Applied Thermal Engineering 29 (2009) 550–557

Contents lists available at ScienceDirect

Applied Thermal Engineering

journal homepage: www.elsevier.com/locate/apthermeng

Investigation of coal-fired power plants in Turkey and a case study: Can plant

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ARTICLE INFO

Article history:
Received 26 July 2006
Accepted 10 March 2008
Available online 21 March 2008

Keywords:
Power plant
Coal-fired plant
Rehabilitation
Turkey

ABSTRACT

About 61% of the total installed capacity for electrical power generation in Turkey is provided by thermal resources, while 80% of the total electricity is generated from thermal power plants. Of the total thermal generation, natural gas accounts for 49.2%, followed by coal for 40.65%, and 9.9% for liquid fuel. This study deals with investigation of the Turkish coal-fired power plants, examination of an example plant and rehabilitation of the current plants. Studied plant has a total installed capacity of 2 × 160 MW and has been recently put into operation. It is the first and only circulating fluidized bed power plant in the country. Exergy efficiencies, irreversibilities, and improvement factors of turbine, steam generator and pumps are calculated for plant selected. Comparison between conventional and fluidized bed power plant is made and proposed improving techniques are also given for conventional plants.

1. Introduction

Energy consumption is one the important problems for the whole world. In the 21st century which energy consumption per person determines the level of development of nations, some environmental problems have appeared such as global warming and air pollution [1–3].

In most countries, numerous steam power plants driven by fossil fuels are in service today. During the past decade, many power generation companies have paid attention to process improvement in steam power plants by taking measures to improve the plant efficiencies and to minimize the environmental impact. Today, many electrical generating utilities are striving to improve the efficiency at their existing thermal electric generating stations, many of which are over 25 years old and mature. Often, a heat rate improvement of only a few percent appears to be desired as it is thought that the costs and complexity of such measures may be more manageable than more expensive options [4].

In the present study, thermal power plants (TPPs) installed in Turkey are given by capacities and fuels used first. Then can thermal power plant (CTPP), which was built in 2004, has been chosen for the analysis and investigated. Finally, rehabilitation and performance improvements techniques of the current TPP installations are presented.

2. Thermal power plants in Turkey

Additions to installed capacity have come in bursts, as Fig. 1a illustrates. Fig. 1b shows the evolution of the energy sources and related technologies used in power generation, with hard coal almost entirely replaced (first by petroleum and then by hydropower) in the course of 40 years. In the 1950s, the dominant fuel for power generation in Turkey was hard coal. Its share in total installed capacity declined gradually from 52.1% (212.6 MW) in 1950 to 27.4% (348.3 MW) in 1960. By that year, hydroelectric energy supply had reached a share in capacity of 32.4% (411.9 MW) [5].

A noticeable increase in the consumption of the fossil fuel sources was observed as a result of the increased energy demand in 1990s. In recent years, imported natural gas has played a greater role in power generation. This trend toward natural gas is driven by both economic and environmental concerns. Among the fossil fuels, coal has always had a prominent place. Fuel type and capacity values of Turkish thermal power plants are shown in Table 1. It is determined from this table that most of thermal power plants have been used lignite as fuel source, 53.82% of total capacity.

Almost one-fourth (23%) of Turkey's total electric production (149,882 GW h) was obtained from coal [6]. In Fig. 2, the locations of the existing coal-fired thermal power plants are shown.

3. Can thermal power plant and analysis

3.1. Description of the plant

The can thermal power plant (CTPP) is a circulating fluidized bed (CFB) plant located near Can, Canakkale [7,8]. The Can plant is fired by lignite, a type of soft coal, which is also referred to as brown coal. A flow diagram of the single unit of the CTPP is illustrated in Fig. 3, while its some components are briefly described below.

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doi:10.1016/j.applthermaleng.2008.03.025

Nomenclature

$\dot{m}$	mass-flow rate (kg/s)
$\dot{E}$	energy rate (kW)
ex	specific exergy (kJ/kg)
Ex	exergy (kJ)
$\dot{E}x$	exergy rate (kW)
h	specific enthalpy (kJ/kg)
$\dot{I}$	irreversibility rate, exergy consumption rate (kW)
$I\dot{P}$	improvement potential rate for exergy (kW)
$\dot{Q}$	heat transfer rate (kW)
s	specific entropy (kJ/kg K)
T	temperature (°C or K)
W	work (kJ)
$\dot{W}$	work rate or power (kW)
$\dot{S}$	entropy (kW/K)

Greek letter

ε	exergy (second law) efficiency (%)

Indices

in	input
out	output
PH	physical
0	dead state or reference environment
gen	generation
r	system boundary

Superiorindices

Q	heat
W	work
PH	physical

Abbreviations

TPP	thermal power plant
TPPP	Turkish thermal power plant
TTPPs	Turkish thermal power plants
CTPP	can thermal power plant
CFB	circulating fluidized bed
FGD	flue-gas desulphurization
FB	fluidized bed
FBC	fluidized bed combustion
FBCS	fluidized bed combustion system

