall results obtained from the project. The result of this assessment was a guideline report which, besides sending it to direct contact mines in Poland, Spain, Germany and UK, will be publicly available. The findings concerning ignitions sources, fire propagation methods and prevention strategies of belt fires, aid not only in the installation of conveyor belts but also in their maintenance. The implementation of new technologies for early detection of fires in conveyor belts and fire fighting methods was also incorporated in the guidelines to present to mines the newly developments and technologies. The outcomes of the trials and field test lead to recommendations in the placement of control points along conveyor belts for early detection of fires, as well as, the integration of the early detection devices with a ventilation management system.

2 SCIENTIFIC AND TECHNICAL DESCRIPTION OF THE RESULTS

2.1 WP1 – FUNDAMENTAL MECHANISMS OF CONVEYOR BELT FIRES

2.1.1 Objectives of WP1

The objective of this work package was to establish the fundamental mechanisms behind the initiation and propagation of belt conveyor fires, as well as the characteristics and effects of the combustion products. The output of this WP formed the basis for the work developed within the remaining work packages. A specific goal was to identify the potential ignition sources in and around conveyors. This permitted the mechanisms behind fire propagation to be determined. This, in turn, led to a study of the influence on the above of other installations, materials and equipment present in the same roadway, to characterise the combustion process, including an estimation of fire load and characteristics of combustion products, and the effect of these combustion products on persons (including workers and local population) as well as on the environment.

2.1.2 Comparison of initially planned activities and work accomplished

During the course of the project, all tasks were rescheduled due to the delayed project start or technical reasons. Accordingly, the due dates of deliverables were also changed. However, none of these actions had negative impacts on subsequent work within the work package or on other work packages of the project. The planning changes related to WP1 were as follows:

- The start of Task 1.1 was in Q2/Y1 instead of Q1/Y1. The duration of the task remained the same; therefore the end of this task was Q1/Y2 instead of Q4/Y1.
- Although Task 1.2 has started on time, because of the delay to the start of the project, it was necessary to extend the work until Q2/Y2. In order to complete the work on fire propagation mechanisms, additional tests were made according to DIN EN 12881-1, procedure C so the end of this task was moved to Q4/Y2.
- Task 1.3 was extended to Q4/Y2. The reasons for this delay were: (i) technical difficulties were encountered caused mainly by the aggressive gases identified in the samples tested, and (ii) the collection of double the number of samples to be tested than originally anticipated. The increase in the number of samples allowed more precise results to be obtained, thereby increase the research value of the work.
- Task 1.4 was extended to Q2/Y3. CFD simulations are very time consuming even when using modern IT equipment. The calculation times needed for one single simulation can be in the order of up to two weeks Due to the very complex fire behaviour, many parameters needed to be taken into account.

2.1.3 Description of activities and discussion

Task 1.1 – Identification of ignition sources and their acting mechanisms

The focus of the work was on detailed and systematic investigations to identify as many ignition sources as possible for conveyor belt fires together with their acting mechanisms. The investigations were shared between the partners involved on a regional basis and information from outside Europe was also included. Some more details about the work and results obtained from this task can be found in the annex (see section 6.1.1).

Ignition sources

The investigations into possible ignition sources for conveyor belt fires showed various reasons for the occurrence of fires. The following non-exhaustive list summarises causes for conveyor belt fires without any classification:

- Friction of belts
- Collapsed idler bearing
- Fires of flammable liquids
- Slide of a belt in a drive

- Jammed rollers
- Friction from brake
- Coal spillage
- Excessive temperature of the drive
- Seizing of bearings
- Seizing of gears
- Collapsed pulley bearing
- Sparks, electrical causes
- Friction between belt and construction
- Hot surfaces
- Smouldering fires of coal dust

In order to show a comparable overview of the causes of conveyor belt fires in the different countries, the individual sources were classified in the categories shown in the following Figure 2.1-1.

Statistics about ignition sources (value in % of occurrence)

Ignition source	DE	ES	UK	PL	Ukraine	Czech Rep	Australia	South Africa	USA
Failures in roller idler sets and bearings	Main reason	No figures obtained, information too generic	46,7	24,5	Main reason	No data available	51,0	No big issue due to intensive patrolling	Main reason
Failures around the drives			6,7	44,4			36,0		
Failures in alignment			26,7	11,1			13,0		
Coal spillage	Main reason		13,3	11,1					
Other sources			6,6	8,9					

Figure 2.1-1: Ignition source statistics for conveyor belt fires in different countries

Although the absolute values shown in Figure 5-1 are not comparable due to different data or time intervals, the Figure clearly shows that the main causes of conveyor belt fires are associated with failures in roller idler sets and bearings (main cause(s) in the different countries marked yellow). A second major reason for fires is coal spillage.

Prevention of conveyor belt fire should therefore focus on this part of the installation. However, technical installations are never 100% save. A certain failure risk will always remain. Investigations into fire prevention in conveyor installations need to address the whole system in order to guarantee maximum safety.

<u>Other ignition sources</u>

Apart from the ignition sources mentioned above, which are related to the conveyor belt installation itself, other flammable materials are present in the vicinity of conveyor belt. Such materials, while considered basically inert in terms of acting as fire sources, may under certain conditions alone or in combination with other materials, act as sources of ignition for a conveyor belt fire.

In underground coal mining, flammable materials like wood, diesel fuel, mineral oil, hydraulic liquids, solid or liquid types of plastic, and plastic equipment, are present. Effects and incidents such as smouldering coal dust, hot surfaces, burning liquids, electric arcs or welding beads, and fire beads may qualify as sources of ignition.

<u>Tests of ignition behaviour</u>

In order to investigate the ignition behaviour of belts used in European underground mining, some tests were carried out according to DIN EN 14973. This standard recommends tests representing different ignition energy levels. It was decided to conduct tests according to this standard in order to produce comparable results.

The test showed that all test samples have the recommended properties for the general application in underground mining. However, all samples can be ignited if they are exposed to high energy sources.

The implication of these test results is that high fire loads in the vicinity of conveyor belt installation should be avoided.

Idlers and bearings

Special attention was given to idlers and bearings since these are among the key elements of a conveyor belt installation. Most roller bearings fail by inadequate lubrication (36%), by fatigue (34%), by contamination (14%) or by other causes (16%). In the normal life of a machine only 0.5% of bearings are replaced because of bearing failure.

There is unlikely to be a simple solution to this problem. Higher standards of bearings with improved lubrication, dust and water seals, or reduced pulley bearing or load capacity may extend the period between failures, but is unlikely to eliminate the problem. Means of giving earlier warning of potentially dangerous situations are required.

Detection of the failure conditions is difficult, with failure progressing to fire within minutes in some cases. There is a range of possibilities including thermal and acoustic options. Early detection can at least allow sufficient warning to be given for mineworkers to escape. Technical aids (possibly based on infra-red or acoustical methods), and on-going training for patrol personnel also need to be considered.

Task 1.2 – Mechanisms of conveyor fires propagation

The objective of this task was to extend as much as possible the knowledge in the field of fire propagation in underground conveyor belt installations. The question to be answered was how the propagation of the fire is affected by the presence in the roadway of materials like electrical cabling, ventilation pipes, etc.

Anything that can burn is a potential source of fuel. Amongst the possible sources in a coal mine are coal or coal dust, wood, diesel, tyres, plastic materials such as cable insulation or piping, mineral oils and greases, firedamp, flexible ventilation ducting, rubbish and other waste, and conveyor belting. Conveyor belt fires at coal mines can have a ready source of fuel from the coal on the belt or the coal in the roadsides or roof. The possible sources of fuel, along with other factors, have been considered. UK, US and Australian documentation and statistics were studied and indicate the potential sources of fire.

In the 12th U.S./North American Mine Ventilation Symposium, Verakis (2008) [14] showed that the main causes were attributable to the ‘abundant’ fuel load in the belt entry, for example conveyor belt, coal (run of the mine coal and fine coal), hydrocarbons (grease and oil), roof control (wood supports). He also states that the speed of fire spread can be caused by the amount of fuel available, fire resistance of conveyor belting, width, thickness and construction of conveyor belting and ventilation.

Cliff (2007) [2], in Queensland, Australia shows that the ‘size and nature’ of a fire depends on how long it has been burning, what is burning, whether the fire was spontaneous or was externally initiated, the air flow to the fire (supply of oxygen), the geometry and composition of the material and where the heat goes. Factors involved may be the combustibility of the fuel, whether it needs to dry out, how permeable it is, and the surface area available to react.

Similar results apply to the situation in Europe. Also in European coal mining the mentioned types of combustibles are present in the vicinity of conveyor belt installations. Therefore, the following factors are to be considered:

Coal: Coal may be present on the conveyor belt itself, as well as in the roadway roof and sides. The coal on the conveyor may also be a mixture of product from different seams, and therefore have different combustion properties. Spillage has been a recurring factor in mine fires and it is considered that the fine particle nature of this spillage may act in much the same manner as a pulverised fuel.

Conveyor Belt: The amount of fuel from conveyor belting can be reduced by using only fire resistant conveyor belting. Some of the materials used in conveyor belting are highly inflammable and when combustion of rubber has begun, it can be difficult to extinguish. Chemicals can be added in the manufacture of fire resistant conveyor belting to make the rubber compounds less inflammable. This type of belting is self-extinguishing.

Cables and other electrical materials: PVC will provide a source of carbon fuel to a fire once started, but it has low flammability and a low rate of heat release. It will self-extinguish if the external heat or flame source is removed. There may be other cables in roadways, using XLPE (cross-linked polyethylene), PCP (polychloroprene), or EPR (ethylene-propylene-rubber) for insulation or sheath.

Fuels, Lubricants and Greases: Diesel fuel, hydraulic fluid, lubricating oils and greases may be present in some quantities, and available in a roadway to be consumed as a fuel in a fire.

Ventilation Ducting: Non-metallic flexible ducting is in widespread use. This can be manufactured in PVC, polyethylene woven fabric or PVC coated polyester fabric. The possible additional effect of the forced airflow of higher velocity should also be recognised.

Flame spread theory: Apte et al (1991) [1], studied fire propagation across ventilated solid polymeric surfaces with a view to applying their findings to conveyor belts in coal mines. They found that fire propagation occurs in two successive modes. Initially, flame spread is confined within a boundary layer. Later, the dominance of buoyancy of the heated air over the horizontal wind force results in a plume mode in which the flame 'stands up'. The transition between the two modes was influenced by the wind speed and was smaller when the wind speed was lower and larger when the wind speed was higher.

Fires in Tunnels compared with fires in Mines: there are many common features between mine and tunnel fires. Heat is enclosed in a confined space, compared with an open fire. Mines are always positively ventilated to dilute any methane which may inherently occur in coal mining. Computational Fluid Dynamics (CFD) results show that the fuel type and the ambient temperature have negligible effects on the value of the critical velocity (Edwards and Hwang, 2006) [3] . Tunnel slope does have an effect.

Air Velocity: It was found that the flame spread rate was affected by the air velocity and the distance of the conveyor surface from the roof. Closely related to air velocity is the dimensions of the roadways, and in particular the height, with lower height tunnels limiting the maximum temperature. Air velocity will also influence how dust and spillage is distributed. Aerodynamic effects of conveyor or other structure will also influence spillage distribution, depending on particle size.

Sloping tunnels: The investigation into the Aracoma fire indicated that a number of factors influenced the spread of fire in the area of the belt drive and take-up storage unit. These included the slope of the roadway where the fire occurred. These conditions significantly influenced the direction of fire spread. Even a few degrees of incline can have a measurable effect on driving the plume upwards. The degree of slope of the tunnel will vary the effect, with steeper tunnels tending towards performing like chimneys.

Simulations: Computational Fluid Dynamics (CFD) modelling of fires with high speed computational capability now makes it is possible to model fire spread in mine roadways and tunnels, with particular attention to the roadway dimensions, air velocity, fuel combustion properties, and the char formation process.

There are many questions to be answered in regard to the factors highlighted above. The effect of these, acting individually, or in combination, needs to be researched further, before their effect can be fully understood. Only then could appropriate precautions be taken to counter their effect.

Fire tests for studying the ignition and spread of fires at conveyor belts

In order to study the ignition behaviour and also the fire propagation characteristics, conveyor belts from different countries of the EU were examined considering aspects of fire protection regarding the incipient fire and the spread of fire, first of all according to DIN EN ISO 14973. It was decided to use the test procedures laid down in this standard because it guarantees comparability of results obtained with different belts and it provides procedures simulating small, medium and large ignition sources as well as for fire propagation.

Details of individual fire tests carried out can be obtained from the annex (see section 9.1.2).

Although all test samples came from belts of self-extinguishing quality, the individual results of the test series were quite astounding.

Looking at the German conveyor belts we found that numbers 2078 and 2079 are heat-resistant to high heat energy impacts, e.g. 300 kg of wood, but, surprisingly, fail to pass the test involving medium heat energy, e.g. double propane gas burner. However, if the same test was repeated at a larger tunnel cross section, again the two belts mentioned passed the double burner test.

Looking at the English conveyor belt no. 2094, the final results are exactly the opposite: the belt burns completely at a fire source of 300 kg of wood, but manages to pass the double propane gas burner test.

The Polish conveyor belts numbers 2095 and 2096 succeeded in passing all three tests.

The contrasting behaviour of the different conveyor belts may be explained by the composition of materials, especially flame-retardant substances, used for the individual belts. The formula used for the composition seems to be a decisive factor influencing the spread of a fire on a belt conveyor. The negative result of conveyor belt no. 2115 during the double propane gas burner test seems to provide further evidence of that: in comparison to the other belts, this contained relatively few flame-retardant substances.

Task 1.3 – Investigations into combustion gases

Qualitative, quantitative and thermogravimetric analyses of the combustion gases emitted during the fire of conveyor belts in underground mining was the first step of the task implementation. The identification of chemical substances and determination of their quantities provided the basis for an environmental impact assessment that was the second part of the study within the task.

The tests were performed through the burning of the following types of conveyor belts used in the underground mining: rubber-fabric belts, polyvinyl chloride-rubber and polyvinyl chloride belts (see annex, section 9.1.3). Studies were carried out in three types of research environment: micro-chamber (sample dimension: 8 x 8 cm), test chamber (sample dimension: 30 x 60 cm) and DMT gallery (sample dimension: 1.2 x 2.5 m). In–situ measurements, colorimetric, titrimetric, chromatographic, ICP and gravimetric analyses were used as methods of testing.

<u>Qualitative analysis</u>

The qualitative analysis focused on identification of substances released in conveyor belts combustion. In all tested belts, the phosphorate plasticizers were identified, in some belts - phthalan plasticizers, fatty acids and aliphatic hydrocarbons C5-C14 that form oil group. Chlorobutadiene and dichlorocyclooctadiens were also found – it may be assumed that the chloroprene rubber was used for the production of this belt. On the basis of results of chemicals identification it is assumed that in the combustion products mineral and organic phosphor and chloride compounds are present. Nitrogen derivatives such as caprolactam will generate mineral and organic nitrogen compounds in the combustion process.

In the case of polyester fabric, trace amounts of terephthalic acid and isophthalic acid were identified in only a few samples. In the belt production also plasticizers were identified – phthalates and acrylophosphoranes, although their concentrations were not significant.

Other combustion products come from pisolite transformations of rubber or PVC contents used for production of the belts. Hydrocarbons, both saturated and unsaturated, are formed from polymer degradation. Among them there are both straight-chain coal-related products as well as highly isomerised products which are the result of the network polymerization of raw materials. It was observed, in case of trace amount of organic connections of sulphur used for rubber vulcanization, that sulphur almost entirely oxidizes to non-organic products or forms hydrogen sulphide and sulphides.

The wide range of toxic polycyclic aromatic hydrocarbons (PAHs) and their alkyl and oxygen derivatives were identified in the tested samples. In almost all samples naphthalene and its alkyl derivatives – e.g. methyl, phenanthrene and pyrene occur. Also, their hydrogenated analogues are present, which confirms the well-known process of formation of aliphatic hydrocarbons, although the mechanism of these reactions is not fully understood. They are related with oxygen substances occurring in combustion products, as part of the incomplete oxidation.

Apart from caprolactam, other products containing nitrogen were identified - benzothiazole and its derivatives, carbazole or pyridazine.

Quantitative analysis

The quantitative analyses focused on determination of the concentration of hazardous chemicals in combustion products. Table 2.1-1 below presents the average concentration of these substances in the tested belts in comparison with their minimum and maximum concentrations:

Table 2.1-1: Concentration of hazardous chemicals in combustion products

Substance	Average concentration [mg/m^3]	Maximum concentration		Minimum concentration	
		[mg/m^3]	Belt	[mg/m^3]	Belt
NO_x	20,46	41,3	NG3	4,06	NG10
SO_2	40,4	56,2	NG13	12,0	NG10
CO_2	14663	17911	NG15	11009	NG10
CO	973	1444	NG3	430	NG14
HCL	3020	6619	NG2	851	NG7
CN^-	4,1	11,32	NG9	0,25	NG10
HCHO	0,4	1,36	NG16	0,001	NG2
Dust	47,5	92,6	NG10	32,4	NG16
PAHs	0,553	1,03	NG1	0,031	NG8
Petroleum hydrocarbons	43,17	171	NG10	2,8	NG5
Benzene	20,4	79,6	NG6	5,6	NG2
Toluene	5,5	14,1	NG11	2,8	NG2
Ethylobenzene	2,3	8,6	NG9	0,74	NG15
Xylene- o,m,p	4,2	14,5	NG7	1,95	NG1
BTEX (sum)	30,9	97,5	NG6	12,04	NG2
Total benzine	88,9	171,8	NG5	38,6	NG1

Thermogravimetric analysis

Thermogravimetric analysis showed a different thermal decomposition of conveyor belts samples, despite similar composition of covers (rubber, PVC) and separators (polyamide, polyester). The differences in thermal decomposition result from chemical composition of rubber and inflammable additives of covers or even the thickness of covers.

Environmental Impact Assessment

On the basis of the qualitative and quantitative analyses of combustion products the environmental impact assessment was done. Two main aspect of the study of the environmental impact of the conveyor belts fires in underground excavations were considered:

- Air pollution – air impact of conveyor belts combustion products,
- Management of the waste produced in the combustion of conveyor belts.

Through the analysis of the pollutants emitted, it was found out that the conveyor belts combustion products have a negative impact on air quality (particularly in case of hydrogen chloride emission values for all types of conveyor belts).

The analysis presented relates to the calculation option that complies with the conditions of test chambers – emitter parameters, thermodynamic parameters of the waste gas, magnitude of the pollutant emission, terrain conditions and meteorological conditions.

The elaboration of a universal model is not possible due to the inconsistency of factors influencing the spread of air pollution such as emission conditions, local terrain conditions, local weather conditions, pollution characteristics.

The waste produced after the combustion of conveyor belts was analysed to detect the presence of metals: As, Ba, Cd, Cr, Cu, Hg, Mo, Ni, Pb, Sb, Se, Zn. Spectroscopic ICP-OES and atomic absorption techniques were used for determination of particular element concentrations. In the case of mercury, the study was performed with the atomic absorption spectrometer using the technique of amalgamation.

The magnitude of the emission of air pollution is dependent on fire characteristics (access to the air, type of burning material – type of the belt) and the duration of the fire.

Taking into consideration all the observations and calculations, it is reasonable to conduct a proper fire prevention policy. In addition, in the case of a fire, fire fighting should be carried out without delay in order to eliminate the potential source of air pollution.

The analysis of the eluate related to the determination of content of such metals as: Ba, Cd, Cr, Cu, Hg, Mo, Ni, Pb, and Se indicate a very low content in the filtrate or even below the detection level. In the case of As, Sb, and Zn, indicated concentrations reached significant levels.

Due to the high concentration of heavy metals, the waste produced in the conveyor belt combustion threatens underground waters contributing significantly to their pollution.

Task 1.4 – Mathematical modelling

Beside the real fire tests, one aspect of EDAFFIC was to identify to what extent computer-based simulations may reflect the research results gained from the tests.

In order to simulate fire tests, the program Fire Dynamics Simulator (FDS), developed by the US National Institute for Standards and Technology (NIST), was used. The CFD (Computational Fluid Dynamics) code FDS is presumably one of the internationally most used simulation programs in fire engineering. The program simulates fires and fire-induced flows based on Navier-Stokes-equations. However, the simulation of the flow is only one part of the full functionality of FDS as furthermore physical effects such as heat radiation, temperature transfer to components and the chemical combustion process are considered, too.

In order to simulate a test of a conveyor belt, some details on the following material parameters of the test specimen – besides those of the test environment – are required by FDS:

- Specific heat capacity
- Heat conductivity
- Density
- Heat of combustion
- Reaction enthalpy

However, no such details on the material properties were available in databases or similar documents for the complex design of the conveyor belts involved. Therefore, these values had to be determined by experiments in relevant tests.

A first rough approximation of the conveyor belt properties may be derived from values of vulcanised rubber. Assuming the properties of pure, vulcanised rubber, the parameters needed were derived from real fire tests as follows:

- When conducting a fire test on a conveyor belt according to EN DIN 12881-2 the temperature development, the fire propagation and the fire duration were all measured and thus available.
- Then the parameters of the simulation were modified in such a manner that the simulated fire process corresponded with that of the real fire.
- Then the results of the fire test were used as a basis for test specimen no. 2078.

After the material-specific parameters had been determined, the next step was the variation of ignition sources. Due to the enormous computing effort that one simulation required and also due to the amount of time needed to determine the material-specific parameters, no more than one test specimen could be considered. The computation of one fire test took about 10 days (including computation time, time for preparation and reworking and maintenance of the computation).

The results of the fire simulations are in very good agreement with the results of the real fire tests given the inevitable tolerance of 10% of the Fire Dynamics Simulator. Table 2.1-2 shows a comparison of the results of the real fire tests with those of the simulations. It is obvious that the results of the simulations are slightly worse than those of the real fire tests.

The fire simulations also confirm the impact of the test environment on both the fire development and the fire spread that had already been recorded during the real fire tests. The fire tests done in a test chamber with a larger cross section (other test conditions kept similar) showed a milder progress than the fire tests done in the test chamber with a smaller cross section – clarified by the burned lengths.

Table 2.1-2: Comparison of results of real fire tests and fire simulations

Test	Real fire test (burned off length)	Simulation (burned off length)
DIN EN 12881-1, procedure A	1.38 m	1.40 m
DIN EN 12881-1, procedure B (small cross-section)	2.50 m	2.50 m
DIN EN 12881-1, procedure B (large cross-section)	2.00 m	2.00 m
DIN EN 12881-1, procedure C	0.47 m	0.50. m
DIN EN 12881-2	6.50 m	7.00 m

If the material-specific parameters required for a fire simulation are available, then it is possible to use FDS as a method to determine the fire resistance of a conveyor belt during the development of a new conveyor belt. The parameters can be determined, for example, by tests using a cone calorimeter. The big advantage of this method is the rather low amount of material required which helps the manufacturers of conveyor belts to reduce costs.

In the annex (see chapter 9.1.4), the results of some additional simulations are shown where we varied the air velocity.

2.1.4 <u>Conclusions</u>

A lot of possible ignition sources could be identified around the conveyor belt installation and in close vicinity to it. Tests according to DIN EN 14973 showed that the belt samples from different countries all showed the recommended properties for underground application. However, all samples can be ignited if they are exposed to sufficiently high energy sources.

The primary heat source might, for example, be a hot roller idler set caused by friction. The grease may then be heated up and released to drop to the floor below the conveyor. If large quantities of coal dust are lying there, smouldering fires can result and these may develop to a bigger fire producing enough energy to ignite the belt. If other flammable materials are also located in close vicinity to this location, the situation will get even worse.

There are many factors which could affect the intensity and development of a fire in a mine roadway as well as determine fire propagation. The effect of some of these is documented. Many questions need to be answered in regard to the factors highlighted in this project. The effect of these, acting individually, or in combination, needs to be researched further, before their effect can be fully understood. Only then could precautions be taken to counter their effect.

The investigations into combustion gases showed the differences between emissions of hazardous substances dependent on the belt composition. Information on the composition of combustion products and the concentration chemical substances in gases was used for environmental impact assessment and provided the basis for health risk assessment.

Fires on conveyor belts are the sources of emission of smoke, particulate matter, gases – combustion products that are irritants and toxicants. Gases are spread through the ventilation system in the direction of the air flow, to be finally emitted through the air shaft to the atmosphere.

In the process of combustion the following chemicals were identified as of the highest concentration and impact on environment: hydrogen chloride, CO, SO_2, NO_x, benzene, total benzine, CN^-, toluene, xylene, formaldehyde, aromatic hydrocarbons, aliphatic hydrocarbons, particulate matter, ethylobenzene, bezno(a)pyrene.

Among the most toxic substances that were identified the following chemicals profoundly impact on human health: HCL, CO, CO_2, NO_x, CN, SO_2, C_6H_6, benzo(a)pyrene, caprolactam. Most of them cause respiratory problems, eye and throat irritations, and headaches. The serious danger comes from benzo(a)pyrene which is a cancerogenic compound.

Numerical simulations of conveyor belt fires using the FDS code are in good agreement with the test results. If the material-specific parameters of conveyor belts are known, simulations can replace the large scale fire tests prospectively. Ideally, manufacturers of conveyor belts could use the results of simulated fire tests to reduce development costs and the amount of time to develop a new conveyor belt. Furthermore, mining companies could evaluate their fire risks by using simulations. The influence of fire loads and ventilation could be ascertained numerically. Therefore, more fire tests have to be done to adjust the necessary parameters for FDS to the different conditions. Especially the influence of different ventilation conditions concerning the fire spread shall be analysed more precisely.

2.1.5 Exploitation and Impact of the Research Results

The results of the investigations have direct impact on the daily work of the partners involved in the project. The findings concerning ignition sources and fire propagation indicate methods of improving fire safety in underground conveyor belt installations. Furthermore, mining companies could evaluate their fire risks by using simulations.

For dissemination purposes, we will aim to get into discussion with manufacturers of conveyor belts in order to disseminate the results obtained from fire testing and the simulations. A member of the DMT team has a personal membership in the CEN TG 188 WG3 dealing with standardisation of fire tests for conveyor belts. Through this membership, we are in close and regular contact with belt manufacturers in Germany, UK, the Netherlands and other European countries. The results of the project will have direct impact on the standardisation work and probably also on the production processes of individual manufacturers.

There are a couple of possibilities for the manufacturers to improve their products. The investigations into analysis of combustion gases and the environmental impact assessment showed that the belts of the current material composition will seriously pollute the environment in case of fire. Manufacturers of conveyor belts could use the results of simulated fire tests to reduce development costs and the amount of time to develop a new conveyor belt.

The results also provide for development of new research activities. The influence of fire loads and ventilation could be ascertained numerically. Therefore, more fire tests have to be done to adjust the necessary parameters for FDS to the different conditions. Especially the influence of different ventilation conditions concerning the fire spread shall be analysed more precisely. Not all questions are solved according to fire in conveyor belt installations.

2.2 WP2 – PREVENTION: ASSESSMENT OF DEVELOPMENT POSSIBILITIES OF (AUTOMATED) CLEANING AND DUSTING EQUIPMENT

2.2.1 Objectives of WP2

The objective of this work package was to develop cleaning equipment, possibly automated, to facilitate local removal of carbonaceous material build-up, as well as of the development of plant to rapidly and evenly deposit stone dust in roadways. Specific goals were:

- Establishing the mechanisms behind spillage and build up of coal-dust deposits.
- Preparing the functional specifications of an automated de-dusting and of an automated inertization unit.
- Preparing the manufacturing drawings for small scale models of the above machinery.
- Building and testing small scale functional models.

2.2.2 Comparison of initially planned activities and work accomplished

In WP2 two newly designed devices were described with the objective of avoiding the dangers of coal accumulation surrounding the conveyor belts. At the proposal state the main idea was to design fully automated machinery of static devices in key points of the conveyor belts like in the transitions made by the change of directions. Further analysis showed that wider solutions would be required because previous concepts didn't appear to be profitable. For instance, the fully automation of the de-dusting process is very difficult to perform, some of the movements (*e.g* moving up and down continuously the slider with the disk) can be programmed to help the operator to make the tasks faster, having the machine in a semi-autonomous control. For this reason, new machinery was designed and semi-autonomous small-scale prototypes were implemented.

2.2.3 Description of activities and discussion

Task 2.1 – Spillage and coal-dust build-up mechanism

Design of the belt conveyor

In order to fully understand the mechanisms behind the accumulation of coal dust and spillage the design of the belt conveyor was studied.

The loading and discharge of bulk solids using conveyor belts is governed by the need to ensure effective haulage of a maximum payload without spillage. Therefore, one important consideration during the design stage is the interaction effects between the conveyor belt and the bulk solid being conveyed, which concerns the stability of the bulk solid during transportation and the discharge characteristics.

The basic components of a belt conveyor are: the belt, the pulleys (the drive pulley and the tail pulley), the conveyor drive, the belt support system (idlers), the structure and the enclosure. The conveyor belt stretches between two pulleys, (i) the drive pulley which is driven by a motor and powers the belt, and is where the material is usually discharged at the enclosure; (ii) the tail pulley, located at the tail end of the conveyor, near where the loading takes place and it turns freely. Each pulley has a steel shaft which turns on a bearing to keep the pulley shaft and the conveyor bed from rubbing together. Because it is dangerous to have the belt hang down under the conveyor, small rollers are put under the conveyor to hold up the belt, and as they turn freely, are just "idlers". Idlers help to shape and support the belt, prevent slippage, and maintain tracking.

Other equipment can be added to these components in order to improve performance and decrease maintenance. Impact idlers can be used to cushion impact by the falling material, and protect the belt and idlers from damaged at material loading section. They also guide the belt from the tail pulley of the conveyor into the desired troughed angle. To increase the carrying capacity of conveyor belts, troughed idlers can be use to angle the sides of the belt, reducing spillage and helping to centre the loaded material. There are troughed idlers with guide rollers to ensure the proper alignment of belt, prevent belt misalignment, and protect the belt edges from wear and tear. On the return side of the belt, bend pulleys are commonly used to bend the belt into the take-up pulley, which ensures proper belt tensioning through the use of counterweights. The structure helps to align the components and supports the weight of the materials being transported.

Additional equipment can be used for belt cleaning. Included here are blade scrapers or plows, which remove excessive carry-back while reducing belt wear, and dust suppression systems which may be added to the conveyor system to help improve performance. More equipment may be need depending on the desired outcome of the operation.

Coal dust and spillage

Material escaping from belt conveyors arises in three ways (Swinderman R.T. et al.,2008): (i) as spillage and leakage from transfer points, (ii) as carry-over (or carry-back), that is bulk solid that has adhered to the belt after the point of discharge and dropped off along the conveyor return, and (iii) as airborne dust that has been carried off the load by loading forces and air currents.

Coal spillage is commonly found near belt feeders, at belt drives, along ribs in entries and at driving drums. After the discharge point, some material will adhere to the belt as carry-back. This is an adhesive condition that arises as a result of negative or tensile stresses which occur between the bulk solid and the belt surface. While these stresses are very small, they can have a significant influence on the amount of carry-over that may occur. Belt conveyors are a potential fine coal dust producer. Conveyor transfer points are primary sources of the creation and release of airborne dust.

This escaped material not only represents an important drain on conveyors' efficiency and productivity, but also an important source of hazard, which under certain conditions, may be the cause of a fire. Typical problems caused by coal spillage, carry-back material accumulation and coal dust generated are as follows:

- Accumulations on the conveyor components and other nearby equipment can produce (a) a failure in idlers and pulleys, (b) bearing seizure causing premature component wear, (c) belt sag, (d) vibrations, (e) increasing friction that increases power consumption of the conveyor.
- Reduction of the life of components (idlers facing spillage are replaced prematurely, in advance of their expected wear life).
- Material build-up on the face of pulleys and idlers can cause the belt to run off-centre (mistracking). If it runs beyond the edge of the pulley, the belt can rub and even fold over into the conveyor structure.
- Accumulations of material around conveyor structures can speed up corrosion. This problem is difficult for workmen to observe and it can lead to serious damage.
- The dangers arising from excessive airborne dust that escapes from conveyor systems in the mines are mainly the effect on the health of the workmen, and the risk of dust explosions, if sufficient coal dust is produced and ignited by different sources of ignition.
- Bad loading conditions can produce severe edge damage and cover.

All these problems lead to higher down times, increased maintenance and cost due to the replacement of components, cost of lost production and the time required performing installation.

Figure 2.2-1: Material accumulation on idlers

Figure 2.2-2: Keeping the belt on track

Each conveyor belt system is different and requires an individual study depending on load, material, environment, etc. The performance of the whole system depends on the design, installation and maintenance. There are many components and types of auxiliary equipment which are used to improve the conveyor belt performance, to minimize spillage and decrease maintenance. Included here are impact beds, skirt boards, wear liners, tail pulleys (wing pulleys and wrapped wing pulleys), scrapers, V-Plows, guide rollers, take-up pulleys, etc.

Belt cleaning systems are frequently used to remove carry-back material that adheres to the belt. Cleaning systems are typically composed of a pre-cleaner on the face of the head pulley to remove the majority of material and one or more secondary cleaners positioned further along the belt return to remove sticky fines that have passed the pre-cleaner. More cleaners can be positioned further on the return to remove any residual material.

One of the ways used to reduce airborne dust is the application of water and/or chemicals to the body, with sprays and nozzles placed along the conveyor or at transfer points. Transfer chutes are considered critical elements of the handling system, since they are points where the conveyor belt receives more damage and chute design can lead to spillage, dust creation and blockage. Hence the correct design of transfer chutes is very important. This is influenced by conditions such as the capacity, size, and characteristics of the material handled, and the speed and inclination of the belt. The ideal situation would be to load material onto the belt at the same speed as the belt is moving, in the same direction and with minimum impact.

Conveyor belt misalignment can cause material spillage, component failure and damage to the belt and structure. There are different factors that cause the belt to come out of alignment: faults with the belt, faults in the structure or faults in the loading. Operators and maintenance personnel will make the necessary adjustments to the conveyor in order to centre the belt, and correct any tendency of the belt to run outside the desired path.

Machinery of any type needs periodic inspections and planned maintenance. There are many factors that contribute to belt life. The steps necessary to ensure good conveyor performance include regular inspections, close monitoring of motors and reducers, keeping key parts in stock, and proper training of personnel. To facilitate maintenance, conveyors, chutes and loading zones must be designed to allow access for checking the components. Access requirements for maintenance must be considered during the design stage of a conveyor system. Some of these requirements include proper spacing, and the provision of walkways and access ports to allow inspection of the operation and service of the various components.

The cause of conveyor devices to control and monitor conveyor belts will be also very useful not only for detection of anomalies in the conveyor belt performance but also to help in maintenance. Included here are: misalignment switches, belt speed monitors, conveyor backstops, belt condition sensors, electronic interlocks, fire detection systems, etc.

Task 2.2 – Automated de-dusting plant

The goal of this task is to develop a mechanism that collects the material dislodged from the conveyor belt and return it to the conveyor or deposit in another place for easy collection. Rather than just a de-dusting machine it would be a cleaning/coal-recovering device. By minimizing or eliminating completely the accumulation of coal below conveyors, on conveyor belt parts, and along the conveyor line, the risk of fire hazard will decrease.

In order to eliminate the material build-up, an easy approach would be to shovel up all the build-up and clean the entire area. First investigations in the design of the cleaning machine followed from the above concept, and its specifications were introduced in Deliverable D.2.2. Given various investigations, the end tool was modified in order to improve its manoeuvrability, robustness and finally, the assembly process of the system. The concept of both prototypes is to dislodge the dust accumulations under the conveyor belts.

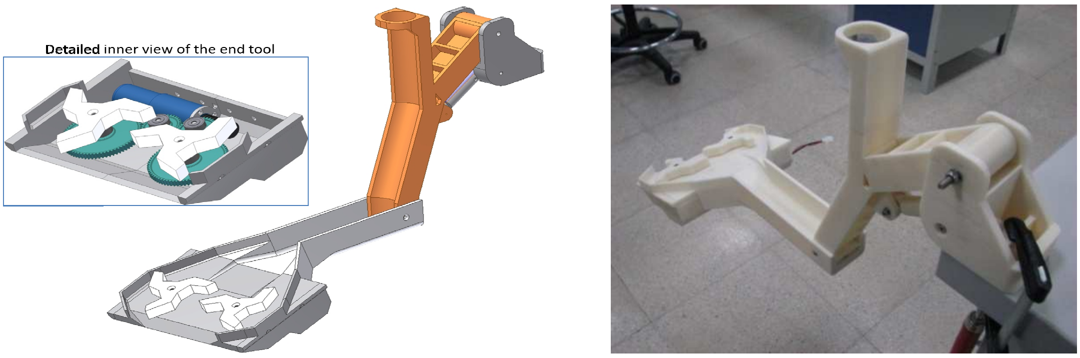
The drawings of the final prototype cleaning device are presented in Figure 2.2-4 (a). The design is based on the backhoe PRZ-330 from ZITRON (see Figure 2.2-3). The PRZ-330 has an articulated arm with 3 degrees-of-freedom (DoF). The cleaning device would use the first DoF of the PRZ-330. The tool that accumulates the coal dust uses a bucket chain that collects the coal and stores it inside a reservoir (the base of the orange mechanism): the bucket chain is moved by a hydraulic motor.

Figure 2.2-3: ZITRON Back digger PRZ-330

The Figure 2.2-4 (a) shows the end tool of the 3 dof de-dust arm device more in detail. The idea is to accumulate the dust collected by the two helical blades over the tray of the final tool. This solution has several advantages compared to the first one:

- The dust accumulation under the conveyor belt can be approached from the bottom.
- The robustness and effectiveness of the system has been extensively tested.
- The implementation and assembly is much more practical.

As a disadvantage from the first design, the tool is wider which may make access inside small spaces difficult. Nevertheless it is expected that the wider dimension of the tool won't exceed 500mm which is considered adequate for this purpose.



a. *b.*

Figure 2.2-4: Cleaning-recover coal device a) Design b) Prototype

The material accumulated in the tray has to be removed. For this purpose, the solution presented was to use a flexible screw conveyor which transports the material to the upper part of the arm to return it to the conveyor belt. This design has been inspired on common solutions used by roadheaders to collect coal.

From the reservoir, the coal is raised by a flexible worm gear which will return the coal to the conveyor belt. The idea of the flexible screw conveyor is based on a Spiroflow Systems Inc design, shown in Figure 2.2-5. It has the ability to deal with a wide range of material particle sizes and bulk densities. The moving part is a motor driven spiral which rotates within a sealed tube to move materials along with it. The worm drive is electrical and would need to be changed to a hydraulic type for two reasons: (i) the backdigger would activate and move a hydraulic motor and (ii) ATEX certification.

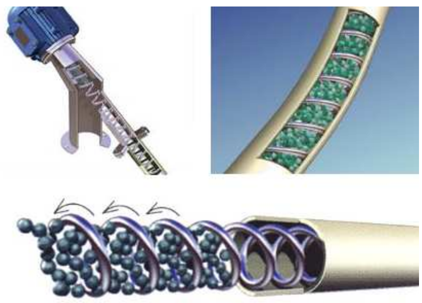


Figure 2.2-5: Flexible screw conveyor by Spiroflow Systems Inc.

A scaled functional prototype has been built (Figure 2.2-4 (b)). The real prototype is made of ABS polymer and it has been manufactured with the 3D impression technology of Fused Deposition Modelling (FDM®) from Stratasys.

Task 2.3 – Automated inertization plant

Inertization Techniques

Manual spreading using a stone dust named Fosforin is the most commonly used inertization technique at the HUNOSA facilities. However UK Coal Mining has a number of automatic/semi-automatic inertization systems/plants in use at its mines. These vary from very simple bin type blowers to large volume piped systems. Some mines have semi-automatic systems that are vehicle mounted with automatic spreaders. Below is a brief description of the differing types.

Large Volume Piped System

These systems consist of a large cylindrical pressure vessel, approx 3m in length and 0.9m in diameter, which acts as a container for the stone dust which has a compressed air inlet on top and a piped outlet on one end. The container is filled with stone dust and sealed compressed air is then fed into the container in a manner where it agitates the stone dust and is carried along the outlet pipe by the compressed air and can be either released through sprays along the pipe length or emitted via valved 'T' pieces at specific places along the pipe length which can be up to 2km in length. The pipe diameter used can be 60mm-100mm dependent on pipe length. The only non automatic function is the filling of the container which is by hand. The unit can be fitted with electronic valves for automatic operation of the stone dusting function.

Vehicle Mounted Semi-Automatic Systems

There are a number of different types of vehicle mounted stone dust spreading machines within UK Coal. These differ according to the type of vehicle used. They can be mounted on a flat tram at the back of a locomotive and either powered by diesel compressor or cryogenic via liquid nitrogen, as previous the dust is agitated by the pressurised air/gas and emitted via tubes on the outlet of the pressure container these can be fixed positions or adjustable to suit varied conditions and requirements in the underground roadways. Again these have to be manually filled and in the case of the cryogenic type brought out of the mine to replenish with liquid nitrogen.

Another type of vehicle mounted spreader is capable of being fitted to a FSV (free steered vehicle). This sits on the front bed of the vehicle and is powered by the machine's hydraulics whereby two flinging arms rotate and fling stone dust from within the small on board bunker around the periphery of the roadway. These types of machines are adaptable and can travel most roads in the mine and do not require rail track. Filling of these machines with stone dust is again done manually but can be done at a central point within the mine due to the versatility of this machine.

Bin Type Blowers

Most of UK Coal Mines have the bin type blowers situated around the mine. These are simply a hopper shaped bin with a compressed air feed at one side at the bottom and an outlet pipe at the other side. When compressed air is fed into the hopper it carries stone dust within the hopper out via the outlet pipe and into the ventilation air stream where dependant on the velocity gets carried and deposited both on the floor and on the roadway sides. This type of spreader can be sited at places where the deposition of coal dust is heavy and operated at regular intervals manually. Of course this should only happen when persons are not on the immediate downwind side as coal dust can be displaced from the roadway roof and sides and carried much further inbye than stone dust will be. The filling operation of these bin type spreaders is carried out manually.

Inertization Device

An inertization device was developed to eliminate the risk of combustion of the dust accumulated along the conveyor belts inside coal mines. A requirement was that, irrespective of what automated devices are used to spread the rockdust in coal accumulations, an operator should still be able to manipulate the hose manually. But given that this accumulation may be found all around conveyor belts, it was necessary to develop a device which could permit this task to be carried out periodically by the mining companies.

It is not intended to develop a fully autonomous device because the need of inertization may generate very complex problems, the solution to which may not be necessary for this application. The concept design has different automation components and the mechanical configuration is designed to be fully automatable in further applications and developments.

The inertization device is based on the same mobile platform as the de-dusting device, the back digger ZITRON PRZ-330. The concept design (see Figure 2.2-6) consists on a 3 Degree of Freedom (DoF) mechanism that may give an operator the ability to reach dust accumulations under or over the conveyor belt or in any other place of the mine where a railroad is available.

The first design of the end tool had a nozzle installed on the slider of a linear guide that provided the nozzle with vertical movement, allowing the spraying of the inertization products under or over the conveyor belt depending on the disposition of the accumulated dust. Usually the sliders of linear guides are actuated by electric motors. In this case the electric motor has to be replaced for a hydraulic actuator to fulfil the intrinsically safety requirements (or ATEX).

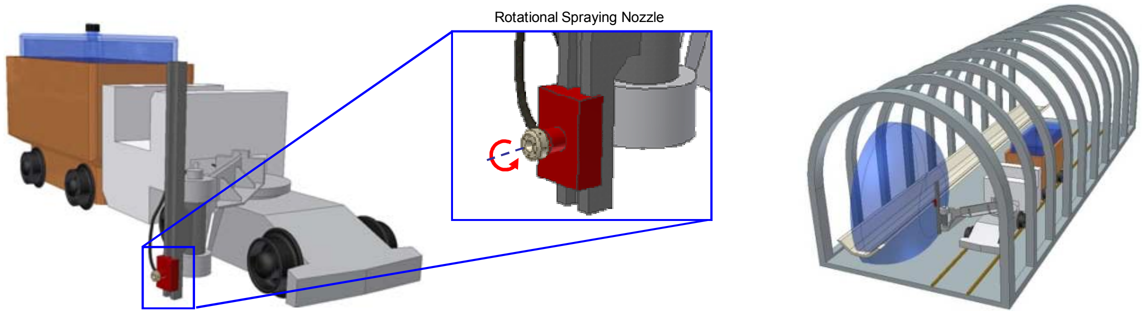


Figure 2.2-6: Concept design of the inertization device

According to the previous design, in order to protect the areas of a certain position inside the roadway, a unidirectional nozzle sprayed the flame retardant rockdust, *i.e.,* over a conveyor belt. It was determined that in order to completely protect a certain area, the entire section of the roadway has to be sprayed with rockdust. Therefore, the single nozzle has been replaced with a rotational spraying set of nozzles. With this design it is expected to reach a wider range of positions of the infrastructure inside the mine as it may be able to cover with rockdust underneath a conveyor belt and also to cover the complete geometry of the roadway.

The stone dust, usually liquid based, has to be stored in a tank installed on a wagon attached to the back digger. It is intended that a hydraulically actuated pump would be used in order to spray the stone dust on to target from the tank and through the nozzle. Another possibility is that instead of using an ordinary wagon, it is possible to use commercial devices (i.e. A.L. Lee Corporation. “Rockdusters”) for storing and transporting the pumps to spread the rockdust.

It may be controlled by an operator but the automation may be implemented with very simple and adjustable controls in order to reach dust accumulations while controlling automatically the rockdust feed. The main advantage of this concept, according to the existing devices, is that using a semi-automatic articulated arm it is possible to reach most of the problematic places with a very simple device and without the need of a complex installation system.

Figure 2.2-7: Scaled Prototype: Design and Real implementation identifying the 3 DOF.

2.2.4 Conclusions

Any machine that takes part in the transfer of coal (conveyors, loaders, shuttle car) will cause fine dust to be thrown into the air. The hazards arising from excessive coal dust in the mine air are mainly: (i) the effect on the health of the miners and (ii) the possibility of a fire or an explosion.

Activities carried out consisted of establishing the basis for the prevention of belt fires, focusing on the study of the structure of conveyor belts, the characteristics of the coal accumulation and the problems caused by coal spillage, carry-back material accumulation, and coal dust generation. The performance of the whole system depends on the design, installation and maintenance. Regular inspections close monitoring of motors and reducers, keeping key parts in stock and proper training of personnel are a must for proper maintenance.

It was determined that de-dusting the material accumulated below a conveyor belts requires a capacity that can only be achieved using a back digger based articulated arm.

The end tool has been modified according to the initial design and a prototype has been built to test the functionality of the de-dusting device. It was found that the system was insufficient because the blades were not able to accumulate enough dust in order to be collected by the lifting system. A mini-conveyor belt (combined with the flexible screw conveyor) was considered as an initial solution but it was determined that an embedded conveyor belt would be very difficult to implement. Additionally, the Spiroflow system wouldn't be as efficient at it was initially expected. Hence, it is thought that a vacuum device is probably a better solution that may solve both problems: (i) to pick up the collected dust from the blades and (ii) to transport it to a wagon or place it again over the main conveyor belt. A vacuum conveyor is a device that transports material, just like a vacuum cleaner, but with the capacity to suck up different types of solid material including dust or even sludge and with enough energy to transport the solid to longer distances. The vacuum conveyor model Volkmann VR 170 is an example of an ATEX certified vacuum conveyor system. Its results are discussed on T5.1.

