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AN ANALYSIS AND COUNTERMEASURES OF FATAL ACCIDENTS CAUSED BY FIREDAMP EXPLOSIONS IN UNDERGROUND COAL MINES IN TURKEY

TÜRKİYE'DE YERALTI KÖMÜR MADENLERİNDE GRİZU PATLAMALARININ NEDEN OLDUĞU ÖLÜMLÜ İŞ KAZALARININ ANALİZİ VE KARŞI ÖNLEMLER

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ABSTRACT

Fatal accidents in underground coal mines in Turkey are common and experienced frequently. The major accident categories for underground coal mining in Turkey are gas related accidents (firedamp and outbursts), roof falls, flooding, fire and transport. In recent years, coal mine gas related accidents in Turkey, which are usually caused by firedamp and outbursts, are still threatening miners' lives. Firedamp explosions are majorly serious mine accidents that can occur quickly and cause great deal damage. In this study, work-related accidents caused by firedamp and another gas accidents in Turkey between the years 2010-2016 were analyzed. As a result of these analyses, the number of deaths in underground coal mines in the past 7 years is 550 and the fatality rate is found to be 96.86%. The percentage of gases as the cause of the deaths is 70.18%. In this study, countermeasures are proposed that can prevent and control firedamp explosions and other gas related accidents.

Anahtar Sözcükler:
Yeraltı kömür madenciliği,
Ölümlü iş kazaları analizi,
Grizu patlamaları,
İş sağlığı ve güvenliği,
İstatistiksel analiz

ÖZ

Türkiye'de yeraltı kömür madenlerinde ölümlü iş kazaları yaygındır ve çok sıklıkla yaşanmaktadır. Türkiye'de yeraltı kömür madenciliğinde yaşanan başlıca kaza kategorileri grizu patlamaları ve püskürmeler, göçükler, sel baskını, nakliye ve yangınlardır. Son yıllarda, Türkiye'de genellikle grizu patlamaları ve püskürmeler nedeniyle oluşan gaz patlamalarının neden olduğu yeraltı kömür madeni kazaları, madencilerin hayatlarını tehdit etmektedir. Grizu patlamaları, ani ortaya çıkan ve büyük zarar verebilen büyük çaptaki ciddi maden kazalarıdır. Bu çalışmada Türkiye'de 2010-2016 yılları arasında yeraltı kömür madenlerinde grizu ve diğer gazların neden olduğu iş kazaları analiz edilmiştir. Analizler sonucunda bu 7 yıl içerisinde yeraltı kömür madenlerinde meydana gelen ölüm sayısı 550 ve ölüm oranı %96,86 olarak bulunmuştur. Bu ölümlerin nedenleri arasında gazların oranı %70,18'dir. Bu çalışmada grizu ve diğer gaz kazalarını önleyebilecek ve kontrol altına alabilecek önlemler önerilmektedir.

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INTRODUCTION

Mining, especially underground coal mining is a complex organization of many work disciplines. Needs and facilities such as underground excavation for production, support to roof in order to provide a safe environment, ventilation, drainage of the mines, transportation etc. are important in terms of occupational safety. The occupational safety problem emerges mainly during the production process. The production process consists of main activities such as excavation, support, transportation, installation and operation of the necessary equipment and systems and related activities such as provision of material support. Accidents can occur at any moment during this process as a result of the environmental conditions, the machines used and the negativities that occur in the harmony of the workers. For this reason, underground coal mining is accepted as the riskiest field of work in the world (Sarı et al., 2004; Sarı et al., 2009; Maiti and Khanzode, 2009; İphar, 2010; Khanzode et al., 2011; Durşen and Yasun, 2012; Mahdevari et al., 2014; Dursun et al., 2017a; b). Accidents in underground coal mines are caused by collapses, pillar outbursts, gas and dust explosions, coal dust explosions, blasting accidents, roof falls, transport and hoisting accident, flooding, use of machinery and equipment, electricity usage, mine fires, blasting accident and shock waves, materials dropping or slipping, lack of air, poisonous and choking gases etc. (Güyagüler and Bozkurt, 1993; Chen et al., 2013; Küçük and Ilgaz, 2015).

Looking at the history of world mining, it is seen that many accidents occur in underground coal mines resulting in death and major financial losses. It is known that a significant majority of the causes are due to the sudden increase in the concentrations of explosive and poisonous gases such as methane (CH_4), carbon monoxide (CO) and carbon dioxide (CO_2) and that the oxygen (O_2) required for the workers falls into inadequate concentrations (Aydin and Barış, 2015).

When investigated the major problems in the underground mining industry occurring in Turkey and globally, risks factors such as firedamp explosions and coal dust explosions that cause mass fatalities, are frequently encountered and are pointing to these two risk factors as the main problems of underground mining (Güyagüler, 2002; Xian-gong et al., 2009; İphar, 2010; Chen et al., 2013; Chunli et al., 2014; Wang et al., 2014; Fu et al., 2017; Yin et al., 2017).

Since the objective in occupational health and safety is prevention and protection, the prevention of risks that cause mass fatalities is very important in terms of occupational health and safety (Ergun, 2007).