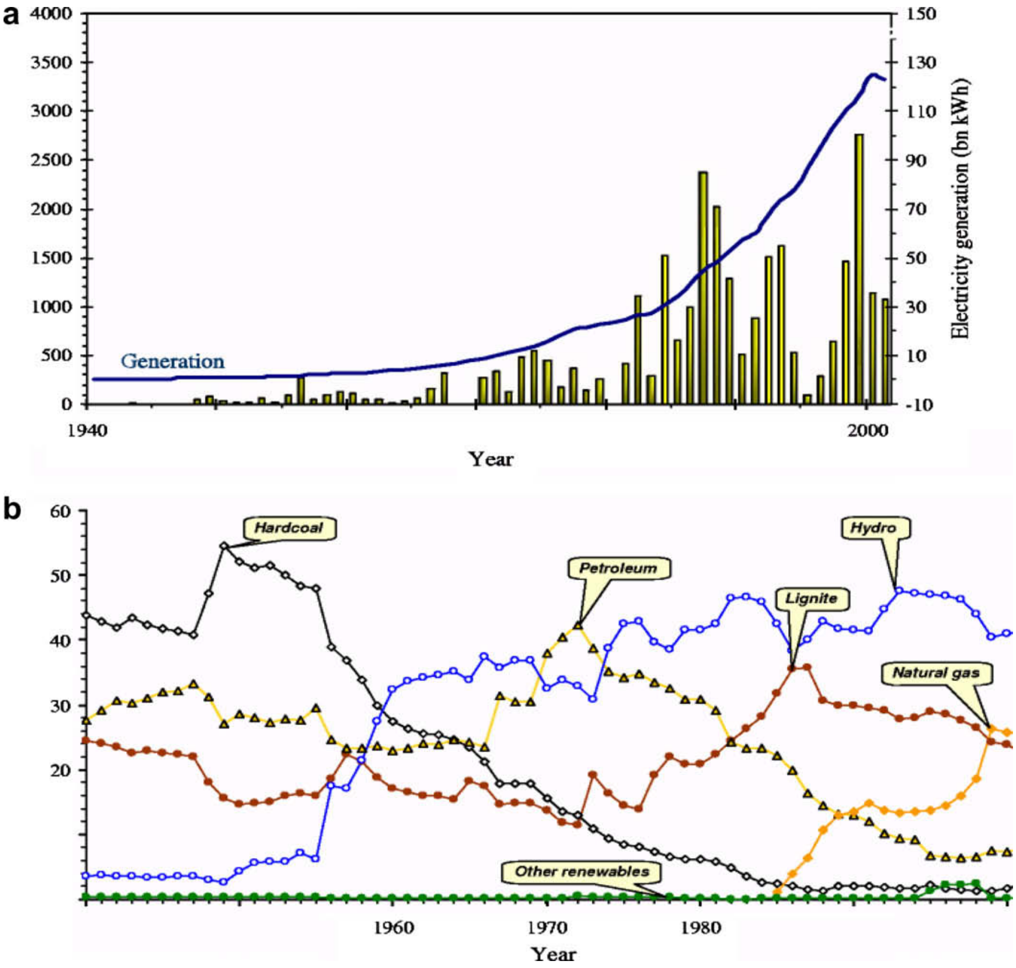

Fig. 1. (a) Additions in installed capacity (left scale) and power generation (right scale), 1940–2001. (b) Shares of installed capacity by energy source, 1940–2001 (modified after Ediger, 2003b,c).

