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11–15 AUGUST 2024

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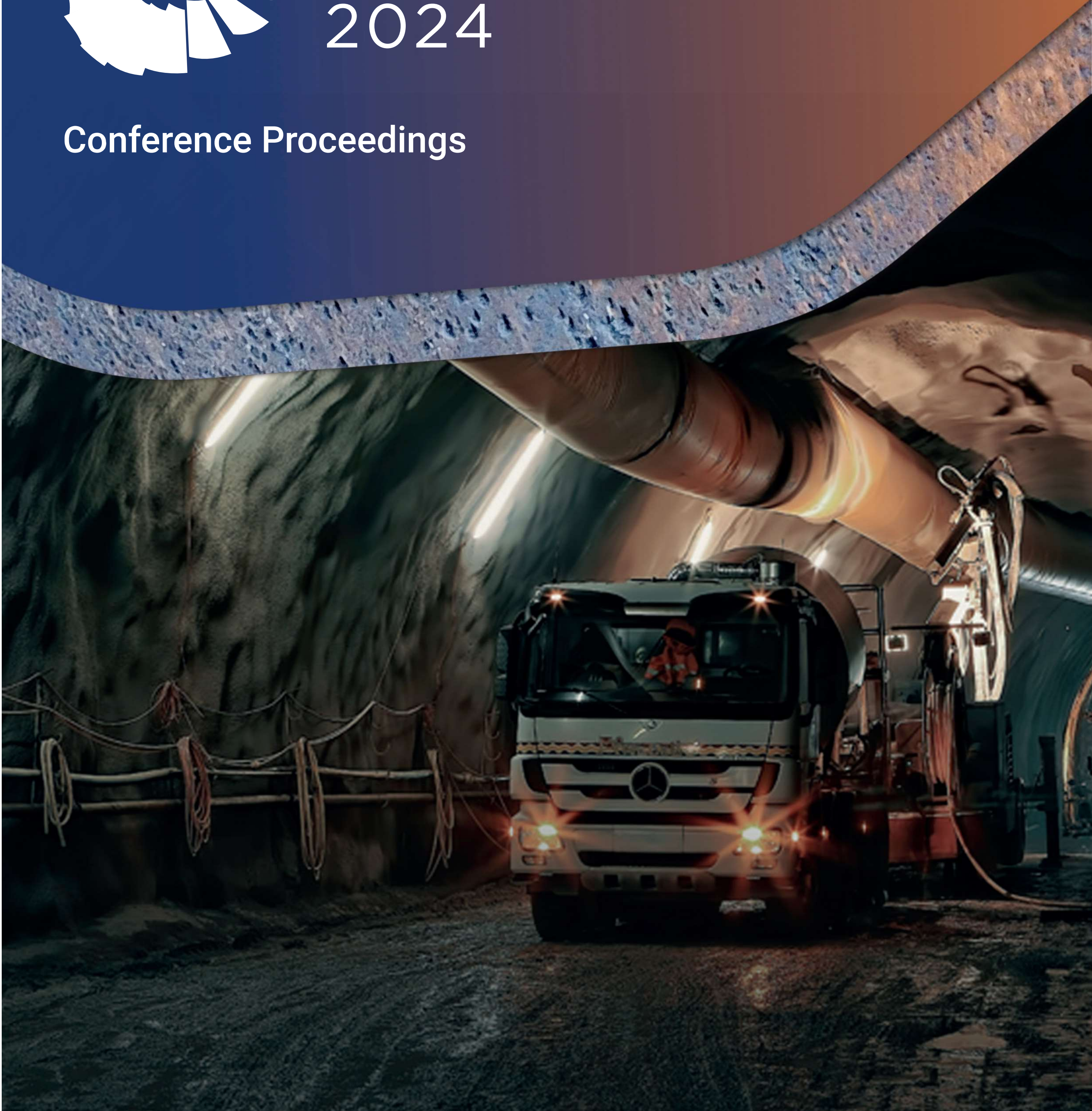
Conference Proceedings



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History of the International Mine Ventilation Congress (IMVC) Series

1975 Johannesburg, South Africa

1979 Reno, USA

1984 Harrogate, UK

1988 Brisbane, Australia

1992 Johannesburg, South Africa

1997 Pittsburgh, USA

2001 Cracow, Poland

2005 Brisbane, Australia

2009 New Delhi, India

2014 Sun City, South Africa

2018 Xi'an, China

2024 Sydney, Australia (delayed due to COVID)

WELCOME FROM PREVIOUS HOST – XI'AN UNIVERSITY OF SCIENCE AND TECHNOLOGY

We are honoured to be invited to deliver this greeting at the 12th International Mine Ventilation Congress (IMVC) in Sydney, Australia. The 1st IMVC was initiated by the industry and academic organisations of the world's major mining countries in 1975. It is held every four years and is the international academic conference with the longest history and with the highest academic influence in the field mining. It has been an important platform for the exchange of new technologies, concepts, products and all innovative achievements of ventilation, safety and occupational health in the mining industries.

The 11th IMVC was held for the first time in Xi'an, China, the world's largest coal mining country, from September 14 to 20, 2018. More than 500 delegates in the field of mining from over 39 countries and regions attended the congress, focusing on the theme of mine ventilation technology and management under economic, environmental, health and safety challenges. The participating experts shared their knowledge and scientific research progress in ventilation, mine environment, health and safety, energy efficiency and management in recent years, and jointly published excellent articles combined with Springer. It has made great contributions to the scientific and technological progress of the world's energy and resources.

As the host of the 11th IMVC, we were very honoured to take over the baton from Mr Frank von Glehn, Chairman of the 10th Executive Committee, and to now transfer the hosting right of the 12th Congress to the University of New South Wales (UNSW), the Mine Ventilation Association of Australia, and the Australasian Institute of Mining and Metallurgy (the AusIMM). Recognised as the best engineering University in Australia, UNSW's Mining Engineering programmers possess a high reputation in the mining industry. The Mine Ventilation Association of Australia and the Australasian Institute of Mining and Metallurgy have been committed to providing a world-class technical exchange platform for the global mining and mine ventilation fields, showcasing the latest technologies, innovations and industry best practices, and actively promoting the development of mine ventilation technology.

Due to the global pandemic, the 12th IMVC was postponed to August 2024, and we would like to express our heartfelt thanks to the ventilation engineers and experts in the field of mine safety from all over the world, the organisers of the conference for providing a rare and broad communication platform for mine ventilation safety experts and practitioners from all over the world, and the members of the conference team for their efforts for the smooth convening of this conference, and wish experts and scholars from all over the world the opportunity to exchange and learn during the congress. We wish the 12th IMVC2024 to be a smooth and successful event.