As known, Turkey is in the top rankings in the world when it comes to occupational related accidents, and mining accidents have increased significantly in recent years. According to The Social Security Institution (SGK) data; a total of 911 mine workers lost their lives during mining activities (Coal (lignite and hard coal) mining + metal ore mining + other mining and quarrying) within the last 7 years (2010-2016). When these fatal accidents are examined, it is seen that most accidents occur in underground coal mines, and the most frequent cause of these accidents are firedamp explosions, collapses and mine fires. In order to eliminate threats of firedamp explosions and other gas related accidents, it is necessary to establish control and an early warning system where hazardous gases can be continuously monitored in underground coal mines of Turkey. Since the use of remote monitoring and control systems in underground mining has become quite widespread, along with the advancement in electronics, usage of these systems has become a legal requirement in most of the developed countries. This study aims to highlight basic health and safety problems in underground mining enterprises as well as preventative countermeasures against firedamp explosions which are one of the leading problems of the mining industry.

1. COAL RESERVES AND PRODUCTION IN TURKEY

In terms of Turkey national reserves and production quantities, lignite can be evaluated as being at medium level and hard coal at low level on the world scale. Turkey has 2.1% of total world coal reserves including anthracite and which those of 8.7% of total world lignite reserves and 3.6% of total world lower bituminous coal and lignite. Since most of Turkey's lignite has low calorific value, its

use in thermic power plants is at the forefront. Approximately 46% of Turkey's lignite reserves are located in the Afşin-Elbistan coalfield. The most important hardcoal reserves of Turkey are in and around Zonguldak coalfield. The lignite/lower bituminous coalfields are spread over all regions in Turkey, and the calorific values of the lignite/lower bituminous coal in these areas range between 1000-5000 kcal/kg. Approximately 68% of the total lignite/lower bituminous coal reserves Turkey are low in calories, with 23.5% between 2000-3000 kcal/kg, 5.1% between 3000-4000 kcal/kg, 3.4% are over 4000 kcal/kg. The most important coal reserves in Turkey are located in the Zonguldak coalfield. As of 2017, the total reserve amount of Turkey together with lignite, asphaltite and hard coal is around 18.77 billion tons. Lignite and lower bituminous coal reserve quantities are 17.27 billion tonnes whereas hard coal reserve is 1.5 billion tonnes (Figure 1) (TKİ, 2018). In Turkey where the type of production is underground and open pit mining, the underground coal mines are mostly located in the Trakya coalfield (Edirne, Tekirdağ), the Aegean coalfield (Soma, Gediz, Muğla, Eynez), the Karaman coalfield (Karaman, Ermenek), the Bursa-Balıkesir coalfield, Kütahya/Tavşanlı coalfield, Ankara/Beypazarı coalfield and the Zonguldak coalfield (Zonguldak, Bartın). There are also underground coal mines in Çayırhan, Merzifon and Suluova which are smaller in scale. During the period of 2010-2016, when the total amount of coal produced by underground mining was evaluated, it was found that within these seven years 76 million tonnes of lignite and 15.1 million tonnes of hard coals were extracted in total (Figure 2).

2. GASES THAT CONSTITUTE OF MINE AIR

Mine air that fills the underground mine area is a type of air that is almost always dusty and consists of water vapour and a mixture of gases. Negative changes in the underground air are generally seen as a decrease in the amount of

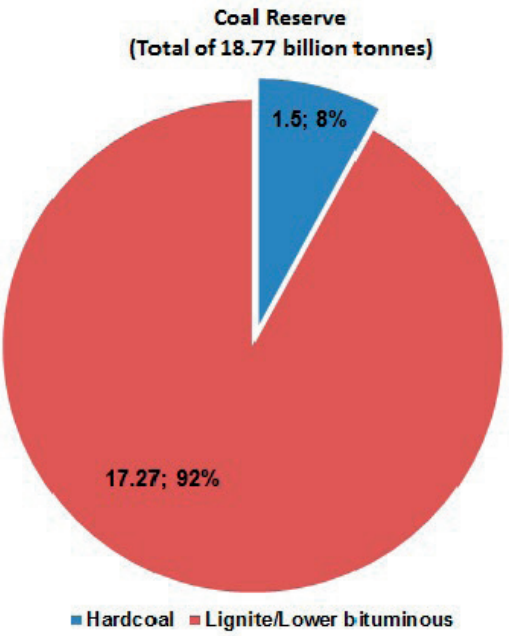

Figure 1. Lignite and hardcoal reserves in Turkey since 2017 (TKİ, 2018)