Table 1
Main characteristics of coal-fired TPPs in Turkey

Properties	Lignite												Hard coal
Thermal power plant name	Cayırhan	A.Elbistan	Kangal	Orhaneli	Seyitömer	Tunçbilek	Yatağan	Kemerköy	Soma-A	Soma-B	Yeniköy	Can	Catalagz
Net production (GW h)	2501.1	4292.8	2153.7	1219	3107.9	1672.4	3838.9	263.1	335.6	5607.3	1911.3	2000	2025.9
Unit number	4	4	3	1	4	5	3	3	2	6	2	2	2
Opening date of first unit	1987	1984	1989	1992	1973	1956	1982	1983	1957	1981	1986	2004	1989
Total setup power (MW)	620	1360	457	210	600	429	630	630	44	990	420	320	300
Loading factor (%)	53.5	42.5	57.6	75.9	65.6	48.3–60.4	77.6	57.5	94.6	74.8	62.8		80.7
Fuel (*t*/year)	3,696,266	10,970,167	5,194,456	1,413,436	5,384,720	1,907,753	5,538,279	4,563,781	284,726	8,663,775	3,412,505	1,800,000	1,658,630
Low heat value (kW/kg)	7411–8629	4727–5652	4702–5246	7532–11,455	5853–1746	8503–18,640	5472–8194	5439–6418	11,765–13,770	6071–8323	4530–7302	4368	11,782–13,691
Average thermal efficiency	34.5	30.1	30.4	36.2	33	31.5	32.7	33.2	30.3	32.4	34.8	37	33.6
Cost (gross)	3.91	2.45	2.8	4.53	2.43	3.64	1.86	2.18	3.68	3.68	1.96		4.17
(Cent/kW h) (Net)	4.49	2.7	3.07	5.18	2.74	4.2	2.07	2.42	4.16	4.16	2.22	2.61	4.55
Industrial analysis of lignite (%)													
Moisture	22.77–27.62	49.22–52.24	7.72–51.91	31.54–31.97	33.27–36.03	13.86–23.46	30.59–42.93	30.20–33.29	18.43–22.57	16.89–23.21	25.08–30.47	22	12.56–16.77
Ash	35.71–42.42	18.76–19.66	19.21–24.22	24.57–30.99	32.33–37.10	16.07–50.52	25.65–35.76	31.22–35.87	25.29–28.36	39.05–49.63	31.75–40.43	32	40.55–48.21
Volatile matter	22.48–23.56	21.28–22.69	20.30–21.60	24.16–26.02	17.78–20.63	20.17–27.77	21.63–25.51	26.17–29.84	24.65–27.40	20.41–24.86	27.30–31.52		14.28–15.70
Constant *C*	22.47–24.98	16.9–19.25	16.87–18.18	23.49–31.05	18.28–22.68	23.54–47.56	18.77–24.07	19.14–21.35	34.27–38.24	19.01–24.44	1.35–22.75	58	32.15–35.89
Total sulfur	2.44–2.77	1.01–1.65	1.81–2.10	1.37–1.56	0.79–1.08	1.25–1.76	1.27–1.91	1.92–2.45	0.70–0.88	0.47–0.80	1.35–2.07	4.5	0.30–0.58
Stack gas emissions (kg/MW h)													
SO_2	4.23	52.55	110.48	1.91	25.59	31.88	43.03	72.11	12.81	10.78	57.12	3.4	4.76
No_x	7.4	2.26	4.54	4.44	2.32	2.57	3.82	2.01	1.58	3.15	2.32	2.72	4.11
Dust	3.15	4.02	14.56	0.48	6.27	9.62	1.63	0.55	38.85	0.92	0.65	0.51	3.75
Flue gas desulfurization	+	–	+	+	–	–	Started	Started	–	–	Started	Started	–

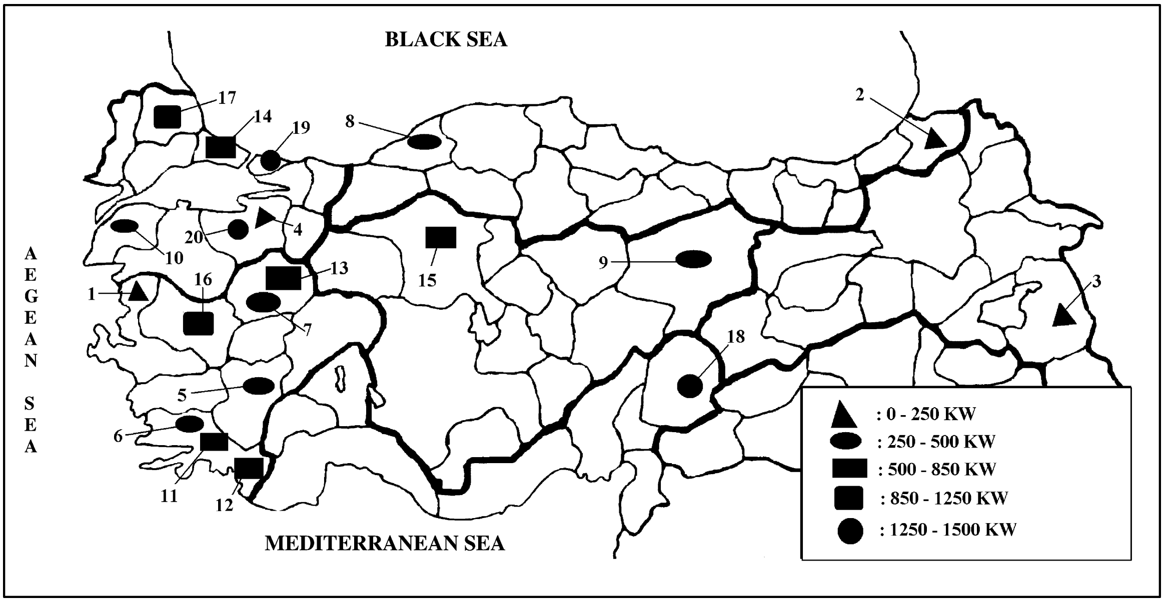

Fig. 2. Distribution of the Turkish thermal power plants (1: Aliaga Gas TPP, 2: Hopa Oil TPP, 3: Engil Gas TPP, 4: Orhaneli TPP, 5: Denizli Geotermal TPP, 6: Yeniköy TPP, 7: Tuncbilek TPP, 8: Çatalagzı TPP, 9: Kangal TPP, 10: Can TPP (it is being constructed), 11: Yatagan TPP, 12: Kemerköy TPP, 13: Seyitomer TPP, 14: Ambarli Fuel Oil TPP, 15: Cayırhan TPP, 16: Soma A-B TPP, 17: Hamitabat Natural Gas TPP, 18: Afşin-Elbistan TPP, 19: Ambarlı Natural Gas TPP, 20: Orhaneli Natural Gas TPP).

