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Investigation of the effects of different drying methods on coal grindability

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Abstract

Some factors affect the coal grindability such as moisture content, petrographic composition, hardness, fragility and rank of the coals. The grindability of the pre-heated coal is assumed to be positively affected and facilitates size reduction processes. In this study, effects and relationship of traditional drying methods (air circulated fan oven and air drying) and microwave drying on the grindability of coals were investigated. For this purpose, two different lignite coals; Tufanbeyli and Ilgın lignite coals were selected. The research parameters; drying method, drying temperature, drying time were selected as independent variables. The particle size distributions of ground coal samples in a rod mill, under the same conditions were determined. The particle size distribution, d_{50} and d_{80} values of the ground coals were considered as dependent variables. As a result of the experimental studies, it was found that the finest coal particle size distribution was determined to be Tufanbeyli lignite, which was dried at 105 ºC for 240 minutes. The d_{50} and d_{80} values were 95 µm and 130 µm and Ilgın coal was reached at the microwave-dried coal at 800 W for 20 minutes, while the d_{50} and d_{80} values were 100 µm and 205 µm, respectively.

Keywords: Coal drying, Grindability, Lignite, Microwave energy

Farklı kurutma metotlarının kömür öğütülebilirliği üzerine etkilerinin araştırılması

Özet

Kömürlerin öğütülebilirliğini; nem oranı, petrografik birleşimi, sertlik, kırılabilirlik ve yaşı gibi faktörler etkilemektedir. Ön ısıtma işlemine tabi tutulan kömürlerin öğütülebilirlikleri olumlu yönde etkilenmekte ve boyut küçültme işlemlerini kolaylaştırabileceği bilinmektedir. Bu çalışmada geleneksel kurutma yöntemleri (sabit ısıtmalı fanlı hava sirkülasyonlu etüv, havada kurutma) ile mikrodalgada kurutmanın kömürün öğütülebilirliğine olan etkileri ve ilişkileri araştırılmıştır. Bu amaçla iki farklı linyit kömürü; Tufanbeyli ve Ilgın linyit kömürleri seçilmiştir. Araştırma parametreleri olarak; kurutma tipi, kurutma sıcaklığı, kurutma süresi bağımsız değişkenler olarak seçilmiştir. Aynı koşullarda çubuklu değirmende öğütülmüş kömür numunelerin tane boyu dağılımları; d_{50} ve d_{80} değerleri ise bağımlı değişken olarak kabul edilmiştir. Yapılan deneysel çalışmalara göre Tufanbeyli linyit kömüründe en iyi sonuç etüvde 105 ºC 240 dk kurutmada d_{50} ve d_{80} değerleri 95 µm ve 130 µm olarak, Ilgın linyit kömüründe ise mikrodalga kurutmada 800 W 20 dakikada d_{50} ve d_{80} değerleri 100 µm ve 205 µm olarak bulunmuştur.

Anahtar Kelimeler: Kömür kurutma, Öğütülebilirlik, Linyit, Mikrodalga enerji

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1. Introduction

The majority of the energy consumed to make the coal burnable in the thermal power plants is the energy consumed for grinding the coal. The energy consumed for coal grinding process in coal fired power plants is rather high, such as consumption 70-80% of the powdered coal to reduce below 75 μm. Due to this, any economic improvement in the grindability of coal will significantly reduce the power requirements utilized in the size reduction processes. In conventional drying processes that are widely used in power plants or in the mining industry, drying proceeds inwardly from the outer surface of the heated material. In contrast, in microwave heating or drying, the heat is emitted from the inside of the material as energy waves. In addition, a phenomenon of selective heating that makes it inhomogeneous for microwave heating. In this case, the different components / parts of the material show different heating characteristics depending on the different heat absorption and wave energy transmission characteristics. It is known that the water molecules that make up the moisture content of the coal are polar and they absorb the microwave energy very well [1]. It is thought that the water that is exposed to microwave energy will quickly evaporate from the coal structure [2]. During evaporation some micro cracks and macro cracks occurred and there would be stresses on the coal structure which will facilitate the coal grinding. Such studies have been conducted in the literature the effect of moisture on some coal samples and their results have been published [1-7].