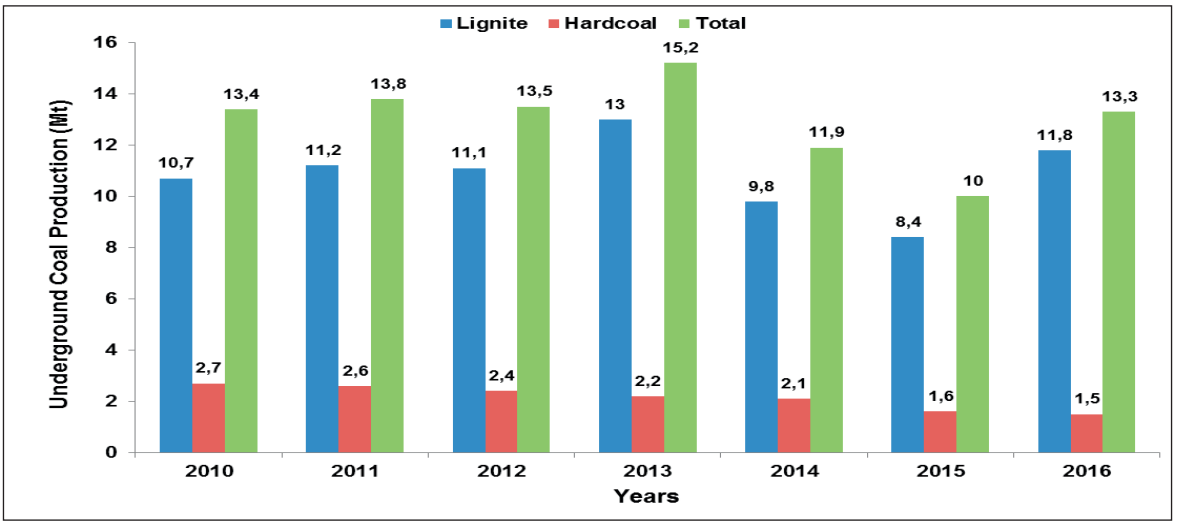

Figure 2. Coal production from underground coal mines in Turkey during 2010-2016 (TKİ, 2016; TTK, 2016)

O_2 and an increase in CO_2 and other gases. This change pollutes the air of the mine, causing the accumulation of flammable, suffocating and poisonous gases in the environment. Examples of flammable gases include CH_4, CO and hydrogen (H_2); suffocating gases include CO_2, nitrogen (N2) and CH_4. Whereas poisonous gases include CO, all oxides of nitrogen (N), hydrogen sulfur (H_2S), sulfur dioxide (SO_2) and etc. (Durşen and Yasun, 2012).

The air that comes out of the mine is called exhaust or return air. Any poisonous or explosive gas present in the mine air is called “active gas”. The mixing of air with dangerous gases (CH_4, CO, H_2S etc.) causes the formation of gases such as firedamp and blackdamp. These are extremely dangerous gases for the workers’ health and mines.

CH_4+ Air: Also known as CH_4 marsh gas is highly flammable. The combination of air, and CH_4, an explosive and suffocating gas that is extremely dangerous, is called firedamp.

CO + Air: Carbon monoxide which is a light gas, with a specific weight similar to the air, is a highly toxic gas and also has an explosive nature. It is mostly found in coal mines.

H_2S + Air: Sulphurous hydrogen or hydrogen sulphide is a highly toxic gas. It has a harsh smell similar to rotten eggs. Hydrogen sulphide, which is rarely seen in dangerous quantities, is also explosive at high concentrations.

CO + CH_4+ CO_2 + H_2 + N_2: Creates a toxic, suffocating and explosive atmosphere. These are known as the poisonous gases that emerge after firedamp explosions.

CO_2 + N_2 is known as blackdamp or choke damp. It is a suffocating gas (Durşen and Yasun, 2012).

In this context, the primary requirement for keeping the atmosphere in underground coal mines safe is to consistently and regularly monitor the concentrations of gases such as O_2, CO, CO_2, H_2S and CH_4 in the mine air (Dursun et al., 2017a, b; Mallı et al,. 2014; Liu et al. 2013). By doing so, short and long term changes in the mine air can be observed from the obtained data, which provides early warning against the explosive and poisonous atmosphere that may occur in all sections of the mines where the miners are located. The gases in the underground mines and the hazards they create are given in Table 1.

3. MAJOR GLOBAL MINING ACCIDENTS CAUSED BY GASES

In many countries around the world, especially China, France and Japan, thousands of people have lost their lives due to mining disasters. A total of 6811 miners lost their lives in 12 of the largest mining disasters with the highest death tolls in history. The mining disaster which occurred in China, in 1942, has had the most fatalities so far. 1549 people lost their lives in the accident in China. Mine accidents have usually occurred as a result of trapped gas, CH_4 explosions, CO poisoning and coal dust explosions. In Table 2 lists global mining disasters caused by major, deadly firedamp explosions and other gas accidents.

Table 1. The main toxic gases found in underground coal mines

Gases	Hazards
Methane (CH_4)	Explosion, burning and asphyxiation (Suffocation)
Carbon Monoxide (CO)	Asphyxia (Suffocation), Explosion
Carbon dioxide (CO_2)	Suffocating
Hydrogen Sulfide (H_2S)	Eye and respiratory irritation
Oxygen shortage	Anoxia (lack of oxygen in the body tissues)
Diesel engine smoke, nitrogen oxides (NO, N_2O, NO_2)	Respiratory irritation, lung cancer

Table 2. Major global mining disasters caused by firedamp and other gas accidents (Yasar et al. 2015)

Place	Year	Cause	Death Toll
Benzihu / China	1942	Explosion of Gas and Coal Dust Mixture	1549
Courrieres / France	1906	Fire/Explosion	1099
Mitsubishi Hojyo / Japan	1914	Firedamp Explosion	687
Laobaidong / China	1960	Firedamp Explosion	684
Mitsui Miike/Japan	1963	Coal Dust Explosion/CO Poisoning	458
Senghenydd / Wales	1913	Coal dust explosion	439
Wankie / Zimbabwe	1972	Gas explosion	426
Dhori / India	1965	Firedamp Explosion	375
Chasnala/India	1975	Firedamp Explosion	372
Oaks / England	1866	Firedamp/coal dust explosion	361
Monongah / USA	1907	Firedamp/coal dust explosion	361

