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Chapter 1

Introductory Chapter: Application of Power Plants in the Industry

Tolga Taner and Mecit Sivrioglu

Additional information is available at the end of the chapter

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1. Introduction

Power plants are very significant for all industry sectors that depend on exergy processes. Since many factories use such energies for their major processes, they have installed power plants on account of their factories. Installing power plants can gain their energy in an efficient way for the factory. This book poses exergy and application technology to energy processes. This book impresses on the exergy with an overview of all of the energy systems. Energy and exergy efficiencies related to thermodynamic laws are carried out for the power plant and technology. All processes depend on energy that is used more than other similar factories.

These calculations can be determined by thermodynamics laws and their general and specific formulas. Using a Rankine Cycle is more effective than the other thermodynamic cycles. In addition, it includes mass and energy conversion according to a dead state. All these formulas and calculations pose energy and exergy efficiencies.

This book poses energy and exergy efficiency of energy systems and industry about several different factories. Technoeconomic analysis is carried out for the energy and exergy efficiency progresses that should be applied in power plant of factory, which is the center of a factory. In addition, power plant can be an essential influence for factories' lucrativeness. Hence, process stream for the factory energy solutions can be determined energy and exergy efficiencies. This application also can be used for energy saving by power plant's exergy. This book aims to define a comprehensive overview of the application of power plants. In conclusion, this book aims to demonstrate the efficiency of energy and new technological developments in many different areas for power plants.

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2. A brief of power plants

This book covers energy and exergy efficiency of power plants in the industry. Technoeconomic analysis is carried out for the energy and exergy efficiency progresses that should be applied in power plant of many different factories, which are the center of a factory. In addition, power plant can be an essential influence for factory profit. For this reason, the process flow in the factory energy solution, the energy and exergy efficiencies contained in the Thermodynamic Law can be determined [1]. This application can be used for energy saving by the power plant. Moreover, there are Thermodynamic Laws in nuclear energy studies [2]. Energy and exergy analysis studies are also applied in wind energy [3]. Different topics and advantages such as solar energy and fuel cell energy and exergy analyses are emphasized from renewable energy sources [4-6]. Energy production also plays a major role in the power plants with fluid bed boiler [7-9]. Power plants are very significant for all industry sectors that depend on exergy processes. Since many factories use such energies for their major processes, they have installed power plants on account of their factories. Installing power plants can gain their energy in an efficient way for the factory. This book explores the view of general exergy that is valid for all energy systems. In this way, the cost of thermoeconomic, energy and exergy is known as exergoeconomic (technoeconomic) [10, 11]. These data can be analyzed by sensitivity, uncertainty, and other data analysis methods [1, 2, 4, 6, 12, 13]. Power plants are very significant for all industry sectors that depend on exergy processes. Since many factories use such energies for their major processes, they have installed power plants on account of their factories [14]. Installing power plants can gain their energy in an efficient way for the factory. These calculations are based on the laws of Thermodynamics and their general and special formulas.

2.1. Methods, calculations, and Rankine cycle

Using general cycle Rankine cycle that is more effective cycle than the other thermodynamic cycles. The Rankine cycle for the steam power plant is given in **Figure 1**. Boiler feed water is pumped to the economizer. From here, the pressure-reducing valve is sent to the boiler. In detail, energy calculations are made according to the input and output data from 6 points of Rankine cycle [1].

The temperature-entropy diagram in the Rankine cycle used for the steam power plant cycle is shown in **Figure 2**.

Rankine cycle calculations are calculated according to the following formulas. Thermodynamic vapour tables are used in calculations. The turbine dryness fraction is calculated from Eq. (1) as below [1]:

$$x_{t6,o} = (s_{t5,i} - s_{c1,i})/s_{c1,fg} \tag{1}$$

where $x_{t6,o}$—turbine dryness fraction output, [−]; $s_{t5,i}$—turbine entropy input, [kJ/kg K]; $s_{c1,i}$—condenser entropy input, [kJ/kg K]; and $s_{c1,fg}$—condenser entropy (difference between saturated liquid and steam), [kJ/kg K].