Concerning the inertization device, there are different approaches to avoid the problem of secondary combustions from coal dust accumulations. The concept of using an articulated mechanism may solve efficiently the problem by introducing a flexible 3 DoF arm. With this arm dust accumulated in different positions of the roadway can be reached and by using a mobile platform may help the workers to spread the rockdust in almost all the problematic area including the ones nearby the conveyor belts.

At the beginning of the project it was expected to design a fully automatic de-dusting machine. But further analysis concluded that static devices placed on strategic places of the conveyor belts like in its intersections, didn't solve the complete problem. So a much more complete device has been implemented but much more difficult to make fully autonomous. What it is more plausible is to implementing different aids *e.g.* in order for the operator to avoid obstacles. Nevertheless, its manoeuvrability to reach any desired position is very simple as the arm only has 3 DoF.

2.2.5 Exploitation and Impact of the Research Results

The establishment of the prevention strategies (focusing on the study of the structure of conveyor belts and the characteristics of the coal accumulation) are part of the work to be included in the guidelines report for dissemination of the results, with the aim of aid in the installation of conveyor belts and in their maintenance.

The conclusions and impact of the prototypes research is discussed on T5.1 where different tests of the prototypes and concepts detailed on WP2 are described.

2.3 WP3 – EARLY DETECTION: INVESTIGATION OF ADVANCED DISCRIMINATING FIRE DETECTORS AND THEIR APPLICATION

2.3.1 Objectives of WP3

The objective of this work package was the investigation of early detection of fires on conveyor belts, through the study of fire detectors technologies, and the development of measurement devices and methods for detecting incipient fires in underground coal mines. Specific goals of this WP were the following:

- measuring fire signatures and point detector responses with a view to developing an advanced discriminating fire detector capable of the early detection of fires on conveyors;
- analysis and tests of various types of sensors for detection of products of combustion emitted from a fire source;
- test characteristics of an integrated merged visual-IR image fire detector within visual and infrared radiation of an object to be monitored;
- development of wireless heat detectors for temperature monitoring of conveyor belt elements.
- high reliability signal processing in a multi-sensor device for early fire detection; structure, technical documentation and manufacturing of a multi-sensor device conformity with ATEX requirements.
- location of fire detector devices along conveyor routes to provide effective fire detection;

2.3.2 Comparison of initially planned activities and work accomplished

Some anomalies were detected concerning the tasks and deliverables in WP3. D3.2 (report on transducers response/sensitivity) was numerated as D3.3 and is the deliverable corresponding to Task 3.4 (in addition to D3.4). D3.3 (report on merged visual-IR fire detection techniques) was numerated as D3.2 and is the deliverable corresponding to Task 3.2.

In the first semester of the project the duration of Task 3.1 and Task 3.2 (MRSL and UKC) was changed according to their needs and the hours associated. Both tasks would then have three quarters for each task (starting in Q3), which is more realistic taking into account the number of hours associated to both task are 1300 and 1400 respectively.

Task 3.2 was rescheduled. Despite the attempt to start this task early, as referred to in the previous point, it did not prove possible in practice to make staff available to work on the task before the scheduled start date. Reasonable progress had been made on the task but in order to complete the scheduled work it was necessary to work for two quarters extra quarters (Y2/Q2, Q3).

The work done under Task 3.3 (wireless heat point detectors) was finally reported in D3.4. Although at the start of the project it was decided to be reported under D4.3, the initial planning was correct and the description of the task fits more in D3.4, especially for the conclusions regarding the placement of sensors, which was one of the main aims of the deliverable

In order to calculate the fire hazard indexes of multisensor (Task 3.4), as well as the placement of multisensor devices and heat point detectors along conveyor belt lines, it has been necessary the underground tests, which correspond to the work to be done within the WP5. Hence, the delivery of D3.4 was put off to the end of the project.

2.3.3 Description of activities and discussion

Task 3.1 – Measurement of fire signatures and point detector response

State of the Art Review

An appraisal of the state of the art in fire detection was carried out to identify technologies for the early detection of incipient fires on conveyors. Initially the broad categories of flame sensors, smoke sensors and product of combustion (POC) sensors were appraised. It was concluded that POC sensors are the most suitable although smoke sensors were not totally discounted because there is an unclear dividing line between an incipient fire (that produces gaseous POCs) and a smouldering fire (that produces smoke which, initially, might be invisible).

The following POC sensor technologies were appraised in more detail: Infrared absorption, metal oxide semiconductor (MOS), electrochemical, and catalytic pellistor. For each technology the principle of operation was investigated, suppliers of commercial products were identified, and the advantages and disadvantages were documented. The following conclusions were drawn:

1. It is unlikely that a single sensor will be able to sense incipient fires involving all possible fuels and not cause false alarms with common non-fire gases so multiple sensors will be needed. This is consistent with the rationale of developing a multi-sensor device. Because multiple sensors will be needed the cost of the individual sensors becomes very important so low-cost sensors (i.e. semiconductor or catalytic pellistor) are recommended. However, the pellistor offers poor performance in three respects, so was not considered further.
2. MOS sensors have a medium to poor rating for specificity. However, there are indications that, by using multiple MOS sensors, sufficient specificity could be achieved. Indeed there are numerous reports of high levels of discrimination being achieved using an array of MOS sensors together with a neural network. The consequential requirement for rather more local intelligence isn't considered onerous since a neural network can be implemented on low-cost hardware.
3. Taking these considerations into account, MOS sensors have considerable merit and should be considered in the design of multi-sensor devices such as the one developed in Task 3.5.
4. Other POC sensor technologies that are also worthy of consideration, given that they score highly in at least two characteristics, are electrochemical and infrared absorption. IR absorption is of particular interest for CO_2 detection because MOS sensors are not able to detect this gas.

EMAG, who are primarily responsible for the development of the multi-sensor device in Task 3.5, had considerable experience of electrochemical sensors, IR detectors, ionising smoke detectors, and thermal sensors. However, little use has been made of MOS sensors in the Polish mining industry and (with the notable exception of the now obsolete FIDESCO instrument in the UK) little has been reported from elsewhere in Europe. Because of this limited experience of MOS sensors for the early detection of fires in European mines, and because of the potential advantages, a follow-up programme of experimental evaluation work was carried out. The aim of these tests was, potentially, to offer additional options for the design of the multi-sensor device with the potential benefits of reducing the component cost and reducing the maintenance overhead.

<u>Experimental Evaluation of MOS Sensors</u>

Several MOS sensors from market leader Figaro Engineering Inc were evaluated with incipient fires involving conveyor belt material, coal, wood, grease, and diesel fuel, with and without diesel exhaust and hydrogen (to simulate battery charging) which might produce false positives or false negatives. This work was carried out in UK Coal Mining Plc's training gallery at Welbeck Colliery.

The photographs presented as Figure 2.3-1 show the tests in progress, and Figure 2.3-2 is an example of the results from one test run.

Figure 2.3-1: Evaluation of MOS Sensors in the Welbeck Colliery Training Gallery

These tests showed, as expected, that MOS gas sensors exhibit poor selectivity. However, it was recognised at the outset that, because of their advantages of low cost and low maintenance overhead, it would be viable to use several MOS sensors if necessary. The results suggest that it might be possible to design a fire detector, based on MOS sensors, using combinational electronics, probably a neural network. Such a multi- sensor device would be able to detect incipient fires involving a variety of fuels (with the exception of a grease fire) while discriminating against the use of an FSV and battery charging. In order to be able to be more definitive, though, it would be necessary to conduct a more extensive set of tests, involving a greater variety of conditions, and process the data using neural network software.

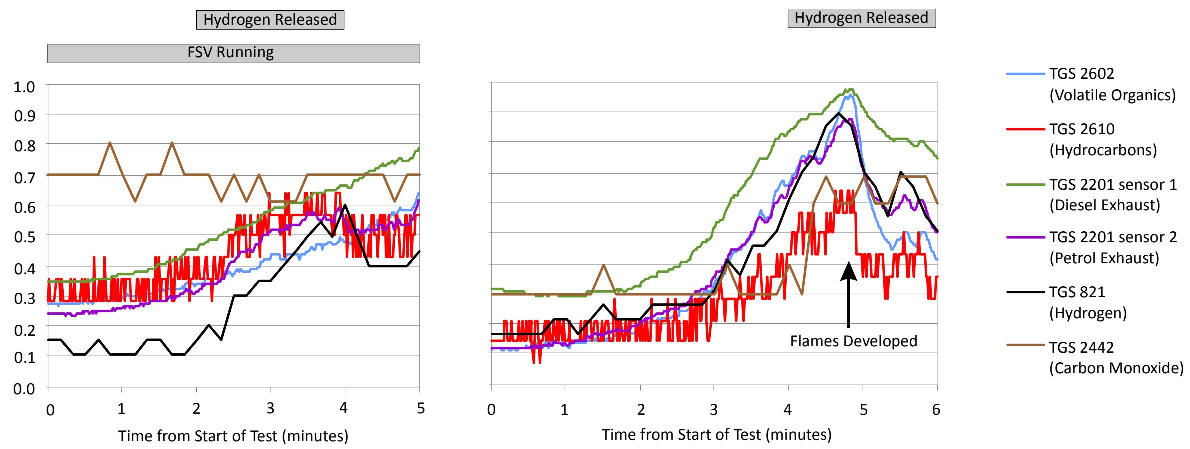


Figure 2.3-2: Results of the Evaluation of Six MOS Sensors in Response to a Wood Fire

However, the aim of Task 3.5 was not necessarily to design a fire detector that uses a single sensor technology, indeed the stated aim, which takes into account the fact that the optimal solution would probably involve a mix of sensor technologies, is to produce a "multi-sensor" device. In fact, the specific aim of the work reported here, bearing in mind that there is little experience of the use of MOS gas sensors within the European mining industry, was to evaluate the technology so that its potential, in combination with other sensor technologies, could be assessed. Accordingly, MOS gas sensors were recommended for consideration as part of the mix of sensor technologies within the multi-sensor that would subsequently be developed in Task 3.5.

Task 3.2 – Development of a merged visual-IR image fire detector

Merged-IR Imaging Technology

A review of merged visual-IR imaging technology was carried out to examine the benefits associated with using merged visual-IR imaging for fire detection on belt conveyor drives. The review highlighted key advantages of blending high resolution imaging with infrared (at differing percentage levels) for early warning fire detection. As a result of the review it was proposed to investigate the potential advantages of adopting this technology in the mining industry through a series of tests using commercially available equipment. In terms of the test conditions, it was noted that the technical difficulties in being able to represent a full idler bearing failure on a belt conveyor within actual operating conditions were unfeasible, due to both safety and cost implications. Therefore, three scenarios were evaluated (1) Static heat source, (2) Friction heat source and (3) Dynamic heat source, at two locations: Welbeck surface coal preparation facility and a hard rock test mine.

Tests at Welbeck Surface Coal Preparation Facility

The limitation of the bespoke idler test equipment, as described above, is that it does not represent the nominal operating conditions of a full scale belt conveyor operating *in situ*. Therefore, in order to represent a 'dynamic heat source', i.e. scenario (3), it was decided to perform a series of measurements using the thermal imager at a surface coal preparation facility.

Tests were carried out at the surface coal preparation facility at Welbeck Colliery, operated by UK Coal Mining Plc. The thermal imaging technology used was a Fluke Ti25, incorporating IR-Fusion ® technology, supplied Radir Ltd in UK. IR-Fusion is Fluke's own implementation of merged visual-IR technology. Figure 2.3-3 shows a belt conveyor image captured from a distance. The instrument automatically detects hot spots, and using the merged image setting, the location can quickly be established. The results have shown favourable results in using hand-held equipment to quickly establish potential failure points (heat sources). This work was considerably further examined using the dedicated bespoke idler testing equipment that has been constructed during the project.

(a) Visual Only | (b) Merged image – Full visual with 50% IR | (c) IR Only

Figure 2.3-3: Full Belt Conveyor IR-Fusion Test

<u>Merged visual-IT tests using belt roller test frame at the CSM Test Mine</u>

Figure 2.3-4:Belt roller test frame

The test frame comprised ABB 1.5 kW 3-phase motor, an ABB 3-phase inverter drive for motor, and belt with tension adjustment to drive various sections of the rollers/idlers.

A series of tests were carried out at the CSM (Camborne School of Mines) test mine facility, in the UK, using de-commissioned rollers/idlers. The Fluke Ti25 and Ti50 merged visual-IR thermal imaging technology were both used for evaluation and comparison during the tests. The Ti25 and Ti50, along with a description of the main features, are shown below in Figure 2.3-4.

The tests were carried out under controlled conditions in the test mine, with varying parameters including lighting condition, heat source and distance of temperature measurement/detection. The heat source was initially generated through drilling into the bearings and introducing sand, in order to replicate bearing failure. Further tests were carried out using a blow torch as an external heat source to raise the temperatures significantly higher, and beyond the 150 °C point.

The standard EN50303:2000 (Group I, category M1 equipment intended to remain functional in atmospheres endangered by firedamp and/or coal dust) states that ignition of a coal dust layer can occur at temperatures below 200°C, and its prevention is achieved by limiting all exposed surfaces where layers might form to a temperature of 150°C.

A bespoke frame was constructed to house two types of rollers/idlers, as typically used in UK collieries – straight-section and v-section. The test frame equipment is shown below in Figure 2.3-5.

Fluke Ti25 main features: IR-Fusion™ (merged visual-IR), 9 Hz refresh rate, moderate resolution, view moving images and store still images.

Fluke Ti50 main features: IR-Fusion™ (merged visual-IR), 50 Hz refresh rate, high resolution, view and store video images.

Figure 2.3-5: Fluke Ti25 & Ti50 Thermal Imaging Equipment

The results from the test with varying distance against temperature detection, for both the Ti25 and Ti50, are shown below. The graph in Figure 3-6 are the measurements taken using only the friction heat source and Figure 3-7 are the measurements taken using the blow torch. These results only show measurements taken under medium lighting conditions. Overall, the results demonstrated relatively high detection distances achieved using both Ti25 and Ti50. The Ti50 maintained a higher degree of accuracy at these distances due to the higher resolution and FOV (field of view).

From an application perspective, the Ti25 is better suited to providing rapid 'heat spot' detection capabilities for hand-held type applications. The Ti50, with higher resolution and refresh rate (50Hz), would allow further signal processing of image in a wider FOV to detect a heat source from further distances, and may suit a fixed infrastructure type application.

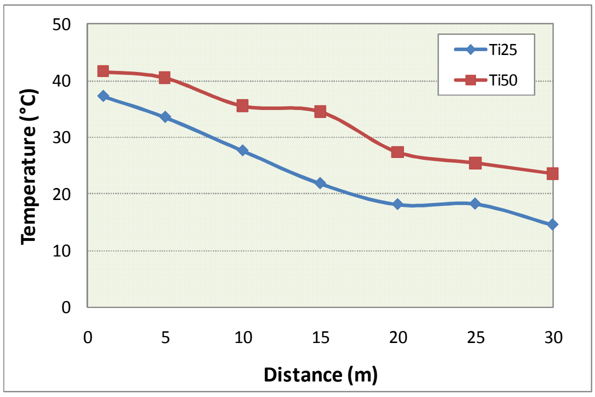


Figure 2.3-6: Temperature vs. distance tests using friction heat source in medium light

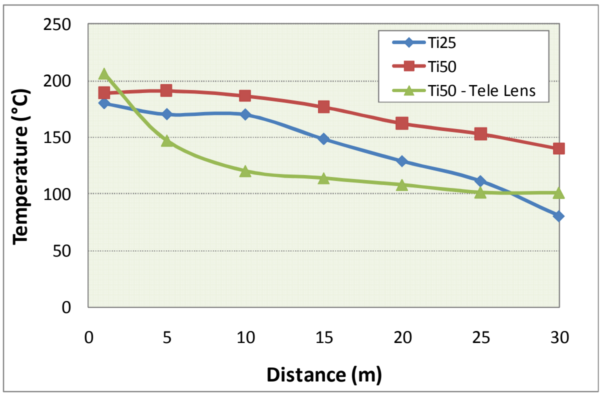


Figure 2.3-7:Temperature vs. Distance tests using blow torch heat source in medium light

For early detection of fire sources from belt conveyors, there are essentially two types of applications: (1) hand-held periodic survey (similar to maintenance observations/practices already used with IR technology), and (2) fixed-cameras at various locations with image processing for trigger point alarms. One of the main issues with providing a fixed infrastructure solution would be the cost. For example, the Fluke Ti50 that has been tested is essentially designed as a high-value hand held instrument. Using such technology in the coal industry would require ATEX certification, which would significantly increase the cost. From the tests carried out, it was shown that a key advantage of using merged visual-IR technology in this type of application is that the user can quickly physically locate hotspots. Although for fixed infrastructure, requiring several different installations, this may not be economically viable. However, there are other IR systems (not merged visual-IR) available on the market, which are specifically designed for fixed infrastructure installations. The Raytek ThermoView Pi20 is an IR thermal measurements instrument designed to run across an Ethernet network in industrial environments (IP54 rated). Achieving ATEX certification for such a device would be more feasible; however, this would need careful consideration beyond the scope of this project. In a fixed location, it possible to account for the lack of a visual image using image processing and the fact that the much of the environment inside the FOV would be relatively static. Therefore, application such as this would merit further work in the future.

Task 3.3 – Application of low cost wireless heat detectors

A mechanical failure within the conveyor system or frictional overheating in the belt drive area or near idlers along the belt structure can cause enough heat build up to start a coal fire. Although heat sensors can be used for early detection of fire, experience has shown that CO and smoke detectors, when used at proper spacing and with appropriate alarm levels, are more effective, providing better results in the early detection of fires than heat sensors. Litton and Lazzara [8] conducted experiments to determine the alarm times of smoke, carbon monoxide sensors and point type heat sensors while slowly developing coal-conveyor belt fires. The results of the experiments show that smoke and CO sensors provide earlier warning than point heat detectors. Results from those tests also present that the success rate of the point heat detectors decrease when the air velocity increases.

Nevertheless, a heat activation system would not only be capable of warning and signalling the presence of a developing fire, but would also serve as a method to help identify the cause and the location of the fire. In short, wireless point heat detectors would not be effective for early fire detection, but can be very useful when the fire is more developed.

The monitoring system will always be based on using discrete temperature sensors, wireless as data transmission media and low cost devices. The development of the system is based on the next key points: sensor element, processing and transmission unit and energy source.

Prior to design the electronic circuit of the wireless node, a testing board was developed. This board is basically composed by a low power consumption microcontroller and a multi-socket to allow different radio modules to be plugged in.

This next version of the device (Figure 2.3-9) was designed to be used with the SHT75 temperature from Sensirion manufacturer (Figure 2.3-8) and humidity sensors. This kind of device provides a wide range of temperature measurement (from -40ºC to +123.8ºC) with better than ±0.5% of accuracy in the central region of its measurement range. However, the most important feature provided by these sensors is a repeatability of ±0.1ºC due to the fact that in the aimed application the most important parameter is the evolution of the temperature against time instead of the absolute temperature value.

Figure 2.3-8: SHT75 Temperature sensor in a steel shell

Figure 2.3-9: Wireless sensor node

The communication infrastructure using wireless transmission system (Figure 2.3-10) consists of a wireless network composed of:

- A coordinator, which will communicate with the wireless nodes and the computer data acquisition application.
- The discrete temperature sensor nodes distributed along the conveyor belt line.

The function of the system is to gather the values from the temperature sensors in each portable device through the coordinator. This information will be received by a computer, and can be processed by a stand-alone application or be integrated in a SCADA system. Additional information of using this topology is reported in the Appendices Section 6.4.4 .

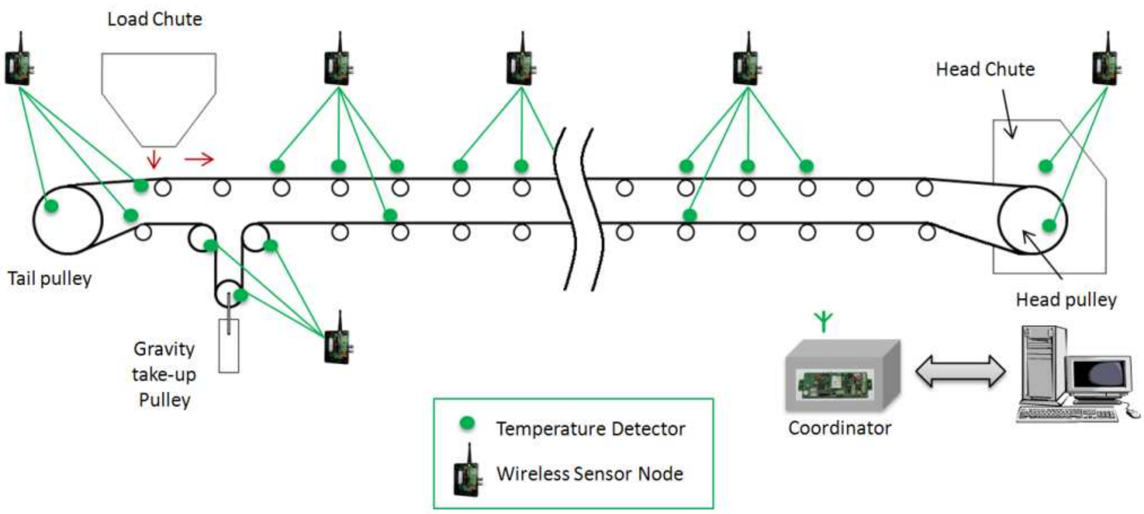
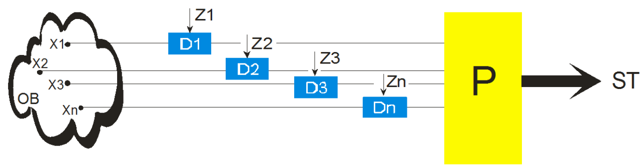


Figure 2.3-10: Wireless heat point detectors system

Task 3.4 – Development of signal processing and guidelines (layouts) of a multi-sensor meter for fire detection in belt conveyors

A method of signal processing was developed on the basis of the results of the tests and research work. The signal processing aims at determination of fire hazard states of an object to be protected on the basis of independent analogue signals.

The structure of the signal and information flow in the multi-sensor device is presented below in the Figure 2.3-11.



OB: object to be protected;

Xn: parameter to be measured (characteristic parameter for the phenomenon);

Zn: disturbances of measurements;

Dn: measuring detectors;

P: signal processing functions;

ST: states of the object to be protected and of the multi-sensor device (normal, warning, alarm, failure).

Figure 2.3-11: Structure of signal and information flow in the multi-sensor device

The determination of the states of the object and the multi-sensor device is realized by the module P (Figure 2.3-11). The functions performed by the module P and the algorithm of signal processing (schema presented in Figure 2.3-12) are described more in detail in the appendix section. Additionally the criteria of placement of multi-sensor devices is analysed as an Appendix.

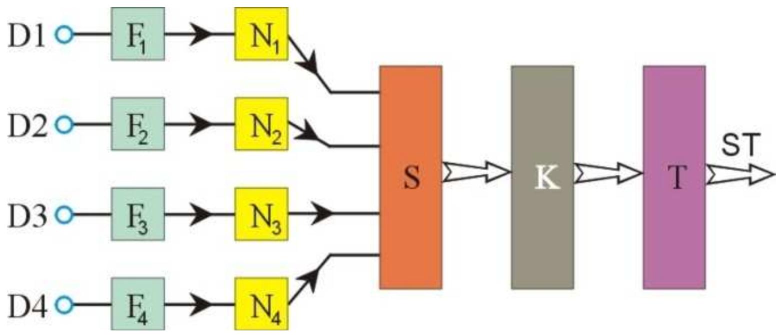


Figure 2.3-12: Algorithm of signal processing in the multi-sensor device

Figure 2.3-13 and Figure 2.3-14 present time diagrams as well as spatial and time-spatial distributions of fire hazard indexes for the results gained at the tests made in the experimental adit in CSRG Bytom (Poland). The results of the test #2 are presented. In this test the decrease of mass of a non-flammable belt sample (Test No 2) was Δm=336,1g (m1= 365,1g and m2= 29,1g), which corresponds to a 92,1% decrease in mass.

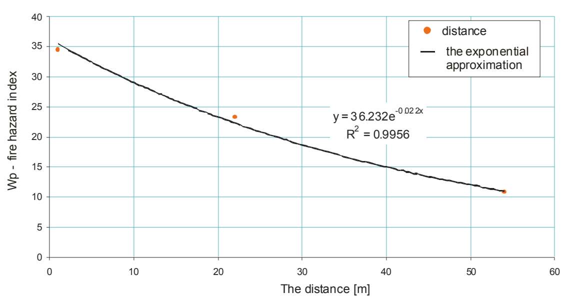


Figure 2.3-13: Distribution of a fire hazard index in an excavation after a time of 30 min from the beginning of heating a non-flammable belt – Test No 2

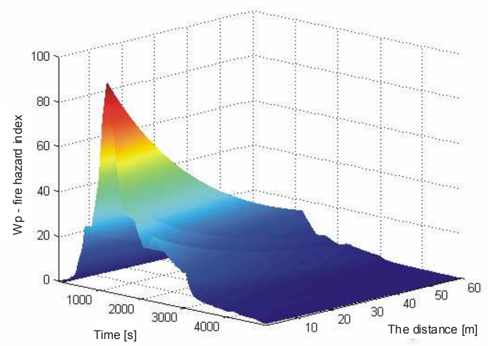


Figure 2.3-14: Time-spatial distribution of fire hazard index in an excavation for a non-flammable belt – Test No 2

The time functions of the fire hazard indexes allow the fires to be early and reliably detected on the basis of the values of the fire indexes and their increments (derivative). The time-spatial distributions allow the interrelation characteristics between the maximum value of the fire index W_p and the mass decrement of a belt sample Δm to be determined for the individual test stands. The Figure 2.3-15 presents a family of characteristics. On the basis of these it is possible to determine a maximum distance between the sensors for early detection of fires when the warning and alarm levels W_p and the sensitivity (emission of a belt sample Δm) are given.

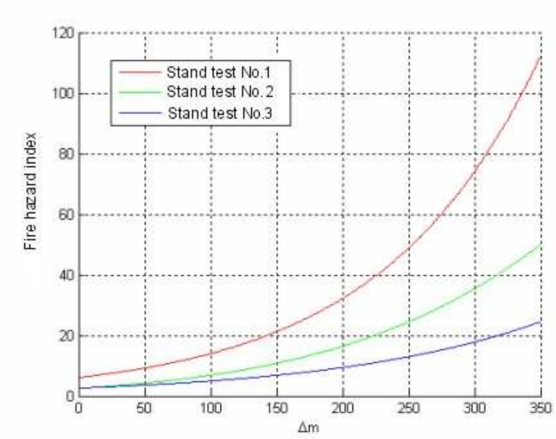


Figure 2.3-15: Family of characteristics of interrelations between the max value of a fire index W_P and a mass decrement of a belt sample Δm: for the individual test stands

The theoretical models and experimental data are the basis for the placement of multi-sensor devices in the area to be protected. The criteria of layout of the multi-sensor devices are as follows:

- minimizing the distances of multi-sensor devices from the sources of the potential fire hazard in the underground area;
- air flow direction;
- a parameter value of a fire source (concentration of gases, smoke, temperature) measured at a place of installation of a multi-sensor device should satisfy the following inequality:

$$x > x_{min}$$

where x_{min} is a minimum parameter value measured by a measuring sensor,

- a delay time of transport of combustion products should satisfy the following inequality:

$$t < t_{max}$$

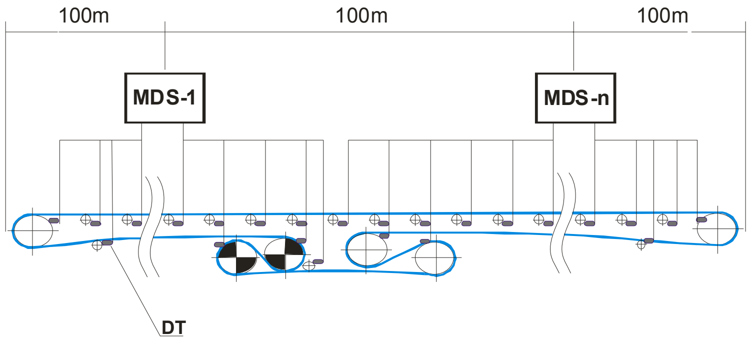
where t_{max} is a maximum time of transport of combustion products resulting from a distance and a manner for transport from a potential fire source to a measuring sensor. The allowable value of t_{max} results from the character of a potential fire source and is a significant criterion for early detection systems of open fires which develop very quickly.

- minimizing measuring disturbances acting on a multi-sensor device;
- destroying factors or the factors which have an adverse influence on the measuring devices.

Due to possible flexible configuration of a multi-sensor device, the different criteria may be accepted for the following types of detectors:

- for gas detectors (CO, HCN) the zone to be protected is determined only by a time of transport of gas products to a place of location of a sensor;
- for smoke detectors the zone to be protected is determined by a time of transport of smoke (fumes products) of a fire source and a drop of smoke concentration;
- temperature detectors of a belt conveyor construction should control the elements of conveyor construction which are especially put at a risk of damage.

An example of the layout of sensors is shown in the figure below.

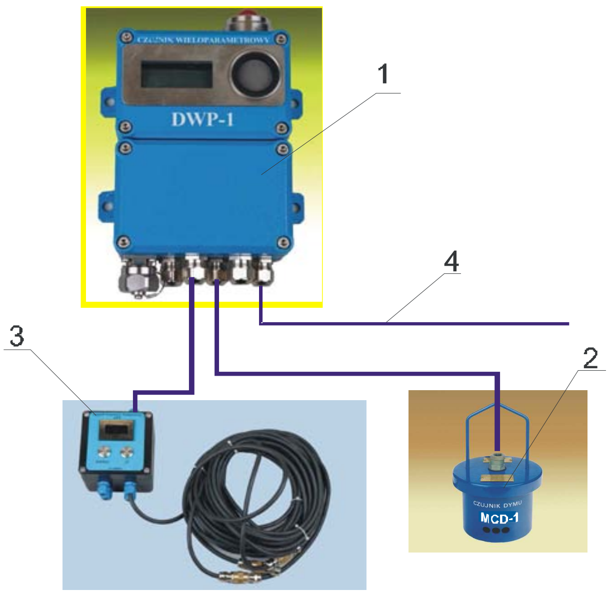


- MDS-n – multi-sensor device including:
- DWP – multi-parameter sensor,
- MCD-1 – smoke detector,
- CPT – temperature increment sensor
- DT – temperature sensor

Figure 2.3-16: Layout of multi-sensor devices along a belt conveyor route

Task 3.5 – Development of a multi-sensor meter and its tests and trials

The technical documentation and the prototypes of multisensor devices were produced in Task 3.4. An ATEX certificate has been issued for the multisensor. The multisensor device is presented in Figure 2.3-17, and its structure consists of the following elements: (1) multi-parameter sensor DWP-1, (2) microprocessor smoke detector MCD-1 and (3) temperature increment sensor CPT.



(1) multi-parameter sensor DWP-1

(2) smoke detector MCD-1

(3) temperature increment sensor CPT

(4) supply-transmission line

Figure 2.3-17: Structure of a multisensor device

<u>The multi-parameter sensor DWP-1</u>

The multi-parameter sensor DWP-1 (Figure 2.3-17 (1)) has been made in two versions:

- DWP-1v.1 – to be supplied from a surface supply-transmission line of a telemetric transmission central station;
- DWP-1v.2 – to be supplied from an intrinsically safe power supply; analogue output and RS 485 output.

<u>Temperature increment sensor</u>

The temperature increment sensor CPT consists of a basic unit and temperature detectors which are designed for measurement of temperature at selected points of a belt conveyor construction. It is possible to connect to the temperature increment sensor a maximum of four measuring lines each of which may include up to 20 temperature detectors. The schematic diagram of the CPT sensor is shown in the Figure 2.3-18.

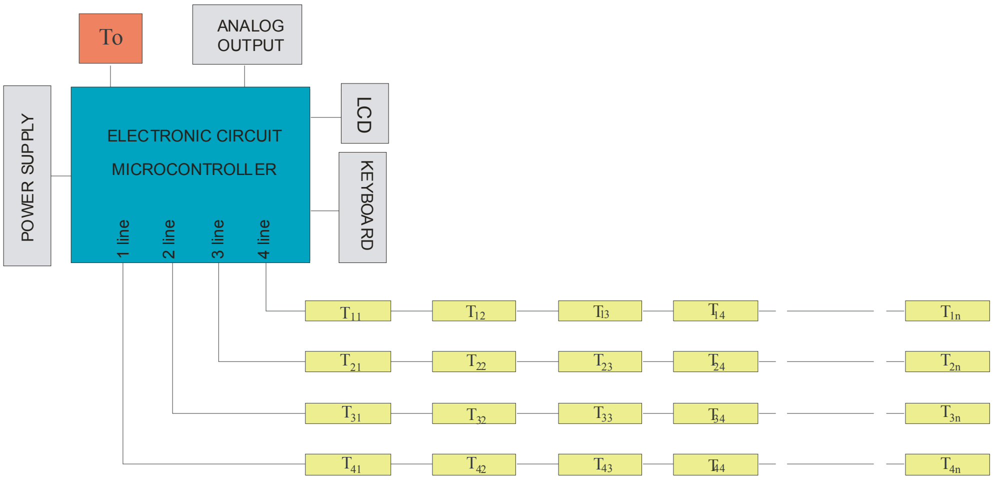


Figure 2.3-18: Schematic diagram of temperature increment sensor CPT

Figure 2.3-19: Temperature increment sensor CPT

Figure 2.3-20: A single temperature detector of CPT temperature increment sensor

The temperature increment sensor CPT is shown in the Figure 2.3-19 and a single temperature detector in the Figure 2.3-20. The CPT sensor signals when a temperature measured by a random temperature T_0 detector (installed at a belt conveyor construction) exceeds a set temperature reference value. The value of the increment temperature is set in the range of 4 to 20ºC with resolution of 4ºC by means of the push button at the front side of the CPT. The CPT sensor can control the temperature increments of up to 80 points, located at a belt conveyor construction.

<u>Microprocessor smoke detector MCD-1</u>

The smoke detector MCD-1 (Figure 2.3-21) is designed for protection of mine workings against fire hazards. It's adjusted to operation under conditions of high air humidity and temperature as well as a high and variable air velocity. The isotope smoke sensor type DIO-40W made by POLON-ALFA Sp. z o.o. in Bydgoszcz (Poland) and an electronic unit developed by EMAG are used in the smoke detector MCD-1.

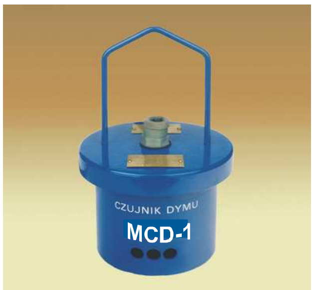


Figure 2.3-21: Smoke detector MCD-1

2.3.4 Conclusions

A review of POC sensor technology carried out in T3.1 identified MOS sensors as having several important benefits, most notably low cost and low cost of ownership. Because such sensors have had little application in the European mining industry, an experimental evaluation was conducted. As anticipated, MOS gas sensors exhibited poor selectivity to specific gasses however, the tests indicated that by using multiple sensors (quite feasible in the light of their low cost) and processing their outputs using a neural network, it would be possible to detect incipient fires at a very early stage while avoiding false positives or false negatives due to diesel fumes or hydrogen from battery charging. Although the MOS gas sensors were recommended for consideration as part of the mix of sensor technologies within the multi-sensor they have also some disadvantages, like low long-term stability, relatively high current consumption for heating the detecting element, and low temperature stability which results in a long time to stabilize the working point. The systems for early detection of fires should be originally very sensitive and this requirement is very difficult to meet using the MOS detecting elements with current parameters.

A study into the potential use of merger visual-IR technology for early fire detection of belt conveyor fires was carried out in T3.2. The key advantages of merged visual-IR technology are that it allows heat sources to be more accurately located in relation to its surroundings, and also that other relevant information can be visualised alongside the thermographic images. There are essentially two types of applications: hand-held periodic survey (similar to maintenance observations/practices already used with IR technology), and fixed-cameras at various locations with image processing for trigger point alarms. The results have shown that merged visual-IR technology would have significant advantages in both types of applications. However, the cost of installing such systems in fixed infrastructure type applications would need careful consideration, particularly versus using IR-only detection for fixed-infrastructure applications along with image processing. However, for hand-held or temporarily installed detection devices the merged visual-IR technology offers key advantages in being able to quickly locate and detect heat source for these types of mine safety applications.

From the point of view of our application in T3.3, where a huge amount of conveyor belt meters must be monitored and sensors must be installed each few meters, the use of a wired system would mean the installation of kilometers of mining cable and connectors with the subsequent costs. In addition, the conventionally used temperature sensors have a resolution of 0.5ºC in most of the cases, not accurate enough to detect a hot spot through a reasonable distance over the air. The developed wireless transmission system has been designed to fulfill the requirements of the application especially from the point of view of i) installation straightforwardness, ii) maintenance, iii) accuracy and iv) cost feasibility.

The research work in T3.4 resulted in a determination of the thermal and gaseous/smoke products produced during the development of a fire in a belt conveyor. Furthermore the time-spatial distributions of combustion products were determined along the workings, taking the ventilation air flow in consideration. The methods of measuring signal processing for early fire detection were developed on the basis of the research and testing work. The following fire indexes were developed:

- a simplified fire index calculated in the multisensor device based on average standardized values and filtered signals of carbon monoxide, smoke and hydrogen cyanide;
- a fire index calculated in the system by a "fuzzy logic" method – calculation based on test and research works as well model teaching.

The measuring results and calculated time-spatial distributions allowed us to define the principles of location of the sensors for the most effective fire protection of belt conveyor routes. The placement of sensors has to be close to the elements of belt conveyor construction which are especially a risk of damage. It has been considered that critical elements which are strongly recommended to monitor are (i) tail pulleys, (ii) head pulleys, (iii) bend and take-up pulleys, (iv) transfer points, (v) loading and discharge points and (vi) hydraulic and electrical devices.

The structure of a multisensor device was developed in T3.5. The multisensor device consists of: (i) a multi-parameter sensor DWP-1, (ii) a smoke detector MCD-1 and (iii) a temperature increment sensor CPT. The tests to approve the metrological and functional parameters of the multisensor device and its conformity with the ATEX requirements were made.

Software designed for measuring functions and signal transmission to measuring systems was developed. The multi-parameter sensor was developed in two versions (with different interfaces) to allow the operation with both monitoring systems, i.e. a methane-fire monitoring system type SMP-NT/* (Poland) and RELIA monitoring system (Spain).

2.3.5 Exploitation and Impact of the Research Results

Publications and Conferences Presentations

A summary of the work carried out in T3.1 and T3.2 has been presented and published in the following conference paper:

- Kennedy G.A., Bedford, M.D. and Jobling, S. (2011) Early-warning detection of fires in coal mines using POC sensors and merged visual-IR imaging technology. In: *Proceedings of the 34th International Conference of Safety in Mines Research Institutes*, 7-10 December, New Delhi India.

A summary of the work carried out in T3.4 and T3.5 has been presented and published in the professional journal ("Przegląd Elektrotechniczny") and in the following conference papers:

- S. Trenczek, J. Mróz, D. Babecki, P. Wojtas, Title: "Possibilities of protection of belt conveyors in underground mines" given at the International Conference of Copper Ore Mining in Lubin (Poland) 24-25.09.2009.
- Szczygielska M., Mróz J., Małachowski M. „Badania produktów rozkładu taśm przenośnikowych dla opracowania czujnika wczesnego wykrywania pożarów" Przegląd Elektrotechniczny Nr 10/2010 str.86.
- Mróz J., Broja A., Małachowski M., „Czujnik do wykrywania źródeł pożarów przenośników taśmowych", Cuprum 3/56/2010 Wrocław 2010.
- Szczygielska M., Kłosiński J., Małachowski M., „Badania temperatury konstrukcji przenośnika taśmowego w stanach awaryjnych" Materiały Konferencji EMTECH 2010 MiAG
- Szczygielska M., Mróz J., Trenczek S. „Badania produktów charakterystycznych dla źródła powstającego pożaru przenośnika taśmowego" XVIII Szkoła Naukowa „Podstawowe problemy transportu przenośnikowego" Szklarska Poręba 15 ÷ 17.09.2010.
- J. Mróz, M. Małachowski, A. Broja; „Czujnik wielodetektorowy do wykrywania pożarów przenośników taśmowych"; Seminarium ROW Rybnik 20.10.2010.
- J. Mróz, M. Szczygielska, A. Broja, M. Małachowski „Badanie i wykrywanie produktów powstających podczas pożarów przenośników taśmowych"; VI Międzynarodowa Konferencja „Bezpieczeństwo pracy urządzeń transportowych w górnictwie"; Ustroń 03÷05.11.2010.

The participants in conferences, i.e. mainly the representatives of mines have shown interest in the multi-sensor devices for early detection of fires in belt conveyors. Talks about possible implementation of early fire detection system have also been held.

Exploitation of the results

Multisensor devices and the wireless heat detection system are commercially available for early detection of fires, especially for conveyor belts placed in underground environments (ATEX).

2.4 WP4 – FIRE FIGHTING AND MANAGEMENT: APPLICATION OF VENTILATION CONTROL AND INERTISATION TO MANAGE AND SUFFOCATING CONVEYOR BELT FIRES

2.4.1 Objectives of WP4

The main goal of this WP was to develop specific methods and tactics for controlling, confining and fighting fires in conveyor belts, with a scope ranging from ventilation control to inertization and firemen protection. Specific goals were as follows:

- To determine the ways of application of ventilation for limiting gas and smoke expansion during fires in conveyor belts (especially in miners workplaces), developing new control algorithms.
- To establish the possibility of using inertization techniques for suffocating belt conveyor fires, and the plant and methods needed for carrying out this operation.
- To develop specific hardware and software for controlling the ventilation applying the above algorithms, including general connections to mine's SCADA and environmental control system
- To develop local fire-fighter thermal environment management techniques based on water sprays or water mists to ensure that access roadways are available and protected from excessive heat build-up. These measures will enhance the personal safety of firefighters and possibly extend considerably their safe working time at the fire location

2.4.2 Comparison of initially planned activities and work accomplished

The work followed the plan with the following exceptions.

As a result of the work done in Task 4.1, it was realized that it would be necessary to start Task 4.3 before it was planned, and also the duration of Task 4.3 would need to be longer. Therefore the advanced start of this task was Q1/Y2.

The required algorithm for Task 4.1 was completed and described in D4.1. Nevertheless, further research continued under this task (second stage of a fire) and it was finished under T4.3. Therefore, this mathematical model of the fire in a mine gallery with longitudinal ventilation was reported in Deliverable D4.3, and the description of the work carried out was included in T4.3.

The final part of the work which had been planned under Task 4.4 was actually reported under T4.5 because it was more closely related to that task. Although this represented a small delay to the final element of the work initially planned under T4.4, it permitted an early start of preparations for the experimental work.

2.4.3 Description of activities and discussion

Task 4.1 – Fire fighting and containing through ventilation control

Application of Ventilation Systems to Reduce Gas and Smoke Spread

The ventilation system plays an important role when a mine fire is initiated, since rapid spread of the fire and rapid contamination of the working places from the products of combustion, would result in a reduction in the escape time. Once a fire starts, the distribution of the airflow rate in a network changes, therefore a coordinated ventilation and escape route planning system is needed.

The aims of a ventilation sub-system that creates independently ventilated areas in mines are (a) to maintain the required air parameters in workplaces, and (b) to prevent the possibility of explosive gas mixtures from forming in those workplaces.

It was concluded that a simple ventilation network (e.g. one-way) cannot guarantee independent air in every workplace because workers in distant workplaces would receive polluted air. In the event of a fire, therefore, the entire mine would be at risk. Instead it is necessary to create a large number of independent air streams via a highly branched ventilation network.

The issue of the division of the network into ventilation areas is not a new issue; it has been solved by intuition for many years. Consequently, rules concerning such a division are present in mine ventilation literature and mining law. The division of ventilation networks should include the following:

- structural criteria – necessary to correctly manage the air distribution and simplify air distribution control, plus an analysis of the efficiency of applied changes (input function),
- hazard scale criteria – determination of threshold limit values for gases and dust in workings, the range of these concentrations and possible disturbances of air flow direction,
- hazard localization criteria – determination of groups of people who may be at risk at the same time (also including the possibility of creating safety devices to localize the hazard).

Existing workings and new workings (created only for ventilation purposes) are used for the construction of ventilation networks. There is often a conflict between the requirements of ventilation and other functions so it is often necessary to create a compromise solution. Accordingly it is necessary to consider this aspect during both normal and emergency conditions (e.g. during fires).

In practice, all real networks have dependent streams in the intake air and return air. Several networks have dependent streams in the return air (which exist between sub-networks of main fans). The determination of these streams is possible by analyzing either graphical or numerical models of the network. Methods that may be applied during the analysis of the network structure include (a) the division of the set into layers, (b) determination of the total cross-section of the network, and (c) determination of accessibility and availability relations in the set of networks.

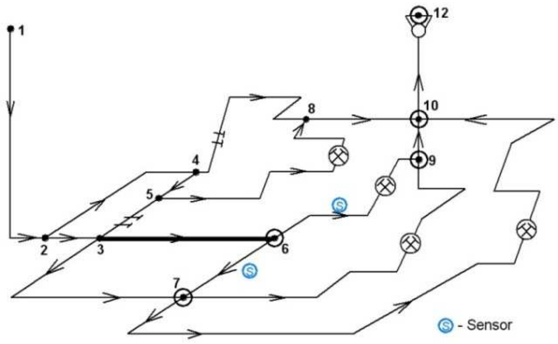


Figure 2.4-1: Example of unique determination of side branch 3 6 being the source of smoke based on information from the sensors

Networks without dependent streams in the return area have an associated risk in just one path. Networks that do have dependent streams in this area would have associated risks in more than one path. For networks that have inter-system streams the risk may appear in more paths which also include the paths in sub-networks of two or more main fans.

The initial stage in the development of conveyor belt fires is characterized by a state of balance between a heat source and flammable material in which a flame has not yet developed. Working on the assumption that the emission of smoke, gases and heat does not change the density of the air flowing from the centre of the fire, the air distribution in the ventilation flow network can be calculated.

It is further assumed that during the first stage in the development of a fire, there are sufficient conditions to permit its detection, by the use of a proper monitoring system. In the case of a rapid detection of the location of the ignition, it is possible to determine the zone of direct smoke emission and this should be considered as a hazardous zone for miners. In simple cases this determination is not difficult. However, in large mines it may be time-consuming. Optimization for large ventilation networks could be the subject of further work.

Using proper ventilation diagrams (space and canonic diagrams) it is possible to build accessibility and attainability matrixes. Such matrixes should be prepared by the mine ventilation services and need to be continuously updated, for example due to changes in the ventilation flow network resulting from the advance of mine operations, closure of abandoned workings, etc. In the case of fire detection these matrixes create a basis for PC simulations which allow the fire source to be localized and possible smoke and gas flow routes to be identified. It is also necessary to quickly determine escape routes.