4. ANALYSIS OF FATAL MINE ACCIDENTS IN TURKEY CAUSED BY FIREDAMP EXPLOSIONS

When analyzed the major mine accidents that have occurred in Turkey, firedamp explosions comes as one of the top causes of many accidents with a large number of deaths. Firedamp explosions, which are caused by methane gas, are the first causes of fatal mine accidents. The major mining accidents that have occurred in underground coal mines in the last 30 years in Turkey are given in Table 3 (TMMOB, 2010; Atalay, 2015). As can be understood from this, firedamp explosions, mine fires and gas poisonings are the major causes of fatal mine accidents.

In this study, firedamp and other gas accidents are investigated in underground coal mines at Turkey between 2010-2016. Firedamp and other gas accidents data obtained from The Social Security Institution (SGK) and Chamber of Mining Engineers and also two websites named devmadensen.org.tr and madenciyim.com which are recording mine accidents on a daily basis have been examined.

During the years of 2010 to 2016, the percentage of accidents in the mining sector (Hardcoal and lignite mining + metal mining + other mining and quarrying) was 6.72% compared to occupational accidents in all sectors. In the mining sector, the percentage of mine accidents in coal mining is 82.96% (Table 4). When analyzed the rate of fatal mine accidents, the percentage in all of the coal mining is 46.90% whereas underground coal mining is 82.74% (Figure 3) (SGK, 2016, Dev Maden Sen, 2017.

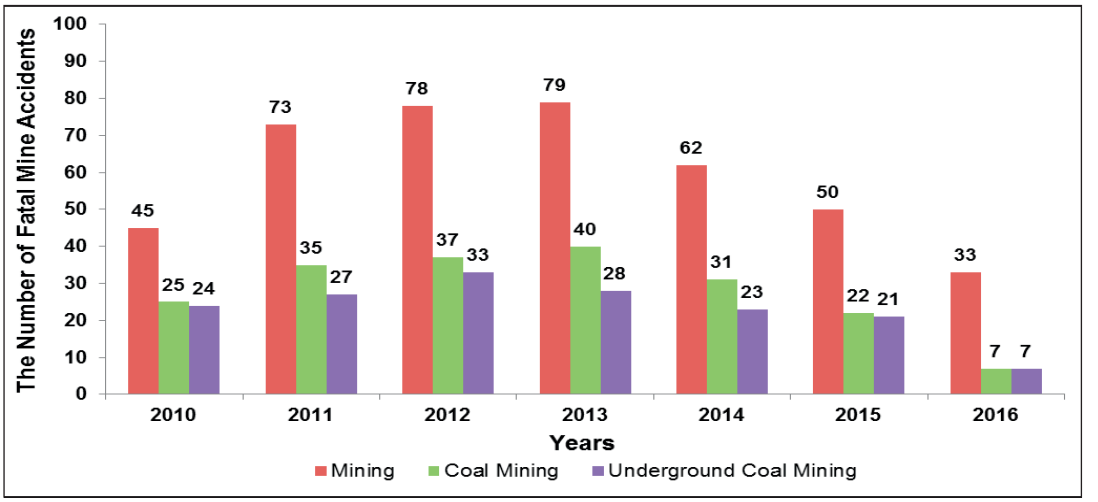

Figure 3. The number of fatal mine accidents in Turkey's mining sector between 2010 to 2016 (SGK, 2016; Dev Maden Sen, 2017;

Table 3. Major firedamp explosion and other gas accidents in Turkey (TMMOB, 2010; Atalay, 2015)

Place	Year	Cause	Fatalities
Armutçuk	March 7, 1983	Firedamp Explosion	103
Kozlu/	April 10, 1983	Firedamp Explosion	10
Yeni Çeltek	July 14, 1983	Firedamp Explosion	5
Amasra	January 31, 1990	Firedamp Explosion	5
Yeni Çeltek	7 February, 1990	Firedamp Explosion	68
Kozlu	March 3, 1992	Firedamp Explosion	263
Sorgun	March 26, 1995	Firedamp Explosion	37
Aşkale	August 8, 2003	Firedamp Explosion	8
Ermenek	November 22, 2003	Firedamp Explosion	10
Bayat	August 9, 2004	Firedamp Explosion	3
Gediz	April 21, 2005	Firedamp Explosion	18
Dursunbey	June 2, 2006	Firedamp Explosion	17
Mustafakemalpaşa	December 10,2009	Firedamp Explosion	19
Dursunbey	February 23, 2010	Firedamp Explosion	13
Karadon	May 17, 2010	Firedamp Explosion	30
Kozlu	January 8, 2013	Firedamp Explosion	8
Soma	May 5, 2014	Fire because of gas explosion/CO poisoning	301
		Total	**918**

Table 4. Occupational accident statistics in Turkey's mining sector between 2010 to 2016 (SGK, 2016; Dev Maden Sen, 2017)

