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A comprehensive study on the effect of moisture content on coal spontaneous combustion tendency

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Abstract

There are several phenomenons for polluting the environment, especially in coalfields; which coal spontaneous combustion is one of them. The moisture content is one of the intrinsic characteristics of coal, which has an important role in the occurrence of this phenomenon. Therefore, this research predicts the coal spontaneous combustion tendency based on moisture content. The percentage of moisture content is a very important parameter on the occurrence of this process; so far a conclusion about the effect of moisture content on coal spontaneous combustion, a comprehensive study was done. 55 coal samples with different percentage of moisture content for the training of overall underground coalfields in Iran were collected and the CPT test method for each coal sample was carried out. Then, the method of regression analysis was used for modeling and predicting the coal spontaneous combustion tendency. The results show, the coal sample undergoes oxidation most rapidly when the moisture content supply is about under 20%, and it can reduce coal spontaneous combustion in excessed of 20%, because when moisture is present in excessed of 20%, the heat released by oxidation is used to evaporate the moisture. For validation and testing, 15 coal samples of another coalfield were collected and the CPT test method for each coal sample was carried out, and the results of the test method were compared by the regression equation. The results obtained from the models show that a good appropriate prediction has been done for determining the coal spontaneous combustion tendency by regression analysis.

Keywords: *Pollution, Coal Spontaneous Combustion, Moisture Content, CPT.*

1. Introduction

The coal spontaneous combustion hazard is a very common phenomenon in coal mines. In this occurrence, coal is exposed to the atmosphere and reacts with oxygen as a result of which it catches flame. This phenomenon is caused by two interrelated processes, viz. the interaction between oxygen and coal (oxidation) and the exothermic reaction (heat produce process), leading to heat build-up in coal due to intrinsic characteristics, and start an open flame (Singh et al. 2018). This phenomenon can occur anywhere in all stages of coal mining. Environmental components are badly affected due to the release of noxious gases after the occurrence of coal spontaneous combustion. This phenomenon affects the direct loss of equipment, damage to the surface, loss of country's precious coal reserves, release noxious gases, heat, smoke, dust, and poses a serious environmental, economic, and social threat. Due to occurrence of coal spontaneous combustion, the basic elements of the environment, i.e. air, water, and land, are seriously affected, which described in following and shown in Figure 1 (Kuenzer et al. 2007; Querol et al. 2011; Singh et al. 2018).

Air- The coal spontaneous combustion release noxious gases such as CO, CO_2, NO_X, SO_X and other particulates, toxic organic compounds, toxic trace elements such as arsenic, Hg and selenium, and heat are being continuously discharged to the atmosphere and polluting the environment (Finkelman 2004).

Water- The coal spontaneous combustion pollutes water, increasing its acidity as well as pollutions it with tarry distillation products. Due to the presence of sulfur (higher percentage of 1-2%) in coal in the form of pyrite, mine water may be acidotic, and coal oxidases easily in the presence of air and moisture at an ordinary temperature as shown in following equations (Wiese et al. 1987, Beamish et al. 2012, Arisoy and Beamish 2015, Deng et al. 2015):

$$FeS_2 + 8H_2O + \frac{7}{2}O_2 \rightarrow FeSO_4.7H_2O + H_2SO_4 \ (\Delta H = -1465.49 kJ)$$

$$FeS_2 + 8H_2O + 7O_2 \rightarrow FeSO_4.7H_2O + SO_4^{2-} + 2H^+$$

$$FeS_2 + 7O_2 + 16H_2O \rightarrow 2H_2SO_4 + 2FeSO_4.7H_2O + 1321 \text{ kJ}$$

$$FeS_2 \xrightarrow{O_2+H_2O} FeSO_4 \underset{O_2+H_2O+FeS_2}{\overset{O_2+H_2O}{\rightleftarrows}} Fe_2(SO_4)_3$$

The above equations suggest that oxygen and moisture are two prime weathering factors, which contribute to the pyrite alteration shown and it also leads to the formation of sulphuric acid as by-product of the alteration process. The presence of moisture doubles the reactivity rate of coal and the presence of pyrite in dispersed form 10 folds the actual reaction rate (Mahananda 2014).

Land- The surface structure is damaged due to the coal spontaneous combustion; cracks have been developed and nearby vegetation are badly affected due to heat, smoke, dust and high temperature.

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In general, the most important hazards created by this phenomenon are listed below, which include (Saffari et al. 2013; 2017; 2019):
- Mortality of personnel;
- Psychic perturbations in survivors of calamity;
- Pollution of the air, water, and soil in the vicinity of the burning coalfield; this is a hazard to the ecosystem of the region;
- Emissions from coal spontaneous combustion not only pollute the local atmosphere but also add substantial amounts of the greenhouse gases (CO_2 and CH_4) along with SO_x, NO_x, H_2S, and CO;
- Subsidence of land surface;
- Climate change and its contribution to global warming;
- Mine closures;
- Loss of equipment;
- Loss of production;
- Useless loss of a non-renewable energy resource;
- Loss of popularity and market position;
- Costs of therapeutic and recovery measures.