Sometimes it is possible to obtain two or more potential smoke flow ways. In this case it is necessary to have additional technical data concerning the conditions in the ventilation network. Technical data refers to knowledge and experience concerning the structure of workings, their functions, location of equipment etc. At this stage of analysis, these factors must be considered manually, using the experience of mine engineers.

Air Power Caused by a Fire. Influence of Heat on the Airflow

Fires cause two opposite effects on the airflow (1) a thrust caused by the increase in the volume of the air and a reduction of its density, (2) the strangulation effect due to the head pressure loss of the expanded volume of air through the duct (the rise of the head pressure loss is proportional to the rise of the air volume).

If the fire is in a mine working with an upward flow, experience shows that the air force due to the fire is added to the airflow. But, if the flow is downward, the air force caused by the fire is opposed to the airflow so the likelihood of a U-turn is greater than in the first case.

Research in Germany in the ’60s made several conclusions about the effect of fires in the airflow of a mine that should be considered:

- An airflow inversion is likely due to heat in a mine working with a downward flow. If the flow is upward, the likelihood of a ventilation U-turn is reduced.
- Increasing the pressure produced by the main fan could stabilize the direction of the flow, preventing the inversion. In this case the rate of this increase should be assessed.
- Reducing or cutting the pressure produced by the fan could be a mistake because the possibility of an inversion rises.
- The pressure produced by the main fan could be increased by using a secondary fan.
- Isolating the area with ventilation doors could be another way to prevent a U-turn but the fact that there could be miners in the fire areas should not be ignored.

Analysis of the air power due to fire suggests that the fire can produce a constricting effect in the gallery, the strength of which depends on the location of the fire. This effect causes changes to the characteristics of the gallery. Changes to the head loss and air resistance can alter the mine’s ventilation flow network and the main fan requirements. It is necessary to work with the main fan or the gallery characteristics to redesign a ventilation network without air U-turns.

- When the fire causes a decrease of the airflow by 30%, a U-turn occurs. If the narrowing effect of the fire causes a head loss of $5kp/m^2$, that U-turn becomes stable.
- The stabilization of the direction of the airflow could be achieved in two ways. First, by laying obstacles in the air net. This reduces the constriction of the gallery and with it, the oxygen which is feeding the fire, thereby decreasing the air power of the fire. Second, by increasing the power of the main fan. Both strategies are equivalent.

Defining Escaping Routes

In emergency situations, such as mine fires, an emergency plan is required to allow miners to escape and prevent more areas from being damaged. An emergency plan includes procedures that will indicate to the miners the escape routes in case of a fire. An escape route could be defined as the exit route composed of branches not polluted by fire contaminants.

The design of the ventilation system is important in emergencies, not only to help in preventing the spread of fires but also during the course of the event. In case of a conveyor belt fire, it is important that a separation exists between the conveyor belt entry and the intake escape route.

The ventilation airflow could carry contaminated gases to working areas and expose miners to products of combustion. The mine ventilation plan should provide escape routes that can easily be accessed from either the intake or return airways of the mine. The aim is to make sure that there is an escape route which is free of smoke when a fire or explosion occurs. Therefore, in order to define a safe escape, is very important to provide an early warning of the fire, providing an escape route that is relatively free of smoke, and by responding immediately. The role of ventilation during emergencies, and the main aspects of emergency plans in mines have been studied more in detail in this task.

Task 4.2 – Other firefighting methods

Water Mist System Test in Fire Gallery

Tests were carried out in a fire gallery in Mina Escuela (León, Spain) – see (Tuñón & Morillo, 2003). Ten Hi-Fog spray nozzles (manufactured by Mariof Corporation) were distributed along the gallery and were fed via a pumping system. The installation required minimal space since it used small diameter tubes so that the water consumption and reservoir were also small. The high pressure water mist system reached an average droplet size of about 50µm. Different parameters, including fuel type, nozzles position, fire extinction and/or confinement, were evaluated.

During the tests the fire was allowed to develop for two minutes to achieve the highest energy before starting the extinguishing system. The air speed was the fastest possible. It was concluded that the system is an efficient method in confined spaces with low air speed. In these cases the system creates a consistent water mist which extinguishes the fire in a few seconds. If the air speed is above a certain value, the water mist is not formed because the ventilation causes the water to be dispersed. It was observed that the fire first increased in intensity and temperature due to the increase of oxygen, then the radiation heat was absorbed (evaporation is endothermic) expanding and extinguishing the combustion reaction by displacing oxygen. When the system was working the fire was extinguished in seconds but when it was stopped, the combustion reactivated.

Water Mist with Chemical Additives

A test rig was developed to investigate the novel use of chemical agents in spray mist form to combat spontaneous combustion fires. The chemicals were sodium silicate solution and a mix of sodium silicate solution with hydrochloric acid at a range of concentrations and mix ratios with pure water for comparison. The objective was to extinguish the spontaneous combustion fire in coal without the formation of 'water gas' or its constituents of hydrogen and carbon monoxide, each of which has an explosive range. A modified fire extinguisher cylinder containing one litre of liquid and pressurised to 15 bar with nitrogen was used to produce the spray. The solution was converted to spay (19ml/s flow) via an RXT 0510 hollow cone water mist nozzle (manufactured by PNR).

Tests involved a test rig (Figure 2.4-2) which consisted of a chamber where a coal sample, which has a high liability to spontaneous combustion, encapsulated in concrete, was sealed in position with fire clay. The coal sample (Figure 2.4-3) was exposed to air at each end to feed the fire and remove products of combustion, through a condensation unit to remove coal tar, to a point where gaseous POCs could be sampled. A thermocouple was placed through the casing so it could be positioned into the coal sample via a pre-drilled hole in the concrete tablet. This allowed the fire seat temperature to be monitored throughout a test. It was anticipated that spray effectiveness would be indicated by a temperature drop over a period of time until complete extinguishment.

Figure 2.4-2: Test Rig

Figure 2.4-3: Burning Coal in Test Rig

Tests showed that using a spray mist in any combination used in these trials can extinguish fires rapidly with very small quantities of fire fighting media. The most effective fire fighting medium was that of pure water in a spray mist form but the adverse effect is that hydrogen was given off during the application of the water mist. Hydrogen was also given off but to a slightly lesser degree with the application of a mist constituting 50:50 mix of sodium silicate solution and water. This appears to be related to using either pure water mist and/or the test sequence utilising a very high percentage water concentration in the spray mist. No hydrogen was detected when applying either the 100% sodium silicate solution or the 75:25 sodium silicate solution mixed with hydrochloric acid. Fuller details of the experimental results appear as an appendix in *Section* 6.3.1.

Fire fighting Using CAFoam

CAFoam, a synthetic foam concentrate intended to fight Class A fires developed by AUXQUIMIA S.A, has been demonstrated by HUNOSA to effectively and reliably extinguish fires in coal mines. It is intended for use in compressed air foam systems (CAFS). Added to water in low concentrations, it reduces the surface and interfacial tensions and increases penetration and spreading. It reduces water consumption, achieves faster extinction and makes re-ignition more difficult. It can be applied with standard low, medium expansion and high expansion foam equipment and spray nozzles.

Backfilling and Grouting Techniques for Firefighting

Underground utilization of waste has been applied to fire fighting. Solid and tight filling of voids around a fire area was shown to totally remove any possibility of the fire continuing or spreading. Preventative actions, like grouting of cavings or lining of workings, enable numerous other benefits not only related to fire prevention, thus making these measures effective and attractive for mine operators.

Some further advances in this use of grouting and backfill technologies can be expected by the introduction of mobile slurry preparation plants, which can be transported into any location and be ready to use in a short time.

Damming of Fire Fields and Excavations under Fire

In fires, without using active suppression, there is a need to isolate the region containing the fire with explosion-proof fire dams.

The preliminary conclusion is that to avoid the spread of fire it is necessary to conduct gas concentration measurements and proper fire index calculations. In the case of non-suppressed fire at the endogenous stage, there is a requirement to apply dams to avoid spread of combustion products to other parts of a mine and to allow the safe escape of miners. There are many kinds of dams that can easily be fitted depending on the particular conditions. Balancing of aerodynamic potentials around fire fields is another method of fire suppression. The method is based on pressure equalization to stop or limit air flow to the fire thereby causing self-suppression. Depending on the mining conditions, there are several methods of balancing the potentials. These include the application of the dams, lay-bys, regulation dams, auxiliary fans, and one-sided chambers.

Task 4.3 – Implementation of control algorithm

Mathematical Model of a Conveyor Belt Fire in a Mine Gallery with Longitudinal Ventilation - Development of Algorithm (Second Stage of a Fire)

A possible algorithmic description of the processes that occur in a ventilation network system during the second stage of a fire was assessed. The second stage of a fire is produced when the emission of smoke is intensive enough to change significantly the density of air flowing out from the centre of a fire and a reversal of air flow is potentially possible. Determination of smoke and combustion gas flows, as well as safe escape routes, becomes much more complicated in this case, even in relatively simple mine ventilation networks. The algorithm needs to determine potential pathways of flow of gases and smoke. It should also reduce the number of potentially probable variants to a single strictly determined route, by using ventilation system control tools.

A model of gas and smoke expansion over a ventilation network for an advanced phase of fire has been developed. Furthermore, the problem of the real-time response of the future system has been considered. Existing software tools often require additional analysis and determination of final results on the basis of knowledge and experience, which is beyond the existing level of algorithmization of the processes considered.

Another problem that was addressed was coping with the extension of the capabilities of the algorithms to the scale of large, complex mine ventilation networks.

The mathematical model of a fire in a gallery with longitudinal ventilation is similar to the model of tunnel ventilation during a fire and similar to the process of fire in any compartment with one horizontal size significantly larger than others and with one opening (i.e. a door). However, the model must fit certain mining conditions and there are several necessary assumptions. The model applied is the zone model, a type of deterministic model in heat theory.

The control volume (CV) comprises two layers (see Figure 2.4-4). The belt conveyor is located in the lower layer, and it is considered a rectangular box. Conservation of mass and energy are applied in the CV in order to obtain the equations involved during the early stage of a conveyor belt fire in an underground excavation, given a non linear model of fire spread in a gallery. It is assumed that the direction of the smoke produced during a fire is the same as the direction of the air flow. The equations that describe the temperature change over time in the upper and lower layers are given in differential equation form. The value of the temperature depends on the heat transported to the upper layer, mainly by convection (Hc) and radiation (E), from the fire. Radiation, convection and fire load can be written for a selected CV in any excavation with a conveyor belt by applying energy conservation in the CV (see Figure 2.4-5).

Full details of the mathematical model and its equations have been reported in Deliverable D4.3.

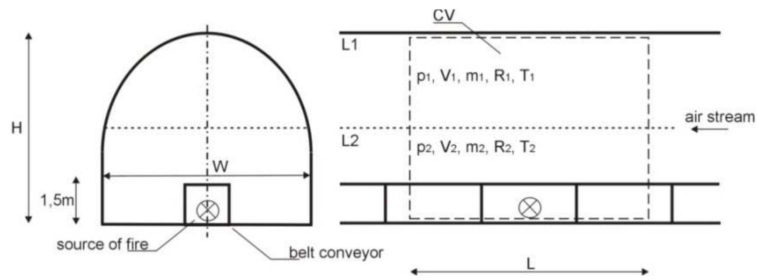


Figure 2.4-4: View of the Excavation

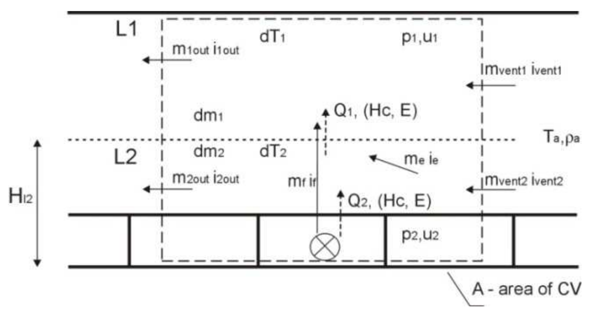


Figure 2.4-5: Energy conservation during early stage of the conveyor belt fire

<u>Smoke Distribution in a Ventilation Network During a Conveyor Belt Fire – Simulation Results</u>

The spread of gas and smoke in a real Polish coal mine (referred to in this report as Mine “X”) was studied. AERO software, produced by the Mining Institutes of SUT - IFK S.C., and POK "Zachód" Sp. z o. o. (from city of Ruda Śląska), has been used for calculation purposes. The software has implemented the algorithms described in above.

The area of direct smoke was determined by graph theory applied to the ventilation network. Starting from the first smoke-filled node (the fire source), the simulations allow possible smoke and gas flow routes to be identified. It also determines the escape routes.

The explanation of simulations carried out is described in the appendixes (see *Section* **6.3.2**) which shows one simulation in more detail. The results of the other simulations were reported in D4.3.

<u>Ventilation Management</u>

The aim of ventilation management is to develop a system that works in real time, serving data to a supervisory system, which will help the mine operators to take decisions during a fire emergency situation. The ventilation management system starts with the network ventilation design software (VenPri, developed by AITEMIN), which has to interact with the control environment system RELIA (to obtain information from sensors located underground). A real-time simulator integrated in the VenPri software calculates the gases movement, providing information on the escape routes in case of a mine fire in a particular location (an escape route is defined as a smoke-free route). Therefore, the results provided could be used to provide guidance on the method of evacuation.

The system has been designed according to open standards in order to facilitate its integration with any SCADA (Supervisory Control And Data Acquisition). For this purpose an OPC Server software tool has been developed. It allows the communications between the ventilation network and real-time simulation software, and the supervising and monitoring application (SCADA). In order to calculate the safest escape route the application is based on previous studies using simulations of mine fires under certain circumstances, theory and mine engineers' knowledge.

The final architecture for the system is presented in Figure 2.4-6. This scheme has been changed from the first one initially proposed, in which the ventilation management was integrated in one OPC Server. The idea is that instead of using a unique OPC Server to send and receive variables between the underground control environment system, the ventilation application and the supervising and monitoring application (SCADA), the OPC Server is split into two: OPC Server RELIA and OPC Server VENT. This simplifies the creation of TAGs, and allows independent configuration of the environmental control system and the ventilation network. Once both systems are defined, the ventilation network would be updated with the placement of the sensors (CO, smoke, temperature, etc.) along the branches of the previously configured network.

The VenPri software has been adapted to be used to control the network in real-time, therefore communicating with other programs or "drivers". Program data obtained through calculations in real time are stored in database tables which can be made accessible by other programs, setting temperatures in branches, giving certain values to smoke sensors or fixing air speed in a particular branch. VenPri can obtain the data needed to model ventilation networks in real time and store the results so other applications can access them and take decisions based on them (i.e. open/close doors, increase or decrease fan power, etc.). Note that the databases are only to store real time values and not historical data or alarms. That functionality is reserved with the supervisory system.

The sensor readings obtained in RELIA are sent to the network ventilation design software (VenPri) through the OPC Server. Based on these readings, VenPri calculates the gases movements, sending the results of the simulation to the SCADA. All the variables involved in this data transmission must be defined and configured previously by the expert engineer. After the configuration, the OPC Server is executed and will create the corresponding tags for the communication.

The OPC Server VENT has the following characteristics:

- Communication with VENPRI, Ventilation Design Software, developed by AITEMIN,
- Use of External Libraries (OPC Server Toolkit Software) to communicate with client applications (i.e. WinCC SCADA Siemens)

The OPC Server ventilation application (OPC Server Vent) for communication with the SCADA and the ventilation net software VenPri was fully developed and tested.

For the development of the SCADA a commercial tool has been chosen, in particular, the Simatic WinCC 7.0 design tool from Siemens was used. For its design, a HUNOSA coal mine in the Sueros area was chosen (see Figure 2.4-7).

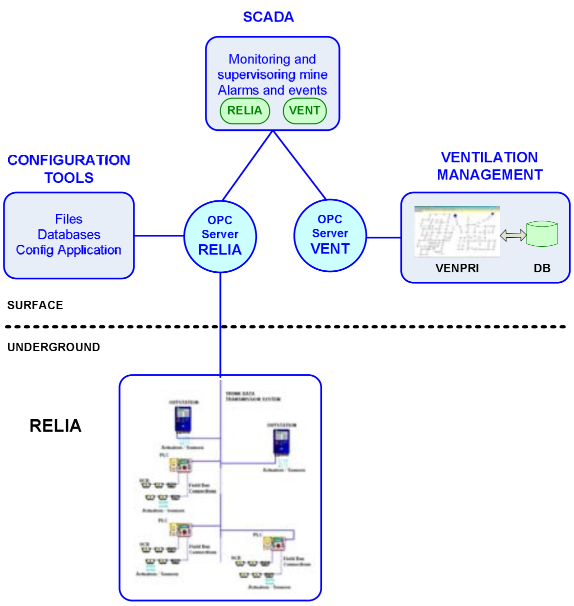


Figure 2.4-6: Ventilation Management

Once the ventilation network of the mine had been designed with the VenPri software, the graphical representation of the network was drawn in the SCADA. The SCADA communicated with both the Relia Environmental Control System and the VenPri Software. This allowed the control of the ventilation network in real time.

The SCADA system is able to set different parameters:

- Temperatures in branches (manually or by temperature sensors located in mine). If a temperature sensor is located in the branch, the temperature of that branch can be set to the temperature read by the sensor, and be updated for each iteration. If several temperature sensors are located in the airway, the mean temperature value will be calculated. The variations in the temperature due to a fire modify the airflows significantly.
- Fixed flow: if the air speed is known for a branch, the value can be set in the network properties, recalculating the ventilation and flow which the entire network must adapt.
- Giving certain values to gases sensors (CH_4, CO, CO_2, SO_X, NO_X, O_2).

The results of the real-time ventilation calculations (outputs of VenPri) are the following: (i) flow, (ii) air speed, (iii) fans depression and (iv) natural depression. These results cannot be changed. That information is transmitted to the SCADA system and would reflect in real time what is happening in the ventilation network.

The advantages of the SCADA is that supervisors in the environmental control room can easily monitor what is happening in the mine, and in case of fire, inform the engineer responsible for emergencies, providing assistance in taking decisions about evacuation.

For initial testing purposes a small mine was chosen and also drawn in the SCADA. The study of this mine, test and results are presented in deliverable D4.3. The development of the SCADA system of an HUNOSA coal mine is also under the work done in Task 4.3. The chosen mine was Pozo San Nicolás and Monsacro (both coal mines are connected), which are unified into Sueros Area (see Figure 2.4-7). The ventilation supervisory system will be integrated into the mine SCADA which is installed in the environmental control room at corresponding HUNOSA coal mine. The integration of the system in the real mine was made under WP5

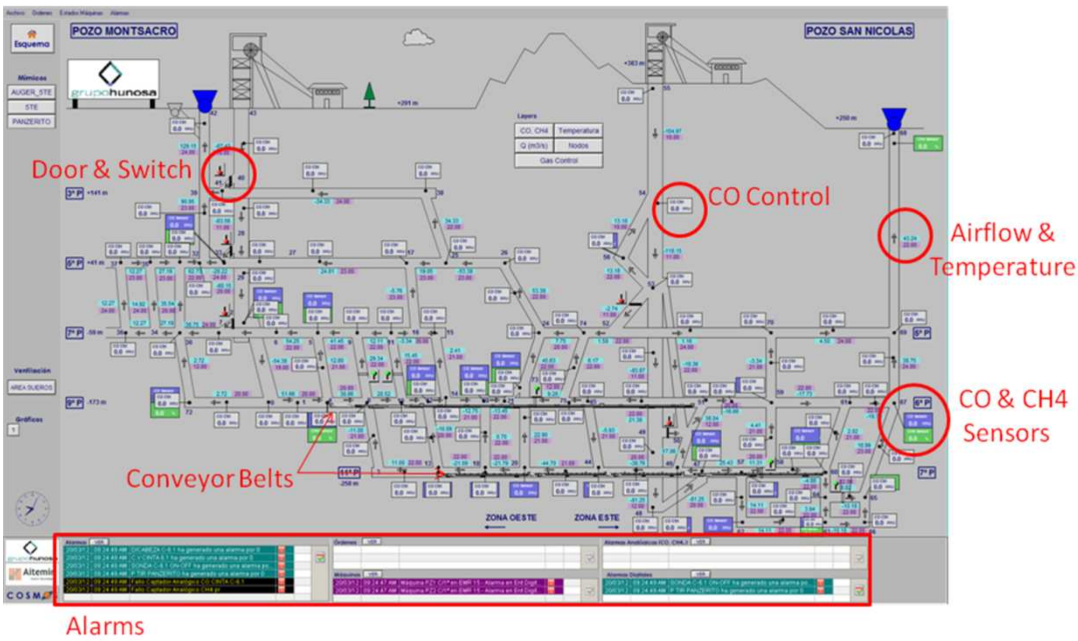


Figure 2.4-7: SCADA - Ventilation Scheme of Area Sueros Coal Mine (HUNOSA)

Task 4.4 – Review of heat strain potential and mitigation options

Exposure to Radiative Heat Sources

Excessive exposure to heat can inflict heat related illness (hyperthermia), skin burns and burns in the respiratory tract. For prolonged exposure to a hot environment the risk increases for increase in the clothing ensemble and is further increased by high activity and high moisture content of air. The risk models for this have been considered under RFCS SAFETECH and RFCS EMTECH.

A literature review has shown that at dry air temperatures above 120°C, burns are inflicted to naked skin. The heat transfer to the skin increases with increasing air humidity thereby increasing the risk of burns. A higher degree of clothing increases resistance to burns, in contrast with hyperthermia, where a high degree of clothing increases the risk. Burns to the respiratory tract may have a lower relevance because they never occur in the absence of skin burns so limits designed to protect victims from incapacitation by skin burns would protect them from respiratory tract burns. Breathing apparatus wearers would have at least short term protection from the respiratory tract burn potential of a hot and humid atmosphere. Where the environment contains significant moisture or steam, the heat stress by convection is increased. Steam burns result from condensation associated with large heat transfer to the skin. Target limits for firefighters in tunnels are poorly documented in the literature and are often prescriptive and not performance based. For firefighters tackling fires in tunnels an air temperature ≤ 100°C and radiation ≤ 5 kWm kWm^{-2} has been recommended, and for personnel with light clothing ensembles the figures are convection temperature ≤ 60 °C and radiation ≤ 2 kWm^{-2}.

The Use of Personal Cooling Systems

In general, underground rescue teams do not employ specialised clothing providing total coverage and protection against radiative heat loads from open fires because of the common requirement for an extended energetic walk. The factors determining imposed heat include: air temperature, radiant heat, air water vapour pressure, air velocity, metabolic heat production, body surface area exposed, and clothing insulation/permeability. Factors determining resulting thermal strain include: heat tolerance, increase of core temperature, exposure duration, skin wettedness, and vasodilation.

The use of ice jackets in reducing heat load on men working in hot conditions has been investigated for a number of years, and it has been suggested that unacclimatised personnel would benefit considerably from wearing pre-frozen jackets in wet bulb temperatures as low as 31°C. It has been shown that the physiological cooling response has a relatively long time constant, and that resting and recovery may require quite lengthy periods to accomplish cooling.

There remains a degree of uncertainty regarding the most effective means of achieving rapid cooling. Cooling methods include water spray, warm air spray, face fanning, rotary blade downdraft, whole-body liquid cooling garments, head cooling units, cooling vests, ice packs or towels, cold water immersion, and ice water immersion. In general, the impact of any cooling garments is likely to be modest in countering the significant potential radiative heat flux from developed open fires underground. In this respect, a more 'substantial' cooling approach is called for. This is reflected in subsequent work on assessing water mist spray cooling in Task 4.5.

The final part of the review work which had been planned under this task is reported under T4.5 because it is closely related to that task.

Task 4.5 – Protection of fire fighters using water mist techniques

Assessment of Likely Cooling Impacts Compared to Alternative Strategies

Prior to the start of practical work in Task 4.5 it was necessary to undertake some initial work, transferred from T4.4, to gauge the likely cooling impacts and the relationship with other cooling strategies. To date, the only relevant research which can be identified from the literature is that undertaken within EU FP5 Contract G1RD-CT-2002-766, UPTUN (Cost effective sustainable and innovative UPgrading Methods for Fire Safety in existing TUNnels). Here fixed zonal water mist fire protection schemes involving significant water tanking, pumping, admixing and delivery systems were examined (McCory T and Achille T, 2008; Wighus R, 2008). The generic scheme is shown below:

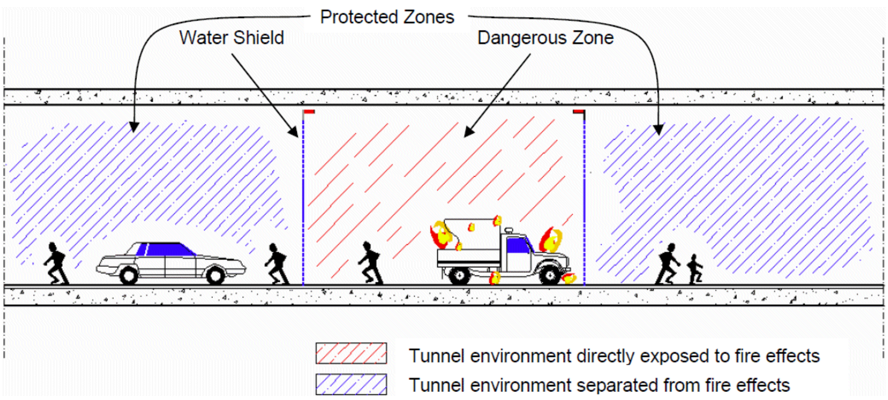


Figure 2.4-8: Generic water mist zonal protection scheme (from EU FP5 Contract G1RD-CT-2002-766, UPTUN)

The effect of water droplet size has been considered by Wighus (2008). With reference to the figure below showing various droplet size effects, two types of spray are used in water-based fire-fighting technology, differentiated by the droplet sizes of the water.

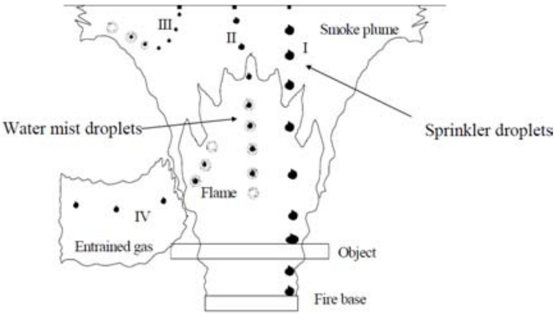


Figure 2.4-9: Destiny and effect of varying droplet size

The figure shows the destiny of droplets of different sizes, when the droplet is released into a fire plume. Droplets (I) represent a size intended to penetrate the fire plume, survive the travel from the nozzle to hit a target, with the intention to cool and/or wet the target. The effect of the droplet is primarily to cool an object or the fire base, or the pre-wet un-burnt material.

This is a typical intention of a sprinkler spray, for instance large drop sprinkler technologies. This spray however does not cool the combustion products much, related to the mass flow rate of water, since the surface area of water droplets is small. Droplets (II) represent a size intended to penetrate the fire plume to some extent, and to evaporate inside the flame and smoke plume. The effect is primarily to cool and inert the combustion zone, to reduce combustion and eventually extinguish the fire. The cooling effect of water is obtained both by a large surface area of droplets, transferring energy, and utilising the large quantity of energy related due to the latent heat of evaporation of water. Water mist systems normally utilise this droplet size as much as possible, to combine penetration ability of the spray with the cooling and inerting effect of water. Droplets (III) represent a size that has little penetration effect, but will rapidly evaporate and cool and inert the smoke with air and combustion products. Droplets (IV) explicitly utilise the principle of evaporation in the combustion zone, without the need for penetrating an opposed-direction smoke plume. This effect is obtained if the water spray nozzles are located relatively close to the possible fire sources, and which may require a predictable localisation of the fire base. The impact of water mist droplet size is profound.

Figure 2.4-10 shows the influence of mean droplet size on modelled evaporation time. Droplet lifetime (or time to act) here can be as little as 100ms.

While the fixed schemes developed for large arterial roadway tunnels under EU Contract G1RD-CT-2002-766, UPTUN cannot be employed in the mining context, where a mobile or transportable capacity is called for, there is significant promise offered by the approach advocated below.

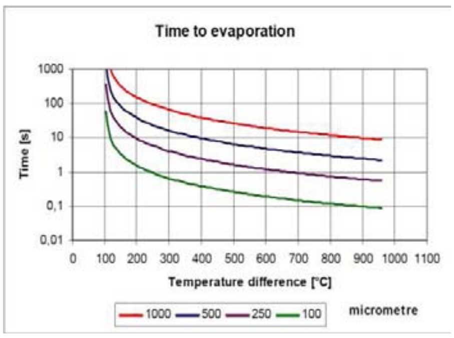


Figure 2.4-10: Effect of water mist size on evaporation time

Experimental Evaluation

The human body is designed to operate at 37°C. Background work carried out within T4.4, the later part of which was transferred to this task, confirmed that when the air temperature, combined with humidity, moves the Heat Stress Index above 32°C the human body becomes stressed, extracted from a NASA report (Roth, 1968), shows how this affects behaviour. Hyperthermia at or above about 40°C (104 F) is a life-threatening medical emergency that requires immediate treatment. The experimental work involved the evaluation on a system for cooling firefighters using a water spray mist.

	Heat Stress vs Productivity						
Effective Temp (°C)	23.9	26.7	29.4	32.2	35.0	37.8	40.6
Loss in work Output(Productivity)	3%	8%	18%	**29%**	**45%**	62%	79%
Loss in Accuracy(Mistakes)	--	5%	40%	**300%**	**700%**	--	--

Figure 2.4-11: Effect of Heat Stress vs. Temperature from (Roth, 1968)

A 30m long concrete lined gallery approximately 2.5m wide and 2.5m high was used for the experimental work. To simulate a mine roadway spontaneous combustion site, a 4kW propane gas radiant heater was used as a heat source. A second similar heater was also available to provide additional heat if necessary. An air flow was set up in this gallery to simulate mine ventilation.

The spray equipment comprised a 12 litre pressure vessel which supplied water to a hydraulic atomizer which is designed to deliver a very finely atomized 80° hollow cone spray, even at low pressure values. The nozzle contained a precisely machined insert with tiny passages, and an inline filter was used to try to minimise clogging. Three differently sized nozzles were selected from PNR UK Ltd.

Seven temperature sensors, providing a resolution of 0.1°C were being positioned within the gallery. The longitudinal spacing of the temperature sensors along the gallery was fine tuned following preliminary tests and some were placed at a different height. The longitudinal spacing of the sensors permitting an area extending 2m to 4m to be monitored. The output from the sensors and a humidity sensor were be logged for subsequent analysis. It was initially expected that the temperature would rise and then fall over a short duration after each spray burst and that it would be higher downstream than upstream. Accordingly, the multiple spatially-separated sensors would show a sequential fall and rise and this would show how far area of the expected cooling effect extends.

A series of experiments was conducted using combinations of three different sizes of nozzles and four different pressures (5, 10, 15 and 20 Bar). The droplet size (which is expected to have a bearing on the cooling characteristics) and the flow rate (which dictates the max spray duration for a given sized water reservoir) are a function of the nozzle type and pressure as shown in Figure 2.4-12.

	Pressure							
	5 bar		**10 bar**		**15 bar**		**20 bar**	
	Flow Rate (l/h)	**Droplet Size (µm)**	**Flow Rate (l/h)**	**Droplet Size (µm)**	**Flow Rate (l/h)**	**Droplet Size (µm)**	**Flow Rate (l/h)**	**Droplet Size (µm)**
RXT 0060 T1	4.65	106	6.57	68	8.05	60	9.3	N/A
RXT 0910 T1	70.5	182	99.7	126	122	112	141	N/A
RXT 1166 T1	115	190	182	132	223	117	257	N/A

Figure 2.4-12: Nozzle Characteristics for Water Spray Cooling

For each combination of nozzle type and pressure, several different spray burst lengths were tested (1, 2, 3 minutes) to measure the temperature reduction and hence effectiveness of the cooling process.

All the nozzles had a cooling effect, but some raised the humidity substantially, detracting from the improvement in conditions as shown in Figure 2.4-13.

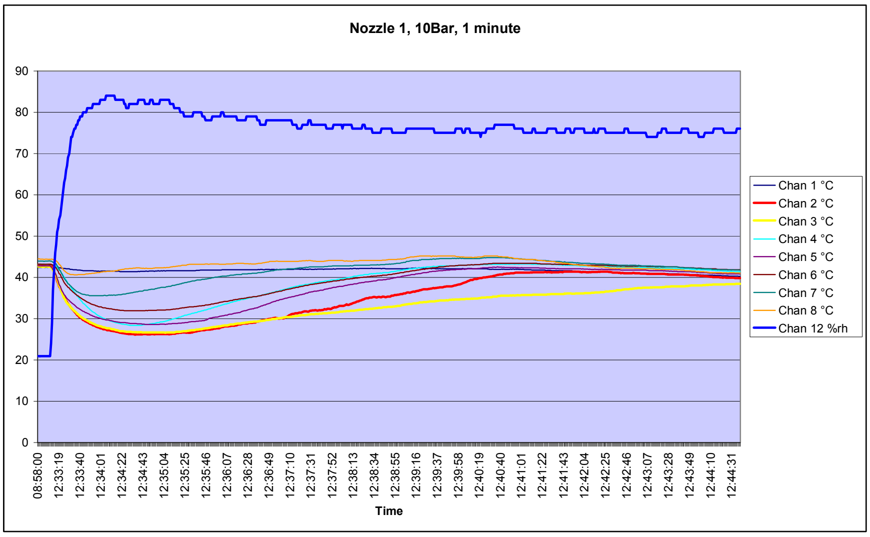


Figure 2.4-13: Temperature & Humidity vs. Time for Nozzle 1

The cooling effect improves with diminishing droplet size. The droplet size decreased from 190 microns with 10 Bar on nozzle 1 to 55 microns at 20 Bar on nozzle 3.The cooling effect achieved by nozzle 3 for a 5 minute burst (shown in Figure 2.4-14) at 20 Bar pressure, reduced the temperature in the vicinity of the ‘Rescue Worker’ from 47.3°C by 5°C for 8.5 minutes and by 10°C for 5 minutes, with a maximum fall of 14.42°C.

The lower flow rate of nozzle 3 at 20 Bar (0.15 litres / minute) gave a lower rise in the humidity in the test area, and there was little evidence of any ‘wetting’ effect on the apparatus or surrounding area. There are lower benefits with lower ambient starting temperatures.

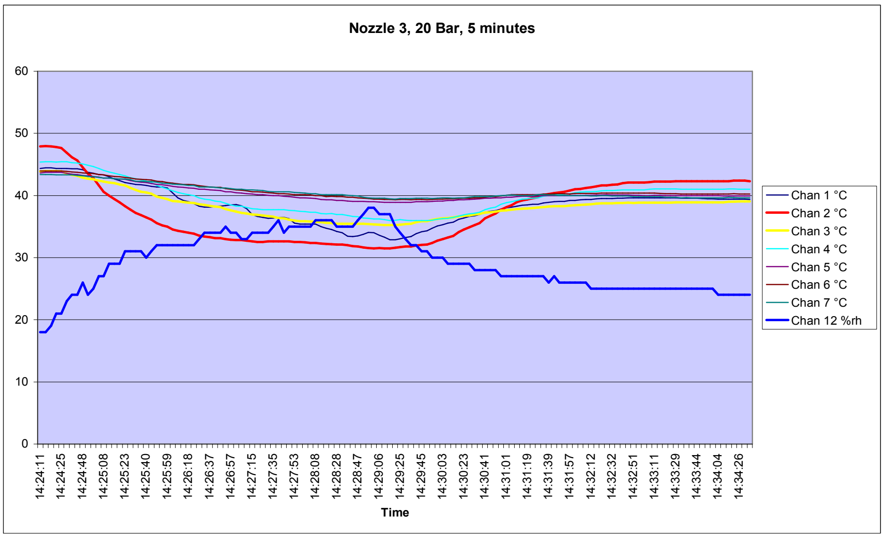


Figure 2.4-14: Temperature & Humidity vs. Time for Nozzle 3

The cooling effect achieved by nozzle3 would lower the Heat Stress Index by a sufficient amount to enable workers to extend time spent on site, even allowing for the increase in humidity. The effect is fairly localised, being limited to 1 to 1.5m in an airflow of 1.68m/S, but would be adequate to give amelioration of adverse temperatures.

A guide can be given by referring the temperature reductions to Figure 2.4-15 showing heat stress index and humidity.

Carbon Monoxide Removal using Water Mist Additives

No apparent improvement in the reduction of Carbon Monoxide was evident, using the nine selected additives at the concentrations chosen. It is felt that there is scope for further work in this area, with differing concentrations of the chosen additives, or a different range of additives.

Improvements in Mine Air Obscuration

Improvements in mine air obscuration by smoke, using water mist spays, was investigated. This appears to vary with droplet size, there being some benefit discernable, but there may be a conflict with cooling effect against smoke amelioration, for a given droplet size.

		Temperature (C)										
		21.1	23.9	26.7	29.4	32.2	35	37.8	40.6	43.3	46.1	48.9
Relative Humidity (%)	0	17.7	20.6	22.8	25.6	28.3	30.6	32.8	35	37.2	39.4	41.7
	10	18.5	21	23.5	26.7	29.4	32.2	35	37.8	40.6	43.9	46.7
	20	19	21.6	24.5	27.8	30.6	33.9	37.2	40.6	44.4	48.9	54.4
	30	19.4	22.8	25.6	28.9	32.2	35.6	40	45	50.6	57.2	64.4
	40	20	23.3	26.1	30	33.9	38.3	43.3	50.6	58.3	66.1	
	50	20.6	23.9	27.2	31.1	35.6	41.7	48.9	57.2	65.6		
	60	21.1	24.4	27.8	32.2	37.8	45.6	55.6	65			
	70	21.1	25	29.4	33.9	41.1	51.1	62.2				
	80	21.7	25.6	30	36.1	45	57.8					
	90	21.7	26.1	31.1	38.9	50						

Heat Cramps / Heat Exhaustion / Heat Stroke

Figure 2.4-15: Heat Stress vs. Temperature and Relative Humidity

It is felt that there may be an optimum droplet size which could contribute to the reduction of both temperature and smoke density without adversely raising humidity to an unacceptable level, but this would need to be considered as the subject for further investigation. Since this was a secondary requirement of this Work Package it was not taken further.

Prototype Fire-fighting Support Equipment

In pursuance of Deliverable D4.5, a prototype portable firefighting support system suitable for use underground in coal mines was developed. A 9 litre system using a standard firefighting container, fitted with nozzle 3 and modified for use underground, weighing 15kg and operating at 20 Bar will give an effective cooling mist for a period of around one hour.

Figure 2.4-16: Prototype Fire-fighting Support Equipment

2.4.4 Conclusions

The development of new algorithms for ventilation control during fires was assessed. The characterization of both the early development of the fire (i.e. when the flame has not yet been produced), and the second stage of a fire (i.e. where the emission of smoke is intensive enough to change significantly the density of air flowing out from the centre of a fire), was included.

Ventilation inversion has been analysed, since the reversal of air flow is more likely to occur as the fire progresses and there should be an actuation plan if an air inversion occurs.

Studies carried out have established the basis for the development of a ventilation management system, the main aim of which is to provide information about the ventilation state of the mine. This application interacts with ventilation network design software for computational calculations and obtains information from the environmental control system sensors in real time. The conclusions of the research are that the main factors that have to be studied when planning for a fire emergency situation are the following: (i) doors, (ii) fans and (iii) temperature increments (iv) natural ventilation. When a fire occurs, a first approach is to operate the ventilation system without changes, since altering the air direction could confuse and endanger mine personnel, as they are taught to escape through previously established escape routes. In addition, changes in the airflows could send contaminated air into work places, hence worsening the situation.

The results obtained from simulations of smoke distribution during a conveyor belt fires were used to analyse and determinate areas of direct smokiness considering different starting points of the fire. Ventilation of connected subnets allows the air flow to be controlled. The following conclusions were obtained: (i) It is possible to use mathematical modelling, and subsequently numerical modelling, for solving the problems of fire hazards involving belt conveyor; (ii) After the selection of points of ignition, possible variants of the spread of fire can be produced.

All the situations and variants must be studied carefully, and depending on the fire produced, it will be applied (if needed) the appropriate ventilation methods for fire hazard reduction (such as main fans, doors) according to authorized procedures designed by the engineering experts.

From the tests carried out in a fire gallery into the use of pure water sprays to combat fires, it was concluded that the system is efficient in confined spaces with low air speed but if the air speed is above a threshold, water mist is not formed because the ventilation causes the water to be dispersed.

A test rig was developed to also investigate the novel use of chemical agents in spray mist form to combat spontaneous combustion fires. The aim was to extinguish fires without the generation of water gas (hydrogen and carbon monoxide) which are potentially explosive and which can be generated when using pure water sprays. Although pure water was the most effective at extinguishing fires, hydrogen was given off. However, by using either a 100% sodium silicate solution or a 75%:25% mixture of sodium silicate and hydrochloric acid, no hydrogen was detected.

Other initiatives involved (1) the use of a synthetic foam concentrate to effectively and reliably extinguish fires in coal mine, (2) the use of waste to fill the voids around a fire area to totally prevent the fire continuing or spreading, and (3) the use of explosion-proof dams to isolate the region containing the fire. From the point of view of mining economy, utilization of waste in fill technologies leads to savings and a reduction of operational costs. Benefits can result from the use of saline mine waters and the replacement of cement fly by selected types of fly ashes.

Issues of the exposure of personnel to radiative heat sources and the potential of personal cooling systems were studied. Excessive exposure to heat can inflict heat related illness (hyperthermia), skin burns and burns in the respiratory tract. Detrimental effects are exacerbated by increases in the moisture content of the air, of the clothing ensemble, and by high activity. Recommended maximum air temperatures and radiation levels, consistent with the safety of fire fighters in tunnels, were obtained. In studying options for personal cooling systems, it was concluded that the effect of cooling garments or other personal equipment was likely to be modest and, accordingly, the more substantial approach described below was called for.

The theoretical requirements of water mist equipment for cooling firefighters were studied. It was recognised that the ideal droplet size would be a compromise in order both to penetrate a zone of high temperature gasses and to provide adequate cooling while minimising the volume of water.

A gallery was equipped with temperature and humidity sensors along its length. Gas burners simulated a fire and an air flow simulated mine ventilation. The spray equipment was pressurised and was used with three different nozzles each of which was tested at three pressures. Significant temperature reductions were demonstrated for a substantial period of time and the results allow the correct choice of nozzle type and pressure to be selected for a range of scenarios.

2.4.5 Exploitation and Impact of the Research Results

Publications and Conferences presentations

The following conference presentation was based on work carried out under T4.1.

> Sulkowski J., Musiol D., Wrona P. "Determination of Application of Ventilation System to Limit Spread of Gases and Smoke Spread During the First Stage of a Fire on a Belt Conveyor", presented at "Actual Problems of Fire Fighting in Mining", Brenna, Poland, 13-15th April 2011, pp. 375-387.

Further Works

In T4.3 the mathematical model for the second stage of a fire was presented. Further work would involve the modelling of a fire in an excavation at the second stage and its software implementation, which would mean a significant increment of the temperature until the flashover effect. Additionally, future work would involve the development of an escape system which could be controlled on-line based on the information from the sensors and personnel location, acting as a support in the decisions making in emergency situations.

Regarding the ventilation control some further work could be done. For simulations purposes, the SCADA is able to control the opening/closing of doors, although the reality is that the doors and the fans cannot be open or closed automatically from the environmental control room. In this way, the SCADA is working like a simulation tool with the VenPri software. In order to control the doors and fans further work should be made.

Further research can be made in carbon monoxide removal using water mist additives, improvements in mine air obscuration and in fire fighting methodology.

Exploitation of the Results

The prototype portable firefighting support system developed by MRSL is available for use internally and it is suitable for use in underground in coal mines.

The ventilation control algorithm is included in AERO Software, generating an improved version of the application. The software is already commercialized by SUT and widely used in Polish mines to help the mine engineers in ventilation management's solutions.

An enhanced version of VenPri software with the capability of interacting with commercial SCADA is available. VenPri software is already commercialized by AITEMIN and used in Spanish mines. The SCADA developed can be applied to other mines by using the same methodology of design.

2.5 WP5 – FIELD TESTS

2.5.1 *Objectives of WP5*

WP5 comprises the activities related with the integration tests and trials under real or near real operating conditions of the systems, devices and software developed more or less independently in the previous Workpackages. These tests combine the efforts of coal producers and research institutes to trial the apparatus and systems developed in the project. Therefore the goals of this WP were:

- Appraise the performance of small scale prototypes.
- Perform the final integration of the systems developed in the project
- Carry out field tests of all systems and devices
- Health risk assessment in real conditions.
- Critically assess of the results obtained in the project and extract conclusions.

2.5.2 *Comparison of initially planned activities and work accomplished*

Regarding the prototypes test, initially it was said that test where going to be carried out in real underground conditions. But, as it was specified in Section 5.2.2 where more complex prototypes than expected where implemented, even though the electronic control of such prototypes is ATEX compliant it was determined that the electric motors use to move the joints where dangerous to use in long testing runs inside a coal mine. That is why it was determined that a scaled simulation of a conveyor belt has to be implemented in laboratory conditions to test and analyze the operation of such prototypes.

2.5.3 *Description of activities and discussion*

Task 5.1 – Test of small-scale machine prototypes

Test of small-scale machine de-dusting prototype

The main uncertainty of the prototype was to know if the system is able to permanently accumulate the collected dust until the lifting system may be able to transport it. To test it the prototype has been installed inside trying to collect different amounts of very soft sand emulating what it would be to collect the sand from deposits accumulated under the conveyor belts (see Figure 2.5-1). The dust collection is made by a couple of circular blades just like the ones used in a commercial roadheader. From the conclusions obtained from the preliminary test, it was determined that a vacuum device was a probable better solution, not only to pick up the collected dust from the blades but also to transport it to a wagon or place it again over the main conveyor belt. An example of an ATEX certified vacuum conveyor is the model Volkmann VR170.

