Title

Quantifying the fire hazards and risks associated with the use of fire retardant conveyor belt in underground mines.

JHB van Eeden

(Student number: 698217)

Faculty of Engineering and the Built Environment

University of the Witwatersrand

Johannesburg, South Africa.

Supervisor:

Professor T J Sheer

A Research Report submitted to the Faculty of Engineering and the Built Environment, University of the Witwatersrand, in partial fulfilment of the requirements for the degree of Master of Science in Engineering.

Johannesburg 2019

DECLARATION

I declare that this research report is my own unaided work.

It is being submitted to the Degree of Master of Science to the University of the Witwatersrand, Johannesburg.

It has not been submitted before for any degree or examination to any other University.

JHB van Eeden

Student No. 698217

30 August 2019

ABSTRACT

The purpose of this study was to determine whether the hazards associated with changes from the standard values of the variables applied during conveyor belt fire testing, namely heat input, air velocity and belt cover wear, as well as combinations of these variables, will result in higher risks as a result of easier ignition and greater flame propagation rates of flame retardant belting.

The approved South African Standard for fire retardant belting was used as the basis for the study. The dependent variables stated in the adopted Standard BS EN 12881-1 Method C, namely ‘Temperature Rise above Ambient’, ‘Length Consumed by Mass’ and ‘Length Undamaged’, were used to measure the influence of changes in conditions by varying independent variables, namely air velocity, gas consumed (energy supplied) and cover thickness. Sixteen fire tests were carried out with a section of textile-reinforced flame-retardant belt as typically used in South African mines, using the mid-scale fire tunnel at the South African Bureau of Standards.

The study found that changes in independent variables from the standard values could result in greater flame propagation rates of flame retardant belt when compared to the standard test done in accordance with the specification. A factorial experiment was used to conduct the study and an analysis of variance conducted to determine which factors and combinations of factors contributed to the higher risk.

The study ends with proposals of how to prevent and manage the additional risks identified of flame propagation of flame retardant conveyor belt. The purpose and objectives of the study were thereby achieved.

ACKNOWLEDGEMENTS

I wish to extent my gratitude to the following organisations and individuals:

1. This study is based on studies required by Sasol Mining. The permission to use and publish this information is gratefully acknowledged. The opinions express in this report are those of the author and do not represent the policy or the views of Sasol Mining.
2. Sasol Mining Management.
3. Professor TJ Sheer for guidance and support as Supervisor.
4. Dr. Roelof Coetzer, Data Science Team, Sasol Central Digital Office.
5. Clive Erasmus, Lead IP Legal Advisor, Legal, IP & Regulatory Services, Sasol Group Services.
6. Schalk van Wyk, Senior Manager Engineering, Engineering Services, Sasol Mining.
7. Koos Janse van Vuuren, VP SHE Mining, Safety Health and Environment Department, Sasol Mining.
8. All others who provided input and support to make this report possible.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

NOMENCLATURE

ANOVA	Analysis of Variance
BS EN	British Standard European Norm
PVC	Polyvinyl Chloride
SBR	Styrene-butadiene Rubber
MHSA	Mine Health and Safety Administration
SABS	South African Bureau of Standards
SANS	South African National Standards
SANAS	South African National Accreditation System
COP	Code of Practice
SOP	Standard Operating Procedure
HIRA	Hazard Identification and Risk Assessment
T1B2	Refers to Top Cover of 1mm facing upwards and Bottom Cover of 2mm facing downwards The cover thicknesses are changed in this report.
VP	Vice President
CSO	Chief Safety Officer
IP	Intellectual property
CO	Carbon Monoxide
SO2	Sulfur Dioxide

1 INTRODUCTION

1.1 Research background / context

Conveyors are used as the primary transport mechanism for raw materials in the mining industry. The usage of conveyors has inherent hazards that must be controlled to manage the associated risks. This report focuses on the risks of fire hazards associated with the usage of flame retardant conveyor belts.

Fires in underground mines have resulted in catastrophes in the mining industry which have usually involved, at least, extensive equipment damage and long production downtimes [22, 23, 24, and 25]. In order to reduce the likelihood and effect of fires in underground mines, governments globally legalized measures regulating flame resistant and flame retardant conveyor belts. Table A1 in Annexure A lists Fire Resistant Standards used globally.

Flame resistance and flame retardant standards were introduced to set a minimum acceptable standard of belt to be used in high risk areas. The purpose of flame resistance standards is to limit combustion of the belt due to external influences and to limit flame propagation along the belt after combustion.

As a result of various incidents and accidents related to belt conveyor fires, legal requirements have been introduced by governments to reduce and to eliminate the risks associated with belt fires in mines. These requirements evolved over time and became stricter as the usage of conveyor belt became the principal means of transporting raw materials in the mining industry.

The European standard, BS EN 12881-1 Method C [15], has been adopted by the South African Bureau of Standards (SABS) as a national standard in 2013. This standard describes the method of testing the flame retardant properties of conveyor belts that can legally be used in hazardous underground mines. The South African National Standard (SANS) 971[27] described the test methods for flame resistant belts including reference to BS EN 12881-1 Method C15], for flame propagation testing. SANS 968[28], SANS 1173[29] and SANS 1366[30] describe the minimum requirements to pass the tests done in SANS 971. Table A2 in Annexure A lists compliance tests required for fire resistant belt globally.

1.2 Problem statement / motivation

1.1.1 Identified Gaps

When the new flame retardant belts were introduced in 2013, the SABS was not in a position to test affected types of belts in accordance with the new standard, SANS 1173, resulting in several tests done at the suppliers to confirm conformance with the specification.

When testing was done in India on flame retardant belts [6] it was found that increases in heat input and air velocity had substantial influences in the flame propagation behaviour of belt samples that would typically pass the standard tests prescribed in the specifications. It was seen that thickness of the covers influenced the flame propagation properties of flame retardant belts; in the standard test however, belts are normally tested with full covers.

1.2.1 Purpose of the Study

The purpose of this study was to determine whether the hazards associated with changes in standard variables, namely, heat input, air velocity and belt cover wear as well as combinations of these variables, will result in higher risks as a result of easier ignition and greater flame propagation rates of flame retardant belting.

Heat input is measured as the amount of gas consumed and is specified as 565 g of gas (propane) consumed over a period of 50 minutes. The air velocity is specified as 1 m/s measured inside the gallery. The belt cover thickness is as manufactured by the supplier. The specification does not differentiate between cover thicknesses nor specify specific cover thicknesses.

1.3 Research Motivation

In order to quantify the impact of changes to the standard test parameters research was to be conducted to prove / disprove assumptions that the changes in heat, air velocity and cover thickness would affect flame propagation of conveyor belting.

The Mine Health and Safety Act [26] requires the employer to determine the risks in the mine and to take reasonable measures to eliminate, control and minimize these risks.

Further research is required in terms of the Mine Health and Safety Act into the risks involved in the usage of flame retardant belt in order to improve current risk mitigation measures to manage additional risk.

1.4 Problem Statement

The problem statement was to identify and quantify risks with regard to flame propagation of fire retardant conveyor belt should the conditions differ from the standard conditions required by the specification.

It is assumed that additional risks exist with regard to flame propagation of fire retardant belt when the conditions in the mine differ from conditions in the specification. Flame retardant tests specify a minimum requirement that may not be comprehensive enough to address specific conditions found in a mine. Additional preventative actions may be required by the end user to ensure the safety of personnel and to prevent damage to equipment as a result of belt fires.

1.5 Research questions

To what extent will the risk of ignition and flame propagation, in typical mining conditions, be different from the result that the standard testing methodology indicates when the ventilation velocity at that point in the mine, the amount of heat input into the belt from a fire and the amount of belt cover wear are changed?

1.6 Research objectives

Research objectives were:

1.1.1 To determine whether changes in air velocity, heat input and thickness of belt cover, away from the conditions specified in the Standard BS EN 12881-1 Method C, would affect flame propagation of fire retardant conveyor belting.

1.1.2 To determine which factors and / or combinations of factors would affect flame propagation in flame retardant belt (ANOVA analysis).

1.1.3 To conduct an Issue Based Risk Assessment to find controls to reduce high risk items.

1.1.4 To propose possible solutions to any perceived risks and hazards and communicate that to end users.

1.7 Summary of research method

The purpose of the research was to determine influences of dependent variables on the flame propagation properties of fire retardant belt.

A specific belt was tested, namely a textile reinforced carcass conveyor belt commonly in use in fiery mines. The belt was a four ply construction flame retardant belt with a 4 mm top cover and a 2 mm bottom cover. This excluded other types of belt such as solid woven carcass construction belt and steel reinforced construction belt. To further reduce variables all samples were cut from the same piece of belt that was cut from existing inventory at the Sasol Middelbult Mine.

To ensure conformity all tests were done at the South African Bureau of Standards by the same personnel on the same approved equipment.

Quantitative research was done as numerical data was collected and analysed. Analysis was done to explore the outcome by considering various independent variables and the interrelationship of these variables with dependent variables. Experimental research was done as answers were derived from experimenting and varying an existing standard method to explore simultaneous changes in conditions.

Three independent variables were manipulated simultaneously to observe their effect on the dependent variables. Statistical analysis, namely an analysis of variance, was done to explore the interrelationships.

1.8 Limitations and scope

The limitations of this Research Project were that due to budget constraints more tests with a wider range of heat input and air velocities could not be done. (What will happen when the fire is hotter or when the air velocity is more?)

The tests conducted were limited to a specific type of belt, namely a textile reinforced belt, 1500 mm wide class 1250, consisting of four carcass plies, to reach the strength of 1250 kN/m width, stuck together by intermediate rubber and covered with a 2 mm bottom cover and a 4 mm top cover. The air velocity was limited between 0,6 m/s and 1,6 m/s as additional tests could not be done. Similarly the heat input, which is measured in terms of gas consumed, was limited to intervals from 545g to 600g of propane usage over a period of 50 minutes. The corresponding heat release rates were limited between 9, 14 kW and 10, 07 kW. (Refer to Annexure G, Table G1 for power calculations.)

Belts are sourced from different suppliers in Industry. Each supplier will provide the belt to the specification ordered, but each supplier’s belt will differ with materials used and amounts of materials in the composition of the final product.

2 LITERATURE REVIEW

The purpose of this research was to determine whether a change in variables would result in additional or residual risk of flame propagation in fire retardant conveyor belt. Fire retardant belt refer to belt that was tested and passed the flame propagation tests as set out in SANS 971[27] that refers to BS EN 12881-1 Method C [15] the Mid-scale Flame Propagation Test.

The criteria for these tests are compiled in SANS 968[28], SANS 1173[29] and SANS 1366 [30] which are the belt specifications for the different constructions of belts. The variables that can cause additional risk are the ventilation velocity (airflow), the heat input (hotter fires) and the amount of cover wear. More flame retardant chemicals are normally added to the covers of the belt than to the carcass, which is the tension member carrying all forces to convey the material.

Common chemicals used to manufacture flame retardant belt include chloroprene, aluminum hydrate, antimony, Di (2-ethylhexyl) phthalate, chlorinated paraffin, carbon black, sulfur, mineral oils and antioxidants.

The belt carcass will be solid woven fabric normally used with PVC belts (SANS 968), textile reinforced normally used with rubber ply belts (SANS 1173) or steel reinforced (SANS 1366) in steel cord constructed belts. This research proposal focuses on textile reinforced (plied) rubber belting that is commonly used in the mining industry for underground applications.

The literature review showed that most research was done during the years ranging from 1980 to 2000. It must be noted that the specifications for flame retardant belting changed from the time that research was done to the present day. All experiments done in the United States of America (USA) have been done on different equipment such as the MSHA Large Scale Gallery and the MSHA Small Scale Gallery. The regulating body in the USA, namely the Mine Safety and Health Administration (MSHA), selected other standards to test to, as approved by the MSHA, for flame resistance of conveyor belting which included the flame propagation aspect. The results of these tests are included in the discussion below.

Previous research [1, 2, 3, 4] indicates that flame propagation increases from low air velocities to approximately 1,5 m/s and decreases with an additional increase of air velocity. Higher heat input also results in an increase of flame propagation. The cover thickness was not tested as a variable although some of the belts that were tested had a thinner construction than the others.

The effect of ventilation was tested by Lazzara and Perzak [1] in a full-scale gallery test at airflows of 1,5 m/s and 4,1 m/s respectively. Three rubber ply belts ignited and burnt out completely. The flame spread rates and downstream temperatures were less at the higher velocity. A PVC (Polyvinyl Chloride) belt ignited and burnt with rapid flame spread at 1,5 m/s air velocity. At 4,1 m/s a PVC belt did not propagate and damage was limited to the ignition area. Some PVC belts and a Chloroprene type of belt did not burn at either air velocity. Results indicated that the fire propagation rates were more aggressive at the 1,5 m/s airflow than at the 4,1 m/s airflow. The heat input values to get the different belts ignited differed between experiments. More heat was added to get the belt ignited. Cover thicknesses were not considered. Different types of belts, such as SBR 4 ply, SBR 3 ply, SBR 2 ply, Neoprene 1 ply and PVC belts, were tested with reference to flame resistance and flame retardancy properties.

Testing of fire resistant belting was undertaken by Perzak, Spencer and Sapko [2] to evaluate a moderate scale (1/5th) gallery introduced by the MSHA versus the full-scale gallery test. Flame spread was found to be a function of heat input, air velocity and belt width and height of test sample above gas nozzles. Air velocity affected the flame spread directly.

Findings indicated that flame propagation increased from zero to 1,5 m/s air velocity and that the flames were blown out at an air velocity of 2,5 m/s. This serves as an indication that the air velocity and heat input affects the flame propagation rates of conveyor belts as tested in that gallery.

Experimental studies were done by Yuan and Litton [3] on a laboratory scale gallery to determine the effect of air velocity on flame propagation. Findings indicated that at a distance of 0,22 m below the roof of the gallery, flame propagation increased with air velocity up to 1,52 m/s and reduced at higher air velocities. The effect of the height in the tunnel was also measured and indicated that the effect of flame propagation changes with the height below the gallery roof. This indicates a relationship between flame propagation and air velocity which is relevant to the research at hand.

The impact of entry air velocity on the fire hazards of conveyor belts was tested by Verakis and Dalzell [4]. The large-scale and the small-scale gallery test equipment were used to determine a correlation between the tests. Tests were done at air velocities between 0m/s and 1,5 m/s. Flame propagation was found to be higher at 1,5 m/s air velocity and lower at higher and lower air velocities than 1,5 m/s. Findings indicate that the apparatus used, the heat input, air velocity as well as the type and composition of the belts tested had a significant impact on the flame propagation results.

The literature review confirms that different types of belts with different compositions will give different results when tested for flame retardancy. The specification refers to one test criterion for all belt types and constructions. The fact that the belt samples are tested with full covers may have been an oversight that was to be investigated by the author.

Previous research indicates that the air velocity and heat input have a direct correlation with the amount of flame propagation mostly tested in large galleries and the MHSA small scale gallery. Belt cover thickness was not considered as a factor influencing flame propagation. Testing should be done under controlled circumstances to determine the effect of heat input and air velocity on current approved belt [15].

3 RESEARCH METHODS

3.1 Research design

The primary purpose of the research was to determine the effects of changes in heat input, air flow and belt cover wear on fire propagation for flame retardant conveyor belt. To do this a standard matrix was drawn up to test the selected belt under different conditions. The initial matrix consisted of 270 tests that would have been too expensive and time consuming. Other methods of analysis were investigated to determine which method of test to use and the outcome indicated that a full factorial experimental design can be done [5] to give statistically acceptable answers that will limit both the expenses and duration of these tests. The belt test matrix was drawn up using the statistical software to ensure that no alienation exists, that enough samples are tested to give representative results and that randomization happens.

Design-Expert statistical software was used to do the analysis of variance (ANOVA) when testing was completed. Three independent variables, namely heat input (gas consumed), air velocity and belt cover wear (cover thickness) were investigated to determine the effect of changes of these independent variables on the dependent variables. The dependent variables that are specified to measure in the standard BS EN 12881-1 Method C are the temperature rise over ambient temperature, the length of belt undamaged and the length of belt damaged by mass.

Quantitative research was done as numerical data was collected and analyzed. The relationships between variables were explored, whether independent (single or multileveled) or dependent (single or multileveled). Analysis was done to explore interactions between variables. Factorial Design was applied where the researcher manipulates two or more independent variables simultaneously to observe their effects on the dependent variable. This design allows for the testing of two or more hypotheses in a single project. An ANOVA (analysis of variance) [5] was done to determine the interrelationships between variables.

3.2 Sampling

In order to have representative results a piece of the same belt, as discussed under Chapter 1.8; Limitations and Scope, was used and cut into samples. The mid-scale gallery and equipment, as discussed in Chapter 3.3; Instrumentation, was checked for calibration and a full calibration test run was done. A standard test in accordance with BS EN 12881-1 Method C was done to prove the usage of flame retardant belt as per the requirements of the specification.

The full test in accordance with BS EN 12881-1 was done to prove fire retardancy of the conveyor belt used. Conditions of test were changed as depicted in the matrix, as displayed in Table 3.1 to test under varying conditions of all determining factors. Three repetitions of each test listed in the matrix, shown in Table 3.1, were done.

Table 3.1: Test matrix

Run Order	Cover thickness (mm) (upper cover / lower cover)	Air Velocity (m/s)	Gas flow (g / 50 minutes)	Variance
1	2/1	1.2	575	Covers = 50% Air = + 20% Gas = +1,8%
2	0/0	1.6	600	Covers = 0% Air = + 60% Gas = + 6,2%
3	0/0	0.6	545	Covers = 0% Air = - 40% Gas = - 3,54%
4	4/2	1.6	600	Covers = 100% Air = + 60% Gas = + 6,2%
5	0/0	0.6	600	Covers = 0% Air = - 40% Gas = + 6,2%
6	0/0	1.6	545	Covers = 0% Air = + 60% Gas = - 3,54%
7	4/2	0.6	600	Covers = 100% Air = - 40% Gas = + 6,2%

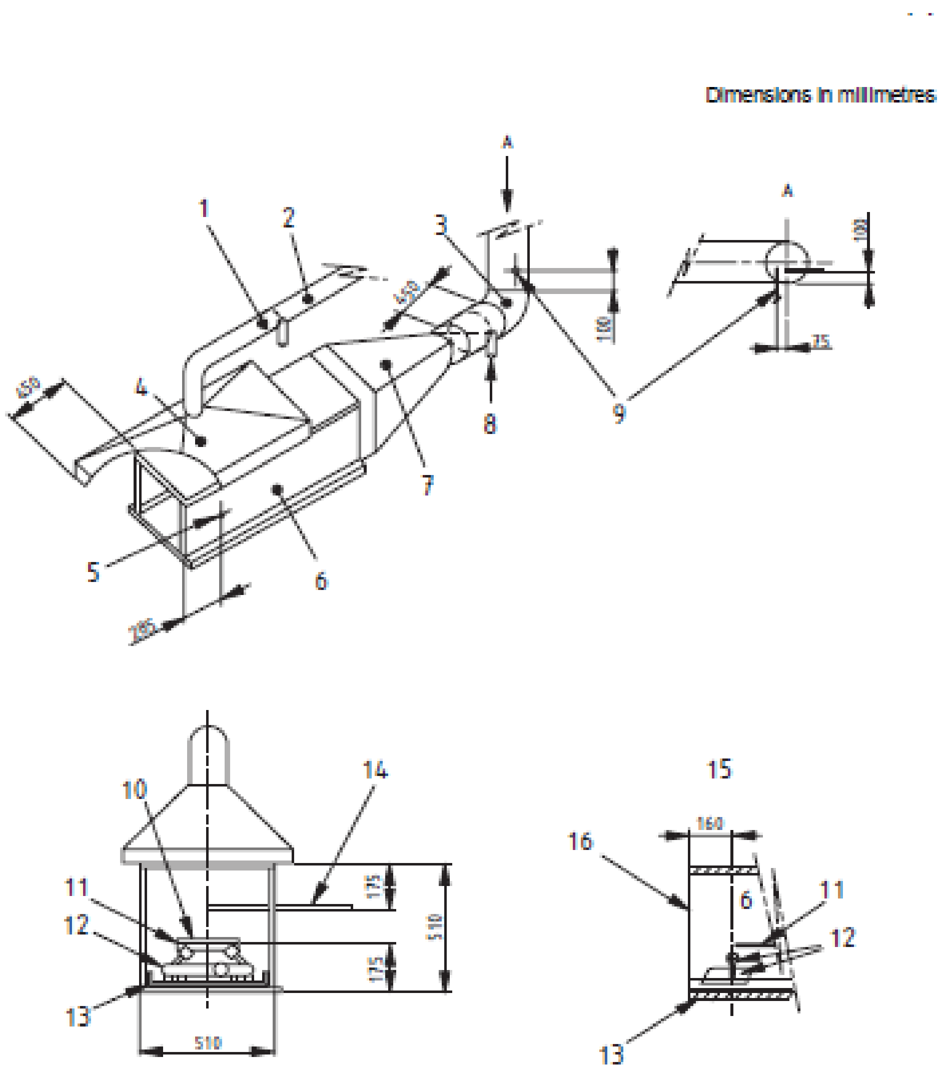
8	4/2	1.6	575	Covers = 100% Air = + 60% Gas = + 1.8%
9	0/0	0.6	575	Covers = 0% Air = -40% Gas = + 1.8%
10	4/2	0.6	545	Covers = 100% Air = - 40% Gas = - 3,54%
11	4/2	1.6	545	Covers = 100% Air = + 60% Gas = - 3,54%
12	2/1	0.75	600	Covers = 50% Air = - 25% Gas = + 6,2%
13	2/1	0.6	600	Covers = 50% Air = - 40% Gas = + 6,2%
14	2/1	1.6	575	Covers = 50% Air = + 60% Gas = + 1.8%
15	4/2	0.6	575	Covers = 100% Air = - 40% Gas = + 1.8%
16	4/2	1	565	Control sample tested

3.3 Instrumentation

Equipment used was a Mid-Scale Gallery as required by the specification BS EN 12881-1 Method C (Figure 3.1[15]). The air speed through the gallery was adjustable using a variable frequency fan and an adjustable exhaust valve. An array of six 3 kW gas nozzles was used to ignite the belt and to burn for 50 minutes. The gas flow was set and adjusted to the required values. The temperature of the exhaust stack was measured to determine the increase above ambient temperature. All equipment was SANAS accredited for calibration and approved for testing. The standard procedure as per the specification was followed to ensure representative results. (Refer to Annexure H for the testing procedure.)

Equipment used included:

Propane gas supplied at a constant rate to the burner via a flow meter, such that the mass of gas consumed during the test is (565 ± 10) g over 50 minutes. Weighing instrument, capable of weighing the belt sample and the gas bottle before and after the test to an accuracy of 5 g or better. The tolerance as given by the specification is 5/565 or within 0, 88% of the target range. Anemometer, positioned on the centreline of the test chamber at a height of 310 mm above the floor and 285 mm from the front. (Refer to Figure 3.1[15] for exact positioning of equipment.) The air velocity was changed in accordance with the matrix and the tolerance was 0, 05/1 or within 5% of the target range.
K-type thermocouple, positioned in the exhaust duct that is connected to a recording device.
Recording device, capable of recording the temperature at least six times per minute.
Timer, capable of measuring to within 1 s.