Years	2010	2011	2012	2013	2014	2015	2016
Number of General Occupational Accidents	62,903	69,227	74,871	191,389	221,366	241,547	286,068
Occupational Accidents in Mining	9,007	10,368	9,818	13,901	12,613	10,062	11,356
Occupational Accidents in Coal Mining	8,150	9,217	8,828	11,285	10,026	7,426	8,274
Number of Fatal Occupational Accidents in Mining	45	73	78	79	62	50	33
Number of Fatal Accidents in Coal Mining	25	35	37	40	31	22	7
Number of Fatal Accidents in Underground Coal Mining	24	27	33	28	23	21	7
Number of General Fatalities	1,444	1,700	744	1,360	1,626	1,252	1,405
Number of Fatalities in Mining	124	114	44	80	387	79	83
Number of Fatalities in Coal Mining	86	55	20	36	352	26	11
Number of Fatalities in Underground Coal Mining	73	28	38	37	343	23	8

When analyzed deaths of all mine accidents, the fatality rate in all coal mining is 64.32%, while fatality rate in underground coal mining has increased considerably at a rate of 93.86% with almost every case of mine accidents resulting in death. In Turkey during the years 2010-2016, coal production by using underground coal mining methods, the death rate per 1 million tonnes reached its highest in 2014, and was found to be 28.824 (Figure 4). Figure 5 shows the fatal mine accident rates versus the production rate of 1 million tonnes of coal. And figure 6 shows the death from firedamp and other gas related accidents versus the production rate of 1 million tonnes of coal. According to Fig 5, the fatal mine accident rate per 1 million tonnes was the highest in 2012 at 2.44, while in Fig 6 the death rate from gas per 1 million tonnes was the highest in 2014 at 25.294.

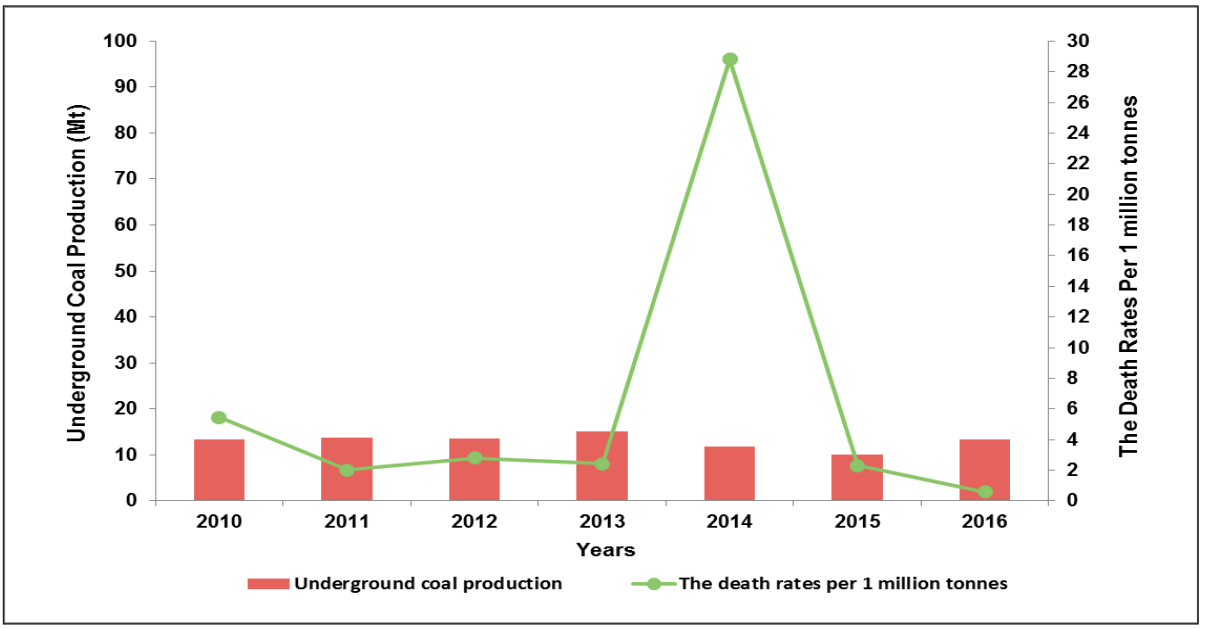

Figure 4. Coal production in Turkey's underground coal mines (lignite, hard coal) between 2010 to 2016, and the death rates per 1 million tonnes (SGK, 2016; Dev Maden Sen, 2017; TKI, 2016; TTK, 2016)