Jun Deng and Shugang Li

President of Xi'an University of Science and Technology

FOREWORD AND EDITORIAL

VENTILATION ENGINEERING – THE HEARTBEAT OF MINING

Worldwide, mining engineering has taken significant strides since the beginning of the last century. Considering the resource boom and the maximum number of mines opening and expanding in recent years, the theme of this Congress 'Ventilation Engineering – the Heartbeat of Mining', is particularly appropriate. Congress like this provide an excellent opportunity for the exchange of knowledge among our colleagues.

Congratulations to you all in the mining and ventilation engineering discipline for this unique specialist mining engineering discipline of technical experts. The IMVC 2024 core committee has come up with a unique logo 'windmill'. The windmill is one of the Australian Outback's most recognised and respected icons. It's simple yet persistent action turns an otherwise inhospitable environment into a safe and productive one. Similarly, the ventilation engineering systems in mines create safe working environments, which is necessary to produce the globally essential minerals for human health, happiness, safety and security of nations.

I believe that the re-gathering of this unique specialist mine ventilation engineering talent to Australia for the 3rd time in its history provides a fitting platform to what is an important occasion for the people in the mining fraternity. I hope that this opportunity for interaction will assist mining operations across the world in the design of a safe and healthy work environment for the future and re-visit the challenges in the current operations.

Since its inception over many centuries, the mining industry with all commodities represented, has made an enormous contribution to humankind, global infrastructure, economy, and to each nation's safety and security. No doubt, mine ventilation has played a crucial role in the frontiers of mining and engineering design for mines. Global mining operations have achieved significant milestones and expanding mining frontiers, demonstrating to the world that what was once considered impossible in mine ventilation engineering is now possible and has become a routine, thanks to the support of other core disciplines. The mining industry worldwide has entered a new era of mining imperative such as Zero Serious Harm, which requires close interaction with all disciplines to address every potential safety, health and environment concern of our mines. In order to achieve this, we must operate our mines without an implicit belief that mines are dangerous. This can be only justified if the evidence supports this notion, which is not the case currently.

This leads to the question of history of the IMVC. The South African mining industry had made memorable and pioneering contributions to improve the health and safety of global mine workers, one being the International Conference on Pneumoconiosis held in Johannesburg in February 1959 and the second being the first International Mine Ventilation Congress (IMVC) in 1975, along with a globally unique mine ventilation engineering society to promote the art and science of mine ventilation engineering in 1945.

What is the context and connection between South Africa and Australia? The discovery of a gold-bearing conglomerate on the Witwatersrand of South Africa in February 1886 and diamonds caused a sensation worldwide, resulting in mines that required ventilation. One can argue that it can be linked to an Australian, Mr. George Harrison, an insignificant gold digger, who had taken a temporary job of building a house for a widow on the farm, Langlaagte, near Johannesburg or its African name Egoli and had unmistakably found the gold. Therefore, in some sense, this Australian IMVC originates in South Africa, which held the 1st IMVC at the University of the Witwatersrand with 661 local and overseas delegates in attendance on 15th Sept. 1975. The 1st IMVC was inaugurated by the South African Minister of Mines and attended by world experts, including Mr Henry Doyle, doyen of Industrial Hygienists in the USA. The IMVC was to be the forerunner of the North American, South American and Australian Mine Ventilation Symposiums, commanding professional respect within the mining community.

So what is the origin of the mine ventilation engineering professional? The history of current specialist mine ventilation engineers can be traced back to erstwhile role of 'dust inspectors' created in 1901 after the Boer War in South Africa, who were given the responsibility of protecting workers from the hazards of the mining environment through adequate ventilation, at the request of employers, workers and the government. This evolved specialist expertise and knowledge in an area that is now fully recognised as integral to the mining profession and its standing globally as the mine ventilation engineer.

Over the years, many speakers at mine ventilation meetings predicted future challenges facing mine ventilation engineering. At the Third US Mine Ventilation Symposium in 1987, Dr. Howard Hartman previewed his vision and stated that the 'Elimination of catastrophic disasters in mines' would be the 'crowning accomplishments-to-be in mine ventilation.' This task often falls heavily on us as mine ventilation engineers where we are faced with providing advice or making decisions that can have profound consequences.

Returning to the present, the mine ventilation challenges we are now facing require innovative solutions, technology and Zero Serious Harm Vision. Where do you lean to for guidance and solutions or advice in situation like these? Over the last two decades, major explosion events and re-identification of black lung and silicosis in Australia have highlighted the deficiencies in managing the catastrophic risks in the ventilation engineering profession. These explosion events have shown that the drift from 'compliance' based legislation to 'risk' based solutions without critical checks and balances is insufficient. The situation demands risk ownership and accountability by ventilation engineers, mine managers, vigilant regulators, and consultants who may be tempted to propose deficient solutions with 'disclaimers.' This is not about a lack of 'trust' or integrity but about the ability to provide assurance to frontline workers and our wider society that our operations are safe. For the mine ventilation engineering[1] profession – *There is no tertium quid*.

Health and safety at work is the core of workers, their families and communities. Mine explosions, fires (including spontaneous combustion) and respirable dust are catastrophic risks with operational challenges and controls managed by the mine ventilation engineering profession. Major mine unsafe events create an undesirable, unique and ambiguous setting for operators and regulators, with the continued presence of constraints in terms of time, complex natural and mining environments, resources, and intuitive decision-making expertise. These require making step changes from compliance-based designs to expert risk-based routes through design intervention and driving out or controlling 'the Bads' when sabotaging the harm. As expert engineers, it is hoped that we all assure the face worker and community by sharing distinctive control of 'Bads' and promoting 'Goods' and cast out any hurdles in front towards Zero Serious Harm.

Winning the bid to host this 12th IMVC some six years ago in China was a recognition of the capability of Australian mine ventilation engineering professionals, academics, researchers, suppliers, and regulatory bodies. We would not have succeeded in this endeavour without the stellar support from Prof Canbulat of the UNSW and Mr Steve Durkin, Ms Melissa Holdsworth and Ms Julie Allen of the AusIMM, the CSIRO, Universities, the mining industry, union members, our advisory committee, and our equipment suppliers and sponsors. The selection of technical papers for this congress has been a mammoth task. There were a total of 182 abstract submissions, with a final paper submission of 90 papers from 17 countries. I would like to thank the Core Committee members, and most importantly, my deputy Editors, Dr Guangyao Si and Dr Hsin-Wei Wu, for their immense contribution to a successful Technical Programme. The technical committee and global voluntary technical peer reviewers are a vital part of the quality assurance program for the papers being presented. We also thank the superlative work by the sub-committee chairs and members organising the field trips, the technical workshops and the social programme.