Due to the intrinsic characteristics of coal, the phenomenon has occurred in coal mines. Moisture exists, more or less, in all kinds of coal. The moisture in coal exists either as surface moisture, inherent moisture, or as constitutional moisture. Coal oxidation is usually affected by surface and inherent moisture. Surface moisture can be removed by drying at 40-50 ºC, but the inherent moisture cannot be removed below temperatures of 105-110ºC (Xuyao et al. 2011).

The moisture content has an important role in this phenomenon. In particular, the influence of moisture content of coal which, leading to spontaneous combustion has remained unclear despite has been studied over a long period by researchers. It is generally accepted that there are competing influences of the heat of wetting and moisture evaporation depending on the environmental circumstances of the coal. The moisture content of coal influences coal oxidation, and there are opposite effects of moisture content on the coal spontaneous combustion (Bhat and Agarwal 1996; Liang and Wang 2003; Xu et al. 2013). By some the presence of moisture content has been considered as absolutely required before spontaneous combustion will take place; others told that moisture merely facilitates or accelerates the self-heating that would take place without it; while still others claim that even a small amount of moisture will prevent of coal spontaneous combustion.

Scholars have already conducted researched on how moisture content affects coal spontaneous combustion propensity, which, a summary of the results of this researches is following.

Jones and Townend (1949) claimed that coal moisture content controls peroxide complex formation, and humidity is essential in the process, because it not only acts as a catalyst but also directly determines the amount of the peroxide complex formed. Yohe (1958), observed a more rapid oxidation rate for coals with greater moisture content than those with lesser moisture content. King et al. (1964) believed that humidity catalyzed the formation of the peroxide complex. Hodges and Hinsley (1964) and Bhattacharyya et al. (1968) stated that the reactivity of coal with oxygen when coal is wet much faster than coal is dry. Bhattacharyya (1972) studied the effect of desorption of moisture from coal and concluded that moisture acted as an inhibitor to the spontaneous heating of coal. Hodges et al. (1976) claimed that higher moisture content or higher humidity leads to higher coal oxidation rates. Armstrong (1979) reported at higher moisture levels, heating was much reduced, possibly rate-limited by oxygen diffusion through a thick boundary layer of water surrounding iron particles. Schmal et al. (1985), and Li and Skinner (1986) owing to the presence of the moisture and expressed, the time after which self-ignition can begin may be appreciably longer than in dry coal. It follows that local self-ignition can be delayed by injecting water at points where the coal is becoming dry. Buckmaster and Kudynska (1992) is considered that moisture in coal also leads to the release of the latent heat during vaporization and the heat will raise the temperature of the coal and increase the rate of oxidation. Also, moisture plays an important role in producing peroxide complexes and free radicals in coal, which leads to the oxidation of coal more rapidly. Reich et al. (1992) demonstrated that the external moisture can fill the space between the coal particles and blocks oxygen from the coal; once heated, high steam pressure resulting from the moisture evaporation can also block oxygen from the coal and hinder coal spontaneous combustion. Chen and Stott (1993) compared the oxidation rates of Ohai coal at 50ºC and found that a maximum oxidation rate occurred at a critical moisture content range of 7%–17%. The calculations of a mathematical model for the spontaneous combustion of stored coal carried out by Arisoy and Akgün (1994), showed that the moisture content of coal had a major retarding effect on spontaneous heating. Field observations of Bhat and Agarwal (1996) have consistently indicated that moisture condensation can enhance the potential for spontaneous combustion. Vance et al. (1996) reported a maximum oxidation rate in sub-bituminous coal at a moisture content of about 7% and temperatures < 80°C. Ceglarska-Stefanska et al. (1998) expressed the interaction of coal with water (deposition of water molecules on coal) and the relationship between moisture content and spontaneous combustion of coal, is dependent on adsorption, absorption, and desorption processes and the physico-chemical characteristics of the coal. Gong et al. (1999) reported the oxidation rate increases with moisture content. According to Kawatra and Hess (1999), 10-15% moisture-induced rapid heating, via atmospheric oxygen, of iron grinding swarf. Ren et al. (1999) observed that dry coal had a higher tendency to combust spontaneously. Kaymakçi and Didari (2002) and