A substantial amount of coal consumed in pulverized coal-fired thermal power plants go through a particular process, where coal is reduced to a required particle size of below 75 μm [7]. The hardness, moisture and petrographic properties of coal are important parameters in these crushing-grinding/size reduction operations [8, 9]. In order to increase the amount of mill output (crushed or ground) product, lowering the amount of energy input is necessary, therefore a technology that increases structural cracks and stresses before size reduction should be possible [10].

By burning high moisture content and dried lignites; the effects of the boiler on the flue gas emission were investigated. As a result; it was stated that the effect of coal on the environment was reduced by decreasing the moisture content of the coal, the energy consumed to pulverize the coal was reduced and the efficiency of the plant was increased [11-12]. In order to examine the effect of moisture content on the grindability of coal, two coal with high and low moisture content were investigated. The effect of moisture content on grindability was determined as a result of experiments. It has been determined that the drying process increased the grindability because of created fractures in the coal structure [13].

Coals of various ranks were exposed to microwave radiation to quantify the effect on grindability. Reductions of up to 50% of the relative grindability of the coals were reported after 5 min microwave exposure [3]. These are believed to be a combination of fracture mechanisms, inherent moisture within the coal structure changing phase under considerable pressure and differential expansion by gangue mineral components. The overall effect of microwave radiation on the coal calorific value was minimal and compares equally to conventional drying techniques [1].

In this study, on the two different origin lignite coals; Tufanbeyli lignite coal and Ilgın lignite coal samples, different drying techniques (air drying, air circulated fan oven drying, microwave drying) and drying parameters (drying temperature and drying time) are applied and their impacts over the coal grindability has been examined. The experimental results are presented and examined comparatively.

2. Materials and methods

2.1. Materials

In this study, lignite coals from two different coal fields are used. The reason for the selection of the lignite coals of interest is that they have not been investigated in detail in the literature involving the effects of drying techniques on coal grindability. The first coal used in the experiments is Tufanbeyli lignite coal. Because of the recent use of this lignite coal reserve, no detailed research has been conducted on this coal in the previous academic studies. Ilgın-Konya lignite coal sample is the second selected coal sample used in the experiments.

2.2. Methods

2.2.1. Preparation of coal samples used in the experiments

The lignite coals from two different coal fields were primarily subjected to particle size reduction in order to be ready for use in the experiments. Oversized lignite coals were first crushed with a hand hammer in order to feed into jaw crusher. The hammer-crushed samples were then fed to the laboratory type jaw crusher. The jaw crusher was adjusted to the optimum discharge aperture and the crushing was done for both lignite coals separately for reducing the sample particle size below to 20 mm for using in the experiments. All of the crushed samples were sieved through a 20 mm aperture size sieve and labeled and put in sealed sample bags separately to keep their original moisture.

2.2.2. Proximate analysis of coals

The codes of lignite coal samples taken from Tufanbeyli-Adana and Ilgın-Konya were made as Tufanbeyli-1, Tufanbeyli-2, and Ilgın-1, Ilgın-2, respectively, because they were taken from two different points of both coal fields. Four representative samples were taken from each of the samples coded in this way. Representative samples were dried in a laboratory oven until constant weight. The coal moisture content of both the original base of the samples were determined and the dry coal samples were used to determine the other parameters of the coal proximate analysis. These samples that dried in the oven were ground separately at the laboratory scale rod mill. Approximately 50 g representative samples were taken and ground below to 200 µm in the laboratory scale mechanical mortar to use for the determination of the coal proximate analysis parameters.

The standards and devices used for the proximate analysis of lignite coal samples used in the investigation of coal drying-grindability tests are summarized in Table 1.