On a personal note, I also reflect back some 30 years to when I was a young mining engineering student at the Pennsylvania State University, where I had the opportunity to contribute to the IMVC held in Pittsburgh in 1997. It is therefore a particular source of pleasure and gratitude for me to now have the honour to contribute again to this wonderful congress series; this time as the Congress Chair along with Mr Duncan Chalmers as Deputy Chair, whose support has been invaluable to me in my role. I sincerely hope that the energy derived from this Congress will enable the global

[1] Belle, B, 2009. Ventilation engineering – There is no *tertium quid,* Mine Ventilation Society of South Africa Presidential Address, Johannesburg, South Africa.

ventilation engineering profession to regain its lost luster amongst global mining companies. It is hoped that the IMVC 2024 proceedings presented herein will be a valuable reference material.

I am very confident that this Congress will provide renewed impetus and resolve for us all, together, to contribute to develop and apply new solutions to the existing and emerging issues and opportunities that face our industry and our profession. In order to achieve the various challenges presented by all of us here and at our operations globally, we are required to commit to:

1. Providing superior mine ventilation engineering designs that consider every aspect of safety, health and environment towards Zero Serious Harm.
2. Providing exceptional mine designs that give an edge to improve safety with appropriate use of technology, automation, revision of historic design parameters, global leading practices and innovation.
3. Delivering enhanced fail-safe mine designs and systems that were built through close interaction between every core discipline of mining engineering.
4. Providing outstanding technical and engineering assurance to provide a health and safety work environment and rectification of sub-standard situations in the current operating mines.
5. Adopting a non-negotiable winning formula for the success of our profession – Zero Serious Harm Ventilation Engineering Challenge.
6. Providing appropriate use of technology, revising design parameters, and providing innovative ventilation engineering solutions which admirably serve to protect the worker and the community.
7. Mentoring and sharing your wealth of experience with new entrants to the profession locally and globally. As the IMVC Chair, I have taken the initiative to expand the current IMVC Committee to include the other mining nations that were not previously represented in this unique engineering profession.

With the above self-commitments in mind, I hope you will enjoy the next three days and use the occasion to get to know people from other specialist areas, cultures and geographies. Several suggestions, practices and recommendations made during the Congress should be scrutinised with further discussions. We should debate their intentions and the logic behind innovative operational practices to benefit all and improve mine health and safety. It is important that you take away new ideas from this Congress and have the determination to make a difference when you return to your place of work. I hope this international Congress will mark the rejuvenation of Ventilation Engineering as a core stand-alone discipline in every corner of the world.

Best wishes for a successful congress.

Dr Bharath Belle MAusIMM(CP)

Chair and Honorary Editor, IMVC2024

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Ventilation economics and optimisation

Ventilation monitoring and control

Ventilation planning for coal and metalliferous mines (case studies)

Preliminary study on laboratory scale for studying the effect of limestone dust for preventing coal dust explosion in Indonesia

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ABSTRACT

This study aims to analyse the effect of the size and ratio of limestone dust on the pressure value, the rate of change of pressure and the critical ratio of limestone dust immediately before the explosion. This study used a Siwek 20 L Explosion Chamber explosive tube with a coal concentration of 600 g/m^3 and an ignitor energy of 5 kJ. This test uses limestone dust with sizes of 177–74 µm and 74–37 µm and coal dust with sizes of 74–53 µm and 53–44 µm. The results of the first study on coal dust size 53–44 µm showed that the critical ratio between coal dust and limestone dust size 177–74 µm was at a ratio of 44.3:55.7 and for limestone dust 74–37 µm at a ratio of 45.1:54.9. Whereas for coal dust size 74–53 µm, the critical ratio of coal dust to limestone dust size 177–74 µm was obtained at 62.82:37.18 and for limestone dust size 74–37 µm at 81.99:18.01. In terms of the ratio of coal and limestone dust, the result is that the greater the ratio of coal dust compared to the ratio of limestone dust, the greater the pressure and the rate of change of pressure of the coal dust explosion. Based on the size of the limestone, the finer the size of the limestone dust, the lower the pressure and the rate of change of pressure from the coal dust explosion. Meanwhile, based on the size of the coal, the finer the size of the coal, the greater the potential to cause an explosion.

INTRODUCTION

The earliest stage to take advantage of coal is the coal mining stage which can be carried out using open pit and underground mining methods. At this mining stage, there is one aspect that needs to be considered, namely occupational health and safety issues. Occupational health and safety are an effort to create a healthy and safe work environment, to reduce the possibility of work accidents or exposure to disease which can cause deficiencies and demotivation at work.

There are several factors that can cause occupational health and safety problems at the coal mining stage. Especially in underground mines, dust can cause occupational health and safety problems because it can cause dust explosions. A dust explosion is an explosion triggered by combustible dust material (combustible dust) suspended in the air in a closed space and exposed to a heat source (Eckhoff, 2003; US Chemical Safety Board, 2006).

According to analysis results (Yuan *et al*, 2015), in 2000–2012 there were 193 cases of dust explosions in the world, of which 142 cases occurred in the United States, 92 cases occurred in China, and the rest happens in other countries. The biggest causes of explosions are food dust such as sugar, flour and powdered milk (40 per cent), wood dust (17 per cent), metal (10 per cent), others (10 per cent), coal (9 per cent), rubber (7 per cent), unknown (4 per cent), and inorganic material (3 per cent) according to Yuan *et al* (2015).

Therefore, coal dust is an element that needs more attention because it can cause explosions in mining activities which can cause destruction and even death of mine workers. There have been several studies carried out to analyse dust explosions, especially coal dust, such as Siwek (1977) who conducted coal dust explosion experiments on a laboratory scale, then experiments on coal dust explosions (Cashdollar, 1996) and ways to prevent or suppress their occurrences. One way to prevent a coal dust explosion is by adding rock dust into a room where there is coal dust.

Several researchers have examined the effect of rock dust on coal dust explosions. As in Mishra and Azam (2017) research which tested the effect of rock dust on coal dust explosions in India. The percentage requirement for limestone rock dust will increase as the size of the rock dust particles decreases. So, from this research it can be concluded that the smaller the particle size, the more effective its use. Rock dust acts as both a heat sink (by increasing the solid heat capacity of the mixture) (Amyotte, Mintz and Pegg, 1992) and a thermal inhibitor (by undergoing endothermic decomposition) (Man and Teacoach, 2009).

METHODOLOGY AND SAMPLE

Method

Coal dust explosion testing will focus on testing on a laboratory scale. There are several steps that need to be carried out to carry out explosion testing of coal dust mixed with limestone dust including, the coal and limestone sample preparation stage, ultimate and proximate testing stage of coal samples, the XRD testing stage to determine the mineral composition of limestone, the dust explosion test equipment preparation stage, and the coal dust explosion testing stage with limestone. The variable that will be varied here is the grain size of coal and limestone. Coal grain size variations are 74–53 μm and 53–44 μm and grain size variations for limestone are 177–74 μm and 74–37 μm.

