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Experimental And Economic Comparison Of Fuels Used In Rotary Kilns On Energy Efficiency

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Abstract:
Different methods are used for the heat energy desired to be obtained from large-scale furnaces used in industry. Our study includes the analysis of petroleum coke and natural gas data used in the firing of large-scale rotary kilns. After firing, the temperature must rise to 1800 ^{0}C in order to sinter the material in the kiln. Therefore, two fuel type hybrids are used for the desired energy. Rotary kilns are fired with natural gas fuel since it is easier to control. Then, petroleum coke is used to increase the temperature and perform the sintering process. Rotary kilns can have certain lengths according to the material to be sintered. After this process, the waste heat goes to the boiler. After the processes carried out here, it is released into the atmosphere at flue gas temperature. Our study includes the amounts of natural gas and petroleum coke of the energy obtained in the rotary kiln. In the firing process, 15.07% of the maximum total energy is obtained from natural gas. It is seen that the cost will be high as a result of this method being performed with natural gas, and the environmental effects will increase when only petroleum coke is used. In the current system, there are various particles in the waste heat generated after the furnace. The particle formation is due to the fact that one of the fuels is petroleum coke and the mineral sintered in the furnace is magnesite. These particles will reduce the boiler efficiency after a while. Therefore, it would be appropriate to use a cyclone group to reduce the particles after the rotary furnace. In conclusion, although petroleum coke is an economical and high energy density fuel in energy production, it presents various difficulties in terms of sustainability when its environmental effects are taken into account. Therefore, it is necessary to both increase the energy efficiency of petroleum coke and reduce its environmental damage. In this context, academic studies on the use of petroleum coke should focus on ensuring the balance between energy efficiency and environmental management.

Keywords: *Rotary kilns; Energy; Natural gas; Waste heat; Petroleum coke.*

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I. Introduction

Rotary kilns are important facilities used in various production processes and by reaching high temperatures. They are used in many areas such as ceramics, chemistry and mining in the industry [1]. Sintering process in rotary kilns is a method applied for heat treatment of the material and gaining new properties. When industrial facilities and literature are examined, it is seen that one of the purposes of using rotary kilns is to perform sintering process widely. Rotary kilns are in continuous rotation, which ensures homogeneous distribution of temperature in the kiln. Good internal insulation shows us that heat treatment is applied without any problems. There are many studies on rotary kilns in the literature. These studies are mainly about energy and materials. Apart from this, the combustion systems of rotary kilns, insulation materials and fuel types used are at the forefront of these topics. The fuel system is important in reaching high temperatures in rotary kilns. Different systems are used in this field and in our study, there is a hybrid combustion system data where natural gas and petroleum coke fuels are used together.

The production of hazardous waste in the world is increasing every year. In order to achieve higher efficiency and lower pollution, hazardous waste combustion technology needs to be further investigated. A study has been conducted on the impact of rotary kilns on the environment and workers [2]. There are harmful gases such as CO_2 and SO_2 that are formed in processes requiring heat treatment such as sintering and continue to be a current problem for the natural environment [3]. It shows that the lower the combustion efficiency of pulverized coal injection, the higher the residual carbon content in the combustion products [4]. With the decrease in the combustion efficiency of pulverized coal, the adhesion percentage of deposits on the refractory brick surface increases. In order to prevent further accumulation of deposits, the combustion efficiency of pulverized coal should be improved by adopting methods that appropriately reduce the particle size of pulverized coal and increase the oxygen density in the rotary kiln [5-6]. Magnesite and dolomite bricks resistant to high temperatures are used in rotary kilns. They provide insulation and help the kiln to remain durable for a longer period of time. The refractory bricks used are resistant to temperatures up to 2000^{0}C [7]. 60% of steel producers working with crucible metallurgy in Turkey use dolomite refractories [8]. In this section of the rotary kiln, which is less affected by chemical and thermal stresses, chemically agglomerated bricks of different qualities containing 50-60% Al2O3 are used [9].