Kadioğlu and Varamaz (2003) declared that the values of ignition temperatures increased with an increase in moisture. Küçük et al. (2003) emphasized the increase in the moisture content of the air caused a directly proportional increase in the values of ignition temperatures. Also, they said, moisture content had a significant influence on the heat released during the low temperature oxidation of coal, for it will not only affect the physical characteristics of coal but also will affect the chemical reactions of coal. Wang et al. (2003) found a "threshold" for coal moisture content that depends on maximum oxygen consumption. When coal moisture content surpasses the "threshold", extra water formulates a multilayer structure and hinders oxygen diffusion in pores and tunnels. Therefore, the chemical adsorption reaction between coal and oxygen slows down. Beamish and Hamilton (2005), and Beamish et al. (2005) are considered that the relative reactivity of wet coal is lower compared to dry coal, and the coal spontaneous combustion reactivity index is sharply reduced in wet coals. Pone et al. (2007) stated the interaction of coal with water may be described by two opposing processes. In the first process, the moisture content of coal is driven off by evaporation during the early stages of heating. Hence, some of the heat is removed in water vapor as latent heat of evaporation. The second process involves the adsorption of water vapor from air by coal. The heat of adsorption produces an increase in the temperature of the material. The net effect depends on which of the two processes dominates. Singh et al. (2007), Beamish and Beamish (2010, 2011), and Saffari et al. (2013) stated that with increasing moisture content of coal samples, the temperature of coal also increased more strongly and the tendency to coal spontaneous combustion increases. After performing a thermal dynamic analysis, Li et al. (2009) explained that dry coal is prone to spontaneous ignition under high humidity conditions. Wang et al. (2009) found that moisturized coal powder is easier to spontaneously ignite than coal power. Wang et al. (2013) found that lignite was prone to spontaneous combustion when the coal moisture content reaches 35 %. On the contrary, spontaneous combustion is unlikely to occur when its moisture content registers just 30%. When gas coal moisture content was higher than 35 %, it showed little tendency of spontaneous combustion. As for meager coal, moisture content of 25 % also showed a slight tendency of spontaneous combustion. Xu et al. (2013) expressed, the maximum heat release occurred for moisture content of 25% while the minimum heat release occurred for moisture content of 20%. Also, they said lignite had a stronger exothermicity for the different moisture contents. The exothermic condition occurred during the entire oxidation process, which may be the reason for lignite being the coal with most prone to spontaneous combustion. Panigrahi and Ray (2014) concluded that statistical analyses indicate that with the increase of moisture, volatile matter, and oxygen and hydrogen susceptibility to spontaneous heating of coal increases. Choudhury et al. (2016) obvious, due to higher inherent moisture content (30-40%) of lignite than sub-bituminous coals (10–15%), the attainment of equilibrium moisture with atmospheric humidity is delayed, thus inhibiting spontaneous heating phenomena. Onifade and Genc (2018) said an increase in moisture can complement the proneness to spontaneous combustion. Wang et al. (2018) showed that increasing the humidity of oxygen gas plays a very important role in initiating the process of coal spontaneous combustion. Wu et al. (2018) showed the moisture content has a distinct retardation effect on the heating process of the coal dust samples, which the higher the moisture content, the slower the heating process.

All of these endeavors have shown how moisture plays a significant role in low-temp oxidation of coal, but the results of these researches are contradictory and moisture content has a complex influence on the coal spontaneous combustion tendency. So a comprehensive study for evaluation of the effect of moisture content on coal spontaneous combustion tendency is necessary. Heat is a direct parameter to reflect the oxidation process of coal, because coal with a higher tendency for spontaneous combustion will release more heat during oxidation. Therefore, in this study, 55 coal samples with different percentage of moisture content for training of overall underground coalfields in Iran (Tabas Parvadeh coal mines, Eastern Alborz coal mines, and Kerman coal mines) was collected and CPT test method for each coal samples was carried out, and general equation was regression between moisture content and these indexes. Then for validation and testing of this equation, 15 coal samples of Central Alborz coal mines, which is one of coalfields in Iran was collected and CPT test method for each coal sample was carried out, and the results of the test method were compared with the regression equation.