Table 1. Applied standards and devices for proximate analysis of lignite coal samples

Parameters	Standard	Device
Moisture (%)	ASTM D3302-15 [14]	Memmert UF450 Oven
Ash (%)	ASTM D3174-12 [15]	Carbolite HTF 1700 Muffle furnace
Volatile Matter (%)	ASTM D3175-11 [16]	Carbolite HTF 1700 Muffle furnace
Sulfur Content (%)	ASTM D4239-14 [17]	Eltra CS 580 Sulfur Analyzer
Higher Calorific Value (kcal/kg)	ASTM D5865- 13 [18] - ISO 1928 [19]	IKA C2000 Basic Bomb Calorimeter
Lower Calorific Value (kcal/kg)		
Fixed carbon (%)	Weight % fixed carbon = 100 – weight % moisture + weight % volatile matter + weight % ash	

2.2.3. Different drying methods of coals

Three different drying methods have been applied to lignite coal samples prepared -20 mm particle size using a jaw crusher to obtain suitable particle size coals to be used in drying tests.

Air drying: Lignite coal samples, prepared -20 mm particle size, were dried in air at natural ambient in the laboratory. Some cracks were observed on the surface of coal particles due to air drying which will contribute the grindability during grinding.

Oven drying: Lignite coal samples, prepared -20 mm particle size, were dried in a laboratory air circulated fan drying oven for 60, 120, and 240 minutes at 60, 75, 90, and 105 ^{o}C.

Microwave drying: Lignite coal samples, prepared -20 mm particle size, were dried in a kitchen type microwave oven. The microwave oven was set to 800 W (2.45 GHz). In the light of the information obtained from both the literature and the preliminary experimental studies, drying times were selected as 4, 12 and 20 minutes.

Samples of lignite coal exposed to different drying techniques for different conditions were subjected to grinding under specified conditions. The ground coals were subjected to sieve analysis and particle size distributions, d_{50} and d_{80} were determined and examined.

2.2.4. Grinding method of different dried coals

As explained above, differently dried lignite coal samples were subjected to grinding under specified conditions. For this purpose, a laboratory type rod mill was used. Detailed information about rod mill and working conditions are given in Table 2.

Table 2. Detailed information about rod mill and working conditions

Parameter	Condition
Mill Chamber Length / Diameter	33.4 / 21 cm
Rod Length / Diameter	29.6 / 3.17 cm 4 pieces 29.6 / 2.46 cm 4 pieces 29.6 / 1.59 cm 9 pieces 29.6 / 0.98 cm 8 pieces
Number of Rods	25 pieces
Critical Speed	91.96 rpm
Mill Rotation Speed	55 rpm

The lignite coal samples were ground for 10 minutes under the conditions given in Table 2 with the help of the rod mill and the drive unit. For the sieve analysis of the ground coal samples, 50 grams of representative samples (coning&quartering) were taken from each try and dry sieved for 15 minutes with an automatic laboratory screen shaker. The obtained fractions were weighed on the laboratory analytical balance and the particle size distribution graphs were plotted using the results obtained.

2.2.5. Sieve analysis method of different dried coals

The ground coals were subjected to sieve analysis using standard aperture size laboratory sieves; 75, 106, 150, 250, 355, 500, and 1000 µm aperture size to determine the particle size distribution. Sieve shaking process with automatic sieve shaker was applied under the same conditions in all sieve analysis for 15 minutes. The weights of each of the lignite coal samples sieved in the above-mentioned sieve fractions were weighed on the laboratory analytical balance. The particle size distribution of each ground coal samples were drawn and examined. d_{50} (50% passing screen aperture size) and d_{80} (80% passing screen aperture size) values of each ground coal samples were determined and compared each other.

3. Results and discussion

3.1. Proximate analysis results of coals

According to the results of the proximate analysis of coal carried out in accordance with ASTM standards mentioned in Table 1, obtained values are given in Table 3 for Tufanbeyli-Adana lignite coal and Ilgın-Konya lignite coal.