In a study, the physical properties of rotary kiln waste were analyzed, and the results showed that dust and rotary kiln waste have high-value recovery conditions [10]. In another study, the process control development of rotary kilns over the last 40 years was examined. Suggestions were made for development in the control approach with three different methods [11]. In another study, it was about the use of waste heat from rotary kilns in energy generation. In the study, both operational and energy aspects of integration were considered as a basis for energy sustainability and low environmental impact of rotary kilns [1]. In another study, rotary kilns were selected for high-temperature solar processes. The focus was on the use of devices used in this system in thermal and thermochemical processes carried out by concentrating solar energy [12].

In our study, an analysis was made with the data obtained from the rotary kiln. In addition, the effect of the natural gas and petroleum coke fuels used on the total energy and their comparisons were made, and a cost calculation was proposed according to their percentage amounts. The boiler inlet and outlet temperatures of the waste heat coming out of the rotary kiln were presented in a graphical form, and the values where the waste heat could be evaluated in energy production were highlighted. The percentage data of the natural gas used in the rotary kiln were analyzed according to the total energy in the kiln. Information was given about the high cost of using natural gas as a single fuel instead of hybrid in the combustion system.

II. Material And Methods

Heat Treatment and Fuel Usage in Rotary Kiln

The sintering process in a rotary kiln is a heat treatment method frequently used in the metallurgical, ceramic and chemical industries. This process is carried out at high temperatures in a controlled atmosphere in order to increase the mechanical strength and thermal properties of the materials. Rotary kilns are cylindrical structures that rotate at an inclined angle from the part where the material is given to the other end. While the material is fed from one end, the sintered products are taken from the other end. During rotation, the material inside moves continuously and a homogeneous heat distribution is formed in the kiln. During the process, the materials are heated to a temperature below their melting temperature and bonding is provided between the particles. This bonding results in an improvement in the microstructure of the material and an increase in its macroscopic properties [13-14]. The advantages of rotary kilns include high production capacity, homogeneous heat distribution and flexible parameters for different materials. In the rotary kiln where the data were taken, heat treatment is carried out so that the magnesite mine can gain new properties. Magnesia (MgO) is formed by thermal decomposition in the magnesite mine furnace through heat treatment. The following thermal decomposition reaction occurs at approximately 900^{0}C in the furnace, which reaches a temperature between 1400-1800 ^{0}C.

$$MgCO_3 \rightarrow MgO + CO_2 \quad (1)$$

After this process, CO_2 gas is released. By increasing the furnace temperature, the sintered material gains some properties. With the sintering process carried out at high temperatures, the pores are closed and the crystals grow. During sintering, the grain boundaries are rearranged and the mechanical strength increases. The final product (MgO) is generally a refractory material with high density and low porosity. The new material formed has high refractoriness (melting point >2800°C), low thermal conductivity and high chemical resistance.

Natural gas and petroleum coke are two important fossil fuels widely used in energy production and industrial processes. Natural gas is preferred in heating, electricity production and industrial applications due to its high energy density. In addition, SO_2 emissions are quite low due to its low sulfur content. However, the use of natural gas is dependent on the pipeline infrastructure and the limited reserves are a disadvantage [14]. However, its high cost compared to petroleum coke has led to the emergence of a hybrid system in the combustion systems of rotary kilns. On the other hand, petcoke is a solid fuel with a high carbon content obtained as a byproduct of oil refineries. Its energy density is lower than natural gas, but due to its low cost, it is frequently used in many sectors, such as in rotary kilns. However, high SO_2 and CO_2 emissions resulting from the combustion of petcoke can cause adverse environmental effects. This situation requires limiting the use of petcoke with filtering and purification systems in accordance with environmental regulations [13][15]. In general, while natural gas is superior in terms of clean energy, petcoke stands out with its low cost, but it carries environmental risks.

Total energy in kWh can be found by using the amounts and calorific values of natural gas and petroleum coke.

$$T(kWh) = [(N * C_{v1}) + (P * C_{v2})] * 0{,}001163 \quad (2)$$

Here, P (kg/h) represents the amount of petroleum coke, N (sm^3/h) represents the amount of natural gas. C_{v1} represents the calorific value of natural gas ($kcal/sm^3$), C_{v2} represents the calorific value of petroleum coke (kcal/kg).

