Utilization of a Parabolic Trough Solar System in a Direct Type Rotary Coal Dryer

Ehsan Amirabedin[1], M. Zeki Yilmazoğlu[2]

Abstract — In this study, design of a direct type rotary coal dryer is carried out. In design, first a natural gas burner is used for producing required heat of coal drying. Because of high natural gas consumption, it has a vital importance in today's competitive economy to find an alternative source and minimize cost of products. For this reason, a parabolic trough solar system is employed as a heat source, in order to reduce the fuel consumption and the environmental impact of the conventional drying systems. A costs/advantages analysis of the implementation is performed. By applying the parabolic solar system to the coal dryer, the results show that; annual energy saving and prevented CO_2 emissions from emitting to the atmosphere are 637,700 m^3NG and 1,152 ton CO_2 per year, respectively. Moreover, annual cost saving with considering carbon credits and payback time are evaluated to be 376,500 $ per year and 6.6 years, respectively.

Keywords — carbon tax, direct type rotary coal dryer, economic analysis, parabolic trough solar system

1 Introduction

Coal is a valuable and abundant fuel that is used as raw material for many chemical synthesis processes and combustion systems. The calorific value of coal and its friability can be increased by drying. Friable coal is suitable for combustion in steam power plants and the presence of moisture in coal causes a reduction in its friability. The final moisture content requirement for coal depends on the combustion process in which it is utilized. In the briquetting process the moisture content of coal should be less than 4%, while in a low temperature carbonization process it should be nearly 0%. In a gasification process it should be in the range of 5 to 15%.

Two types of moisture can be defined for a coal particle, surface and hygroscopic. Surface moisture depends on coal washing or soaking processes. Therefore, it is easy to evaporate the surface moisture, which at a constant drying rate the evaporation of the surface moisture is the first drying period. Hygroscopic moisture depends on the rank of the coal and it decreases with its age [1].

There are several types of coal dryers; rotary dryers, pneumatic dryers, fluidized bed dryers and etc. Rotary dryers may be classified in two groups, direct and indirect types. Direct type dryers utilize combustion gases and indirect type dryers use steam to dry the coal particles. In direct type rotary dryers combustion gases contact with the particles, while in indirect type, coal particles come in contact with the heated walls or pipes by steam. Also, rotary dryers are classified depending on the flow of combustion gases and coal particles. In a co-current rotary dryer design coal particles and combustion gases enter the dryer shell and flow in the same direction. Generally in coal drying applications co-current flow is preferred to avoid the possibility of self-ignition of coal particles.

In a direct type rotary dryer, normally a combustion chamber produces combustion gases for drying the coal particles. But in order to decrease the fuel costs and environmental impacts of the process, a solar collector can provide required energy of the dryer, by heating outlet air of fan.

There are some experimental and numerical studies dealing with the coal drying and rotary dryer designs. Arruda et. al. [2] compared the performance of a rotary dryer to a rotor-aerated dryer. The residence time, the difference between inlet and outlet temperatures of solids and air temperature variations were compared. The residence time in the shell decreased 48% and as a result the process capacity increases when rotor-aerated dryer is preferred. Fagernas et. al. [3] compared several types of dryers in a biomass drying process. They also investigated the environmental effects of dryers and offered different dryer types with respect to the feed characteristic and feed mass flow rate. Kemp [4] compared the residence time models and offered a new formula which includes all possible particle motions in a rotary dryer. Margono et. al. [5] analyzed the effects of feed rate and residence time in rotary dryer using steady-state and unsteady-state plug flow models. Partial differential equations describing heat and mass transfer in the rotary dryer were derived from shell balance. The results show that evaporated feed moisture content in plug flow back mixing model was lower than in plug flow model. Drying system is used in processes to obtain the required moisture content of the feed. M. V. Ramana Murthy [6] reviewed various aspects of solar driers applied to drying of food products at

1. *Department of Mechanical Engineering, Faculty of Engineering, Gazi University, 06570, Maltepe, Ankara, E-mail: Turkey ehsan.amirabedin@gmail.com*
2. *Department of Mechanical Engineering, Faculty of Engineering, Gazi University, 06570, Maltepe, Ankara, Turkey, E-mail: zekiyilmazoglu@gazi.edu.tr*

small scale. He found that there is a shorter way of estimating the performance of a drier.