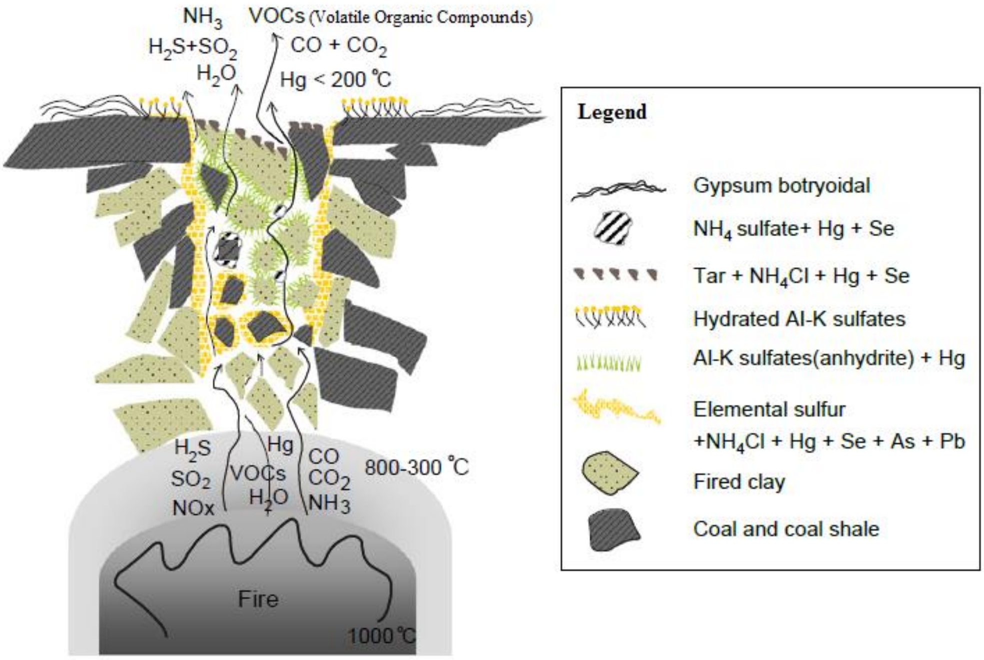
2. Materials and methods

2.1. Coal samples and Laboratory studies

There is several numbers of tests available to an assessment of the spontaneous combustion propensity of the coal. The CPT test method is used successfully for this purpose (Arisoy 2010). In this study of datasets, 70 coal samples were collected and laboratory tests (Moisture content, and CPT test method) were conducted.

Coal samples were freshly collected directly from the worked face of the mine, after removing a coal seam of approximately 25 cm thickness to avoid the possibility of peroxidation and sent in a plastic container- air sealed, which was filled with nitrogen, containing approximately 5 kg of coal, mostly in lump form. The samples were transported to the laboratory in an ice-filled insulated container to avoid its peroxidation.

(a)



(b)

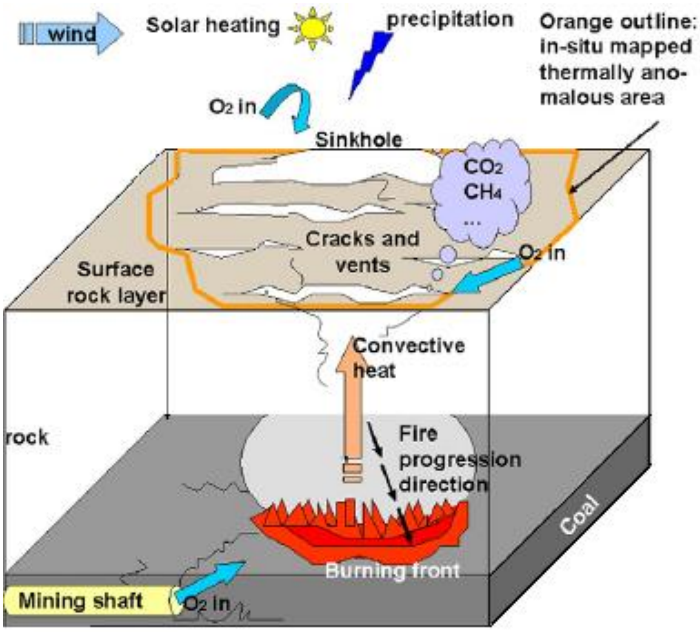


Fig 1. a) Air pollution due to coal spontaneous combustion (Querol et al. 2011), b) Differnet aspects of pollution due to coal spontaneous combustion (Kuenzer et al. 2007).

The samples were delivered to the laboratory as rapidly as possible. On arrival, the samples were transferred to a freezer for storage until required for testing. To minimize unnecessary oxidation, the sample was maintained in lump condition and was kept undisturbed in the laboratory before each test. After the test facility was ready, the plastic bag was unwrapped and the surface was removed and the interior core was crushed to obtain the samples. For the CPT test, the coal particles ranging from 0.18 mm to 0.38 mm were sieved to provide the experimental procedure. The CPT test method requires 60 g (±0.01 g) and 150 g (±0.01 g) of crushed coal samples were packed into the coal reaction vessel, respectively.

To minimize the effects of oxidation on fresh surfaces, coal test samples just before each run created by the grinding of the coal.

Samples were prepared from different coalfields from Iran which 55 coal samples for training were collected from Tabas Parvadeh coal mines, Eastern Alborz coal mines, and Kerman coal mines and general equation were regression between moisture content and the CPT index. Then for validation of this equation, 15 coal samples for testing of Central Alborz coal mines, which is one of coalfields in Iran was collected and the CPT test method for each coal sample was carried out, and the results of the test method were compared with the regression equation.

The coal deposits of Iran are Mesozoic (Jurassic) in age, with some Lignites of Paleogene-Neogene age. The Jurassic coals are bituminous with high ash and sulfur contents and have coking properties. All are strongly tectonized with seam thicknesses ranging from 1 m to 4 m. The coal supplies local needs and the metallurgical industry (Thomas and Thomas 2002).

Figure 2 shows the locations of case studies. The basic descriptive statistics of the moisture contents for this study are given in Table 1.

Fig 2. Locations of Case studies. (1. Eastern Alborz Coal Mines, 2. Tabas Parvadeh Coal Mines, 3. Kerman Coal Mines, 4. Central Alborz Coal Mines)

Table 1. Basic descriptive statistics of the moisture contents for this study.