The ignition phase of a rotary kiln operating with petroleum coke and natural gas is a process that requires careful planning and safety precautions. Before ignition, the kiln, burners, fuel lines, air blowing systems and sensors are checked in detail to ensure that there are no leaks or malfunctions. The interior of the kiln is cleaned of waste and deposits from previous operations. Ignition usually begins with a low natural gas flow, because the controlled combustion feature of natural gas provides a safe environment at the beginning. First, the operation of the burners is ensured by creating a pilot flame. After the pilot flame becomes stable, the main fuel is fed and the oxygen required for combustion is provided by the air blowing systems. At this stage, the air-fuel ratio is carefully adjusted to ensure complete combustion. After combustion begins, the temperature is gradually increased and the kiln reaches its operating temperature. If ignition has started with natural gas, a switch to petroleum coke can be made as the process progresses in order to reduce energy costs. During the fuel change, the system balance is maintained, and the air-fuel ratio is readjusted. When the kiln reaches the constant temperature required for production, the ignition phase is completed, and the process is continuously monitored and optimized by the automation system. In all these stages, necessary safety measures are meticulously implemented for potential risks such as flammable gas leaks, air-fuel imbalances and burner failures [13-15].

Bricks used for internal insulation of rotary kilns must meet important requirements in terms of high temperature resistance, low thermal conductivity and mechanical properties. It is stated that these bricks are generally refractory materials known for their high alumina content and their ability to withstand high temperatures [16]. In addition, it is emphasized that the mechanical strength and thermal shock resistance of these bricks are quite critical in systems exposed to high temperature and thermal shock conditions such as rotary kilns [17]. The use of these bricks is important because their thermal conductivity should be low and thus provide energy efficiency [18]. In addition, the chemical resistance of refractory. bricks ensure their longevity, especially in harsh conditions such as high alkaline and acidic environments in furnaces [16]. As a result, refractory bricks used in rotary kiln internal insulation are materials that increase the efficiency of the furnace and ensure its longevity by exhibiting high performance in terms of both mechanical and thermal properties.

III. Result

In the graph made with 134 measurements, it is seen that natural gas is used before ignition due to its feature of providing controlled combustion and the furnace is fed with petroleum coke to increase the temperature to the desired level. Table no1 shows the ratio of the amounts of natural gas and petroleum coke used in the furnace to the total energy.

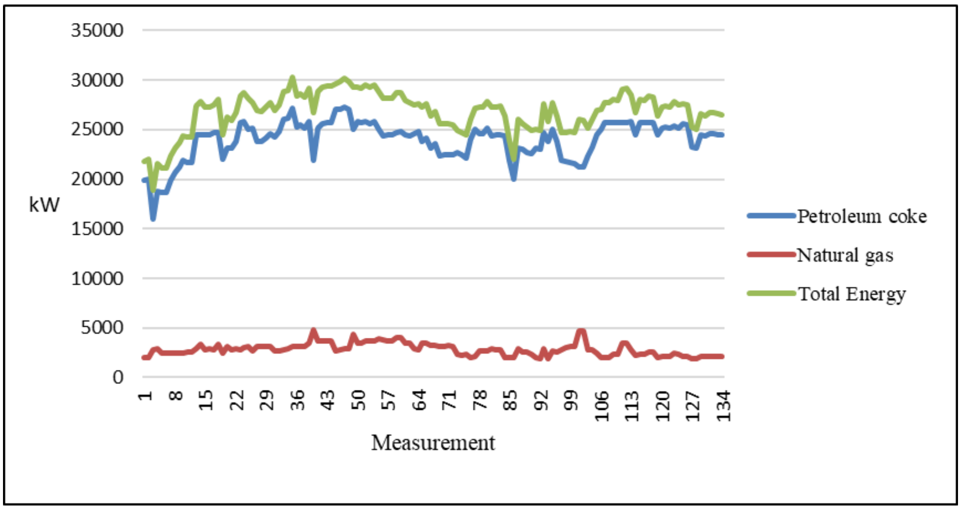

Table no 1. Ratio of fuels used in rotary kiln to total energy

During the sintering process in the rotary kiln, the heat required was used for the material inside the kiln, and some of it was lost through the kiln walls and passed to the outside environment. The kiln insulation is made with refractory bricks. Although there is internal insulation in the kiln from the ignition to the kiln exit section, there are heat losses. Heat losses can be determined from the amount of heat entering the boiler after the kiln.