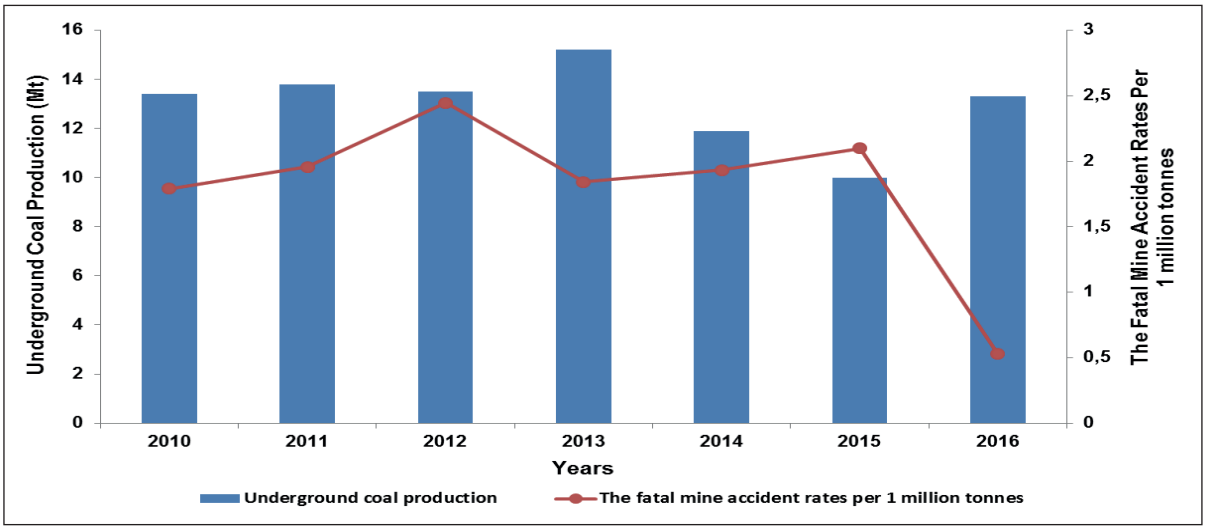

Figure 5. Coal production in Turkey's underground coal mines (lignite, hard coal) between 2010 to 2016, and the fatal mine accident death rates per 1 million tonnes (SGK, 2016; Dev Maden Sen, 2017; TKI, 2016; TTK, 2016)

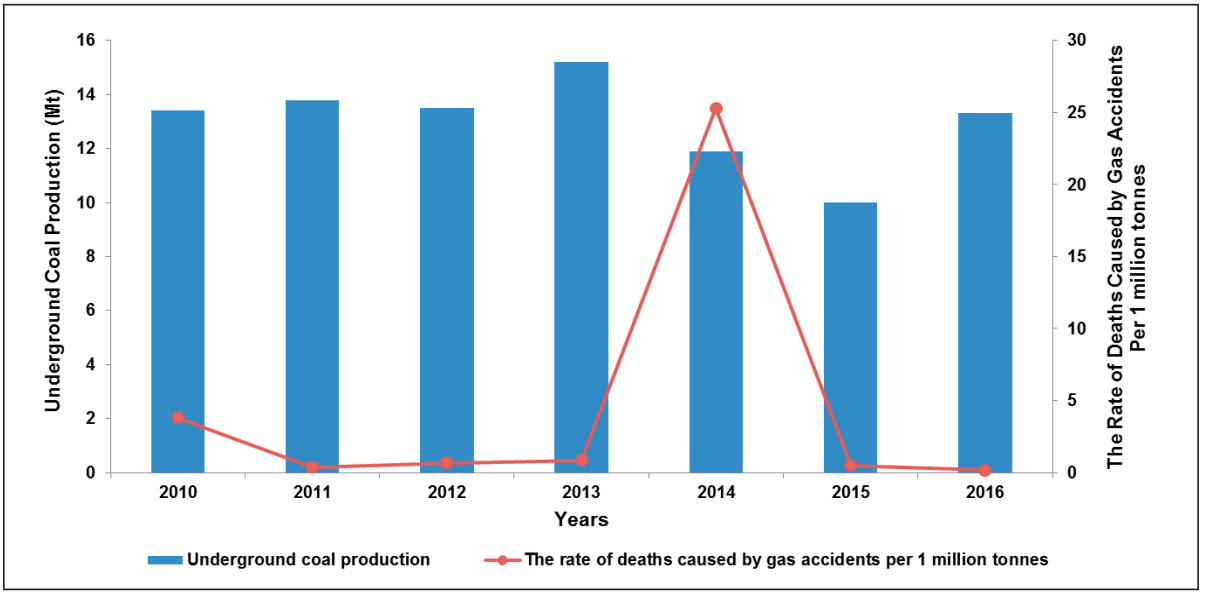

Figure 6. Coal production in Turkey's underground coal mines (lignite, hard coal) between 2010 to 2016, and the rate of deaths caused by gas accidents per 1 million tonnes (SGK, 2016; Dev Maden Sen, 2017; TKI, 2016; TTK, 2016)

Underground coal mine accidents are caused by firedamp explosions, coal or gas outburst, coal dust explosions, collapses, mine fires, transport and hoisting accidents, accidents involving energy and mechanics, poisoning and suffocation caused by various gases, water floods, electricity, use of explosives and other risks. In Turkey, the number of fatal mine accidents in underground coal mining between 2010-2016 was 163 and the total number of deaths was 550. Of these deaths, 386 were caused by deaths from firedamp and other gas accidents. When we investigated the causes of fatal mine accidents in underground coal mining in Turkey, between 2010 and 2016, it is seen that the causes of mine accidents are gathered six main categories. These categories are gas related accidents (firedamp explosion, poisoning-suffocation, and other gas accidents), collapses, transportation-support-falls, mine water floods, electrical currents and other accidents. The most frequent cause of death is firedamp explosions or other gas related accidents and the fatality rate is the highest at 70.18% (Figure 7). When analyzed the distribution of deaths caused by firedamp and