Table 3. Proximate analysis results of Tufanbeyli-Adana and Konya-Ilgın lignite coal samples

Parameter	Tufanbeyli - 1		Tufanbeyli - 2		Ilgın - 1		Ilgın - 2	
	Dry basis	Original basis	Dry basis	Original basis	Dry basis	Original basis	Dry basis	Original basis
Total moisture (%)	---	44.35	---	43.31	---	48.54	---	45.73
Ash (%)	56.44	31.41	59.36	33.65	29.31	15.08	22.01	11.94
Volatile Matter (%)	34.61	19.26	32.35	18.34	46.53	23.94	48.51	26.33
Sulfur Content (%)	5.31	2.96	5.33	3.02	5.88	3.03	5.22	2.83
Higher Calorific Value (kcal/kg)	2177	1212	1948	1104	4491	2311	4976	2700
Lower Calorific Value (kcal/kg)	2045	894	1827	797	4277	1934	4749	2325
Fixed Carbon	8.95	4.98	8.29	4.70	24.16	12.43	29.48	16.00

According to the results of proximate analysis, the coals taken from two different points of the coal field, original moisture of Tufanbeyli lignite coal was found as 43-44%, and Ilgın lignite coal was found as 45-48%. The ash contents of the coals on dry basis were found to be 56-59% for Tufanbeyli lignite coal and found to be 22-29% for Ilgın lignite coal. It was observed that volatile matter of Ilgın lignite coal was greater than the volatile matter of Tufanbeyli lignite coal. According to results, Ilgın lignite coal has 46-48% volatile matter, on the other hand Tufanbeyli lignite coal has 32-34% volatile matter on the dry basis.

When the sulfur contents of the coals are examined, it was seen that the sulfur contents of both coals are greater than 5% sulfur on dry basis. This sulfur content is considered as high for environmental pollution when they are burned in thermal power plants or in any other combustion applications such as domestic heating purpose or industrial factories; cement industry, brick industry. Therefore, some desulfurization process should be applied before the combustion, during or after the combustion [6].

The lower calorific value of Ilgın lignite coal on dry basis was determined to be 4277-4749 kcal/kg, on the other hand, the lower calorific value of Tufanbeyli lignite coal was found to be 1827-2045 kcal/kg. The lower calorific value of Tufanbeyli lignite coal on the original basis was 797-894 kcal/kg, lower calorific value of Ilgın lignite coal on the original basis was 1934-2325 kcal/kg.

According to these results, it can be said that Ilgın lignite coal has greater calorific value than Tufanbeyli lignite coal. Although Ilgın lignite coal has a greater calorific value than Tufanbeyli lignite coal, it is obvious that those calorific values should be increased in order to be used for domestic heating purposes. For this purpose, coal cleaning operations can be carried out to reduce the ash content and to increase the calorific value of these coals. However, according to these calorific value results, it can be said that Tufanbeyli lignite coal is only suitable for using in thermal power plants due to its relatively low calorific value.

3.2. Effect of drying method on coal grindability

Both of coals have been subjected to drying in natural laboratory conditions (spring weather, 25 ºC, 78% humidity) for one week without any energy requirement.

In order to compare the grindability of Tufanbeyli lignite coal by different drying techniques (air - oven - microwave) and conditions, particle size distribution graphs for different temperature and duration were given in Figures 1, 2 and 3 respectively.