The waste gas entering the boiler at an average temperature of 506^{0}C exits the boiler at an average temperature of approximately 196^{0}C. The waste coming from the boiler to the chimney filters is released into the atmosphere with the chimney fan speed varying between 860-1200 rpm (Table no:2).

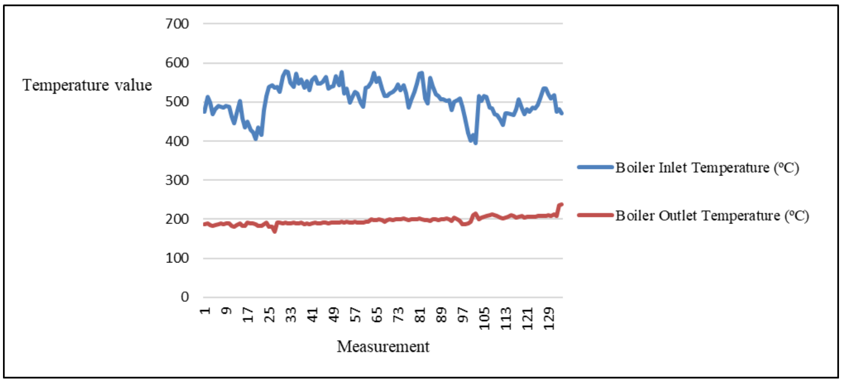

Table no 2. Waste heat boiler inlet and outlet temperatures

It is possible to evaluate waste heat with the heat transfer that takes place in the boiler. It can be used in heating or it can be evaluated in the steam turbine with an investment to be made. The waste gas that comes out of the boiler with a reduced temperature is drawn by the flue gas fan and thrown into the atmosphere. The fan speed depending on the boiler temperature is shown in Table no3. The change in the fan speed is caused by the particles in the waste gas. The mineral properties fed to the rotary kiln for sintering may change. Mineral materials with different contents are sintered in the kiln according to the desired material quality. This situation also changes the particle amounts in the gas formed in the environment.

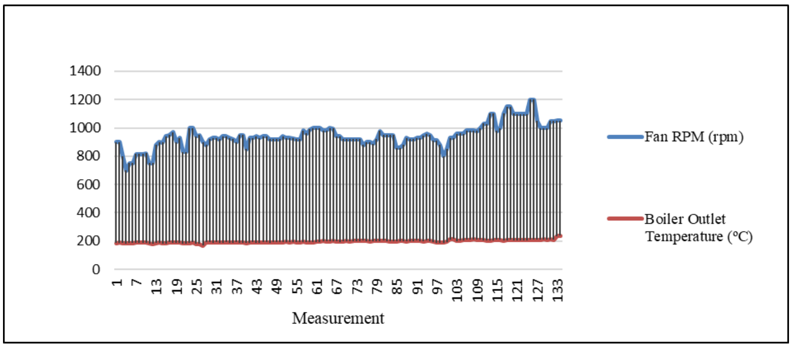

Table no 3. Comparison of boiler outlet temperature and fan rpm

The different values in the measurements were obtained during the creation of a pilot flame to ensure the operation of the burners and to stabilize the flame (Table no4). These are naturally met in the first ignition where external environmental effects can be effective. Then, oxygen is provided for combustion with the air blowing system and combustion is carried out by adjusting the air fuel ratio.