There are references or standards for laboratory scale coal dust explosiveness tests. The standard used in this explosive test is ASTM E1226 (2010) which explains the standard test method for characterising the explosion of dust in two ways. First by determining whether the dust explodes, which means that dust scattered in the air can spread deflagration, which can cause flashes of fire or explosions. If it can explode, determining the level of explosion or potential explosion hazard from dust can be identified by dust explosion parameters, maximum explosion pressure (P_{max}), maximum pressure increase rate ($(Dp/dt)_{max}$) and deflagration index (K_{st}). In addition, there is another test standard, namely ASTM E1515 (2022) which describes the test standard for determining the minimum explosive concentration (MEC) of a mixture of dust and air that will spread deflagration in a nearly spherical closed vessel with a volume of 20 L or greater.

According to ASTM 1226, coal dust can be said to explode when the Pressure Ratio (PR) ≥ 2. Determination of PR can be done using the following calculations:

$$PR = (P_{ex,a} - \Delta P_{ignitor})/P_{ignition} \quad (1)$$

US Occupational Safety and Health Administration (US OSHA, 2009) classifies dust explosions based on the deflagration index (K_{st}) value, which is the maximum rate of pressure rise obtained from a 1 m^3 chamber:

$$K_{st} = (Dp/dt)_{max}.V^{(1/3)} \quad (2)$$

Sample

The coal samples that will be used in the explosion test come from East Jambi District, Jambi Province. Analysis of the characteristics of coal samples begins by preparing a 1.5 kg coal sample. Testing and analysis of HGI, ultimate, proximate, and calorific value of coal samples was carried out at the Laboratory of the TekMIRA Mineral and Coal Testing Center, Bandung. The analysis results are expressed on an air-dried basis (adb) which states the percentage of coal without surface water parameters.

In determining coal ranking, the ASTM or American Society for Testing and Materials D388 standard guideline regarding Standard Classification of Coals by Rank is used. Coal samples according to ASTM D388 (2023b) are classified as **sub-bituminous coal C**.

The limestone samples that will be used in the coal dust explosion prevention test come from Padalarang, West Java, Indonesia. Analysis of the mineral composition of limestone samples begins by preparing a 20 g sample of limestone dust with a size of <177 μm. Testing and analysis of the mineral composition of limestone samples was carried out at the Hydrogeology and Hydrogeochemistry Laboratory, ITB using the XRD method. The X-Ray Diffraction (XRD) method is a fast, non-destructive analytical variable that can be used to identify the phase of crystalline materials and can provide important information regarding the dimensions and composition of unit cells. It is known from the test results that the limestone sample has a composition of 88.3 per cent calcite, 11.3 per cent quartz, and 0.39 per cent wüstite. Table 1 shows the results of the ultimate and proximate analysis of the coal samples used.

TABLE 1

Proximate and ultimate analysis of coal samples.

Analysis parameters	Sample marks	Unit	Basis
HGI	74	-	-
Proximate:			
Moisture in air dried	22.62	%	adb
Ash	4.5	%	adb
Volatile matter	39.88	%	adb
Fixed carbon	33	%	adb
Ultimate:			
Carbon	49.68	%	adb
Hydrogen	6.2	%	adb
Nitrogen	0.6	%	adb
Sulfur	0.24	%	adb
Oxygen	38.78	%	adb
Gross calorific value	4615	Kcal/Kg	adb

The preparation process for coal and limestone samples is carried out in several stages, namely the first is the crushing process using primary and secondary crushers. Coal and limestone with a size >5 cm will be crushed using primary crushing with a jaw crusher then if there is coal and limestone with a size >1 cm it will be crushed using secondary crushing with a roll crusher. Crushing using both crushers is carried out until a finer size is obtained so that it can be continued to the grinding stage using a ball mill.

Then proceed with the drying process. In this process, before the samples are crushed and sifted, the coal and limestone samples have humidity that meets standards and to make it easier to grind and sift, the coal and limestone are dried using an oven for 12–24 hrs. The samples resulting from crushing and drying are continued to be crushed using a ball mill repeatedly until they obtain the desired size. Then finally is the sifting process. From the results of the sieve, the desired size will be obtained, namely 53–44 μm and 74–53 μm for coal in accordance with ASTM 1226, which recommends that coal dust samples be at least 95 per cent < 75 μm. The reason for choosing these two sizes is actually to see the effect of the size of the coal dust grains on the explosive properties of coal dust. Whether the smaller particles make coal dust more explosive or not. Then, Figure 1 shows the sample preparation process from using a jaw crusher, roll crusher to the sieving process.

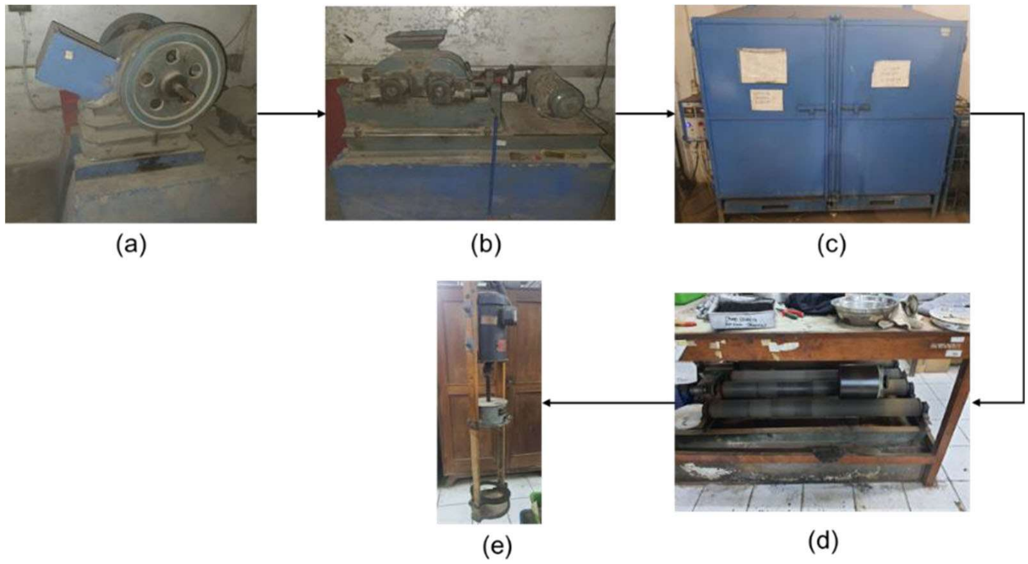

FIG 1 – Sample preparation process with information; (a) jaw crusher, (b) roll crusher, (c) oven, (d) ball mill, (e) sieving.

