Prediction of The Dust Concentration in Coal Mine by Fuzzy Fault Tree Analysis

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Abstract: The coal dust explosion is a serious problem in under ground coal mines. Especially, Turkish Hard Coal Enterprise (TTK) has high dust concentration levels. Many parameters (humidity, ash, volatile matter, Fixed-C, calorific value, toxic gas amounts et al.) effect to dust concentration. In this study, ash, volatile matter and Fixed-C parameters are evaluated by fuzzy fault tree analysis for dust concentration in the coal seams in Karadon, Kozlu, Armutçuk, Amasra and Üzülmez collieries of TTK. The fuzzy fault tree analysis (FFTA) assesses the risks to control measurement and support decision-making for personnel safety. The model can be decision of coal dust factors to remove before dust explosions occur. Results show that the volatile matter mainly effects than others to dust concentration level. Additionally, the Armutçuk colliery (the Büyük coal seam) has maximum dust level (6.36 mg/m3) and the Üzülmez colliery (the Taban Acılık coal seam) has minimum dust level (0.77 mg/m3).

Key-Words: Dust concentration, coal, volatile matter, fixed-C, fuzzy fault tree analysis (FFTA), TTK.

1 Introduction

Dust control is essential to prevent dust explosions and spontaneous combustion in underground coal mines. Dust concentration levels depend on chemical (ash, volatile matter, fixed-C, calorific value, carbon and oxygen amount and physical properties (density, porosity, gas adsorbsion, hardness, thermal conductivity, color, specific heat, friability, brightness). The volatile matter is gas and liquid materials regard on heating. The fixed-carbon is rest amount of the volatile matter [1]. When the humidity and volatile matter increase in the coal structure, the spontaneous combustion occurs in coal mine. But, the spontaneous combustion decreases due to increase the carbon amount and ash percentage [2].

Risk assessment provides a guidance for risk management since it identifies and eliminate the existing hazards. The fuzzy method uses verbal variables on behalf of quantitative exposition. The fuzzy fault tree analysis (FFTA) supplies the probability of many parameters to determine effect in underground coal mines. It assesses them from highest to lowest. Thus, it analyses the risk interested with health and safety of coal miners.

Shi et al. (2018) identified to the risk factors of coal dust and gas explosions by a fuzzy fault tree in the Xingli coal mine. Expert opinions were calculated the degrees of importance of all events [3]. Lul and Tripathy (2012) predicted of dust pollution with ANN by the meteorological data, geographical data and emission rate [4]. Sastry et al. (2015) estimated dust concentration by USEPA models [5]. Erol et al. (2013) investigated to dust levels and quartz contents by variance analysis in Turkish Hard Coal Enterprises (TTK) [6]. Jiang et al. (2020) forecasted to the safety investment decision making in coal mining enterprises [7]. Mahdevari et al. [8] collected information from three hazardous coal mines (Hashouni, Babnizu and Hojedk) in İran. They identified to 12 risks groups: materials falling, catastrophic failure, instability of coal face and immediate roof, firedamp explosion, gas emission, misfire, stopping of ventilation system, wagon separation at inclines, asphyxiation, inadequate training and poor site management system by fuzzy TOPSIS method [8]. Mottahedi and Ataei (2019) combinated of fuzzy fault tree analysis for coal burst occurrence probability analysis. According to results, the self-initiated and remotely triggered coal bursts are equal to 0.9% and 11.6% [9]. Li et al. (2019) determined to risk assessment of gas explosion ignition causes by fuzzy Bayesian network (FBN) of Babao coal mine in China [10]. Two main ignition sources are electric sparks and blasting operation. Impact friction sparks, open fire and spontaneous heating follow them. Then, Li et al. (2020) proposed the risk of gas explosion in underground coal mine by fuzzy Bayesian network (FBN) and fuzzy analytic hierarchy process (FAHP) methods of Babao coal mine in China [11]. AHP and FBN methods are feasible to provide decision makers for coal mine gas explosion risk. Yan et al. (2012) found an early warning mechanism to the risk sources by fuzzy AHP method for coal mining operations [12]. It is a human-machine-environment system. Natural geological, personnel, equipment and management factors are the risk factors of coal mine. Prostanski (2015) developed on empirical models to describe dust deposition and dust concentration in the tailgate and headgate of longwall 121 of Brzeszcze coal mine [13]. Models were concerning to air flow velocity, humidity, air temperature and distance from the longwall face.