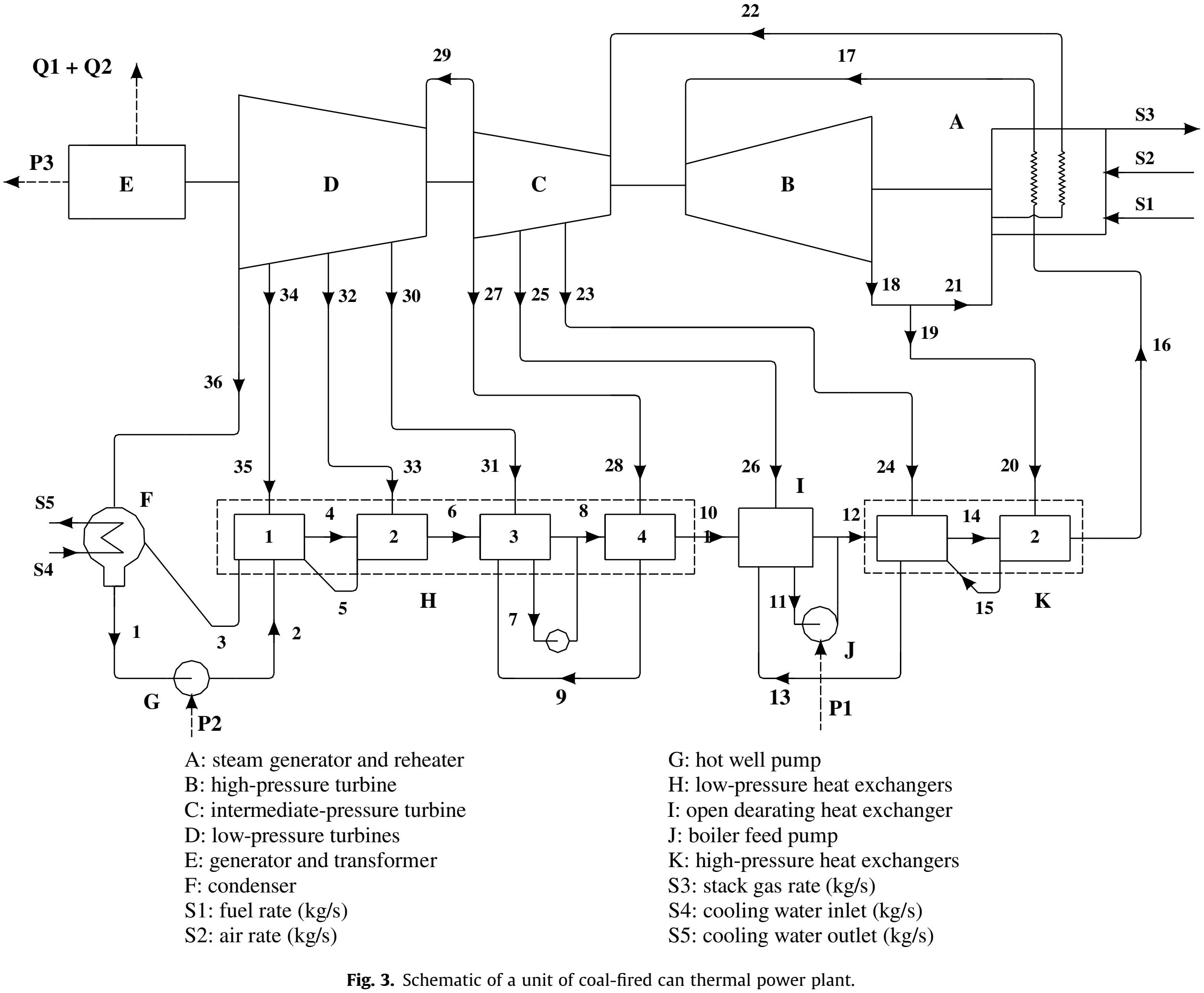

Fig. 3. Schematic of a unit of coal-fired can thermal power plant.