EXPERIMENTATION AND PROCEDURES

The experiment to test coal dust explosions used a 20 L blast tube which was shaped like a sphere so that the resulting pressure could be damped and could be calculated by the tool in the blast tube and provide homogeneous pressure. Coal dust that is inserted into the chamber will be dispersed, which is expected to be uniform, because it is pushed with compressed air at a pressure of 19 bar. Figure 2 shows a schematic of the explosion chamber.

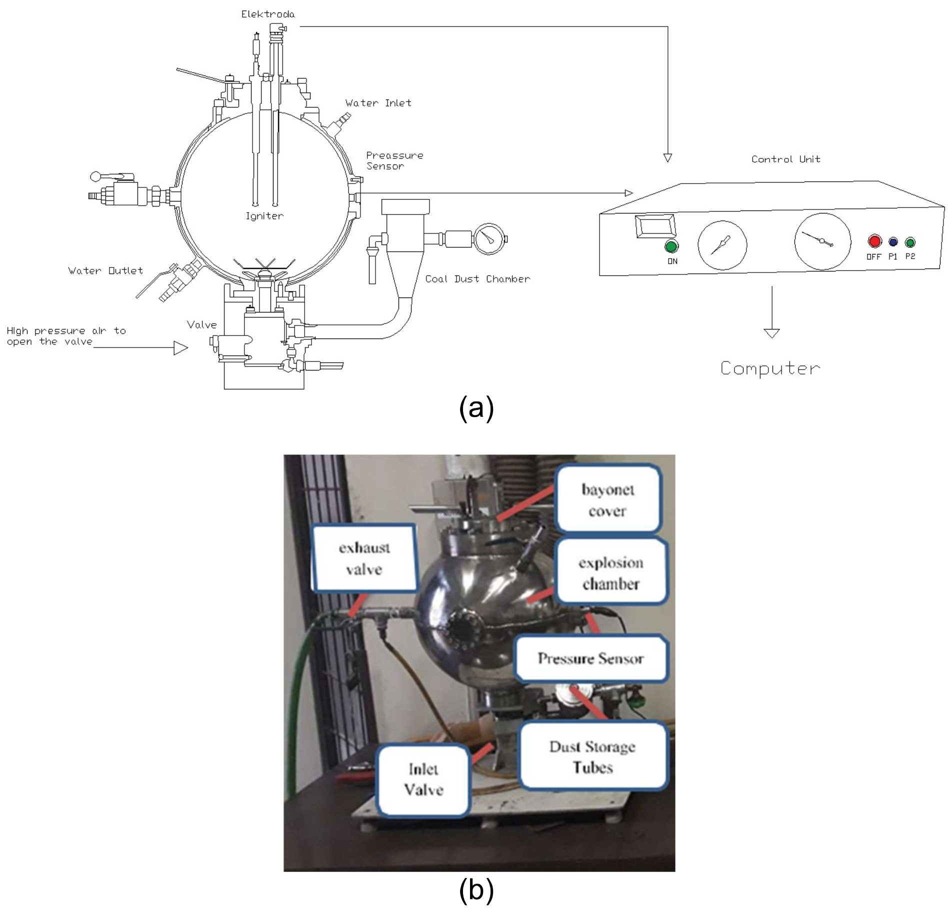

FIG 2 – The 20 L explosion chamber used for the tests: (a) Schematic of explosion chamber apparatus; (b) Physical appearances of the explosion chamber.

Later this coal dust will burn because it is ignited using pyrotechnics with an energy of 5 kJ (uses two ignitors with 2.5 kJ each). In the explosion tube, a sensor is installed in the form of a flange to read the pressure from the coal dust explosion. The data collection from this explosion test will be processed using the LabView application which acquires data every 0.06 sec or 17 data per second. The LabView application is also used to adjust the delay of the pyrotechnic ignition so that it can ignite simultaneously when the coal dust is dispersed into the explosive tube. Coal and limestone will later be put into the sample vessel according to the concentration and ratio specified. Ignitors used pyrotechnic ignitors type, consisting of zirconium, barium nitrate, and barium peroxide in a ratio of 4:3:3, with a total mass of 1 g (for pyrotechnics energy of 4.2 kJ).

Then the sample will be dispersed into the chamber using compressed air. The explosion test used pyrotechnics with a total energy of 5 kJ. The test was carried out using a ratio of coal dust to limestone dust ratio of 100:0, then decreased until the experimental coal dust explosion did not occur. The reduction is carried out in multiples of a decreasing ratio of ten for coal dust and a gradual increase in the ratio of ten for rock dust. However, if there is a possibility that coal dust will still explode, the ratio will be reduced by twofold.

RESULTS AND ANALYSIS

Pyrotechnic explosion test

The pyrotechnic ignitor explosion test was carried out in conditions without coal dust or limestone dust. The pyrotechnic ignitor explosion test aims to consider and calibrate the 20 L explosion chamber tool, as well as calculating the actual energy of the ignitor used. Bomb Calorimeter data was obtained from the tool's heat capacity of 2440 cal/°C, sample weight of 1 g, temperature rise on the calorimeter of 0.405°C.

$$Pyrotechnic\ energy = \frac{\left(2444\frac{kal}{°C}\right)x(\ 0.405°\ C)}{1g}$$

$$Pyrotechnic\ energy = 988.2\ \frac{kal}{g}$$

$$Pyrotechnic\ energy = 4125\ J$$

The sample weight used in each pyrotechnic was 0.6 g = 2.481 kJ, two pyrotechnics were used in this test so that a pyrotechnic energy of 4.962 kJ was obtained. Figure 3 shows a graph of the explosion test using two pyrotechnics showing the pressure values of the pyrotechnics.

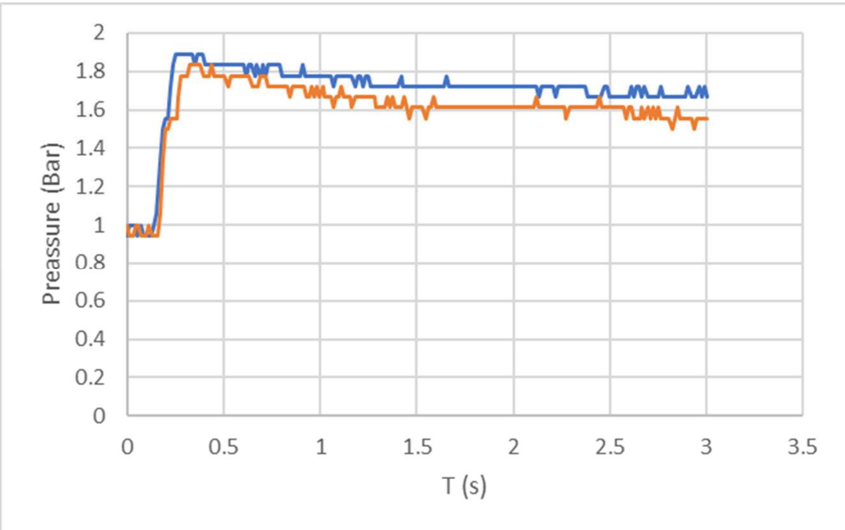

FIG 3 – Graph of pyrotechnic explosion test results.