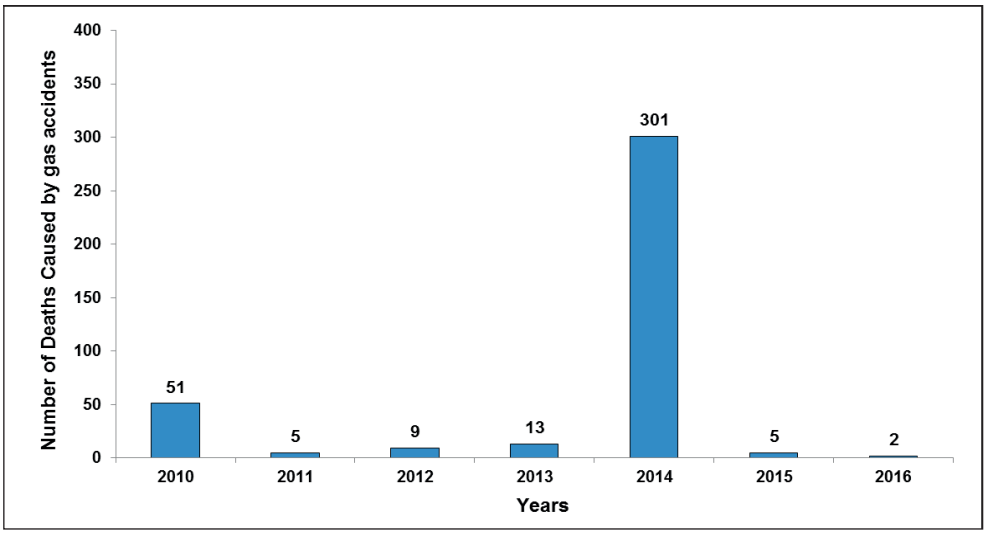

Figure 7. Percentage of different type of accident in underground coal mines in Turkey between 2010 to 2016 (SGK, 2016; Dev Maden Sen, 2017.)

other gas related accidents in years the highest rate was in 2014 due to an accident that occurred in Soma that year. In addition, the second highest rate in 2010 was due to the deaths that occurred in a firedamp explosion at Dursunbey and Karadon (Figure 8).

5. MEASURES REQUIRED TO BE TAKEN AGAINST FIREDAMP EXPLOSIONS

Since the purpose in occupational health and safety is prevention and protection, the prevention of firedamp explosions that cause mass fatalities is the most important in terms of occupational health and safety. The presence of CH_4 gas in underground is an unchangeable fact in most underground coal mines. Therefore, learning to work with CH_4 that is present in the mine, and taking precautions while being aware of the risks of CH_4 hazards, provides an accident-free working environment. It is essential that the necessary data is collected and the work is carried out in advance and done in a timely manner in order to prevent firedamp explosions and to minimize the negative consequences. It has been emphasized in this study that in order to minimize and prevent accidents caused by firedamp explosions and other gas related accidents, it is necessary to take precautions in advance. Some recommendations that need to be taken in order to avoid firedamp explosions and other gas related accidents in Turkey underground coal mines are given below;

The majority of Turkey's coal mines are small coal mine, generally coal production technology is poor, equipment is inadequate, mining methods is underdeveloped, and the adequate safety guarantee is lack.

Firstly, safety technology especially gas monitoring system should be obligated by Turkish State. Gas monitoring systems should be established in underground coal mines and abnormal gas accumulation, that is to say, the concentration of gas in the environment, should be detected immediately in case it exceeds the determined limit value and it should be dealt with in a timely manner. Continuous monitoring of the hazardous gases in mine environment is essential for ensuring safe coal production. Nowadays, in many countries, wireless sensor network technique is widely used for monitoring of hazardous gases concentration in underground coal mines. So, in Turkey, wireless sensor network technique should be used