This study is aimed to design a direct rotary type coal dryer. Apart from the literature, an alternative method, solar drying of coal with parabolic trough type collectors, is suggested. The conventional and solar drying system with parabolic trough type collectors are compared with respect to economic analysis and the effects of systems on global warming potential with CO_2 emissions. In this regard, first a direct rotary type coal dryer operating with NG burner has been simulated in THERMOFLEX [7] simulation software, and then modified for operating with parabolic trough type collectors.

2 DESCRIPTION OF SYSTEMS

2.1 Combustion Chamber as Heat Source

In a direct type rotary dryer a combustion chamber produces combustion gases to dry the coal particles. Quench air is supplied to the combustion chamber to control the inlet temperatures of the combustion gases. In the exit of the dryer cyclone collectors and fans are installed to capture the dusts. Rotation system controls the residence time of the coal particles and therefore, the final moisture content of a particle is directly related to the peripheral speed of the shell. In a co-current rotary dryer design, coal particles and hot gas enter the dryer shell in the same direction. Generally in coal drying applications co-current flow is preferred to avoid the possibility of self-ignition of coal particles. A schematic diagram of the simulated direct type rotary dryer with co-current flow is shown in Fig.1.

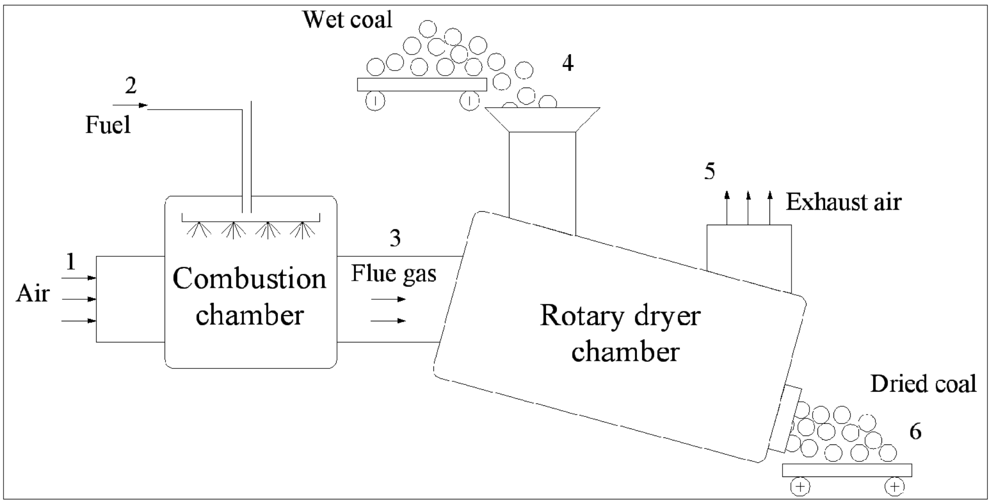

Figure 1. A simplified diagram of the drying unit operating with NG combustion chamber as heat source

General description of the process can be summarized as bellow; the continuous supply of ambient air at 25 °C is ensured to the combustion chamber, where combustion takes place via NG with mass flow rate of 318.85 m3/h. Then combustion gas leaves the combustion chamber at 200 °C and enters dryer chamber, where the temperature of the co-current coal flow at the inlet is 25°C. Coal feed rate to the dryer is 12 t/h and initial humidity ratio of coal is given 20%. The humidity ratio in the product is considered to be 1%. The gas is cooled and humidified while the coal is heated and dried. Then gas and coal are separated, leaving the dryer as two distinct streams. Table 1 shows thermodynamic properties of the different points of the system.

Table 1. Thermodynamic properties of each stream of the coal dryer with combustion chamber

Point	T[˚C]	P [kPa]	m [kg/s]
1	25	91.27	15.72
2	25	200	0.062
3	200	91.2	15.78
4	25	90.71	3.33
5	90	90.71	16.42
6	75	101	2.691

2.1 Parabolic Trough Solar as heat source

Solar energy could be chosen as an alternative method instead of burning natural gas or other fossil fuels in drying applications. There are two types of the solar collectors, e.g., parabolic trough and flat type solar collectors. Parabolic trough type solar collectors provide higher working fluid temperatures than flat plate collectors. This useful heat can be used to produce electricity, heating and cooling applications or industrial processes. The main obstacle in this area is the discontinuity of solar energy. However, in recent years a lot of projects are performed to store the solar energy. Therefore, it should be noted that solar energy might be an alternative or a support in any kind of energy conversion processes.