Data such as $P_{ex,a}$, $P_{ignition}$, and $\Delta P_{ignitor}$ will later be used to correct pressure values using coal dust and/or limestone to obtain PR (Pressure Ratio) values. The $P_{ex,a}$ value (maximum absolute explosion pressure achieved in one explosion test without any consequences of using an ignitor) from pyrotechnics for experiments 1 and 2 was 1.89 bar and 1.83 bar, $P_{ignition}$ value (absolute pressure when the ignitor was activated) was 1.06 bar for experiments 1 and 2, and the $\Delta P_{ignitor}$ value (pressure increase due to activation of the ignitor at atmospheric pressure) is 0.11 bar and 0.06 bar.

Coal explosion test results

Coal dust explosion testing was carried out based on ASTM E1515, ASTM 1226, and research that had been carried out previously with a 20 L laboratory scale explosion tube. Coal dust testing uses coal dust measuring 74–53 μm. According to ASTM E1515, it is recommended to carry out tests with a coal dust concentration of 100 g/m^3. If an explosion occurs, the concentration is reduced until no explosion occurs, but if an explosion has not occurred, the concentration must be increased until an explosion occurs. Meanwhile, according to ASTM E1226, it is recommended to carry out tests with a concentration of 250 g/m^3.

From Table 2 it can be seen that at concentrations of 250 g/m^3 and 400 g/m^3 the $P_{ex,a}$ is 1.72 bar, while at the concentration of 600 g/m^3 the $P_{ex,a}$ is 10.33 bar. Data processing to obtain PR and K_{st} values with formulations referring to Equations 1 and 2 shows that concentrations of 250 g/m^3 and 400 g/m^3 have a PR value of less than 2 with both K_{st} values being 0.62 bar.m/s. So that at this concentration there will be no coal explosion. However, at a concentration of 600 g/m^3 with a PR value of 7.4 and K_{st} 5.02 bar.m/s, at that concentration an explosion occurred. So, in this study the concentration of 600 g/m^3 was used as a reference in determining the influence of limestone dust on coal explosions. Figure 4 shows the value of the coal dust explosion pressure measured at a concentration of 600 g/m^3 reaching 10.33 Bar.

TABLE 2

Initial testing of coal dust explosion.

Initial testing							Information
Concentration (gr/m^3)	$P_{ex,a}$ (Bar)	$P_{Ignition}$ (Bar)	P_{ex} (Bar)	$(dP/dt)_{ex}$ (Bar/s)	K_{st}	PR	
250	1.72	1.00	0.72	9.26	0.62	0.63	Did not explode
400	1.72	1.05	0.67	9.26	0.62	0.78	Did not explode
600	10.33	1.06	8.44	111.11	7.41	5.02	explode

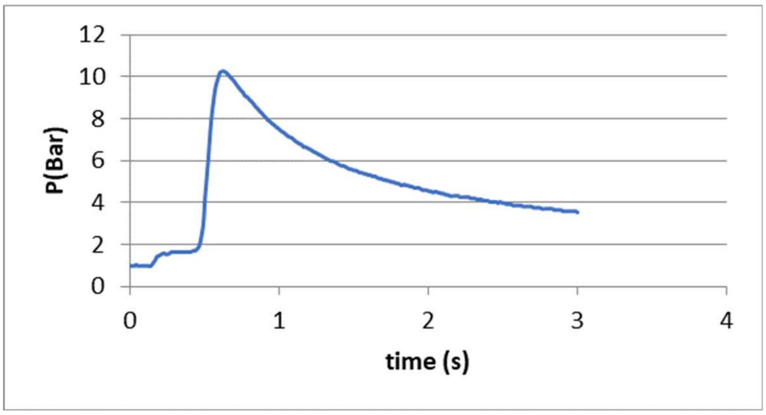

FIG 4 – Graph of coal dust explosion concentration 600 gr/m^3

Coal dust and limestone explosion test results

The coal dust explosion ability test was carried out using a 20 L explosion chamber with variations in the mixture ratio of coal dust to limestone dust and two variations of limestone dust sizes 177–74 and 74–37 μm with a coal dust concentration set at 600 g/m^3, the size of the coal dust namely 74–

53 µm and 53–44 µm. and pyrotechnic ignitor energy of 5 kJ. In underground mines, the energy of 5 kJ is equivalent to the energy produced by a short circuit for 0.015 sec in a 7LSO type shearer.

The following are the results of coal dust explosion tests with varying mixture ratios and limestone sizes carried out.

Based on Table 3 For coal dust sizes of 74–53 µm, two experiments were carried out for each variation of the ratio of the mixture of coal dust to limestone dust. It was found that in the mixture of coal dust and limestone dust the ratio of coal dust to limestone dust was 100:0 to 70:30 for limestone dust sizes of 177–74 µm an explosion occurs, while for limestone dust sizes of 74–37 µm an explosion occurs at a ratio of coal dust to limestone dust of 100:0 to 90:10.

TABLE 3

Coal dust explosion test data processing results with varying limestone dust mixture ratios (coal dust 74–53 µm).

Limestone dust size	Coal dust: limestone dust ratio	Testing	$P_{ex,a}$ (Bar)	$P_{Ignition}$ (Bar)	$\Delta P_{Ignitor}$ (Bar)	$(dp/dt)_{ex}$ (Bar/s)	K_{st} (Bar.m/s)	PR	Information
177–74 µm	100:0	Test 1	10.00	1.72	0.78	92.59	25.13	5.02	Explode
		Test 2	10.61	1.67	0.72	149.57	40.60	5.93	Explode
	70:30	Test 1	6.44	1.78	0.72	23.15	6.28	3.22	Explode
		Test 2	7.17	1.72	0.78	27.78	7.54	3.71	Explode
	60:40	Test 1	1.67	1.11	0.11	8.55	2.32	1.40	Did not explode
		Test 2	1.67	1.06	0.11	10.42	2.83	1.47	Did not explode
	50:50	Test 1	1.67	1.00	0.06	10.10	2.4	1.61	Did not explode
		Test 2	1.72	1.06	0.06	12.82	3.48	1.58	Did not explode
	40:60	Test 1	1.56	1.06	0.11	12.82	3.48	1.37	Did not explode
		Test 2	1.56	1.00	0.06	8.55	2.32	1.5	Did not explode
	30:70	Test 1	1.72	1.17	0.11	13.07	3.55	1.38	Did not explode
74–37 µm	100:0	Test 1	10.00	1.72	0.78	92.59	25.13	5.35	Explode
		Test 2	10.61	1,67	0.72	149.57	40.60	5.93	Explode
	90:10	Test 1	7.89	1.72	0.56	37.04	10.05	4.26	Explode
		Test 2	6.78	1.72	0.78	25.64	6.96	3.48	Explode
	80:20	Test 1	1.61	0.94	0.06	10.10	2.74	1.65	Did not explode
		Test 2	1.67	1.06	0.11	12.82	3.48	1.47	Did not explode
	70:30	Test 1	1.67	1.06	0.11	12.82	3.48	1.47	Did not explode
	60:40	Test 2	1.72	1.33	0.33	20.83	5.66	1.04	Did not explode