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The turbine enthalpy output is calculated from Eq. (2) as follows [1]:

$$h_{t6,o} = h_{t6f,o} + x_{t6,o}.h_{t6fg,o} \tag{2}$$

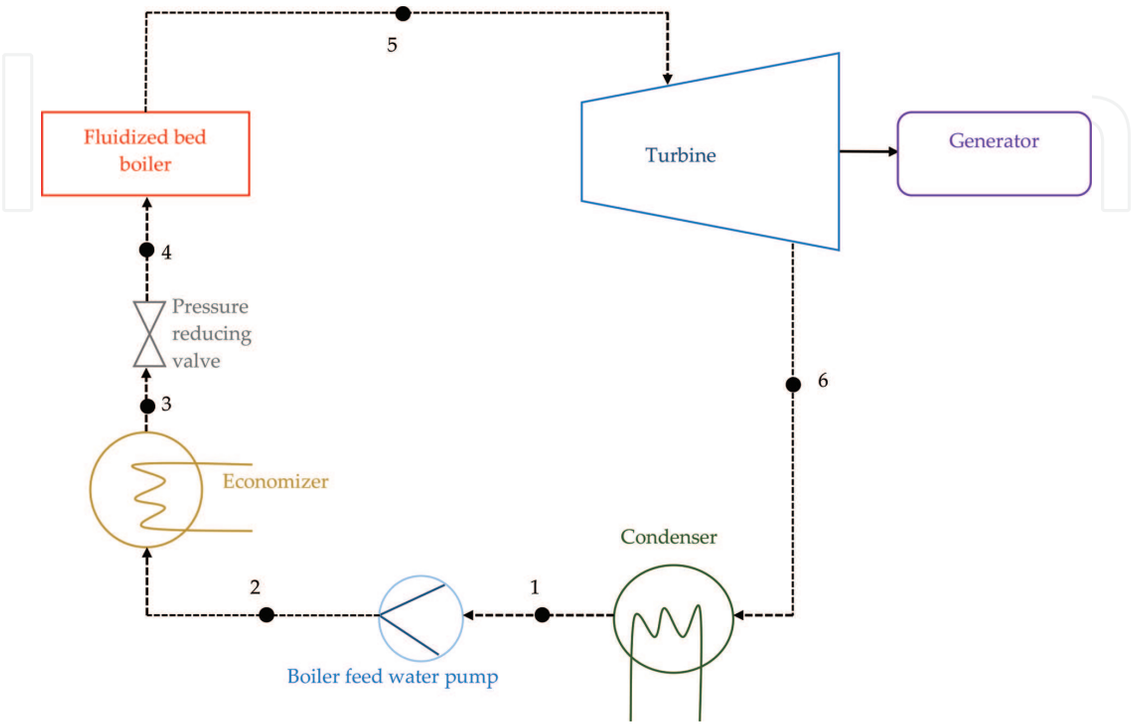


Figure 1. Steam power plant, Rankine cycle [1].

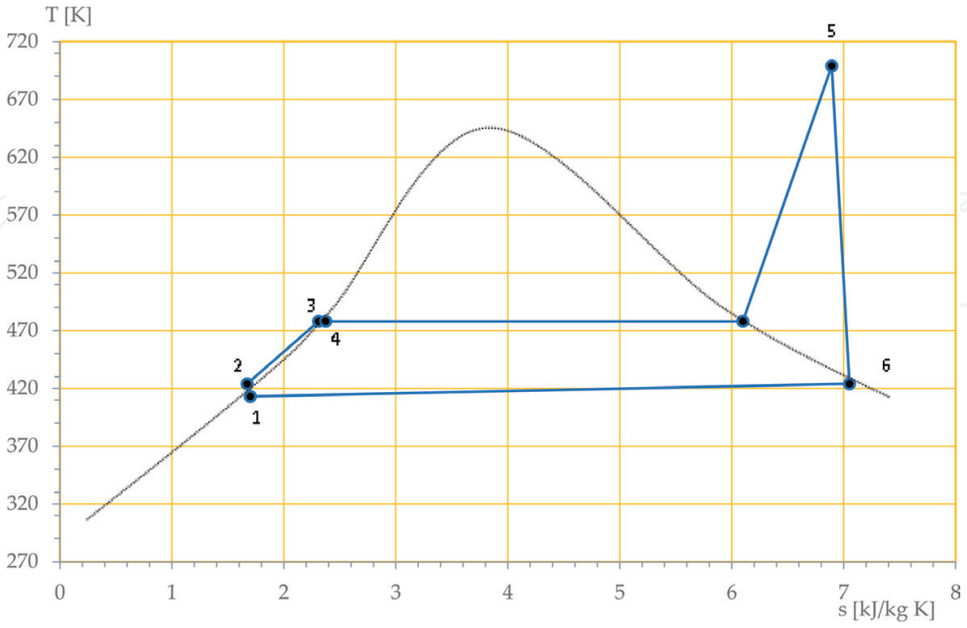


Figure 2. Steam power plant, Rankine cycle T-S diagram [1].

where $h_{t6,o}$—turbine enthalpy output, [kJ/kg]; $h_{t6f,o}$—turbine-saturated fluid enthalpy output, [kJ/kg]; and $h_{t6fg,o}$—urbine-saturated liquid and vapor enthalpy output, [kJ/kg].