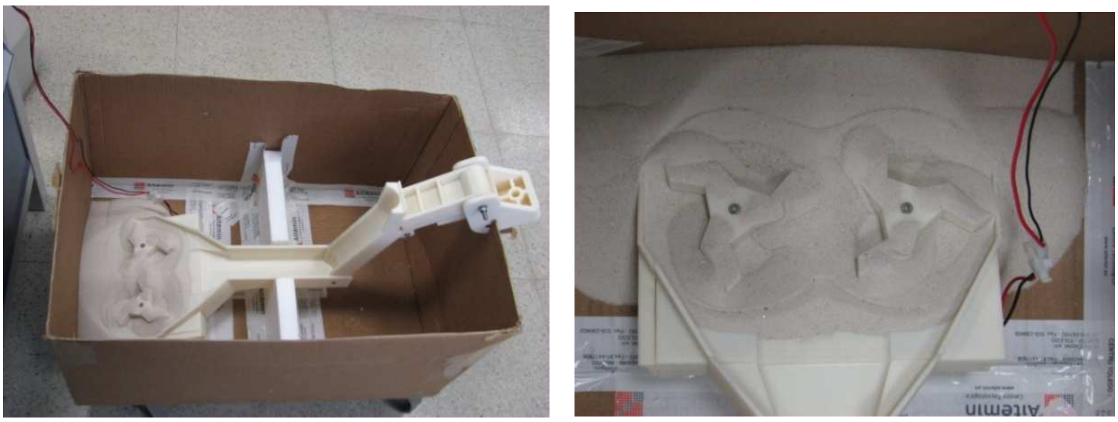


Figure 2.5-1: De-dusting collection system (test bench)

According to the scaled dimensions of the prototype, a scaled conveyor belt has also been built. The simulation conveyor structure (see Figure 2.5-2) has been designed and implemented in the laboratory to test the ability and behaviour of the de-dusting device to work in different types of conveyor belt installation configurations (like floor supported or hanged conveyors). These placements have been done manually. As it was expected, the system showed that the configuration of the de-dusting device is much appropriate and efficient to avoid, for example, the supporting frame of a floor based conveyor belt. Additionally test showed that its dimensions were also appropriate to reach difficult places like the ones generated by the intersection between two belts.

Figure 2.5-2: Scaled structure of the conveyor belt and installation of the de-dusting device.

It was determined that the dust is collected according to what it was expected and, according to the final design, it is possible to use an additional mechanism to replace it collected dust to the conveyor belt again or to secondary wagon attached to the main locomotion system, that in this case is the ZITRON PRZ – 330.

Finally, tests were made to verify the behaviour of a vacuum system to transport material from the dust collector blades by fixing flexible tube to a traditional vacuum cleaning device. A hose that comes from a common vacuum cleaner has been attached to the end tool of the de-dusting device. From these tests it was concluded that dust transport device should be the vacuum based solution and that's why these tests lead to the definition of a vacuum conveyor as the best dust collecting system.

<u>Test of small-scale machine inertization prototype</u>

The tests designed for the scaled inertization device had the same purposes than the ones used for the de-dusting device. Using the same scaled simulation of a conveyor belt it has been determined that the geometry configuration of the arm is appropriate for inertization purposes and that, according to the way the inertization chemicals are sprayed, movements have to be made differently.

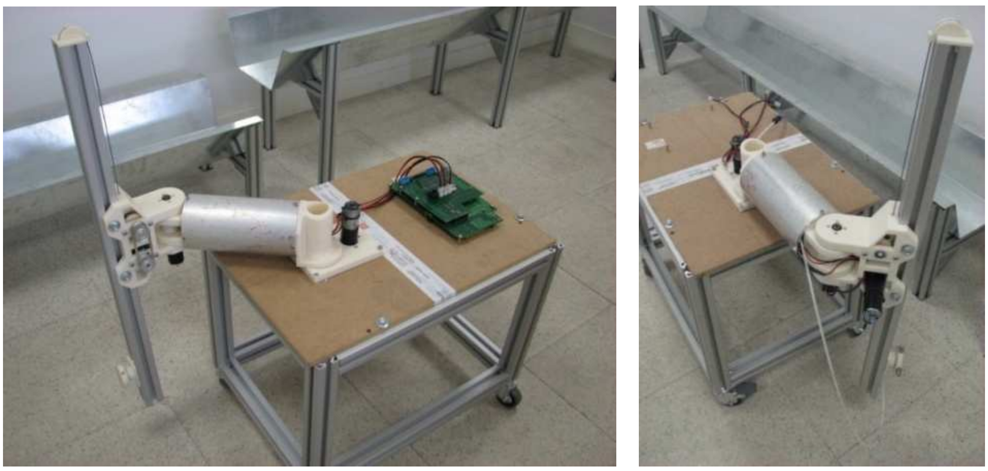


Figure 2.5-3: Small-scale inertization prototype

Additionally, the prototype was tested using two spraying techniques: the first one is integrated in the design. The second one is using the nozzle Flo-Jet® Flat Spray of STEINEN. As shown on the image (Figure 2.5-4) the spraying disk has been designed to rotate using the reaction of the of the pressure of the sprayed liquid as the disk is attached to a rotating coupling and supported by bearing installed in the slider. It was determined that with these techniques it is not possible to spray the inertization products in the opposite side of conveyor belt, but it is suitable cover completely the surface of a gallery.

Figure 2.5-4: Spraying setup

The spraying efficiency changes according to the type of nozzles used. With the first option, the water jet reaches further, but it was necessary to make more movements to cover the surface of the surroundings. But with a special nozzle which sprayed a cone shaped liquid with a 45º incidence, covered the surface easier, but it reached less distance.

Other inertization devices

Inertization devices have been developed in the UK Coal mines to enable simple dusting of conveyor drive, transfer points and return end areas and places where regular inert dusting is required and accessibility for larger devices is problematic.

The devices are termed dusty bins and comprise of a hopper feeding onto a compressed air line with a piece of 50mm rubber hose approximately 4 to 5 m in length enabling stone dusting in small constricted areas such as around conveyor drives and transfer houses. In areas of high ventilation velocities the dust gets carried some 50m down wind. This being the area where the larger volumes of airborne coal dust raised from conveyor transfer points is deposited. The hopper will hold up to 20kg of inert dust and will discharge this amount in less than 5 minutes with compressed air pressures of between 50 and 70 psi.

Other device used for inertization is a wheel borne inert duster using gearing from the wheels to drive a scroll and flinger. This was originally to have been powered hydraulically from a wheel driven hydraulic pump and flinger, but problems with the hydraulic system required a change in the drive mechanism to a geared drive.

Task 5.2 – Systems integration

Integration of the systems

A) Connecting a Multi-Sensor to RELIA System

The RELIA system is an automatic control and monitoring system specially design and developed for underground mining. Its versatility allows the underground installations, like belt conveyor transport systems to be monitored and controlled. The field bus topology of the RELIA system means that the input/output signals are transferred from/to master modules (EMR) to remote control units (UCR) by means of single communication cables with high transmission speed.

Currently in the mine there are two versions of the RELIA system: (1) RELIA2000 and (2) RELIA-AV (High Speed), which corresponds to the upgrade of RELIA2000. Nowadays in the mine there are areas which continue operating with the old system until the update to the new system is fully installed. The SCADA in RELIA2000 is called SISCOM and the SCADA in RELIA-AV is called COSMOS, which has been developed using Siemens WinCC tool. The ventilation monitoring has been implemented in the new SCADA.

In order to connect EMAG Multisensor in RELIA System, several solutions were proposed to integrate the sensor by means of the standard protocol RS-485. The most suitable option was to adjust the transmission protocol to the requirements of the system.

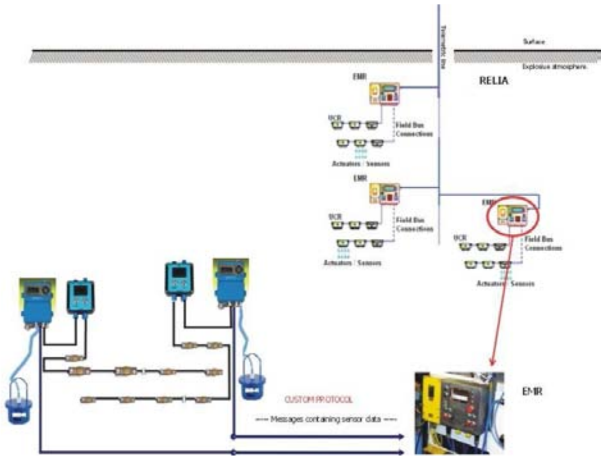
Regarding the physical connection, there are two possibilities: (1) connection to a remote control unit (UCR). The problem here is the limitation of current (each UCR port has a maximum current of 100 mA). The number of sensors which may be connected simultaneously to one supply-transmission line depends on the power consumption of each sensor individually; and (2) connection to the master station (EMR). More intensity than when it goes to the UCR (allows a maximum current of 0.2-0.3A). The second option (direct connection to the Master Station) was chosen because the UCR current restriction prevents the use of the multisensor device with these remote control units. Another drawback is regarding the communication protocol used in RELIA (Figure 2.5-5).

After the first trials in AITEMIN labs, the multisensor was taken into a real situation at San Nicolás mine, to test all the system working together (SCADA + OPC + EMR + Multisensor). Since the programming (firmware) of the EMR had been changed for the field test, after them the EMR and everything was left as it usually works.

B) Connecting a Multi-Sensor to SMP-NT/ Methane fire monitoring system (Poland)*

The structure of the integration of the multisensor to SMP-NT/* Methane fire monitoring system used in the Polish mines is shown below (Figure 2.5-6). The signals to be sent from the multi-sensor device to the mine monitoring systems have been established. The software of signal processing and transmission has been developed as well.

Both integrations are represented below.



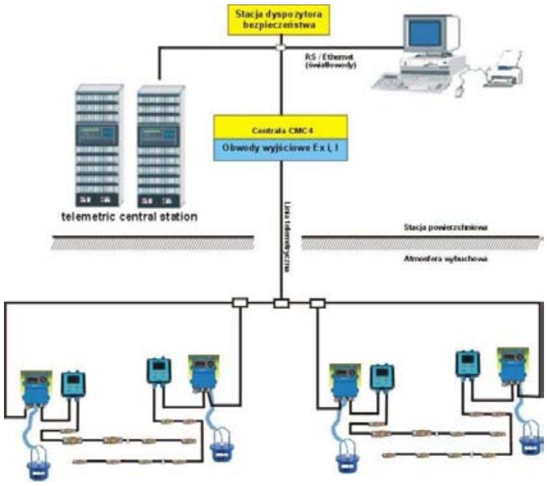


Figure 2.5-5: Multisensor connection to the RELIA system through the master station (EMR)

Figure 2.5-6: Multisensor connection to the SMP-NT/* system

The following information is sent from the multisensor to both mine monitoring systems:

- a signal from CO sensor in the range of 0 ÷ 200 ppm;
- a signal from HCN sensor in the range of 0 ÷ 20 ppm;
- a signal from temperature sensor in the range of -20 ÷ +40°C;
- a signal from air humidity sensor in the range of 0 ÷ 95%;
- a signal from air barometric pressure in the range of 800 ÷ 1200 hPa;
- a signal from temperature increment sensor CPT in the range of 0.4 ÷ 2.0 V;
- a signal from smoke detector in the range of 0.4 ÷ 2.0 V;
- a fire hazard index in the range of 0 ÷ 100%.

<u>Ventilation Management - Simulation Tests during Conveyor Belt Fires</u>

The integration of the SCADA System was implemented in a real coal mine. The coal mine selected is Área Sueros (HUNOSA), which comprises two shafts: Pozo Montsacro and Pozo San Nicolás.

The ventilation management system developed within WP4 was integrated inside the SCADA (COSMOS) in one of the computers used for controlling the coal mine in the environmental control room. This control room is located in San Nicolás area and controls all the activity that occurs in both areas: San Nicolás and Montsacro.

The feedbacks of the sensors located in the mine are transferred to VenPri software, which re-computes in real time the ventilation network parameters. This coal mine is currently installing the update into the new RELIA system, for which the ventilation application has been developed for. Therefore, not all the mine can be controlled with the ventilation management system. Nevertheless, while the upgrade is carried out, the introduction of the input sensors in the program is immediate.

Figure 2.5-7: Environmental Control Room (HUNOSA) and Ventilation SCADA in one of the control computers

Simulations of gases movement and air distribution in a ventilation network during different conveyor belt fires were carried out. In order to simulate a fire, the values obtained by EMAG experiments have been used. These values were stored in a file and they serve as an input for real CO sensors placed in mine. This is an approximation to estimate the gases movement through the coal mine. The duration of the fire from occurring to extinguish is approximately less than an hour. The results show the evolution of gases if a fire is produce in a determined place. The areas that will be contaminated along time are presented in different colours depending on the control sensor values. The results obtained from the simulations allow determining the escape routes or areas of smokiness for different ignition fire sources.

A detail description of the mine as well as a simulation of a conveyor belt fire is presented in the appendices (section 6.4.1). More cases of fires were reported in D5.3.

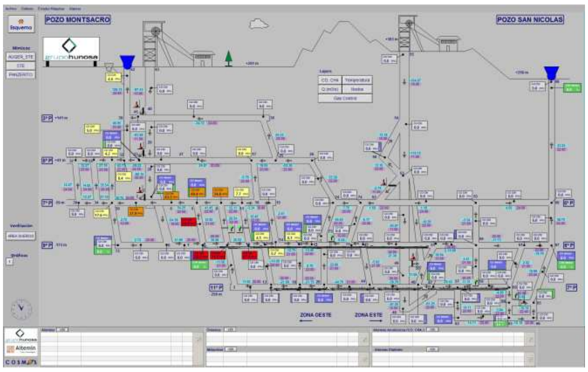


Figure 2.5-8: Evolution of gases in the SCADA

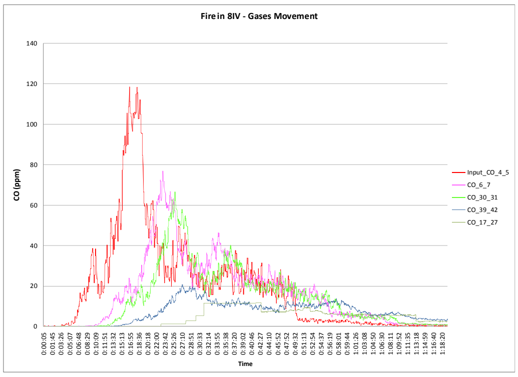


Figure 2.5-9: CO Evolution in different airways

Task 5.3 – Join Test of “Early Detection” and “Fire management and fighting” subsystems

The selected scenarios chosen for trials and to carry out the field tests for early detection of fires were the following: (1) experimental adit in the Central Mine Rescue Station in Bytom (Poland) and (2) Area Sueros coal mine located in Asturias region (north of Spain). For the health risk assessment the test were carried out at the same time that the trials for multisensor and wireless heat point detectors in San Nicolás coal mine.

Specifically, for the simulation of an early fire at San Nicolás coal mine (Spain), and after analyzing several places along the colliery installations, the best one was found at the end (deepest side) of a conveyor belt installed in one of the development faces in the 6th level (Figure 2.5-10). The cross section of the excavation was $13m^2$ (3.14x4.14). This was selected as the most suitable bearing in mind several factors like:

- Safety: the lower methane presence the better,
- Mobility :a lot of persons and equipment are needed around (working space),

- Extraction work interruption: the conveyor belt had to be stopped during the tests, also stopping the coal extraction activities,
- Feasibility: since no hot spots were found along the installed conveyor belts (an inspection was done using a thermal camera) a mechanical interference had to be caused to get friction in the conveyor (Figure 2.5-11), with the objective of provoking a very early stage of a fire development. Due to security reasons and in order to perform the test in a real underground coal mine the simulation of the seizing was one of the most suitable options.

This part of the mine uses the old monitoring system RELIA, for which the ventilation management is not implemented. Hence, the readings were transfer to SISCOM. For the communication with the monitoring system COSMOS, which includes the ventilation management developed within the project, other place in San Nicolás mine was selected.

Figure 2.5-10: Field Test in San Nicolás

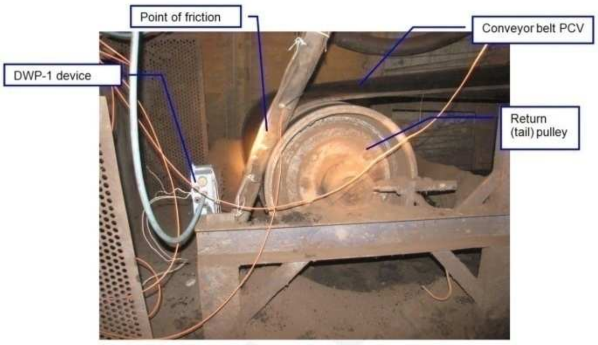


Figure 2.5-11: Simulation of belt friction (seizing)

<u>Multisensor Tests</u>

The multisensor device designed for early detection of fires in conveyors belts was tested in two underground coal mines: (1) in the coal mine Area Sueros, in particular in San Nicolás (Spain) using the RELIA monitoring system and (2) experimental adit in the Central Mine Rescue Station in Bytom (Poland) using the monitoring system SMP-NT/*

The tests in Spain were carried out in two places: the first ones aimed at the connection of the multisensor to the RELIA system which has implemented the ventilation management application. The second ones aimed at checking detection of products emitted at very early stage of fire development in a belt conveyor.

The tests results from Poland allowed calculating the distributions of the emitted products along a working during development of a fire. The tests and trials allowed determining, within the WP3, the fire indexes that permit to detect changes of signals from all detectors built in the multisensor. They allow a quick and reliable (minimization of false alarms) detection of a fire at its early stage.

The description and results obtained from the tests were reported in WP3 and in the appendices section 6.2.2, in order to understand the process of calculation of the fire index, which was part of the work to be done within WP3. All the test, description and results are included in D3.4, D3.5 and D5.2.

The measurements of the products emitted at the tests showed that a concentration of emitted products decreases along the flow in gallery; this results from diffusion of particles and inflow of additional stream of air to the test stand.

The early detection of fires based only on measurements of one parameter may be unreliable due to disturbances in the environment of the objects being controlled or in the measuring system. It may cause false alarms. Therefore various methods of signal processing (static and dynamic values) were used for more reliable and quicker detection of a fire, e.g. filtering signals based on the data from a defined period to eliminate partly some interference. Additionally, the calculated spatial and time-spatial distributions are a basis for early detection of fires and location of sensors along conveyor ways.

Wireless Heat Detectors Test

The field test for the wireless heat point detectors were carried out in San Nicolás coal mine, in one of the development faces in the 6th level. With the objective of producing an increment of the local temperature, a mechanical interference was done in the conveyor belt.

Once all the human equipment and measuring devices were moved to the trials scenario, the heat detection system was installed. During the tests the following stuff was used: (i) 4 temperature sensors; (ii) 2 wireless nodes (2 sensors per node); (iii) 1 sensor coordinator (implemented into a prototype board); (iv) 1 PC to show and log received data in situ.

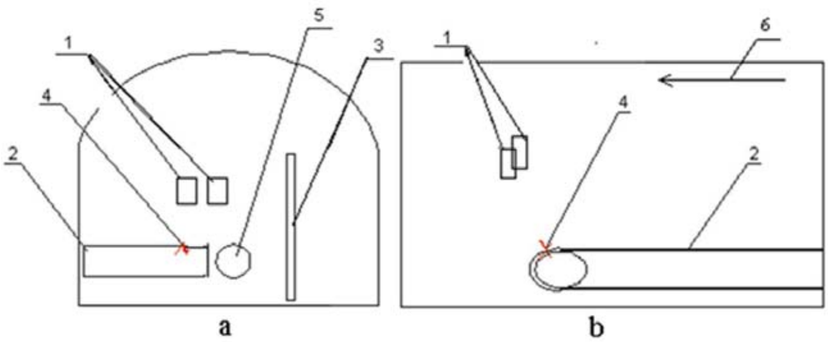
The system was set up to transmit 1 data per 5 seconds. It is a higher frequency (lower period) than the one used in a normal situation, but it was modified to get more data (more transmissions) during the test development.

One of the key points to get trial tests as similar as possible to the real situation is the generation of an intentional hot spot with enough temperature to catch some fire. The first attempt was to put a metal bar across the structure of the conveyor belt (in parallel with the carrying idlers) and in constant friction with the belt. This way simulates a blocked roller that will supposedly be heated up by the permanent friction. After some changes in the bar position and even increasing the contact surface and pressure between the PVC belt and the bar, the maximum temperature was only 80ºC. This was measured in the centre of the bar where most of the friction was applied, being only 40ºC at the ends. Other attempt was using a similar method, but in this case the friction was applied with a metal bar (also) but directly to the tail pulley surface. This allowed increase the pressure (the metal bar could be pushed easily) but minimize the contact point. In short terms with this technique a huge amount of pressure is applied on a small area, getting a high temperature but in a focused point. From the point of view of the detection system, this means a very unfavourable situation due to the amount of radiated energy is lower than in other cases, when for example, a idler shaft is overheated, and consequently, more difficult to be detected.

A detail description of the distribution of the sensors and test results are presented in the appendices, section 6.4.4.

Health Risk Assessment Tests

A conveyor belt made of polyvinyl chloride PVC was put to tests. The simulation of friction (seizing) was made at the return (tail) pulley, at the end of a working place which was ventilated by separate pipe lines. The aspirators and the probes were placed directly above the place of friction (Figure 2.5-12) where the largest emission of the dust and soot was observed.



1. Aspirators
2. Conveyor belt
3. Partition
4. Friction place
5. Ventilation pipe
6. Air flow 1m/s

Figure 2.5-12: Schematic layout of the test equipment in the mine excavation a) cross section of the excavation b) horizontal section of the excavation

In the test there were taken samples for determination of BTEX, total benzine, PAHs, petroleum hydrocarbons and dust particulates. Sampling time was 60 minutes. The duration of appearance of intense smoke was about 20 minutes. The belt tested in real conditions (NG17) was also tested in micro-chamber conditions. Due to the different way of combustion, air flow, magnitude of the experimental site, the obtained results must have been different – what was expected. Nevertheless it was confirmed that above mentioned substances determined in laboratory combustion products were also identified in real conditions. The results of benzene, toluene, ethylbenzene, xylene, BTEX and total benzene tests of the belt NG17 and other belts are presented in Table 6.4-1 in the Annex section 6.4.3.

The belt NG17 was made of PVC and could be comparable with the belt tested in DMT Gallery and micro-chamber marked as NG15 also made of PVC. The concentrations of benzene, toluene, ethylobenzene, xylene, BTEX and total benzine in both samples are shown in Table 6.4-2 in the Annex section 6.4.3.

In tests performed for determination of PAH and petroleum hydrocarbons and particulate matter, the results obtained in real conditions ranged beyond the scope of the determination method. PAHs emission values in NG17 sample and other tested conveyor belts are presented in Table 6.4-3 and Table 6.4-4 in the Annex section 6.4.3.

In the real conditions it was not possible to take samples of substances particularly harmful, such as HCl and HCN. In the studies performed previously these substances were taken at absorbing solution in glass scrubbers. This solution must be examined in a very short time following absorption. Therefore it was not possible to apply regular methods of its determination without direct access to the laboratory. In order to compare the results obtained in experimental and real conditions, values of HCN and CO marked with the sensor DWP-1 by the project partner EMAG were adopted. The concentration of HCN measured with the sensor was 28,9 mg/m^3 while in laboratory tests – 7,57 mg/m^3. The differences were also observed in relation to CO: 256 mg/m^3 measured by sensor and 2242 mg/m^3 measured in laboratory tests. Due to the different conditions of tests performance, the quantitative results obtained in laboratory and coal mine tests are different as it was expected. The qualitative results have been confirmed. Full conclusions of the test performed are presented in appendices (Section 6.4.3).

A comprehensive detail of the tests and the results obtained were reported in Deliverable D5.3.

Task 5.4 – Overall assessment and conclusions. Final Report

The aim of this task was to perform a detailed appraisal of the required dissemination activities and an assessment of the overall results obtained from the project. The result of this assessment was a guideline report which, besides sending it to direct contact mines in Poland, Spain, Germany and UK, will be publicly available.

Establish the fundamental mechanisms behind the initiation and propagation of belt conveyor fires and the prevention strategies (focusing on the study of the structure of conveyor belts and the characteristics of the coal accumulation) aid not only in the installation of conveyor belts but also for their maintenance.

The characterisation of the combustion process (including an estimation of fire load and characteristics of combustion products), and the effect of these combustion products on persons (including workers and local population) as well as the impact on the environment, allowed the manufactures of conveyor belts to used the results to reduce development costs. The results obtained from the test showed that the belts with the current material composition will seriously pollute the environment in case of fire.

The implementation of new technologies for early detection of fires in conveyor belts and fire fighting methods was also incorporated in the guidelines to present to mines the newly developments and technologies. The outcomes of the trials and field test lead to recommendations in the placement of control points along conveyor belts for early detection of fires, as well as, the integration of the early detection devices with a ventilation management system which aids in the decision making in case of emergency.

Besides the commercial products, the dissemination of the results on the research task and achievements made constitute a keystone in the project goals.

2.5.4 Conclusions

It has been determined that the de-dusting tool can be used in every configuration of the conveyor belt even if it is placed on the floor or held from the roof. If it is used in conveyor belts placed on the floor some additional movements have to be made by the operator in order to avoid the supporting legs. However, the end tool can be placed between the transition of the conveyor belts correctly. Using a vacuum cleaner collected the dust was much faster than it is expected to be done by the Spiroflow system. Regarding the inertization tool, it can be used to cover the surface around the conveyor belts as expected using the same locomotion system. The purpose of designing both arms in such a way that they can be implemented in the same locomotion system was to reduce operation costs if these systems are built in full size version.

The trials of multisensor devices were made under mining conditions. The tests results were used for development of principles of signal processing and placement of sensors along conveyor routes for effective detection of fires. Moreover, the multisensor is able to work with other monitoring systems like RELIA. The measurements were successfully seen in the EMR (underground) and transmitted to the surface in the supervisor program COSMOS. Nevertheless, there is one disadvantage in using the multisensor with RELIA system. As the multisensor occupies an entire bus it would be needed to take an extra line to be able to read the multisensor values and act on the output at the same time. For instance, if the fire index exceeds the threshold, the conveyor belt stops. If one bus is only used, the capabilities of the RELIA systems would be wasted (see section 6.4.2). The solution to this would be to connect the multisensor to the UCR, but as it has been studied, the current limitation makes this connection not possible at the moment. Further work should be made in the transmission software of the multisensor in order to share the bus with the UCRs.

However, the advantages and the potential of the multisensor devices are enormous. They have the most suitable sensors to detect hazard problems in coal mines; they have their own logic to generate a fire index according to the conditions of the mine; they are perfect to detect fires in the vicinity of conveyor belts, which are one of main sources of fire hazards in coal mines.

The trials carried out for the wireless heat point detectors system were performed simulating a scenario as real as possible. However, both the temperature and the hot spot(s) size got during the test was not similar (much lower temperature and size) to the produced in a real situation. From this point of view the test were carried out in a very unfavourable condition. The heat detection system is clearly capable of monitoring and recognizing anomalous situations that could involve fire generation from a temperature increment. Nonetheless, some consideration must be taken into account: (i) the closer the sensors are to a possible hot spot, the better and faster the detection is (as expected); (ii) the placement of the sensors in contact (or even close to) a metal parts produces a delay in the detection of the high temperature spots; (iii) although further tests should be performed to get a more accuracy results form the point of view of sensor positioning, a distance of 5 meters between sensors and 1 meter from sensor to belt structure is estimated as enough to detect temperatures capable of catch fire.

The tests performed in the real conditions in HUNOSA coal mine allowed confirm the results of identification measurements of the substances emitted in the combustion process. It is not possible to compare quantitative results as the conditions of the testing performance were different: in the laboratory conditions the belts were combusted directly over the flame while in the coal mine due to the safety procedures and protection only the simulation of the friction was possible. It came out that it was reasonable to assess health risk on the basis on the average or highest concentrations of identified substances determined in laboratory experiments in order to be able to predict the highest risk and to undertake efforts to protect workers' health and life.

2.5.5 Exploitation and Impact of the Research Results

Exploitation of the results

Based on the studies and tests performed with cleaning prototypes, it is been considered whether to build full size versions. A contact with a manufacturer for construction of machinery was made with the ideas developed within the project. Nevertheless, it seems that the benefits and complication of building and installing the devices would not compensate the large-scale construction.

Multisensor devices and the wireless heat detection system are commercially available for early detection of fires, especially for conveyor belts placed in underground environments (ATEX).

Dissemination

The outcomes from the trials and test were used for development of principles of signal processing and placement of sensors along conveyor routes for effective detection of fires.

The detailed appraisal of the required dissemination activities and an assessment of the overall results obtained from the project allow writing a guidelines report which, besides sending it to direct contact mines in Poland, Spain, Germany and UK, will be publicly available.

The health risk assessment gave the information on potential danger related to exposure to the combustion products. This information could be addressed to the workers in coal mine in order to build their awareness on potential risk, routes of absorption, and health symptoms of poisoning, proper reactions as well as to implement prevention actions. These activities should focus on (i) training of workers; (ii) development of emergency procedures; (iii) preliminary and periodic medical tests of workers exposed to the combustion products.

Publications and Conference Presentations

The preliminary results of the research studies within the project were presented the Polish Mining Congress in September 2010 in the speech prepared by Joanna Pruchnicka and Małgorzata Ryszka. The final outcomes were presented in publications in magazines regarding industry and environment.

3 ACRONYMS AND ABBREVIATIONS

ABS	Polymer (Acrylonitrile, Butadiene, Styrene)
As	Arsenic
ATEX	EU Directives on "Appareils destines a etre utilises en **AT**mospheres **EX**plosibles"
Ba	Barium
BTEX	**B**enzene, **T**oluene, **E**thylbenzene, **X**ylenes
Cd	Cadmium
CFD	**C**omputational **F**luid **D**ynamics
C_6H_6	Benzene
CN	Cyanide
CPT	**C**rujnik **P**rayrost **T**emperature (Temperature Increment Sensor)
CO	Carbon Monoxide
CO_2	Carbon Dioxide
Cr	Chromium
Cu	Copper
CV	**C**ontrol **V**olume
EPR	**E**thylene-**P**ropylene-**R**ubber
DoF	**D**egress **o**f **F**reedom
FDM	**F**used **D**eposition **M**odelling
FDS	**F**ire **D**ynamics **S**imulator
HCHO	Formaldehyde
HCl	Hydrogen chloride (hydrochloric acid)
Hg	Mercury
ICP	**I**nductively **C**oupled **P**lasma (spectroscopy)
ICP-OES	**I**nductively **C**oupled **P**lasma **O**ptical **E**mission **S**pectroscopy
Mo	Molybdenum
NASA	**N**ational **A**eronautics and **S**pace **A**dministration.
Ni	Nickel
NIST	US **N**ational **I**nstitute for **S**tandards and **T**echnology
NO_x	**N**itrogen **O**xide (NO and NO_2)
OLE	**O**bject **L**inking and **E**mbedding

OPC	**O**LE for **P**rocess **C**ontrol
PAH	**P**olycyclic **A**romatic **H**ydrocarbons
Pb	Lead
PCP	**P**oly**c**hloro**p**rene
POC	**P**roducts **O**f **C**ombustion
PVC	**P**oly**v**inyl **C**hloride
RELIA	Control and monitoring system for mining applications by AITEMIN
Sb	Antimony
SCADA	**S**upervisory, **C**ontrol **A**nd **D**ata **A**cquisition
Se	Selenium
SMP-NT/A	Methane/fire system by EMAG
SO_2	Sulfur Dioxide
UK HSE	**U**nited **K**ingdom **H**ealth & **S**afety **E**xecutive
VenPri	Software for design of ventilation systems in underground mines by AITEMIN
WLAN	**W**ireless **L**ocal **A**rea **N**etwork
WP	**W**ork **P**ackage
XLPE	Cross-linked Polyethylene
Zn	Zinc

4 LIST OF FIGURES AND TABLES

4.1 LIST OF FIGURES

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5 LIST OF REFERENCES

5.1 REFERENCES

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5.2 COMPANIES REFERRED TO IN THIS REPORT

AUXQUIMIA S.A
Polígono Industrial de Baiña, Parc 23. 33682 Baiña (Mieres), Asturias, SPAIN
http://www.auxquimia.com/

Central Mine Rescue Station (CSRG)
Bytom (Poland)
http://www.csrg.bytom.pl/

Conveyor Belt Factory Wolbrom S.A.
1 Maja str., no. 100
Wolbrom, 32-340
Poland
www.fttwolbrom.com.pl

Informatyczna Firma Konsultingowa LTD
Parkowa 3 street, 44-230 Czerwionka-Leszczyny, Poland
http://ifk.com.pl/newsy/strona-glowna/31.html

Mariof Corporation
PO Box 86 / Virnatie 3, FI-01301 Vantaa, Finland
http://www.marioff.com

PNR Italia Srl
Via Gandini 2 - 27058 Voghera (PV), Italy
http://www.pnr.eu

POK "Zachód" Sp. Z.o.o (Plant of Methane Removing)
Ks L. Tunkla 147B Street, 41-707 RUDA Śląska, Poland

POLON-ALFA Z.U.D. Sp. z o.o.
Glinki Street 155 85-861 Bydgoszcz Poland
http://www.polon-alfa.pl/ang/index.php

Spiroflow Ltd.
"Flexible Screw Conveyors"
http://www.spiroflow.com/es/about-flexible-screw-conveyors

VOLKMANN GmbH
Schloitweg 17, 59494 Soest, Germany
http://www.volkmann.info/

6 APPENDICE 1 - ADDITIONAL INFORMATION ON WP

6.1 WP1

6.1.1 Additional information to Task 1.1: Standards and Test, Idlers and Bearings, Conclusions

1 STANDARDS AND TESTS

There are many different international standards for conveyors, for performance, quality and testing. Fire specifications and requirements vary from country to country. Some countries may also perform additional testing, including tests for toxicity or hygiene factors.

In order to study the ignition behaviour and also the fire spreading characteristics, conveyor belts from different countries of the EU have been examined considering aspects of fire protection regarding the incipient fire and the spread of fire, first of all according to DIN EN ISO 14973. It was decided to use the test procedures laid down in this standard because it guarantees comparability of results obtained with different belts and it provides procedures simulating small, medium and large ignition sources as well as for fire spread.

1.1 The European Standard DIN EN 14973

DIN EN 14973 is a standard that describes the safety requirements for electricity and fire protection for conveyor belts used in underground mining. In order to classify the conveyor belts according to their relevant fire categories the following fire examinations have to be done first:

- Fire tests according to EN 1554 – test of drum friction
- Fire tests according to DIN EN ISO 340 – fire behaviour during laboratory test
- Fire tests according to DIN EN 12881-1 – test with propane gas burner: (i) Test with single burner and (ii) Test with dual burner
- Fire tests according to DIN EN 12881-2 – large scale fire test (class C2)

Additionally, incipient fires are to be simulated using the following sources of ignition: (1) Glowing pulleys and (2) Smouldering coal dust

The results of those fire tests and examinations shall provide information on the behaviour regarding ignition and fire development and propagation of the conveyor belts from the different EU countries.

Beside coal, other flammable materials exist in underground mines such as wood, diesel fuel, mineral oil, hydraulic liquids, solid and liquid plastics and plastic equipment. Additionally, settlements of coal and coal dust on the level as well as bound coal sticking and settling in the faces and ridges are in place. Incidents such as smouldering coal dust, hot surfaces, burning liquids, electric arcs or beads of welding and fire are regarded as sources of ignition.

In order to cause a fire a combination of sources of ignition and flammable materials is necessary. The most crucial scenarios of how a fire may occur at a conveyor belt are shown in DIN EN 14973.

The European standard DIN EN 14973 defines the safety requirements for electricity and fire protection on conveyor belts used in underground mining in the presence of flammable and non-flammable atmospheres.

Additionally, it lists the following hazards for the use of conveyor belts in underground mining:

- Risks due to the emission of static electricity;
- Risks caused by the standstill of a conveyor belt while the drive is still running which leads to a local heating of the conveyor belt and which may cause frictional heat due to the contact with the motor drum or other parts causing frictional heat;
- Risks regarding the impact small open flames on the cover or the casing of the conveyor belt can have;
- Risks caused by fire spreading along a conveyor belt. Such a fire may be caused by a rather small hot spot, for example the overheated bearing of a pulley, or by larger fires caused by other materials inside the gallery. The impact of the latter increases if a large concentration of plastics exists, too.

1.1.1 Testing procedures

Static electricity

Measuring the electric resistance of conveyor belts according to DIN EN ISO 284

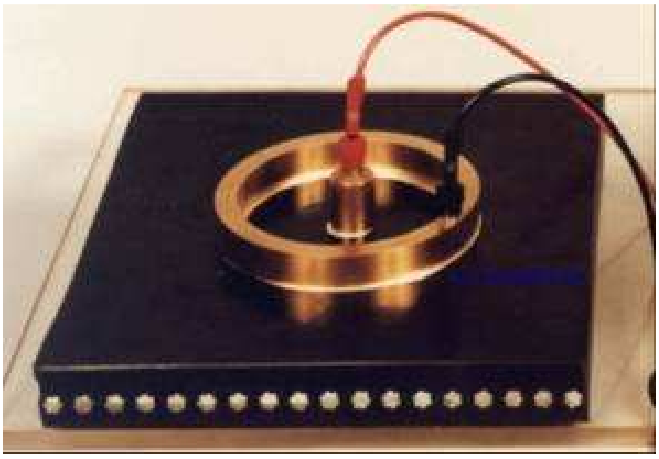


Figure 6.1-1: Electrical resistance testing

Frictional heat between the drive and the conveyor belt

This hazard can be assessed sufficiently by applying the drum friction test according to DIN EN 1554

Figure 6.1-2: Drum Friction Test

Ignition caused by small open flames on the cover or the casing of the conveyor belt. This hazard can be assessed by the test with a laboratory gas burner as described in EN ISO 340

Propagation of fire

The resistance against a propagation of the fire – caused by a rather small hot spot, e.g. an overheated damaged bearing – along the conveyor belt is measured by the tests described in EN 12881-1:2005, i. e. procedure A, B or C.

In procedure A the lower side of a conveyor belt sample is exposed to a flame of one propane burner for 10 minutes. The propane gas flow is 1.3 kg/10 minutes. Procedure B is the same as procedure A but with two propane burners, one applying the flame to the lower side of the belt, the other the upper side. The gas flow rate is 1.3 kg/10 minutes for each burner. In procedure C a burner with 6 nozzles is used for 50 minutes with a flow rate of 565 g/min of propane.

If the conveyor belt is not completely ignited during the fire test according to procedure A, then either procedure B or C is applied.

The resistance against a propagation of the fire – caused by a large fire in the haulage road – along the conveyor belt is measured by using the test described in DIN EN 12881-2. This test simulates a situation in which sources of fuel are present in addition to the source of ignition on the conveyor belt and these may be ignited, too. This simulation is done by starting a fire load of wood.

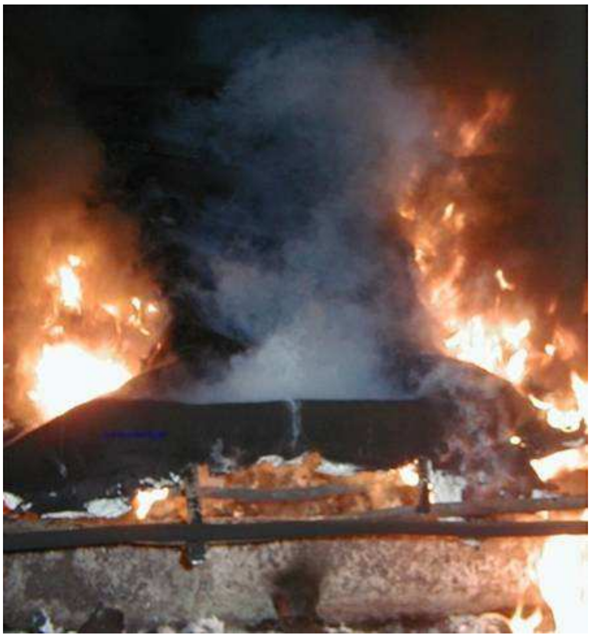


Figure 6.1-3: Large scale fire test

1.2 Results of tests related to ignition behaviour of belt samples

1.2.1 Conveyor belt samples

Conveyor belts from different EU countries intended for use in underground mining will be analysed for aspects of fire protection according to DIN EN 14973, namely the incipient fires and the spread of fire, to allow for their classification into the applicable fire categories, i.e. A, B1, B2, C1 or C2. Additionally, these conveyor belts are subjected to tests of fire safety using glowing belt pulleys and smouldering coal dust.

The results of the fire examinations and test should provide information for conveyor belts from different EU countries about their behaviour during and after ignition as well as their behaviour concerning fir propagation. The following conveyor belts suitable for use in underground mining were provided:

- Conveyor belts from Germany
  - Conveyor belt type EPP 800/2 1.5/1.5, width 1000 mm, VG-no. [2078]
  - Conveyor belt type EPP 800/2 1.5/1.5, width 1000 mm, VG-no. [2079]
- Conveyor belt from United Kingdom
  - Conveyor belt type E/P-B-P/B 1000/1 PVC 2.5/2.5, width 1000 mm, VG-no. [2094]
- Conveyor belts from Poland
  - Conveyor belt type EP 1000/3 2/2, width 1000 mm, VG-no. [2095]
  - Conveyor belt type EP 1250/3 2/2, width 1000 mm, VG-no. [2096]

The German samples are rubber belts with textile inlay. The UK belt is made of PVC.

1.2.2 Test results according to ignition behaviour

In the context of this report the abovementioned samples have been tested according to their individual ignition behaviour according to DIN EN 14973. As outlined in the standard the tests according to DIN EN 1554, DIN EN ISO 340 and DIN EN 12881-1 were carried out.

1.2.2.1 Results according DIN EN 1554

The results of the tests according to DIN EN 1554 representing the ignition behaviour resulting from frictional heat are shown in Table 6.1-1.

Table 6.1-1: Test result according to DIN EN 1554

Belt sample	Test according DIN EN1554 Drum friction test		
	Ignition Yes/No	**Glowing Yes/No**	**Temperature max. [°C]**
No 2078 (Germany)	No	Yes	395
No 2079 (Germany)	No	Yes	407
No 2094 (UK)	No	No	272
No 2095 (Poland)	No	Yes	363
No 2096 (Poland)	No	Yes	407

The results show that all European test samples were not ignited by frictional heat sources. The only showed, apart from the sample of the UK, only some glowing. This indicates that the quality of the belts under investigation is good enough to withstand frictional heat.

1.2.2.2 Results according DIN EN ISO 340

The results of the tests according to DIN EN ISO 340 representing the ignition behaviour resulting from small heat sources are shown in Table 6.1-2.

Table 6.1-2: Test result according to DIN EN ISO 340

Belt sample	Test according DIN EN ISO 340 Small heating source		
	Ignition Yes/No	**Afterburning time**	
		With cover [s]	**Without cover [s]**
No 2078 (Germany)	Yes	3	25
No 2079 (Germany)	Yes	4	39
No 2094 (UK)	Yes	2	26
No 2095 (Poland)	Yes	1	3
No 2096 (Poland)	Yes	1	3

The results show that all test sample starts burning even with this relatively low but locally concentrated heat source. However, due to the self-extinguishing properties of the belt material the fire didn’t propagate. With belt cover intact the fire stops almost immediately. With belt cover removed the fire stops after around half a minute. This shows that also the inner core of the belt does not support fire propagation. Here the Polish samples showed the best characteristics. They almost stop fire propagation immediately even without cover.

1.2.2.3 <u>Results according DIN 12881-1</u>

The results of the tests according to DIN EN 12881-1 representing the ignition behaviour resulting from big heat sources are shown in Table 6.1-3.

Table 6.1-3: Test result according to DIN EN 12881-1

Belt sample	**Propane burner test DIN EN 12881-1, proc. A, B or C Big heating source**
	Complete ignition Yes/No
No 2078 (Germany)	Yes
No 2079 (Germany)	Yes
No 2094 (UK)	Yes
No 2095 (Poland)	Yes
No 2096 (Poland)	Yes

The results simply indicate that all belts can be fully ignited if the heat source is only big enough.

In general it can be stated that all belt samples under investigation showed good behaviour against ignition. They all would pass test according to DIN EN 14973 and would receive the highest classification possible. This means that all belt samples can be applied underground without general restrictions.

2 IDLERS AND BEARINGS

2.1 Idlers

In ‘Prevention of overheating at conveyor idler rollers’ published by HSE Laboratory services in 1980, it is shown that 1.0 to 1.5 kW of energy could be supplied by a conveyor belt to an idler, before the belt began to slip on the idler. This energy could be absorbed in friction from:

1. a roller rubbing against coal dust
2. a roller rubbing against a fixed object
3. deterioration of bearings

It was also stated in the same document that coal dust can be ignited if it is in contact with a roller at 175^{o}C for about 2 hours.

2.2 Health and Safety Laboratories Project EC/03/59.

In the Health and Safety Executive publication ‘Ignition from Conveyor Idler Rollers’, conveyor idler roller failure was identified as the major cause of fires in UK coal mines over the period 1993 to 2000. It was felt that this failure mode could have acted as a possible ignition source for explosive atmospheres, and that this needed to be investigated.

It was considered that two indirect methods of ignition could arise. These were smouldering leading to flame from coal dust, or ignition of the lubricant. Fire resistant lubricants are used so the possibility of ignition by this method was discounted. Since it is possible for a layer of coal dust to ignite at temperatures below 200°C, its prevention is achieved by not allowing exposed surfaces to rise above 150°C.

The Health and Safety Laboratories set up a project to investigate the temperatures generated during idler bearing failure. A test rig was set up, with British Coal Specification 549:1987 bearings, and a system to measure the temperatures generated within the bearings during controlled failure was devised. Instrumentation used was:

1. Thermocouples fitted into the inner race measuring the temperature at each end of the idler roller.

2. A Thermal imaging camera, measuring temperatures up to 2,000°C and able to detect temperature differences of 0.1°C.

There was a slight difference in the readings given by the 2 measurement techniques. The thermocouple gave lower temperatures recorded with a short time delay, compared with the thermal imaging camera. This was considered due to the physical separation between the thermocouple and where the frictional heating was taking place.

The bearings have an 'L10 rating', meaning that under normal full load, 10% are expected to fail within 10^6 revolutions. Contaminants such as coal dust and water, or the loss of lubricant can shorten the life of bearings. A standard speed of 3.8 m/s was used but the axial load was increased by 25% and the bearings were cleaned of all lubricant to accelerate failure.

After approximately 11 hours, bearings failed in what was termed the '1st stage of failure', where the temperature gradually increases to around 100°C followed by a sudden increase to around 200°C. This critical temperature indicated the melting of the polyamide roller cage, as shown in Figure 6.1-4.

Figure 6.1-4: Bearing with melted cage

The roller race is then destroyed with ball bearings beginning to bind, and not being captive, may be lost completely. During this, the 'second stage of failure', the bearing has collapsed. The outer and inner races make contact and steel starts to rub against steel with consequent temperature rise. Tests concluded that the bearings reached a temperature greater than 800°C.

Thus a failing bearing can not only produce temperatures able to ignite layers of coal dust or dust clouds, but could also cause the auto ignition of methane (595°C). No incidents of this type have been reported in UK coal mines, but a zinc dust explosion 'most likely' caused by a failed bearing occurred in a zinc dust recovery system. Tests showed that the bearing reached a temperature greater than 600°C, high enough to ignite a zinc dust cloud (450°C) or initiate a zinc dust explosion (570°C).

Since it seems that the failure of the polyamide cage accelerates the failure of the bearing, it was proposed that further tests took place with steel cage bearings.

This project showed good agreement with a European Commission funded MECHEX project (Mechanical Ignition Hazards in Potentially Explosive Gas and Dust Atmospheres, CONTRACT N°: G6RD-2001-00553, PROJECT N°: GRD2-2000-30035).

2.3 Bearing Life

The "life" of a roller bearing is defined as the number of revolutions (or hours at a given speed) which the bearing runs before the first evidence of fatigue develops in the material of either ring or of any of the rolling elements.