Meanwhile, based on Table 4 for coal dust sizes of 53–44 µm, it is found that in a mixture of coal dust and limestone dust at a ratio of coal dust to limestone dust of 100:0 to 50:50 for limestone dust sizes of 177–74 µm, an explosion occurs, while for limestone dust sizes of 74–37 µm an explosion occurs at a ratio of coal dust to limestone dust of 100:0 to 50:50. The test stopped at a ratio of 30:70 because after reducing the ratio of coal to limestone dust several times, there was no explosion.

TABLE 4

Coal dust explosion test data processing results with varying limestone dust mixture ratios (coal dust 53–44 μm).

Limestone dust size	Coal dust: limestone dust ratio	Testing	$P_{ex,a}$ (Bar)	$P_{Ignition}$ (Bar)	$\Delta P_{Ignitor}$ (Bar)	$(dp/dt)_{ex}$ (Bar/s)	K_{st} (Bar.m/s)	PR	Information
177–74 μm	100:0	Test 1	10.33	1.89	0.83	111.11	7.4	5.02	Explode
		Test 2	10.28	1.78	0.78	111.11	7.4	5.33	Explode
	50:50	Test 1	8	1.83	0.83	45.45	3.03	3.91	Explode
		Test 2	7.5	1.83	0.83	45.45	3.03	3.64	Explode
	40:60	Test 1	1.83	1.78	0.78	45.45	3.03	0.59	Did not explode
		Test 2	1.83	1.61	0.67	17.09	1.14	0.72	Did not explode
	30:70	Test 1	1.89	1.83	0.61	23.15	1.54	0.69	Did not explode
		Test 2	1.94	1.72	0.44	14.81	0.98	0.87	Did not explode
74–37 μm	100:0	Test 1	10.33	1.89	0.83	111.11	7.4	5.02	Explode
		Test 2	10.28	1.78	0.78	111.11	7.4	5.33	Explode
	50:50	Test 1	7.2	1.94	0.94	38.19	2.55	3.22	Explode
		Test 2	7.17	1.83	1	42.74	2.85	3.37	Explode
	40:60	Test 1	1.61	1.51	0.57	12.82	0.85	0.68	Did not explode
		Test 2	1.61	1.5	0.61	13.89	0.93	0.67	Did not explode
	30:70	Test 1	1.61	1.61	0.61	10.42	0.69	0.62	Did not explode
		Test 2	1.67	1.61	0.67	13.89	0.93	0.62	Did not explode

ANALYSIS OF THE EFFECT OF VARYING RATIOS OF COAL DUST MIXTURE WITH LIMESTONE DUST ON THE PREVENTION OF COAL DUST EXPLOSIONS

According to ASTM 1226 and ASTM E1515, coal dust that can still explode when PR ≥ 2 or K_{st} ≥ 1.5 bar.m/s with 0 < K_{st} ≤ 200 according to (US OSHA, 2009) is included in the weak explosion class category.

From the Figure 5 in coal dust measuring 74–53 μm to limestone dust measuring 177–74 μm ratio of 40 per cent (37.18 per cent) no explosion occurred, whereas in coal dust measuring 53–44 μm no explosion occurred when the ratio of limestone dust measuring 177–74 μm is 60 per cent (55.70 per cent). In coal dust measuring 74–53 μm to limestone dust ratio measuring 74–37 μm of 20 per cent (18.01 per cent) no explosion occurred, while coal dust measuring 53–44 μm did not occur when the ratio of limestone dust measuring 74–37 μm is 60 per cent (54.90 per cent).

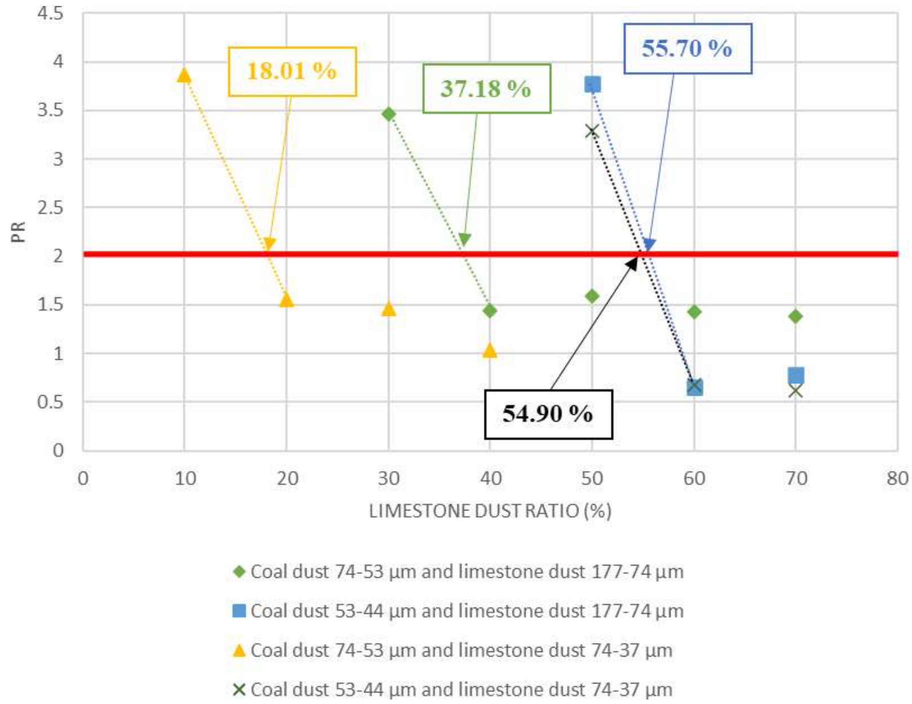

FIG 5 – Graph of coal dust explosion test results, PR versus limestone dust ratio

This shows that the larger the size of the coal dust, the smaller the explosion pressure produced, so that at larger coal dust sizes the need for limestone dust will be lower to reduce or prevent coal dust explosions. Coal dust with a larger size will be more difficult to produce an explosion due to several factors, including a decrease in the reaction surface area of coal dust grains with a larger size and it will be difficult to disperse or form dust clouds in the room because it will easily fall so that it has not yet had time to react to produce an explosion (Coal dust particles cannot be controlled because they are influenced by the mining method and tools used. However, this prevention technique can be done by sampling coal dust in the field (ASTM E1226), then coal dust explosions can be mitigated so that they do not occur).