Boiler feed water pump work calculations are presented in the following equation Eq. (3) [1]:

$$w_{pp} = \left[v_{pp,f} \times \left(P_2 - P_1\right)_{pp}\right] / \eta_{pp} \tag{3}$$

where w_{pp}—pump work, [kJ/kg]; $v_{pp,f}$—specific volume of saturated liquid of feed pump, [m^3/kg]; $(P_2 - P_1)_{pp}$—supply pump pressure difference, [kPa]; and η_{pp}—pump efficiency is accepted as 80% [1].

The heat input to the fluidized bed boiler is found in the following equation Eq. (4) [1]:

$$q_{k4,i} = \left(h_{k5,o} - h_{v4,o}\right) \tag{4}$$

where $q_{k4,i}$—boiler heat input, [kJ/kg]; $h_{k5,o}$—boiler enthalpy output, [kJ/kg]; and $h_{v4,o}$—pressure-reducing valve enthalpy outlet, [kJ/kg].

Turbine work can be given in Eq. (5) as follows [1]:

$$w_t = \eta_t \eta_j \left(h_{t5,i} - h_{t6fg,o}\right) \tag{5}$$

where w_t—turbine work [kJ/kg]; η_t—turbine yield was accepted as 85% [1]; and η_j—generator efficiency is accepted as 95% [1].

Net work (The amount of energy production) is found in the following equation Eq. (6) as follows [1]:

$$w_{net} = w_t - w_{pp} \tag{6}$$

where w_{net}—net work, [kJ/kg]; w_t—turbine work, [kJ/kg]; and w_{pp}—pump work, [kJ/kg].

Thermal efficiency can be given in equal Eq. (7) as follows [1]:

$$\eta_{th} = w_{net} / q_{k4,i} \tag{7}$$

where $q_{k4,i}$—boiler heat input, [kJ/kg]; η_{th}—thermal efficiency, [%]; and w_{net}—net work, [kJ/kg].

Irreversibility equation can be defined by Eq. (8) as follows [1]:

$$I = \left[T_\infty x\left(\left(s_{k5,o} - s_{pp,f}\right) + \left(-q_{k4,i}/T_{k4,i}\right)\right)\right] + \left[T_\infty x\left(\left(s_{pp,f} - s_{t6,o}\right) + \left(q_{k4,o}/T_\infty\right)\right)\right] \tag{8}$$

where I—irreversibility, [kJ/kg]; $s_{k5,o}$—boiler entropy output, [kJ/kg K]; $s_{t6,o}$—turbine entropy output, [kJ/kg K]; $s_{pp,f}$—feed-pump-saturated liquid entropy output, [kJ/kg K]; and T_∞—dead state temperature, [K].

Exergy lost can be given in equal Eq. (7) as follows [1]:

$$E_{x\ell} = (h_{t5,i} - h_{pp2,o}) - [T_{\infty} \times (s_{t5,i} - s_{pp2,o})] \quad (9)$$

where Ex_{ℓ}—exergy lost, [kJ/kg]; $h_{t5,i}$—turbine enthalpy input, [kJ/kg]; $h_{pp2,o}$—feed pump enthalpy output, [kJ/kg]; $s_{t5,i}$—turbine entropy input, [kJ/kg K]; and $s_{pp2,o}$—feed pump entropy output,[kJ/kg K].

The application of net energy transfer can be calculated from Eq. (10) as follows [1]:

$$En_{net} = w_t + h_{t6,o} - h_{k4,i} \quad (10)$$

where En_{net}:—net energy transfer, [kJ/kg]; w_t—turbine work, [kJ/kg]; $h_{t6,o}$—turbine enthalpy output, [kJ/kg]; and $h_{k4,i}$—boiler enthalpy input, [kJ/kg].

2.2. Lime production energy and exergy calculation

According to the data obtained from the factory, the energy and exergy calculations of the lime from the fluid boiler were made according to the following formulas.