Statistic	Value	Percentile	Value
Sample Size	55	Min	0.244
Range	35.256	5%	0.6702
Mean	6.6566	10%	1.0888
Variance	92.328	25% (Q1)	1.385
Std. Deviation	9.6088	50% (Median)	2.739
Coef. of Variation	1.4435	75% (Q3)	5.036
Std. Error	1.2956	90%	26.56
Skewness	2.0628	95%	32.844
Excess Kurtosis	2.9775	Max	35.5

2.2. Experimental apparatus and method

2.2.1. Crossing point temperature (CPT) method

The temperature at that point where the coal temperature begins to exceed the surrounding temperature is the so-called crossing point temperature (CPT) (Xuyao et al. 2011).

The method of CPT is a very important way to reveal the mechanism of coal spontaneous combustion and it is still widely used today. In the experiment, a prepared coal sample is placed into a gauze container and the oven temperature is controlled. The progression of temperature with time in the process of coal's reaction with air or oxygen and the oven temperature is recorded. When the coal sample temperature equals the linearly ramped oven temperature, the temperature is called the crossing point temperature, as shown in Figure 3. The CPT is used as an index to classify the propensity of coal to spontaneous combustion. (Chen 1991). The CPT method is widely used in India, Turkey, New Zealand South Africa, Poland, and China and has been improved recently (Mohalik et al. 2016).

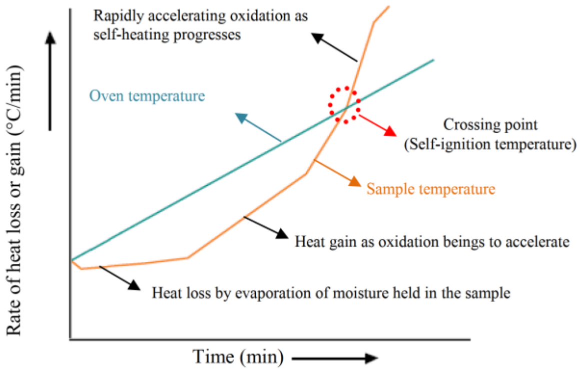


Fig 3. Schematic diagram of crossing point temperature (Kim 1995).

The essence of this method is as follows. The coal sample is placed in the oven which is being heated at a constant rate. The programmed adiabatic oven was set to run at a constant temperature of 50 °C while dry air with oxygen was permitted to flow through the coal reaction vessel at a rate of 50 mL/min. The temperature logger was used to continuously monitor the coal and surrounding temperatures. When the coal temperature reached 50 °C, the programmed adiabatic oven was set to increase the temperature at a programmed rate of 1 °C/min while the flow rate of dry air was maintained at 50 mL/min. The experiment ended when the coal temperature was higher than the surrounding programmed adiabatic oven and when the coal sample temperature equals the linearly ramped oven temperature, the temperature is called CPT (Nugroho et al. 1998; Xuyao et al. 2011).

2.2.2. Testing system

Figure 4 shows a schematic diagram of the set applied for the low-temperature oxidation of coal. Figure 5 shows a schematic Sample container (Bomb) of the apparatus. The instrument is consisting of the following,

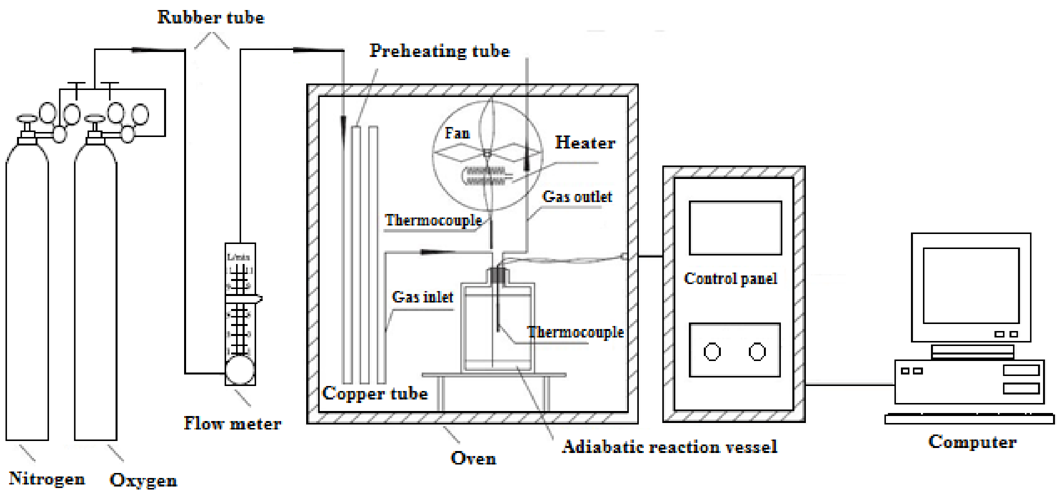


Fig 4. A schematic diagram of the apparatus applied for the low-temperature oxidation.