The L_{10} or "rating life" of a group of roller bearings is defined as the number of revolutions (or hours at some given constant speed) that 90% of the group of bearings will complete or exceed before fatigue develops.

Bearings which have been properly mounted, lubricated, and protected will operate with minimal, if any, internal wear until fatigue of the rings or rolling elements takes place. Fatigue is the first evidence of spalling of the rolling contact surfaces of these parts, and occurs because of the repeated stressing of the contacts.

Most roller bearings fail by inadequate lubrication (36%), by fatigue (34%), by contamination (14%) or by other causes (16%). In the normal life of a machine only 0.5% of bearings are replaced because of bearing failure.

Bearings will eventually fail as a result of a surface fatigue phenomenon known as spalling (see Figure 6.1-5). It starts as particles that are liberated from the surface of a race. Surface fatigue leaves craters that act as stress concentration sites. Subsequent contacts at those sites cause progression of the spalling process.

Figure 6.1-5: Fatigue Spalls on Bearing Inner Race

2.4 Grease

In the early 1980s in the UK, the National Coal Board requested manufacturers to produce fire resistant grease for use in conveyor idlers. This was intended to reduce the incidence of fires in coal mines, but give the performance of good mineral oil based greases. In response to this, Shell Research produced a grease based on phosphate ester which was put under test.

2.5 Consequences

Conveyors have been in widespread use in many countries, for many years, in a diverse range of surface and underground applications. For a number of reasons, they have been the cause of fires. In the specific case of underground coal mines, these have often been fatal, due to the toxic nature of the gases which can be generated, and the difficulties associated with escape.

Changes in the way fire is reported, or the definition of 'fire', or inconsistent reporting, or differing interpretations of the law, or legislation changes, do not hide the frequency of occurrence or the seriousness of fire underground in a coal mine caused by conveyors.

Statistically there are high numbers of rollers on conveyors; with many conveyors having in excess of 5000 bearings per kilometre with a 'normal' life of 5 years. Given the published failure rates for bearings under 'normal' operating conditions, it is inevitable that in the dusty and often wet conditions found in coal mines, this design life would be lower. The failure mode for bearings generates heat, with inevitable consequences. Collapsed rollers also result in conveyor belt frictional rubbing against fixed structures, often again resulting inevitably in heat and fire.

In a UK HSE experiment with dry bearings, there were two stages of failure. The first stage was illustrated by a gradual rise in temperature to around 100^{o}C followed by a sudden increase to around 200^{o}C. This indicated the melting of the polyamide roller cage, which was followed by the second stage where the bearing has collapsed, the outer and inner races make contact, and a temperature greater than 800^{o}C is reached. It was therefore demonstrated that a failing bearing can not only produce temperatures able to ignite layers of coal dust or dust clouds, but could also cause the auto ignition of methane.

Most roller bearings fail by inadequate lubrication (36%), by fatigue (34%), by contamination (14%) or by other causes (16%). In the normal life of a machine only 0.5% of bearings are replaced because of bearing failure.

There is unlikely to be a simple solution to this problem. Higher standards of bearings with improved lubrication, dust and water seals, or reduction in pulley bearing or load capacity may extend the period between failures, but is unlikely to eliminate the problem. Means of giving earlier warning of potentially dangerous situations are required.

Francart (2006) states that an "an analysis of reported mine fires in belt entries shows many belt fires could have been prevented with proper maintenance of the haulage system. CO detectors may have contributed to reducing the frequency of reported fires, but prevention of the conditions that allow fire to occur is more effective".

Detection of the fail conditions is difficult, with failure progressing to fire within minutes in some cases. A range of possibilities exist for this, including thermal and acoustic options. Early detection can at least allow sufficient warning to be given for mineworkers to escape. Technical aids (possibly based on infra-red or acoustical methods), and on-going training for patrol personnel also need to be considered.

3 CONCLUSIONS

The main targets of the EDAFFIC research activities consist of minimising the risk of the spread of conveyor belt fires, acting on all control points of the fire initiation and propagation process and fighting and managing such fires, should they acquire great dimension, in order to minimize their impact.

The focus of the work in Task 1.1 of EDAFFIC Work Package 1 was on detailed and systematic investigations to identify as many as possible ignition sources for conveyor belt fires together with their acting mechanisms. The investigations have been shared among the partners involved on regional basis including also information from outside Europe.

Although the data bases or time intervals under investigation were different and the absolute values are therefore not comparable, the investigation clearly showed that still the main causes for conveyor belt fires are associated with failures in roller idler sets and bearings. A second big reason for fires is coal spillage.

Prevention of conveyor belt fire should therefore focus on this part of the installation. However, technical installations are never 100% save. A certain failure risk will always remain. Investigations into fire prevention in conveyor installations need to address the whole system in order to guarantee maximum safety.

Apart from the ignition sources mentioned above, which are related to the conveyor belt installation itself, other flammable materials in the vicinity of conveyor belt can be found. Such materials, considered being basically inert in terms of acting as fire source, may under certain conditions alone or in combination with other materials, act as sources of ignition for a conveyor belt fire

In underground coal mining flammable materials like wood, diesel fuel, mineral oil, hydraulic liquids or solid and liquid types of plastics as well as plastic equipment can be found: Effects and incidents like smouldering coal dust, hot surfaces, burning liquids, electric arcs or welding beads and fire beads may qualify as sources of ignition.

In order to investigate the ignition behaviour of belts used in European underground mining, some tests have been carried out according to DIN EN 14973. This standard recommends tests representing different ignition energy levels. It was decided to make tests according to this standard in order to come to comparable results.

The test showed that all test samples have the recommended properties for the general application in underground mining. However, all samples can be ignited if they are exposed to high energy sources. The consequence of these test results is to avoid high fire load in the vicinity of conveyor belt installation.

The primary heat source might be e. g. a hot roller idler set caused by friction. The grease may then be heated up and released to drop to the floor below the conveyor. If large quantities of coal dust are lying there smouldering fires can be caused which may develop to a bigger fire exposing enough energy to ignite the belt. If further to that other flammable materials are located in the close vicinity of this location, the situation will get even worse.

Once a conveyor starts burning it is essential to stop fire propagation. This was investigated in T1.2.

6.1.2 Additional information to Task 1.2: Test Results and Discussion

Test results

Results according to DIN EN 12881-1, procedure A

Fire source:	Propane gas burner (low heat energy)
Tunnel cross section:	6 m²
Volume of air flow:	9 m³/s (low air flow)
Air speed:	1.5 m/s
Belt length:	2 m

Table ***6.1-4*** shows the results of the tests using the propane gas burner according to DIN EN 12881-1, procedure A

Table** 6.1-4**: Results of tests according to DIN EN 12881-1, procedure A

Belt sample	Exposed belt side	Single propane gas burner test DIN EN 12881-1. proc. A. profile: 6 m²	
		Burned Length [m]	Complete ignition Yes/No
No 2078 (Germany)	Conveying side	Top side: 0.96	No
		Bottom side: 1.11	No
	Running side	Top side: 0.89	No
		Bottom side: 1.38	No
No 2079 (Germany)	Conveying side	Top side: 1.01	No
		Bottom side: 1.21	No
	Running side	Top side: 0.92	No
		Bottom side: 1.15	No
No 2094 (UK)	Conveying side	Top side: 0.80	No
		Bottom side: 1.09	No
	Running side	Top side: 0.80	No
		Bottom side: 1.17	No
No 2095 (Poland)	Conveying side	Top side: 0.95	No
		Bottom side: 0.87	No
	Running side	Top side: 1.76	No
		Bottom side: 0.98	No
No 2096 (Poland)	Conveying side	Top side: 1.05	No
		Bottom side: 1.02	No
	Running side	Top side: 0.67	No
		Bottom side: 1.02	No

For all samples, it was noted that they did not ignite across their full width. For such cases, standard DIN EN 14973 prescribes a test according to DIN EN 12881-1, procedure B or procedure C. The following Figure 6.1-6 shows a snapshot of a test carried out according to DIN EN 12881-1, procedure A.

Figure 6.1-6: Single propane gas burner test according DIN EN 12881-1, proc. A

Results according to DIN EN 12881-1, procedure B (small profile)

Fire source:	Double propane gas burner (medium heat energy)
Tunnel cross section:	6 m²
Volume of air flow:	9 m³/s (low air flow)
Air speed:	1.5 m/s
Belt length:	2.5 m

Table* 6.1-5*: Results of tests according to DIN EN 12881-1, procedure B

Belt sample	**Exposed belt side**	**Double propane gas burner test DIN EN 12881-1, proc. B, profile: 6 m²**		**Test passed**
		Burned length [m]		
No 2078 (Germany)	Conveying side	Top side:	2.50	-
		Bottom side:	2.50	-
	Running side	Top side:	2.50	-
		Bottom side:	2.50	-
No 2079 (Germany)	Conveying side	Top side:	2.50	-
		Bottom side:	2.50	-
	Running side	Top side:	2.50	-
		Bottom side:	2.50	-
No 2094 (UK)	Conveying side	Top side:	1.62	+
		Bottom side:	1.59	+
	Running side	Top side:	1.42	+
		Bottom side:	1.43	+
No 2095 (Poland)	Conveying side	Top side:	1.92	+
		Bottom side:	2.01	+
	Running side	Top side:	1.52	+
		Bottom side:	1.56	+
No 2096 (Poland)	Conveying side	Top side:	1.46	+
		Bottom side:	1.54	+
	Running side	Top side:	1.68	+
		Bottom side:	1.67	+

Results according to DIN EN 12881-1, procedure B (big profile)

Fire object:	Double propane gas burner (medium heat energy)
Tunnel cross section:	10 m²
Volume of air flow:	15 m³/s (high air flow)
Air speed:	1.5 m/s
Belt length:	5 m

These tests were carried out in combination with tests done to determine the concentration of emerging flue gases in fire incidents at conveyor belts. In addition to the belts tested so far, this test series used a belt of type EP 630/4 4/2 VG-No 2115 from Germany as reference, a belt not yet approved for use in underground mining. Table ***6.1-6*** shows the results.

Table* 6.1-6*: Results of tests according to DIN EN 12881-1, procedure B (large cross section of space)

Belt sample	Exposed belt side	Double propane gas burner test DIN EN 12881-1, proc. B, profile: 10m²	Test passed
		Burned length [m]	
No 2078 (Germany)	Running side	Top side: 1.61	+
		Bottom side: 1.70	+
No 2079 (Germany)	Running side	Top side: 1.71	+
		Bottom side: 1.69	+
No 2094 (UK)	Running side	Top side: 1.28	+
		Bottom side: 1.85	+
No 2095 (Poland)	Running side	Top side: 1.33	+
		Bottom side: 1.26	+
No 2096 (Poland)	Running side	Top side: 1.58	+
		Bottom side: 1.39	+
No 2115 (Germany)	Running side	Top side: 5.00	-
		Bottom side: 5.00	-

It is obvious that especially the German belts burned across a significantly shorter length compared with the test conducted previously, i.e. according to DIN EN 12881-1, procedure B. Contrary to that the conveyor belt no. 2115 burned completely. The following Figure 6.1-7 shows a snapshot of a test carried out according to DIN EN 12881-1, procedure B.

Figure 6.1-7: Double propane gas burner test in the large fire gallery

Results according to DIN EN 12881-1, procedure C

Fire source:	Double propane gas burner (very low heat energy)
Test chamber cross section:	0,21 m²
Volume of air flow:	0,21 m³/s (very low air flow)
Air speed:	1.0 m/s
Belt length:	1,5 m

The results of tests done in this series according to DIN EN 12881-1, proc. C are shown in Table ***6.1-7***.

Table 6.1-7***: Results of tests according to DIN EN 12881-1, proc. C***

Belt sample	Exposed belt side	Propane rack test with the double burner DIN EN 12881-1, proc. C		Test passed
		Burned length [cm]	**Average burned length [cm]**	
No 2078 (Germany)	Conveying side	47,00	47,85	+
	Running side	48,70		
No 2079 (Germany)	Conveying side	28,06	30,84	+
	Running side	33,61		
No 2094 (UK)	Conveying side	35,26	36,40	+
	Running side	37,54		
No 2095 (Poland)	Conveying side	29,14	29,51	+
	Running side	29,87		
No 2096 (Poland)	Conveying side	28,58	29,15	+
	Running side	29,72		
No 2115 (Germany)	Conveying side	150,00	150,00	-
	Running side	150,00		

The following picture (Figure 6.1-8) shows a snapshot of a test carried out according to DIN EN 12881-1, procedure C.

Figure 6.1-8: Fire test according to procedure C

Results according to DIN EN 12881-2

Fire source: 300 kg wood (high heat energy)
Tunnel cross section: 10 m²
Volume of air flow: 12 m³/s (high air flow)
Air speed: 1.2 m/s
Belt length: 18 m

The results of tests done in this series according to DIN EN 12881-2 are shown in Table 6.1-8.

Table 6.1-8: Results of tests according to DIN EN 12881-2

Belt sample	Large scale fire test DIN EN 12881-2, profile: 10 m²	Test passed
	Burned length [m]	
No 2078 (Germany)	6.5	+
No 2079 (Germany)	5.5	+
No 2094 (UK)	18.0	-
No 2095 (Poland)	3.0	+
No 2096 (Poland)	7.0	+

Apart from the British belt all belt samples passed this test. The following picture (Figure 6.1-9) shows a snapshot of a test carried out according to DIN EN 12881-2.

Figure 6.1-9: Large scale fire test in the large fire gallery according to DIN EN 12881-2

Discussion

Table ***6.1-9*** shows a summary of all test results obtained.

Table* 6.1-9*: Summary of all test results

		Procedure A	**Procedure B (small profile)**	**Procedure B (large profile)**	**Procedure C**	**Large scale fire test**
	Air flow (m^3/s)	9	9	15	0.21	12
Belt type	No.2078 Germ.	+	-	+	+	+
	No.2079 Germ.	+	-	+	+	+
	No. 2094 UK	+	+	+	+	-
	No. 2095 Pol.	+	+	+	+	+
	No. 2096 Pol.	+	+	+	+	+

The heat energy acting on the conveyor belts was increased from procedure A to procedure B and reached its top at the large scale fire test. Based on experiences, rubber conveyor belts not containing any flame-retardant would not be able to pass these tests.

The two Polish conveyor belts passed all the fire tests. Probably the positive results of the Polish belts are based upon kind and the amount of the flame-retardants included.

The English conveyor belt passed procedure A, B and C but failed the large scale fire test with its high heat energy impact. One explanation can be that the English conveyor belt contains less flame-retardant as the two Polish conveyor belts.

The cover plate of the UK belt is made of PVC. Chlorine is known for being flame-retardant. Obviously, the chlorine presence and the amount of other flame-retardants are not sufficient to stop the fire at high energy input rates. As long as the exact composition of the belt material is not known, this can be the only explanation for the observed behaviour.

Surprisingly the two German conveyor belts passed the large scale fire test but failed in procedure B test with the lower air flow of 9 m^3/s. Increasing the air flow up to 15 m^3/s it also passed this test. This fact shows the cooling effect of higher air flows. Therefore, the conclusion is possible that there is a lower fire spread in galleries with a higher air flow than in galleries with a lower air flow. On the contrary, higher air flows stoke a fire at a conveyor belt and thus increase the fire spread. This effect was especially observed on smouldering conveyor belts. Normally smouldering emerges on conveyor belts containing many flame-retardants. Based upon experiences this effect starts at an air speed of 3 m/s.

However, the negative result of the German conveyor belts cannot in any case be explained by low or insufficient content of flame-retardants because both belt samples passed the heavier large scale fire test. Looking closer at the build-up of theses belts, it turned out that the German conveyor belts show thin covering plates of 1.5 mm. This is less than the other samples showed. The Polish belts showed 2 mm covering plate and the English one even 2.5 mm. It is likely that this fact has a negative influence on the test results of procedure B.

Procedure B is set up to inflame the conveyor belts from both sides, while procedure A only inflames one covering plate, and procedure C and the large scale fire test inflame the belts from the sides. There is a need for further tests in order to investigate the mentioned effect. If the conclusion presumed proves to be right, conveyor belts with thin covering plates have to be excluded from procedure B because they will likely be rated too negative. An alternative would be to demand the large scale fire test for these types of belts.

Additionally, table 9-9 shows that procedure C cannot serve to distinguish the fire spread behaviour of the conveyor belts because all examined conveyor belts passed this test without any problems. The same holds for procedure A. Only the large scale fire test and the above mentioned procedure B allow statements to be made concerning the fire behaviour.

As a consequence, it is not possible to characterise conveyor belts concerning their fire spread behaviour by carrying out only one of the test procedures outlined. At least our investigations showed that a reliable characterization is only possible when results of tests according to all procedures (A, B, C and large scale) are present. The procedures are not equitable. Any future revision of DIN EN 14973 should take this result into account.

As to fire spreading behaviour, the Polish and German belt samples showed similar results considering the thickness of the cover plate respectively. Although we do not have any detailed information about the amount of flame-retardant included in the belt material we assume that there are differences in the samples under investigation. If this assumption is correct, the amount of flame-retardant is a factor influencing the fire spreading behaviour. It also turned out clearly that when it comes to higher energy exposure rates rubber belts showed better characteristics compared to PVC belts. Finally, the build-up of the belt itself may also influence the behaviour according to fire spreading.

It has to be stated clearly that the described results and the consequences drawn are only valid for the belt samples under investigation and cannot be generalised, because not all belt characteristics are known.

6.1.3 Additional information to Task 1.3: Types of conveyor belts

The types of conveyor belts used in the underground mining: rubber-fabric belts, polyvinyl chloride-rubber and polyvinyl chloride belts are shown in Table ***6.1-10***.

Table* 6.1-10*: Types of conveyor belts tested for identification of chemical substances in the combustion products

Sample	Type of Belt	Belt characteristics	
		Core	Separator
NG1	Textile Conveyor belt E/P P800/2 1,5/1,5 VG	Rubber	Polyester / polyamid
NG2	GT-1200-P-1250-3	Rubber	polyamide
NG3	14890 GTP PP 1000 3 1000 4+3 nr 1681	Rubber	polyamide
NG4	14890 GTP PP 1250 3 100 4+3 nr 1698	Rubber	polyamide
NG5	14890 GTP EP 1250 3 1000 4+3 nr 1459	Rubber	polyamide / polyester
NG6	14890 GTP EP 1600 4 1400 4+3 nr 1552	Rubber	polyamide / polyester
NG7	14890 GTP PP 1250 3 1000 4+3 nr 1406	Rubber	polyamidee
NG8	14890 GTP PP 1600 4 1200 4+3 nr 1407	Rubber	polyamide
NG9	14890 GTP PP 1600 3 1200 4+3 nr 2117	Rubber	polyamide
NG10	FR 7000 1000 mm 2/2	PVC	polyester/cotton nylon/cotton
NG11	Textile Conveyor belt E/P P800/2 1,5/1,5 VG	Rubber	polyester / polyamide
NPO12	N/A	N/A	belt with no inflammable additives, object for comparison study
NG13	GTP EP 1250 3 1000 2+2 nr 1459	Rubber	polyamide/ polyester
NG14	GTP EP 1000 3 1000 2+2	Rubber	polyamide / polyester
NG15	E/P-B-P/B 1000/1 PVC 2,5/2,5 1000 mm	PVC	polyester/cotton nylon
NG16	PVNi 1400/1-1200-4+3	Rubber	polyester/cotton nylon

6.1.4 Additional information to Task 1.4: Additional Fire Test and Simulations

In the course of the EDAFFIC project it turned out that there were some spare resources that we used to carry out some additional tests and simulations.

Due to the fact that changing the geometry of the test facility lead to different test results of the real fire tests as well as of the simulations, it has been decided to change the air velocity within the next step.

Therefore, the tests according to DIN EN 12881-1, procedures A, B and C were done with an increased air velocity of 2 m/sec.

Real fire tests

Test according to DIN EN 12881-1, procedure A (air velocity 2.0 m/sec)

Fire source:	Propane gas burner
Tunnel cross section:	6 m²
Volume of air flow:	12 m³/s
Air speed:	2.0 m/s
Belt length:	2 m

Table ***6.1-11*** shows the results of the tests using the propane gas burner according to DIN EN 12881-1, procedure A.

Table** 6.1-11**: Results of tests according to DIN EN 12881-1, procedure A

Belt sample	**Exposed belt side**	**Single propane gas burner test DIN EN 12881-1. proc. A. profile: 6 m²**		
		Burned Length [m]		**Complete ignition Yes/No**
No 2078 (Germany)	Conveying side	Top side:	1.03	No
		Bottom side:	1.05	No
	Running side	Top side:	0.85	No
		Bottom side:	1.22	No
No 2079 (Germany)	Conveying side	Top side:	1.16	No
		Bottom side:	1.15	No
	Running side	Top side:	0.98	No
		Bottom side:	1.22	No
No 2094 (UK)	Conveying side	Top side:	0.92	No
		Bottom side:	1.13	No
	Running side	Top side:	0.82	No
		Bottom side:	1.14	No
No 2095 (Poland)	Conveying side	Top side:	1.24	No
		Bottom side:	1.34	No
	Running side	Top side:	1.02	No
		Bottom side:	1.21	No
No 2096 (Poland)	Conveying side	Top side:	1.09	No
		Bottom side:	1.18	No
	Running side	Top side:	0.96	No
		Bottom side:	1.14	No

Test according to DIN EN 12881-1, procedure B (air velocity 2.0 m/sec)

Fire source:	Double propane gas burner
Tunnel cross section:	6 m²
Volume of air flow:	12m³/s
Air speed:	2.0 m/s
Belt length:	2.5 m

Table ***6.1-12*** shows the results of the tests using the propane gas burner according to DIN EN 12881-1, procedure B.

Table** 6.1-12**: Results of tests according to DIN EN 12881-1, procedure B

Belt sample	Exposed belt side	Double propane gas burner test DIN EN 12881-1, proc. B, profile: 6 m² Burned length [m]		Test passed
No 2078 (Germany)	Conveying side	Top side:	2.50	-
		Bottom side:	2.50	-
	Running side	Top side:	2.50	-
		Bottom side:	2.50	-
No 2079 (Germany)	Conveying side	Top side:	2.50	-
		Bottom side:	2.50	-
	Running side	Top side:	2.50	-
		Bottom side:	2.50	-
No 2094 (UK)	Conveying side	Top side:	1.67	+
		Bottom side:	1.75	+
	Running side	Top side:	1.44	+
		Bottom side:	1.58	+
No 2095 (Poland)	Conveying side	Top side:	2.50	-
		Bottom side:	2.50	-
	Running side	Top side:	2.50	-
		Bottom side:	2.50	-
No 2096 (Poland)	Conveying side	Top side:	2.50	-
		Bottom side:	2.50	-
	Running side	Top side:	2.50	-
		Bottom side:	2.50	-

Test according to DIN EN 12881-1, procedure C (air velocity 2.0 m/sec)

Fire source:	Double propane gas burner (very low heat energy)
Test chamber cross section:	0.21 m²
Volume of air flow:	0.42 m³/s
Air speed:	2.0 m/s
Belt length:	1.5 m

Table ***6.1-13*** shows the results of the tests using the propane gas burner according to DIN EN 12881-1, procedure C.

Table** 6.1-13**: Results of tests according to DIN EN 12881-1, procedure C

Belt sample	Exposed belt side	Propane rack test with the double burner DIN EN 12881-1, proc. C — Burned length [cm]	Average burned length [cm]	Test passed
No 2078 (Germany	Conveying side	15.7	16.45	+
	Running side	17.2		
No 2079 (Germany)	Conveying side	12.6	13.6	+
	Running side	14.6		
No 2094 (UK)	Conveying side	13.0	13.9	+
	Running side	14.8		
No 2095 (Poland)	Conveying side	11.5	11.95	+
	Running side	12.4		
No 2096 (Poland)	Conveying side	13.0	12.5	+
	Running side	12.0		

Simulated fire tests

Remark: Again the following simulations are for a belt like the German conveyor belt no 2078. Therefore the results of the simulations are compared with the results of the belt no 2078.

Test according DIN EN 12881-1, procedure A (air velocity 2.0 m/sec)

As required by procedure A of DIN EN12881-1 a 15 m long test space with a cross-section of 6 m² was used. The air velocity was 2.0 m/sec.

The conveyor belt placed in the tunnel had a length of 2.0 m; it was exposed to fire from a gas burner with a total power of 490 kW/m² for a period of 10 minutes.

Burn-off length (test): 1.03 m
Burn-off length (simulation): 1.00 m

Test according DIN EN 12881-1, procedure B (air velocity 2.0 m/sec)

As required by procedure B of DIN EN12881-1 a 15 m long test space with a cross-section of 6 m² was used. The air velocity was 2.0 m/sec.

The conveyor belt placed in the tunnel had a length of 2.5 m; it was exposed to fire from a gas burner with a total power of 490 kW/m² for a period of 20 minutes.

Burn-off length (test): 2.50 m
Burn-off length (simulation): 2.50 m

Test according DIN EN 12881-1, procedure C (air velocity 2.0 m/sec)

As required by procedure C of DIN EN12881-1 a 1.67 m long test space with a cross-section of 0.21 m² was used. The air velocity was 2.0 m/sec.

The conveyor belt was exposed to fire from a dual burner with a total power of 360 kW/m² for a period of 50 minutes.

Figure 6.1-10 shows the simulation of a test according to DIN EN 12881-1, procedure C with an air velocity of 2.0 m/sec.

Burn-off length (test): 16.45 cm
Burn-off length (simulation): 00.00 cm

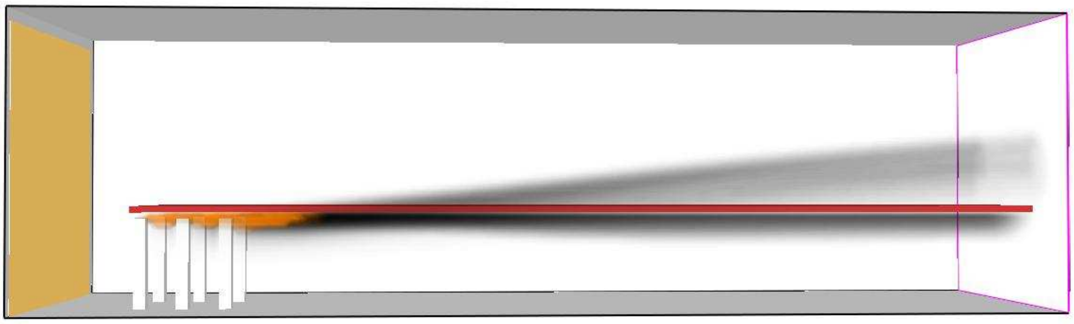


Figure 6.1-10: Simulated propane gas test using dual burner (air velocity: 2.0 m/sec)

The simulation does not allow observing damaged surfaces by the influence of the burner flames. Therefore, the simulation does still fit with the test result of the real fire test because the tested conveyor belt (VG-No. 2078) also did not ignite and also did not burn away.

Assessment of the results and conclusion

Simulation

Table ***6.1-14*** shows the results of the additionally simulated fire tests with an air velocity of 2.0 m/sec compared with the results of the tests simulated according to DIN EN 12881-1 with 1.5 m/s and 1.0 m/sec as well as the results of the equivalent real fire tests of the belt no 2078.

Table* 6.1-14*: Comparison of the results with the requested air velocity according to DIN EN 12881-1 of 1.5 m/s and 1.0 m/sec and with an air velocity of 2.0 m/sec

Test	Air velocity	Real fire test (burned off length)	Simulation (burned off length)	Air velocity	Real fire test (burned off length)	Simulation (burned off length)
DIN EN 12881-1, procedure A	2.0 m/sec	1.03 m	1.00 m	1.5 m/sec	1.38 m	1.40 m
DIN EN 12881-1, procedure B	2.0 m/sec	2.50 m	2.50 m	1.5 m/sec	2.50 m	2.50 m
DIN EN 12881-1, procedure C	2.0 m/sec	16.45 cm	0.00 cm	1.0 m/sec	0.47 m	0.50 m

The fire simulations confirm the impact of the air velocity on both the fire development and the fire spread recorded during the real fire tests.

Influence of the air velocity

As before, the test results show the influence of the air velocity on the test results.

Increasing the air velocity resulted – for all conveyor belts - in a negligible increased fire spread by the test according to DIN EN 12881-1, procedure A.

Increasing the air velocity for procedure B showed an interesting result. While the Polish conveyor belts felt to pass the test - they passed the test with an air velocity of 1.5 m/sec - the increased air velocity had only a small effect on the test results of the British conveyor belt. The British conveyor belt is made up of polyvinyl chloride (PVC) which is probably the cause of the extremely positive test results. With its thermoplastic characteristics and its big chlorine content PVC melts rapidly and therefore withdraws itself from the fire and extinguishes without the impact of the flames of the burner.

An increased air velocity for procedure C resulted in better test results for all tested conveyor belts. Due to the limitations of the simulation, it is not possible to define a damaged surface of the simulated conveyor belt. Anyhow, the simulation still represents the test result of the real fire test as the conveyor belt showed only damages at the surface in the real fire test.

Increasing the volume of the test facility showed more positive results for all conveyor belts whereas increasing the air velocity resulted in worse test results. The test results also show the immanent influence of the material of which the conveyor belt is made of. The British conveyor belt was the only one made of PVC and showed a very contrary behaviour, compared with the other conveyor belts.

Conclusions

Considering the test results mentioned above it is absolutely essential to consider the influences of air velocity and space of the test facility while comparing and rating the significance of the test results of the different test procedures.

Finally, it can be postulated that the results of the simulated fire tests reproduced the test results of the real fire test very well. With some further research, simulated fire tests may become an essential part for a prospective analysis of the properties of newly constructed conveyor belts even before testing them in real fire tests. However actually simulated fire tests are not able to replace real fire tests for the certification of conveyor belts.

6.2 WP3

6.2.1 Additional Information to Task 3.3: Wireless Heat Point detectors

The designed system consists of high accuracy temperature sensors based on SHT-75 model from Sensirion manufacturer. One or more sensors (up to 4) are connected (wired) to the wireless sensor nodes. These devices are battery powered and provide energy to the sensors to take the measurements. Once the temperature values have been read are sent to the sensor coordinator by means of a wireless link.

This topology allows:

- Perform a wireless communication between remote nodes (installed along the conveyor belt longwall/structure) and the sensor coordinator placed several meters away, reducing the installation costs because of the needless of cable.
- Easy installation of the sensors. The use of small size (aprox. 30x10mm) temperature sensors (only the measure element is attached at the end of the cable) allows to be easily installed along the conveyor belt structure and/or nearby places.
- Low maintenance. The use of battery powered wireless sensor nodes with an expected autonomy of 10 years reduces its maintenance to almost zero.
- Installation flexibility. Wireless devices allow to be installed in the conveyor belt structure segments and be moved together with them when the conveyor belt is reallocated.
- Easy system integration. The treatment of the received data is performed by the coordinator, which is in charge of alarm/alert triggering in case of the detection of suspicious hot points. This coordinator can be easily integrated with third parts, like environmental monitoring systems without any special requirement from the processing point of view because of it gives out the processed information. From the point of view of the interface, it can be connected using a RS485 port or analog signal.

The designed monitoring system has the following technical features:

- Low power wireless communication radio stages based on European ISM band (100mW, 868 Mhz).
- Long distance link (from 50 to 200 meters depending of longwall layout) from the sensor to the node.
- Diagnostic functions allow knowing if a node is alive, battery level, etc.
- High accurate (±1.8ºC) sensors with a repeatability of ±0.1ºC and a digital interface with 12bits of resolution.
- Smart microcontroller/algorithms implemented in wireless nodes are capable of managing the battery energy in the most efficient way and only provide power to the sensors when a measure is needed. During no activity periods (neither transmission nor readings are performed), the current consumption of the wireless node is lower than 1μA.
- Small size, low cost and user replaceable battery allowable to be used in EX environments.
- Designed according to ATEX directives (intrinsically safe circuit, “ia”).
- Cost efficient designed. Radio stages are implemented by means of discrete components (no commercial radio module is used).

<u>Placement of heat point detectors along conveyor belts</u>

One key in the integration of a communication infrastructure using wireless transmission is the number of temperature sensor elements needed for the monitoring of hot spots.

Even though heat sensors can be used for early detection of fire, experience has shown that other type of sensors (CO and smoke detectors) could provide better results. Hence, temperature detectors should be treated as auxiliary devices that will control critical elements of the conveyor construction.

Additionally to work as warning and signalling device, they would also serve as a method to help identify the cause and the location of a fire.

The placement of temperature sensors have to be close to the elements of belt conveyor construction which are especially a risk of damage. It has been considered that critical elements which are strongly recommended to monitor with heat point detectors are (i) tail pulleys, (ii) head pulleys, (iii) bend and take-up pulleys, (iv) transfer points, (v) loading and discharge points and (vi) hydraulic and electrical devices.

For the carrying and return idlers the placement of sensor on each of them would be the perfect situation. The separation between idlers in a conveyor belt line depends on the material density and the belt width. The higher the material density is, the less separation between idlers. The wider the conveyor belt is, the less separation between idlers.

Assuming a separation between idlers of 1 m, and a conveyor belt length of 1 km, there would be one thousand idlers distributed along the conveyor belt line (taking only into account the carrying idlers). The carrying idlers could be considered more critical because they hold or “conveyor” the belt which carries the material. Nevertheless, the return idlers are also exposed to damage and if the conveyor belt is located on the ground, the coal spillage accumulated near the vicinity of the conveyor belt could behave as a source of ignition. The ideal situation for the temperature heat point detectors would be to install them on each idler in both sides, but this would lead in a high cost system, even when the wireless heat point detectors are low cost itself.

A lower cost solution would be to place the heat detector every 5-10 m, alternating the location of the detectors in both sides

6.2.2 Additional information to Task 3.4: Tests and research on products of a fire source

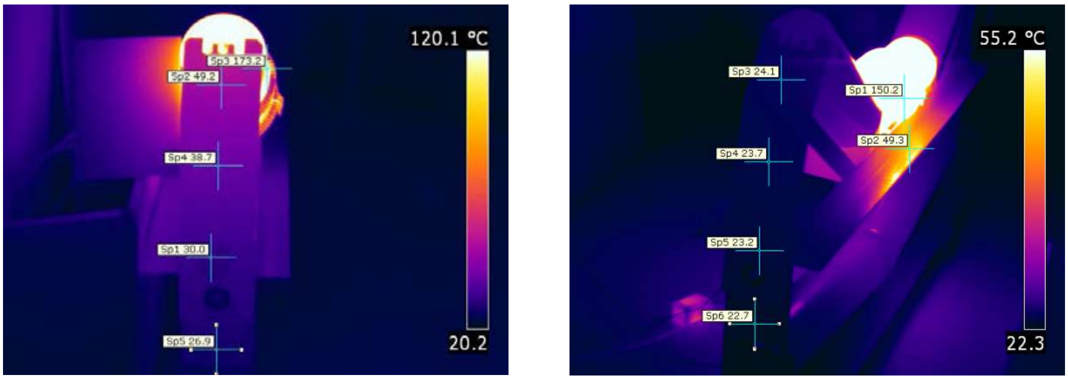
The simulative tests of fires in belt conveyors allowed us to determine a correct fire index. To analyse a thermal decomposition of various types of belts (characteristics of components) more precisely, each belt sample was weighed before and after a test of heating in order to estimate the result emission of volatile (gaseous) substances. This is necessary to create an additional index which would determine a fire hazard.

The tests were made at a friction test stand in the conveyor belt factory FTT Wolbrom (Poland). Underground test were done within WP5 in the experimental adit of the Central Mine Rescue Station in Bytom (Poland) and in the hard coal mine of San Nicolás in Spain. In order to calculate the fire hazard indexes of multisensor as well as the placement of multisensor devices, it has been necessary the underground tests, which correspond to the work done within the WP5.

1) Lab tests of temperature increment at a construction of a belt conveyor

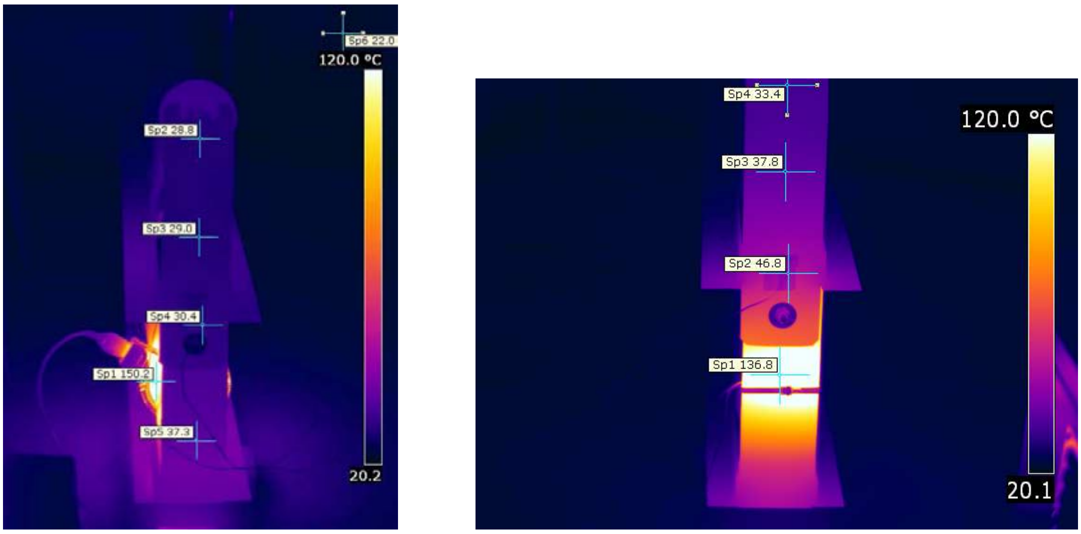
The laboratory tests of simulated failures were carried out within the previous tasks of the EDAFFIC project. The temperature distribution at elements of conveyor construction is presented in the following figures:

1. heating a top-side idler (Figure 6.2-1a) (simulation of belt slide or seizure of bearings),
2. heating a top-centre idler (Figure 6.2-1) (simulation of belt slide or seizure of bearings),
3. heating a bottom idler (Figure 6.2-2a) (simulation of belt slide or seizure of bearings),
4. heating a side flat bar (Figure 6.2-2b) (simulation of friction between low belt and a flat bar).



a) *b)*

Figure 6.2-1: Results of thermovision measurements obtained during heating: a) a top-side idler, b) a top-centre idler; side view – the values of temperatures at selected points



a) *b)*

Figure 6.2-2: Results of thermovision measurements obtained during heating: a) a bottom idler, b) a side flat bar; a view of a side part of a conveyor – the temperature values are marked at selected points

The temperature measurements were made at selected points of construction of a model belt conveyor (Figure 6.2-3).

Figure 6.2-3: Single element of the belt conveyor construction including idlers and measuring points marked (T1 and T2)

The Figure 6.2-4 and Figure 6.2-5 present the temperature increments at the conveyor construction in the measuring points T1 and T2. The temperature increments were calculated in relation to ambient temperature (temperature of reference) which was 18°C in each case.

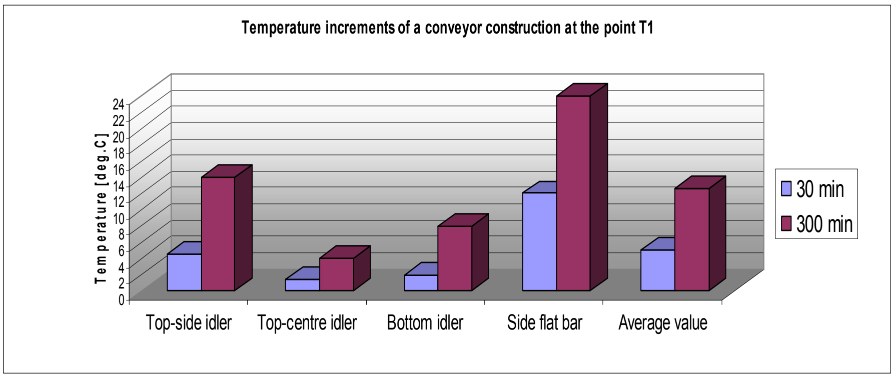


Figure 6.2-4: The temperature increments of a conveyor construction in the measuring point T1

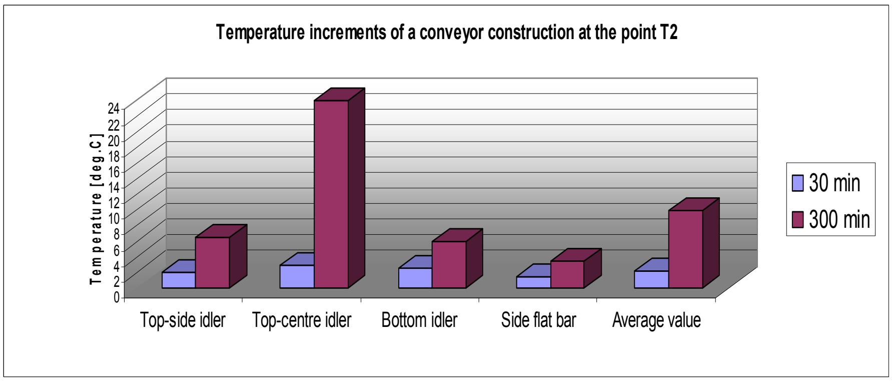


Figure 6.2-5: The temperature increments of a conveyor construction in the measuring point T2

The diagrams show that the selected points for temperature measurements at the conveyor construction meet the diagnostic expectations. In order to complete the control of an individual constructional bar, the measurements should be done at two points at least (better at three points). The temperature increments of the construction should be detected in relation to the ambient temperature in the range of 2°C to 10°C with accuracy of ±0.5°C.

2) Tests on objects to develop the principles of placement of sensors and signal processing

The detection of the products emitted during development of a fire in a belt conveyor has been checked in the following tests:

- tests of temperature increment at a belt conveyor construction by means of a temperature increment sensor CPT;
- tests of gaseous products and smoke close to a fire source;
- tests of distribution of gaseous products and smoke.

The above mentioned tests are described in detail in the reports related to WP5. The abridged version of the reports is presented below.

2A) Tests of temperature increment at a belt conveyor construction by means of a temperature increment sensor CPT

The tests were made with use of a temperature increment sensor CPT developed by EMAG for purposes of the EDAFFIC project. The CPT sensor consists of several measuring detectors to measure the temperature at selected points of conveyor construction. Max 4 measuring lines, each of them consisting of up to 20 detectors may be connected to the CPT sensor.

The block diagram of the CPT sensor is presented in the Figure 6.2-6. If a random temperature detector installed at a conveyor construction detects that the temperature at this place exceeds the reference temperature T_o by the set value (difference temperature), then the CPT signals this case.

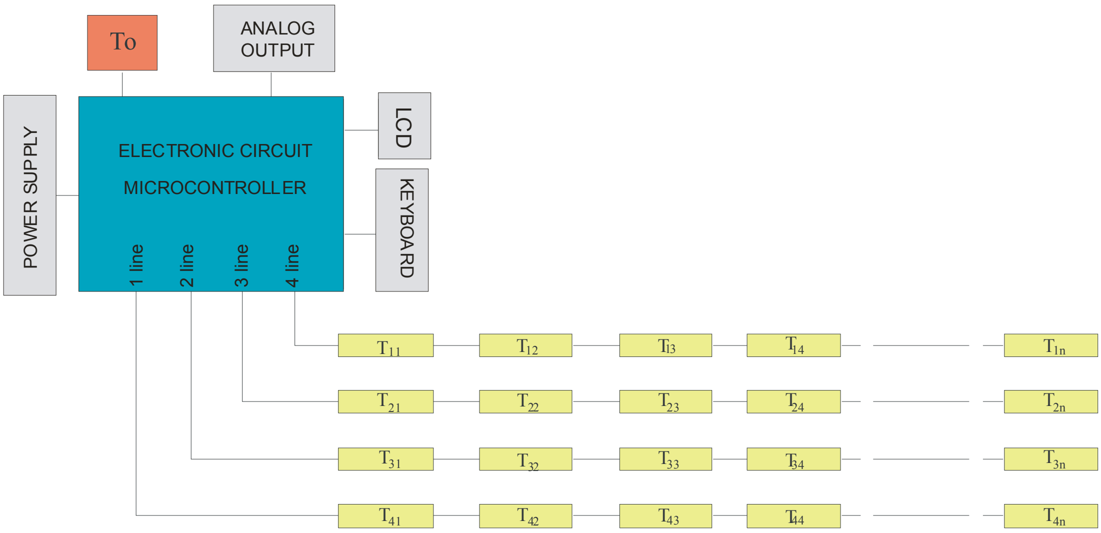


Figure 6.2-6: Block diagram of the CPT sensor

The tests were made in the experimental adit in the CSRG Bytom. A single section of a belt conveyor was put in the working with the air ventilation velocity of about 1m/s. The heating was simulated by means of ceramic electric heaters with temperature regulation up to 300°C. Two heating simulations of the conveyor construction (simulation of belt friction) were made:

- simulation of friction between a belt and a side flat bar of the construction;
- simulation of friction between a belt and a seized idler.

The measuring results are presented in the Figure 6.2-7 and Figure 6.2-8.

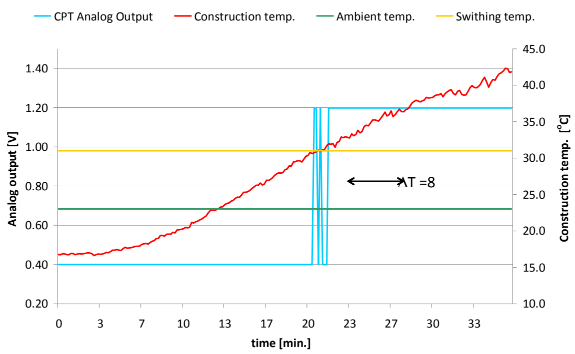


Figure 6.2-7: Tests results for simulation of a friction between a belt and a side part of cb

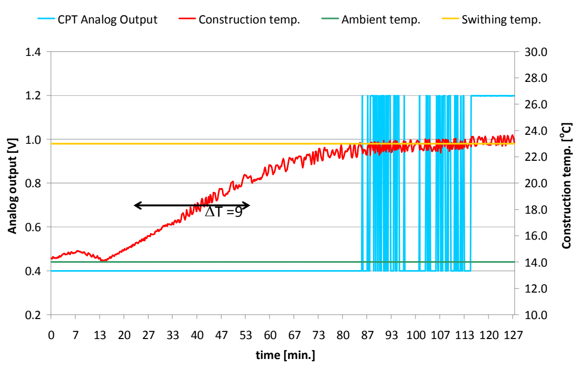


Figure 6.2-8: Tests results for simulation of a friction between a belt and a seized idler

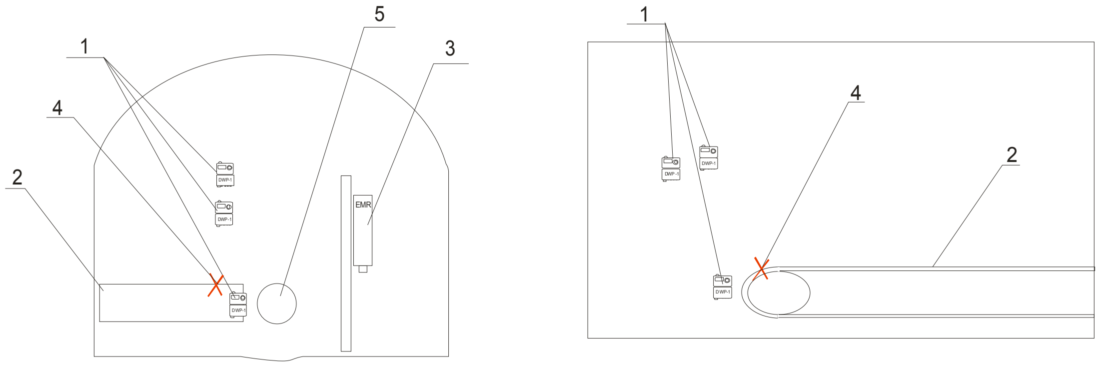
2B) Tests of gaseous products and smoke close to a fire source

The trials were made at the 7th floor in the hard coal mine San Nicolás in Mieres (Spain), which is at -258m (the entrance to the mine is located at a height above sea level of +291m). The mine is included in the HUNOSA group, which is the partner of the project. The trials were carried out at a conveyor belt.