Key

1.	Exhaust control gate	9	Thermocouple
2.	Exhaust duct, diameter 150mm	10	Test piece
3.	Exhaust duct, diameter 300mm	11	Trestle
4.	Exhaust hood	12	Burner
5.	Anemometer position	13	Debris tray, stainless steel 1,5mm
6.	Test chamber	14	Anemometer position
7.	Plenum	15	Exhaust hood not shown
8.	Exhaust control gate	16	Front face

Figure 3.1: Mid-scale Gallery Test Equipment

3.4 Data collection and analysis procedure

The SABS technician who operated the equipment compiled a report with raw data for analysis and interpretation. The SABS technician worked under the writer's guidance to determine the values as required to do the analysis. The writer was fully responsible for planning and overseeing the tests. All instrumentation and equipment were checked by a quality control specialist and the writer for calibration before any tests were done. The quality control specialist was on site with every test to ensure correct equipment settings for testing, the use of calibrated equipment and for the testing to be done within the tolerances as prescribed by the specification, to ensure representative results.

The tests required for the research required that the air flow, the gas consumed and the cover thicknesses changed with every test. Testing was done by the SABS utilising a dedicated technician trained and employed by the SABS. (The SABS does not allow others to operate their equipment.) In order to prevent expensive mistakes a Quality Control Person verified all settings. An Analysis of Variance (ANOVA) was done to determine the effect of the factors and combination of factors on the dependent variables using statistical software.

3.5 Reliability and validation

Validation criteria:

The parameters determined in the base case (control) scenario done under standard conditions were used to compare the results of the samples tested under varying conditions considering the thickness of the covers, the air velocity and the heat input causing the deviations, assessing:

Length of belt damage in millimeters.

Length of belt damaged by mass.

Temperature rise over ambient temperature in degrees Celsius.

The control sample was tested in accordance with the national specifications SANS 1173 to ensure conformance with the standard with the following criteria:

Length of belt undamaged across the whole width of the test piece: Standard: < 600 mm.

Length of belt undamaged by mass: Standard: < 1250 mm plus portion undamaged > 50 mm across the whole width of the belt. Temperature rise shall not exceed 140 °C.

Reliability:

The international specification BS EN 12881-1 Method C was used to test the samples.

4 DATA ANALYSIS AND RESULTS

4.1 Data test results

The test results are categorized as displayed in Table 4.1 that shows the test matrix. The Sample ID displays the sample number to be tested. The specimen ID displays the three pieces of belt that made up one sample. The cover thickness and orientation are displayed next showing T1B2, for instance, that describes the orientation, in this case the cover of one millimeter facing the top of the tunnel and the cover of 2 mm facing the bottom of the tunnel receiving the flame from the gas nozzles. The gas target in grams is displayed next followed by the air velocity as per the matrix displayed in Table 3.1. This conclude the independent variables in Table 4.1.

The dependent variables, which are the findings of the experiment, follow next displaying temperature rise above ambient, length consumed by mass and length undamaged as specified to be measured by the standard BS EN 12881-1 Method C.

Sample 16 was tested with full covers at the air velocity (1 m/s) and heat input (gas consumption) (565 g/50 minutes) with full covers (4 mm top cover and 2 mm bottom cover) as specified in BS 12881-1 Method C. The reason for testing sample 16 was twofold. Firstly this was done to determine whether the belt used was flame retardant, measured against values specified in the specification. The findings indicated that the belt used for testing complied with the requirements of flame retardant belt in accordance with the SANS 1173 standard. The temperature rise above ambient was less than 140 °C, the length undamaged across the whole width of the test piece was more than 600 mm and the length of belt undamaged by mass was less than 1250 mm plus a portion undamaged of more than 50mm across the whole width of the belt.

The second purpose was to determine the results of the standard test for comparison purposes. This sample is referred to as the ‘control sample’. The test findings of the samples were compared to the control sample findings. Findings exceeding the control sample findings would indicate the effect of the changing conditions’ impact on the dependent variables.

The control sample threshold values are displayed at the bottom of Table 4.1: Test Results Data. These values indicate the approximate average findings of the independent variables, namely temperature rise above ambient and length consumed by mass. ‘Length undamaged’ values were taken from the minimum results for 2 mm thick cover facing the fire and 4 mm cover facing the fire and were smaller than 1020 mm and 960 mm respectively.

The results correlate well with previous results of tests done on similar belts in India [6]. The average results from belt tested in India were 47, 45 °C ‘Temperature rise above Ambient’, 972,5 mm ‘Length Undamaged’ and 204,6 mm ‘Length Consumed by Mass’. The results of the control sample tested were 69 °C for ‘Temperature Rise above Ambient’, 960 mm ‘Length Undamaged’ on the minimum value and 270 mm ‘Length Consumed by Mass’. The slight differences in findings can be attributed to conditions such as ambient temperature, air pressure and weather conditions. It was humid, wet and hot in India, actually at the beginning of the monsoon season.

Table 4.1: Test Results Data

Sample ID	Specimen ID	Cover and Orientation	Gas Target (g)	Air Velocity (m/s)	Temp rise above Ambient (°C)	Length Consumed by Mass (mm)	Length Undamaged (mm)
1	1	T1 B2	575	1.2	97.9	367.0	970
	2	T2 B1	575	1.2	75	280.5	1070
	3	T1 B2	575	1.2	90.8	399.3	970
2	1	T0 B0	600	1.6	85.3	360.3	1000
	2	T0 B0	600	1.6	61.5	287.5	1060
	3	T0 B0	600	1.6	60	301.9	1040
3	1	T0 B0	545	0.6	60.5	233.3	1110
	2	T0 B0	545	0.6	63.7	258.4	1135
	3	T0 B0	545	0.6	61.1	254.8	1105
4	1	T2 B4	600	1.6	94	492.8	625
	2	T4 B2	600	1.6	56	271.7	1010
	3	T2 B4	600	1.6	85.8	585.8	825
5	1	T0 B0	600	0.6	64.7	260.1	1140
	2	T0 B0	600	0.6	67.9	267.2	1160
	3	T0 B0	600	0.6	65.5	273.7	1100
6	1	T0 B0	545	1.6	47.1	303.9	1000
	2	T0 B0	545	1.6	52.2	331.8	950
	3	T0 B0	545	1.6	44.4	250.9	1010
7	1	T2 B4	600	0.6	74.8	320.2	950
	2	T4 B2	600	0.6	71.7	248.9	1020
	3	T2 B4	600	0.6	74.8	299.0	945
8	1	T2 B4	575	1.6	99.9	492.0	880
	2	T4 B2	575	1.6	50.1	273.0	980
	3	T2 B4	575	1.6	74.2	408.6	900
9	1	T0 B0	575	0.6	63.9	246.1	1130
	2	T0 B0	575	0.6	62.2	258.7	1170
	3	T0 B0	575	0.6	58	250.2	1120
10	1	T2 B4	545	0.6	66.5	275.8	990
	2	T4 B2	545	0.6	64.1	259.7	1010
	3	T2 B4	545	0.6	71.5	271.7	965
11	1	T2 B4	545	1.6	60.4	336.6	945
	2	T4 B2	545	1.6	46.8	261.7	975
	3	T2 B4	545	1.6	68.2	419.6	920
12	1	T2 B1	600	0.75	72.9	236.4	1010

	2	T1 B2	600	0.75	89.6	375.5	965
	3	T1 B2	600	0.75	78.7	279.2	980
13	1	T1 B2	600	0.6	79.1	336.5	990
	2	T2 B1	600	0.6	66.3	246.5	1085
	3	T1 B2	600	0.6	78	349.1	980
14	1	T1 B2	575	1.6	78.5	464.5	915
	2	T2 B1	575	1.6	48.3	277.8	1015
	3	T1 B2	575	1.6	77.7	460.8	910
15	1	T2 B4	575	0.6	70	302.4	1080
	2	T4 B2	575	0.6	65.6	269.6	1120
	3	T2 B4	575	0.6	68.1	299.5	1050
16	1	T2 B4	565	1	68.3	265.9	960
	2	T4 B2	565	1	66.2	269.9	1020
	3	T2 B4	565	1	72.4	275.2	985
Control Sample minimum values					>70	>270	<960 (4), <1020 (2)

The results derived from sample 16 indicate that more than 70 °C temperature rise above ambient and more than 270 mm length consumed by mass were considered as an indication of results exceeding the results of the control sample. The T4B2 (top 4 mm and bottom 2 mm) covers as tested with sample 16 indicated the value of less than 1020 mm length of sample undamaged used for all covers of 2 mm thickness and less than 2 mm covers facing the bottom and fire. The T2B4 cover tests minimum of 960mm was used to compare the independent variables results for length undamaged against all 4 mm cover thicknesses facing the bottom and fire results of less than 960 mm were considered as results exceeding sample 16 results. Test results sorted by cover thickness and orientation are shown in Annexure C, Table C1, for information only.

4.2 Statistical analysis findings

A statistical analysis of variance (ANOVA) was done to determine the influence of independent variables used in the tests on the dependent variables selected to determine results of flame propagation changes. The analysis of the data is given in Annexure D, Table D1, Table D2 and Table D3. The analysis findings are summarized in Table 4.2 for individual factor contributions and in Table 4.3 for combined factor contributions to flammability of fire retardant belt.

A statistical analysis of variance tests main effects and interactions for significance. When doing statistical analysis of variance a hypothesis is selected to describe the outcome. A hypothesis is a statement to describe the outcome of the analysis. The hypothesis to validate the selected outcome is called the null hypothesis (Ho). The null hypothesis (Ho) for instance in this case is that no factors contribute individually or in combination to the flame propagation of flame retardant belt if independent variables change. Should the outcome of the analysis indicate that the null hypothesis is not valid, the alternative hypothesis (Ha) is valid which will be the inverse of the null hypothesis. The alternative hypothesis (Ha) will be that all factors contribute individually or in combination to the flame propagation of flame retardant belt if independent variables change.

With statistical terminology a ‘factor’ is another word for an independent variable. Within a factor there are levels or groupings, for example gender can have two levels namely male and female. In a factorial ANOVA there are two (or more) factors influencing a single outcome. These factors can have any number of levels in them.

Statistically the alternative hypothesis is valid when the probability response is smaller than or equal to 0.05 ($\alpha \leq 0.05$); this means a ninety-five percent probability to be correct exists as analysed by the analysis of variance. When the probability response is more than 0.05 the null hypothesis [5] is valid.

The alternative hypothesis (Ho when $p \leq 0.05$) indicates that the variable and combination of variables contributed significantly to the outcome. When $p < 0.01$ the contribution of the independent variable is seen as highly significant statistically. The null hypothesis (Ha when $p > 0.05$) indicates that the contribution of the variable and combination of variables did not contribute significantly.

From Table 4.2 it is evident that the air velocity was not a significant factor in the 'Temperature Rise above Ambient'. Similarly the gas consumed was found to be not a significant factor influencing the 'Length Undamaged'. All other factors were found to contribute significantly to 'Temperature Rise above Ambient', 'Length Consumed by Mass' and 'Length Undamaged'.

The influence of individual factors is summarized in Table 4.2.

Table 4.2: Influence of individual factors on flame propagation of fire retardant belt

Dependent variables	Independent variables	Findings significant $p < \alpha$ ($\alpha \leq 0.05$)	Probability (p)
Temperature rise above ambient (°C)	Air velocity Gas consumed Cover thickness	No Yes Yes	0.1972 <0.0001 <0.0001
Length consumed by mass (mm)	Air velocity Gas consumed Cover thickness	Yes Yes Yes	<0.0001 0.0043 <0.0001

Length undamaged	Air velocity Gas consumed Cover thickness	Yes No Yes	7.89×10^{-8} 0.32 5.89×10^{-9}

Findings of the tests done as displayed in Table 4.3 indicates that all factors contribute to the 'Temperature Rise above Ambient' with the most contribution found by cover thickness and air velocity. This is followed by air velocity and gas consumed with the least contribution coming from gas consumed and cover thickness.

In combination with the other factors the cover thickness and air velocity were found to contribute most to the 'Length Consumed by Mass,' followed by gas consumed and cover thickness with the least contribution from gas consumed and which is not a significant contribution. All other findings are statistically significant with p-values smaller than 0.05.

In combination with other factors gas consumed and cover thickness contributed significantly. All other factors did not contribute significantly.

The influence of combined factor contribution is summarized in Table 4.3.

Table 4.3: Influence of combined factors on flame propagation of fire retardant belt

Dependent variables	Combination of Independent variables	Findings significant ($\alpha \leq 0.05$)	Probability (p)
Temperature rise above ambient (°C)	Air velocity and gas consumed	Yes	0.0048
	Gas consumed and cover thickness	Yes	0.0391
	Cover thickness and air velocity	Yes	0.0014
Length consumed by mass (mm)	Air velocity and gas consumed	No	0.1326
	Gas consumed and cover thickness	Yes	0.0437
	Cover thickness and air velocity	Yes	0.0011
Length undamaged	Air velocity and gas consumed	No	0.37
	Gas consumed and cover thickness	Yes	0.012
	Cover thickness and air velocity	No	0.42

Findings for tests done for ‘Temperature Rise above Ambient’ with gas consumed as the variable are displayed in Figure 4.1. Findings indicate that with a moderate air velocity of 1,1 m/s and low gas consumed of 535 g, higher temperatures were reached with T2B1 and T1B2 covers. With no covers and thicker covers the temperature rise was substantially less.

The conclusion reached is that with covers worn to 50 % the likelihood was found to be greater to ignite the belt under low heat input conditions with moderate air velocities.

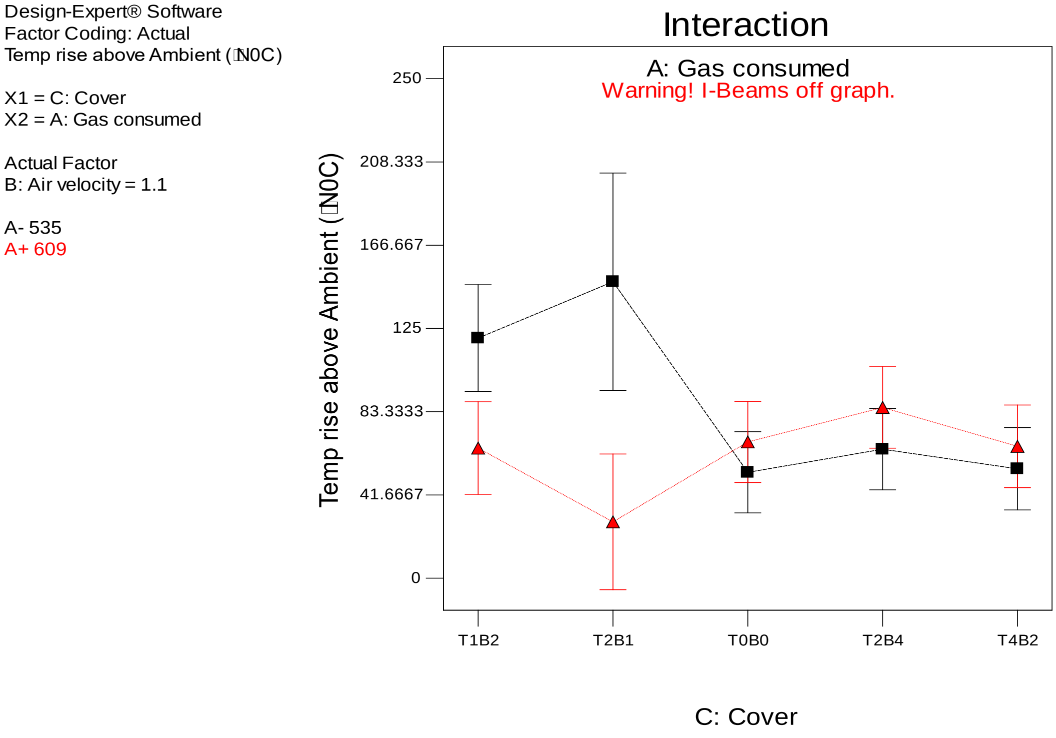


Figure 4.1: Temperature Rise above Ambient with Gas Consumed as Variable

The results of the ‘Temperature Rise above Ambient’ with air velocity as the variable are displayed in Figure 4.2. The gas consumed was 572 g and the air velocity 1,1 m/s are displayed in this graph. The results indicated that at an air velocity of 0,6 m/s with covers T1B2 and T2B1 higher temperatures were reached than at other air velocities and other cover thicknesses tested. This result confirmed that higher temperatures were reached with 50 % cover thicknesses at higher heat input.

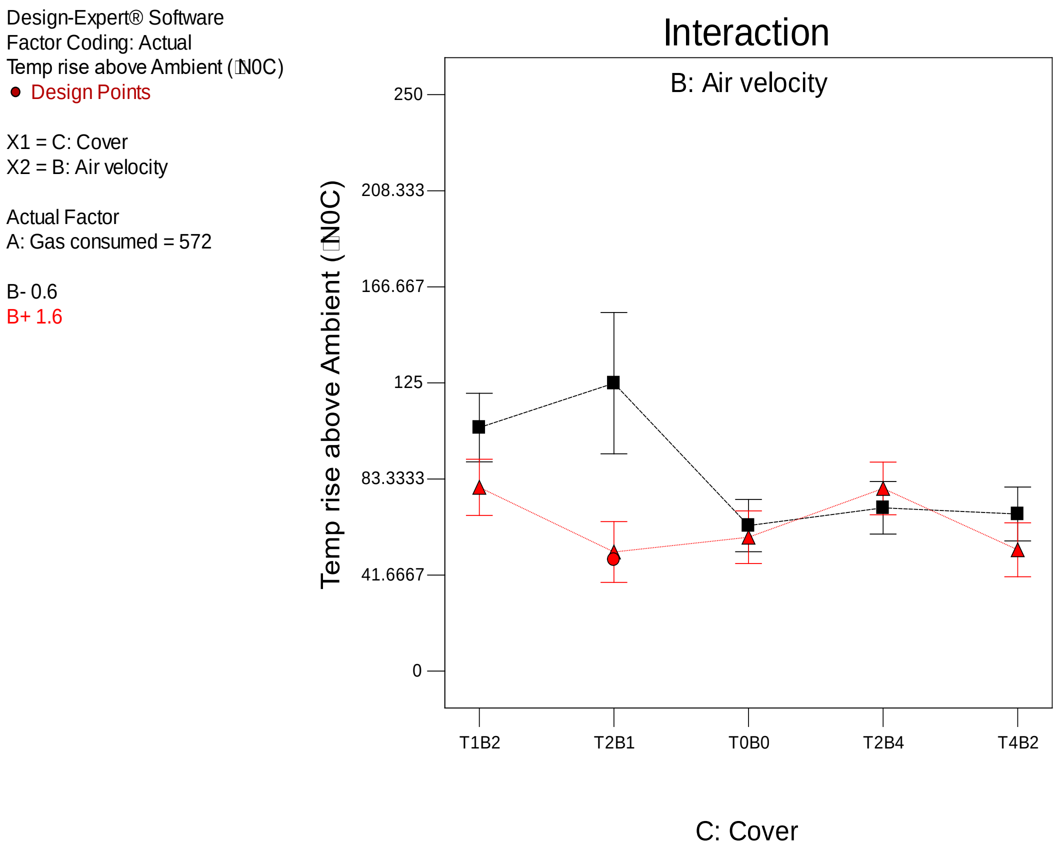


Figure 4.2: Temperature Rise above Ambient with Air Velocity as Variable

Tests done for ‘Length Consumed by Mass’ with air velocity as the variable are displayed in Figure 4.3. The ‘Length Consumed by Mass’ was found higher with 1,6 m/s air velocity than with 0,6 m/s air velocity except for T4B2 cover thickness where the length consumed by mass was similar for both air velocities. The highest value of length consumed by mass was found with T1B2 covers and with T2B4 covers.

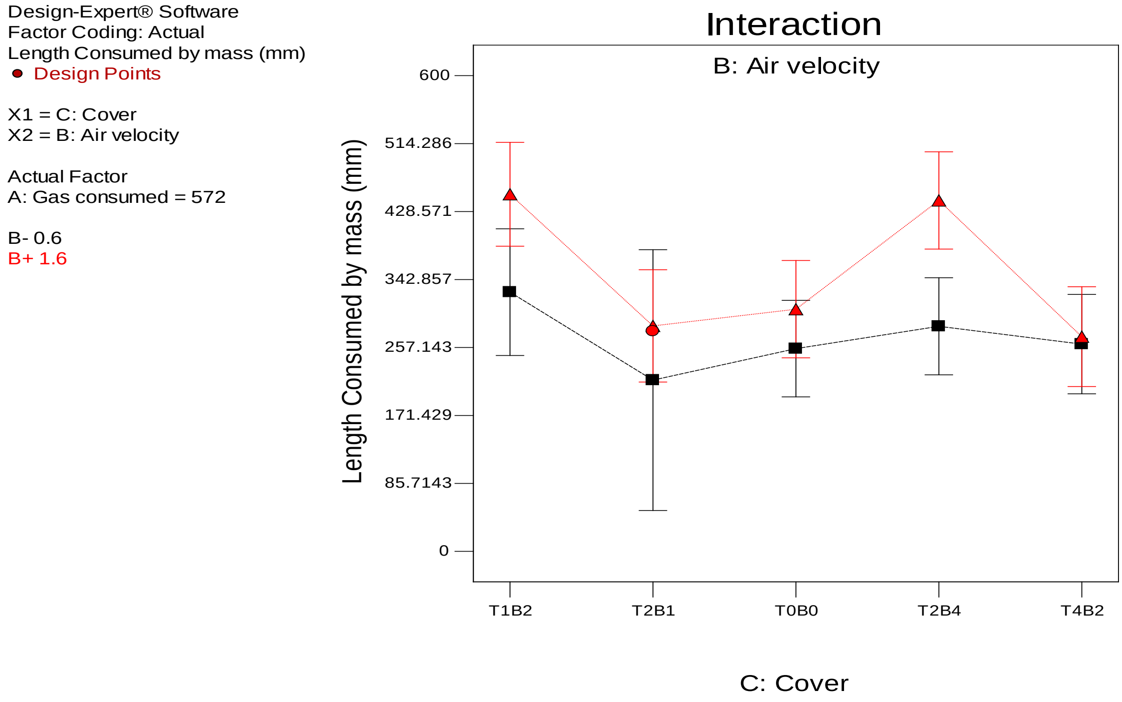


Figure 4.3: Length Consumed by Mass with Air Velocity as Variable

Test results for “Length Consumed by Mass” with an air velocity of 1,1 m/s are displayed in Figure 4.4. Gas consumed values of 535 g and 609 g were used.

The higher gas consumed correlated with more length consumed by mass for all cover thicknesses except T4B2 where length consumed by mass was found similar for both the 535 g and 609 g gas consumed.

The largest 'Length Consumed by Mass' happened with Covers T1B2 and T2B4. The length consumed maximum was at 609 g of gas consumed and T2B4 cover. At 535 g of gas consumed with T1B2 cover the length consumed by mass was almost similar to 609 g gas consumed with the same cover.

Higher heat input with moderate air velocities resulted in more 'Length Consumed by Mass' with covers T2B4 followed by cover T1B2.