In this study, same amount of energy, provided from sun, is fed to the dryer for the same coal properties. An indirect solar dryer is basically the same of the dryer which is described in previous section. The only difference is that in a solar dryer, instead of combustion chamber, the parabolic trough solar collectors supply the required heat of the drying.

As illustrated in Fig.2 system consists of the parabolic trough solar collectors, a heat exchanger, a pump and a rotary coal dryer chamber. In the design, the working fluid is chosen as Therminol VP-1. Inlet and outlet temperatures of the working fluid are taken 200 °C and 300 °C, respectively with a pressure of 5 bar. Here, the heat exchanger plays the same roll of the combustion chamber of the ordinary coal dryer. Hot Therminol VP-1 supplies the required heat for producing the hot air. In the air side of the heat exchanger ambient air enters the system via a fan and then hot air enters the direct type fuel dryer with temperature of 200 °C same as the first design.

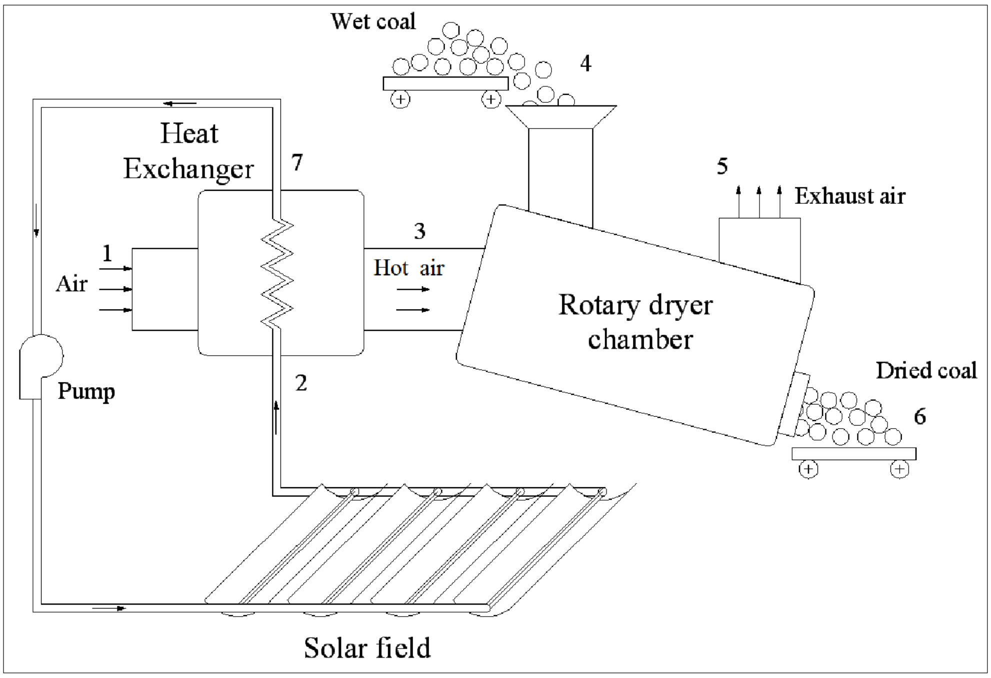

Figure 2. A simplified diagram of the drying unit operating with Parabolic Trough Solar collectors as heat source

The design of parabolic collectors has an important effect on solar system efficiency. Table 2 summarizes the parabolic collector properties to provide the same amount of energy into the dryer.

Table 2. Parabolic solar collector properties

Characteristic	Value
Receiver tube outside diameter [mm]	70
Receiver tube wall thickness [mm]	3
Reflector aperture width [m]	5.6
Reflector geometric concentration ratio	80
Reflector rim angle	80
Reflector focal length [m]	1.668
Reflector cleanliness factor	0.95
Receiver tube emissivity	0.15
Receiver glass envelope emissivity	0.9
Convective heat transfer coefficient outside glass envelope [W/m2°C]	56.78

3 ECONOMIC APPRAISAL OF THE PROJECT

Economic appraisal models provide an objective framework for the assessment of the profits obtained from investments in integrating a parabolic trough solar system to the coal dryer unit.