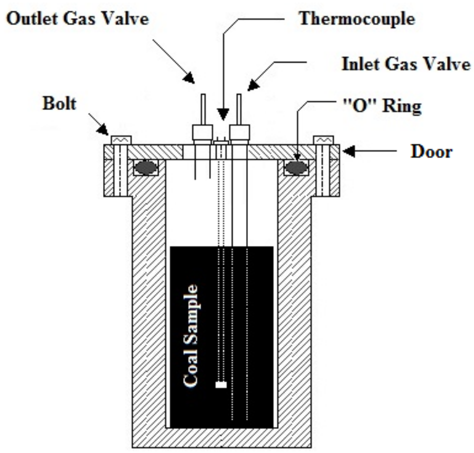


Fig 5. Sample container (Bomb).

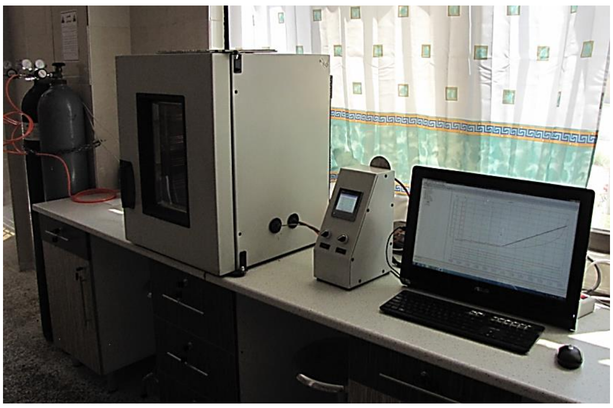


Fig 6. The testing system.

which shown in Figure 6, and was made in Shahrood University of Technology in Iran (Faculty of Mining, Petroleum & Geophysics Engineering).

- Temperature-programmed adiabatic oven (It is applied to control the temperature of the coal samples, whose temperature ranges from room temperature to 400°C with the precision of 1°C in the control).
- Electric heater
- Fan
- Sample container (Bomb) (was made of pure aluminum and is respectively connected with an inlet for air supply path, thermocouple for temperature measurement and an outlet for the air outlet path) (Figure 5).
- 15 m gas preheating copper tube
- Two thermocouples (Thermocouple #1, used to monitor the oven temperature, and thermocouple #2, was used to measure the coal sample temperature)
- JUMO Dicon touch (Control panel), which is consist of:
- Data logger (For records the temperature changes in the coal sample with time)
- Micro-controller (the programmed adiabatic oven was set to increase the temperature with a micro-controller).
- Computer
- 50 kg O_2 gas cylinder (The air supply system).
- 50 kg N_2 gas cylinder (For preheating of coal sample to 50°C for start test).
- Pressure reducing valve
- Flowmeter

3. Modeling and discussion

This section aims to provide an optimal model for predicting the coal spontaneous combustion tendency based on the regression analysis. For modeling in this research, after conducting the experimental tests, a set of data including 70 experimental tests is collected, among which 55 test samples are selected as training data and the rest, 15 data, are selected as the test data. Additionally, as mentioned above, the moisture content is considered as the input data and the CPT test method is the output parameters of the coal spontaneous combustion tendency model.

Results of moisture content fit CPT test method in Tabas Parvadeh, Eastern Alborz, Kerman coal mines which used for training data are shown in Figure 7, and regression analysis is given in Equation 1.

$$CPT = \begin{cases} 199.82M^{-0.274}; \quad M \le 20\%; \quad R^2 = 0.74 \\ 0.1981M^{1.9876}; \quad M > 20\%; \quad R^2 = 0.9897 \end{cases}$$

Where, M is moisture content.

As shown in Figure 7, the coal spontaneous combustion status shows two different stages due to the moisture content of coal. Generally, the maximum propensity of coal spontaneous combustion increases steadily for low-medium moisture content (about fewer than 20%) of coal.

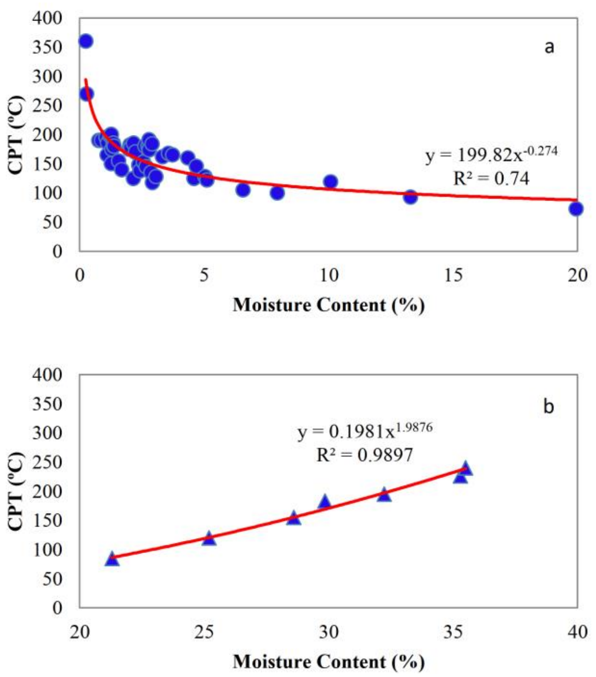


Fig 7. Integration results of moisture content fit CPT test method, a) Moisture content ≤20%, b) Moisture content >20%.