This study presents a simple risk assessment using fuzzy fault tree method. Ash, volatile matter, Fixed-C percentages are evaluated to effect by fuzzy method for dust concentration levels. Thus, these values are taken in Karadon, Kozlu, Armutçuk, Amasra and Üzülmez collieries of TTK.

2 Study Area

The Zonguldak basin has major bituminous coal deposits along the Black Sea of Turkey. There are five collieries in for Kozlu, Üzülmez, Amasra, Armutçuk and Karadon of TTK (Fig. 1). TTK produces 704.172 tones and the workable coal reserves are 170.260.821 tons in 2012.

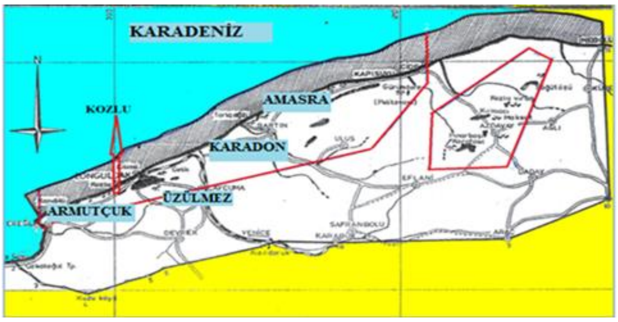


Fig. 1 Zonguldak coal basin [14]

Various parameters can effect to dust concentration levels. Such as, humidity, coal rank, ash, volatile matter, Fixed-C, calorific value, hydrogen, oxygen, nitrogen, Sulphur and carbon percentage. Ash, volatile matter and fixed-carbon values of every seams are showed in Table 1 [6].

Table 1 Ash, volatile matter and fixed-carbon values for coal seams of TTK [6]

Colliery	Coal seam	Ash (%)	Vol.matter (%)	Fixed-C (%)
Üzülmez	Kurul	7.07	28.38	64.55
	Piric	8.95	25.75	65.30
	Acun	6.83	27.08	66.09
	Taban Acılık	9.68	26.94	63.38
Karadon	Sulu	5.81	31.06	63.13
	Hacımemiş	7.24	30.60	62.16
Amasra	6. seam	14.81	39.15	46.04
	Kalın	20.45	33.53	46.02
	Tavan	27.15	30.68	42.25
Armutçuk	Büyük	8.65	34.01	57.25
Kozlu	Acılık	6.83	27.08	66.09
	Çay	6.27	29.12	64.61

The dust concentrations are estimated using fuzzy method according to Table 1.

3 Mathematical Model

Fault tree analysis (FTA) was developed in 1962 at Bell laboratories by Watson. It is a deductive failure analysis which top event (TE) estimate by combination of basic events (BEs) failure probability (Fig. 2) [9].

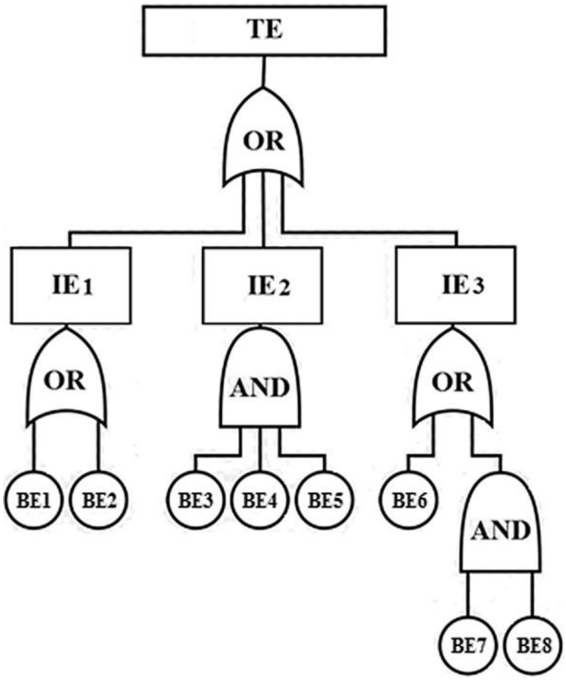
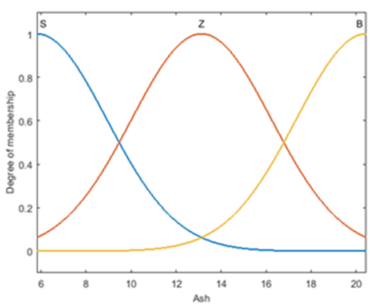
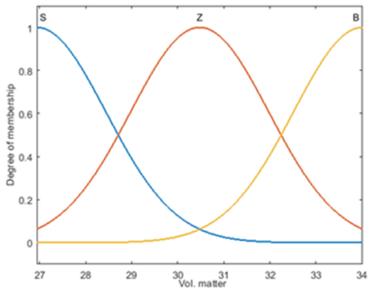


Fig. 2 Typical fault tree [9].