A conveyor belt made of polyvinyl chloride PVC was put to tests. The belt consists of several cotton protective inter-layers (carcass), covers and cover wraps. The simulation of friction (seizing) was made at the return (tail) pulley at the end of the working ventilated by separate pipe lines.

A synoptic plan of layout of multi-parameter sensors during trials in the St. Nicolas mine in Mieres (Spain) is presented in the Figure 6.2-9, whereat:

1. multi-parameter sensors DWP-1;
2. belt conveyor;
3. reading system EMR-HS – underground outstation;
4. seizing point of the belt (simulation of seizing – friction);
5. separate ventilation (air pipe).



a) cross section of the working; b) along the working

Figure 6.2-9: Layout of sensors in the working:

The Figure 6.2-10 presents the results of seizing (friction) tests on the tail pulley of the belt conveyor.

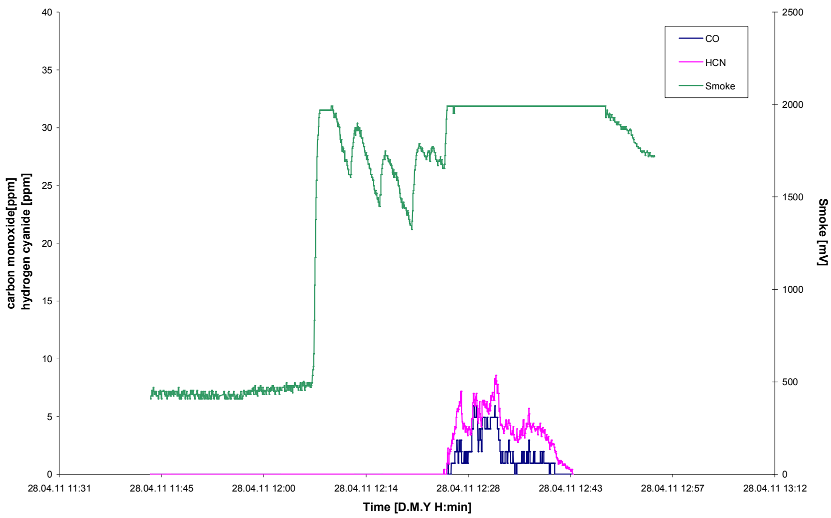


Figure 6.2-10: Output signals from the multi-parameter sensors DWP-1 – seizing tests of a belt produced in Spain – simulation of seizing in the hard coal mine San Nicolás.

2C) Tests of distribution of gaseous products and smoke along a mine working

The transport of products generated during a fire in a belt conveyor was tested in the experimental adit of the Central Mine Rescue Station in Bytom (Poland). On the basis of the test results there have been analysed the parameters which are crucial for the layout of the sensors along the conveyor belt lines.

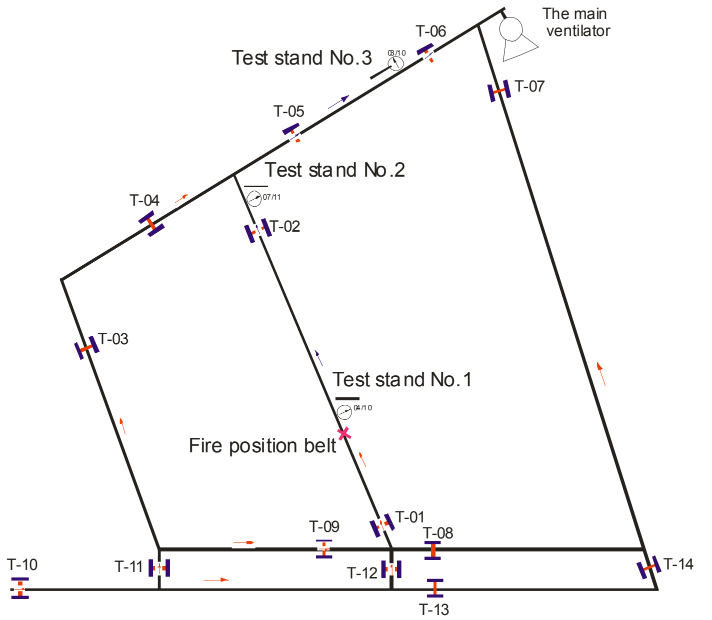


Figure 6.2-11: Scheme of the working (experimental adit) at CSRG in Bytom

The measuring sensors were located in a distance of ~ 3m, ~ 25m and ~ 60m from the fire source.

The fires were simulated by heating belt samples and the construction of a belt conveyor.

The recorded time diagrams of measuring concentrations of carbon monoxide, hydrogen cyanide and smoke are presented below. The time-spatial distributions of the products emitted at a fire have been calculated. Test for a non-flammable belt:

a) b) c)

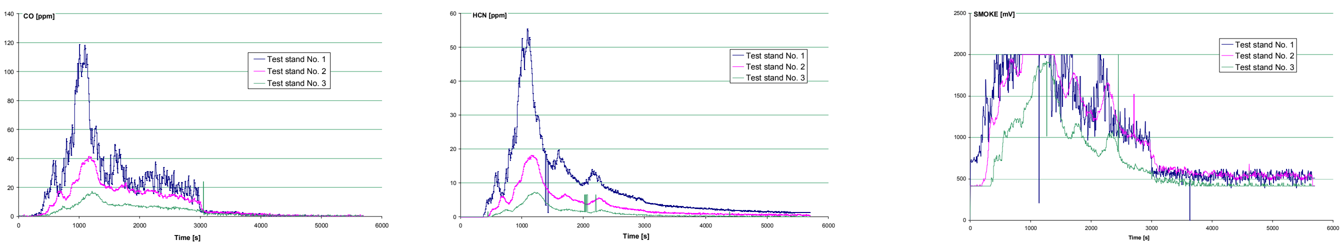


Figure 6.2-12: Diagrams recorded for the products emitted at a fire – non-flammable belt a) carbon monoxide, b) hydrogen cyanide, c) smoke

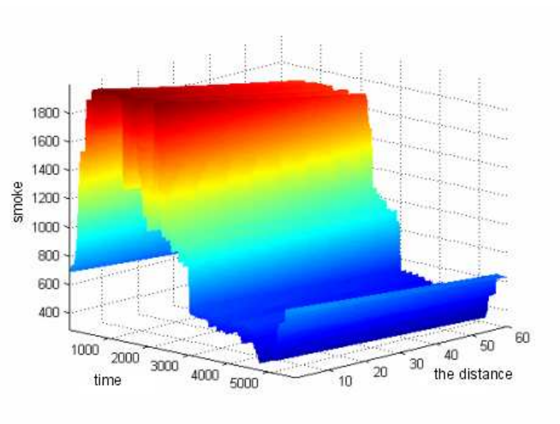


Figure 6.2-13: Time-spatial distribution of smoke in a working for a non-flammable belt

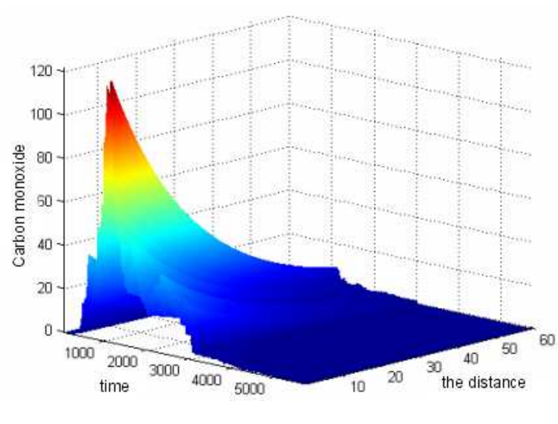


Figure 6.2-14: Time-spatial distribution of carbon monoxide in a working for a non-flammable belt

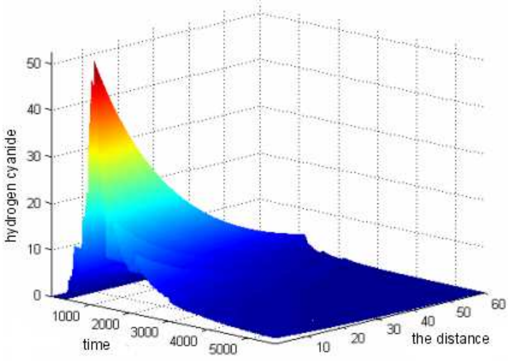


Figure 6.2-15: Time-spatial distribution of hydrogen cyanide in a working for a non-flammable belt

6.2.3 Additional information to Task 3.4: Fire hazard indexes calculated on the basis of the measured sets of parameters which are typical For a fire source

The main feature of a reliable system for early detection of fires is its high sensitivity with minimization of number of false alarms. The system should show a state of an object to be supervised on the basis of as many data as possible. Many independent parameters, i.e. products emitted from a fire source, are measured; therefore to compare them to each other it is necessary to calculate a common fire hazard index. Depending on a type of signal processing it is possible to calculate two kinds of fire hazard indexes:

- a fire hazard index simplified, calculated in a processor of a multi-parameter sensor;
- a fire hazard index extended, calculated in a central station of a fire early detection monitoring system.

Fire hazard index calculated inside a multi-parameter sensor

A fire hazard index W_p has been calculated on the basis of a physical characteristic of a fire source. In a short time of fire development there occur the most important products: carbon monoxide, hydrogen cyanide and smoke which are measured by means of detectors. The calculated fire hazard index W_p is a "through" average value of the signals from the detectors above mentioned which have been filtered and standardized previously.

In case of a failure in one of detectors, it is still possible to detect a fire.

The fire hazard index W_p has been calculated on the basis of the formula:

$$W_p = \frac{\bar{x}_{CO} + \bar{x}_{HCN} + \bar{x}_D}{3}$$

where:

$\bar{x}_{CO}$ – a filtered and standardized signal value of carbon monoxide;

$\bar{x}_{HCN}$ – a filtered and standardized signal value of hydrogen cyanide;

$\bar{x}_D$ – a filtered and standardized signal value of smoke.

The measuring signals were filtered by means of a low-pass filter. Averaging various parameters of a fire source improves reliability of decisions regarding the object being monitored.

The figures from Figure 6.2-16 to Figure 6.2-19 present time diagrams as well as spatial and time-spatial distributions of fire hazard indexes for the results gained at the tests made in the experimental adit in CSRG Bytom. A type and quantity of a belt sample and a mass decrement during a thermal degradation process were presented.

Test No 2 – non-flammable belt:

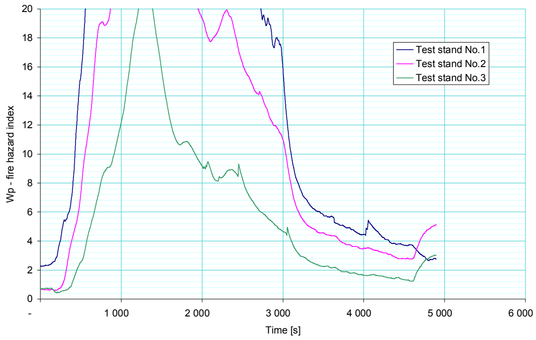


Figure 6.2-16: Determined fire hazard index at test stands – Test No 2 – non-flammable belt

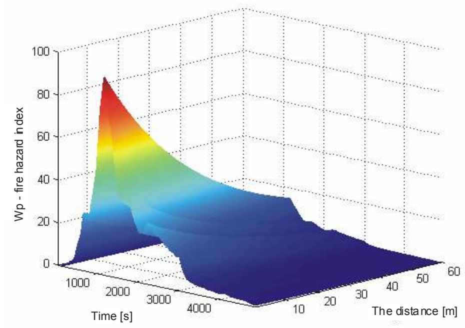


Figure 6.2-17: Time-spatial distribution of fire hazard index in an excavation for a non-flammable belt – Test No 2

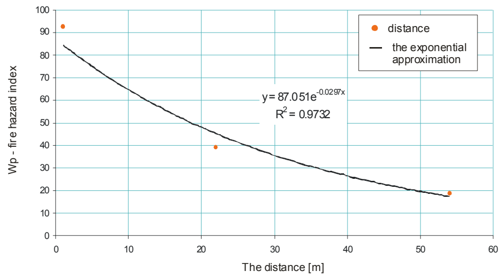


Figure 6.2-18: Distribution of a fire hazard index in an excavation after a time of 20 min from the beginning of heating a non-flammable belt (max value of fire hazard index) – Test No 2

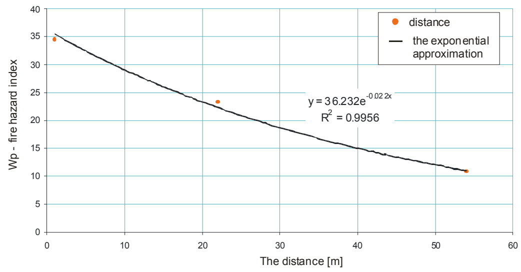


Figure 6.2-19: Distribution of a fire hazard index in an excavation after a time of 30 min from the beginning of heating a non-flammable belt – Test No 2

Mass decrement of a non-flammable belt sample (Test No 2):

m_1= 365,1g
m_2= 29,1g

mass decrement Δm=336,1g = 92,1% mass decrement of a non-flammable belt sample.

6.2.4 Additional information to Task 3.4: Fire hazard index calculated in the central station of the fire early detection system (fuzzy logic)

To detect the fires by means of the system it can be used a fuzzy logic method. As opposed to the fire hazard index W_p, which reflects a physical fire event, the index W_R (fuzzy model) has been determined on the basis of a wide measuring data base (model training). This method has been presented in the literature. The output index (fire hazard index W_p) is standardized and has values in the range of [0, 1]; this is recommended in the literature when using this method.

An example of determining the states of the monitored object on the basis of the measuring data gained in the experimental adit is shown below.

Fuzzy logic may be divided into three stages. The first stage is the fuzzification which comprises the process of transforming crisp values into membership grades for fuzzy sets in the input of the multi-sensor device (values of smoke, CO, HCN). The next step is the inference mechanism, which is responsible for calculation of the output membership function on the basis of input grades. For this purpose fuzzy if-then rules and inference procedures are used. The fulfilment grades of premises are determined and next the fulfilment grades of conclusions are calculated. The final stage is the determination of an output membership function of conclusion of all rules. This way an output fuzzy set is created which is put into a defuzzification process which consists in the transformation of the received fuzzy set to a quantifiable (numerical) result.

To create a model, the results of the Test 5 (multi-sensor No 4/11, a non-flammable belt) were used. To define the parameters of the fuzzy model, the fuzzy clustering of data was used, which automatically divides the dataspace into data-subspaces. The result of this process is determining cluster centres of the measuring samples i.e. determining parameters of the model including organisation of its structure. A number of inputs of the model is related to a number of measuring sensors: smoke detectors, carbon monoxide sensors, hydrogen cyanide – 3 inputs, determination of fire hazard state – 1 output. The gained clusters represent the rule base. The number of clusters corresponds with the number of rules of the model. The position of cluster centres corresponds with the parameters of a membership function of the inputs and the output. The determined cluster centres are the basis for creating a structure of a fuzzy model. A model of Mamdani type has been chosen for further description. The Figure 6.2-20 presents the location of cluster centres of the input space based on the results of heating tests of belts.

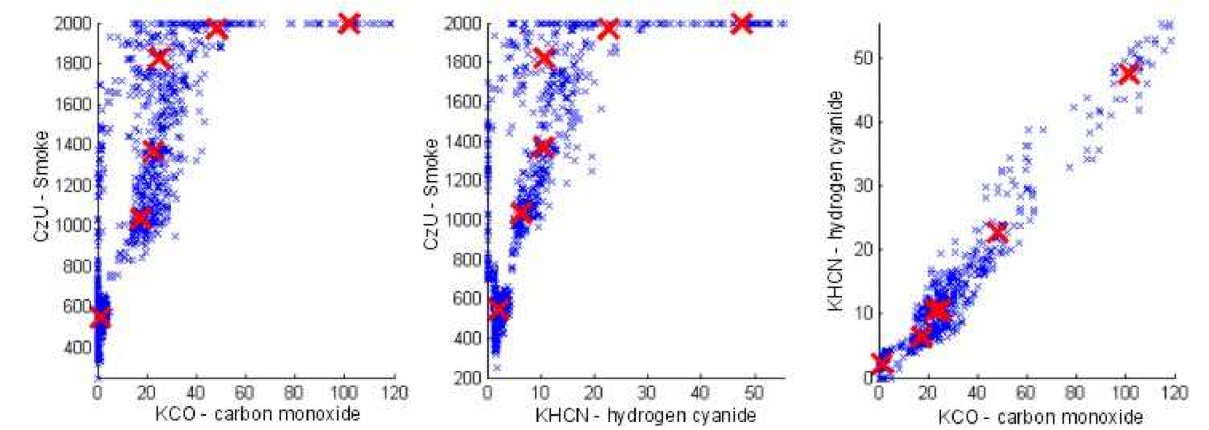


Figure 6.2-20: Location of cluster centres of the input space

The clustering process resulted in 5 clusters; therefore 5 membership functions have been placed in the output space. There has been assumed that the determined fire hazard index would take on a values in the range of [0,1], where 0 – no fire hazard, 1 – fire.

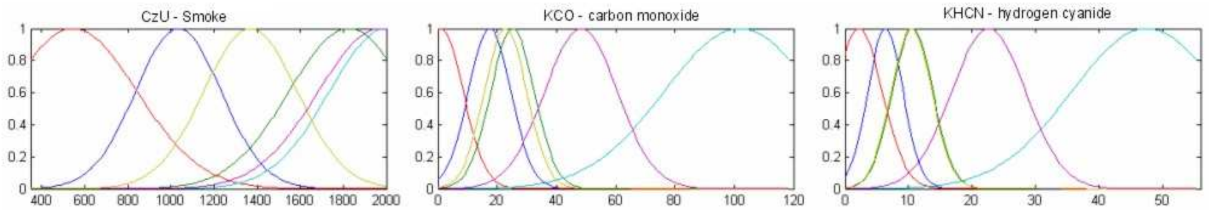


Figure 6.2-21: Membership functions of inputs of a fuzzy model

A very important factor influencing a fuzzy reasoning mechanism is a selection of fuzzy operators. The membership grades of input data $\mu_{Ai}(x_i)$ of individual rule premises are calculated with use of Gauss function (Figure 6.2-21). The premises in fuzzy rules are joined using a MIN operator and a common activation grade is calculated:

$$\beta_i = \min\left(\mu_{A1}(x_1), \mu_{A2}(x_2), \ldots, \mu_{An}(x_n)\right)$$

The activation grade of conclusions of individual rules is calculated as follows:

$$\mu_{C'i}(y) = \min\left(\beta_i, \mu_{Ci}(y)\right),$$

where $\mu_{Ci}(y)$ – membership function of output.

The result membership function is created as a result of aggregation of rules conclusion of a fuzzy model. This function is calculated using a MAX operator according the rule:

$$\mu_C(y) = \max\left(\mu_{C'1}(y), \mu_{C'2}(y), \ldots, \mu_{C'n}(y)\right)$$

The last stage of the fuzzy logic is the defuzzification of the output fuzzy set. There are several methods for calculating the value of fire hazard index, but in our case the centre of gravity method has been used.

The Figure 6.2-22 presents a fuzzy logic for three cases. The Figure 6.2-22 a shows a fuzzy logic method for the measured values classified as a normal state of a belt conveyor. The Figure 6.2-22 b shows the same for a warning state and the Figure 6.2-22 c for an alarm state.

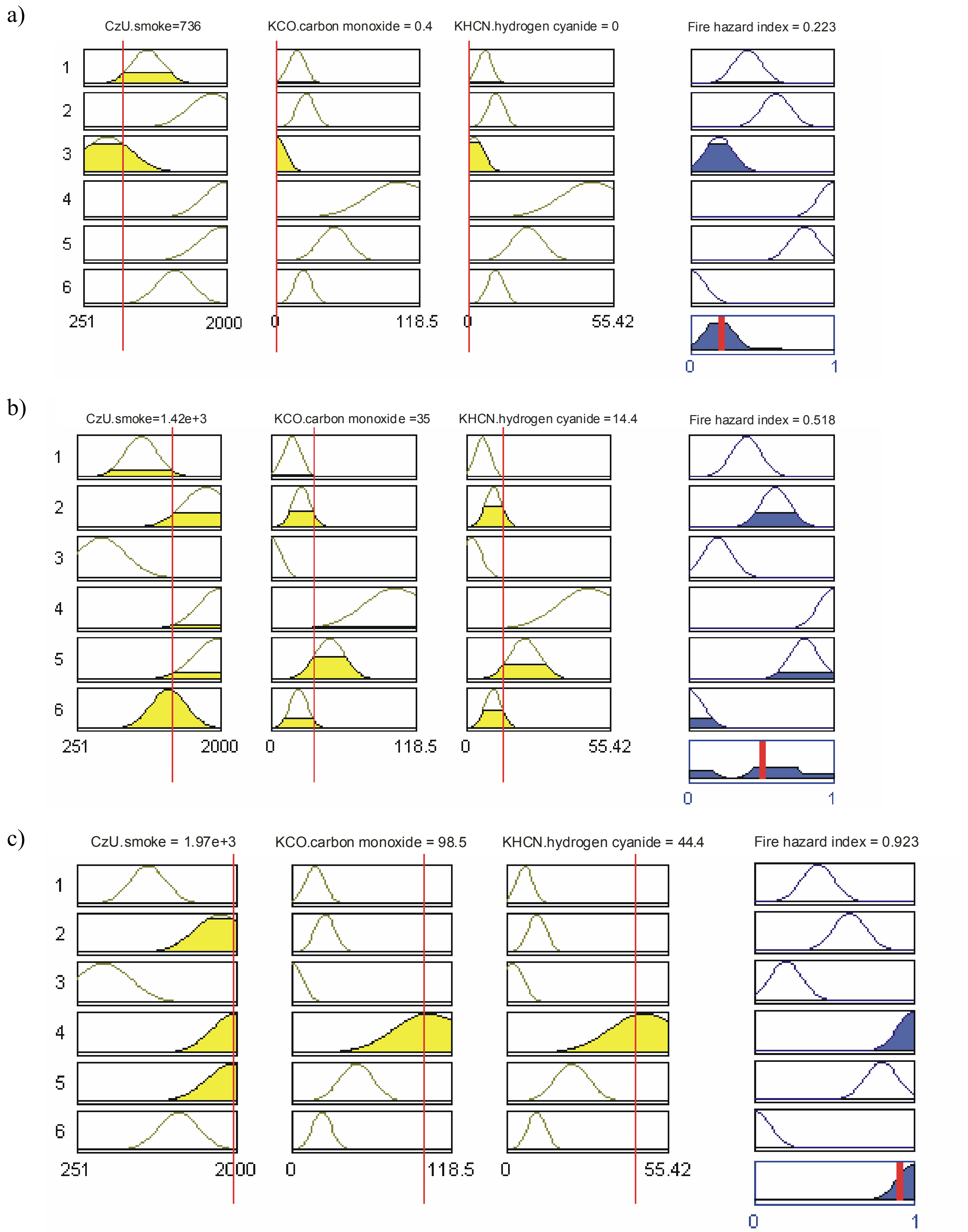


Figure 6.2-22: Fire hazard index (fuzzy logic) for fire hazard states: a) normal; b) warning; c) alarm

The time functions and the time-spatial distribution of the fire hazard index W_R were determined on the basis of the measuring results. The time functions after and before digital filtering are presented in the figures Figure 6.2-23 and Figure 6.2-24.

The calculated thresholds of warning (1) and alarm (2) for early fire detection are marked in the Figure 6.2-24. The time function of the fire hazard index after filtering was differentiated and the derivative diagram is presented in the Figure 6.2-25. Analysis of this diagram allows a quick signalling of the growth in fire hazard indexes, which it means there is a fire source. Similar analyses of signals may be made for the fire index W_p presented in the previous chapter.

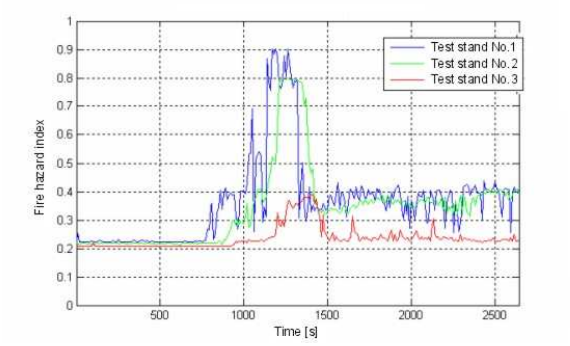


Figure 6.2-23: Time functions of fire hazard index W_R before digital filtering

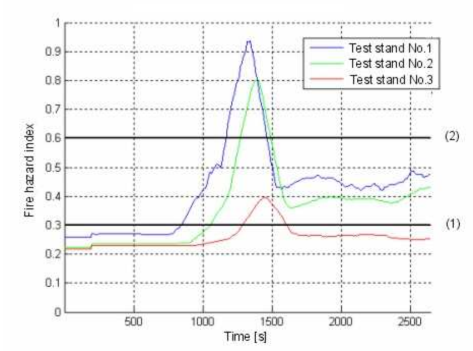


Figure 6.2-24: Time functions of fire hazard index W_R after digital filtering with marked warning (1) and alarm (2) thresholds for early detection of fires

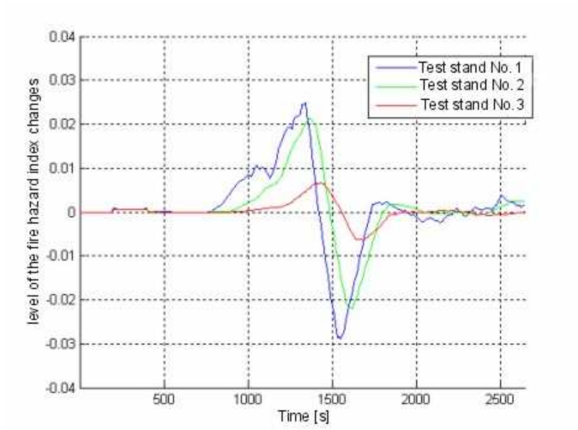


Figure 6.2-25: Derivative of time function of fire hazard index after filtering allowing a quick signalling of growth in a value of fire hazard index and occurring of a fire source

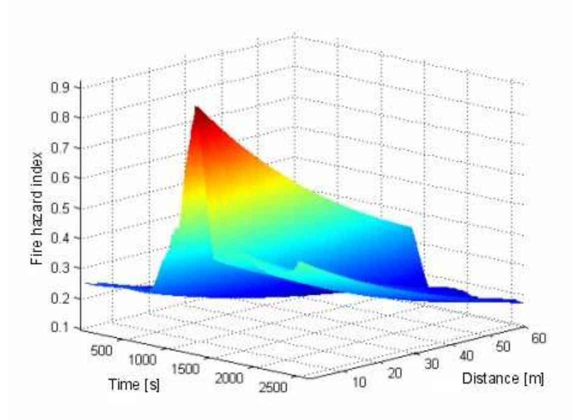


Figure 6.2-26: Example of a time-spatial distribution of W_R index allowing determining max distances of sensors along conveyor routes

The test results and calculations for various test stands allowed also determining an exemplary time-spatial distribution of the W_R index (Figure 6.2-26) to determine max distances of sensors along conveyor routes.

6.2.5 Additional information to Task 3.4: Placement of multi-sensor devices along belt conveyor route

The belt conveyors are the difficult things to protect against fires. They are located usually in very wide excavations and sometimes inaccessible places with accumulated combustible materials (coal, cables, etc.).

The previous analyses of fire sources in belt conveyors in underground mines have shown that they may occur at various places and be caused by various reasons.

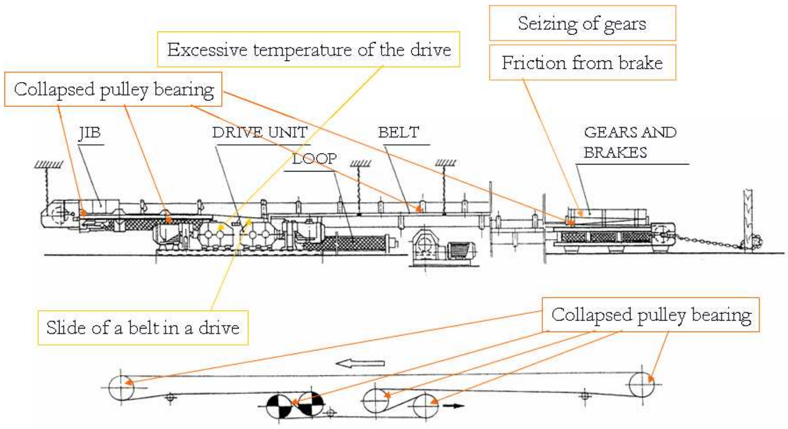


Figure 6.2-27: The most frequently occurred failures in a belt conveyor

A structure of a belt conveyor including elements (marked) which may cause increase in temperature and a fire is shown in the on Figure 6.2-27.

The belt conveyor systems are installed at very broad areas of mines. So it means, according the above presented reasons of fires, the fire sources may be located in various places. The points of installation of multi-sensor devices should be determined on the basis of the analysis of heat transport in conveyor constructions and the analysis of products emitted during development of fires. The products to be analysed are:

- heat energy (temperature);
- gaseous products (CO, HCN);
- smokes (solid and liquid particles).

The heat energy flows in elements of a conveyor construction from heated elements (damaged, seized) according to the tests which were carried out. The thermographic functions have been presented in the Figure 6.2-1 and Figure 6.2-2, and the synthetic growth in temperature has been shown in the figures Figure 6.2-4 and Figure 6.2-8. The summary temperature increments are presented in the figures Figure 6.2-7 and Figure 6.2-8. The processing of the signals of temperature detectors and signalling the temperature increments at the supervised elements of a belt conveyor section in relation to the ambient temperature (temperature of reference) is made by the multi-sensor device.

The theoretical models and experimental data are the basis for the placement of multi-sensor devices in the area to be protected. The criteria of layout of the multi-sensor devices are as follows:

- minimizing the distances of multi-sensor devices from the sources of the potential fire hazard in the underground area;
- air flow direction;
- a parameter value of a fire source (concentration of gases, smoke, temperature) measured at a place of installation of a multi-sensor device should satisfy the following inequality:

$$x > x_{min}$$

where x_{min} is a minimum parameter value measured by a measuring sensor,

- a delay time of transport of combustion products should satisfy the following inequality:

$$t < t_{max}$$

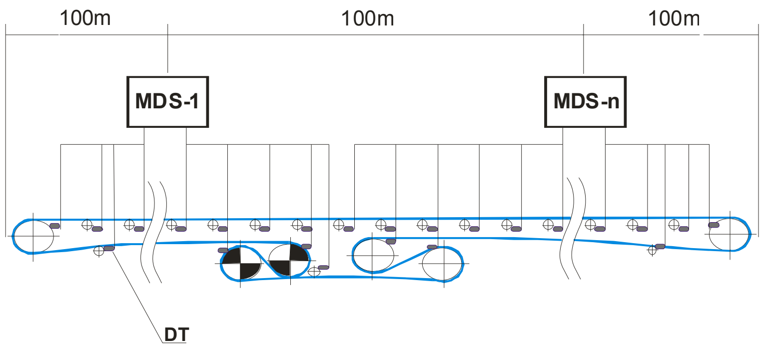
where t_{max} is a maximum time of transport of combustion products resulting from a distance and a manner for transport from a potential fire source to a measuring sensor. The allowable value of t_{max} results from a character of a potential fire source and is a significant criterion for early detection systems of open fires which develop very quickly.

- minimizing measuring disturbances acting on a multi-sensor device;
- destroying factors or the factors which have an adverse influence on the measuring devices.

Due to possible flexible configuration of a multi-sensor device, the different criteria may be accepted for the following types of detectors:

- for gas detectors (CO, HCN) a zone to be protected is determined only by a time of transport of gas products to a place of location of a sensor;
- for smoke detectors a zone to be protected is determined by a time of transport of smoke (fumes products) of a fire source and a drop of smoke concentration;
- temperature detectors of a belt conveyor construction should control the elements of conveyor construction which are especially put at a risk of damage.

The exemplary layout of sensors is shown in the Figure 6.2-28.



MDS-i – multi-sensor device including:

- DWP – multi-parameter sensor,
- MCD-1 – smoke detector,
- CPT – temperature increment sensor and
- DT – sensor of temperature.

Figure 6.2-28: Layout of multi-sensor devices along a belt conveyor route

6.2.6 Additional information to Task 3.5: Characteristic of a multisensor device

The technical documentation and the prototypes of multisensor devices were made within the Task 3.5. The ATEX certificate has been issued for the multisensor. The multisensor device is presented in the Figure 6.2-29.

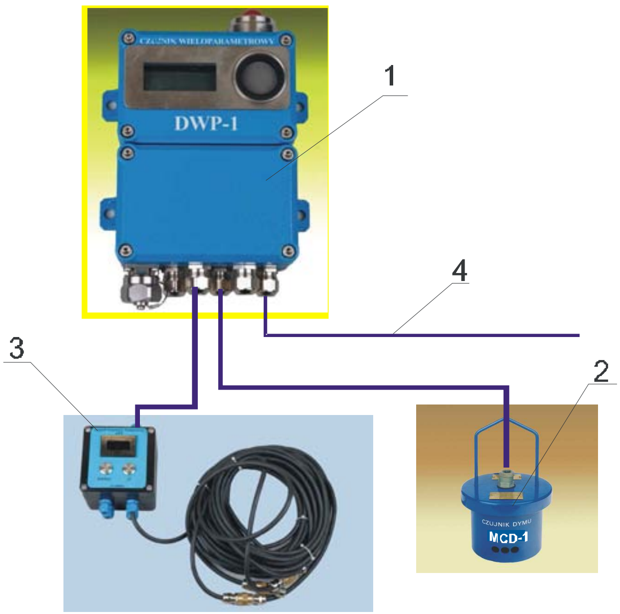


Figure 6.2-29: Max structure of a multisensor device: (1) multi-parameter sensor DWP-1, (2) smoke detector MCD-1, (3) temperature increment sensor CPT, (4) supply-transmission line

The structure of the multisensor device consists of the following elements:

- multi-parameter sensor DWP-1,
- temperature increment sensor CPT,
- microprocessor smoke detector MCD-1.

The fundamental element of the multisensor device is the multi-parameter sensor DWP-1. If necessary, various sensors can be connected to the DWP-1.

Multi-parameter sensor DWP-1

The multi-parameter sensor DWP-1 (Figure 6.2-30) has been made in two versions:

- DWP-1v.1 – to be supplied from a surface supply-transmission line of a telemetric transmission central station;
- DWP-1v.2 – to be supplied from an intrinsically safe power supply; analogue output and RS 485 output.

Figure 6.2-30: Multi-parameter sensor DWP-1

Technical data of a multi-parameter sensor DWP-1

- supply voltage version DWP-1v.1: Ui=60V, Ii=0.05A version DWP-1v.2: Ui=16V, Ii=0.6A
- display of measuring results alphanumeric display LCD
- power supply version DWP-1v.1: remote, from surface supply-transmission module of a safety and production parameters monitoring system SMP-NT/*
- power supply version DWP-1v.2: from an intrinsically safe power supply Exia
- output signal version DWP-1v.1: digital, with FSK modulation;
- output signal version DWP-1v.2: analogue 0.4÷2.0 V
- input RS485 1 – with circuit validity check
- analogue inputs 2 – with circuit validity check
- range of working temperature -10°C ÷ +40°C
- air relative humidity 0 ÷ 95% without condensation
- overall dimensions 123x180x58mm
- mass about 2 kg
- protection rating IP54
- certification type (protection mark) M I Exia I / IIA
- measuring ranges of CO detector 0÷200ppm CO
- measuring transducer of CO detector electrochemical cell
- measuring error of CO detector ± 5 ppm for the range 0÷200 ppm CO
- time of response T90 of CO detector max. 60s
- measuring range of HCN detector 0÷20ppm HCN
- measuring transducer of HCN detector electrochemical cell
- measuring error of HCN detector ± 3 ppm for the range 0÷20 ppm HCN
- time of response T90 of HCN detector max. 60s

Approval of intrinsic safety and degree of protection IP of the casing

The corresponding tests for ATEX certification were made and the approval was issued by the Experimental Mine “Barbara” (Notified Certification Body). The EC Type Examination Certificate ATEX of the multi-parameter sensor DWP-1ver.x is shown in the Figure 6.2-31.

GIG

[1] CERTYFIKAT BADANIA TYPU WE

[2] Urządzenia, systemy ochronne, części i podzespoły przeznaczone do użytku w przestrzeniach zagrożonych wybuchem. Dyrektywa 94/9/WE
(Rozporządzenie MG z dnia 22.12.2005r. Dz.U. Nr 263, Poz. 2203).

[3] Certyfikat badania typu WE:

KDB 10ATEX142

[4] Urządzenie:

Czujnik wieloparametrowy DWP-1v.x

[5] Producent:

Instytut Technik Innowacyjnych EMAG

[6] Adres:

ul. Leopolda 31, 40-189 Katowice

[7] Przedmiotowe urządzenie lub system ochronny wraz z zatwierdzonymi jego odmianami, zostało opisane w załączniku do niniejszego certyfikatu oraz w wymienionych w nim dokumentach.

[8] Główny Instytut Górnictwa, Jednostka Notyfikowana nr 1453 zgodnie z artykułem 9 Dyrektywy 94/9/WE z dnia 23 marca 1994, potwierdza, że urządzenie lub system ochronny będący przedmiotem niniejszego certyfikatu spełnia zasadnicze wymagania bezpieczeństwa i ochrony zdrowia dotyczące projektowania i budowy urządzeń i systemów ochronnych przeznaczonych do użytku w przestrzeniach zagrożonych wybuchem wymienione w Załączniku nr 2 Dyrektywy 94/9/WE (Rozdział 2 Rozporządzenia MG z dnia 22.12.2005r. Dz.U. Nr 263, Poz. 2203).
Wyniki oceny i badań zostały wyszczególnione w poufnym sprawozdaniu KDB Nr 10.210 [T-6680]

[9] Zasadnicze wymagania bezpieczeństwa i ochrony zdrowia zrealizowano poprzez spełnienie wymagań norm:

PN-EN 60079-0:2009, PN-EN 60079-11:2010,
PN-EN 50303 :2004

[10] Znak „X” umieszczony za numerem certyfikatu oznacza szczególne warunki stosowania w przestrzeniach zagrożonych wybuchem wyszczególnione w załączniku do niniejszego certyfikatu.

[11] Niniejszy certyfikat badania typu WE dotyczy jedynie konstrukcji, oceny i badań przedmiotowego urządzenia lub systemu ochronnego zgodnie z Dyrektywą 94/9/WE.
Certyfikat nie obejmuje pozostałych wymagań Dyrektywy dotyczących procesu produkcji i wprowadzania na rynek urządzenia lub systemu ochronnego.

[12] Urządzenie lub system ochronny należy oznaczyć:

I M1 Ex ia I
II 2G Ex ia II(CH_4)

Specjalista ds. Certyfikacji Urządzeń Przeciwwybuchowych
dr inż. Michał Górny

KIEROWNIK
Zespołu Certyfikacji Wyrobów
KD "BARBARA" Mikołów

Data wydania: 12.01.2011

Strona 1 z 3

Figure 6.2-31: EC Type Examination Certificate ATEX of the multi-parameter sensor DWP-1ver.x issued by Experimental Mine “Barbara” (Notified Certification Body)

6.2.7 Additional information to Task 3.5: Additional sensors

Temperature increment sensor

The temperature increment sensor CPT consists of a basic unit and temperature detectors which are designed for measurement of temperature at selected points of a belt conveyor construction. It is possible to connect to the temperature increment sensor maximum 4 measuring lines, each of them may include up to 20 temperature detectors. The schematic diagram of the CPT sensor is shown in the Figure 6.2-32.

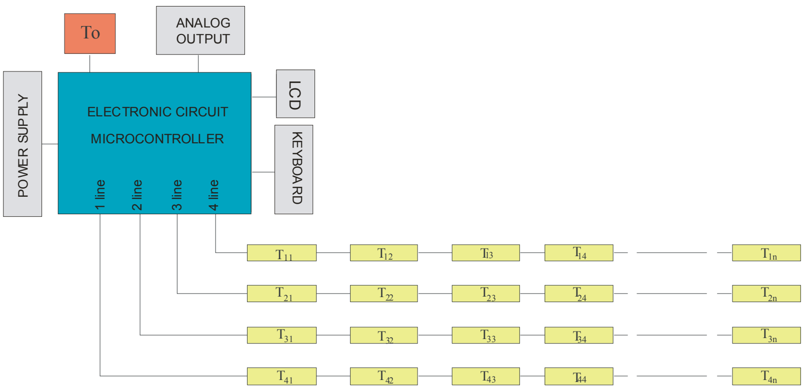


Figure 6.2-32: Schematic diagram of temperature increment sensor CPT

Figure 6.2-33: Temperature increment sensor CPT

Figure 6.2-34: A single temperature detector of CPT temperature increment sensor

The temperature increment sensor CPT is shown in the Figure 6.2-33 and a single temperature detector in the Figure 6.2-34. . The CPT sensor signals when a temperature measured by a random temperature T_o detector (installed at a belt conveyor construction) exceeds a set temperature reference value. The value of the increment temperature is set in the range of 4 to 20ºC with resolution of 4ºC by means of the push button at the front side of the CPT. The CPT sensor can control the temperature increments up to 80 points maximum, located at a belt conveyor construction.

Technical data of the temperature increment sensor CPT

- display of measuring result	alphanumeric display LCD
- power supply	10 – 30 VDC
- max current	12 mA (basic unit + 4 lines)
- analogue output signal	0.4 – 2.0 VDC
- working temperature range	-10ºC ÷ +40ºC
- relative humidity range	0 ÷ 95% without condensation
- overall dimensions	122x120x90mm
- mass	about 1 kg without measuring lines
- protection rating of casing	IP54
- reference temperature range	-40ºC ÷ 125ºC
- construction temperature range	-40ºC ÷ 150ºC
- temperature increment range	4ºC ÷ 20ºC
- measuring error of reference temperature	±0.5ºC
- measuring error of construction temperature	±2ºC
- hysteresis of temperature increment at conveyor construction	±4ºC
- response time T90 of temperature detector at conveyor construction	120s.

Microprocessor smoke detector MCD-1

The smoke detector MCD-1 (Figure 6.2-35) is designed for protection of mine workings against fire hazards. It's adjusted to operation under conditions of high air humidity and temperature as well as a high and variable air velocity. The isotope smoke sensor type DIO-40W made by POLON-ALFA Sp. z o.o. in Bydgoszcz (Poland) and an electronic unit developed by EMAG are used in the smoke detector MCD-1.

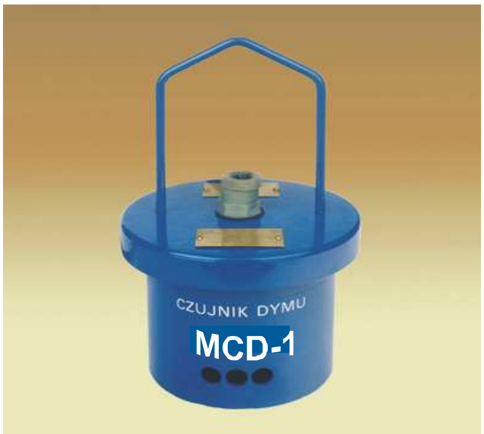


Figure 6.2-35: Smoke detector MCD-1

Technical data of the MCD-1 smoke detector

- Supply voltage	7 ÷ 16 VDC
- Zero output voltage level	0.4 ±0.05 VCD
- Analogue output range	0.4 ÷ 2 VDC
- Current consumption	3 mA
- Protection degree of ionisation chamber	IP-00
- Protection degree of terminals	IP-54
- Certification type	EExia, CE
- Isotope source	Am-241 (7.4kBq)
- Operating temperature	-10 ÷ 40ºC
- Relative air humidity	<95% at 40ºC
- Max. air flow velocity	10 m/s
- Dimensions	∅170 x 200 mm
- Mass	3kg (without cable)

The smoke sensor DIO-40 used in smoke detectors MCD-1 is a double-chamber ionisation device fitted with α-radioactive isotope source Am-241.

The smoke sensor consists of three basic units:

- measuring chamber;
- comparative chamber;
- electronic circuit.

The ionisation chambers of the sensor are connected in series and operate in differential circuit. Smoky air flows into the ionisation and comparative chambers and is mixed with ionised air. The introduced smoke causes the changes in the resistance of the chambers, and consequently the change in voltage on the common electrode of the chambers.

The ionisation smoke sensor reacts to the visible and invisible smoke particles. The signal from the ionisation chamber is analysed in two measuring lines. The first line is used for filtering a signal from noise affected from the operation of a source and ionisation chambers. The filtration is made by software in microprocessor by means of an integrating circuit with time constant less than 1s. The task to be made by the second measuring line is to determine long-term trends of measuring signals on the basis of values collected in a time cycle of a few up to several hours. The output signal is the difference of the signals from the first and second measuring lines. Simultaneously, the signal from the second measuring line (long term) is constantly monitored in order to capture the changes being beyond the allowable range. By using this solution the sensor is able to adopt itself to variable working conditions (air velocity, dust, humidity) in longer periods of time.

The electronic measuring system of the smoke detector makes the following functions:

- power supply of microprocessor;
- supply of measuring circuit;

- supply of ionisation chambers;
- control of operation and state of ionisation chambers and generation of an alarm signal in case of failure in chambers (pollution, ageing of a source);
- adjusting a measuring signal level from ionisation chamber to operating levels of analogue digital converters;
- measurement of signals from ionisation chamber with various frequencies in two separate measuring lines;
- filtering a measuring signal;
- generation of an output analogue signal at a level of 0.4 to 2 VDC;
- generation of an output bistable signal when a set threshold is exceeded (the threshold setting by software);
- visual signalling when a set threshold is exceeded.

6.3 WP4

6.3.1 Additional information to Task 4.2: Combating Fires with Chemical Agents in Water Spray Mist

This appendix provides additional information on the work on combating fires with chemical agents in water spray mist that was carried out in Task 4.2.