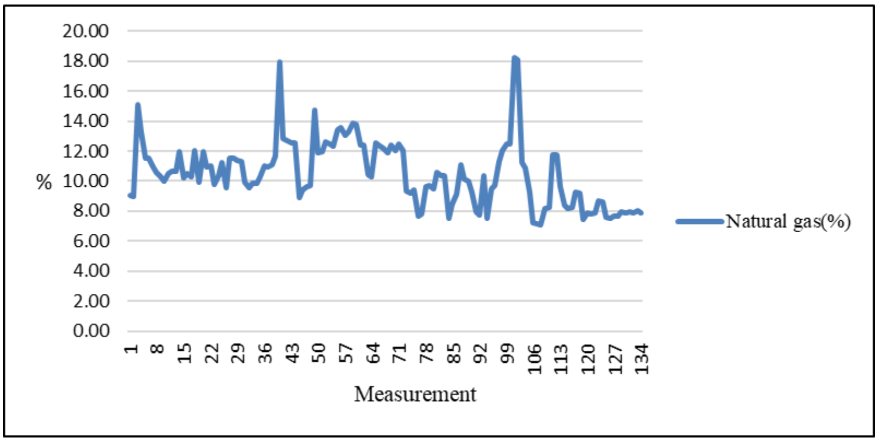

Table no 4. Natural gas used during firing (%)

Depending on the amount of energy obtained, the percentages of fuel types in the rotary kiln will be sufficient to calculate the change in energy costs.

$$EC = \left[\left(\frac{\%N*T}{C_{v1}} \right) * c_1 \right] + \left[\left(\frac{\%P*T}{C_{v2}} \right) * c_2 \right] \quad (3)$$

EC; Energy cost
T; Total Energy (kcal)
c_1; Natural gas ($/m^3)
c_2; Petroleum coke ($/kg)
C_{v1}; Natural gas heating value (kcal/sm^3)
C_{v2}; Petroleum coke heating value (kcal/kg)

The cost can be calculated according to the current natural gas and petroleum coke sales prices to industrial zones. When the calorific value of natural gas is evaluated in terms of cost, it is seen that it is not suitable to use it alone. Using petroleum coke as the main fuel to reach the desired temperature reduces the cost.

The percentage ratio of natural gas used in rotary kiln firing to total energy is shown in Table no5. In these measurements, it was determined that natural gas was used at most 15.07%. The fact that close percentages correspond to different energy amounts according to the total energy ratio may be due to differences in sintered materials as well as to the difference in petroleum coke content. The decrease in the calorific value of petroleum coke to be used in rotary kilns will increase the amount of natural gas. The increase in the natural gas ratio can be seen as positive for the emission in flue gas. However, in terms of production cost, it disrupts the balanced production carried out by considering environmental conditions.

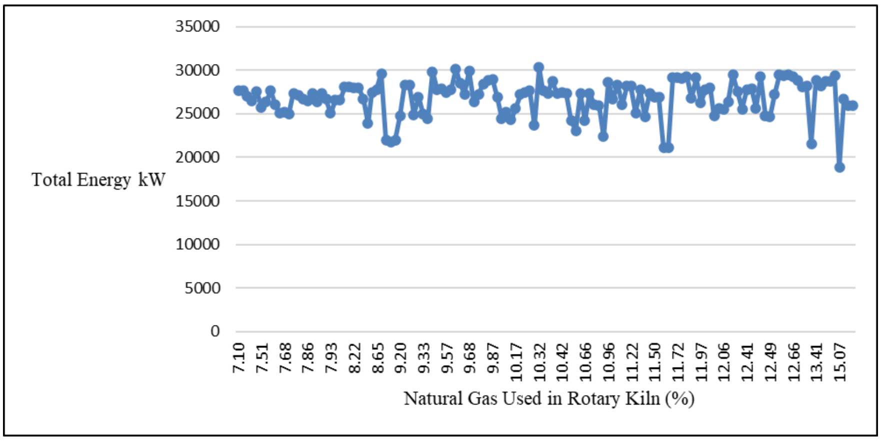

Table no 5. Percentage of natural gas used in the total energy obtained in the rotary kiln

Using only natural gas in rotary kilns can lead to several important changes depending on the characteristics provided by natural gas instead of petcoke. First of all, the combustion characteristics of natural gas are different from petcoke. Natural gas is considered a cleaner fuel because it produces lower carbon dioxide (CO_2), sulfur dioxide (SO_2) and particulate emissions. This reduces environmental impacts and improves air quality [16]. In addition, natural gas provides higher energy efficiency due to its high combustion efficiency and low carbon content, which can help the kiln operate more efficiently [18]. However, the use of natural gas can also have some disadvantages. Petcoke can provide more dense energy per volume than natural gas because it is solid, meaning that less fuel is consumed to achieve the same energy output as petcoke. This means lower fuel costs when petcoke is used. Due to the lower energy density of natural gas, more natural gas may be consumed to provide the same amount of energy, which can increase costs.