3.1.1. Steam generation

Heat is produced and used to generate and reheat steam. In the CTPP, fluidized bed coal-fired steam generators produce steam with a mass-flow rate of 127.04 kg/s at 17.2 MPa and 540 °C, and 115.165 kg/s of reheat steam at 3.719 MPa and 540 °C. Regenerative air preheaters are used. The flue gas passes through an electrostatic precipitator rated at a collection efficiency of 99%. This natural circulation type boiler is equipped with four ash separator cyclones and two ash coolers.

3.1.2. Power production

The steam produced in the steam generation section is passed through a series of turbine generators which are attached to a transformer. Extraction steam from several points on the turbines preheats feed water in several low- and high-pressure heat exchangers. The low-pressure turbines exhaust to the condenser at 0.85 kPa. Each unit of the CTPP has a turbine generator containing one only-flow high-pressure cylinder, one triplicate-flow medium-pressure cylinder and one triplicate-flow low-pressure cylinder.

3.1.3. Condensation

The condenser is of direct contact jet type; the turbine exhaust steam is mixed with cooling water coming from heat exchangers installed in a dry natural draught hyperbolic cooling tower. Cooling water condenses the steam exhausted from the turbines. The flow rate of cooling water is adjusted so that a specified temperature rise in the cooling water is achieved across the condenser.

3.2. Analysis

For a general steady state, steady-flow process, the four balance equations are applied to find the work and heat interactions, the rate of exergy decrease, the rate of irreversibility, the energy and exergy efficiencies [9,10].The mass balance equation can be expressed in the rate form as,

$$\sum \dot{m}_{\text{in}} = \sum \dot{m}_{\text{out}} \tag{1}$$

where $\dot{m}$ is the mass-flow rate, and the subscript in stands for inlet and out for outlet. The general energy balance can be expressed as

$$\sum \dot{E}_{\text{in}} = \sum \dot{E}_{\text{out}} \tag{2}$$

$$\dot{Q} + \sum \dot{m}_{\text{in}} h_{\text{in}} = \dot{W} + \sum \dot{m}_{\text{out}} h_{\text{out}} \tag{3}$$

The general exergy balance can be expressed in the rate form as, assuming that flows are one-dimensional, the input and output terms are net quantities after accounting for imports and exports and the accumulation term is zero, the following may be written

$$\sum_{\text{in}} \dot{m}_{\text{in}} \cdot \text{ex}_{\text{in}} - \sum_{\text{out}} \dot{m}_{\text{out}} \cdot \text{ex}_{\text{out}} + \sum \dot{\text{E}}\text{x}^{\text{Q}} - \dot{\text{E}}\text{x}^{\text{W}} - \dot{I} = 0 \tag{4}$$

where ex denotes the specific exergy, $\dot{\text{E}}\text{x}^{\text{Q}}$ and $\dot{\text{E}}\text{x}^{\text{W}}$ are the exergy transfers associated with Q and W, respectively, and $\dot{\text{I}}$ is the system exergy consumption [11]. The amount of thermal exergy transfer associated with heat transfer rate $\dot{Q}_{\text{r}}$ across a system boundary r at constant temperature T_{r} is

$$\dot{\text{E}}\text{x}^{\text{Q}} = (1 - (T_0/T_{\text{r}})) \cdot \dot{Q}_{\text{r}} \tag{5}$$

The specific exergy of a mass flow with negligible potential and kinetic energy changes as well as no changes in the chemical composition can be written as,

$$\text{ex}^{\text{PH}} = (h - h_0) - T_0(s - s_0) \tag{6}$$

The amount of exergy consumed due to irreversibility during a process is as follows:

$$\dot{I} = T_0 \cdot \dot{S}_{\text{gen}} \tag{7}$$

where $\dot{S}_{\text{gen}}$ is the entropy generation. The exergy efficiency expresses all exergy input as used exergy, and all exergy output as utilized exergy. Therefore, the exergy efficiency ε becomes

$$\varepsilon = \frac{\dot{\text{E}}\text{x}_{\text{out}}}{\dot{\text{E}}\text{x}_{\text{in}}} \tag{8}$$

Gool [12] has also noted that maximum improvement in the exergy efficiency for a process or system is obviously achieved when the exergy loss or irreversibility is minimized. Consequently, he suggested that it is useful to employ the concept of an exergetic ‘*improvement potential*’ when analyzing different processes or sectors of the economy. This improvement potential, denoted $\text{I}\dot{\text{P}}$, is given by [13].

$$\text{I}\dot{\text{P}} = (1 - \varepsilon)(\dot{\text{E}}\text{x}_{\text{in}} - \dot{\text{E}}\text{x}_{\text{out}}) \tag{9}$$