In this study, simple payback period and net present worth (net present value) methods have been employed in order to performing an economical appraisal model of the project.

Payback period refers to the period of time required for the return on an investment to repay the sum of the original investment. Also, the time value of money is not taken into account. Payback period (PBP) can be evaluated as below:

$$\text{Payback period (PBP)} = \frac{\text{Total investment cost}}{\text{Annual benefit}} \quad (1)$$

If it is performed to an energy saving project, it can be written as:

$$\text{PBP} = \frac{\text{Total investment cost}}{\text{Annual saving with current energy prices}} \quad (2)$$

Net present worth (NPW) can be defined as; Difference between the present values of the future cash flows from an investment and the amount of investment. Present worth of the expected cash flows is computed by discounting them at the required rate of return. It can be expressed by [8]:

$$\text{NPW} = \text{PW of benefits} - \text{PW of costs} \quad (3)$$

For calculating of present worth of benefits or cost, following formula can be used:

$$Pr = F(1+i)^{-n} \quad (4)$$

Where Pr is a present sum of money, F is a future sum of money, i is Interest rate per interest period and n present the year.

In addition, series present worth of benefits or costs can be evaluated by following equation:

$$Pr = A\left[\frac{(1+i)^{n}-1}{i(1+i)^{n}}\right] \quad (5)$$

Where, A is an end-of-period cash receipt. At the end, if the computed value of NPW is positive project can be accepted, otherwise it will be rejected.

4 RESULTS AND DISCUSSION

A direct type rotary dryer with two different heat sources was designed in THERMOFLEX simulation program and fulfilled an economic analysis considering the following technical and economical assumptions:

- The minimum pinch temperature difference in the heat exchanger is assumed to be 100 °C
- The isentropic efficiencies for the pump is taken 75%
- Solar duration is taken 2,000 h/year for the region
- Initial investment cost is taken 2,510,000 $ [7]
- Equivalent NG price and inflation rate in turkey are 0.5 $ and 9%, respectively (2011)
- Economic lifetime of plant is presumed as 25 year
- Operation and maintenance (O&M) cost is assumed to be 1% of total investment cost
- Scrap value of the power plant is accepted 5% of primary investment cost
- Carbon credit is assumed to be 35 €/ton

Moreover, it has been assumed that the dryer has been situated in Mediterranean region of Turkey and Table 3 displays the site condition of the system.

Table 3. Site condition of the coal dryer

Properties	Value
Site altitude	925 [m]
Average ambient temp.	25 [°C]
Ambient pressure	0.91 [bar]
Average ambient relative humidity	60 [%]
Average ambient wet bulb temp.	19.28[°C]
Average direct irradiance	651.7 [W/m^2]

4.1 Technical results

In solar collector area, after the calculations, dried fuel mass flow rate is found to be 2.693 kg/s with a temperature of 104 °C. The humidity of the dried coal is found as 1% and the total thermal power requirement of this system is 1,920 kW. In the heat exchanger the mass flow rate of the working fluid is found to be 17.92 kg/s. The total heat transfer between the heat transfer fluid and air is 3,872 kW, where the heat loss to the environment is found to be 39.11 kW. In the collector field, heat transfer to the working fluid is found to be 3,910 kW. Inlet and outlet velocities of the working fluid are found to be 0.46 m/s and 0.514 m/s, respectively. The required collector field area is calculated to be 24376 m^2, where total effective aperture is 6983 m^2.

4.2 Economical results

In the first design, where heat input to the dryer is supplied by a natural gas burner, the natural gas consumption of the process is found to be 318.85 m^3/h. According to the natural gas prices 2011 in Turkey (0.5 \$/m^3), daily energy cost of coal drying is found to be 2,551 $/day with 16 hours operation in a day. CO_2 emissions originated from natural gas combustion are calculated to be 576 kg/h.