Another important difference is that natural gas generally has lower combustion temperatures compared to petcoke. Petcoke provides higher heat, which can help the rotary kiln operate more efficiently at higher temperatures. Therefore, using only natural gas can negatively affect the performance of the kiln, especially in industrial processes with high temperature requirements [17]. In addition, natural gas is slower to reach high temperatures and may not provide the faster heating process achieved with petcoke.

As a result, while the use of natural gas can be more beneficial and efficient from an environmental perspective, the use of petroleum coke can provide a cost advantage. Using natural gas alone can affect the operating conditions, energy consumption and costs of the furnace, but it offers a more positive option in terms of environmental impacts. Petroleum coke is a widely preferred fuel in energy production due to its high carbon content and energy density. While its low cost and accessibility make it an economical alternative, its efficiency in energy production can be increased with modern combustion systems and advanced technologies. Due to the high C content of petroleum coke, it has a greenhouse gas effect of 1.5-2 times that of natural gas. One of the biggest problems in energy production today is the effects of greenhouse gases [19]. For this reason, filter systems in systems where fossil fuels are used for energy production should be evaluated and designed according to environmental impacts.

However, the use of petroleum coke poses significant environmental challenges. Large amounts of fly ash and bottom ash are formed, and these wastes can cause environmental pollution if not managed properly. The high carbon content causes significant CO_2 emissions during combustion, which contributes to global warming and climate change. In addition, due to its high sulfur content, sulfur dioxide (SO_2) emissions increase, which leads to air pollution and acid rain. In addition, the hybrid use of petroleum coke with renewable energy sources can both increase energy efficiency and minimize environmental damage. Therefore, the use of modern technologies and the adoption of environmentally friendly approaches are necessary to both increase the energy efficiency of petroleum coke and reduce its environmental damage. In this context, academic studies on the use of petroleum coke should focus on achieving the balance between energy efficiency and environmental management.

In our study, it was observed that natural gas, one of the fuels used in rotary kilns, was used during kiln firing, as understood from the usage percentage. After the sintering process, the waste heat can be released into the atmosphere by reducing its temperature as a result of the arrival of the boiler to the flue gas. Although the waste heat enters the boiler at an average of 506^0C, when the general graphic characteristic of the boiler exit temperature is examined, it is seen that it is an average of 196^0C at a certain level. It is recommended that the energy to be obtained with this difference is used for a different system design.

However, formula (3) is given for energy cost calculation. The calculation to be made with the fuel types used in rotary kilns will provide cost analysis. Considering today's industrial usage prices, there is approximately a three-fold difference between natural gas and petroleum coke. The cost of natural gas is higher than petroleum coke. Despite environmental factors, the use of petroleum coke in rotary kilns is indispensable in terms of production costs today. In addition, in cases such as a line failure in natural gas or the cessation of purchase due to country policy, major problems may arise in the sector. Therefore, it is important to reduce the environmental effects of petroleum coke with a good filter system. In addition to this system, a cyclone group can be used to eliminate particles in the waste gas during the transition from the rotary kiln to the boiler. In this way, both the heat transfer efficiency in the boiler will increase and the flue gas emissions and atmospheric particles will decrease.

IV. Conclusion

The most important trend in rotary kiln research is the waste-to-energy approach in terms of various waste utilization in the process industry. Processes related to the evaluation of the obtained waste heat in energy production are an ideal option for investment. However, it is necessary to demonstrate a good feasibility. A steam turbine to be installed to utilize waste heat is suitable for generating energy. It is necessary to determine whether all stages of the system are suitable for this system. There should be a boiler system suitable for the system in order to obtain steam at the appropriate temperature and flow rate for the steam turbine. In addition, since it is the mining sector, it should not be forgotten that there will be particles in the material sintered in the rotary kiln [20]. The particles form a layer on the pipes passing through the boiler over time. This layer formed can reduce heat transfer. The temperature of the steam obtained to be sent to the steam turbine in the boiler will decrease due to the particles in the waste.

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