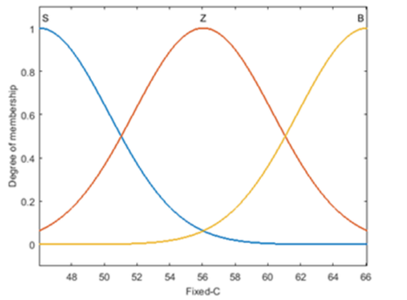
The dust concentration is estimated with the help of fuzzy inference system. Ash, volatile matter, and Fixed-C are three parameters that affect the level of dust concentration, since we take these three parameters as inputs of fuzzy inference system. According to the values given in Table 1, Fuzzy sets of all three inputs are defined as $Ash = \{S, Z, B\}$, $Vol.matter = \{S, Z, B\}$, and $Fixed - C = \{S, Z, B\}$ where the inputs are split to three fuzzy linguistics: "Small" (S), "Zero" (Z), and "Big" (B). Each linguistic is assigned by a gaussian membership function. Figure 3 demonstrates the membership functions of three inputs.



a)



b)



c)

Fig. 3 Membership functions of three inputs (a) Ash (b) Vol. matter (c) Fixed-C

The output is generated separately for each state of input variables using Sugeno inference system (Fig. 4).

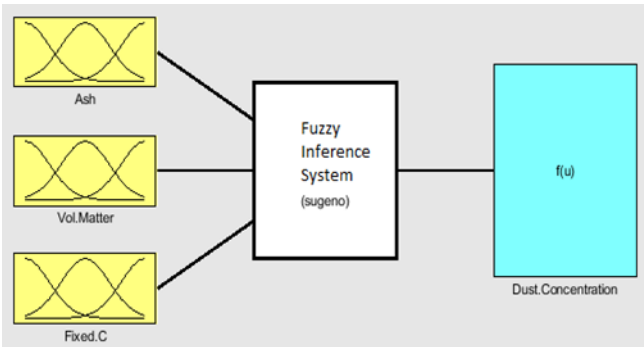


Fig. 4 Inputs and output of Fuzzy Inference System

4 Result and Discussion

In order to demonstrate the effectiveness of proposed method, various level of inputs are defined at each time step. The values of each input versus time graphs are given in Figure 5.

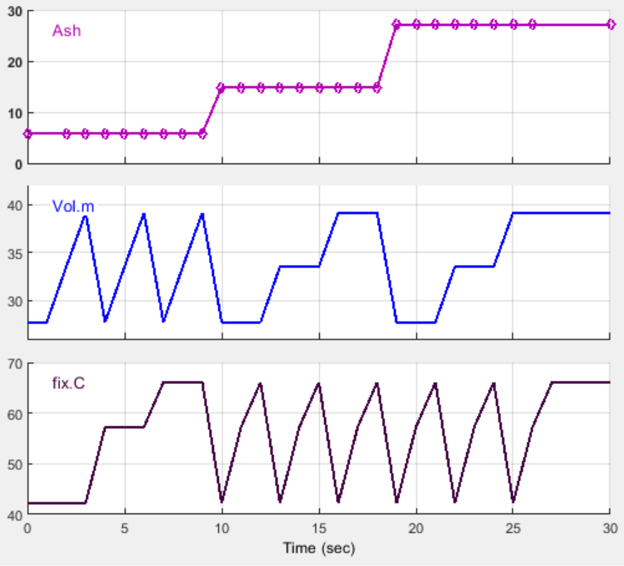


Fig. 5 Input values vs. time

Mentioned three inputs are given to fuzzy inference system and it results the output whose value versus time graph is given in Figure 6. Dust concentration according to ash, vol. matter and fixed C values can be defined using Figure 6. As seen from Figure 6, dust concentration is maximum while ash is minimum and vol. matter and fixed C are maximum.