However, in high moisture content (in excessed of 20%) coals, temperature increase rapidly at the beginning and then evaporation becomes effective and the temperature approaches to a steady-state value. In this stage, heat liberation due to chemical reaction and heat dissipation due to evaporation and other transfer mechanisms are approximately equal, so the propensity of coal spontaneous combustion is decreased. Moreover, the existence of moisture can obstruct oxygen from accessing the coal surface. Hence, moisture in coal can play an inhibiting role in the process of spontaneous combustion of coal. Therefore, at this level, a safety issue is creating which is due to the very high moisture content of coals.

It is considered that another inhibiting effect of moisture in high percentages is that the moisture condensed in pore channels blocks the oxygen diffusion toward the reaction sites at pore walls (Wang et al. 2003). Once oxygen molecules are accessible to almost all reaction sites in coal pores, moisture will play an active role in coal oxidation for it is necessary for the chemisorptions reactions and chain reactions (Clemens et al. 1991; Chen and Stott 1993; Wang et al. 2002; Xu et al. 2013). Thus, moisture's ability of heat-absorbing helps to cool down coal's temperature. Besides, the water film formed isolates oxygen from coal and inhibits its spontaneous combustion (Yang et al. 2017). As shown in Figure 8, when moisture is existing in pores of coal in high percentages, moisture doesn't allow to oxygen for reacting with coal, but when the moisture is evaporating, the porosity of coal is increasing, and the oxygen will be adsorption in micro-pores of coal and the temperature of coal is enhancing, and coal spontaneous combustion tendency is accelerating.

4. Validation of the proposed models

In this section, the performance of the developed prediction models was evaluated using the 15 collected coal samples of Central Alborz coal mines in Iran. CPT test method for each coal sample was carried out and the results of the test method are given in Table 2 and Figure 9. Then based on presented models in Equation 1, the CPT test method for testing data was predicted and the predicted values were compared with measured values. Table 2 and Figure 10 show this comparison between the predicted CPT using the proposed regression models with the actual CPT values.

Table 2. Measured and predicted values by the proposed regression model for testing datasets.

Sample No.	Moisture Content (%)	Measured CPT (°C)	Predicted CPT (°C)
1	1.233	181	188.68
2	1.435	185	181.00
3	0.918	168	204.56
4	3.297	150	144.10
5	1.830	186	169.33
6	0.470	174	245.75
7	1.100	160	194.68
8	0.990	201	200.38
9	3.700	145	139.62
10	1.318	195	185.26
11	2.005	165	165.14
12	25.800	122	126.65
13	34.100	198	220.49
14	35.400	226	237.51
15	36.100	270	246.94

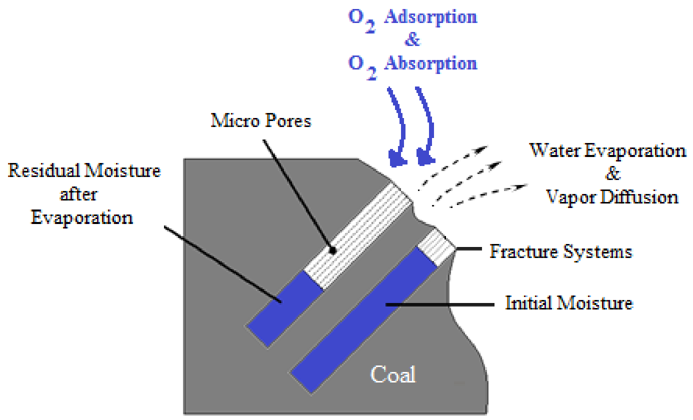


Fig 8. Water evaporation, O_2 adsorption, and O_2 absorption in micro-pores of coal, and accelerating of coal spontaneous combustion tendency.