Accordingly, the amount of CaO can be found from Eq. (11) as follows [1, 9]:

$$m_{CaO} = m_{Ca(OH)_2}\ \%\ CaO \quad (11)$$

where m_{CaO}—lime (CaO) mass flow rate, [kg/h]; $m_{Ca(OH)_2}$—$Ca(OH)_2$ mass flow rate, [kg/h]; and % CaO—lime percentage, [%].

The energy of lime (CaO) is found in the following equation Eq. (12) as follows [1, 9]:

$$En_{CaO} = m_{CaO} \times h_{CaO} \quad (12)$$

where En_{CaO}—lime energy, [W]; m_{CaO}—lime (CaO) mass flow rate, [kg/h]; and h_{CaO}—lime enthalpy, [kJ/kg].

The lime (CaO) exergy can be found in the following Eq. (13) as follows [1, 9]:

$$Ex_{CaO} = m_{CaO} \times \psi_{CaO} \quad (13)$$

where Ex_{CaO}—lime exergy, [W]; m_{CaO}—lime (CaO) mass flow rate, [kg/h]; and ψ_{CaO}—lime-specific exergy, [kJ/kg].

The energy consumption per lime production is found in the following equation Eq. (14) as follows [1, 9]:

$$en = En/m_{CaO} \quad (14)$$

where CaO is lime and en_{CaO} is the energy consumption per lime production, [kJ/kg].

Lime energy quality can be found in the following Eq. (15) as follows [1, 9]:

$$\Theta_{CaO} = Ex_{CaO}/En_{CaO} \tag{15}$$

where Θ_{CaO} is the lime energy quality, [%].

2.3. Thermal energy efficiency calculations of fluidized bed boiler

The following formulas are used for the calculation of the factory thermal boiler energy efficiency.

The energy input amount of the boiler is calculated from Eq. (16) as follows [1]:

$$q_{k,i} = m_{k,i}\, C_p\, (T_{k,o} - T_{k,i}) \tag{16}$$

where $q_{k,i}$—amount of energy entering the boiler, [kW]; $m_{k,i}$—water flow rate, [kg/h]; $T_{k,i}$—fluid boiler water inlet temperature, [°C]; $T_{k,o}$—fluid boiler water outlet temperature, [°C]; and C_p—specific thermal capacity, [kJ/kg K].

The heat transfer resulting from combustion in the boiler is calculated from Eq. (17) as follows [1]:

$$q_{k,o} = m_y\, H_u \tag{17}$$

where m_y—fuel flow in the boiler, [kg/h]; and H_u—combustion temperature (thermal value), [kJ/kg].

Accordingly, the efficiency of the boiler (ηk) is calculated from Eq. (18) as follows [1]:

$$\eta_k = q_{k,i}/q_{k,o} \tag{18}$$

The energy and exergy analysis in the fluidized bed boiler is easily calculated from all these formulas. In addition, lime energy can also be included in the calculations.

3. Conclusion

This book poses application of a power plant technology in terms of calculation with thermodynamic laws. In addition, this chapter indicates energy and exergy efficiency of power plants in the industry. Technoeconomic analysis is carried out for the energy and exergy efficiency progresses that should be applied in power plant of sugar factory, which is the center of a factory. In addition, power plant can be an essential influence for factory profit. It is concluded that the laws and properties of thermodynamics should be the result-oriented, especially for power plants. This application can be used for energy savings by the power plant.

Power plants are very significant for all industry sectors that depend on exergy processes. Since many factories use such energies for their major processes, they have installed power plants on account of their factories. Installing power plants can gain their energy in an efficient way for the factory. This book poses exergy and application technology to energy processes. This book impresses on the importance of an exergy with an overview of all of the energy systems. Energy and exergy efficiencies related to thermodynamic laws are carried out for the power plant and technology.

All processes depend on energy that is used more than the other similar factories. These calculations can be determined by thermodynamics laws and their general and specific formulas. Using a general cycle, Rankine cycle, is a more effective cycle than the other thermodynamic cycles. In addition, it includes mass and energy conversion according to a dead state. All these formulas and calculations pose energy and exergy efficiencies.

This book poses energy and exergy efficiency of energy systems and industry about several different factories. Technoeconomic analysis is carried out for the energy and exergy efficiency progresses that should be applied in power plant of factory, which is the center of a factory.

As a result, power plants can play an effective role in increasing the profitability of factories. For this reason, energy and exergy efficiencies can be determined by thermodynamic laws in order to make the process flow of the plants more efficient in energy solutions. In this way, power generation in power plants can be made more useful by identifying energy and exergy efficiencies.