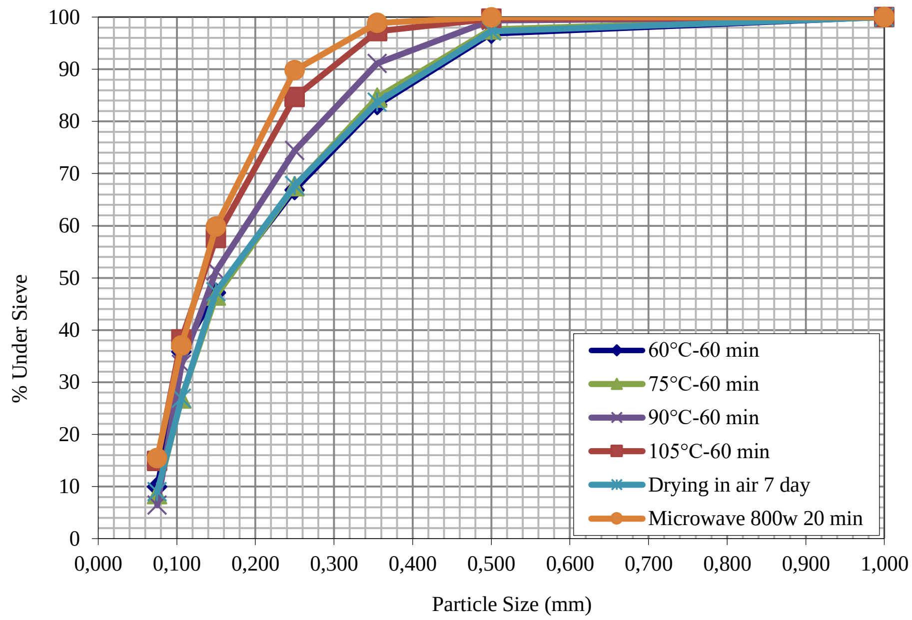

Figure 1. Comparison of the grindability of Tufanbeyli lignite coal by different drying methods (air drying for 7 days; oven drying at 60, 75, 90, 105 °C for 60 minutes; and microwave drying at 800 W for 20 minutes).

When Figure 1 was examined, it was found that microwave drying at 800 W, 20 minutes of the coal sample yielded the best results, i.e. smaller particle size means easy to grind. The particle size distribution of the air-dried coal samples seems to be smaller than oven-drying coal samples in the oven (60-75 °C for 60 minutes). On the other hand, the particle size distribution of the coal oven-dried in the oven at 90 °C for 60 minutes is similar to the particle size distribution of the air-dried coal sample. The coal oven-dried in the oven at 105 °C for 60 minutes was the coal drying condition that provided the second finest particle size distribution to the coal samples after the microwave drying.

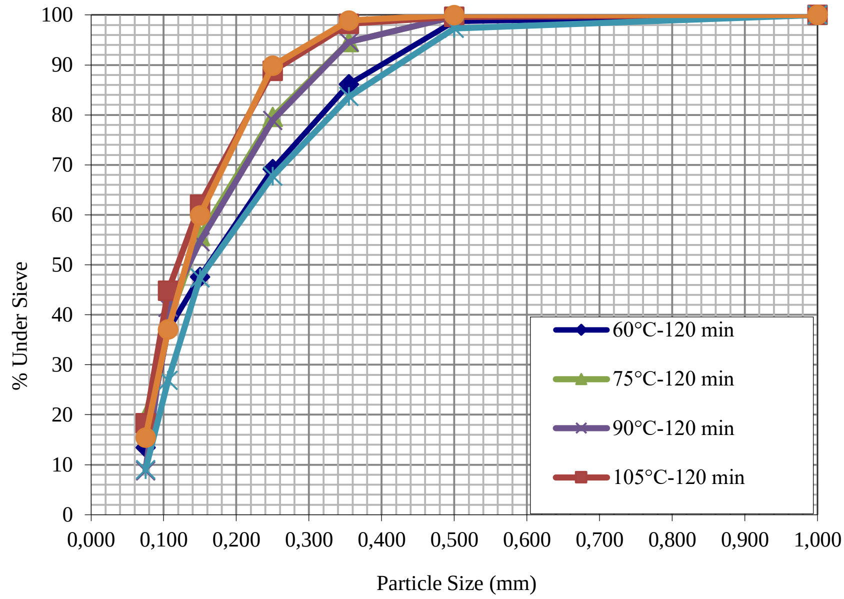

Figure 2. Comparison of the grindability of Tufanbeyli lignite coal by different drying methods (air drying for 7 days; oven drying at 60, 75, 90, 105 °C for 120 minutes; and microwave drying at 800 W for 20 minutes).

In Figure 2, it was found that coal drying with microwave drying still gave the best results (finer product; easy to grind), and oven drying at 105 ºC for 120 minutes provide very close values to microwave drying coal values. It was seen that 120 minutes drying at other temperatures; 60, 75 and 90 ºC in the oven had finer particle size distribution than air-dried coal.