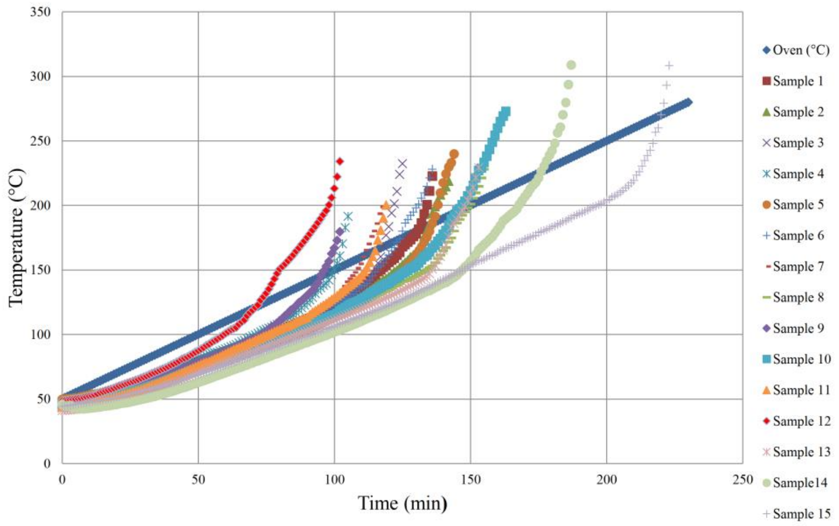


Fig 9. CPT test results for Central Alborz coal mines samples (testing data).

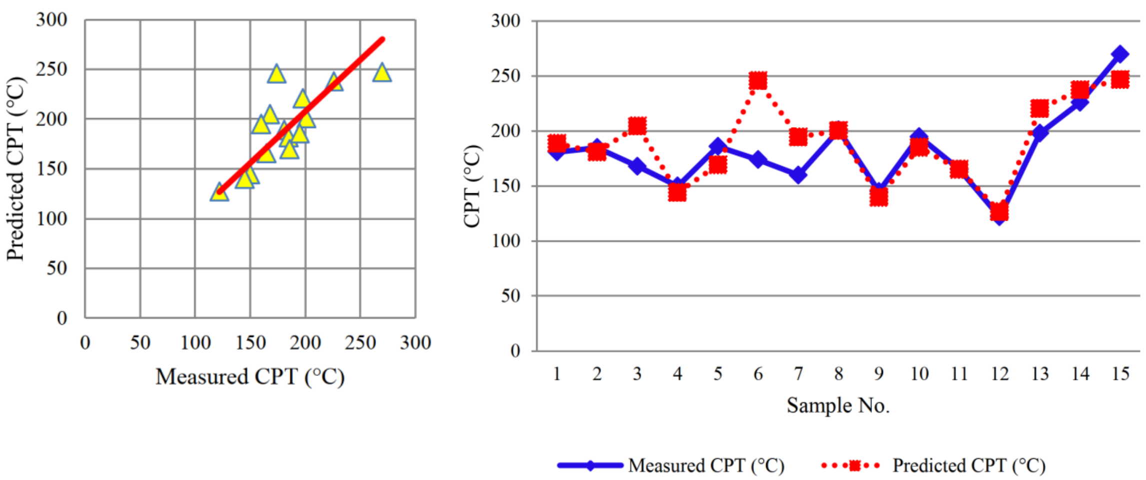


Fig 10. Comparison of the measured and the predicted values of the CPT test method for testing data.

5. Conclusions

Coal spontaneous combustion is one of the most important phenomenon responses for polluting the environment and creating contamination. The moisture content in coal has an important role in this phenomenon. But there are disagreements among researchers about the impact of this key parameter on this occurrence, as they said, the moisture content of the coal can serve as both an initiator and a deterrent for spontaneous combustion. After a comprehensive study in the literature review, that's clean the percentage of moisture content is very important on the occurrence of this phenomenon. Therefore, for a conclusion about the effect of this parameter on coal spontaneous combustion tendency, a comprehensive study was done. In this study, 55 coal samples with different percentages of moisture content for training data of overall underground coalfields in Iran were collected and CPT test method for each coal samples was carried out. Then, 15 coal samples for testing from another coalfield in Iran were selected and used for validation of the regression equation. Coal samples were oxidized in an adiabatic oven in the "as-received" state. The results shown, moisture content cans effects on the coal spontaneous combustion in two ways, which the important findings arising out of this study are summarized below:

1) The presence of moisture a low level in coals is as a catalyst (just as it catalyzes iron oxidation). The process potentially feeds itself as higher temperatures cause faster reaction rates that further raise temperatures and oxygen demand. The results show, the coal sample undergoes oxidation most rapidly when the moisture content supply is about fewer than 20%. So, the moisture content (under 20%) in coal has a great influence on the heat released during coal oxidation at low temperatures. On the other hand, when the process of wetting is followed by evaporation, the coal pores are swelled and then cleared. With the pores cleared, a larger surface area is exposed for the coal to react with the oxygen and advance the process of spontaneous combustion.

2) The moisture content can reduce coal spontaneous combustion in excessed of 20%, because when moisture is present in excessed of 20%; the heat released by oxidation is used to evaporate the moisture. So, at high moisture levels, there is too much water available and the self-heating is hindered by the heat loss from moisture evaporation. As the moisture evaporates, the evaporation cools the surface temperature of the coal and can delay or even stop the spontaneous combustion process.

The results reached in this study indicate that there is a definite need to consider the influence of moisture in the coal on spontaneous combustion because moisture content has a complex behavior, which should be carefully checked.

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