Spontaneous Combustion Test Rig

Figure 6.3-1 and Figure 6.3-2 show the developed coal spontaneous combustion test rig and the test rig operational during the first sequence of test runs respectively. Figure 6.3-3 illustrates the test rig as a schematic diagram and shows the basic components used.

Figure 6.3-1: Test Rig

Figure 6.3-2: Test Rig Operational

The rig consisted of a combustion chamber 380mm in diameter by 480mm in length, where a coal sample encapsulated in concrete (Figure 6.3-4 and Figure 6.3-5) was placed and sealed in position with fire clay (Figure 6.3-6). Coal samples were obtained from a mine which works the Warwickshire Thick Seam which has a high liability to spontaneous combustion. The coal sample (1Kg) was exposed at each end to allow air to feed the fire and products of combustion to be conveyed out of the chamber, through a condensation unit to remove coal tar, to a point where gaseous products of combustion could be sampled. A temperature thermocouple was placed through the casing of the rig and could be positioned into the coal sample via a pre-drilled hole in the concrete tablet (Figure 6.3-7). The fire seat temperature was thus monitored up to and on application of the extinguishing medium. The effectiveness of the spray was indicated by the temperature drop over a period of time to a point of complete extinguishment. This was also compared to the quantity of spray material used.

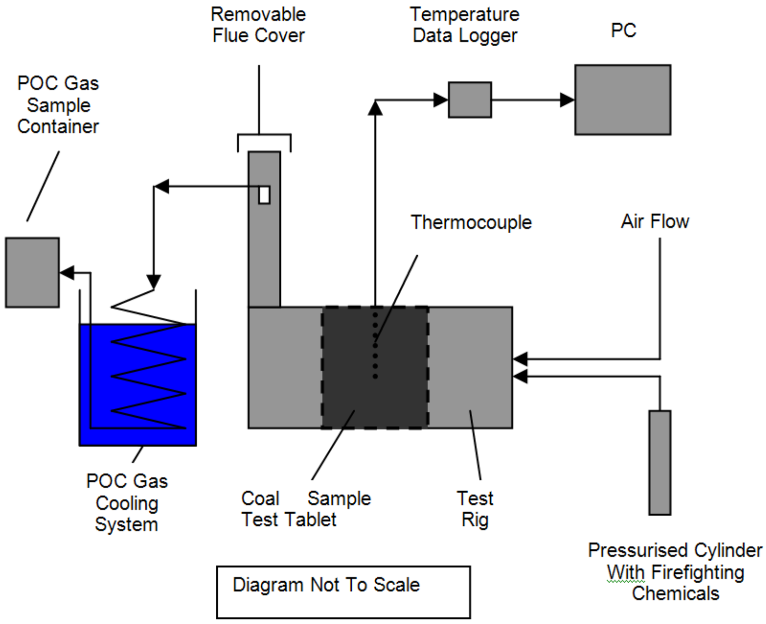


Figure 6.3-3: Schematic Diagram of Test Rig Components

Figure 6.3-4: Coal Test Tablet (Inlet)

Figure 6.3-5:Coal Test Table (Outlet)

Figure 6.3-6: Test Tablet Sealed in Position

Figure 6.3-7: Thermocouple Inserted in Sample

<u>Chemical Agents</u>

The choice of chemical agents was limited to sodium silicate solution (Sodium Oxide 9.1%, Amorphous Silica 29.2% and Water 61.7%) and a mix of sodium silicate solution with hydrochloric acid (0.1M). A range of concentrations and mix ratios were tested and compared with pure water. The objective was to extinguish the spontaneous combustion fire in coal without the formation of ‘water gas' or its individual constituents of hydrogen and carbon monoxide, each which has an explosive range.

Four test sequences, each with three tests under the same parameters were established:

1. Water mist 100%
2. Pure water + Sodium silicate solution 50:50
3. Sodium silicate solution 100%
4. Sodium silicate + hydrochloric acid 75:25

<u>Spray Methodology</u>

A modified fire extinguisher cylinder containing one litre of sodium silicate solution/variation mix was pressurised to 40 bar with nitrogen gas. The sodium silicate solution was forced through a siphon tube within the cylinder and converted to a spray via an RXT hollow cone water-mist nozzle (RXT 0510). This nozzle type gives an average spray volume flow rate of 29ml per second and 87ml for a three second application of water spray. The three second spray time was chosen as a starting point and was determined from previous research as an optimum time for the prevention of re-ignition in open fires.

The chemical sprays varied from 25ml per second for water and sodium silicate 50:50 solution and sodium silicate and hydrochloric acid 75:25 solution to 21ml per second for 100% sodium silicate solution. The variation in flow rate is related to the viscosity of each mix. The choice of using mist sprays was based on the effectiveness of pure water-mist to combat mine fires in previous research projects ECSC PRO94 Fire fighting Systems and RFCS MINTOS. This approach had not been previously researched in the area of combating spontaneous combustion fire in coal.

<u>General Test Methodology</u>

On placing the coal test tablet in position in the combustion chamber and sealing the front tablet rim to the inner surface of the chamber to prevent air leakage (ensuring air flow through the coal only), the coal was ignited with a blow torch and propriety fire lighters. The thermocouple was placed in position at the core of the coal sample. Once the coal had reached red heat, the combustion chamber end plate was fitted, sealed and the air flow was established. The flow rate applied was just enough to bleed through the sample and ensure continued combustion took place. The temperature was monitored and when a stable maximum was reached, the fire fighting spray mist was applied. The temperature data logger was activated at maximum temperature and spray was initiated for a total period of 120 seconds.

Cooled products of combustion gasses were sampled pre- and immediately post-spray application into a 'Tedlar' gas sampling bag. From the gas sample bag, a 'Draeger Tube' analysis was made for carbon monoxide and hydrogen gases for each test.

Results

Figure 6.3-8 to Figure 6.3-11 show the graphs of time versus temperature for test sequences 1 – 4 respectively.

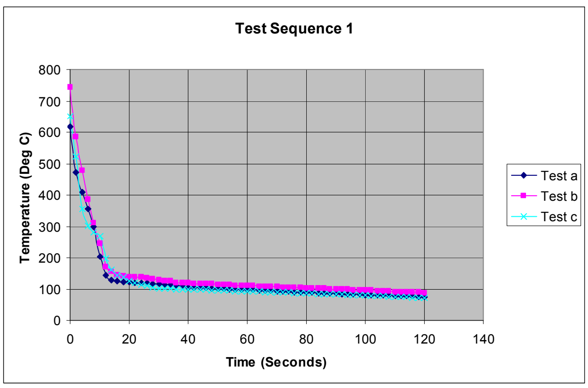


Figure 6.3-8: Graph of Time Versus Temperature for Test Sequence 1

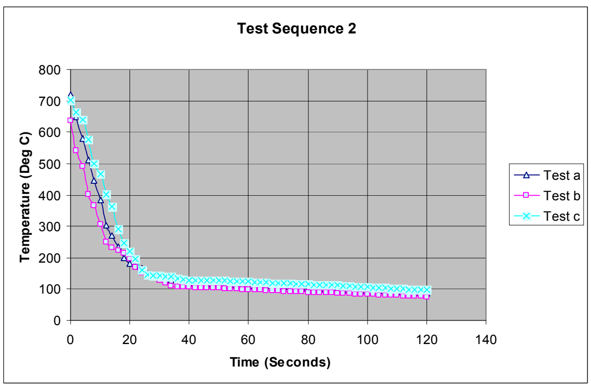


Figure 6.3-9: Graph of Time Versus Temperature for Test sequence 2

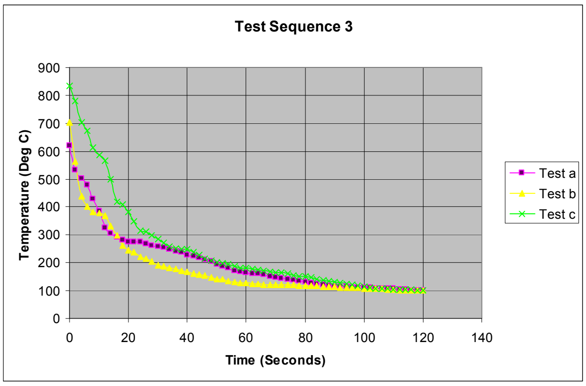


Figure 6.3-10: Graph of Time Versus Temperature for Test Sequence 3

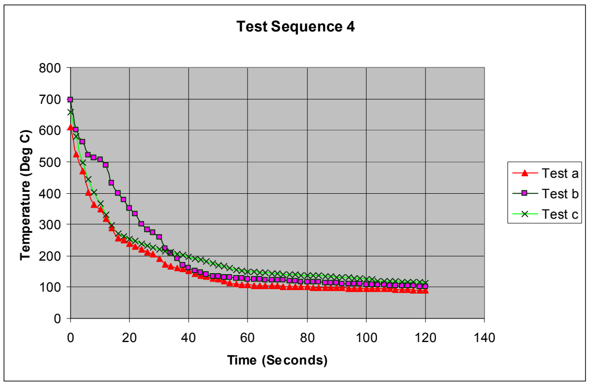


Figure 6.3-11: Graph of Time Versus Temperature for Test Sequence 4

In general, all the test graphs show that the fire fighting capability was effective when using the spray mist technique. The general trend was for rapid cooling of the fire core between 10 to 40 seconds for the temperature to drop to 150 to 200°C, followed by a steady decline in temperature towards 100°C approaching 120 seconds after the application of mist.

The most effective temperature reduction was displayed in test sequence 1 (Figure 6.3-8) which used the pure water mist as the fire fighting medium. The temperature reduced from an average of approximately 650°C to 130°C in 12 seconds, followed by a steady reduction to approximately 80°C for the remaining time to 120 seconds. A similar trend was closely followed by the results of test sequence 2 which used a water and sodium silicate solution mix at 50:50. The rapid initial fall extended over a period of 20 seconds to 180°C followed by the steady reduction to below 100°C to the 120 seconds point.

The results for test sequence 3 and 4 gave a less pronounced two stage process with graphs tending to an exponential reduction in temperature over time. Test sequence 3 consisted of using mist with 100% sodium silicate solution and test sequence 4 utilised the mist consisting of 75:25 sodium silicate solution and hydrochloric acid.

Figure 6.3-12 to Figure 6.3-15 show a sample photo of extinguished coal from each test sequence 1 - 4 respectively.

Figure 6.3-12: Test Sequence 1

Figure 6.3-13: Test Sequence 2

Figure 6.3-14: Test Sequence 3

Figure 6.3-15: Test Sequence 4

The coal extinguished with pure water mist is shown in Figure 6.3-12 and shows no deposition. Where sodium silicate was included in the mist, varying degrees of deposition are illustrated. Figure 6.3-13 shows an example of test sequence 2 where water and sodium silicate 50:50 was used as the extinguishing medium and shows partial deposition and crystallisation of the coal sample. It must be noted that all the samples were quite friable after the test and cool down process. The most effective covering and crack filling crystallisation process was demonstrated in Figure 6.3-14 which illustrated an example in test sequence 3. The extinguishing medium was 100% sodium silicate solution. The crystallisation process and crack filling capability was also demonstrated by the 75:25 sodium silicate solution and hydrochloric acid fire fighting medium (Figure 6.3-15).

Table 6.3-1 shows the results of the individual tests for each of the test sequences for carbon monoxide and hydrogen at pre and post spray application.

Test Sequence	Pre-Spray		Post-Spray	
	CO%	H_2%	CO%	H_2%
1a	0.8	0	0.3	0.4
1b	1.4	0	1.0	0.2
1c	1.0	0	0.3	0.3
2a	1.2	0	1.1	0.2
2b	1.0	0	0.4	<0.2
2c	1.4	0	0.6	<0.2
3a	1.5	0	1.0	0
3b	0.8	0	0.4	0
3c	1.1	0	0.5	0
4a	1.5	0	1.1	0
4b	1.1	0	0.8	0
4c	1.4	0	1.2	0

Table 6.3-1: Gas Analysis

Generally, it can be seen that the carbon monoxide levels decreased on application of the spray and, as expected, the value reduced with the extinguishing process. The most noticeable change was with the production of hydrogen gas with the extinguishing process during test sequences 1 and 2. The higher levels of hydrogen were produced with pure water mist (test sequence 1) and to a lesser extent with the 50%:50% mix of water and sodium silicate solution (test sequence 2). No detectable hydrogen was formed during the extinguishing process of test sequences 3 and 4 which used the extinguishing medium of 100% sodium silicate solution and 75%:25% sodium silicate solution and hydrochloric acid mix respectively. It is also important to note the test sequence 1 was pure water and test sequence 2 had the higher water content of the mixed solutions.

Conclusions and Recommendations

The tests carried out have shown that using a spray mist in any of the combinations used in these trials can extinguish fires rapidly with very small quantities of fire fighting media. This was demonstrated by the monitoring of temperature over time during the application of the fire fighting spray mist. The most effective fire fighting medium was that of pure water in a spray mist form but the adverse effect is that hydrogen was given off during the application of the water mist. Hydrogen was also given off but to a slightly lesser degree with the application of a mist constituting 50%:50% mix of sodium silicate solution and water. This appears to be related to using either pure water mist and/or the test sequence utilising a very high percentage of water concentration in the spray mist.

It is important to note that no hydrogen was detected when applying either the 100% sodium silicate solution or the 75%:25% sodium silicate solution mixed with hydrochloric acid as fire fighting spray mists. On post test examination of the coal sample test tablets, those sprayed with the mist consisting of 100% sodium silicate solution showed that the surfaces of the coal and cracks had been covered and filled by an expanding mass of sodium silicate which was pure white. The mist had penetrated throughout the burning sample and appeared to be very effective in smothering the fire although the rate of cooling was not as rapid as the solutions with higher water percentages.

On inspection, the test samples extinguished with the sodium silicate and hydrochloric acid mix showed a similar crystallisation effect but slightly less pronounced than those extinguished with 100% sodium silicate solution. The crystalline encrustations were also tending to a yellow colour. It is known that by mixing sodium silicate with hydrochloric acid and heating this will result in the formation of ‘silica gel’ which is a well-known desiccant. It is concluded that the formation of ‘silica gel’ will aid in the adsorption of free moisture and aid against the formation of hydrogen as was demonstrated by the results of test sequence 4.

The reduction in carbon monoxide was expected on extinguishing the fires. The pre-spray values were variable and could be altered by reducing the air feed to encourage incomplete combustion.

Although this was a small component of the overall project, there are good indications that this methodology may have some benefit in offering a different way to combat spontaneous combustion fires.

A continuation in the work would be beneficial in terms of cost effectiveness and practical fire fighting methodology especially with minimal quantities of fire fighting media. If further work is to be carried out it would be recommended to carry out the following:

- Larger scale tests
- Continuous POC gas monitoring
- Test a range of water mist nozzles
- More detailed study on the chemical mix ratios and other constituents
- More detailed work on pure water mist to study the rapid extinguishing capability in relationship to time and hydrogen production.
- Higher pressure application of the mist to increase injection effectiveness
- Wider range of coal types
- Wider fire type extinguishing trials.

6.3.2 *Additional information to Task 4.3: Smoke Distribution in Ventilation Network During a Conveyor Belt Fire*

This section provides the results of the simulations carried out in Task 4.3.

In previous research the area of direct smoke was determined from graph theory applied to the ventilation network. Starting from the first node with smoke, node w_i, there is a search of paths ($w_i \rightarrow w_j$) from this node to every other node in the network. The number of possible paths $w_i \rightarrow w_j$ is determined from the matrix of accessibility ***D***. The procedure for determining matrix ***D*** is based on the directed graph structure **G** which is created for network S.

In practice, this is done from one node w_i to any collection of nodes w_j. From data regarding air distribution and its direction (sign), it is possible to find 'manually' a collection of nodes belonging to paths $w_i \rightarrow w_j$. To do the same automatically (using software), it is sufficient to assign which roadway belong to the paths. The air flow through $w_i \rightarrow w_j$ can be replaced by a flow of gases and smoke, establishing an additional parameter to the path: "smoke"/"no smoke". This parameter will identify which roadways belong to the collection of smoke-filled paths from a selected node w_i (which is the final node of the roadways with the fire) to all the nodes.

There are two ways to assign smoke-filled roadways in AERO software:

1. Ascribe a number (percentage) representing the amount (mass) of gase and smoke in the source roadway (with the source of fire) and the amount of gase and smoke in following roadways.
2. Ascribe the colors (in the same way) representing the amount (mass) of gase and smoke.

Figure 6.3-16 is a ventilation network diagram in which the source of the fire is located in roadway 3-6. The results of the AERO calculation regarding air, smoke and gas distribution are presented. Looking at Table 6.3-2 it is possible to see data due to the fan and the roadways (columns 2, 3, 4, 8), and the results of air distribution and the values of head loss (columns 5, 6, 7). Column 9 includes the percentage composition of the gases and smoke in a selected roadway (relatively to the roadway with the fire). All the roadways with a smoke content greater than zero create a smoke-filled area and a color is assigned depending on the quantity. For instance, a smoke content of 100% is shown in red/purple and orange is used when values are less than 100%. The area of smoke is assigned in the same way.

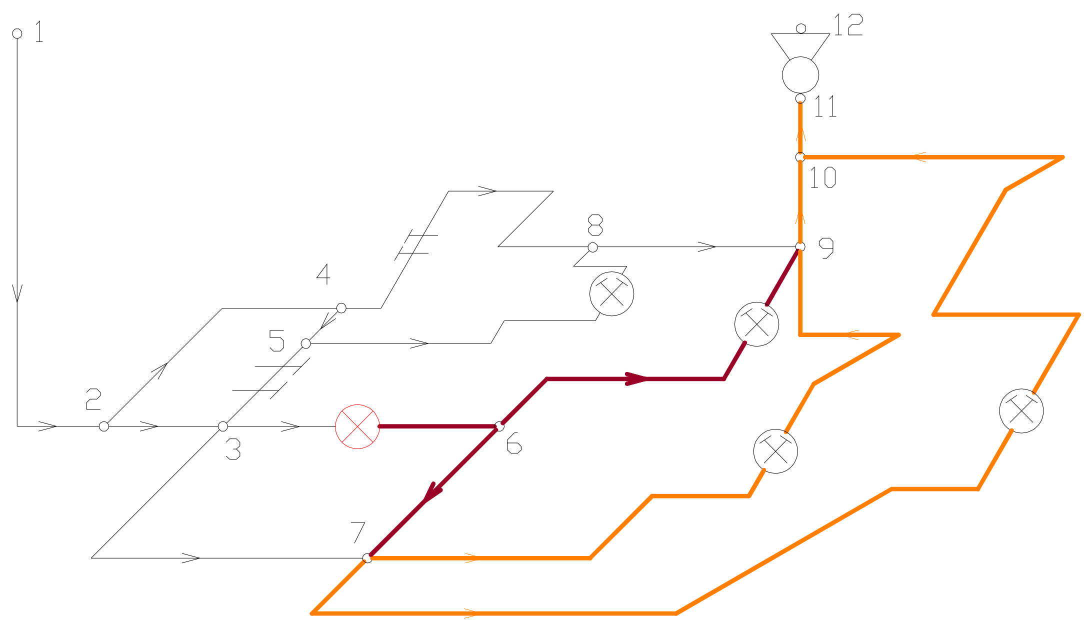


Figure 6.3-16: Space Diagram of a Small Coal Mine with Marked Smoke Zone

Road way	Prim. node	Final node	Resistance (kg/m7 *1000)	Source of fire	Air flow (m3/min)	Head loss (Pa)	Depres. (Pa)	Smoke content
1.	1	2	500.000	0	1969	539	0	0.0
2.	2	3	250.000	0	1234	106	0	0.0
3.	2	4	650.000	0	736	98	0	0.0
4.	3	5	2000.000	0	8	0	0	0.0
5.	3	6	300.000	Yes	712	42	0	100.0
6.	3	7	750.000	0	513	55	0	0.0
7.	4	5	600.000	0	219	8	0	0.0
8.	4	8	300.000	0	517	22	0	0.0
9.	5	8	1000.000	0	227	14	0	0.0
10.	6	7	250.000	0	426	13	0	100.0
11.	6	9	800.000	0	286	18	0	100.0
12.	7	9	500.000	0	200	6	0	45.4
13.	7	10	450.000	0	740	68	0	45.4
14.	8	9	300.000	0	744	46	0	0.0
15.	9	10	150.000	0	1229	63	0	30.6
16.	10	11	680.000	0	1969	732	0	36.2
17.	11	12	0.000	0	1969	0	1500	36.2
18.	12	1	0.000	0	1969	0	0	36.2

Table 6.3-2: Fire in Roadway 3-6

Analysis of Fire Gases and Smoke in a Real Coal Mine

Coal mine "X" has been selected for the analysis. The ventilation system is composed of 3 intake shafts and 3 return shafts. The air is transported for 11 mining sections or preparation sections. Annual output of coal is 1.9 million tons and the intake air volume is 258 m^3/s. The coal beds are classified as having a "level I" methane hazard (which is the lowest in the scale of I - IV). This mine is characterized by a long conveyor belt system network. All the data related to ventilation network have been collected during surveys which have been undertaken personally by workers of Institute of Mining of SUT. Other necessary data have been possessed from the workers of ventilation section of the mine

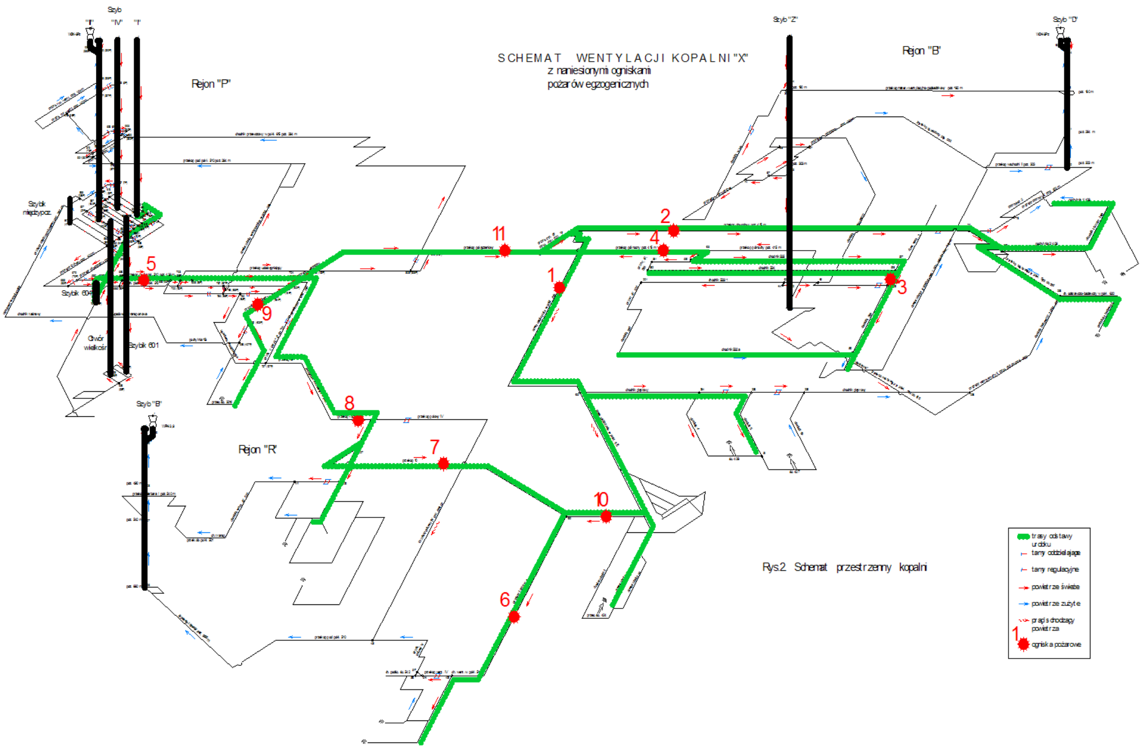


Figure 6.3-17: Space Diagram of the Mine

The mathematical model for mine “X” compresses 179 roadways. Figure 6.3-17 is a graphical view (space diagram) of excavations. Excavations with conveyors belts are marked in green – this indicates a potential source of fire. Potential places of ignition have been shown with red dots and numbers (1-11) and the analysis has been performed for those points. The points have been selected after discussions with ventilation engineers at the “X” mine – considering their knowledge about the mine, and geological and technical factors, which can increase fire hazard in particular places.

Making analysis of selected ventilation networks, it can be observed that it comprises three subnets “B”, “P” and “R” – connected by three return shafts: “II”, “B” and “D”. Subnet “B” is connected with shaft “D”, subnet “R” is connected with shaft “B”. Intake shafts are: “I”, “IV” and “Z”. A simplified schema of connections between mentioned subnets is shown as Figure 6.3-18.

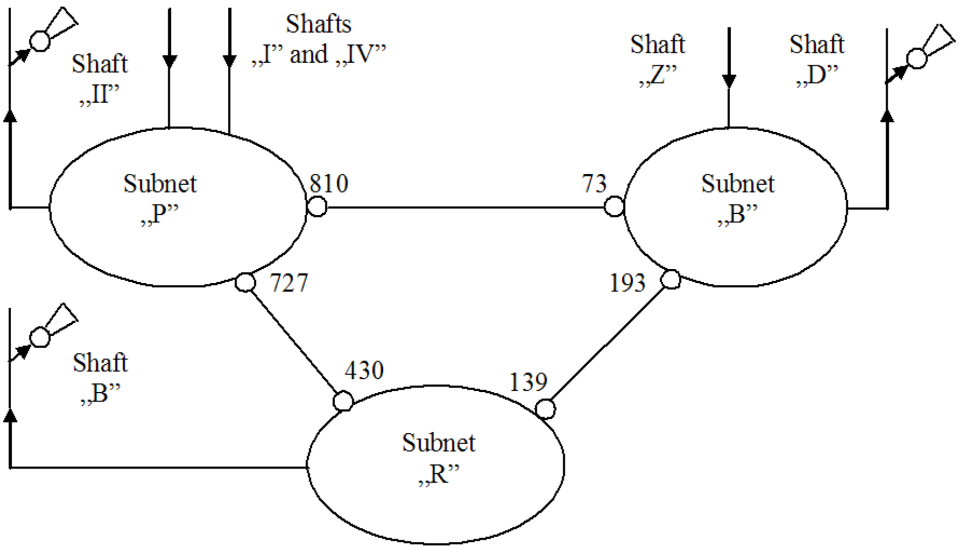


Figure 6.3-18: Conceptual Schema of Mine Ventilation

The subnets mentioned above are connected with several roadways:

- Cross-cut (810-73) between subnets “P” and “B”;
- Inclined drift (193-139) between subnets “B” and “R”;
- Cross-cut B, inclined transport drift, cross-cut 4 (727-430) between subnets “P” and “R”.

Ventilation of connected subnets allows the air flow to be controlled. This is important because in the case of an underground fire it gives the possibility of a change in the direction of the smoke to another part of the excavation where there are no workers. In Table 6.3-2, columns 2, 3, 4, and 7 show the mathematical model of the ventilation network of mine “X”. It includes information about the structure of the network (given by the start and final node of a roadway), values of head loss and the location of sources of air flow (main fans). Node no.1 is the atmosphere. Roadways with fans have head loss value equals to zero.

Simulation of the air distribution in the roadways (excavations) under the influence of main fans has been performed for the given model. AERO software was used for the simulations. It is based on the Cross iteration method. Using the same process, the working points of main fans have been obtained. The results are presented in table 2, columns 5 and 6, which allowed the directions of the air flow in excavations to be determined. The directions of the arrows (Figure 6.3-18) near roadways are the same as the directions obtained during the simulation.

Based on the results obtained, it is clear that intake air form the shafts “I”, “IV” is flowing through every excavation in subnets “P” and “R” and through a significant part of excavations of subnet “B” (with function chambers). The same streams are flowing through the longwall 301d in subnet “P”, and longwalls 406 and 407 in subnet “B”. Intake air from “Z” shaft is flowing only through longwall 532 and longwall 535 which is being developed.

Next, the results allowed the areas of direct smoke to be determined, considering different starting points of the fire. Eleven ignition points have been assumed (red points in Figure 6.3-17) and eleven different cases of smoke-filled areas have been obtained. The last column gives information about percentage concentration of gases and smoke in selected roadways (relatively to the roadway with the source of fire). In the case of dilution of gases and smoke, in roadways there is value 100% (colored red/purple in the tables). AERO allows the simulation of the concentration of gas and smoke in every roadway in the smoke-filled area. The roadways with diluted gases and smoke are shown as orange. Space diagrams have the same colors according to the amount of smoke. The key for space diagrams is presented in Figure 6.3-19. The escape route is given as information to the crew during training and test-procedures.

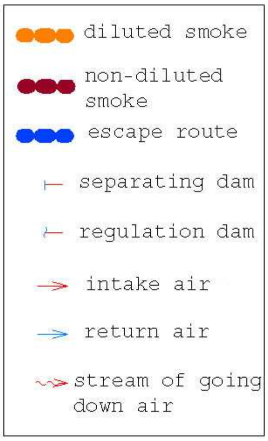


Figure 6.3-19: Key for Space Diagrams

Only one simulation (shown as tables) will be presented in this report as an example.

The rest of the simulations with all the data obtained (*Table 6.3-3*), their corresponding graphs and conclusions are reported in the deliverable D4.3.

For instance, simulation with source of fire #7 is showed in Figure 6.3-20. In this case the workers are able to escape without exceeding the safe time guaranteed by breathing devices (the analysis was conducted with the assistance of mining maps, excavation data and the experience of ventilation engineers from the mine).

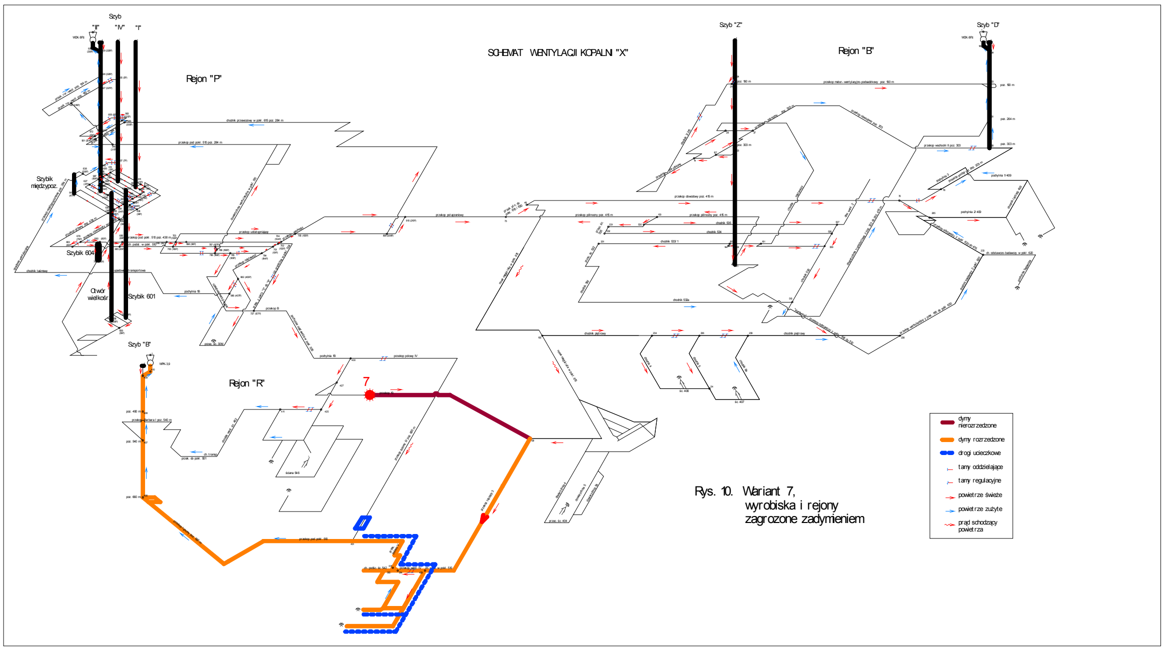


Figure 6.3-20: Fire no.7 – Excavations and Sections Under Risk of Smoke

Road way	Prim. node	Final node	Resistance (kg/m7 *1000)	Fire source	Air flow (m3/min)	Head loss(Pa)	Depres. (Pa)	Smoke content
1.	1	134	4087.000	0	1138	1470	0	0.0
2.	160	1	0.000	0	7176	0	1545	0.0
3.	134	160	5.258	0	7176	75	0	0.0
4.	133	134	16.333	0	6038	165	0	0.0
5.	131	133	3.450	0	5452	28	0	0.0
6.	130	131	3.480	0	3548	12	0	0.0
7.	27	130	522.000	0	1371	272	0	0.0
8.	24	133	102.340	0	587	10	0	0.0
9.	510	131	254.730	0	1904	257	0	0.0
10.	78	130	49.800	0	2177	66	0	0.0
11.	75	78	844.800	0	786	145	0	0.0
12.	285	78	170.900	0	1391	92	0	0.0
13.	285	75	4564.600	0	-205	-53	0	0.0
14.	238	285	115.200	0	1186	45	0	0.0
15.	48	75	378.000	0	991	103	0	0.0
16.	529	510	45.500	0	1362	23	0	0.0
17.	528	529	84.700	0	1067	27	0	0.0
18.	530	528	1003.000	0	730	149	0	0.0
19.	530	528	4726.900	0	337	149	0	0.0
20.	103	530	36.200	0	1067	11	0	0.0
21.	100	510	1749.000	0	542	143	0	0.0
22.	28	161	3966.900	0	139	21	0	0.0
23.	529	161	1328.700	0	-296	-32	0	0.0
24.	1	124	3.830	0	4808	25	0	0.0
25.	124	123	8.040	0	4417	44	0	0.0
26.	123	102	10.820	0	2712	22	0	0.0
27.	124	24	30006.000	0	390	1270	0	0.0
28.	102	41	9.000	0	2013	10	0	0.0
29.	41	103	1000.000	0	1597	709	0	0.0
30.	73	103	1700.000	0	-531	-133	0	0.0
31.	48	193	51.100	0	1611	37	0	0.0
32.	73	48	4.220	0	2602	8	0	0.0
33.	100	161	12742.000	0	157	87	0	0.0
34.	193	234	52.400	0	770	9	0	0.0
35.	234	236	587.700	0	359	21	0	0.0
36.	236	239	133.600	0	503	9	0	0.0
37.	239	238	214.840	0	770	35	0	0.0
38.	234	54	339.000	0	411	16	0	0.0
39.	54	239	740.700	0	267	15	0	0.0
40.	236	54	905.300	0	-144	-5	0	0.0
41.	27	28	10549.000	0	-129	-49	0	0.0
42.	14	24	48559.000	0	196	519	0	0.0
43.	14	28	8320.000	0	269	167	0	0.0
44.	157	14	4520.000	0	465	271	0	0.0
45.	157	27	1138.000	0	1241	487	0	0.0
46.	123	157	540.000	0	1706	436	0	0.0
47.	193	139	635.700	0	841	125	0	0.0
48.	139	427	1350.000	Tak	-372	-52	0	100.0
49.	139	429	63.900	0	1213	26	0	30.7
50.	429	517	1309.000	0	515	96	0	30.7
51.	517	431	191.000	0	1213	78	0	30.7
52.	431	430	9168.000	0	-320	-262	0	0.0
53.	727	430	260.000	0	1780	229	0	0.0
54.	429	517	713.000	0	698	96	0	30.7
55.	430	427	15.400	0	1460	9	0	0.0
56.	427	425	195.000	0	1088	64	0	0.0
57.	425	411	4690.000	0	363	171	0	0.0
58.	425	411	1172.000	0	725	171	0	0.0
59.	411	407	230.400	0	1088	76	0	0.0
60.	431	406	86.400	0	1533	56	0	24.3

Table 6.3-3: Fire no. 7 in Laybay 139-427 – Part 1

Road way	Prim. node	Final node	Resistance (kg/m7 *1000)	Fire source	Air flow (m3/min)	Head loss (Pa)	Depres. (Pa)	Smoke content
61.	406	407	3.520	0	1533	2	0	24.3
62.	407	409	16.500	0	2621	31	0	14.2
63.	409	410	1.200	0	11114	41	0	3.3
64.	1	409	70.000	0	8493	1403	0	0.0
65.	410	1	0.000	0	11114	0	1444	3.3
66.	1	605	16.200	0	5102	117	0	0.0
67.	605	606	14.100	0	4807	91	0	0.0
68.	606	607	2.800	0	4388	15	0	0.0
69.	607	608	14.300	0	3799	57	0	0.0
70.	1	603	32.800	0	5565	282	0	0.0
71.	605	927	29800.000	0	295	721	0	0.0
72.	918	927	46.250	0	495	3	0	0.0
73.	918	928	272.780	0	344	9	0	0.0
74.	603	611	2.550	0	2446	4	0	0.0
75.	603	609	7.810	0	2110	10	0	0.0
76.	609	610	8.420	0	1286	4	0	0.0
77.	609	612	23.800	0	825	4	0	0.0
78.	611	612	12.500	0	1690	10	0	0.0
79.	612	638	58.860	0	2215	80	0	0.0
80.	603	613	34.440	0	1009	10	0	0.0
81.	611	613	34.610	0	756	5	0	0.0
82.	608	614	23.060	0	1575	16	0	0.0
83.	613	614	4.540	0	1765	4	0	0.0
84.	614	616	2.030	0	3341	6	0	0.0
85.	616	987	3.570	0	2983	9	0	0.0
86.	608	610	11.480	0	2223	16	0	0.0
87.	610	619	1.860	0	3509	6	0	0.0
88.	619	989	10.360	0	3137	28	0	0.0
89.	619	620	12.350	0	371	0	0	0.0
90.	620	616	11.290	0	-358	-0	0	0.0
91.	987	988	40039.700	0	191	407	0	0.0
92.	988	989	1112.020	0	-1121	-388	0	0.0
93.	989	633	11.420	0	2017	13	0	0.0
94.	633	634	4.330	0	1614	3	0	0.0
95.	988	914	41.650	0	1312	20	0	0.0
96.	633	770	8532.870	0	402	384	0	0.0
97.	770	911	74.910	0	683	10	0	0.0
98.	987	627	2.870	0	2791	6	0	0.0
99.	627	911	6148.000	0	496	420	0	0.0
100.	627	634	19.990	0	2295	29	0	0.0
101.	634	635	9.130	0	3910	39	0	0.0
102.	635	636	4.090	0	3609	15	0	0.0
103.	635	647	490.000	0	300	12	0	0.0
104.	636	647	400.000	0	-151	-3	0	0.0
105.	636	639	14.400	0	832	3	0	0.0
106.	638	639	36.060	0	1617	26	0	0.0
107.	612	891	8009.090	0	299	199	0	0.0
108.	891	890	38.790	0	-1020	-11	0	0.0
109.	638	890	1083.320	0	598	108	0	0.0
110.	891	914	501.840	0	1320	243	0	0.0
111.	914	915	8.890	0	3810	36	0	0.0
112.	911	914	3.720	0	1178	1	0	0.0
113.	647	838	58734.810	0	150	365	0	0.0
114.	838	915	50.000	0	921	12	0	0.0
115.	607	915	5706.000	0	590	551	0	0.0
116.	636	683	44.420	0	2928	106	0	0.0
117.	639	679	23.720	0	2450	40	0	0.0
118.	679	683	48.810	0	2163	63	0	0.0
119.	679	680	2694.660	0	286	61	0	0.0
120.	680	686	2008.260	0	313	55	0	0.0

Table 6.3-4: Fire no. 7 in Laybay 139-427 – Part 2

Road way	Prim. node	Final node	Resistance (kg/m7 *1000)	Fire source	Air flow (m3/min)	Head loss(Pa)	Depres. (Pa)	Smoke content
121.	683	685	2.440	0	5091	18	0	0.0
122.	685	686	26.670	0	2171	35	0	0.0
123.	686	695	24.780	0	2485	42	0	0.0
124.	695	703	10.720	0	1485	7	0	0.0
125.	703	698	10.740	0	1145	4	0	0.0
126.	698	704	68.170	0	1145	25	0	0.0
127.	685	700	20.280	0	2920	48	0	0.0
128.	700	703	40.000	0	1799	36	0	0.0
129.	700	787	150.000	0	1121	52	0	0.0
130.	787	701	54.060	0	1060	17	0	0.0
131.	701	702	5.770	0	-55	-0	0	0.0
132.	702	704	16.600	0	-988	-5	0	0.0
133.	704	705	5130.000	0	156	35	0	0.0
134.	703	705	50.000	0	2139	64	0	0.0
135.	695	786	485.000	0	1000	135	0	0.0
136.	786	788	23.230	0	497	2	0	0.0
137.	788	787	113000.000	0	-60	-113	0	0.0
138.	788	916	1000.000	0	557	86	0	0.0
139.	705	808	523.000	0	853	106	0	0.0
140.	808	900	3200.000	0	224	45	0	0.0
141.	808	810	484.000	0	628	53	0	0.0
142.	705	810	274.600	0	1443	159	0	0.0
143.	810	73	94.500	0	2071	113	0	0.0
144.	786	785	0.900	0	503	0	0	0.0
145.	785	784	2618.000	0	-344	-86	0	0.0
146.	701	784	25.700	0	1116	9	0	0.0
147.	784	982	62.800	0	772	10	0	0.0
148.	982	986	742.000	0	319	21	0	0.0
149.	982	986	367.000	0	453	21	0	0.0
150.	986	838	493.000	0	772	82	0	0.0
151.	702	727	750.000	0	933	181	0	0.0
152.	727	785	433.000	0	-847	-86	0	0.0
153.	916	901	67.200	0	-283	-1	0	0.0
154.	916	918	61.500	0	840	12	0	0.0
155.	900	901	54.000	0	157	0	0	0.0
156.	901	672	23.260	0	-126	-0	0	0.0
157.	672	917	3600.000	0	17	0	0	0.0
158.	900	993	42.370	0	67	0	0	0.0
159.	606	993	29030.000	0	276	614	0	0.0
160.	606	672	108426.000	0	143	614	0	0.0
161.	993	917	15.480	0	343	1	0	0.0
162.	915	917	6.080	0	5321	48	0	0.0
163.	917	927	1.840	0	5681	16	0	0.0
164.	927	928	0.500	0	6472	6	0	0.0
165.	928	929	21.250	0	6816	274	0	0.0
166.	929	930	8.560	0	9137	198	0	0.0
167.	1	929	747.850	0	2320	1118	0	0.0
168.	930	1	0.000	0	9137	0	1317	0.0
169.	620	651	12.600	0	729	2	0	0.0
170.	651	658	2200.000	0	134	11	0	0.0
171.	651	656	50.000	0	596	5	0	0.0
172.	656	658	1000.000	0	147	6	0	0.0
173.	656	796	2865.000	0	449	160	0	0.0
174.	796	890	294.000	0	422	15	0	0.0
175.	796	680	165458.000	0	27	34	0	0.0
176.	658	770	18873.000	0	280	412	0	0.0
177.	102	144	5800.000	0	698	785	0	0.0
178.	144	100	10.000	0	698	1	0	0.0
179.	41	238	20000.000	0	416	961	0	0.0

Table 6.3-5: Fire no. 7 in Laybay 139-427 – Part 3

Conclusions

The early stage of the spread of a fire on a belt conveyor has been considered. Emission of smoke, gases and small amount of heat energy and radiation are noticed but there is no flame. At this stage, there is a deficiency of fuel and an excess of air. Changes of density in the ventilation air caused by the inflow of smoke and gases are very small. The flow of air contaminated by smoke (called later 'fire smoke') in inclined galleries will not cause natural depression. Therefore distribution of air and fire smoke in the ventilation network will not be disturbed by disadvantageous natural depression. Therefore, if the place of the ignition is known it is easy to estimate areas of direct smokiness of a mine and it is also possible to solve the opposite task, that of finding the source of a fire based on data from smoke or gases sensors.

For tests purposes, a coal mine referred to as "X" has been selected for analysis. The ventilation system comprises 3 intake shafts and 3 return shafts. The air is transported to 11 mining sections or development sections. Annual output equals 1,9mln Mg and amount of intake air is 258 m^3/s. The coal beds are classified as category I methane hazard (the lowest in the scale of I to IV). The spread system of belt conveyors is an important feature of Mine "X". All the ventilation network data has been collected during surveys which were being undertaken personally by the staff of the Institute of Mining of SUT. Other necessary data have been acquired from the charge of ventilation section.

From analysis of the selected ventilation network it can be seen that it is built from 3 subnets "B", "P" and "R" – connected by 3 return shafts: "II", "B" and "D". Subnet "B" is connected with shaft "D", subnet "R" is connected with shaft "B". Intake shafts are: "I", "IV" and "Z".

Ventilation of connected subnets allows the air flow to be controlled. This is important because it allows fire smoke to be directed to areas without workers. Simulation of air distribution in the laybays (excavations) of air under the influence of the main fans has been performed for a given model. This was done using AERO software which is based on the Cross iteration method. In the same way the working points of the main fans have been obtained.

Based on the simulation results it was found that intake air form the shafts "I" and "IV" flows through every excavation in subnets "P" and "R" and through a significant part of the excavations in subnet "B" (with function chambers). The same streams flow through the longwall 301d in subnet "P", and longwalls 406 and 407 in subnet "B". Intake air from shaft "Z" flows only through longwall 532 and longwall 535 which is being developed.

In the next step, the results obtained were used to analyse and determinate areas of direct smokiness considering different starting points of the fire. Eleven ignition points have been assumed and eleven different cases of smoked areas have been obtained.

The following conclusions were made: (1) It is possible to use mathematical modelling, and subsequently numerical modelling, for solving the problems of fire hazards involving belt conveyors and (2) After the selection of points of ignition, possible variants of the spread of fire can be produced. Every variant should be analyzed by ventilation engineers and ventilation methods for fire hazard reduction should be discussed. The most important examples are described below:

Variant 8 provided the option to show the results of the application of ventilation techniques to reduce the fire hazard. Application of ventilation blocking in appropriate locations can reduce the area of smokiness significantly. The source was set in the cross-cut no.4 and the area of smokiness covered mining sections including longwall 546 and development section connected with galleries 1R and 4R (located in the R). Limitation of the area of smokiness by ventilation is connected with the addition of aerodynamic resistance in cross-cut no.3 (laybay 139-426). The existing safety dam TB631 at this location should be replaced by a safety dam which is controlled remotely from a mine dispatcher stand, based on a previously prepared procedure. An increase of aerodynamic resistance in cross-cut no.3 will change the direction of the air stream in cross-cut no.10 (from which gases and smoke flow out) and the flow of intake air to cross-cut no.5 (to node 427). During this time the workers from longwall 546 would be able to escape to cross-cut no.10. They should be well trained because sometimes they have to escape in the opposite direction to the smoke and gas movement.

In Variant 5, which is located in cross-cut at level 438, the area of smokiness will cover almost all sections and evacuation routes will became useless. This example was an important safety problem for Mine "X". It was decided that a special solution must be prepared for this situation. This solution is known as “reversion” and every coal mine in Poland being classified as “methane treat” or “low methane treat” must be prepared for such a manoeuvre.

6.4 WP5

6.4.1 Additional information to Task 5.2: Simulation Test during Conveyor Belt Fires

In 2003 former HUNOSA coal mines San Nicolás (more popularly known as Nicolasa) and Montsacro were integrated into a new one called Sueros. The ventilation network of the mine is divided into two parts. This can be also seen in the diagram drawn in the supervisory program. The entrance to the mine can be done through the vertical shaft in Montsacro or from San Nicolás. Coal haulage is done throw another shaft parallel to San Nicolás shaft.