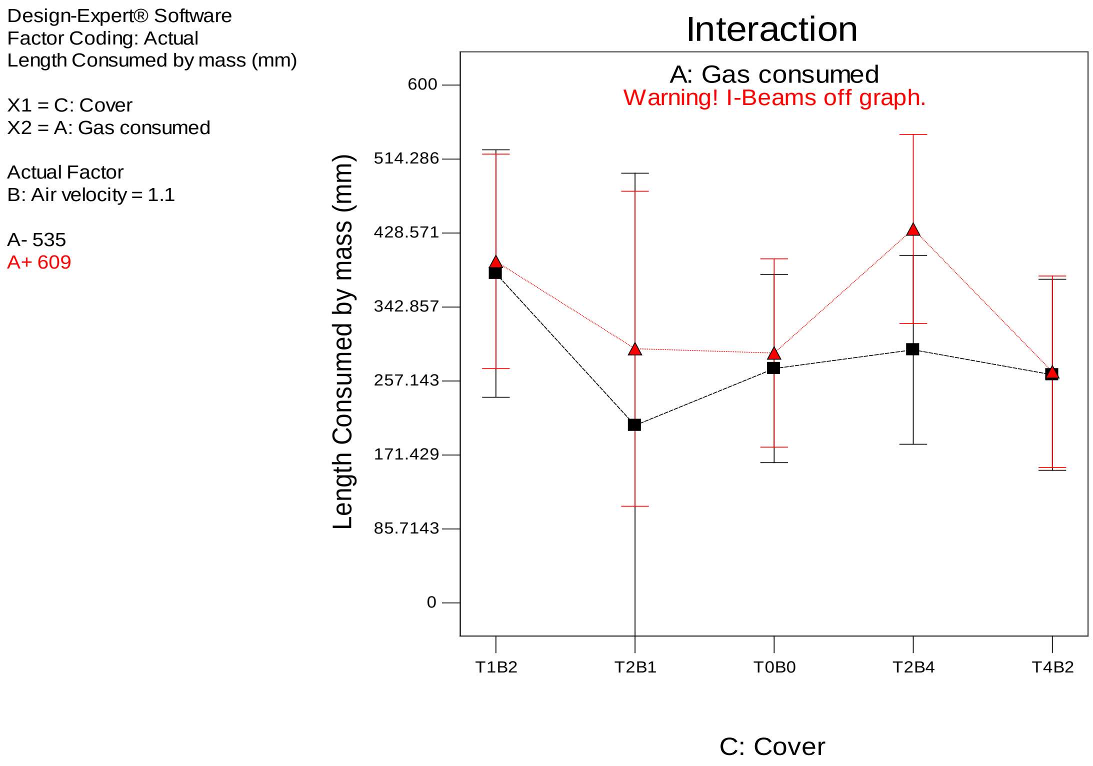


Figure 4.4: Length Consumed by Mass with Gas Consumed as Variable

Findings for 'Length Undamaged' for Cover T0B0 considering air velocity and gas consumed variables are displayed in Figure 4.5. The actual findings are indicated on the graph surface from 1150 mm at the bottom to 950 mm at the top of the graph. Design points mentioned on the right hand side of the graph indicate the actual points where the ANOVA had values used to draw the graph. The colour scheme in this case indicate

1170 mm as red which is the safest value and 625 mm as blue which is the most unsafe value. The meaning of red shows more length undamaged and that of blue less length undamaged. Less length undamaged relates to more flame propagation.

Findings showed a parabolic shape with minimum length undamaged at an air velocity more than 1,4 m/s for all gas consumed readings. The ‘Length Undamaged’ decreased in small steps as evident from the red to the greener portion of the graph with higher air velocities for the full range of gas consumed. The length undamaged stayed above 1000 mm indicating low flame propagation. With 0 mm cover thickness flame propagation is less over the range of gas consumed variables tested.

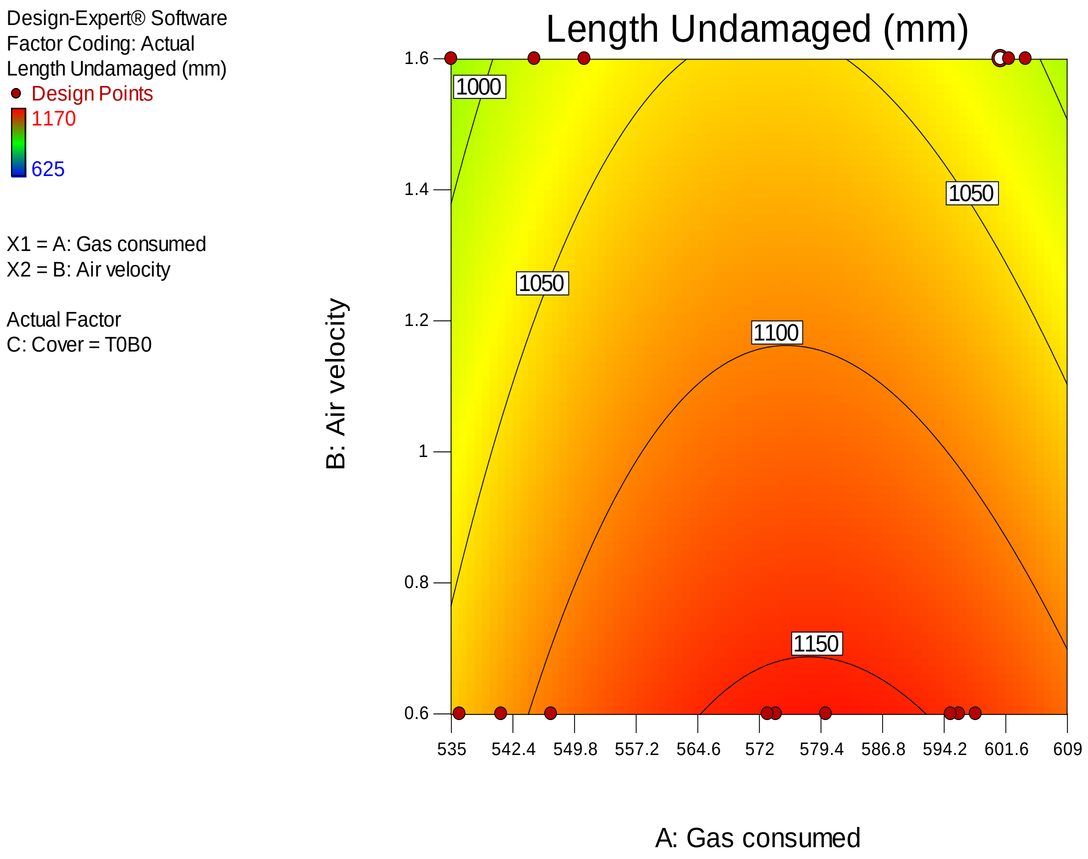


Figure 4.5: Length Undamaged with 0mm Covers

‘Length Undamaged’ findings were analysed for cover T2B1 displayed in Figure 4.6 considering air velocity and gas consumed variables. Minimum length undamaged was found at gas consumed of below 550 g and an air velocity of less than 1,4 m/s. Length undamaged decreased linearly with more gas consumed and more air velocity indicated from blue portion of graph to red portion of graph.

As indicated by the very low length undamaged of below 600 mm, very aggressive flame propagation with lower air velocities and gas consumed happened. From the greener to blue areas of the graph from the right hand side to the left hand side of the graph this is indicated with length undamaged figures from 1000 mm at higher gas consumed reducing to less than 600 mm at the left bottom of the graph.

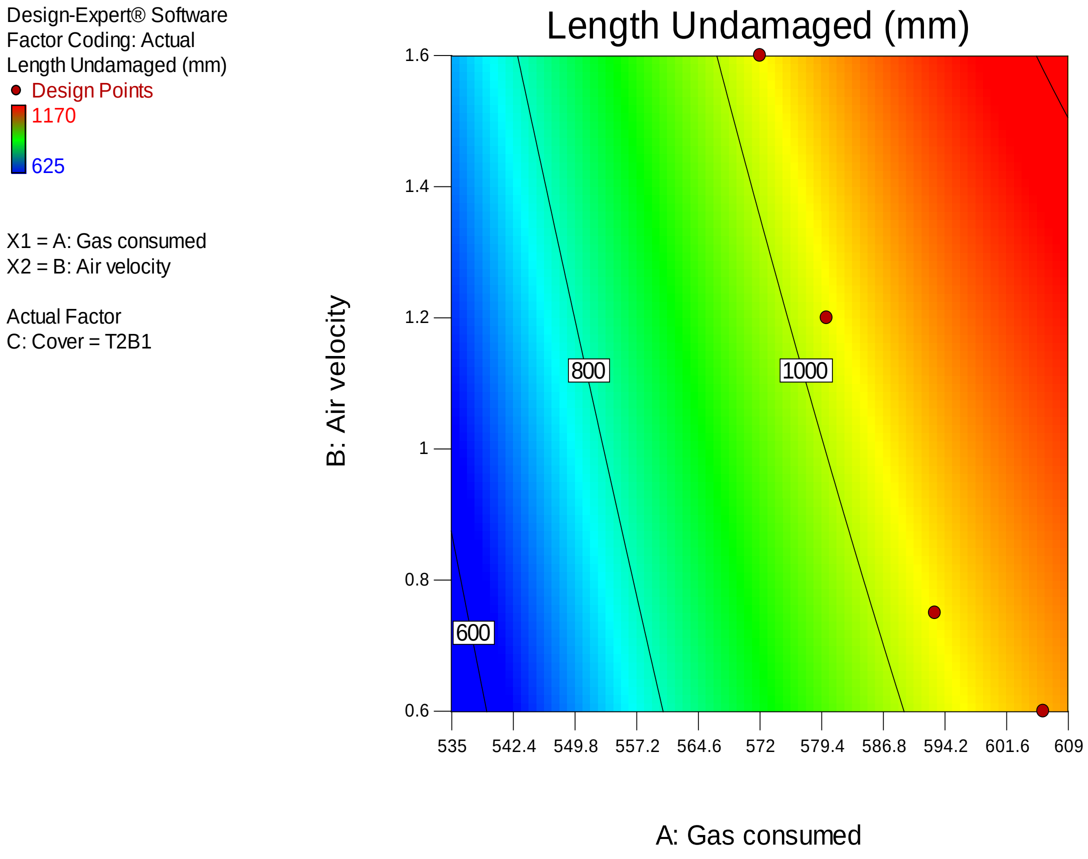


Figure 4.6: Length Undamaged with T2B1 Covers

‘Length Undamaged’ analysis was done for cover T1B2 considering air velocity and gas consumed variables as displayed in Figure 4.7. A parabolic curve effect was found over the gas consumed range as displayed in the greener areas to the top of the graph. The minimum length undamaged was found at higher air velocities over the range of gas consumed tested. More aggressive flame propagation was found at higher air velocities for all gas consumed values. This is indicated by the length undamaged of less than 1000 mm to 850 mm zone at the top of the graph.

Flame propagation is more with higher air velocity over the full range of heat input tested as displayed from the yellow to green areas on the graph.

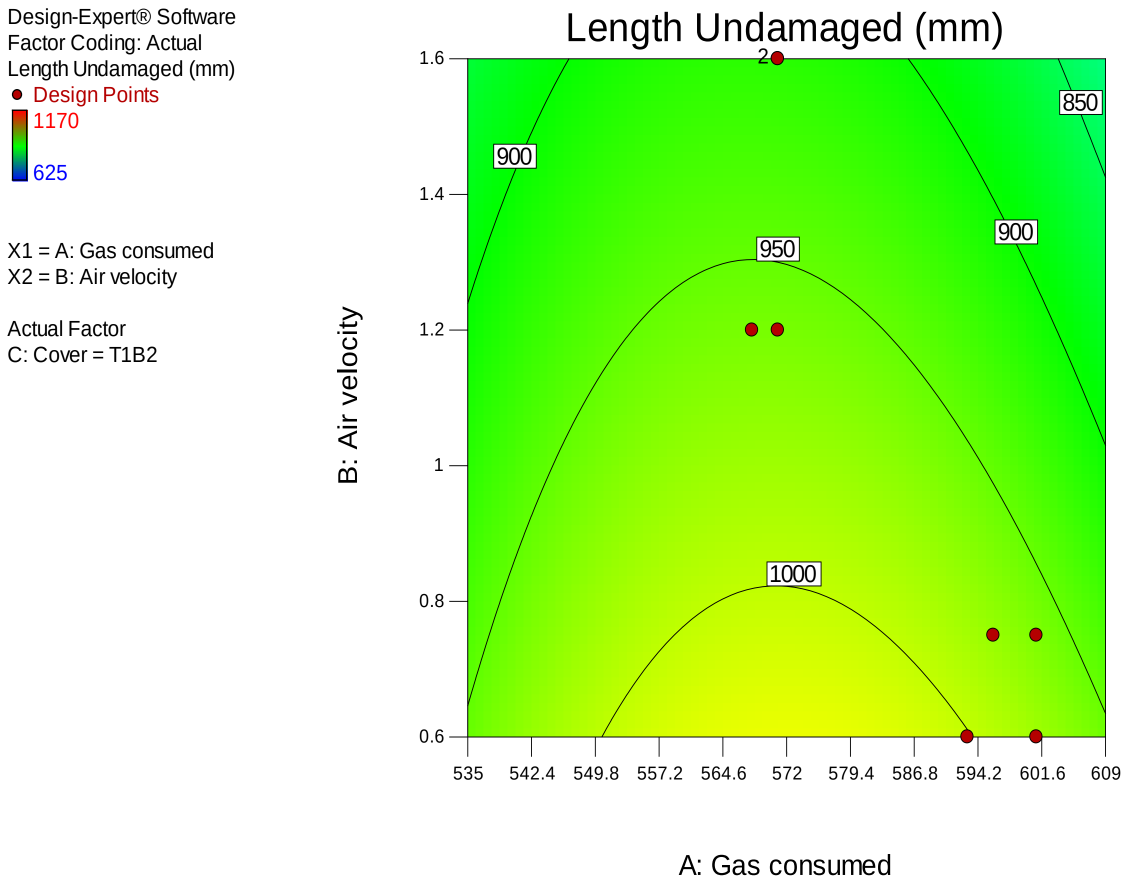


Figure 4.7: Length Undamaged with T1B2 Covers

'Length Undamaged' results are displayed in Figure 4.8 with covers T4B2. A parabolic curve effect was found over the gas consumed range. Minimum length undamaged was found at air velocities more than 1,35 m/s for total gas consumed range.

More flame propagation was found at higher air velocities for all gas consumed values. This is indicated by the length undamaged of the less than 1000 mm zone in the yellow to green areas on the graph. Higher length undamaged was found at higher air velocities over the range of gas consumed tested.

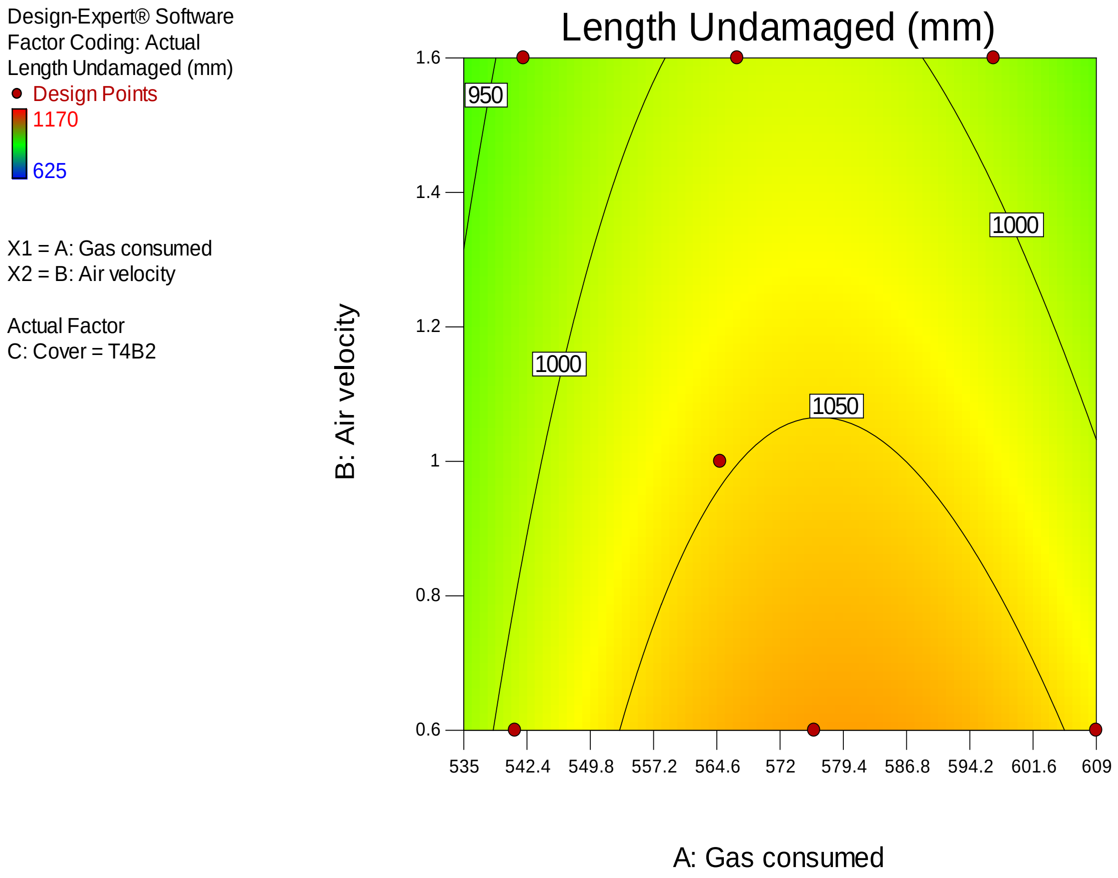


Figure 4.8: Length Undamaged with T4B2 Covers

'Length Undamaged' results are displayed in Figure 4.9 with covers T2B4. A parabolic curve effect was found over the gas consumed range. Minimum length undamaged was found at air velocities more than 1,15 m/s for gas consumed above 600 g. Length undamaged minimized at higher air velocities and higher gas consumed.

More aggressive flame propagation with higher air velocities and gas consumed as indicated from the green to blue areas on the graph. Length undamaged reduced to less than 800 mm at higher air velocities and gas consumed.

Flame propagation was found to be more with thicker covers at higher heat input and higher air velocities.

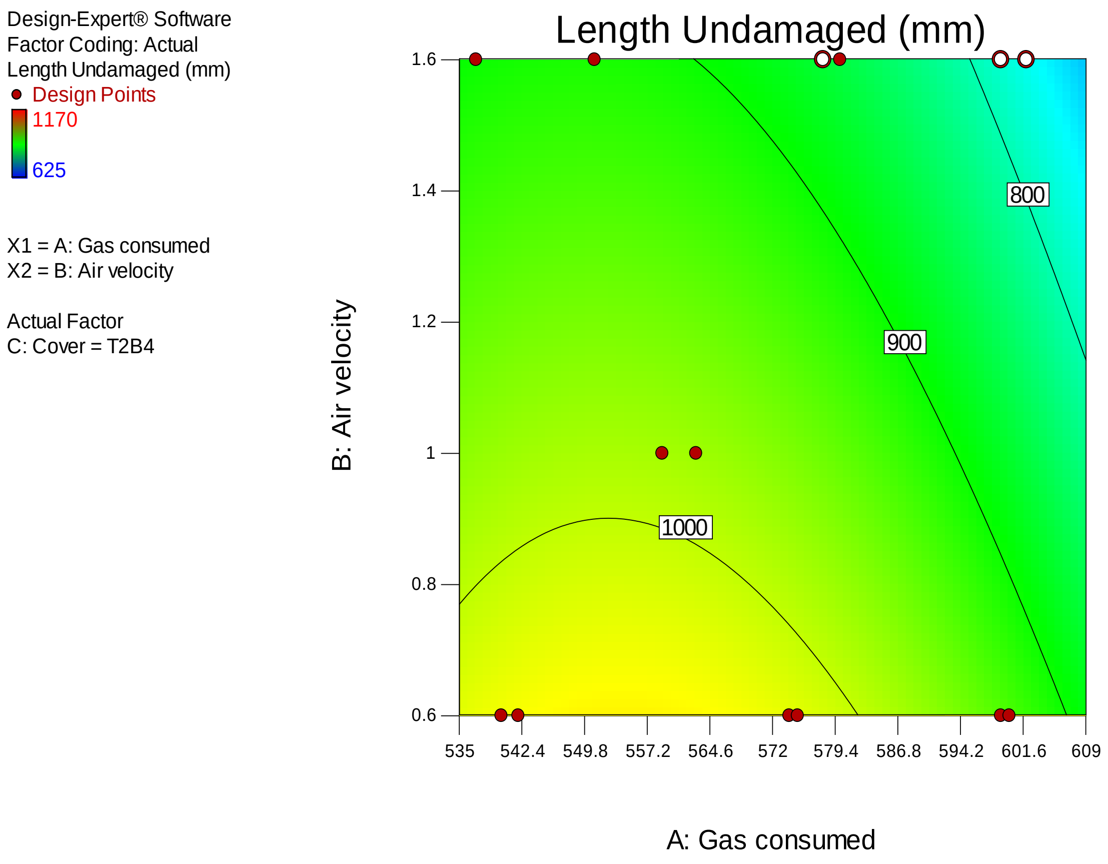


Figure 4.9: Length Undamaged with T2B4 Covers

The ANOVA Analysis was used to determine when the findings exceeded the standard test results done with full covers as per the specification. The Control Sample results were as follows:

Temperature rise above ambient was 70 °C, the length consumed by mass (mm) was 270 mm and the length undamaged was 960mm for 4mm bottom cover and 102 0mm for 2 mm bottom cover.

Findings of tests conducted as displayed in Table 4.4 that gave higher results as mentioned were considered as additional risk in excess of the standard test result.

Table 4.4: Test results exceeding control sample results

Cover Thickness and Orientation	Temperature Rise above Ambient > 70°C	Length Consumed by Mass >270mm	Length Undamaged <960/<1020mm for 4 / 2mm cover thicknesses
T0B0	Yes	Yes	Yes
T1B2	Yes	Yes	Yes
T2B1	Yes	Yes	Yes
T4B2	Yes	Yes	Yes
T2B4	Yes	Yes	Yes

It is evident from the results displayed that more risk exists when the independent variables changed, than when tested in accordance with the standard, which is a possibility that must be managed.

5 DISCUSSION

5.1 Interpretation and discussion of results

Tests were completed using EN BS 12881-1 Method C to determine whether additional risk exists should conditions in practice differ from the conditions as specified by the specification for flame retardant belt.

A portion of the same belt was used to limit the variables so that representative results could be achieved. Sample 16 was tested as per specification to ensure that a baseline case (the Control Sample) was established for comparison purposes. This also confirmed that flame retardant belt was used for these tests. The results achieved from the baseline test compared well with samples of the same belt tested previously [6].

5.2 The influence of individual factor contribution on flame propagation

It was found that the main single factors that contributed significantly for the ‘Temperature Rise above Ambient’ were cover thickness and gas consumed in the order mentioned. The hotter fire will cause a higher temperature rise that can result in easier ignition of the belt. The thicker cover relates to more substance that can burn and act as a heat sink resulting in higher temperature that will ignite as soon as the ignition temperature is reached. The air velocity although contributing could not be identified as a significant factor.

With ‘Length Consumed by Mass’ all single factors contributed significantly, namely air velocity, cover thickness and gas consumed, respectively from most significant contribution to least in the order mentioned. These findings indicate that air velocity and cover thickness were the most significant factors to propagate the fire which would relate to more oxygen and more substance to burn. Although gas consumed contributed significantly, the contribution in relation to the air velocity and cover thickness was substantially less.

With ‘Length Undamaged’ the cover thickness and air velocity contributed significantly. Gas consumed did not contribute significantly. The findings indicate that the portion of belt undamaged became less, thus more flame propagation happened. Air velocity (oxygen) and cover thickness (substance) were required to ensure a propagating fire. Gas consumed became less important as the propagating fire generated its own heat.

The findings for single factors analyzed indicate that a conveyor belt fire could be started with a heat source and flammable material at low air velocity. Once the belt ignites air velocity (oxygen) and cover thickness (flammable substance) are required for a propagating fire.

5.3 The influence of combined factors contribution on flame propagation

The influence of combined factors on ‘Temperature Rise above Ambient’ were investigated. The highest contributing factors were cover thickness and air velocity. The second highest contribution were from air velocity and gas consumed followed by gas consumed and cover thickness. This indicates that all factors were required to result in temperature rise. The more flammable substance and more air velocity with a heat source resulted in a temperature rise that will ignite the substance once ignition temperature has been reached.