4. Comparison of conventional plants and CTPP

Table 2 shows the operational characteristics and the environmental impact assessments of the 13 coal-fired power plants [14,15]. Most of lignite-fired thermal power plants have been run by conventional methods and constructed in places very close to residential areas. Majority of the lignite-fired thermal power plants do not have a desulphurization system. Therefore, it is crucial to decide on the optimal place and technology for the future thermal power plants, and to equip the currently operating plants with newer technologies that will reduce amount of contaminants released into the air. Can thermal power plant is the only example, which has fluidized bed combustion system. In all power plants, dust control systems have been employed, whereas, most of them lack flue-gas desulphurization (FGD) systems. Though most of the thermal power plants are lignite-fired, they lack FGD system and conventional methods have been used lead to air pollution, mainly SO_2 in the regions where these constructions are established [6]. Advanced clean coal technologies, such as pressurized fluidized

Table 2
Mean process data for single unit

Steam generation section: points		
Furnace	(In Fig. 3)	
Coal consumption rate at full load (kg/s)	(S1)	35.714
Flue gas temperature (°C)	(S3)	138
Boiler (heat exchanger temperature component)		
Feed water temperature (°C)	(16)	249.8
Total evaporation rate (kg/s)	(14)	127.04
Steam temperature (°C)	(17)	540
Steam pressure (MPa)	(17)	17.2
Reheat evaporation rate (kg/s)	(22)	115.165
Reheat steam temperature (°C)	(22)	540
Reheat steam pressure (MPa)	(22)	3.719
Power production section		
Turbine		
Efficiency of low-pressure turbine	(D)	0.80
Efficiency of medium-pressure turbine	(C)	0.81
Efficiency of high-pressure turbine	(B)	0.82
Condenser pressure (kPa)	(F)	0.85
Condenser temperature (°C)	(F)	43.4
Generator		
Gross power output (MW)		2x160
Net power output for single unit (MW)	(E)	160
Generator efficiency		0.99
Condensation section		
Cooling water flow rate (m^3/s)	(S4)	4.38
Cooling water temperature rise (°C)	(S5)	4.9

bed combined cycles and the integrated coal gasification combined cycles, which are capable of higher efficiencies, should be used in firing low-grade coal.

Advantages of the fluidized bed combustion system, CTPP, on conventional systems will be as below:

- The capacity to burn high inert content fuels as well as fuel mixtures with widely different characteristics.
- High firing efficiency.
- Simple fuel preparation and feeding.
- High heat transfer rates to the heating surfaces located in the combustion chamber.
- The low combustion temperature (~850 °C) of the FB minimizes NO_x and permits optimum sulphur capture, while the flywheel of circulating solids permits significant variations in fuel properties. FB-furnace heat fluxes are also less than half those of peak heat fluxes in pulverized-coal furnaces. As a result, low mass-flow rates can be used in the furnace tubes without concern for tube overheating.

4.1. Performance improvement and rehabilitation techniques for conventional plants

4.1.1. Exergy-related techniques

Through the better understanding developed with exergy analysis, the efficiencies of devices and processes can usually be improved, often cost-effectively. Consequently, exergy analysis is particularly useful for (i) designing better new facilities, and (ii) retrofitting or modifying existing facilities to improve them [4,16]. These uses are the focus on the present article.

4.1.2. Improving heat transfer

Optimum heat rate can be achieved with careful balancing of the boiler, steam turbine, generator and condenser performance. To improve the plant heat rate: in the boiler, a rehabilitation project must begin with a complete analysis (including emissions limits, existing operational issues and identification of available solutions) [17]. In this review, primary areas to be considered are follows: FBCS using (for boiler), three dimensional blade profile selection (for turbine), new design (for condenser).

4.1.3. Maximizing the output power

Steam turbine blades can be replaced or modified to accommodate the increased steam flow with only selected rows having to be changed. However, the increased heat rejection to consider will give rise to a higher condensing pressure and worsen the heat rate due to the limited margin in it. This is where the trade off comes, and it is easy to see from a chart of electricity pool price why extra megawatt at the expense of heat rate might be more beneficial [18].

4.1.4. Maintenance and control

Numerous measures related to maintenance and controls are possible to reduce losses. Outages of the components are very important to improve reliability. Here re-engineer high maintenance and staff maintenance will improve availability. Outages of a boiler are tube leaks and fouling. Boiler tube leaks should be monitored and recorded. In high corrosion areas, tubes must be coated. Treatment of the feed water should be made continuously. Fouling can be prevented by proper design of tubes and improving cleaning equipments.

4.1.5. Increasing the life time

To increase the life time, components which have creep life or fatigue life limitations should be described. Running hours and stop/starts events should be recorded. Frequent stop/starts will be exist thermal fatigue results. Insulation in the system will be deteriorative with time, fatigue and temperature. Therefore these components must be changed.

4.1.6. Computer-aided design, analysis and optimization

Many efforts to improve coal-fired steam power plants by providing computer-aided tools for simulation, analysis and optimization have been reported. Some of these efforts have focused on processes using Rankin cycles as part or all of a power plant, and have not integrated exergy concepts. Other works have directed the computer tool at addressing exergy considerations or at ensuring a focus on exergy is a central thrust. Such computer tools can aid in developing and evaluating potential improvement measures [4].