The convention for the levels is not the same if you work in San Nicolás or in Montsacro. In Montsacro the levels are counted in an odd way. The entrance to the mine is located at a height above sea level of +291m. The third level is at an altitude of +141m, the fifth level is at +41m, the seventh at -59m, the ninth level at -173m and the eleventh level at -258m. San Nicolás entry is higher than Montsacro, at an altitude of +383m. The fan of Llamas is located at a height above sea level of +250m. The levels in San Nicolás are correlative numbering, starting on the fifth level at a height above sea level of -59m (which corresponds to the seventh level of Montsacro). The sixth level is at -183m approx (ninth level in Montsacro) and the seventh at -265m (eleventh level in Montsacro).

The fan used in Montsacro is on the surface and work exhausting the ventilation. It is an axial fan with a power of 900kW. The fan used in San Nicolás is called Llamas, because is located a bit apart from the entrance to the mine, at a distance of 1690m from San Nicolás shaft. Both fans are exhausting the air from the mine. In the future, it is planned to remove the fan in Llamas, and only work with the fan located in San Nicolás. In Montsacro there is an auxiliary fan. This auxiliary fan will work if the main fain of Montsacro is turned off because some kind of fault.

The Figure 6.4-1 shows the air flows in the ventilation diagram for Area Sueros coal mine. This figure is useful to compare the Ventilation Network diagram with the computations obtained in the branches.

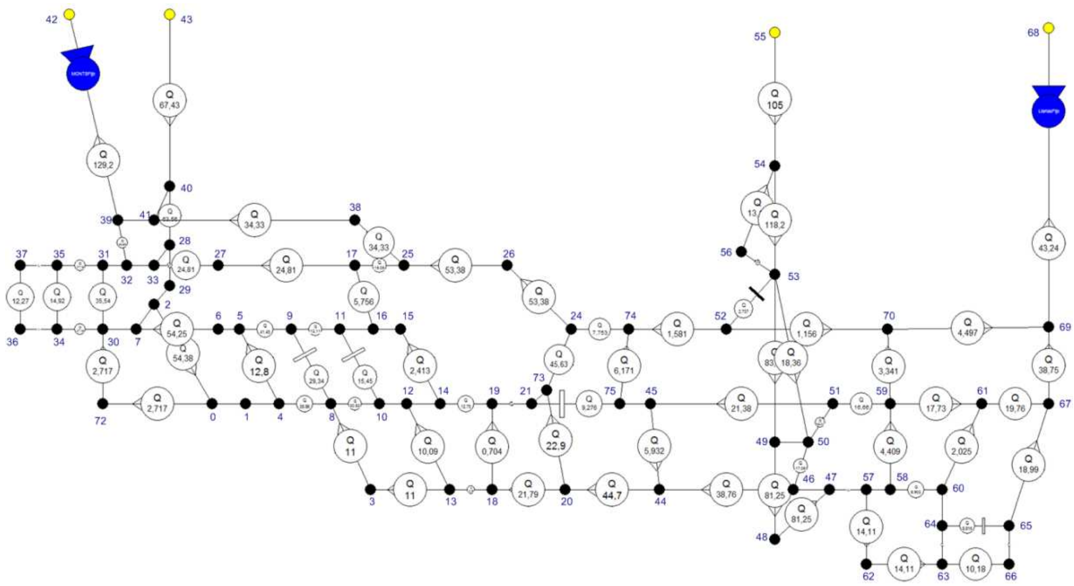


Figure 6.4-1: Area Sueros – VenPri Diagram

All coal extracted underground from both mines goes to the surface through on shaft in Pozo San Nicolás, on the right. Coal produced underground in Montsacro area is conveyed through a conveyor belt line towards the shaft located in San Nicolás. Usually the coal haulage is done in the shaft Nº2, and may end up in surface or on the first level, where there is a tunnel with a long conveyor belt line that carry the coal to a coal washery located near Mieres city (few kilometres away) called Lavadero Batán. This shaft Nº2 has no influence in the ventilation computations, mainly because the airflows in this shaft are very small and thus, they have no impact in the calculations. That’s why only the shaft Nº 1 in San Nicolás has been considered.

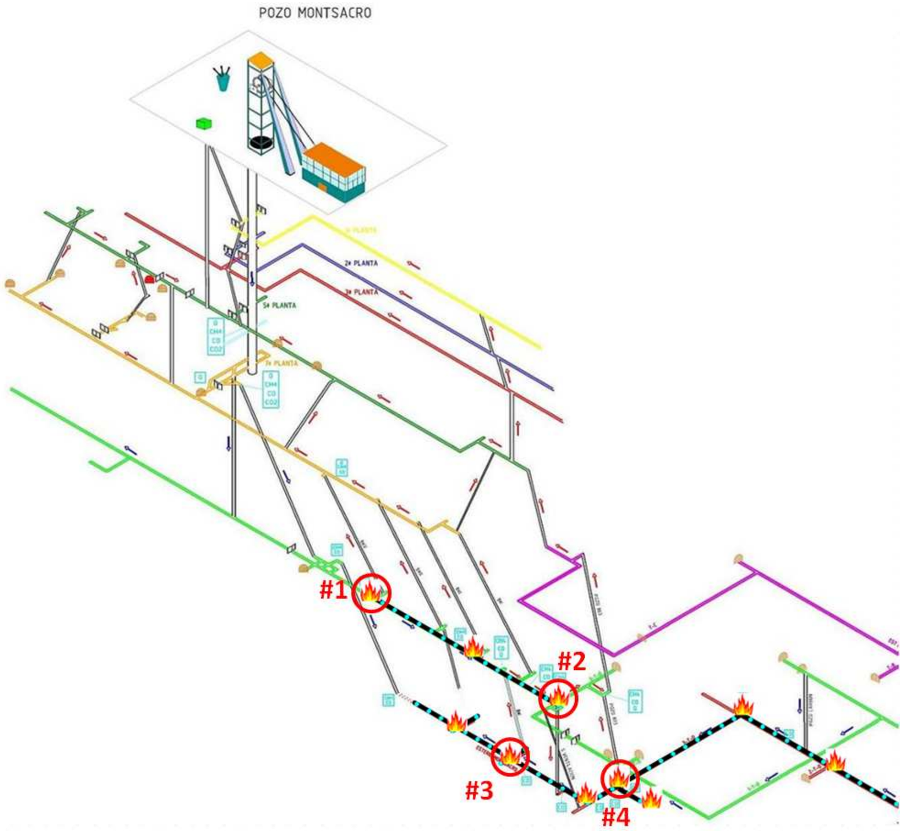


Figure 6.4-2: Pozo Montsacro – Conveyor Belt Fires

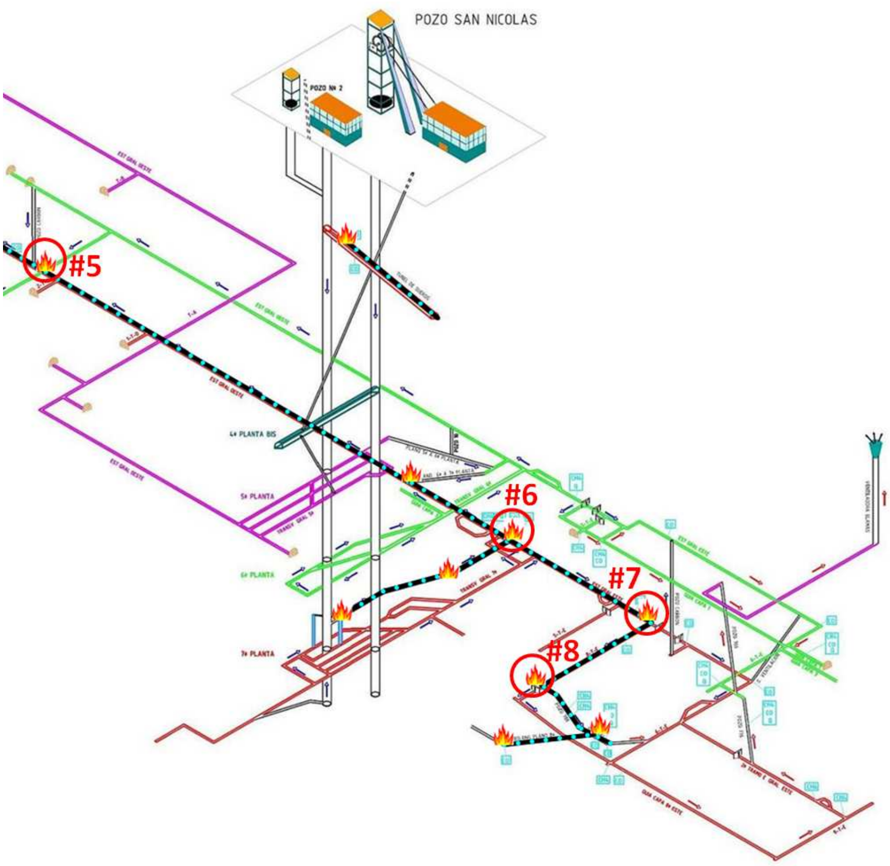


Figure 6.4-3: Pozo San Nicolás – Conveyor Belt Fires

Figure 6.4-2 and Figure 6.4-3 represents the location of the conveyor belts in Pozo Montsacro and San Nicolás respectively, as well as potentially sources for conveyor belt fires. The "fire" drawings represent potential conveyor belt fires for this particular mine. The conveyor belt is drawn with a thick black line with discontinuous points in blue. Deliverable D5.3 presents the results obtained from the simulations for eight cases selected, marked and numerated in the diagrams with a red circle.

On the basis of the tests carried out by EMAG in WP3 in the project and the literature studied, the detectors that are the most "diagnosable" for the early detection of a fire in belt conveyors are the following: (1) temperature detectors (T); (2) carbon monoxide detector (CO); (3) hydrogen cyanide (HCN) and (4) smoke detector (D). For the gases movement simulation through the ventilation network, the CO sensor has been considered to be controlled along different branches of the mine. In order to simulate a fire, the values obtained by EMAG experiments have been used. These values are stored in a file and serve as the input for real CO sensors in mine. This is an approximation to estimate the gases movement through the coal mine. The duration of the fire from occurring to extinguish is approximately less than an hour.

The smoke (CO) distribution in a ventilation network during a conveyor belt fire and the results of simulations are presented in the following sections. The control gases (grey boxes in the SCADA) have been placed along the roadways and galleries in the mine for the monitoring of gases which are useful for the supervisors who are located in the environmental control room. These CO control measurements are provided by the ventilation network program according to the calculations performed by VenPri program (they are not real measures). The real detectors are the blue boxes (CO sensors) and green boxes (CH4 sensors).

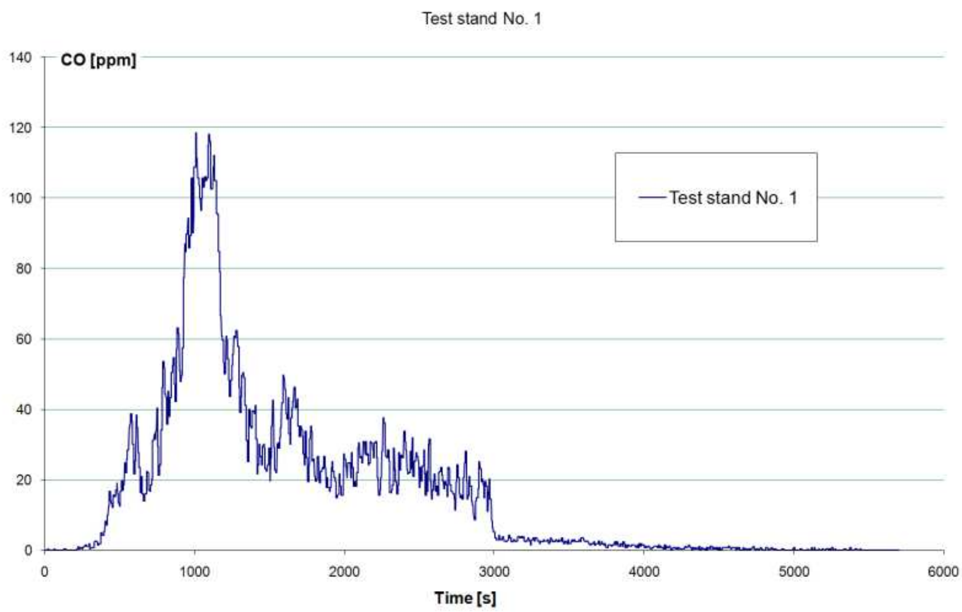


Figure 6.4-4: EMAG CO output from Test Stand Nº1 used as input in Ventilation Test

Case of Fire: Fire #1 in 8IV

Temperatures inside the mine have been set to a value according to measurements taken. The temperature values set for all branches were presented in D4.3. VenPri program takes the mean temperature of an airway. The best way would be to have temperature sensors located in all branches, which is not the real situation for this particular mine.

For simulations purposes, the SCADA is able to control the opening/closing of doors, although the reality is that the doors cannot be open or closed automatically from the environmental control room. The switches placed in the SCADA screen don't work as real switches. Same occurs with the fan. It could be turn off, but it actually does not stop the real fans. In this way, the SCADA is working like a simulation tool with the VenPri software. In order to control the doors and fans further work should be made.

If the concentration of CO is zero, the colour of the control box of CO is grey. If the value is between 0 and 25 ppm, the back colour is light yellow. If the estimated value of CO is between 25 and 50ppm colour is orange. And if the estimated value of CO is greater than 50 the colour is red.

Let's consider the first case of study, a fire produced in 9th level in Pozo Montsacro. The coal obtained from exploitations in 8IV is discharged into a conveyor belt that starts in that point. Once discharged, the coal is then conveyed towards San Nicolás. CO and CH4 detectors are placed there, because the tails and heads of conveyor belts are always being monitored.

If there is a fire, the temperature in the exploitation 8IV will begin to increase, as well as in the adjoining roadways. If the temperature distribution changes, the equilibrium will be disturbed and a new airflow distribution will result. The fire thrust in branch 8IV is added to the effect of the main fan (upward ventilation). Therefore the direction of the airflows remains the same, and no reversal will be produced.

According to the ventilation flows and their directions, the movement of gases when a fire is produced in the exploitation 8IV, would advance through 8IV until it reaches the 7th level in Montsacro. Next, the CO turns left moving through the branches 5-6, 6-7 and 7-30), moving up through the exploitation 5P1 to be expelled by the shaft where the fan of Montsacro is located (which works exhausting the ventilation, moving the dirty air to the outside).

The graphics in Figure 6.4-5 show the evolution of CO in ppm in different branches. Assuming that there is no other concentration of CO in the mine, the first concentrations of CO from the fire in the branch 30-31 would appear approximately after 12 minutes from the first detection of CO in the source of ignition. In branch 39-42 (where the fan is located) the first CO concentrations from the fire would appear in 15 min roughly. As it can be seen in the graphics, the concentrations in this branch never exceed 25 ppm. The CO is distributed and mixed with the clean air coming from other airways.

Figure 6.4-6 shows a screenshot of the SCADA in time t = 1262 seconds of the simulation. The user interface is easy understandable (which was one of the main purposes of the application) and it clearly shows the evolution of gases through the mine. The information provided by the SCADA is very useful when making decisions in real time.

As a general rule, when a sensor for early detection of fires (such as CO, smoke, temperature) reaches the pre-alarm, the workers are put on alert (for the CO the pre-alarm is around 25 ppm) The responsible of the working area tries to find out what is happening by calling to the control environmental room environment. Exceeding the alarm (50 ppm), the responsible of the zone gives the order to stop working. The workers gather together and if the concentrations exceed 100 ppm they must abandon the mine. The most complicated is to locate the source of the fire.

Based on the analysis of the situation on each case, with the information provided from the environmental control room and the information provided from the responsible underground in the mine, in case of abandonment of the mine, the evacuation procedures in case of emergency will be followed.

In the present case, workers located on the left of the fire will exit taking Montsacro shaft. Because of the exhausting ventilation use in the mine, the air in the shaft were the worker enter and exit the mine is clean air. The remaining workers (those that work on the right) will leave from San Nicolás. All the way to San Nicolás remains clean.

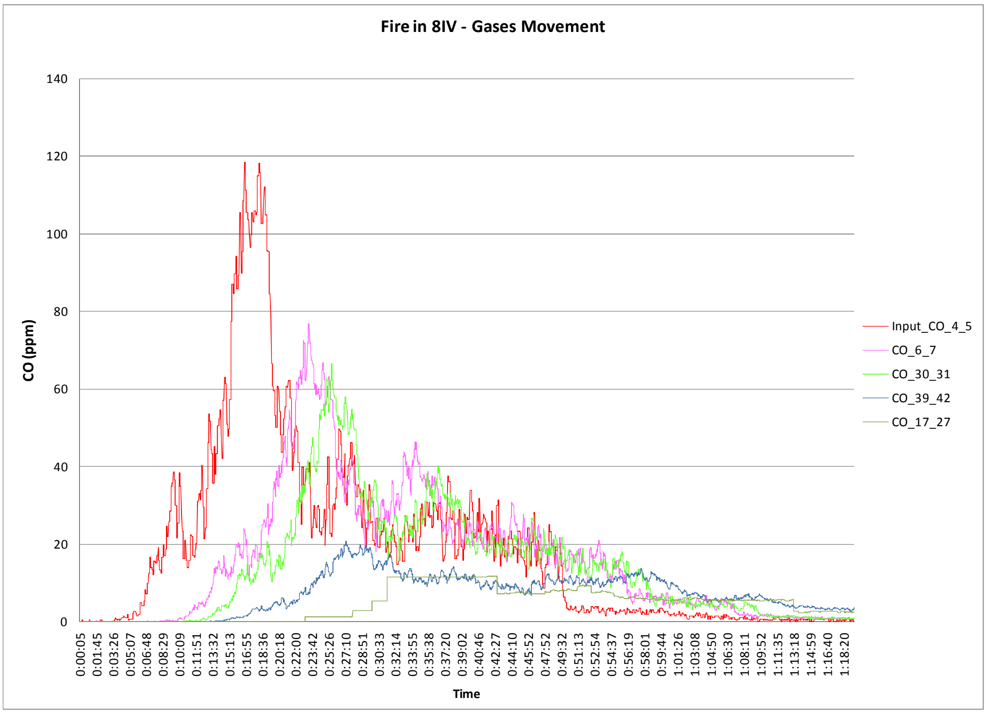


Figure 6.4-5: Fire #1- Exploitation 8IV – Evolution of CO through the airways

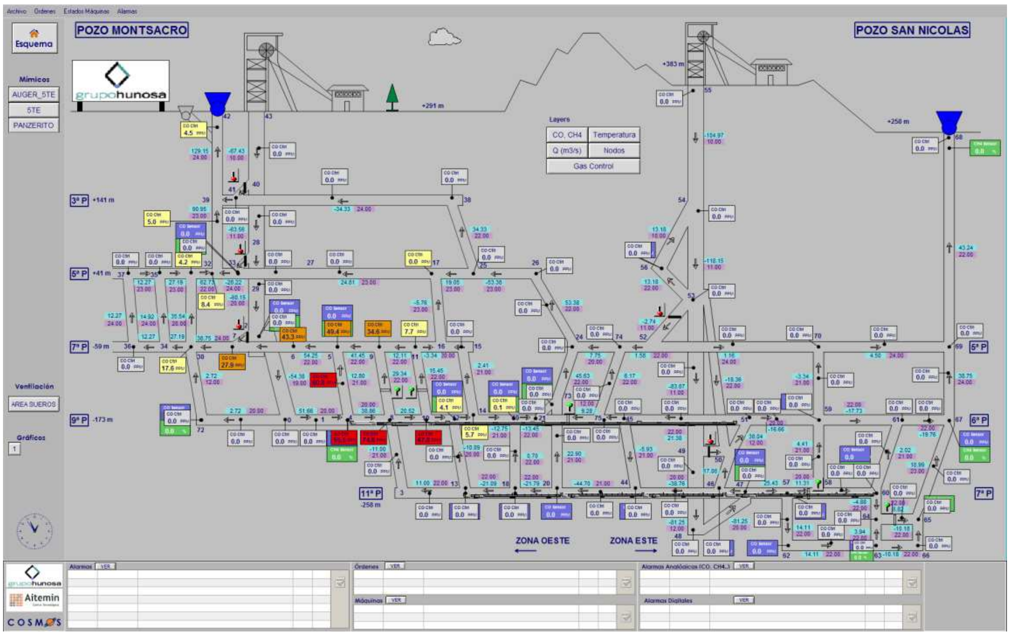


Figure 6.4-6: Fire #1- Exploitation 8IV – Evolution of gases in the SCADA - t=1262s

6.4.2 Additional information to Task 5.2: Integration of Multisensor in RELIA System

Figure 6.4-7 and Figure 6.4-8 represents how the system would operate without the multisensor and using it, respectively.

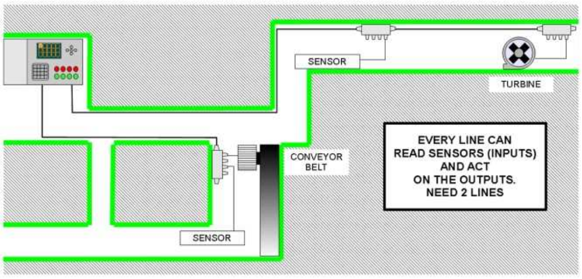


Figure 6.4-7: RELIA without multisensor

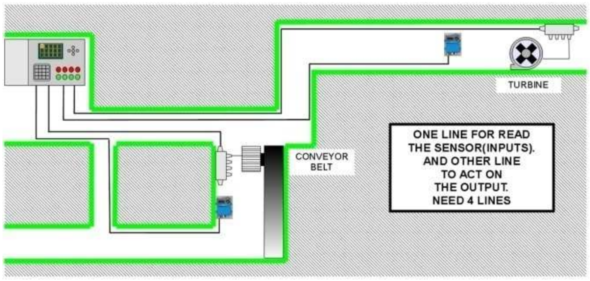


Figure 6.4-8: RELIA with multisensor

6.4.3 Additional information to Task 5.3: Health Risk Assessment - Tables and Conclusions

The results of benzene, toluene, ethylobenzene, xylene, BTEX and total benzene tests of the belt NG17 and other belts are presented in Table 6.4-1.

	NG17 **San. Nicolás**	**NG17** **Micro-chamber test**	**Average concentration of substances identified in test of belts NG1-NG16 tested in micro-chamber**
	mg/m^3	mg/m^3	mg/m^3
Benzene	0,68	3,77	20,4
Toluene	0,29	1,83	5,5
Ethylobenzene	0,13	0,73	2,3
Xylene	0,17	0,97	4,2
BTEX	1,18	6,65	31,0
Total benzine	7,2	40,0	88,9

Table 6.4-1: Comparison of the results obtained in testing of the belt NG 17 and other belts

The concentrations of benzene, toluene, ethylobenzene, xylene, BTEX and total benzine in PVC samples are presented in Table 6.4-2.

	NG17	**NG15**	**NG15** **DMT Gallery**
	Micro-chamber		
	mg/m^3	**mg/m^3**	**mg/m^3**
Benzene	3,77	18,0	13,7
Toluene	1,83	2,93	2,31
Ethylobenzene	0,73	0,74	0,75
Xylene	0,97	3,08	8,75
BTEX	6,65	24,8	23,4
Total benzine	40,0	67,1	45,7

Table 6.4-2: Comparison of substances concentrations in PVC belts

PAHs concentration in NG17 sample and other samples tested in the micro-chamber are presented in Table 6.4-3.

PAHs	NG17 Micro-chamber [mg/m^3]	Average concentrations NG1-NG16 Micro-chamber [mg/m^3]
Naphtalene	0,0125	0,00115
Acenaphtalene	0,0054	0,00132
Acenaphtene	0,0127	0,00094
Fluorene	0,0025	0,00142
Fenantrene	0,003	0,00173
Antracene	0,0789	0,00032
Fluorantene	0,0154	0,00245
Pyrene	0,0141	0,00366
Benzo(a)antracene	-	0,00716
Chryzene	0,0211	0,01305
Benzo(b)fluorantene	0,0000	0,00132
Benzo(k)fluorantene	0,0000	0,00123
Benzo(a)pyrene	0,0133	0,00137
Indeno(1,2,3-c,d)pyrene	0,0014	0,00003
Dibenzo(a,h)antracene	0,0000	0,00009
Benzo(g,h,i)perylene	0,0000	0,00003
Total PAH	0,18	0,03684

Table 6.4-3: Comparison of PAHs concentrations in the sample NG17 and samples NG1-NG16 tested in micro-chamber

PAHs concentrations in PVC belts are presented in Table 6.4-4.

PAHs	NG17	NG15	NG15
			DMT Gallery
	Micro-chamber		
	[mg/m^3]		[mg/m^3]
Naphtalene	0,0125	0,0060	0,0030
Acenaphtalene	0,0054	0,0140	0,105
Acenaphtene	0,0127	0,0158	0,0090
Fluorene	0,0025	0,0166	0,0056
Fenantrene	0,003	0,0342	0,0488
Antracene	0,0789	0,0055	-
Fluorantene	0,0154	0,0395	0,0544
Pyrene	0,0141	0,0058	0,0148
Benzo(a)antracene	-	0,1720	0,0052
Chryzene	0,0211	0,5340	0,0806
Benzo(b)fluorantene	-	0,0720	0,010
Benzo(k)fluorantene	-	0,0454	0,0246
Benzo(a)pyrene	0,0133	0,0268	0,0090
Indeno(1,2,3-c,d)pyrene	0,0014	0,0020	-
Dibenzo(a,h)antracene	-	0,0000	-
Benzo(g,h,i)perylene	-	0,0000	-
Total PAH	0,18	0,988	0,372
Mineral oil	60,8	73,1	24,8

Table 6.4-4: Concentrations of PAHs in the sample NG17 tested in micro-chamber and the sample NG15 tested in DMT Gallery

Conclusions and Recommendations

Analysis of the hazards of the substances and their mixture resulting from the burning of conveyor belts and quantitative risk analysis bring the following conclusions:

Hydrogen chloride is a major risk factor in a mixture resulting from the burning of conveyor belts. The average percentage content of hydrogen chloride (about 16 - 27%) indicates that the resulting mixture of gases will have corrosive properties and will cause toxicity to the respiratory system. Short-term exposure to gaseous hydrochloride may cause irritation, conjunctivitis, lacrimation, burning eyes, blurred vision, photophobia, impaired vision. Main toxic effects hydrochloride exhibits on the respiratory system. Acute poisoning in may manifests cold, dribbling, sore throat, hoarseness, pain in the chest. In the consequence swelling of the larynx, bronchospasm and pulmonary edema may occur. Hydrochloride dissolved in water is also derived from human sweat creating hydrochloric acid on the skin or wet clothing that may cause skin irritation and burns on contact.

Corrosive properties of the hydrogen chloride increase in interaction with sulphur dioxide. Irritation occurs already at very low concentrations of 3.9 - 5.4 mg/m3. Short-term exposure to sulphur dioxide causes shrinkage and changes in bronchial obstructive airway resistance expressed increased air flow, depending on the concentration of this compound. Physical exercise enhances this effect.

The results of calculations of risk for health confirm the qualitative assessment and indicate that the greatest health risks, extremely large, refers to the hydrogen chloride, and the hazard ratio almost always exceeds the value of 100 - which means that the safe level is about 100-fold exceeded. Also in case of sulphur dioxide hazard ratio was estimated as greater than 10 taking into account the medium and maximum values.

The percentage content of carbon monoxide in a mixture of research is relatively high and ranges from 3.54 to 7.98%. The mixture may be harmful or toxic for the respiratory system. Based on a hypothetical relation between carbon monoxide and carboxyhemoglobin (COHb) it can be concluded that exposure to the equivalent concentration of carbon monoxide, obtained during the experiment – i.e. from 136 to 973 mg/m3 - causes increase in the concentrations of carboxyhemoglobin in the blood to several dozen percent. Taking into consideration the dose – effect relationship it is equivalent to the health effects manifested in dilation of skin vessels, headaches and ripple in the temples, weakness, bewilderment, impressions darkness, nausea, vomiting, broken and impaired cardiac function, accelerated pulse and breathing. Quantitative risk assessment has shown that in case of carbon monoxide the hazard ratio is within the exposure limits 1.16 - 8.32 taking into account the medium, and it is about 12, taking into account the peak concentrations.

In the case of carcinogenic compounds such as benzene and polycyclic aromatic hydrocarbons (PAH) the risk was calculated based on the modelling of the dependence between the amount of exposure and the probability of cancer. The exposure risk to benzene was estimated at acceptable level (10 - 3) and for PAH additional risk of lung cancer is less than 0.0006 - is therefore also on the level acceptable for a period of 40 years.

The content of dusts in the mixture is low - a maximum level doesn't exceed 4%. It has been estimated that the content of crystalline silica in dusts is low and the average is about 0.83%. In the available literature no data were found on the possibility of acute toxicity of crystalline silica for humans. It can be assumed that the fibrotic effects of dust containing this amount of silica content, in case of acute exposure, are not indicated. It also can be assumed that the limit for chronic silica is 1% if it is classified as dangerous with assigned the phrase type of risk R48/20 – it is harmful by inhalation, poses a serious threat in prolonged exposure. In epidemiological studies of people exposed chronically to crystalline silica it has been shown that the risk of developing silicosis is proportional to the dose of dust, and after about 40 years of exposure may result: 2 - 3% for concentrations of 0.02 mg/m3, 5 - 10% for the concentration is 0.05 mg/m3, and about 20% for concentrations of 0.1 - 0.15 mg/m3.

On the basis of the analysis of the sensitizing ingredients it is estimated that the dust has no allergenic properties, but irritating - after absorption to the lungs, dust particles are retained on the mucous membranes of the respiratory system, causing inflammation and non specific respiratory diseases. The chemicals contained in the mixture may be absorbed on the surface of dust particles, and then may be dissolved in body fluids.

Taking into account the percentage of combustible substances it can be assumed that the mixture is flammable, and its vapours may form explosive mixtures with air.

Prevention of health risk in relation to the chemicals emerged in the fires of conveyor belts

Potentially exposed persons should be trained and informed on possible hazards. Due to the fact that hazardous substances and mixtures in the environment of work poses a potential risk of health and even lives of the people comprehensive information about their harmful enables features for the rational and efficient use of prevention in the workplace.

There should be developed emergency procedures, such as the necessity of evacuation from the contaminated area, especially in these parts of the coal mine where the belt conveyors operate.

In case of emergency or a significant overshoot of acceptable standards, it is necessary to use: Filter-absorbing hardware-assisted flow or with forced air flow in together with the face protection equipment such as that is part of the protection helmet, hood or mask, isolation equipment in the form of compressed air hose apparatus or devices air cylinder, together with full-face mask.

Selecting suitable gloves tightly adherent, mostly made of natural rubber or synthetic rubber, or plastic (PVC, PVA, Viton) is also very important for workers protection.

The resulting mixture is flammable and explosive. Therefore it is necessary to take precautionary measures against static discharges. Smoking is not allowed in any place threatened with the presence of chemicals. Easy access to fire fighting and equipment necessary during disaster recovery must be guaranteed.

In case of conveyor belt fire it is necessary to find immediate medical advice. Symptoms of exposure to vapor / aerosol mixture may develop up to 48 hours after exposure, usually are deepened by physical exertion. Therefore it is necessary to ensure the exposed person peace, stillness and observation of his reactions.

Substances contained in the mixture can be absorbed by alimentary canal, skin and inhalation. Therefore eating, drinking and smoking tobacco is not allowed at places where combustion products may be present in the air. Special attention should be put on suitable protective clothing as well as avoiding contact with skin and eyes. Workers should take care of not breathing fumes, dust, gases and vapors in case of fire.

Organic solvent vapors formed during the combustion of easily absorbed through the skin. In the case of exposure workers must immediately remove contaminated clothing and shoes, wash skin with plenty of water. Contaminated clothing should be properly protected against accidental contact with the other people, then thoroughly clean and wash before reuse.

According to literature data the toxicity of CO increases due to the increasing temperature. There is also exponentiation hearing dysfunction as a result of cumulative exposure to noise and CO. It should be taken into account that the deteriorating conditions of thermal and noise can increase health effects.

The total exposure to the components of the mixture may cause aggregation of toxic effects. There is also possibility of remote effects of exposure. Therefore it is necessary to carry out preliminary tests and periodic employees or additional medical tests following the incident of conveyor belt fire.

Moreover, there should be reduced the release of a substance or mixture to the environment.

6.4.4 Additional information to Task 5.3: Wireless Heat Point Detectors Test

Test Scenario

The selected scenario to carry out the field tests was San Nicolás coal mine, located in Asturias region, north of Spain. After analyzing several places along the colliery installations, the best one was found at the end (deepest side) of a conveyor belt installed in one of the development faces in the 6th level. This was selected as the most suitable bearing in mind several factors like;

- Safety: the lower methane presence the better,
- Mobility :a lot of persons and equipment are needed around (working space),
- Extraction work interruption: the conveyor belt had to be stopped during the tests, also stopping the coal extraction activities,

- Feasibility: since no hot spots were found along the installed conveyor belts (an inspection was done using a thermal camera) a mechanical interference had to be caused to get friction with the objective of producing an increment of the local temperature.

Once all the human equipment and measuring devices were moved to the trials scenario, the heat detection system was installed. During the tests the following stuff was used:

- 4 temperature sensors.
- 2 wireless nodes (2 sensors per node).
- 1 sensor coordinator (implemented into a prototype board).
- 1 PC to show and log received data in situ.

The system was set up to transmit 1 data per 5 seconds. It is a higher frequency (lower period) than the one used in a normal situation, but it was modified to get more data (more transmissions) during the test development.

One of the key points to get trial tests as similar as possible to the real situation is the generation of an intentional hot spot with enough temperature to catch something fire. The tests were performed during two days because during the first one, a hot spot with enough temperature was not got. The first attempt was to put a metal bar across the structure of the conveyor belt (in parallel with the carrying idlers) and in constant friction with the belt. This way simulates a blocked roller that will supposedly be heated up by the permanent friction. After some changes in the bar position and even increasing the contact surface and pressure between the PVC belt and the bar, the maximum temperature was only 80ºC. This was measured in the center of the bar where most of the friction was applied, being only 40ºC at the ends.

The second day the method used was similar, but in this case the friction was applied with a metal bar (also) but directly to the tail pulley surface. This allowed increase the pressure (the metal bar could be pushed easily) but minimize the contact point. In short terms with this technique a huge amount of pressure is applied on a small area, getting a high temperature but in a focused point. From the point of view of the detection system, this means a very unfavorable situation due to the amount of radiated energy is lower than in other cases, when for example, a idler shaft is overheated, and consequently, more difficult to be detected.

The distribution of the sensors around the hot spot area was the next:

- 1 fixed sensor to 1 cm from the friction zone.
- 1 fixed sensor to 15 cm from the friction zone.
- 1 fixed sensor to 50 cm from the friction zone.
- 1 itinerant sensor (it is moved through 3 different points during the tests development):
    - Position 1: Inside the metal bar (it is hollow).
    - Position 2: 100 cm from the friction zone.
    - Position 3: 150 cm from the friction zone.

The layout is detailed in the following figure:

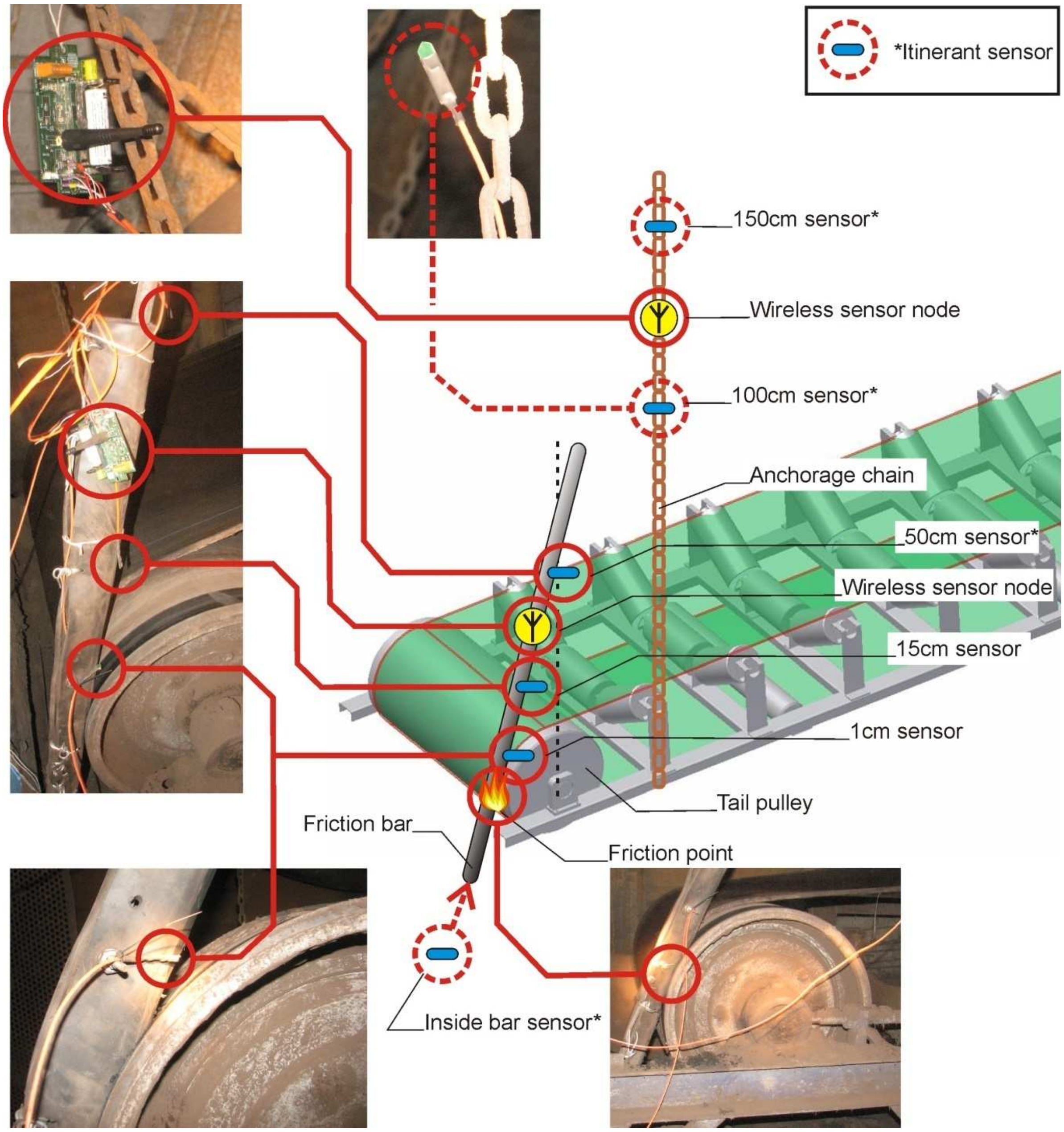


Figure 6.4-9: Overview of test scenario layout and measuring devices position

Test development

The test was carried out during approximately 1 hour and the data were taken with the sensor installed according to the above mentioned distribution. Some problems were found during the set up of the monitoring system due to the lack of enclosures for the PCBs, removed during the sensor connection process. Because of that, the high relative humidity existing in the scenario environment (>80%) and temperature different between the surface and the underground, some water was condensed on the PCBs and consequently the system started to transmit data 2 minutes later since it was switched on. Once this "problem" was solved (just leaving the devices to get acclimatized) the communication was fluid and uninterrupted.

During the tests, the conveyor belt was started and stopped twice. The temperature reached next to the friction point was around 300ºC.

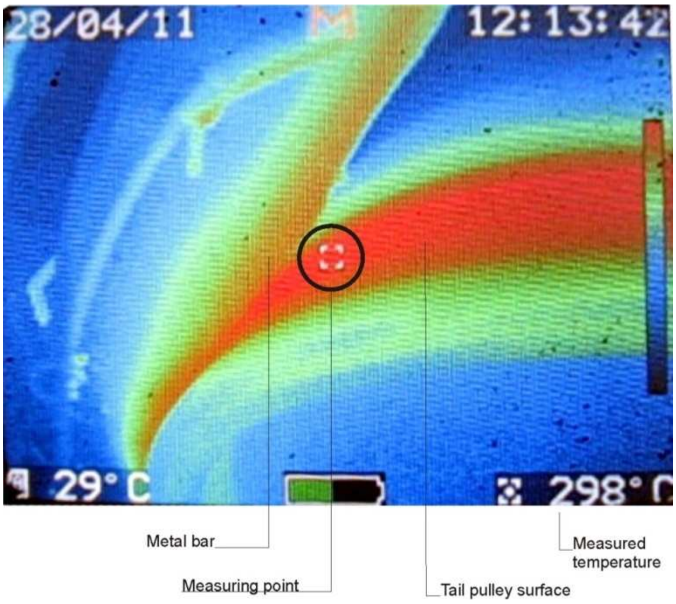


Figure 6.4-10: Temperature on tail pulley surface next to friction point

Test results

After logging and processing the data using a computer connected to the wireless nodes coordinator (using a simple RS232 interface), the temperature chart shows a clear coherence with the events produced during the tests.

Basically there are three stages during the process (see Figure 6.4-11):

- Sensor manipulation: it is the installation of the sensors in the above mentioned points. The sensors are installed by hand, so a increment of the temperature was registered during the process due to the close proximity of the human body (write area)
- Conveyor belt working: Normal function of the conveyor belt (green area).
- Conveyor belt stopped (red area).

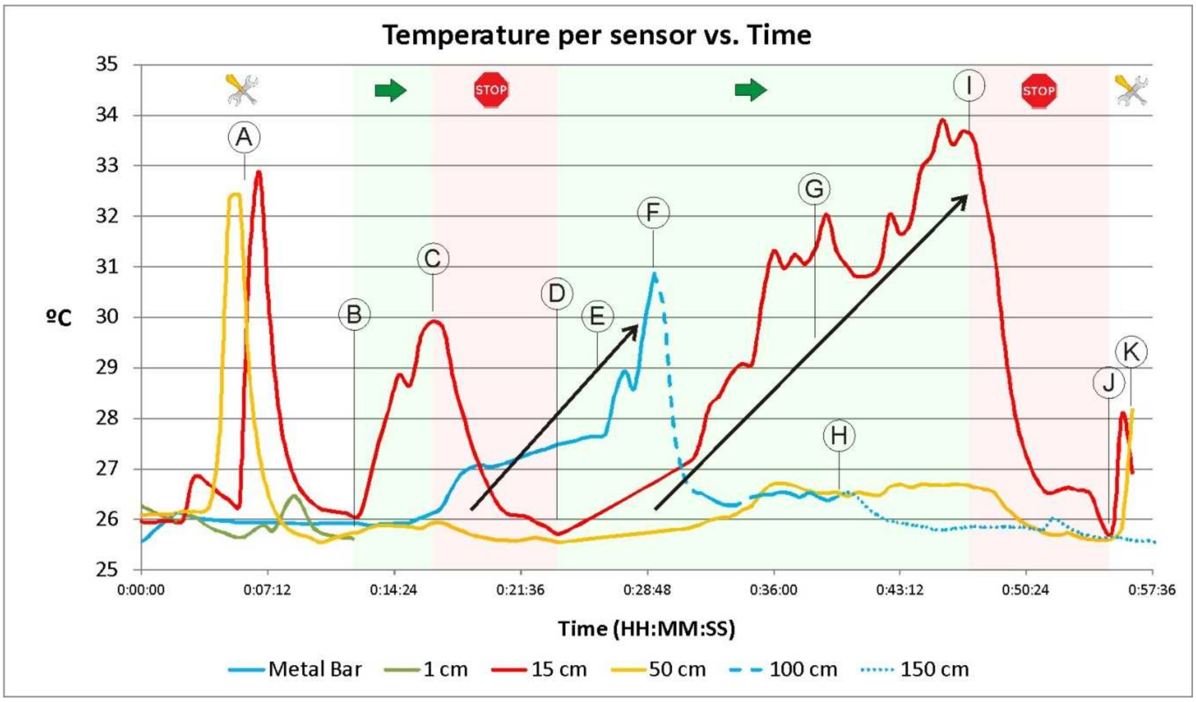


Figure 6.4-11: Test stages, events and Temperature Vs. Time chart

According to the above chart, the next events are shown:

- **A:** Manipulation (installation) of sensors placed at 15 and 50 cm from the friction point. In addition a small peak can be observed due to the same reason (not marked in the chart) in the sensor placed at 1 cm.
- **B:** When all the sensors are stable and measuring the environment temperature, then the conveyor belt is switched on. It is observed that the sensor placed at 1 cm from the friction point is broken in this moment. When the belt started to move, a fragment of material was popped out to the sensor, damaging it and making it useless for the rest of the test.
- **C:** Although the temperature in the friction point reached 290ºC, the belt is stopped to adjust the friction bar. At this point it is observed a clear increment of the temperature in the sensor placed at 15 cm and also a slightly increment in both the sensor 35cm above and the installed inside the metal bar (it is not close to the friction point).
- **D:** After some minutes stopped the conveyor belt is switched on again.
- **E:** An increment of the temperature of the sensor installed inside the bar is observed even when the conveyor belt is stopped (from C to D). It is produced by the thermal inertia of the iron (the metal of which the bar is made of).
- **F:** The sensor initially installed inside the metal bar is moved to 100cm from the friction point. It is observed a quick decrement of the temperature. However, it gets stable after some minutes, crossing under the 50cm sensor line (as expected).
- **G:** Although the maximum temperature in the friction point is reached in less than a minute, the temperature registered by the sensors in increasing through more time (it is clearly shown in the closest sensor from the pulley, 15cm) because of the fact of the thermal inertia of the pulley mass.
- **H:** The itinerant sensor is placed 1.5m above the friction point. Its temperature decreases, but not up to the ambient. That means that the sensor temperature is still influenced by the hot spot.
- **I:** The conveyor belt motor is switched off.
- **J:** The temperatures of all sensors go down and reach the environmental one. Then, the sensors are removed from the installed places.
- **K:** The handling of the sensors shows again temperature peaks. At this point the test process is over.

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Edaffic was a 3-year research project, the main target of which was minimising the risk of initiation and spreading of conveyor belt fires, acting on all control points of the fire ignition and propagation process.

The fundamental mechanisms behind the initiation and propagation of conveyor belt fires were established. The characterisation of the combustion process (including an estimation of fire load and characteristics of combustion products), the evaluation of the effect of these combustion products on persons (including workers and local population) as well as the impact on the environment allowed the manufacturers of conveyor belts to use the results to reduce development costs. The results obtained from the tests showed that the belts with the current material composition will seriously pollute the environment in case of fire.

The prevention strategies analysed, which focused on the study of the structure of conveyor belts and the characteristics of the coal accumulation, aid not only in the installation of conveyor belts but also for their maintenance.

The implementation of new technologies for early detection of fires in conveyor belts and fire fighting methods was developed. The outcomes of the trials and field test lead to recommendations in the placement of control points along conveyor belts for early detection of fires, as well as, the integration of the early detection devices within a ventilation management system which aids in the decision making in case of emergency.

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