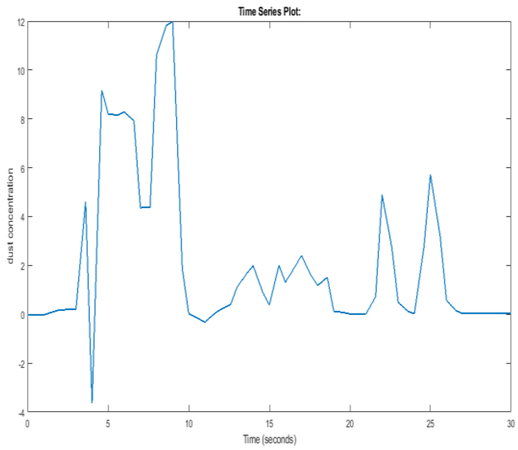


Fig. 6 Output values vs. time

Dust levels are predicted by fuzzy fault tree analysis method in table 2.

Table 2 Predicted dust level (mg/m^3) with fuzzy method

Colliery	Coal seam	Fuzzy method
Üzülmez	Kurul	3.12
	Piric	2.77
	Acun	3.47
	Taban Acılık	0.77
Karadon	Sulu	6.34
	Hacımemiş	5.4
Amasra	6. seam	1.28
	Kalın	4.52
	Tavan	1.5
Armutçuk	Büyük	6.36
Kozlu	Acılık	3.47
	Çay	3.51

When the Taban Acılık coal seam has least dust level (0.77 mg/m^3) in Üzülmez colliery, the Büyük coal seam has most dust level (6.36 mg/m^3) in Armutçuk colliery. If we consider to average values for every colliery, Armutçuk colliery has maximum dust level (6.36 mg/m^3). Amasra colliery has minimum dust level (2.43 mg/m^3). The average dust levels from maximum to minimum are Armutçuk (6.36 mg/m3), Karadon (5.87 mg/m^3), Kozlu (3.49 mg/m^3), Üzülmez (2.53 mg/m^3) and Amasra (2.43 mg/m^3) collieries, respectively. Dust concentrations are estimated by fuzzy method take account of minimum, maximum and average values (Table 3) of ash, volatile matter and Fixed-C values in every condition.

Table 3 Predicted dust concentration values (mg/m^3)

Ash (%)	Vol.matter (%)	Fixed-C (%)	Dust con. (mg/m3)
5.81	27.75	42.25	-0.02
5.81	33.53	42.25	0.18
5.81	39.15	42.25	0.20
5.81	37.75	57.25	**-3.61**
5.81	33.53	57.25	8.19
5.81	39.15	57.25	8.28
5.81	27.75	66.09	**4.36**
5.81	33.53	66.09	0.11
5.81	39.15	66.09	**11.98**
14.81	27.75	42.25	0.02
14.81	27.75	57.25	-0.32
14.81	27.75	66.09	0.20
14.81	33.53	42.25	1.11
14.81	33.53	57.25	1.98
14.81	33.53	66.09	0.37
14.81	39.15	42.25	1.30
14.81	39.15	57.25	2.40

14.81	39.15	66.09	1.18
27.15	27.75	42.25	0.12
27.15	27.75	57.25	0.02
27.15	27.75	66.09	0.02
27.15	33.53	42.25	4.88
27.15	33.53	57.25	0.48
27.15	33.53	66.09	0.02
27.15	39.15	42.25	5.72
27.15	39.15	57.25	0.56
27.15	39.15	66.09	0.06

According to Table 3;

1. When ash and volatile matter are minimum and Fixed-C is maximum, dust concentration is average value.
2. When ash is minimum and volatile matter and Fixed-C are maximum, dust concentration is maximum value.
3. When ash and volatile matter are minimum and Fixed-C is average, dust concentration is minimum value.

5 Conclusions

In this study, ash, volatile matter and Fixed-C values were compared to determine the effect of dust concentration level. The dust concentration levels predicted using fuzzy fault tree analysis. The Taban Acılık coal seam (Üzülmez colliery) is minimum dust level (0.77 mg/m3) and The Büyük coal seam (Armutçuk colliery) is maximum dust level (6.36 mg/m^3). When we are take in to average values for every colliery, Armutçuk colliery is maximum dust level (6.36 mg/m^3), Amasra colliery is minimum dust level (2.43 mg/m^3).

According to minimum, maximum and average values of ash, volatile matter and Fixed-C, the ash percentage does not affect the dust concentration value. On the other hand, the volatile matter percentage maximum effects dust concentration levels. The Fixed-C percentage effects at average degree to dust concentration level.

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