The influence of combined factors on ‘Length Consumed by Mass’ that were found to be most significant were the cover thickness and air velocity, followed by gas consumed and cover thickness, with a non-significant contribution by air velocity and gas consumed. Findings indicated that once the belt fire was propagating, more flammable substance and air velocity were required complemented by a moderate heat source. These findings correlate well with the individual findings that showed that once a fire is propagating the fire source became less important as the heat was generated by the propagating fire.

The Influence of combined factors on ‘Length Undamaged’ that were found to be highly significant were gas consumed and cover thickness whilst the other combined factors did not contribute significantly. These findings indicate that a more heated fire with more substance will result in less length undamaged. More fire propagation will happen in this case.

5.4 The influence of changes in standard variables on the flame propagation risk of flame retardant belt

Analysis was done to determine whether the hazards associated with changes in standard variables, namely, heat input, air velocity and belt cover wear as well as combinations of these variables, would result in higher risks as a result of easier ignition and greater flame propagation rates of flame retardant belting.

To simulate the changes the output of the analysis of variance was used to construct graphs that show the influence of combined factors that resulted in higher risk as compared with the control sample findings.

The graph displayed in Figure 5.1 shows the interaction of the results of the independent variables that exceeded the control sample results. This describes the results where changes in independent variables exceed the findings as tested in accordance with BS EN 12881-1 Method C. The values on the X-axis show the gas consumed between 535 g and 609 g. The Y-axis shows the values of air velocity from 0,6 m/s to 1,6 m/s. Other values on the left hand side of the graph indicate the setup of colours for the graph and give a description of the graphs drawn. Desirability at the top of the graph means the graph is a representation of where actual results exceeds control sample results. This is relevant to all graphs that will be discussed under this topic in Section 5.1.3.

The area showed in blue on the graph, displayed in Figure 5.1, indicates the area where the results of the interaction of independent variables tested exceeded the standard (control) sample test results**.** This graph indicates that more flame propagation in relation to the control sample results will happen for T0B0 covers with an air velocity more than approximately 0,9m/s over the full range of gas consumed tested.

Findings indicate that more flame propagation can be expected in relation to the control sample findings with air velocities above 0,85 m/s.

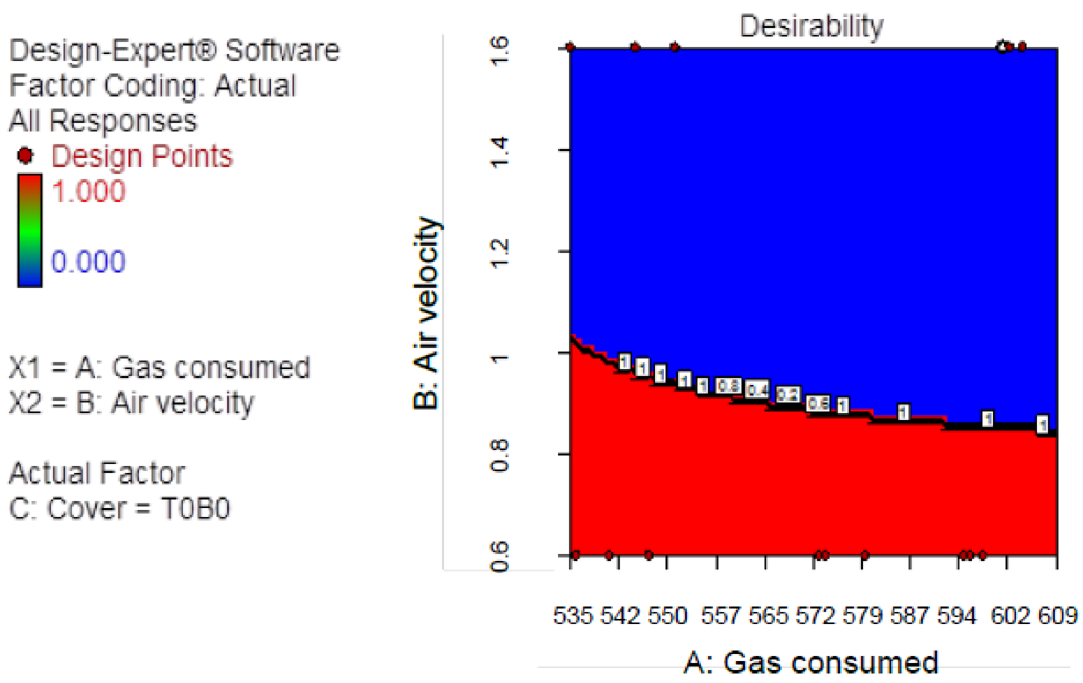


Figure 5.1: Combined factor analysis for belt with no covers exceeding control sample results

The area showed in blue on the graph displayed in Figure 5.2, indicates the area where the results of the interaction of independent variables tested exceeded the standard (control) sample test results. This graph indicates that more flame propagation in relation to the control sample results will happen for T2B1 covers over most of the air velocities and gas consumed range indicated.

This describes the results where changes in independent variables exceed the margin of safety as tested in accordance with BS EN 12881-1 Method C. The values on the X-axis shows the gas consumed between 535 g and 609 g. The Y-axis shows the values of air velocity from 0,6 m/s to 1,6 m/s. The analysis indicates that more flame propagation can be expected with fifty percent worn belt covers compared to the control sample results.

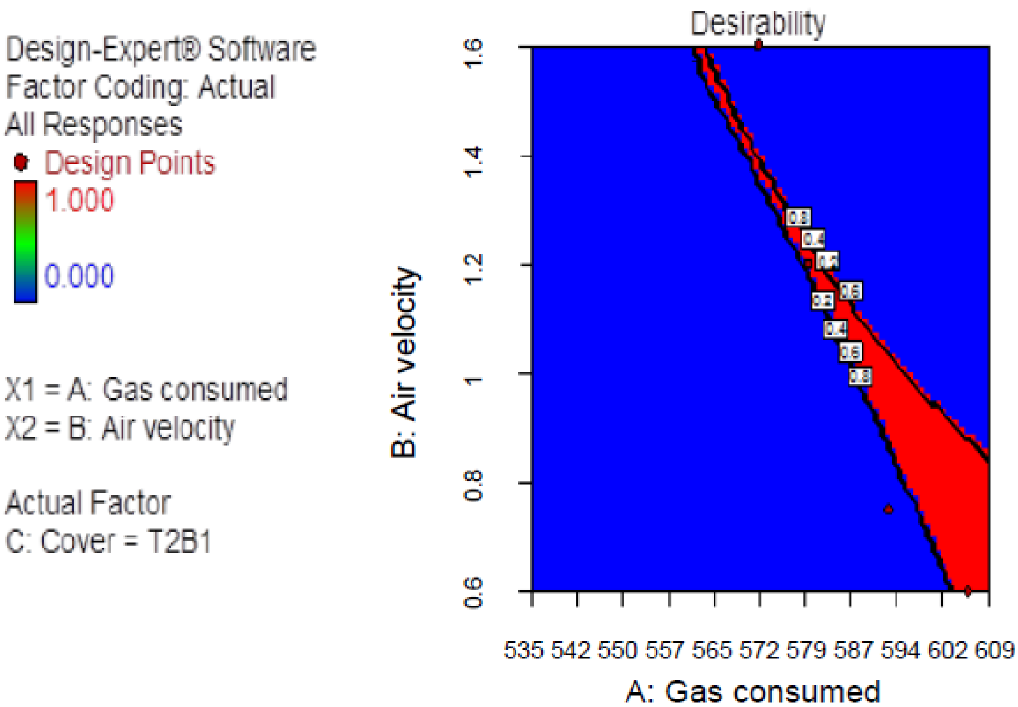


Figure 5.2: Combined factor analysis for T2B1 covers exceeding control sample results

The area showed in blue on the graph, displayed in Figure 5.3, indicates the area where the results of the interaction of independent variables tested exceeded the standard (control) sample test results. This graph indicates that more flame propagation in relation to the control sample results will happen for T1B2 covers over the entire range of the air velocities and gas consumed indicated.

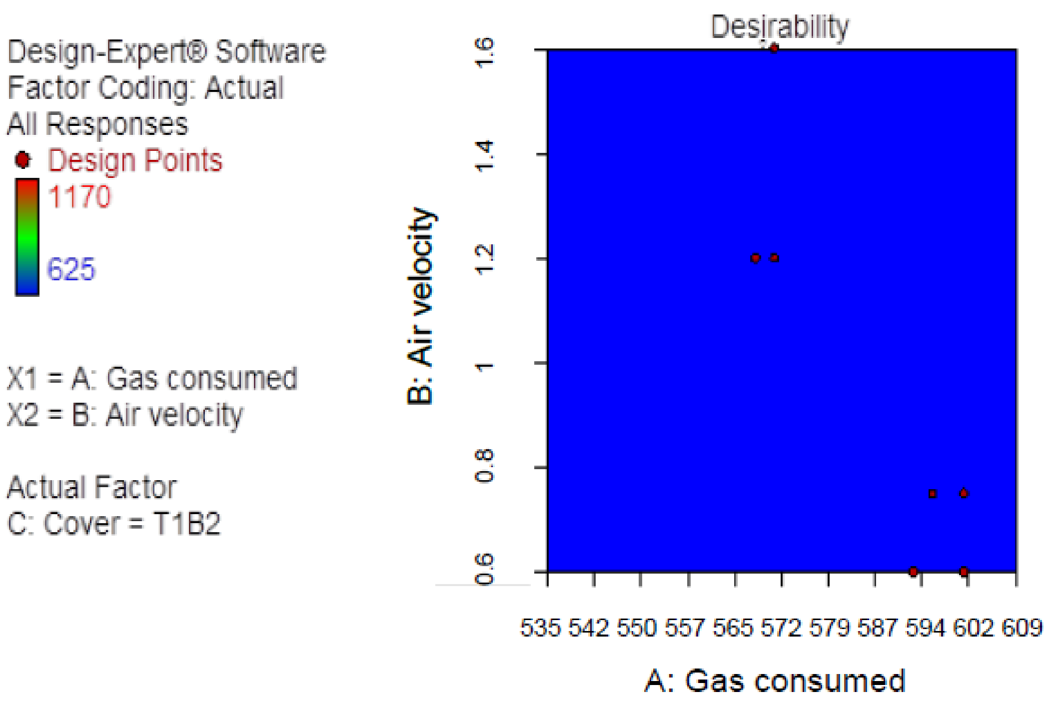


Figure 5.3: Combined factor analysis for T1B2 covers exceeding control sample results

The area showed in blue on the graph, displayed in Figure 5.4, indicates the area where the results of the interaction of independent variables tested exceeded the standard (control) sample test results. This graph indicates that more flame propagation in relation to the control sample results will happen for T4B2 covers over higher air velocities and higher gas consumed indicated. At low air velocities and gas consumed a higher result than the control sample result was also found.

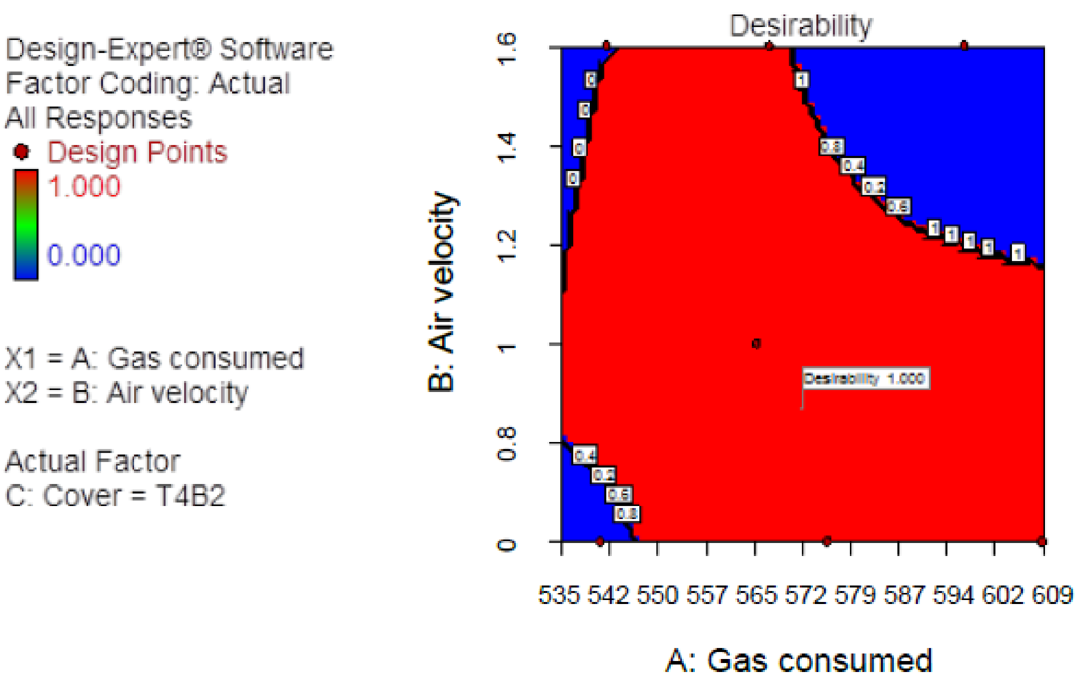


Figure 5.4: Combined factor analysis for T4B2 covers exceeding control sample results

The area showed in blue on the graph, displayed in Figure 5.5, indicates the area where the results of the interaction of independent variables tested exceeded the standard (control) sample test results. This graph indicates that more flame propagation in relation to the control sample results will happen for T2B4 covers over higher air velocities and higher gas consumed indicated. The risk of flame propagation in excess of the control sample indicated was high.

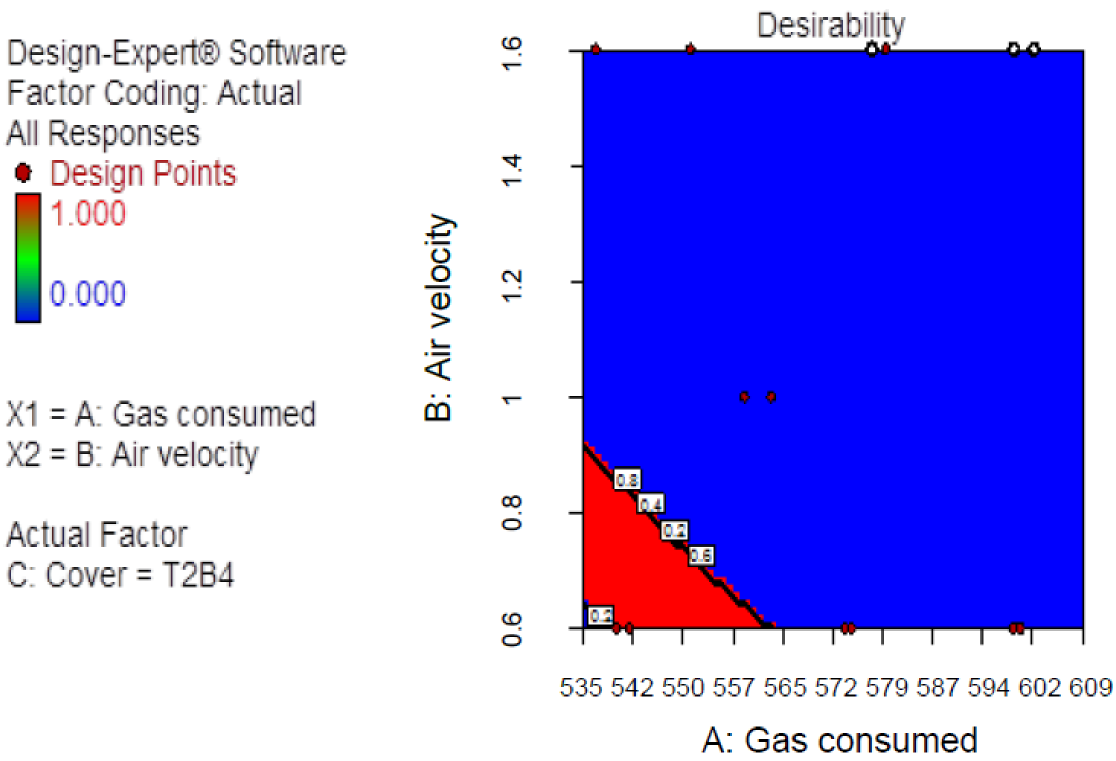


Figure 5.5: Combined factor analysis for T2B4 covers exceeding control sample results

Please refer to Annexure E, Figure E1 to E5, for additional graphical representation of results found. The graphs display the individual factor results and combined factor results. As individual factors, in this case, cannot exist on their own in the mine at any one time, these results are not discussed, but are displayed for information only.

The findings of combined factors analysed exceeded the results of the control sample measured under standard conditions as per BS EN 12881-1 Method C. This indicates that additional risk exists with regard to flame propagation of flame retardant belt when the independent variables changed.

The independent variables in this case represent actual changing conditions in the mine. The flame propagation tests done indicate that changes from the standard test conditions could result in more risk in terms of the flame propagation of fire retardant belt. Risk mitigation measures were carefully considered as more risk exists than initially identified.

5.5 Fire investigation and root causes

By investigating the basic causes of belt fires precautions can be proposed to prevent or limit damage due to propagating belt fires underground. The main causes of fires over more than a ten year period are discussed below.

A study was done at Sasol Mining [20] to determine the main causes of fires underground and this information is used to propose corrective actions. The number of fires encountered and the root causes of these fires are displayed in Figure 5.6 and Figure 5.7 in graphical format.

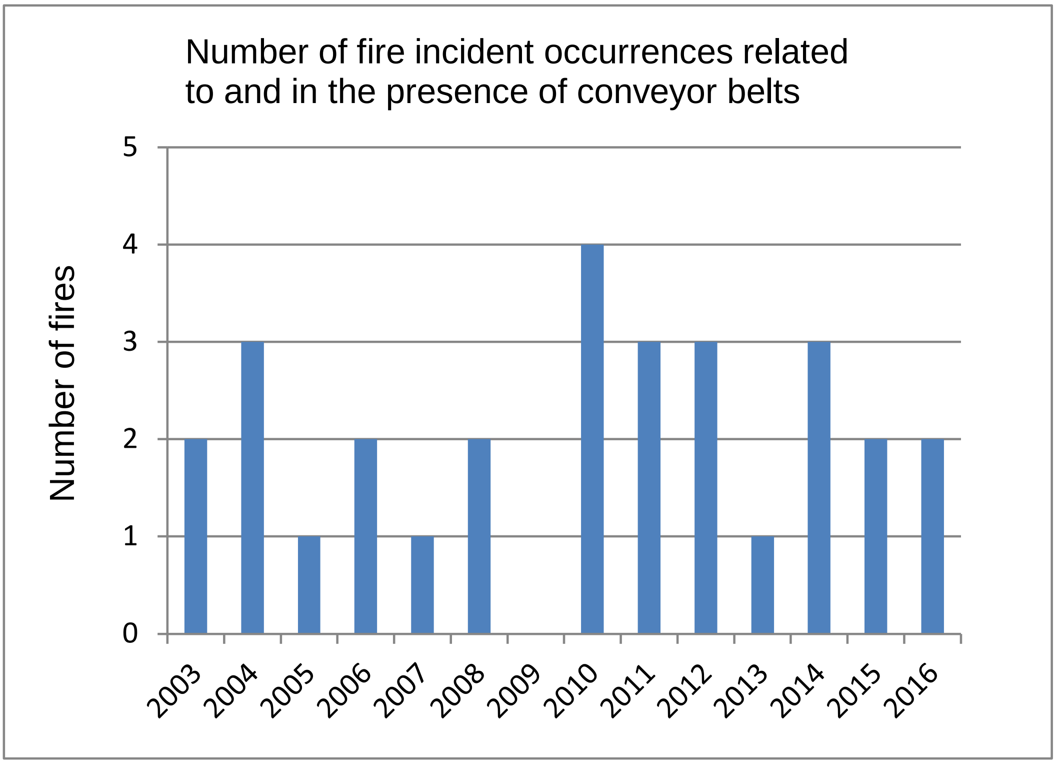


Figure 5.6: Number of fire incidents recorded 2003 to 2016

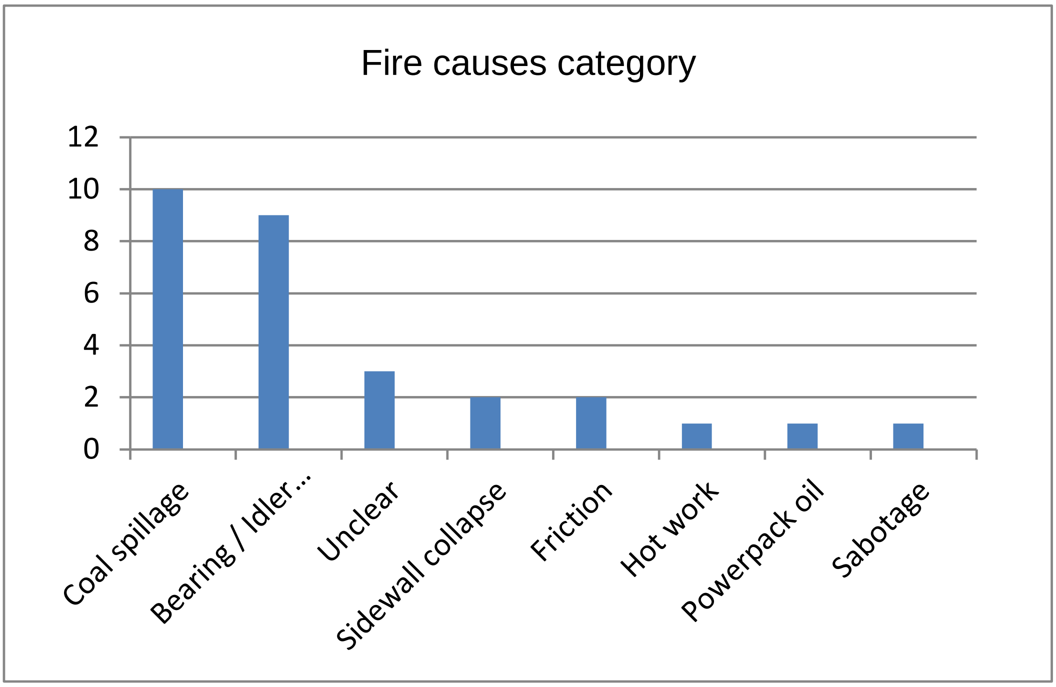


Figure 5.7: Fire causes of fire incidents recorded 2003 to 2016

The basic causes found are discussed below.

Spontaneous Combustion: Spontaneous combustion of coal takes place when exposed to air (Oxygen) and wetness for a period of time. Oxidation takes place that results in self-heating and combustion of coal. Coal spillage must be cleaned up as soon possible and removed from the mine. Idler and belt friction (heat) accelerate the process of spontaneous combustion as more heat is added. Spontaneous combustion happens anywhere where coal was spilled or dumped and not only close to belts.

Bearing and idler roller failures: Mechanical equipment such as pulleys use bearings to enhance rotational movement. Bearings that collapse cause friction that generates heat which will cause combustion of flammable materials. Online bearing monitoring is proposed where the temperature and vibration of mechanical equipment is monitored. Where difficult or impossible to implement manual readings should be taken weekly and corrective actions must be done soonest based on the seriousness of the findings.

Collapsed idler rollers whether because of bearing failure or housing failure must be replaced soonest. The heat generated from the rotational movement on material or structure can ignite fires in flammable material.

Sidewall collapse: Coal from the sidewall or roof falling onto the conveyor system can cause friction with moving machinery that will ignite any flammable material.