5. Results and discussion

In this study, Turkish Thermal Power Plants (TTPPs) capacity values are given and their properties are shortly explained and rehabilitation techniques are investigated. Also a power plant put into operation recently is examined and presented as a case study. Results of this study can be summarized at two groups:

5.1. Results of the CTPP analysis

This plant is one of the most advanced studies, because CTPP is the first and only fluidized bed combustion (FBC) plant in the Turkey. In this plant low grade lignite is fired efficiently and clearly. The coal-fired steam power plant is examined using energy and exergy analyses. Several assumptions and simplifications are used in the energy and exergy analyses are given in Table 3.

A schematic representation of the coal-fired steam power plant is shown in Fig. 3. First, with the data in Table 2 and Eq. (6) through (9), the thermal efficiency and exergy efficiency for the power plant are evaluated and the component irreversibility rates are given in Table 4. Important points obtained are given as follows:

- For overall plant, the energy and exergy efficiencies are found as 37% and 36%, respectively. In the steam generator, efficiencies of energy and exergy are found as 94% and 65%, respectively.
- The most of irreversible losses in the cycle is occurred in the combustion chamber (see Table 4), Fuel preparation and transport, air preheated heating element, good firing system design, convective heat transfer surface arrangement, furnace wall cleaning, change of the reheat steam flow and inlet temperature may be rearrangement.

5.2. Results of the rehabilitation of the plants

Most of TTPPs are constructed 20–25 years ago. Consequently, they have old technology. Absolutely they need to rehabilitation work. Rehabilitation of the plants will be given important benefits as reduction of investment and production cost. These benefits are given follows:

- *Saving Fuel Cost:* even a small improvement in heat rate will represent a significant saving in production costs over the remaining lifetime of the plant. On base load plant, the heat rate improvements do pay back quickly and are a good investment [18]. This is particularly the case in countries where fuel costs are high.
- *Maximizing revenues:* increased output for the same heat consumption is possible and not so expensive. In some circumstances it is a better investment to do this. For a national

Table 3
Stream data for a unit in CTPP

No	Flow rate (kg/s)	Pressure (kPa)	Temperature (C)	Enthalpy (kJ/kg)	Entropy (kJ/kg K)	Specific energy (kJ/kg)	Specific exergy (kJ/kg)	Energy (MW)	Exergy (MW)
S1	35.714	100	15					410	424
S2	165	100	15	63.035		0	0	0	0
S3	196.02	100	138					35.000	22.000
S4	4388.889	100	15	63.035	0.2223	0	0	0	0
S5	4388.889	100	19.3					196.367	18.203
1	94.333	8.5	42.7	179.8	0.6145	116.765	3.75257	11.01479	0.353,991
2	94.333		45.3	191.8	0.6422	128.765	7.77082	12.14679	0.733044
3	2.562	25.8	51.3	214.79	0.7074	151.755	11.9734	0.388796	0.030676
4	94.333		62.7	263.97	0.8647	200.935	15.8274	18.9548	1.49305
5	2.431	50.4	68.7	287.58	0.9389	224.545	18.0567	0.545869	0.043896
6	94.333		78.8	331.38	1.0609	268.345	26.7024	25.31379	2.518918
7	13.511		115.9	486.74	1.4842	423.705	60.0885	5.724678	0.811856
8	135.734		116.2	488.63	1.4864	425.595	61.3446	57.76771	8.326546
9	6.497	503.7	122.2	513.26	1.5513	450.225	67.2737	2.925112	0.437077
10	107.783		151.1	637.67	1.8528	574.635	104.806	61.93588	11.29635
11	129.145		180	763.23	2.1393	700.195	147.811	90.42668	19.08911
12	129.149		183.6	789.07	2.1741	726.035	163.624	93.76669	21.13185
13	6.546	2098	191.5	815.08	2.2499	752.045	167.792	4.922887	1.098367
14	127.042		215.8	930.71	2.4816	867.675	216.658	110.2312	27.52463
15	9.498	3961	223.8	961.73	2.5513	898.695	227.594	8.535805	2.161684
16	127.042		249.8	1085.64	2.7889	1022.605	283.039	129.9138	35.95787
17	127.042	17,200	540	3396.86	6.4062	3333.825	1551.93	423.5358	197.1608
18	122.735	4042	330.5	3044.21	6.6527	2981.175	1128.26	365.8945	138.4764
19	9.665	4042	330.5	3044.21	6.6527	2981.175	1128.26	28.81306	10.90459
20	9.665	3961	329.7	3044.21	6.5079	2981.175	1169.98	28.81306	11.30785
21	115.165	4042	330.5	3044.21	6.6527	2981.175	1128.26	343.327	129.9355
22	115.165	3719	540	3538.61	7.2454	3475.575	1451.87	400.2646	167.2045
23	6.546	2130	454.1	3365.19	7.2721	3302.155	1270.76	21.61591	8.318363
24	6.546	2098	453.9	3365.19	7.1015	3302.155	1319.91	21.61591	8.640154
25	5.983	1045	354.2	3166.59	7.3017	3103.555	1063.63	18.56857	6.363674
26	5.313	1003	353.8	3166.59	7.2899	3103.555	1067.03	16.48919	5.669109
27	6.491	519.2	267	2995.76	7.7856	2932.725	753.36	19.03632	4.89006
28	6.491	503.7	269.1	3000.78	7.5803	2937.745	817.537	19.0689	5.306635
29	99.979	519.2	267	2995.76	7.7856	2932.725	753.36	293.2109	75.32019
30	6.352	195.4	168.6	2807.08	7.4112	2744.045	672.563	17.43017	4.272123
31	6.352	185.8	168.3	2807.08	7.4293	2744.045	667.348	17.43017	4.238994
32	2.431	52.49	84.6	2647.89	7.5796	2584.855	464.849	6.283783	1.130048
33	2.431	50.39	81.5	2646.28	7.5927	2583.245	459.464	6.279869	1.116958
34	2.163	26.87	66.5	2620.12	7.8168	2557.085	368.73	5.530975	0.797563
35	2.163	25.8	65.7	2619.58	7.8214	2556.545	366.864	5.529807	0.793528
36	88.971	8.5	43.4	2599.22	8.0096	2536.185	292.275	225.6469	26.00395
Q1								1.983	0.000
Q2								1.987	0.000
P1								3.283	3.283
P2								0.181	0.181
P3								160.000	160.000