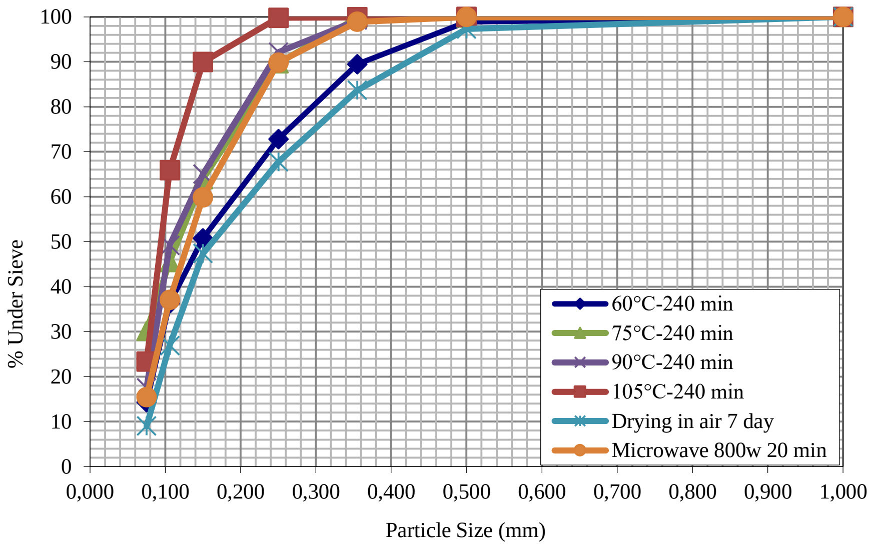

Figure 3. Comparison of the grindability of Tufanbeyli lignite coal by different drying methods (air drying for 7 days; oven drying at 60, 75, 90, 105 °C for 240 minutes; and microwave drying at 800 W for 20 minutes).

Investigation of the effects of different drying methods on coal grindability

As could be seen from Figure 3 that oven-dried coal at 105 ° C for 240 minutes had finer particle size distribution than microwave-dried coal. Coals dried in the oven at 75 and 90 ºC for 90 minutes, and coals dried in the microwave gave almost similar particle size distributions. The reason for the finer particle size distribution of the coals is because of the increasing drying time in the oven.

In order to compare the grindability of Ilgın lignite coal by different drying techniques (air - oven - microwave) and conditions, particle size distribution graphs for different temperature and durations were given in Figures 4, 5 and 6 respectively.

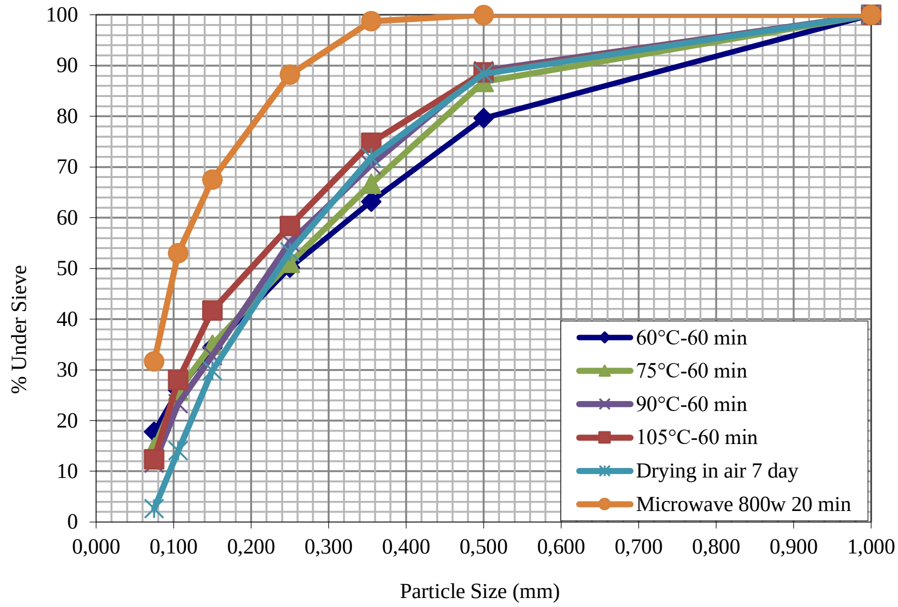

Figure 4. Comparison of the grindability of Ilgın lignite coal by different drying methods (air drying for 7 days; oven drying at 60, 75, 90, 105 °C for 60 minutes; and microwave drying at 800 W for 20 minutes).