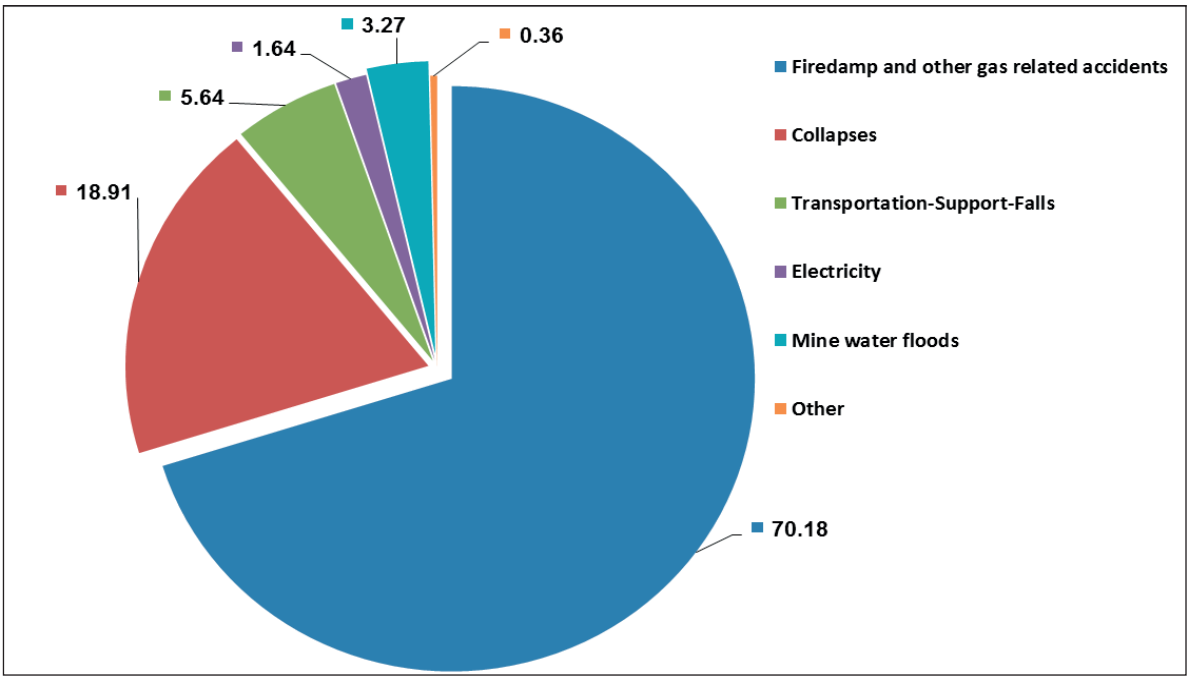

Figure 8. Fatalities caused by firedamp explosions and other gas related accidents between 2010 to 2016 (SGK, 2016; Dev Maden Sen, 2017.)

for monitoring of hazardous gases in the underground coal mine environment.

· Secondly, the No 6331 Occupational Health and Safety Law and Regulation of Occupational Health and Safety in Mine workplaces are poor for gas explosion protection control equipment and safety inspections. Explosion protection control equipment and safety inspections, firedamp explosion preventive equipment and safety measures should be increased by Law.

· Coal mine safety and gas control management is poor in Turkey. CH_4 and CO_2 are the main cause of gas outburst and explosion incidents and its great threat for the underground coal mining. These two gases should been controlled by using safety gas management technology. For this reason, continuous gas monitoring and rapid data retrieval systems should be strengthened by investigating firedamp explosion prevention and control technology in underground coal mines. In the event of the limit values of the gases being exceeded, the emergency signal should be sent automatically to the relevant units and the danger should be determined before an explosion takes place. The control and management of the ignition sources that could cause the explosion should be strengthened, ignition equipment that could trigger an explosion should be removed, and ex-proof materials should be used to prevent electric arc and sparks in electrical equipment.

· The majority of Turkey's coal mine employees don't have high level of educational, and the mobility of worker is relatively large, the training of employee's firedamp explosion knowledge needs to be strengthened. Employees should be educated about the danger of gases. The knowledge of dangers and safety conditions of underground coal mine environment should be given the employees.

· One of the most important precautions to prevent the gas concentration from rising suddenly in the mine is to have control boreholes. The application mechanism of these boreholes can be elaborated. The location of the gas meters in the central monitoring station must be adjusted according to the gas concentration, fire dams (water and dust) that prevent explosions must enter the legislation, ventilation systems must be built with computer-aided designs and scientifically proven to be realistic, the limit values of the gases referred to in the regulations must be rearranged to comply with international standards for safety and the limit values of gases not being in the regulation must be added to the legislation.

· The No 6331 Occupational Health and Safety Law and Regulation of Occupational Health and Safety in Mine workplaces should be rearranged for prevention of firedamp explosions and other gas accidents and some international standards for safety management technology should be entered the regulations.

CONCLUSIONS

This study investigated and analyzed the fatal mine accidents caused by firedamp explosions and other gas related accidents in underground coal mines in Turkey during 2010-2016, and some recommendations were made. In the last 7 years, the primary cause of fatal mine accidents in Turkey has been firedamp explosions and other gas related accidents. A serious number of deaths have occurred due to firedamp explosions. In 2014, the mine accident in Soma (fire because of gas explosion/CO poisoning) was recorded as the biggest fatal mining disaster in Turkey. In the past 7 years, 386 mine employees lost their lives in accidents resulting from firedamp explosions, poisoning, fires and other gas related accidents. These accidents also resulted in serious economic losses. When we examine the major mine accidents that have been experienced in Turkey in the last 25 years, accidents caused by firedamp explosions in underground coal mining are at the top of the list and are accidents in which many deaths occurred. As a result of the studies and researches carried out, it is clear that firedamp explosions are the greatest risk factor in underground mining. This fact is supported by Turkey and world statistics. Mass fatalities in the mining sector have often been the result of the risk of this firedamp explosion resulting in undesirable consequences. For this reason, in this study, the mine accidents caused by firedamp explosions and other gas related accidents in Turkey were analyzed and some measures and recommendations were put forward. As a result,

the main cause of firedamp explosions in the world and in Turkey is that it is not determined in time that the gas concentrations in the environment are above the determined limit values. For this reason, in underground coal mines where more or less gas is generated, gas monitoring and early warning systems must be installed and the air of the mines must be monitored and recorded throughout the existence of the mine. It is necessary to ensure both the safety of the mine and to establish a system in accordance with the relevant laws and regulations by implementing an early warning system for fire and dangerous gases. The most rational measure and solution that can be taken underground, especially in coal mining, is to monitor the levels of the gases and ensure that they are constantly kept under control.

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