Friction: Friction is one of the main reasons for belt fires that can be controlled. Friction is caused by several factors such as collapsed bearings, misaligned structures and spillage. Belt conveyors must be aligned and levelled to ensure no contact with the structures. Equipment design must be correct to prevent skew loading or failures as a result of faulty design.

Flammable lubricants: The fusible plug on the fluid coupling blown causing heated oil to spill and ignite. The use of nonflammable lubricants could have prevented this fire.

Electrical shorts and sparks: Electrical equipment must be safe to operate in the conditions in which they are employed and kept in a safe condition by regular testing, maintenance and condition monitoring.

Hot work: Hot work permits must be issued and competent persons must declare the area safe before the work can be concluded. Open flame cutting and heated steel droppings caused smoldering that ignites flammable material and cause belt fires.

The use of flame retardant idler roller end caps and nonflammable grease are proposed by the writer on underground conveyor systems.

Synthetic idler rollers and scrapers such as HDPE (High Density Polyethylene) and reinforced Nylon should not be used in underground and critical installations (unless special precautions are implemented). Synthetic roller material ignites at lower temperature as belt and will therefore ignite and set the belt alight. Polyurethane makes excellent belt scrapers and is used on conveyor systems by industry. The end users are unaware of the dangers involved in introducing synthetic scrapers in fiery mines.

The melting point of engineering HDPE is 135°C and auto-ignition takes place from 300°C [33]. As an insulator the build-up of static electricity is possible (Resistivity is 6 x 10^5 Ohm-cm). HDPE dust is highly explosive and airborne dust should be avoided. (Will be more dangerous in an enclosed environment such as a mine or tunnel). Molten material tends to flow and drip and will propagate fire. Molten HDPE reacts violently when getting in contact with water or moistness. Airborne HDPE particles are highly explosive and static discharge should be prevented [34, 35].

The melting point of glass impregnated Nylon is 260 °C [36]. Nylon does not stand up against open flames as it is flammable and burns easily when exposed to open flames. Glass impregnated Nylon and HDPE release toxic gases when burning.

5.6 Risk assessment

Based on the findings from the study and other information gathered, an Issue Based Risk Assessment was conducted to find possible solutions to high risk conditions.

The Issue Based Risk Assessment was done according to the following steps as set out by 'OHS Answers Factsheets' [17]:

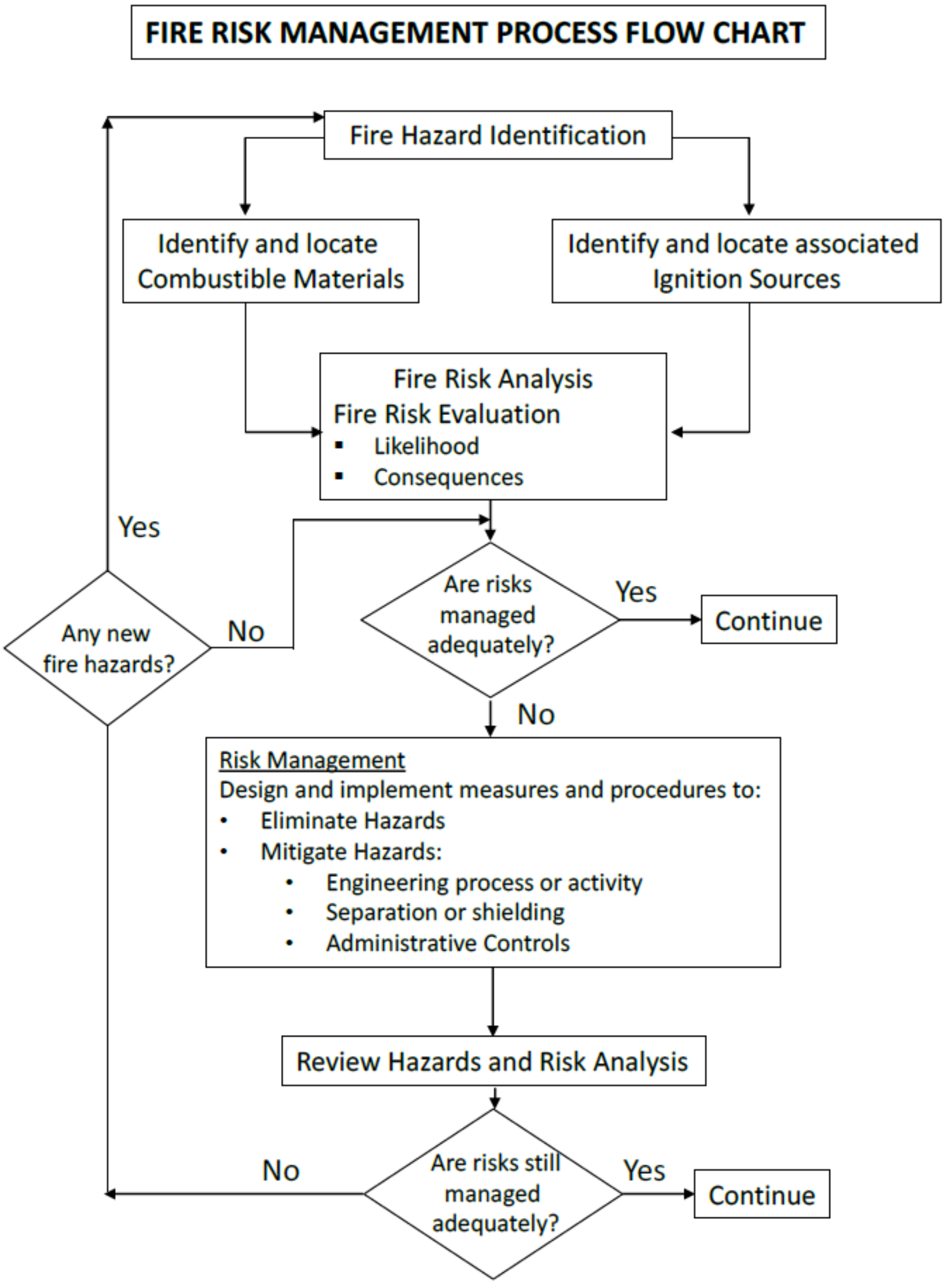
Hazards and risk factors were identified that have the potential to cause harm (hazard identification).

The risk associated with that hazard was analyzed and evaluated (risk analysis, and risk evaluation).

Appropriate ways to eliminate the hazard must be determined, or the risk must be controlled when the hazard cannot be eliminated (risk control).The purpose of the Issue Based Risk Assessment was to identify hazards, then to determine the likelihood of harm, such as an injury or illness occurring, and its severity.

The next step is to identify actions necessary to eliminate the hazard, or control the risk using the hierarchy of risk control methods. Then to evaluate in order to confirm if the hazard has been eliminated or if the risk is appropriately controlled. Lastly monitor to make sure the control continues to be effective.

It is important to keep any documents or records that may be necessary for reference purposes. Documentation may include detailing the process used to assess the risk, outlining any evaluations, or detailing how conclusions were made. This process is displayed below diagrammatically in Figure 5.6.



Diagrammatic Flow Chart of Fire Risk Assessment from Department of Mineral Resources [19]

Figure 5.6: Diagrammatic presentation of the risk management process

The choice of risk assessment was derived from the Mining's Risk Management Process [18] as shown below in Figure 5.7.

Figure 5.7 describes the Mining Risk Management Process. In accordance with the process an Issue Based Risk Assessment was conducted. The process in Figure 5.7 is read from left to right from top to bottom. The first point was to identify the risk, then to do the risk assessment selecting the correct template and using the Bow Tie Methodology.

All risks were identified and then rated according to the risk probability of the undesirable event happening and consequence when it can happen. The higher risk items are then identified for which preventive controls or barriers were put in place. These controls or barriers allow to either eliminate the risk, or if not possible to shield the risk and or to use administrative controls to manage the risk.

The steps were followed (in the sixth column from left) that describe the process from risk rating to putting controls in place, monitoring the effectiveness and to improve on ineffective risk management. This steps are followed frequently to ensure that the risk control measures are effective and if found not effective, corrected to be effective.

Process	Tools				Steps	Outcomes
Plan	Identify the risk	Baseline Risk Assessment Issue Based Risk Assessment	7x7 Matrix Baseline Template Environment Risk Template Health Risk Template Issue Based Template	Bowtie methodology and application of understanding	Understand the context Identify relevant hazards and undesirable events Explore and analyse the undesirable events (causes and consequences)	Risk profile response and controls
	Understand the risks	Task Risk Assessment Continuous Risk Assessment	Issue Based Template Database for Risk Assessment (DRA) SLAM Scorecard Pre-use Inspection Lists MOSH Records		Access the inherent risks Determine the controls. (preventative and corrective controls, control owners) Assess the residual risks Execute controls	
Do	Manage and Monitor the risks	Critical Control Management	SOPs and Work Instructions Critical Control Check Lists PTOs		Monitor the control effectiveness against performance criteria. Take immediate action to improve operating effectiveness Review risk profile movement based on critical control effectiveness and incident investigation results.	Effective management of risks
Review	Govern and Assure	Assurance Reporting	Visible Leadership Life Saving Behaviours Coaching Meetings		Provide assurance on control effectiveness. Report on risk profile, risk exposure and effectiveness of critical controls.	Assurance of effective management of risk
Improve	Analyse and Improve	Analysis and Opportunities Plan for gap closure	Risks Based Leading Indicators 1st line assurance 2nd party audits		Access and analyse trends and review changes.	Improvement action plans
			SHE Reporting Procedure SHE Meetings		Identify improvement opportunities for exposure improvement and risk reduction.	
			Trend Analysis Learnings from incidents SHE Maturity Assessment Internal and External Scan SHE Game Plans Action manager in IMS		Implementation plan for learnings and improvement action.	

Figure 5.7: Diagrammatic presentation of the Mining Risk Management Process

An Issue Based Risk Assessment was conducted involving end users and ventilation personnel. Outcomes were prioritised according to risks identified in order to determine controls to eliminate the hazards identified or put controls in place to reduce the consequences and / or probability where the hazard cannot be eliminated. The complete process was documented [32] and the outcomes communicated to the mines and plants.

Some identified findings resulted in changes required to the Code of Practices at the mines as well as changes to Standard Operating Procedures.

The risk registers shown in Table 5.1 to Table 5.5 contain a summary of the findings selected from the Issue Based Risk Assessment. The left hand column describes the unwanted event followed on the right hand side by the corrective action. The numbers on the corrective action indicate to which unwanted events the corrective action is applicable. The next column contains the current effectiveness before any other actions were taken followed by the type of control selected to reduce the risk. The second last column describes who is in control of the risk and the last column who is responsible to put the controls in place.

The sequence is similar on all risk registers shown in this report. The Risk Registers contains the outcome of the findings of individual risks identified whilst conducting the Issue Based Risk Assessment.

Table 5.1: Risk register for friction points resulting in fires

Risk Register

Date	Safety & Health	Risk Assessment	1. Context and key objectives	Business unit	Reason for Assessment
Document Description		Risk Assessment	• To meet and exceed the SH&E minimum requirements; • Retain OSHAS 18001 certification and Implement IMS; • No Ignitions , Fires or Explosions; • To maintain an effective ventilation system • To engineer the environment so as to ensure a safe and productive workplace. * To comply with MHSA	Sasol Mining	Damage incident
					Source
The prevention of fire on underground, incline and tripper conveyors		Issue based			Machinery/equipment/ tools

Risk number	Risk description	Risk Reduction	Risk owner	Risk Champion
	Friction points resulting in fire	Improve less than effective controls	SME	

Probability		Impact		7x7 Risk rating		Robot rule rating		Business unit
Inherent	Residual	Inherent	Residual	Inherent	Residual	Inherent	Residual	Brandspruit
P7	P3	I7	I7	1	3	H	M	

Causes	Preventative controls	Effectiveness	Barriers	Weighting	Control owner	Resp. person
1. Coal spillages along the belt, resulting in the belt rubbing on the coal	Daily inspection by artisan (1, 2, 3, 4, 5, 6, 7, 8, 9)	Effective - 90%	Admin	Important control	Services Engineer	Chief Foreman
2. Misalignment of the belt can cause friction points on the structure which could heat up and ignite a fire on the belt	Weekly maintenance & cleaning (1, 2, 3, 4, 5, 6, 7, 8, 9)	Effective - 90%	Admin	Critical control	Services Engineer	Chief Foreman
3. Belt slip between the drive pulley and the belt generating heat due to lack of maintenance resulting in pulley lagging damaged or too low tension	Sensors for detecting misalignment (2)	Effective - 90%	Safety devices	Critical control	Services Engineer	Chief Foreman
4. Idler seize / missing / collapsing causing a friction point	Anti-slip detection sensor (3)	Effective - 90%	Safety devices	Critical control	Services Engineer	Chief Foreman
5. Pulley bearing failure causing a friction point	Temperature sensors on pulley bearings except take up (5)	Qualified - 65%	Safety devices	Critical control	Services Engineer	Chief Foreman
6. Roof or sidewall collapse	Fire detection sensors for CO and SO2 at tail end - must still	None - 0%	Safety devices	Critical control	Services Engineer	Chief Foreman

	be installed (1-9)					
7. Nip guard rubbing against the belt	Mesh and shotcrete installed on roof and sidewalls of incline (6)	Effective - 90%	Design	Important control	Mine Manager Services	Mine Overseer Services
8. Foreign objects from main conveyors that was missed by the magnets	Flame retardant belt installed on incline (1-9)	Effective - 90%	Design	Critical control	Services Engineer	Chief Foreman
9. Deterioration of lagging on the pulleys	Condition monitoring of bearings (5)	Effective - 90%	Admin	Important control	Services Engineer	Condition monitoring
Consequences	**Corrective controls**	**Effectiveness**	**Barriers**	**Weighting**	**Control owner**	**Resp. person**
1. Financial losses	Budget (1)	Effective - 90%	Admin	Important control	VP	Financial manager
2. Possible injury (smoke inhalation /burn)	Emergency preparedness and response (2)	Effective - 90%	Admin	Important control	VP	CSO
3. Production loss	Hand held fire extinguishers / fire hydrants / fire hoses(1-3),	Qualified - 65%	Design	Critical control	Services Engineer	Chief Foreman

Remarks/Notes
Temperature sensors on pulley bearings except take-up (5) - Investigation for the installation for wireless communication for vibration and temperature sensors on the take-up pulley - ESS End of October 2018 Fire detection sensors for CO and SO2 at tail end - must still be installed (1-9). End of October 2018 sensors will be installed Hand held fire extinguishers / fire hydrants / fire hoses(1-3), - End of October 2018 replacement strategy for fire extinguishers (water mist and foam mist)

Risk owner			
Name	Occupation	Signature	Date

Table 5.2: Risk register for equipment failure resulting in fires

<table>
<tr><td colspan="11">Risk Register</td></tr>
<tr><td>Date</td><td>Safety & Health</td><td colspan="2" rowspan="3">Risk Assessment</td><td colspan="3">1. Context and key objectives</td><td colspan="2">Business unit</td><td colspan="2">Reason for Assessment</td></tr>
<tr><td colspan="2" rowspan="2">Document Description</td><td colspan="3" rowspan="3">• To meet and exceed the SH&E minimum requirements;
• Retain OSHAS 18001 certification and Implement IMS;
• No Ignitions , Fires or Explosions;
• To maintain an effective ventilation system
• To engineer the environment so as to ensure a safe and productive workplace.
* To comply with MHSA</td><td colspan="2" rowspan="3">Sasol Mining</td><td colspan="2">Damage incident</td></tr>
<tr><td colspan="2">Source</td></tr>
<tr><td colspan="2">The prevention of fire on underground, incline and tripper conveyors</td><td colspan="2">Issue based</td><td colspan="2">Machinery/equipment/ tools</td></tr>
<tr><td colspan="2">Risk number</td><td colspan="4">Risk description</td><td colspan="2">Risk Reduction</td><td>Risk owner</td><td colspan="2">Risk Champion</td></tr>
<tr><td colspan="2"></td><td colspan="4">Equipment failure resulting in fire</td><td colspan="2">Controlled at acceptable level of risk</td><td></td><td colspan="2"></td></tr>
<tr><td colspan="2">Probability</td><td colspan="2">Impact</td><td colspan="2">7x7 Risk rating</td><td colspan="2">Robot rule rating</td><td colspan="3">Business unit</td></tr>
<tr><td>Inherent</td><td>Residual</td><td>Inherent</td><td>Residual</td><td>Inherent</td><td>Residual</td><td>Inherent</td><td>Residual</td><td colspan="3" rowspan="2"></td></tr>
<tr><td>P7</td><td>P2</td><td>I7</td><td>I5</td><td>1</td><td>4</td><td>H</td><td>M</td></tr>
<tr><td colspan="4">Causes</td><td colspan="2">Preventative controls</td><td>Effective ness</td><td>Barriers</td><td>Weighting</td><td>Control owner</td><td>Resp. person</td></tr>
<tr><td colspan="4">1. Poor or lack of maintenance</td><td colspan="2"></td><td>Effective - 90%</td><td>Admin</td><td>Critical control</td><td>Services Engineer</td><td>Chief Foreman</td></tr>
<tr><td colspan="4">2. Inadequate design of component by OEM</td><td colspan="2"></td><td>Effective - 90%</td><td>Admin</td><td>Important control</td><td>Services Engineer</td><td>Condition Monitoring</td></tr>
<tr><td colspan="4"></td><td colspan="2"></td><td>Effective - 90%</td><td>Admin</td><td>Important control</td><td>Services Engineer</td><td>Chief Foreman</td></tr>
<tr><td colspan="4">0</td><td colspan="2"></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td colspan="4">Consequences</td><td colspan="2">Corrective controls</td><td>Effective ness</td><td>Barriers</td><td>Weighting</td><td>Control owner</td><td>Resp. person</td></tr>
<tr><td colspan="4"></td><td colspan="2">Hand held fire extinguishers / fire hydrants / fire hoses(1-3),</td><td>Qualified - 65%</td><td>Design</td><td>Critical control</td><td>Services Engineer</td><td>Chief Foreman</td></tr>
<tr><td colspan="11">Remarks/Notes</td></tr>
<tr><td colspan="11">Fire detection sensors for CO and SO2 at tail end - must still be installed (1-9). End of October 2018 sensors will be installed

Hand held fire extinguishers / fire hydrants / fire hoses(1-3), - End of October 2018 replacement strategy for fire extinguishers (water mist and foam mist)</td></tr>
<tr><td colspan="11">Risk owner</td></tr>
<tr><td colspan="3">Name</td><td colspan="2">Occupation</td><td colspan="4">Signature</td><td colspan="2">Date</td></tr>
<tr><td colspan="3"></td><td colspan="2"></td><td colspan="4"></td><td colspan="2"></td></tr>
</table>

Table 5.3: Risk register for coal spillages resulting in fires

Risk Register					
Date	Safety & Health	Risk Assessment	1. Context and key objectives	Business unit	Reason for Assessment
Document Description			• To meet and exceed the SH&E minimum requirements; • Retain OSHAS 18001 certification and Implement IMS; • No Ignitions , Fires or Explosions; • To maintain an effective ventilation system • To engineer the environment so as to ensure a safe and productive workplace. * To comply with MHSA	Sasol Mining	Damage incident
					Source
The prevention of fire on underground, incline and tripper conveyors		Issue based			Machinery/equipment/ tools

Risk number	Risk description	Risk Reduction	Risk owner	Risk Champion
	Coal spillages	Controlled at acceptable level of risk		

Probability		Impact		7x7 Risk rating		Robot rule rating		Business unit
Inherent	Residual	Inherent	Residual	Inherent	Residual	Inherent	Residual	
P6	P3	I7	I7	1	3	H	M	

Causes	Preventative controls	Effectiveness	Barriers	Weighting	Control owner	Resp. person
1. Misalignment due to skew joints or pulley lagging or tension	Training and coaching of belt splicing, over inspection by supervisor, checklist (1,2,3,4,)	Effective - 90%	Admin	Critical control	Engineer	Chief foremen /mine overseer
2. Line and levelling of structure	Prevent skew cutting, roof and side wall support, level control of floor cutting (2,)	Qualified - 65%	Admin	Critical control	Mine overseer	Shift boss
3. Missing troughing frames	Ensure troughing frames are always correctly installed Ensure frames are properly installed after splicing is done (3, 4)	Qualified - 65%	Admin	Critical control	Mine overseer / chief foreman	Shift boss /foreman
4. Missing, stuck, faulty idlers	Over inspections and	Qualified - 65%	Admin	Critical control	Mine overseer	Shift boss /foreman

	enforce discipline (1 - 13)				/ chief foreman	
5. Miss aligned chutes	Complete alignment of chute after the first delivery of coal as per SOP (5)	Qualified - 65%	Admin	Critical control	Mine overseer / chief foreman	Shift boss /foreman
6. Leaking chutes	Maintain and replace liners inside the chute Apply RCM maintenance schedule (5 ,6, 9,) Operational checklist for belts (1 - 13)	Qualified - 65%	Admin	Critical control	Chief foreman	Foreman
7. Synchronisation of belts in series	Ensure that the belt speeds are tuned Start-up sequence and inter lock testing to be confirmed daily as per RCM requirements (7, 8)	Effective - 90%	Admin	Critical control	Chief foreman	Foreman
8. Overloaded belt	Planning the number of section that feed onto the next receiving belt must be properly done Ensure that the planning is followed Cleaning of old areas Bunker chute control must fit the feed rate of the receiving belt Feeder breakers feed speed to match the receiving belt as per mine specific standard. (8, 7)	Marginal - 40%	Admin	Critical control	Mine manager /planning manager	Mine overseer
9. Pulley lagging	Conduct inspections on lagging. Lagging of	Qualified - 65%	Admin	Critical control	Chief foreman	Foreman

Consequences	Corrective controls	Effective ness	Barriers	Weighting	Control owner	Resp. person
	pulleys must be done after the design tonnage and lifespan. Ensure the correct lagging design as per application (9, 1)					
10. Torn belt	Prevent foreign objects onto the belts Replace ageing belts before they tear Magnets must always be fully operational (10, 3)	Deficient - 20%	Admin	Critical control	Engineer	Chief foremen /mine overseer
11. Skew tail-end	Re-align and anchor tail-ends after belts extension or feeder breaker bumped (11, 1, 2,)	Qualified - 65%	Admin	Critical control	Mine overseer / chief foreman	Shift boss /foreman
12. Belt tension	Belt tension calculation to be done properly according to the length of the conveyor Do not extend belt beyond its design length (12, 1)	Qualified - 65%	Admin	Critical control	Engineer	Chief foremen /mine overseer
13. High air velocity resulting in duff accumulation behind the confined area	Air crossings must be blasted and built according to specification High air velocity (>3m/s) areas must be inspected more frequently i.e. low air crossings, belt bridges and mine entrances (13,)	Qualified - 65%	Admin	Critical control	Mine manager	Mine overseer /shift boss
Remarks/Notes						

202: Long term planning of mine. Unscheduled deployment of sections into areas not designed for it should never be allowed. Section deployment and correct size belt initially installed to accommodate the planned number of sections. Stone must be stored in designated stowing areas and not be loaded onto the belts. Feeder breakers must not be adjusted out of specifications.