In Figure 4, it was found that microwave drying at 800 W for 20 minutes of the sample yielded the best results, i.e. smaller particle size. The particle size distribution of the air-dried coal seems to be smaller than oven drying coal at 60-75 °C for 60 minutes. On the other hand, the particle size distribution of the oven-dried coal at 90 °C for 60 minutes is almost similar to the particle size distribution of the air-dried coal. The coal dried in the oven at 105 °C for 60 minutes was the drying condition that provided the second finest particle size distribution after the microwave-dried coal.

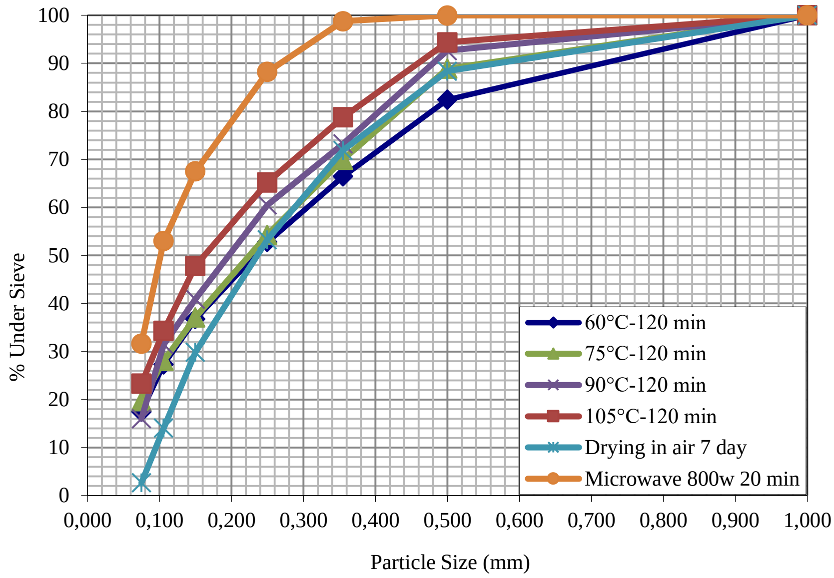

Figure 5. Comparison of the grindability of Ilgın lignite coal by different drying methods (air drying for 7 days; oven drying at 60, 75, 90, 105 °C for 120 minutes; and microwave drying at 800 W for 20 minutes).

As can be seen from Figure 5 that microwave drying of the coal still gives the best results, i.e. smaller particle size. The particle size distribution of the air-dried coal was similar to the particle size distribution of the coal dried in the oven at 75 °C with the drying duration of 120 minutes. The particle size distribution of the coal dried in the oven at 60 °C for 120 minutes can still be said to be larger than the particle size distribution of the air-dried coal. The coal which was dried in the oven at 105 °C for 120 minutes was the drying condition that provided the second finest particle size distribution after the microwave drying.