Nomenclature

% CaO	lime percentage, [%]
ΘCaO	lime energy quality, [%]
$(P\,2 - P\,1)_{pp}$	supply pump pressure difference, [kPa]
h_{∞}	dead state enthalpy, kJ/kg
h_{i}	enthalpy input, kJ/kg
$h_{k5,o}$	boiler enthalpy output, [kJ/kg]
h_{o}	enthalpy output, kJ/kg
$h_{t6,o}$	turbine enthalpy output, [kJ/kg]
$h_{t6f,o}$	turbine-saturated fluid enthalpy output, [kJ/kg]
$h_{t6fg,o}$	turbine-saturated liquid and vapour enthalpy output, [kJ/kg]
$h_{v4,o}$	pressure-reducing valve enthalpy outlet, [kJ/kg]
$m_{Ca(OH)\,2}$	Ca (OH) 2mass flow rate, [kg/h]
$q_{k4,i}$	boiler heat input, [kJ/kg]

$q_{k4,i}$	boiler heat input, [kJ/kg]
s_{∞}	dead state entropy, kJ/kg K
$s_{c1,fg}$	condenser entropy (difference between saturated liquid and steam), [kJ/kg K]
$s_{c1,i}$	condenser entropy input, [kJ/kg K]
s_{i}	entropy input, kJ/kg K
$s_{k5,o}$	boiler entropy output, [kJ/kg K]
s_{o}	entropy output, kJ/kg K
$s_{pp,f}$	feed pump-saturated liquid entropy output, [kJ/kg K]
$s_{t5,i}$	turbine entropy input, [kJ/kg K]
$s_{t6,o}$	turbine entropy output, [kJ/kg K]
T_{∞}	dead state temperature, K
$v_{pp,f}$	specific volume of saturated liquid of feed pump, [m^3/kg]
w_{net}	net work, [kJ/kg]
w_{net}	net work, [kJ/kg]
w_{pp}	pump work, [kJ/kg]
w_{pp}	pump work, [kJ/kg]
w_{t}	turbine work [kJ/kg]
w_{t}	turbine work, [kJ/kg]
$x_{t6.o}$	turbine dryness fraction output, [−]
η_{ex}	exergy efficiency, %
η_{j}	generator efficiency is accepted as 95% [1]
η_{pp}	pump efficiency is accepted as 80% [1]
η_{t}	turbine yield was accepted as 85% [1]
η_{th}	thermal efficiency, [%]
∞	dead state
CaO	lime
C_p	specific thermal capacity, [kJ/kg K]
en_{CaO}	energy consumption per lime production, [kJ/kg]
En_{CaO}	lime energy, [W]
En_{net}	net energy transfer, [kJ/kg]

Ex_{CaO}	lime exergy, [W]
Ex_{ℓ}	exergy lost, [kJ/kg]
h	specific air or steam enthalpy, kJ/kg
h_{CaO}	lime enthalpy, [kJ/kg]
$h_{k4,i}$	boiler enthalpy input, [kJ/kg]
$h_{pp2,o}$	feed pump enthalpy output, [kJ/kg]
$h_{t5,i}$	turbine enthalpy input, [kJ/kg]
$h_{t6,o}$	turbine enthalpy output, [kJ/kg]
H_u	combustion temperature (thermal value), [kJ/kg]
i	input (Inlet)
I	irreversibility, kJ/kg
m_{CaO}	lime (CaO) mass flow rate, [kg/h]
m_{CaO}	lime (CaO) mass flow rate, [kg/h]
m_{CaO}	lime (CaO) mass flow rate, [kg/h]
$m_{k,i}$	water flow rate, [kg/h]
m_y	fuel flow in the boiler, [kg/h]
n	amortization period, year
o	output (Outlet)
$q_{k,i}$	amount of energy entering the boiler, [kW]
s	specific, air or steam entropy, kJ/kg K
$s_{pp2,o}$	feed pump entropy output,[kJ/kg K]
$s_{t5,i}$	turbine entropy input, [kJ/kg K]
T	sugar temperature, K
$T_{k,i}$	fluid boiler water inlet temperature, [°C]
$T_{k,o}$	fluid boiler water outlet temperature, [°C]
v_i	fluid inlet velocity, m/s
v_o	fluid outlet velocity, m/s
w_t	turbine work, [kJ/kg]
Ψ	specific air or steam-specific flow exergy, kJ/kg
ψ_{CaO}	lime-specific exergy, [kJ/kg]

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