Table 4
Irreversibility rate, exergetic efficiency and improvement factor of the components

Component	Irreversibility rate $\dot{I}$ (MW)	Exergetic efficiency ε	Improvement factor $I\dot{P}$ (MW)
High-pressure turbine	13.882	0.75	3.47
Medium-pressure turbine	13.237	0.81	2.515
Low-pressure turbine	4.957	0.88	0.594
Low-pressure pre-heater	2.051	0.85	0.298
High-pressure pre-heater	4.014	0.78	0.883
Pump1	1.295	0.61	0.505
Condenser	7.447	0.70	2.234
Pump2	0.751	0.33	0.503
Boiler	205.228	0.65	71.822

utility there may be a low margin between available installed capacity and the peak demand. Having the ability to produce, say an extra 5% on output could contribute to reduce a medium term shortage but could greatly assist a short-term crisis.

- *Increasing combustion efficiency:* the intensive mixing and high agitation of the particles ensure very efficient combustion and excellent desulphurization. The CFB boiler's staged combustion (progressive combustion and air introduction) and relatively low operating temperature also greatly reduce nitrogen oxide formation. The furnace consisted water walls whose lower parts are protected by a refractory lining.
- *Environmental benefits:* this driver is last but definitely not least. In many cases this is the one reason for undertaking a major refurbishment project. The flue gases are minimized using the fluidized bed boiler technology. The stack gases are directly eliminated during the combustion process as a result of circulating fluidized bed boiler technology and therefore a separate flue gas cleaning system is not required. The Can project will constitute an example for future coal-fired thermal power plants. The dry cooling system minimizes water consumption and pollution.

6. Conclusions

The flue gases are minimized using the fluidized bed boiler technology. The stack gases that can be harmful to the environment are directly eliminated during the combustion process as a result of circulating fluidized bed boiler technology and therefore a separate flue gas cleaning system is not required. Consequently, the possibility of operating the power plant has been eliminated by means of the integrated cleaning process in the boiler and the operation of the plant has been sustained without any impact to the environment. The Can project will constitute an example for future coal-fired thermal power plants.

Several important results drawn from the present study are as follows:

(a) The use of emission-minimizing technologies has to be encouraged and put into practice for the private sectors establishing and operating new power plants.
(a) Taxes of the power plants can be increased according to the level of their emissions.
(b) In the current coal-based thermal power plants, efficiency can be increased by modifying the coal preparation and firing units. In addition, the future thermal power plants should be adopted new and efficient firing technologies such as fluidized bed (FB) combustion.
(c) Government should support, promote and award research and development studies in the area of minimizing the pollutant emissions from the thermal power plants.
(d) The rehabilitation of steam power plant units is an attractive solution for national utilities and independent power producers to improve the plant economy and to keep production cost competitive. Steam power plant rehabilitation is a cost-effective method to regain competitive electricity production cost of older power plant units. The results of a successful rehabilitation are reduced electricity production cost achieved by output increase, heat rate improvement and availability enhancement while at the same time extending lifetime and complying with stricter environmental standards [18].
(e) In the current plants to be obtained maximum work; insulation must be rebuild, new control systems should be used, treatment of the feed water should be made continuously, boiler must be operated at maximum load for maximum output, frequent start/stops must be reduced to prevent thermal fatigue results.

Acknowledgement

The author would like to thank to the CTPP (can thermal power plant) for data support.

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