DISCUSSION

The use of limestone dust is recommended to overcome coal dust explosions. Laws related to the use of rock dust to overcome coal dust explosions also exist in various countries (Luo, Wang and Cheng, 2017). Several countries determine the use of rock dust in the range of 50–80 per cent depending on many factors such as volatile matter, whether there is gas content in the area or not, the channel where the dust will be sprayed and others. Table 5 shows that several countries have set rules for using rock dust in handling coal dust explosions.

TABLE 5
Rules for using rock dust in various countries (Luo, Wang and Cheng, 2017).

Country	Rules
United States of America	US MSHA (Mine Safety and Health Administration) specifies 80% rock dust
Canada	Established 65% on inlet airways (Alberta and British Columbia) 80% on all return airways (Province of Nova Scotia)
Australia	Set 70–85% rock dust (air inlet) 80–85% rock dust (air outlet)
Eastern Europe (Czech, Slovakia, Ukraine, etc.)	Sets 80% rock dust
Poland and Russia	Assign 60–70% air inlet and return (non-gas) Assign 75–80% (gas mine)
South Africa	Sets 80% rock dust
Great Britain	Set 50–75% depending on the Volatile Matter (VM) which varies between 20–35%
Japan	Set 78% rock dust when VM is more than 35%

Mishra and Azam (2017) in Table 6 also conducted research using limestone dust to prevent coal dust explosions with coal type specifications between medium cooking coal – prime cooking coal. Meanwhile, the sizes of limestone dust used range from sizes below 25 μm, 25–38 μm, 38–74 μm, and 74–212 μm. In this construction, the limestone sizes that can be compared are 38–74 μm, and 74–212 μm with the sizes used by painters, namely 37–74 μm, and 74–177 μm.

TABLE 6
Research comparative parameters.

Study	Coal type	Coal class	Volatile matter (%)	Chamber size	Coal size	Limestone size	Concentration
Present research (2024)	Jambi	Subbituminous C	39.88	20 L	74–53 μm and 53–44 μm	37–74 μm and 74–177 μm	600 g/m^3
Mishra and Azam (2017)	Jharia, India	Medium-prime cooking coal (bituminous)	17.73	0.234 L	<212 μm	38–74 μm and 74–212 μm	Varies but reviews are for 600 g/m^3

On Figure 6 There is a comparison between the critical ratio required by limestone dust when an explosion occurs to avoid an explosion. The critical limestone dust ratio for dealing with coal dust explosions in the current study has a smaller value at larger coal dust sizes (74–53 μm) compared to smaller coal dust sizes (53–44 μm).

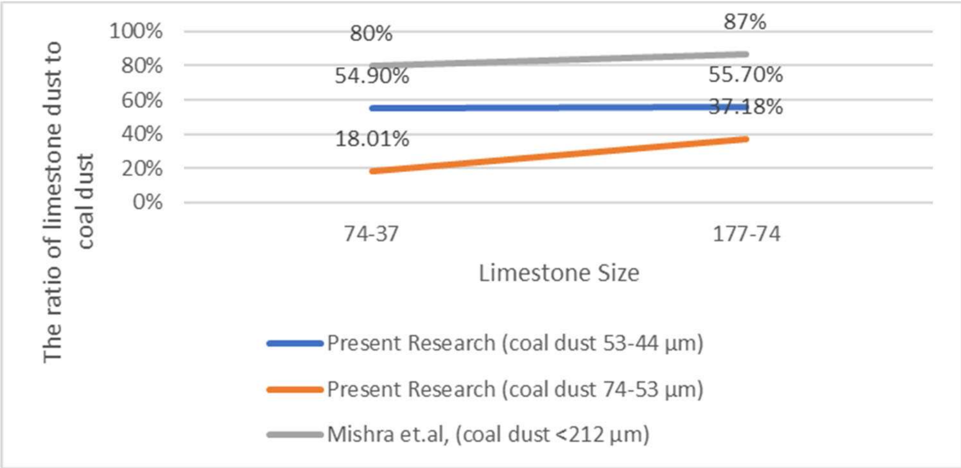

FIG 6 – Comparison chart of critical ratio of limestone dust and limestone size.

The limestone dust ratio required in the current research is smaller than the ratio required in the research of Mishra and Azam (2017). This can occur due to many factors such as differences in the type and origin of coal used, Volatile Matter, as well as the size and type of chamber used.

Indonesia itself has further potential to have more massive underground coalmines, while the regulations regarding the use of rock dust to overcome coal dust explosions are not yet covered, so this research can be initial research to determine the ratio of coal dust to limestone to avoid coal dust explosions. It is necessary to pay attention to the difference between 20 L chamber testing and full-scale testing. In Cashdollar *et al* (1992) it was stated that there were differences such as differences in MEC values where the 20 L room had a lower MEC value than the 1 m^3 room test.

CONCLUSION

This research has resulted that limestone is effective in dealing with coal dust explosions depending on the size of the coal dust, the size of the limestone dust, and the concentration of the coal dust. The larger the size of the coal dust, the smaller the explosion pressure produced, so that at larger coal dust sizes the need for limestone dust will be lower to reduce or prevent coal dust explosions. Coal dust with a larger size will be more difficult to produce an explosion due to several factors, including a decrease in the reaction surface area of coal dust grains with a larger size and it will be difficult to disperse or form dust clouds in the room because it will easily fall so that it has not yet had time to react to produce an explosion.

It was found in this study that coal dust measuring 74–53 µm to limestone dust ratio measuring 177–74 µm was 40 per cent (37.18 per cent) without an explosion, whereas coal dust measuring 53–44 µm did not cause an explosion when the ratio of stone dust limestone measuring 177–74 µm is 60 per cent (55.70 per cent). In coal dust measuring 74–53 µm to limestone dust ratio measuring 74–37 µm of 20 per cent (18.01 per cent) no explosion occurred, while coal dust measuring 53–44 µm did not occur when the ratio of limestone dust measuring 74–37 µm is 60 per cent (54.90 per cent). So that it can effectively obtain a ratio range of 20–60 per cent between limestone and coal dust to reduce coal dust explosions depending on the size of the coal dust and its concentration. This research needs to be continued by examining variations in explosion chamber size, coal rank, coal size, rock dust size, rock dust type, etc.

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