For the second system, the estimated total first investment cost of the solar collector field with labor costs is assumed to be 2,510,000 $. Yearly total operation hours of the solar collector system can be taken as 2000 hours/year. The economical appraise of the system was applied using equations and assumptions in section 3. The results are calculated and summarized in Table 4. It shows that the return on investment occurs approximately in 8 years. As it obvious from given data, the present worth of the benefits and costs at the end of economical lifetime of project are 4.11 and 2.52 m$, respectively. By using eq.3, NPW of the project is calculated 1.61

m$, which is a positive value and as it mentioned in section 3, the project can be economically feasible.

However, the payback time is almost high, in this regard, by adding carbon credits in the total annual income, PBP can be reduced to 6.61 years and NPW increased to 2.63 m$ (Table 4).

We also analyzed another scenario when there is thermal energy storage. If 12 hours energy storage is considered for the given design the total first investment cost will increase up to 3,700,00 $ and the payback time decrease to 4.5 years [9].

Table 4. Cash flow and economic analysis result of the implementation of the parabolic trough solar system to the coal dryer

Years	Investment cost [m$]	A. E S.[1] [$/Year]	A. E S. +CO_2 credit [$/Year]	O&M [$/Year]	Scrap value [$]	Discount rate [%]
0	2.51	318,850	376,500	25,000	125,000	9
1	-	292,523	345,367	22,936	-	9
2	-	268,370	316,850	21,042	-	9
3	-	246,211	290,688	19,305	-	9
4	-	255,881	266,687	17,711	-	9
5	-	207,231	244,667	16,248	-	9
6	-	190,120	224,465	14,907	-	9
7	-	174,422	205,931	13,676	-	9
8	-	160,020	188,928	12,547	-	9
9	-	146,807	173,328	11,511	-	9
10	-	134,686	159,017	10,560	-	9
11	-	123,565	145,887	9,688	-	9
12	-	113,362	133,481	8,888	-	9
13	-	104,002	122,790	8,154	-	9
14	-	95,415	112,651	7,481	-	9
15	-	87,536	103,350	6,863	-	9
16	-	80,309	94,816	6,297	-	9
17	-	73,678	86,987	5,777	-	9
18	-	67,594	79,805	5,300	-	9
19	-	62,013	73,216	4,862	-	9
20	-	56,893	67,170	4,461	-	9
21	-	52,195	61,624	4,092	-	9
22	-	47,885	56,536	3,755	-	9
23	-	43,932	51,868	3,445	-	9
24	-	40,304	47,585	3,160	-	9
25	-	36,976	43,656	2,899	28,992	9
P.B.P [Year]	P.B.P + CO_2 credit [Year]	PW of benefits [m$]	PW of benefits + CO_2 credit [m$]	P.W. of cost [m$]	N.P.W. [m$]	N.P.W. +CO_2 credit [m$]
7.8	6.6	4.11	5.15	2.52	1.61	2.63

A.E.S. Annual energy saving

5 Conclusions

In this study first a direct type rotary coal dryer operating with NG is designed and simulated. Then, in order to decrease fuel consumption and environmental impact of the dryer, solar energy system is recommended to be integrated to dryers instead of burning natural gas. Solar collector field is considered with parabolic trough type collectors. Coupling trough type solar collectors unit to a coal dryer provides economical and enviromental solutions to significiently improve the performance and reduce the energy costs of the coal drying process. The important results drawn from this study are as blow.

1. Parabolic trough type solar collector has been chosen, since it provides higher working fluid temperatures than flat plate collectors.
2. Annually saved energy by installation of solar system unit to coal dryer is 637,700 m^3NG/year.
3. Prevented CO_2 emission from emitting to the atmosphere is calculated to be 1152 ton CO_2/year.
4. The economic analysis performed in this study shows that, without considering carbon credit, the investment can return in 7.8 years, and net present worth of the project is 1.61 m$.
5. In the case that carbon credit is considered as an additional income, the investment can be returned in 6.6 years, and net present worth of the project increased to 2.63 m$.
6. Heat storage increases the first investment cost but, yearly working hours of the dryer increases. The payback time is calculated as 4.5 years when 12 hours heat storage system is added to the system.

However, the payback time of the application is still high for energy efficiency applications. For energy conversion systems the payback period of less than 4 years might be acceptable. But, when looking at in terms of global warming, this type of renewable and alternative energy projects has to be supported by the government to avoid our future negative effects of global warming.

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