Risk owner			
Name	Occupation	Signature	Date

Table 5.4: Risk Register for spontaneous combustion and coal spillages resulting in fires

Risk Register

Date	Safety & Health	Risk Assessment	1. Context and key objectives	Business unit	Reason for Assessment
Document Description			• To meet and exceed the SH&E minimum requirements; • Retain OSHAS 18001 certification and Implement IMS; • No Ignitions , Fires or Explosions; • To maintain an effective ventilation system • To engineer the environment so as to ensure a safe and productive workplace. * To comply with MHSA	Sasol Mining	Damage incident
					Source
The prevention of fire on conveyors		Issue based			Machinery/equipment/tools

Risk number	Risk description	Risk Reduction	Risk owner	Risk Champion
	Spontaneous combustion - coal spillages	Improve less than effective controls		

Probability		Impact		7x7 Risk rating		Robot rule rating		Business unit
Inherent	Residual	Inherent	Residual	Inherent	Residual	Inherent	Residual	
P5	P4	I7	I7	1	1	H	H	

Causes	Preventative controls	Effectiveness	Barriers	Weighting	Control owner	Resp. person
1. Build up coal spillages	Inspections (1)	Effective - 90%	Admin	Important control	Services Engineer	Chief Foreman
	Cleaning of spillages (1)	Effective - 90%	Admin	Critical control	Services Engineer	Chief Foreman
	Operate the belt according to design specifications (1)	Qualified - 65%	Design	Important control	Services Engineer	Impumelelo project manager
	Fire detection sensors for CO and SO2 at tail	None - 0%	Safety devices	Critical control	Services Engineer	Chief Foreman

	end - must still be installed (1)					
Consequences	Corrective controls	Effectiveness	Barriers	Weighting	Control owner	Resp. person
1. Production loss	Budget (1)	Effective - 90%	Admin	Important control	VP	Financial manager
2. Injury	Emergency preparedness and response (2)	Effective - 90%	Admin	Important control	VP	CSO
3. Financial loss	Hand held fire extinguishers / fire hydrants / fire hoses(1-3),	Effective - 90%	Admin	Important control	VP	Operations Manager
Remarks/Notes						
Operate the belt according to design specifications (1) Fire detection sensors for CO and SO2 at tail end - must still be installed (1-9). End of October 2018 sensors will be installed Hand held fire extinguishers / fire hydrants / fire hoses(1-3), - End of October 2018 replacement strategy for fire extinguishers (water mist and foam mist)						

Table 5.5: Risk Register for delayed detection and response to fires

Risk Register										
Date	Safety & Health	Risk Assessment		1. Context and key objectives			Business unit		Reason for Assessment	
Document Description				• To meet and exceed the SH&E minimum requirements; • Retain OSHAS 18001 certification and Implement IMS; • No Ignitions , Fires or Explosions; • To maintain an effective ventilation system • To engineer the environment so as to ensure a safe and productive workplace. * To comply with MHSA			Sasol Mining		Damage incident	
									Source	
The prevention of fire on conveyors		Issue based							Machinery/equipment/tools	
Risk number		Risk description				Risk Reduction		Risk owner	Risk Champion	
		Delayed detection and response to fires				Improve less than effective controls				
Probability		Impact		7x7 Risk rating		Robot rule rating		Business unit		
Inherent	Residual	Inherent	Residual	Inherent	Residual	Inherent	Residual			
P7	P7	I7	I7	1	1	H	H			
Causes				Preventative controls		Effectiveness	Barriers	Weighting	Control owner	Resp. person
1. Limited employees for working shifts										
2. No fire detection systems				Automatic fire detection and suppression activation system (1-3)		None - 0%	Design	Critical control	Services Engineer	Chief Foreman
3. No incline fire patrol after hours or weekends										
				Automatic CO and SO2 detection system, monitored at control room (1-3)		None - 0%	Design	Critical control	Services Engineer	Chief Foreman
Consequences				Corrective controls		Effectiveness	Barriers	Weighting	Control owner	Resp. person
				Firefighting training for employees (1-3)		Effective - 90%	Admin	Important control	Services Engineer	Chief Foreman
Remarks/Notes										
Fire detection sensors for CO and SO2 at tail end - must still be installed (1-9). End of October 2018 sensors will be installed										

Hand held fire extinguishers / fire hydrants / fire hoses (1-3), - End of October 2018 replacement strategy for fire extinguishers (water mist and foam mist) Investigation of automated suppression systems at the tail-end of the incline and drive houses - End of October 2018 finalize the decision of the make and model to be used - ESS

The most important aspects from the Issue Based Risk Assessment are the following.

The basic installation of the conveyor system must be according to standard. Operate the system as designed whilst ensuring good housekeeping and maintenance. Install heat and vibration sensors where possible on pulleys and rotating equipment. Install CO and SO2 sensors in a multitude of positions as determined by an Issue Based Risk Assessment. All sensors must be connected to a control room with levels set to activate alarms at the correct time.

Ensure that the correct firefighting equipment is selected and deployed. Train all personnel in emergency response and firefighting. Where practical and possible investigate automated fire suppression systems. Practice mock emergencies to ensure that personnel can react correctly.

6 CONCLUSION AND RECOMMENDATION

6.1 Conclusion

An investigation was done on flame retardant belt to determine the influence of individual factors and a combination of factors that influence the flame retardancy of such a belt. The factors considered were the air velocity, the cover thicknesses and the heat supplied to the belt.

All the findings in this report are based on the testing of a specific flame retardant belt and an Issue Based Risk Assessment done on the findings.

The findings of the experiment confirmed that all factors considered individually and in combination with other factors contributed to a lesser or higher degree to the flame propagation of a flame retardant belt.

The investigation confirmed that changes in air velocity, heat input and cover thickness that departed from the conditions specified in the Standard BS EN 12881-1 Method C affected the flame propagation of flame retardant belt. It was found that with changes in standard variables more flame propagation can happen than predicted by the standard test when using flame retardant belt.

The belt tested will ignite with heat input (energy) at relatively low air velocity. Once ignited a hotter fire develops and depending on the conditions, more or less flame propagation will develop. The thicker the covers, the higher the air velocity (within the range tested) and higher the gas consumed, i.e. the energy input in the range tested, the more the flame propagation.

The test results showed that the risk of flame propagation increased with the use of flame retardant belt when the conditions changed from the standard test conditions as depicted by the Specification BS EN 12881-1 Method C. The implication of this is that when using flame retardant belt in the mine, where conditions are different from the test parameters, the risk of ignition and fire propagation are higher. This is an additional risk factor that should be considered in doing an Issue Based Risk Assessment of the conveyor installation.

The Issue Based Risk Assessment was conducted considering the findings of the experiment as well as other information acquired from research and testing done to reduce belt fires. The control measures indicated in the findings would prevent fires from happening when implemented correctly. These findings were communicated to the end users to enable them to control the risk on the conveyor installations at the respective mines.

The objectives of the project had been reached as the factorial experiment indicated which factors contributed individually and collectively to flame propagation of flame retardant belt. The risk had been quantified in terms of more or less flame propagation under different conditions. The Issue Based Risk Assessment was done in order to control the risk and the end users were informed with regard to requirements to prevent the ignition and flame propagation of fire retardant belt.

More heat is generated at the early stage of combustion that result in CO and SO2 dissipation may assist to fight belt fires by installing CO and SO2 sensors in the belt road complemented by heat sensors alongside the belt. The use of heat sensors individually is not proposed as a limited area is covered by the heat sensor. The use of thermo-graphic (infrared type) cameras is proposed in critical (selected) areas to complement other early detection devices. This will ensure that the heat source can be attended to before extensive incineration takes place. Where to install must be based on an Issue Based Risk Assessment.

A study done for Sasol Mining showed that the earliest detection of a fire or smoldering material will be through the usage of CO and SO2 sensors in the belt road [21]. The CO and SO2 in the smoldering stage reached a higher level, then reduced before the ignition point of the conveyor belt.

(Please refer to Annexure F where the findings are displayed in Figure F1 to Figure F4.)

The study indicated that flame retardant belt will burn when conditions are suitable. The more the substance that can burn (thicker covers) with higher air velocity, the higher the chance of the fire propagating along the belt.

6.2 Solutions proposed

The study showed that higher energy fires with more substance to consume at higher air velocities will enhance flame propagation of fire retardant belt. The solution proposed is to focus on the prevention of fires by preventing the heat source and by limiting flame propagation by limiting flammable substance.

The use of materials with low melting and low combustion points on conveyors in underground or critical conditions must be minimised. The study done showed that the more the combustible material, the more the chance for an ongoing fire. Examples of flammable materials include synthetic wear surfaces, non-flame retardant pulley lagging, synthetic idler rollers, etc. Where heat and oxygen are present only combustible material is required to ignite a fire. The thicker covers in this study resulted in more damage to the samples.

The use of nonflammable lubricants in underground and critical installations is proposed. Lubricants are normally manufactured from natural oils that are flammable. Once a fire starts this will be another source of fuel.

The use of flame retardant conveyor belt underground is essential. Flame retardant belt in the correct condition should extinguish itself once the source of the fire is removed or once burnt away from the source of fire.

This can be seen with the length undamaged in the study done. Not one sample burned out completely.

In order to prevent friction heat caused by slipping conveyor belt over drive pulleys, ensure correct tensions are used to operate the conveyor system. When slippage happens between pulleys and belts heat is generated that can cause fires. Operate the conveyor system within design parameters. Only install properly designed conveyor systems where the tensions and power required were stipulated. Installations based on common knowledge may not take all variables into consideration.

In order to prevent ignition of coal dust ensure that the area is clean from coal dust or other flammable material dust or particles. Coal dust is highly explosive and can cause not only fires but also dust explosions. Ensure the dust suppression system is in good operating condition to suppress dust particles.

Spillage underneath and around the conveyor system can cause friction heat and add to the flammable substance around the conveyor system. Remove any spillage under and around the conveyor system. Belts and idler rollers running in and on top of material cause friction that will generate heat and can cause a fire, normally once the conveyor system stops as the heat is then not carried away by the running conveyor belt. Clean up all shavings of conveyor belt and twines as this collects underneath the conveyor or entangles itself around pulleys and rollers that can ignite when heated.

The area conditions can cause friction fires due to rocks or coal collapsing onto the conveyor system or close to it that can cause friction of the belt against the coal or rock or between the belt and steel structure should the structures be damaged from the rock fall. Ensure the area is safe to operate the conveyor system in. No coal or rocks must fall from sidewalls or roofs that can cause friction or misalignment that can cause a friction fire. Inspections and barring must be done frequently.

Monitor all critical areas for flammable gases. In fiery mines methane can cause explosions that will cause extensive equipment damage and long downtimes. Ensure that the conveyor operates in a safe environment.

High speed conveyors running against the intake air velocity cause fine material and dust particles to blow off the conveyor and accumulate on top of structures and underneath the conveyor system. This causes difficulty in cleaning as it is an ongoing process which can result in propagating friction fires.

Conveyor installation in itself can also enhance flame propagation of fire retardant belt. From the research done it was found from findings by Yuan and Litton [3] that heat feedback from the roof will preheat the conveyor belt surface causing easier ignition and combustion. This could be assisted with differential air velocities in smaller spaces. It is not advisable to install conveyor systems close to roofs.

In order to detect conveyor fires sooner and extinguish them, it is essential that fire detection systems must be in good working order and connected to the control room. An alarm should sound when CO and SO2 levels reach, for example, 30ppm and 5ppm respectively in order to plan for emergency response. Firefighting equipment must be the correct type for the application to fight these specific fires. Personnel must be trained in emergency response and firefighting.

Standard conveyor belts require approximately 350°C to auto-ignite. Approximately 450°C is required to auto-ignite Bituminous Coal [33]. Experience shows that heat is generated from friction or another sources that ignite fine coal particles. This coal particles smolder until enough heat is generated to ignite any flammable product in close vicinity, normally the conveyor belt that will heat up, smolder and then combust as soon as ignition temperature has been reached.

To prevent fires any one of the three products of combustion should be removed namely heat, air (Oxygen) and fuel (material). As it is physically impossible to remove the air and fuel (the belt), only the heat can be removed to prevent fires on conveyor systems.

A Issue Based Risk Assessment should be done on all installations to determine what measures to implement to reduce the risk to ensure a safe and productive conveyor system. The outcome of the Issue Based Risk Assessment will change the Code of Practice and the Conveyor Standard Operating Procedures in order to reflect the barriers identified in the Issue Based Risk Assessment to ensure safe operation of the conveyor system.

7 REFERENCES

1. Lazzara CP and Perzak FJ, (1987), Effect of ventilation on conveyor belt fires, Paper 7.5 in symposium, Safety in Coal Mining, 1987, Pretoria, South Africa. Cited 24 April 2017

2. Perzak FJ, Spencer ER, Sapko MJ, (Reprinted 1982) Testing of fire resistant conveyor belting, CIM bulletin, Volume 75, No. 844. Cited 6 April 2017

3. Yuan L, Litton CD, (2007), Experimental study of flame spread on conveyor belts in a small scale tunnel. Fires and Materials 2007 - 10th International Conference, January 29-31, 2007, San Francisco, California. London: Interscience Communications, 2007 Feb; 1-10. Cited 15 November 2017

4. Verakis HC and Dalzell RC (1988)
Impact of Air Velocity on the fire hazards of conveyor belts
Fourth International Mine Ventilation Conference
Brisbane, Queensland. Cited 4 June 2017

5. Montgomery DC (2012)
Design and analysis of experiments, 8th edition
Arizona, United States of America
John Wiley and Sons, Inc.

6. Miles AJ (2016)
Report: Fire Propagation Equipment Calibration and Belt Testing
Oriental Rubber Industries – Pune-India. 9th to 20th July 2016. Cited 6 September 2016

7. Verakis HC, (1991) Reducing the fire hazard of mine conveyor belts. US Department of Labor, Mine Safety and Health Administration, Approval and Certification Centre, Triadelphia, West Virginia.
Cited 24 April 2017

8. Lazzara, C.P. and Perzak, F.J., (1989). Conveyor belt flammability tests: *Comparison of large-scale gallery and laboratory-scale tunnel results.*
23rd International Conference of Safety in Mines Research Institutes, Washington, DC, pp. 138-150. Cited 27 May 2018

9. Yuan L and Litton, CD (2007)
Experimental study of flame spread on conveyor belts in a small-scale tunnel
National Institute for occupational Safety
Pittsburg Research Laboratory, Pittsburg, PA. Cited 10 June 2017

10. Kuchta JM, Sapko MJ, Perzak FJ and Mura KE (1981)
Improved Fire Resistant test method for belt materials
Pittsburg Research Centre
Bureau of Mines
Reprinted from Fire Technology, Volume 17, No 2, May 1981
Cited 5 June 2017

11. Yardley ED, Williams M, Wymark S and Stace LR (2004)
Development of a small-scale fire propagation test for conveyor Belts.
Mining Technology (Trans. Inst. Min. Metall. A) March 2004 Vol. 113 A73. Cited 11 June 2017

12. Perzak FJ, Sapko MJ and Spencer ER (1982)
Testing of fire-resistant conveyor belting
Pittsburg Research Centre
Bureau of Mines
Pittsburg, PA
Cited 4 June 2017

13. Luzik SJ (2007?)
Past, present and future fire-retardant / resistant requirements for material used in underground coal mines
United States Department of Labor
Mine Safety and Health Administration (MSHA)
Pittsburgh, Pennsylvania
Cited 10 June 2017

14. Rowland JH and Smith AC (2012?)
Flammability of wider conveyor belts using large-scale fire tests
National Institute for Occupational Safety and Health (NIOSH)
Pittsburg, PA. Cited 28 June 2017

15. BS EN 12881-1 Method C - Mid-Scale Fire Propagation Test. Cited 2016

16. The South African Labour Guide

https://www.labourguide.co.za/health-and-safety/1512-different-types-of-risk-assessments. Cited 4 January 2019

17. OHS Answers Factsheets,
https://www.ccohs.ca/oshanswers/hsprograms/risk_assessment.html.
Cited 27 January 2019

18. Wales M, 15 April 2016, Sasol Mining Risk Management Process. Cited

19. Department of Mineral Resources, Guideline for the compilation of a mandatory code of practice for ‘Prevention of fires in mines’, DMR 16/3/2/4-B3, 28 February 2017. Cited 6 June 2017

20. Labuschagne I, Sasol Mining Summary of Fires Q2 2018. Mine fires summarized from Q3 2013 to Q2 2018, 2018. Cited 7 June 2018

21. Labuschagne I, Sasol Mining: Fire preparedness. Improvement of fire detecting systems, 4 May 2018. Cited 7 June 2018

22. A Summary of US Mine Fire Research - CDC https://www.cdc.gov/niosh/mining/userfiles/works/pdfs/asous.pdf. Cited 29 January 2019

23. Jacey Kruger, Impala Rustenburg, 14 shaft Fire, 22/01/2016. http://www.sacea.org.za/docs/14%20Shaft%20Conveyor%20Fire%2022%20Jan%202016%20AMRE.pdf. Cited 27 January 2019

24. DMR, Occupational Health and Safety Report, July 2017. http://www.dmr.gov.za/Portals/0/MHSI%20Library/Mine%20Accidents%20and%20Disasters/OHS%20Monthly%20Report%202017-07.pdf?ver=2018-03-15-105126-570. Cited 27 January 2019

25. Death toll in Phalaborwa mine fire rises to six - TimesLIVE

https://www.timeslive.co.za/.../2018-07-16-death-toll-in-phalaborwa-mine-fire-rises-to... Cited 4 January 2019

26. Mine Health and Safety Act 29 of 1996, Published under Government Notice R93 in Government Gazette 17725 of 15 January 1997. Cited 24 August 2016

27. SANS 971, Conveyor belting — Methods of testing fire retardant properties of all conveyor belt. Cited 2016

28. SANS 968, Conveyor belting - Textile reinforced solid woven carcass construction Cited 2016

29. SANS1173, Conveyor belting - General purpose textile-reinforced construction. Cited 2016

30. SANS 1366, Conveyor belting - Steel cord reinforced construction. Cited 2016

31. Miles AJ (2016)
Report: Experimental Research and Development – Laboratory Testing
South African Bureau of Standards, Pretoria, South Africa.
Cited 19 April 2018

32. Labuschagne I, Sasol Mining: Prevention of fires on conveyors including inclines and trippers, 5 October 2018

33. Café T, Physical constants for investigators, TC Forensic (Pty) Ltd, http://www.tcforensic.com.au/docs/article10.html, 17 June 2007. Cited 27 January 2019

34. Braskem, High density polyethylene(HDPE), Safety Data Sheet, according to: Federal Register/ Volume 77, No 58,March 26, 2012 / Rules and Regulations, 8 March 2017, Rev 1
http:/www.braskem.co.br/. Cited 9 January 2019

35. Opalene, High density polyethylene(HDPE), Material Safety Data Sheet, 1 March 2016, www.opalindia.in. Cited 7 January 2019

36. Ertalon 66-GF30, Glass Filled Nylon Safety Data Sheet, Product Handling Information Sheet, 15 February 2010, Version 1, www.theplasticshop.co.uk. Cited 14 January 2019

8 BIBLIOGRAPHY

1. Leedy PD and Ormrod JE (2015)
   Practical Research, Planning and Design, 11th edition
   Essex, England
   Pearson Education Limited

2. Montgomery DC (2012)
   Design and analysis of experiments, 8th edition
   Arizona, United States of America
   John Wiley and Sons, Inc.

ANNEXURE A

Table A1: Fire resistant standards used globally

Country	Specification
Australia	AS4606, AS1332
Canada	CSA M422-M87
China	MT 914
Europe	EN 12881, EN 14973
India	IS 3181
South Africa	SANS 971, EN 12881-1(adopted)
USA	MSHA

Table A2: Compliance tests required for flame resistant belt globally

Country	Ignition	Friction	Propagation	Electrical
Australia	✓	✓	✓	✓
Canada	✓	✓	✓	✓
China	✓	✓	✓	✓
Europe	✓	✓	✓	✓
India	✓	✓	✓	✓
South Africa	✓	✓	From 2013	✓
USA	✓	✓	✓	✓

ANNEXURE B

Anova execution

An experimental full factorial experiment was done to enable the writer to determine results by manipulating independent variables to determine the effect on dependent variables.

The experimental design was used to determine whether it would fit an analysis of variance statistical model. Once this has been resolved, the design matrix according to the ANOVA was drawn up.

Factorial ANOVA was used as the experiment would test the influence of two (or more) factors on an outcome and differences between more than two groups were investigated.

The null hypothesis and the alternative hypothesis were determined to be able to reach results when testing and analysis were done.

The decision regarding the probability was made to determine the cut off point for the null and alternative hypothesis. Decision made $\alpha \leq 0.05$.

The experimental testing were done and data collected. The data was then read into the ANOVA design done. The results were calculated by using the program based on the data read in.

This information was then used to interpret results for reporting purposes.

The results is shown below for the calculations done. The first column describe the model used and the terms computed. The second column displays the sum of squares calculated from the data. The third column give the degrees of freedom with regards to the model used and the data analysed. The mean squares is then indicated in the next column which equals the sum of squares divided by the degrees of freedom. The F value is indicated in the second last column which equals the mean square for that source divided by the mean square of the error. The probability is then calculated for all individual and combinations of factors and displayed in the last column.

Should the p-value > 0.05, the null hypothesis would be accepted that all single and combinations of factors do not contribute to higher flame propagation of flame retardant belt. With a p-value ≤ 0.05 all factors and combination of factors contribute significantly to the flame propagation of fire retardant belt. Please refer to Table D1 to D3 in Annexure D for actual results from ANOVAS done for this experiment.

ANNEXURE C

Table C1: Test Results arranged by belt thickness and orientation

Test results with no covers, i.e. a fully worn belt.

Sample ID	Specimen ID	Cover and Orientation	Gas Target (g)	Air Velocity (m/s)	Temp rise above Ambient (°C)	Length Consumed by mass (mm)	Length Undamaged (mm)
2	1	T0 B0	600	1.6	85.3	360.3	1000
	2	T0 B0	600	1.6	61.5	287.5	1060
	3	T0 B0	600	1.6	60	301.9	1040
3	1	T0 B0	545	0.6	60.5	233.3	1110
	2	T0 B0	545	0.6	63.7	258.4	1135
	3	T0 B0	545	0.6	61.1	254.8	1105
5	1	T0 B0	600	0.6	64.7	260.1	1140
	2	T0 B0	600	0.6	67.9	267.2	1160
	3	T0 B0	600	0.6	65.5	273.7	1100
6	1	T0 B0	545	1.6	47.1	303.9	1000
	2	T0 B0	545	1.6	52.2	331.8	950
	3	T0 B0	545	1.6	44.4	250.9	1010
9	1	T0 B0	575	0.6	63.9	246.1	1130
	2	T0 B0	575	0.6	62.2	258.7	1170
	3	T0 B0	575	0.6	58	250.2	1120

Test results with 50% covers, i.e. a 50% worn belt.

Sample ID	Specimen ID	Cover and Orientation	Gas Target (g)	Air Velocity (m/s)	Temp rise above Ambient (°C)	Length Consumed by mass (mm)	Length Undamaged (mm)
1	1	T1 B2	575	1.2	97.9	367.0	970
	2	T2 B1	575	1.2	75	280.5	1070
	3	T1 B2	575	1.2	90.8	399.3	970
12	1	T2 B1	600	0.75	72.9	236.4	1010
	2	T1 B2	600	0.75	89.6	375.5	965
	3	T1 B2	600	0.75	78.7	279.2	980
13	1	T1 B2	600	0.6	79.1	336.5	990
	2	T2 B1	600	0.6	66.3	246.5	1085

	3	T1 B2	600	0.6	78	349.1	980
14	1	T1 B2	575	1.6	78.5	464.5	915
	2	T2 B1	575	1.6	48.3	277.8	1015
	3	T1 B2	575	1.6	77.7	460.8	910

Test results with full covers, i.e. a new belt.