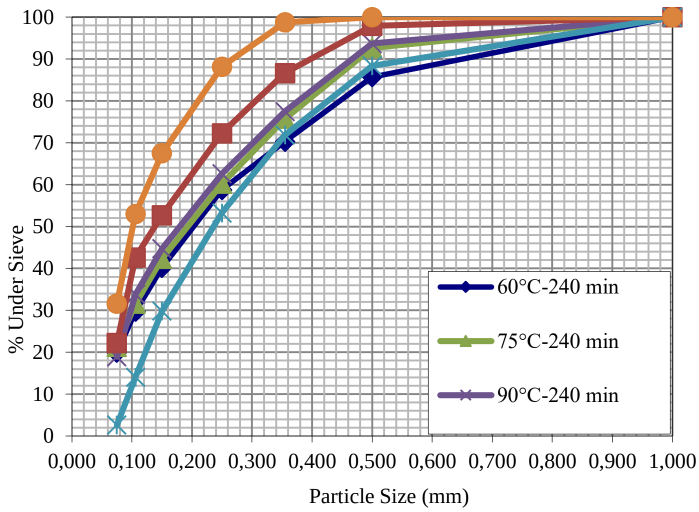

Figure 6. Comparison of the grindability of Ilgın lignite coal by different drying methods (air drying for 7 days; oven drying at 60, 75, 90, 105 °C for 240 minutes; and microwave drying at 800 W for 20 minutes).

Investigation of the effects of different drying methods on coal grindability

As can be seen from Figure 6, although the results given in Figure 5 does not change much, it is seen that the particle size distribution of the air-dried coal is close to oven drying for 240 minutes at 60 °C. The other coal drying conditions provide finer particle size distributions.

4. Conclusions

In this study, the effects of different drying techniques (air drying, oven drying, and microwave drying) with different drying temperature and drying time on coal grindability were investigated. For this purpose, Tufanbeyli lignite coal and Ilgın lignite coal samples were used. The drying experiments parameters are 7 days for air drying; 60, 75, 90 and 105 ºC for 60, 120 and 240 minutes for oven drying; 800 W, 2.45 GHz for microwave drying for 4, 12 and 20 minutes. After drying, dry samples were ground in a rod mill at certain conditions. Ground samples were then analyzed in terms of particle size distribution, d_{50} and d_{80} values. Those values were compared separately.

As a result of the decrease in moisture and drying of the coals in the air, macro and micro cracks formed on the coal surface and inner parts. These macro and micro cracks facilitate the process of crushing coal. The same situation was realized in both the oven and the microwave in the drying and facilitates the size reduction of the coal. Tufanbeyli and Ilgın lignite coals could be ground to finer particle size in a linear way with increasing drying time and drying temperature for oven and microwave drying.

However, the results of Tufanbeyli and Ilgın lignite coal obtained from all experiments showed different particle size distributions, even though they were not directly compared with each other. In other words, Tufanbeyli lignite coal from the coals subjected to drying and grinding under the same conditions had a finer particle size distribution than Ilgın lignite coals. This was because the coals were of different origin and the coal ranks are different.

Microwave energy drying had a more favorable effect on grindability than drying at some temperature and time in the oven and drying in air. In other words, microwave energy causes cracks and fractures in the structure of coals and causes rapid removal of moisture from the coal, and as a result the resistance to grinding decreases.

As the drying temperature and the duration at the oven increased, the particle size distribution of the ground coals was close to the results obtained with the microwave energy. The finest coal particle size distribution was determined to be Tufanbeyli lignite, which was dried at 105 ºC for 240 minutes. The d_{50} and d_{80} values obtained in this drying were 95 µm and 130 µm, respectively. In the same conditions, the d_{50} and d_{80} values of Ilgın coal were 140 µm and 300 µm. The finest coal particle size distribution of Ilgın coal was reached at the microwave-dried coal at 800 W for 20 minutes, while the d_{50} and d_{80} values were 100 µm and 205 µm, respectively. The positive effect of microwave drying on grindability of Ilgın coal was higher than Tufanbeyli coal. This could be explained by the fact that the coal origin is different and more detailed research is required.

As a result, it was revealed that moisture should be removed from the coal structure by any drying method. Air drying which was one of these methods, was time consuming although it did not require energy but requires time and place. Drying in the oven which was a conventional drying, facilitates the grindability of coal with increasing temperature and drying time. It was determined that microwave energy drying had a positive effect on coal grindability due to different drying mechanism.

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Contribution of authors

Burçin Kaymakoğlu completed his master degree under the supervision of Osman Sivrikaya, and both authors contribute the study equally.

Conflict of interest statement

There is no conflict of interest between the authors.

Research and publication ethic statement

This study has been carried out in accordance with the research and publication ethics rules.

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