Sample ID	Specimen ID	Cover and Orientation	Gas Target (g)	Air Velocity (m/s)	Temp rise above Ambient (°C)	Length Consumed by mass (mm)	Length Undamaged (mm)
4	1	T2 B4	600	1.6	94	492.8	625
	2	T4 B2	600	1.6	56	271.7	1010
	3	T2 B4	600	1.6	85.8	585.8	825
7	1	T2 B4	600	0.6	74.8	320.2	950
	2	T4 B2	600	0.6	71.7	248.9	1020
	3	T2 B4	600	0.6	74.8	299.0	945
8	1	T2 B4	575	1.6	99.9	492.0	880
	2	T4 B2	575	1.6	50.1	273.0	980
	3	T2 B4	575	1.6	74.2	408.6	900
10	1	T2 B4	545	0.6	66.5	275.8	990
	2	T4 B2	545	0.6	64.1	259.7	1010
	3	T2 B4	545	0.6	71.5	271.7	965
11	1	T2 B4	545	1.6	60.4	336.6	945
	2	T4 B2	545	1.6	46.8	261.7	975
	3	T2 B4	545	1.6	68.2	419.6	920
15	1	T2 B4	575	0.6	70	302.4	1080
	2	T4 B2	575	0.6	65.6	269.6	1120
	3	T2 B4	575	0.6	68.1	299.5	1050
16	1	T2 B4	565	1	68.3	265.9	960
	2	T4 B2	565	1	66.2	269.9	1020
	3	T2 B4	565	1	72.4	275.2	985

ANNEXURE D

Table D1: ANOVA Results for Temperature Rise above Ambient

ANOVA for Response Surface 2FI model Temperature Rise above Ambient					
Analysis of variance table [Classical sum of squares - Type II]					
	Sum of		**Mean**	**F**	**p-value**
Source	**Squares**	**df**	**Square**	**Value**	**Prob > F**
Model	6568.97	15	437.93	10.16	< 0.0001
A-Gas Consumed	*840.19*	*1*	*840.19*	*19.49*	*0.0001*
B-Air Velocity	*74.76*	*1*	*74.76*	*1.73*	*0.1972*
C-Cover	*3503.66*	*4*	*875.92*	*20.32*	*< 0.0001*
AB	*397.02*	*1*	*397.02*	*9.21*	*0.0048*
AC	*493.67*	*4*	*123.42*	*2.86*	*0.0391*
BC	*980.09*	*4*	*245.02*	*5.68*	*0.0014*
Residual	1379.45	32	43.11		
Lack of Fit	*1379.13*	*31*	*44.49*	*139.02*	*0.067*
Pure Error	*0.32*	*1*	*0.32*		

Correlation Total	7948.42	47			
Std. Dev.	6.57		R-Squared	0.83	
Mean	69.17		Adjusted R-Squared	0.75	
C.V. %	9.49		Pred R-Squared	0.087	

Table D2: ANOVA Results for Length Consumed by Mass

Response	**2**	**Length Consumed by Mass (mm)**			
ANOVA for Response Surface 2FI model					
Analysis of variance table [Classical sum of squares - Type II]					
	Sum of		**Mean**	**F**	**p-value**
Source	**Squares**	**df**	**Square**	**Value**	**Prob > F**
Model	2.56E+05	15	17083.91	13.73	< 0.0001
A-Gas Consumed	*11722.71*	*1*	*11722.71*	*9.42*	*0.0043*
B-Air Velocity	*59387.54*	*1*	*59387.54*	*47.74*	*< 0.0001*
C-Cover	*1.05E+05*	*4*	*26330.44*	*21.17*	*< 0.0001*
AB	*2963.32*	*1*	*2963.32*	*2.38*	*0.1326*
AC	*13805.44*	*4*	*3451.36*	*2.77*	*0.0437*
BC	*29655.72*	*4*	*7413.93*	*5.96*	*0.0011*
Residual	39805.63	32	1243.93		
Lack of Fit	*39798.95*	*31*	*1283.84*	*192.31*	*0.057*

Pure Error	*6.68*	*1*	*6.68*		
Cor Total	2.96E+05	47			
Std. Dev.	35.27		R-Squared	0.87	
Mean	314.83		Adjusted R-Squared	0.80	
C.V. %	11.2		Pred R-Squared	0.68	

Table D3: ANOVA Results for Length Undamaged

Response	3	Length Undamaged (mm)			
ANOVA for Response Surface Reduced Quadratic model					
Analysis of variance table [Classical sum of squares - Type II]					
	Sum of		Mean	F	p-value
Source	Squares	df	Square	Value	Prob > F
Model	371571.64	16	23223.23	11.52	6.68E-09
A-Gas Consumed	2019.88	1	2019.88	1.00	0.32
B-Air Velocity	98142.49	1	98142.49	48.68	7.89E-08
C-Cover	187468.40	4	46867.10	23.25	5.89332E-09
AB	1660.67	1	1660.67	0.82	0.37
AC	30895.58	4	7723.90	3.83	0.012
BC	8075.42	4	2018.85	1.00	0.42

A^2	15221.81	1	15221.81	7.55	0.0099
Residual	62502.84	31	2016.22		
Lack of Fit	62490.33804	30	2083.011268	166.6409014	0.061232526
Pure Error	12.5	1	12.5		
Cor Total	434074.48	47			
Std. Dev.	44.90		R-Squared	0.86	
Mean	1005.10		Adjusted R-Squared	0.78	
C.V. %	4.47		Pred R-Squared	0.30	

ANNEXURE E

Please refer to Figure E1 below where findings for individual factors and combined factors for T0B0 covers are displayed for information only.

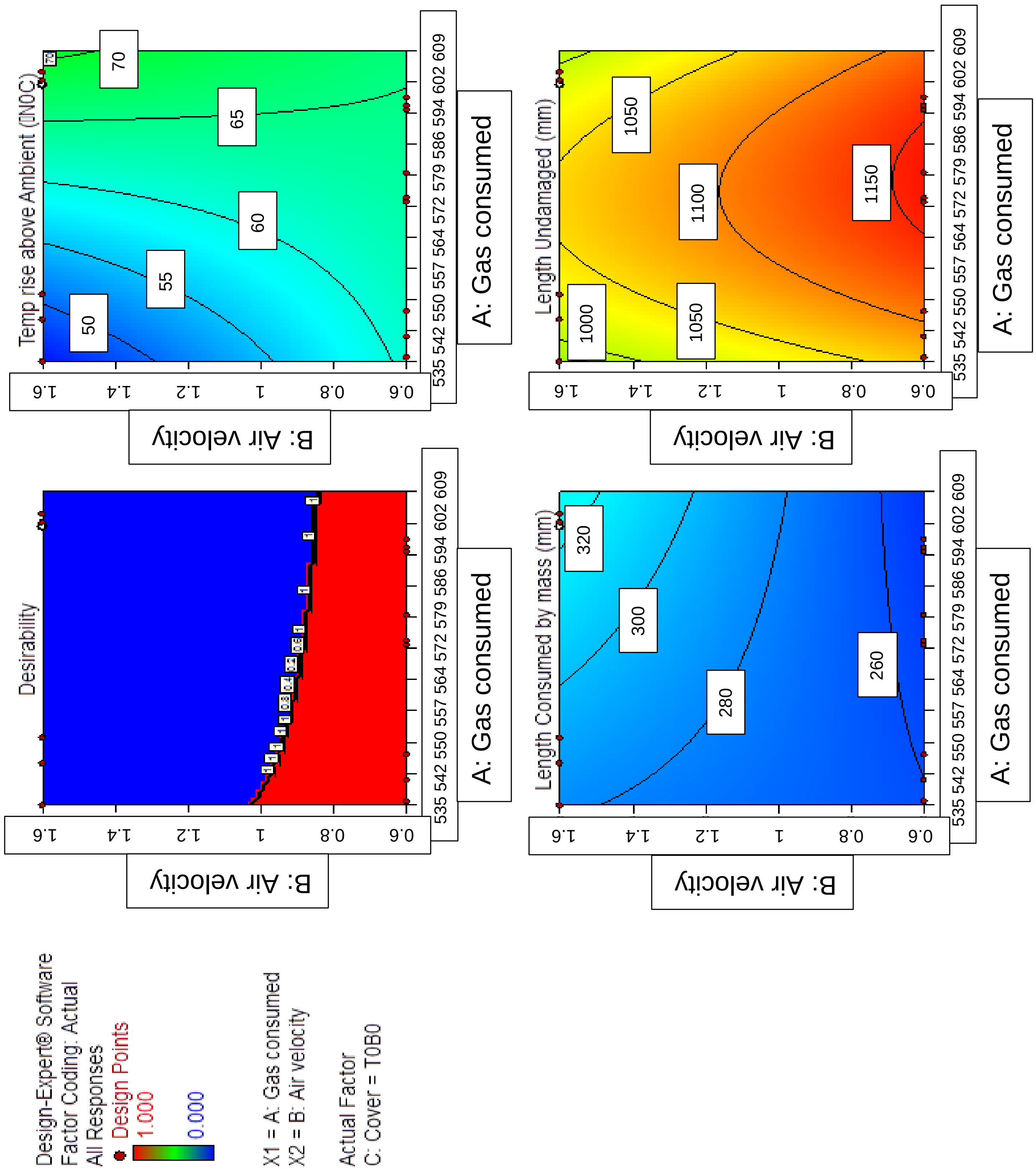


Figure E1: Findings exceeding control sample results for T0B0 covers

Please refer to Figure E2 below where findings for individual factors and combined factors for T2B1 covers are displayed for information only.

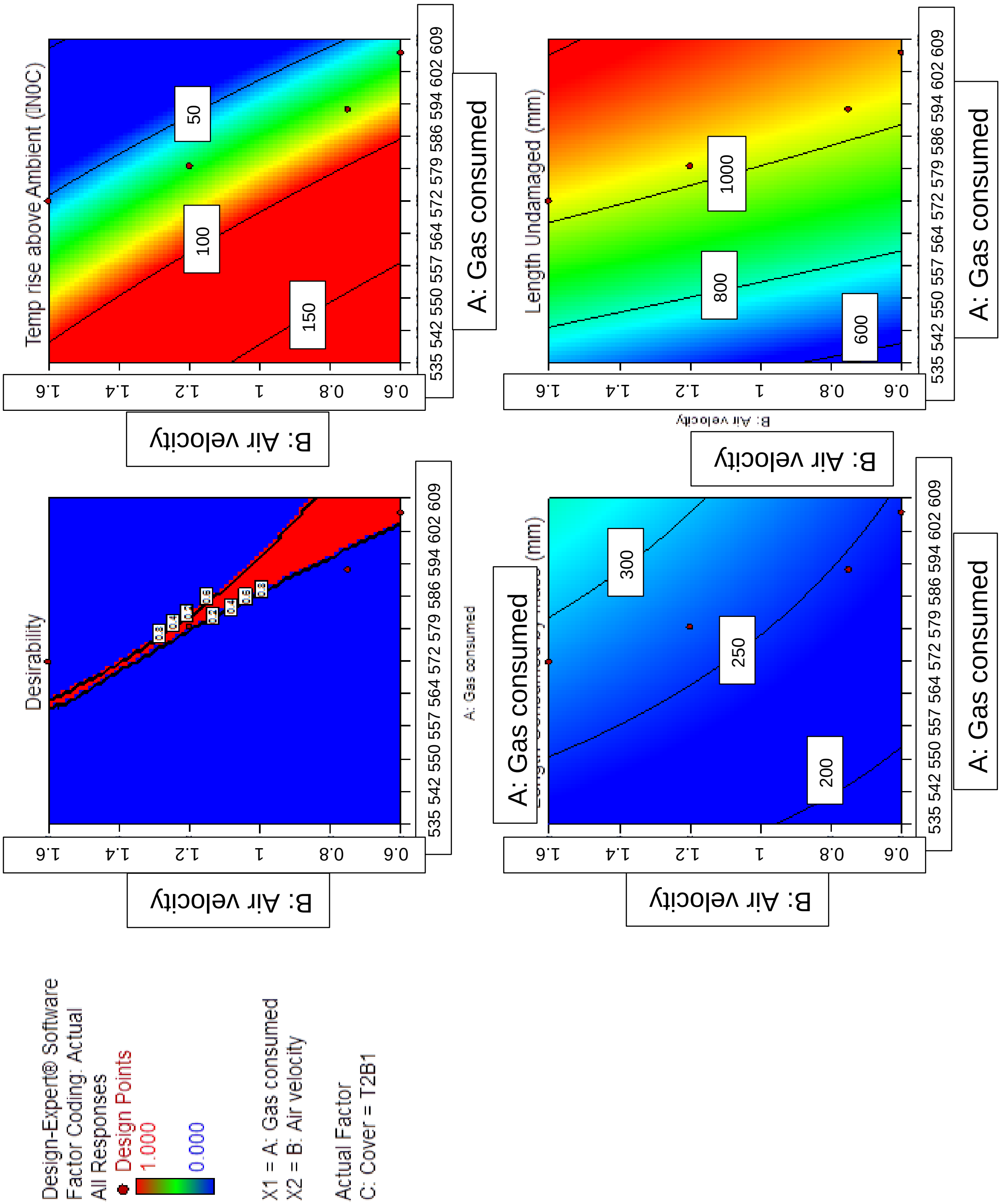


Figure E2: Findings exceeding control sample results for T2B1 covers

Please refer to Figure E3 below where findings for individual factors and combined factors for T1B2 covers are displayed for information only.

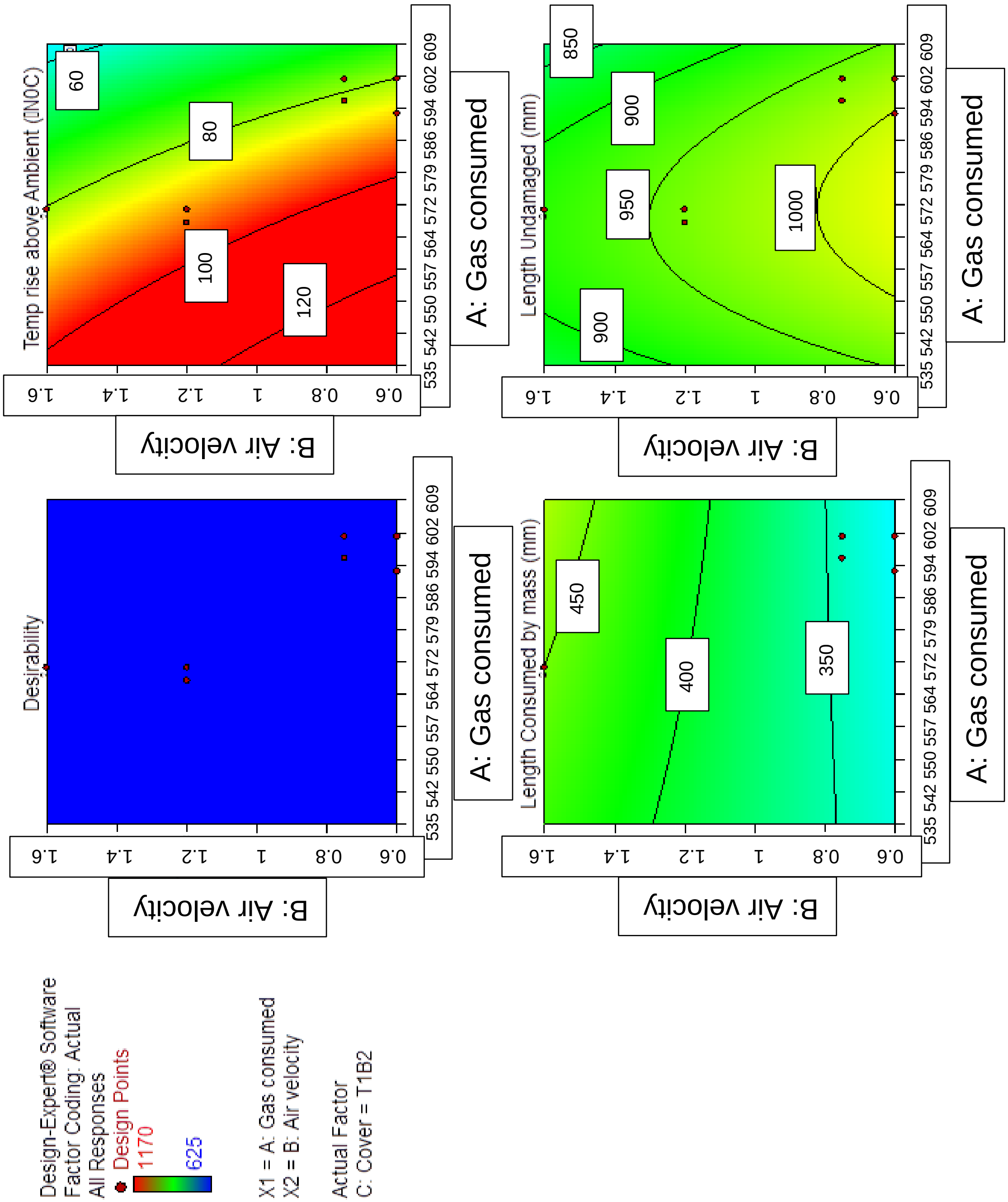


Figure E3: Findings exceeding control sample results for T1B2 covers

Please refer to Figure E4 below where findings for individual factors and combined factors for T4B2 covers are displayed for information only.

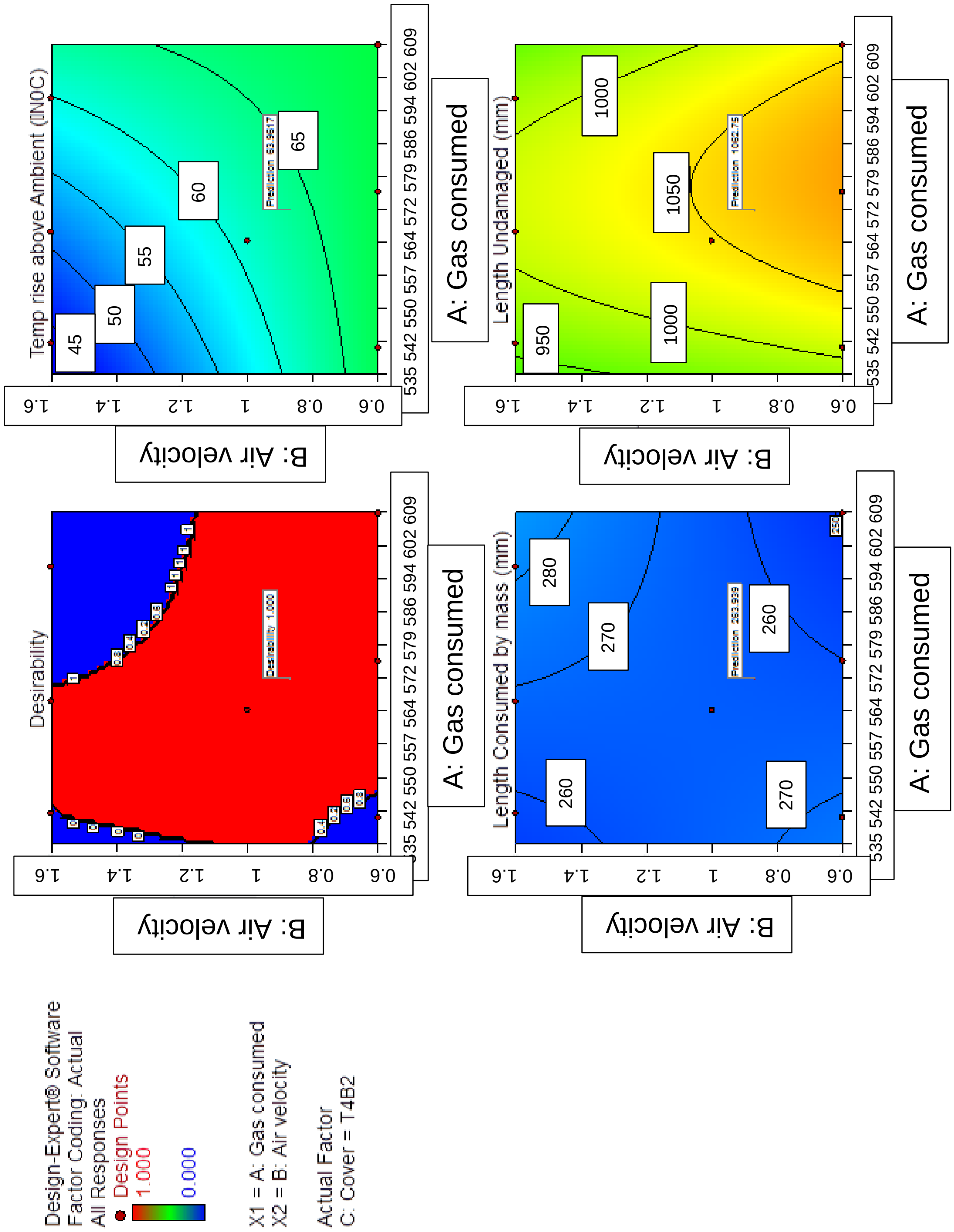


Figure E4: Findings exceeding control sample results for T4B2 covers

Please refer to Figure E5 below where findings for individual factors and combined factors for T2B4 covers are displayed for information only.

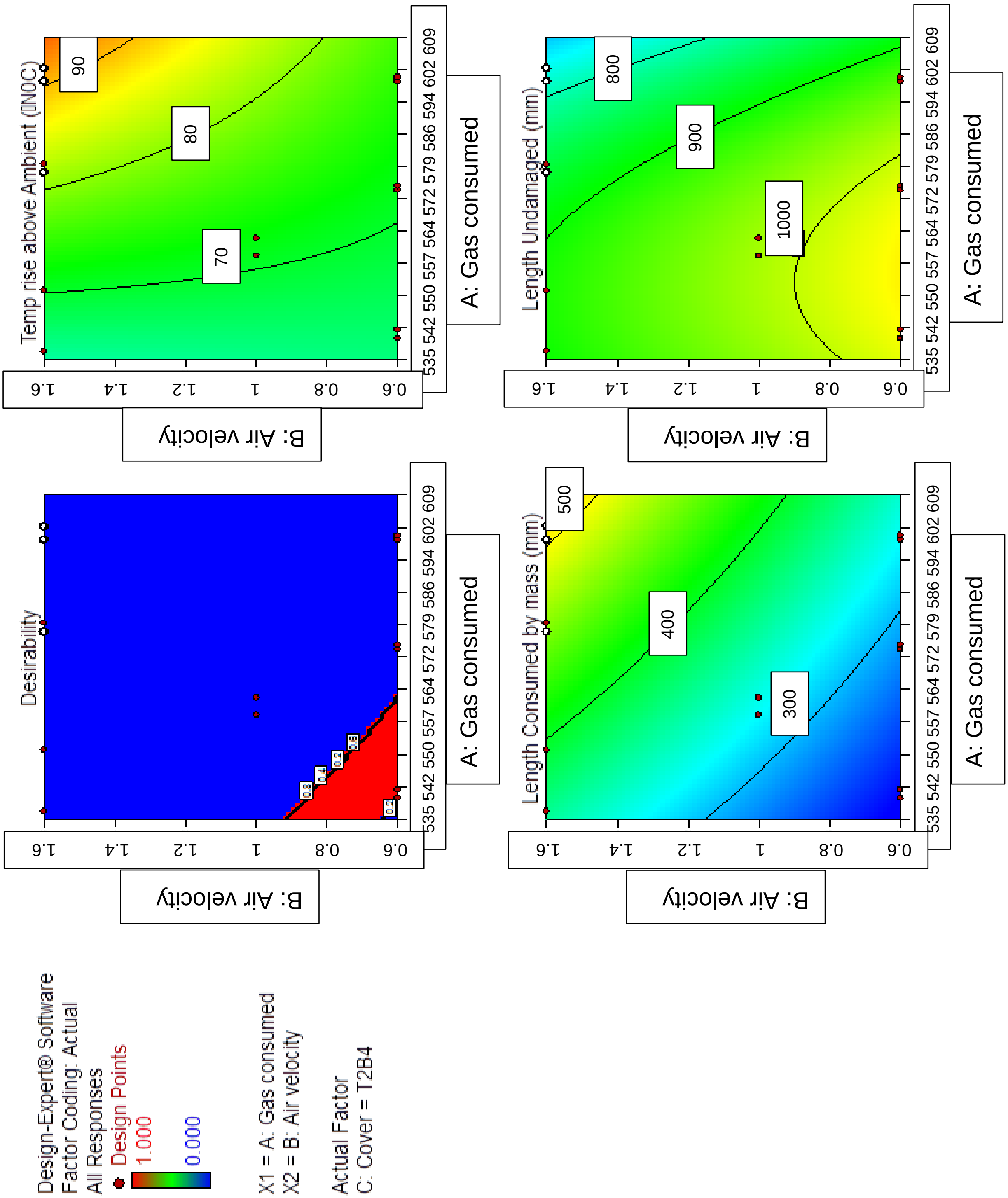


Figure E5: Findings exceeding control sample results for T2B4 covers

ANNEXURE F

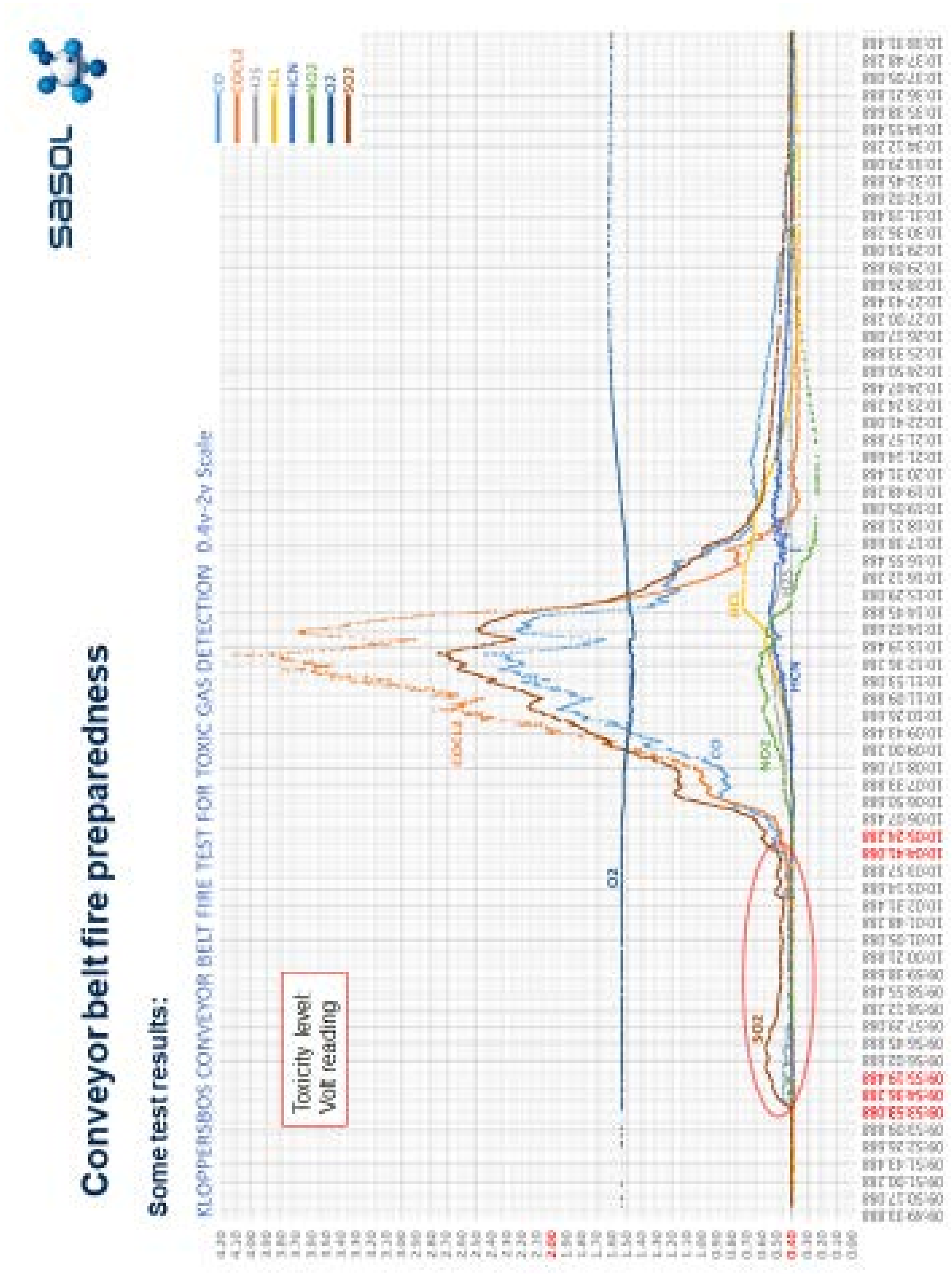


Figure F1: Belt fire test for toxic gas detection

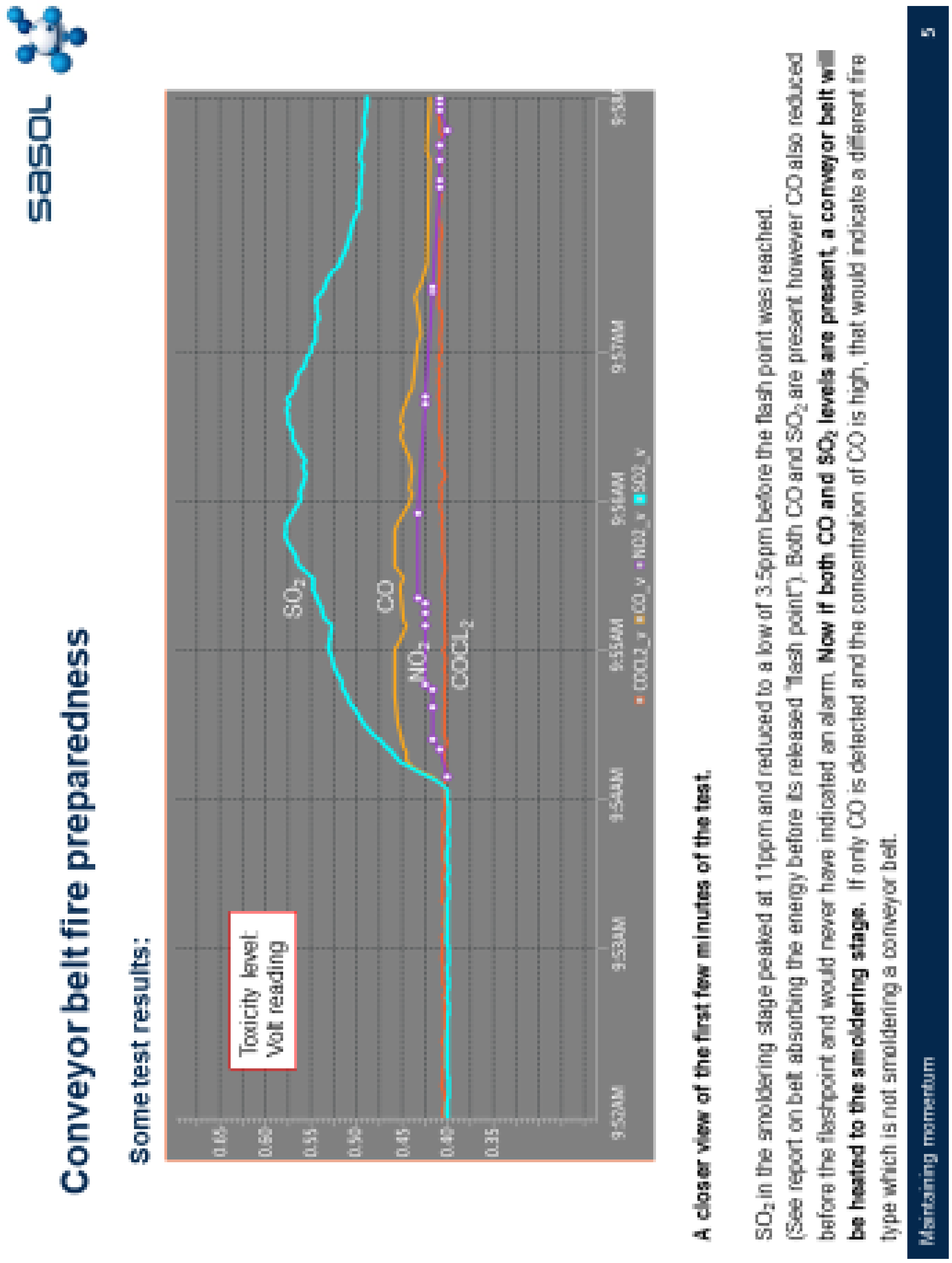


Figure F2: Belt fire test for toxic gas detection zoomed

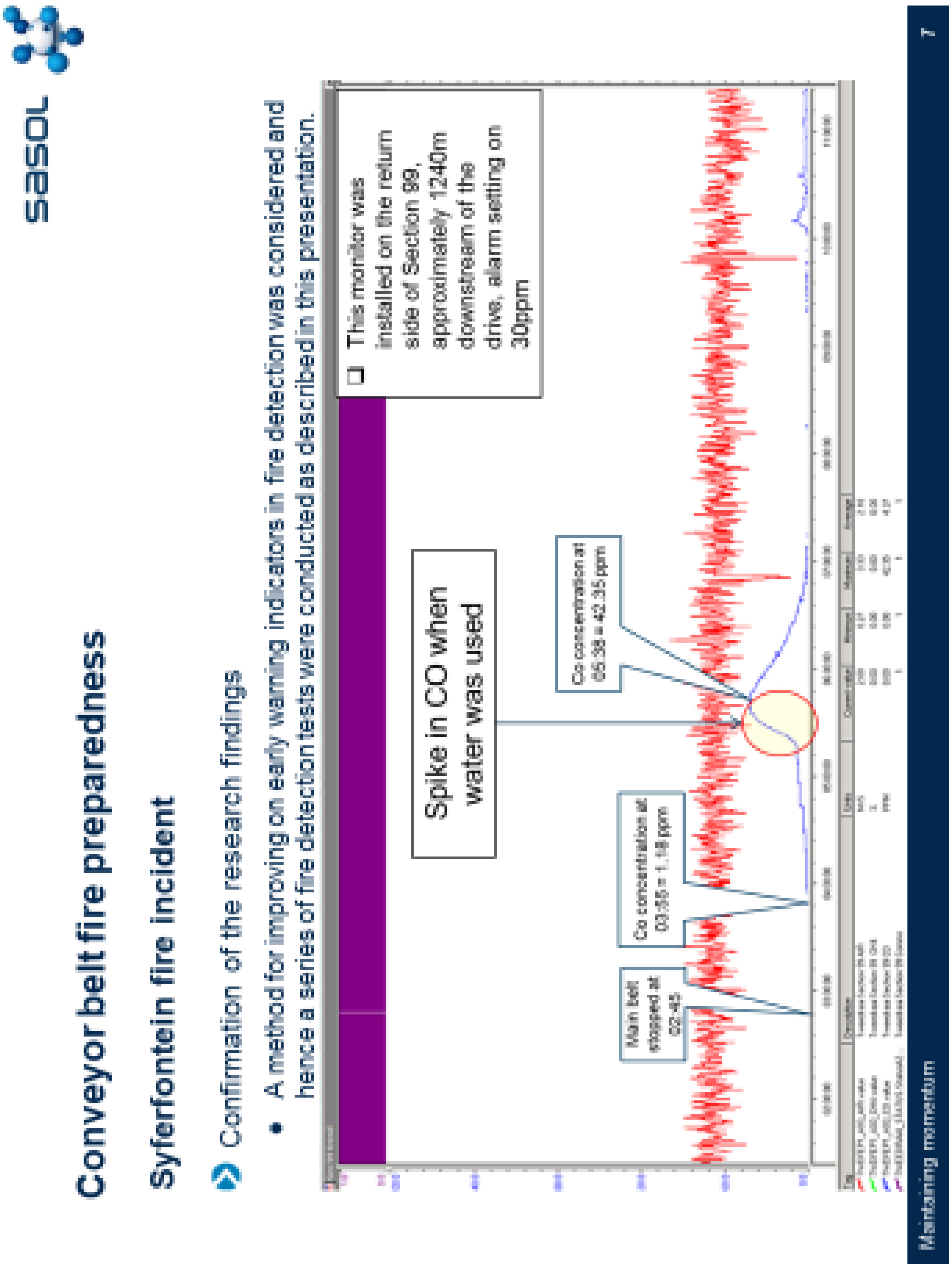


Figure F3: Belt fire test for toxic gas detection proof

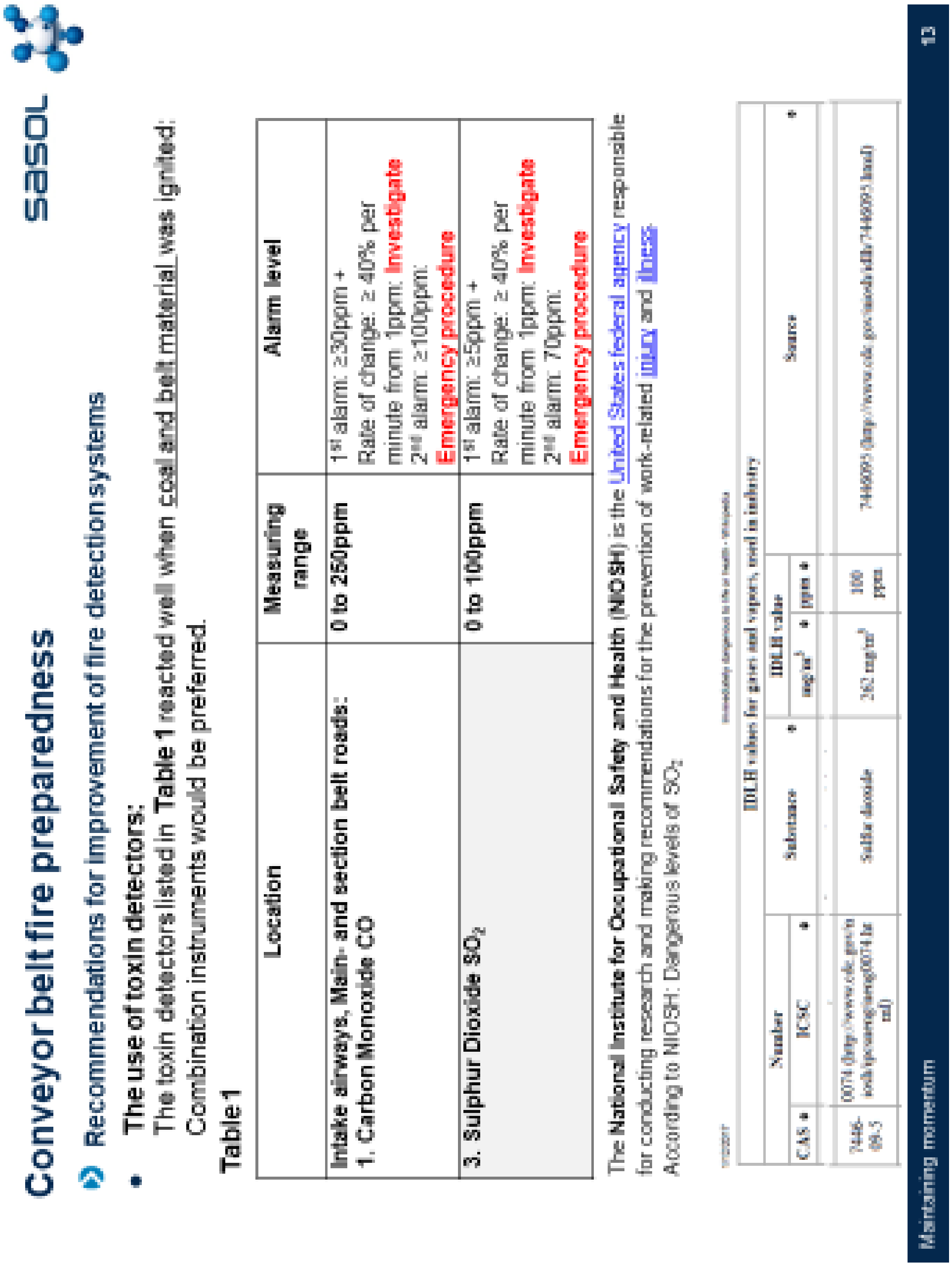


Figure F4: Belt fire test for toxic gas detection recommendations

ANNEXURE G

The following formulae has been used in the calculation for Heat input (Propane) and Heat of combustion (Temperature) difference:

1. Heat input = Gas consumed x Heat of combustion of Propane
   Heat of combustion of Propane taken as 50.33kJ/g
2. Heat of combustion (Temperature) = ρCpvAT

Where:

ρ= density of air taken as 1,205kg/m^3

Cp (air) taken as 1,012kJ/kg°C

V = velocity of air flow (m/s)

A = Area of tunnel (m^2)

T = Temperature rise above ambient (°C)

Table G1: Table of findings with power calculations included

Sample ID	Specimen ID	Cover and Orientation	Gas Target (g)	Air Velocity (m/s)	Temp rise above Ambient (°C)	Length Consumed by mass (mm)	Length Undamaged (mm)	Heat input (kW)	Heat of combustion (kW)
1	1	T1 B2	575	1.2	97.9	366.96	970	9.65	29.01
	2	T2 B1	575	1.2	75	280.49	1070	9.65	22.22
	3	T1 B2	575	1.2	90.8	399.31	970	9.65	26.91
2	1	T0 B0	600	1.6	85.3	360.31	1000	10.07	33.70
	2	T0 B0	600	1.6	61.5	287.54	1060	10.07	24.30
	3	T0 B0	600	1.6	60	301.87	1040	10.07	23.71
3	1	T0 B0	545	0.6	60.5	233.35	1110	9.14	8.96
	2	T0 B0	545	0.6	63.7	258.39	1135	9.14	9.44
	3	T0 B0	545	0.6	61.1	254.84	1105	9.14	9.05
4	1	T2 B4	600	1.6	94	492.76	625	10.07	37.14
	2	T4 B2	600	1.6	56	271.65	1010	10.07	22.13
	3	T2 B4	600	1.6	85.8	585.83	825	10.07	33.90
5	1	T0 B0	600	0.6	64.7	260.06	1140	10.07	9.59
	2	T0 B0	600	0.6	67.9	267.20	1160	10.07	10.06
	3	T0 B0	600	0.6	65.5	273.73	1100	10.07	9.70
6	1	T0 B0	545	1.6	47.1	303.90	1000	9.14	18.61
	2	T0 B0	545	1.6	52.2	331.83	950	9.14	20.62
	3	T0 B0	545	1.6	44.4	250.93	1010	9.14	17.54
7	1	T2 B4	600	0.6	74.8	320.24	950	10.07	11.08
	2	T4 B2	600	0.6	71.7	248.93	1020	10.07	10.62
	3	T2 B4	600	0.6	74.8	299.03	945	10.07	11.08
8	1	T2 B4	575	1.6	99.9	492.04	880	9.65	39.47
	2	T4 B2	575	1.6	50.1	272.96	980	9.65	19.79
	3	T2 B4	575	1.6	74.2	408.56	900	9.65	29.32
9	1	T0 B0	575	0.6	63.9	246.11	1130	9.65	9.47
	2	T0 B0	575	0.6	62.2	258.74	1170	9.65	9.22
	3	T0 B0	575	0.6	58	250.24	1120	9.65	8.59
10	1	T2 B4	545	0.6	66.5	275.80	990	9.14	9.85
	2	T4 B2	545	0.6	64.1	259.70	1010	9.14	9.50
	3	T2 B4	545	0.6	71.5	271.75	965	9.14	10.59
11	1	T2 B4	545	1.6	60.4	336.62	945	9.14	23.86
	2	T4 B2	545	1.6	46.8	261.68	975	9.14	18.49
	3	T2 B4	545	1.6	68.2	419.65	920	9.14	26.95
12	1	T2 B1	600	0.75	72.9	236.42	1010	10.07	13.50
	2	T1 B2	600	0.75	89.6	375.50	965	10.07	16.59
	3	T1 B2	600	0.75	78.7	279.23	980	10.07	14.58
13	1	T1 B2	600	0.6	79.1	336.46	990	10.07	11.72
	2	T2 B1	600	0.6	66.3	246.55	1085	10.07	9.82
	3	T1 B2	600	0.6	78	349.11	980	10.07	11.56
14	1	T1 B2	575	1.6	78.5	464.46	915	9.65	31.02
	2	T2 B1	575	1.6	48.3	277.77	1015	9.65	19.08
	3	T1 B2	575	1.6	77.7	460.81	910	9.65	30.70
15	1	T2 B4	575	0.6	70	302.41	1080	9.65	10.37
	2	T4 B2	575	0.6	65.6	269.60	1120	9.65	9.72
	3	T2 B4	575	0.6	68.1	299.52	1050	9.65	10.09
16	1	T2 B4	565	1	68.3	265.88	960	9.48	16.87
	2	T4 B2	565	1	66.2	269.85	1020	9.48	16.35
	3	T2 B4	565	1	72.4	275.18	985	9.48	17.88

ANNEXURE H

Summarized procedure followed to test belt flame retardancy as per BS EN 12881-1 Method C.

Preparation:

Three samples were cut from belt of 1500 mm long and 230 mm wide in the longitudinal direction of the belt not within 50 mm from the edge of the original belt. The sample covers were skived to the required thickness on the samples selected. Each sample was marked with a white permanent marker as per test matrix displayed in Table 1. Securing holes (six) were drilled and the samples weighted after cutting. The samples were lied flat for at least 24 hours before testing. The test piece selected for testing was weighted and the weight recorded. To test each sample it was secured with 25 gauge wire to the trestle through the holes and around the sample at 100mm and 200mm from the front of the sample.

Testing:

The trestle with sample were placed in the chamber centrally with the front of the test piece 160 mm inside the chamber from the front of the chamber. The burners were placed underneath the test piece centrally so that the front jets were in line with the front of the test piece. The ambient temperature was measured as it must be between 5 °C and 30 °C to conduct the test as per the standard.

The propane bottle was weighted before the test. The air velocity was measured to be 1 m/s (or as per test matrix). The temperature of the exhaust air was measured between 2 minutes and 5 minutes and recorded to determine ambient temperature and recorded. The gas flow was set to 350 l/h and the burners ignited. The gas flow was adjusted right after ignition to 345 l/h for standard test (and as per matrix for experimental tests). The burners were turned off after 50 minutes and the equipment allowed to cool down. The gas bottle was weighted to determine whether the gas consumed was 565 g. When found outside the tolerance of 10 g higher or lower, the gas flow was adjusted and the test redone on another test piece.

The trestle and test piece were removed from the chamber after which the test piece was removed from the trestle. The length from the rear of the sample to determine the length undamaged. Temperature was measured continuously and recorded as stipulated. The maximum average temperature rise over one minute was recorded as per standard. The loose debris was shaken of the test piece and the test piece was weighted. The calculation was done to determine the length consumed by mass.

Length consumed by mass (mm) = ((mass before – mass after) / mass before) x 1500

Three tests were done per sample as required for covers with different thicknesses as per specification. First test piece with the thick cover facing away from the burners, then with the thick cover facing the burner with the second test piece. The worst results achieved determine the orientation of the cover for the third test piece that will be tested according to that orientation.

No emergency procedures had to be followed as none of the samples burned such that it was classified as an emergency. All tests were concluded following the standard. When found that the test results were out of bounds or anything happened during the test, the test was abandoned and a new test done with another test piece.