THERMODYNAMIC MODELING OF A STEAM POWER PLANT USING BIOMASS

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Abstract. The objective of this paper is to perform the energy and exergy analysis for a steam power plant using biomass. In this paper the mass balance, energy balance and exergy balance equations were used to study the influence of the system parameters on energy and exergy efficiencies. An understanding of both energy and exergy efficiencies is essential for designing, analysing, improving and optimizing energy systems.

Keywords: power plant, biomass, energy, exergy, Rankine cycle.

1. INTRODUCTION

Numerous thermodynamic analyses and optimization studies using energy and exergy have been undertaken of various thermal power plants and processes [1].

The fundamentals of the methods of exergy analysis and entropy generation minimization describe the concept of irreversibility, entropy generation, or exergy destruction are defined by Bejan [3].

For the current state of thermodynamics, it seems almost impossible to have a common efficiency definition for all energy systems. The best way of avoiding misuse and misunderstanding is to define the efficiency used in any application carefully [4]. An understanding of both energy and exergy efficiencies is essential for designing, analysing, optimizing and improving energy systems through appropriate energy policies and strategies. Exergy is a key concept and it is a linkage between the physical and engineering world and the surrounding environment. The exergy expresses the true efficiency of engineering systems, which makes it a useful concept to find improvements. Some authors develop in their study an exergy analysis on combustion and energy conversion and they make a comparison between exergy and energy balances in thermodynamic processes.

The authors introduce some examples of exergy and energy balances, for the power generation, heat pump, boiler and combustion processes and they show that the exergy and energy values have a great difference between them, which are supported by their temperature levels [5].

It must distinguish between exergy and energy in order to avoid any confusion with the traditional energy-based methods of thermal system analysis and design [3].

2. ENERGY AND EXERGY ANALYSIS

The performance of an energetic system, form the thermodynamic viewpoint, can be evaluated by the first (energy) and second (exergy) laws.

The most used method of analysing the processes occurring in thermal power systems are currently based on energy balance. Energy analysis is based on first law of thermodynamics. The goal of any energy balance is to quantify energy flows included in the outline process analysed to determine the consumption of energy, useful energy and losses.

Knowing these flows of energy, it can be detected a factor of process performance (yield or efficiency) and can be identified the ways of rationalizing consumption by saving energy on components that allow the application of appropriate technical and organizational measures [6].

Being only a quantitative assessment tool, energy balance performed for a thermodynamic system, allows detecting the coefficient of performance of the process, but it does not provide information about quality of energy flows crossing the boundary. Based on this balance it cannot be established clear conclusions on the need to intervene on the processes so as to increase the coefficient of performance [6].

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In contrast, exergy analysis is based on the second law of thermodynamics and helps to identify the magnitude and locations of the imperfections in order to improve the performance of the system or process [2].

Exergy analysis provides the tool for the clear distinction between energy losses to the environment and internal irreversibility of the process. Exergy analysis is a methodology for the evaluation of the performance of devices and processes, and involves examining the exergy at different points in a series of energy conversion steps. With this information, efficiencies can be evaluated and the process steps having the largest losses can be identified [7].

3. THERMODYNAMIC ANALYSIS

Table 1 reports the ultimate analysis of the selected biomass fuel, the higher heating value and the lower heating value.

In a variety of power plants is used the Rankine cycle (Fig. 1), which consists of four main components (steam generator, turbine, condenser and pump) and additional components which are added to enhance cycle performance and to improve efficiency.

A temperature-entropy diagram of the cycle is given in figure 2.

Table 1

Biomass properties

Wheat straw		
Ultimate analysis	Carbon, %	49.6
	Hydrogen, %	6.2
	Nitrogen, %	0.61
	Sulphur, %	0.07
	Oxygen, %	43.4
	Ash, %	4.7
Higher heating value, MJ/kg		20.032
Lower heating value, MJ/kg		17.967

In order to perform the energy and exergy analysis, mass and energy balance on the system are required to determine the flow rates and energy transfer rates at the control surface.

From the first and second laws of thermosdynamics, it can be found the formula for energy and exergy balances as the following:

Mass balance:

$$\sum_i \dot{m}_i = \sum_e \dot{m}_e \tag{1}$$

Energy balance:

$$\sum_i \dot{m}_i h_i + \dot{Q} = \sum_e \dot{m}_e h_e + \dot{W} \tag{2}$$

Exergy balance:

$$\sum_i \dot{E}x_i + \sum_j \left[1 - \frac{T_0}{T}\right] \dot{Q}_j = \sum_e \dot{E}x_e + \dot{W} + \dot{I} \tag{3}$$

where:

$\dot{m}$ - mass flow rate [kg/s];
h - specific enthalpy [kJ/kg];
$\dot{Q}$ - heat interaction rate [kW];
$\dot{W}$ - net work produced by system [kW];
$\dot{E}x$ - exergy rate [kW];
T - temperature [K];
I - rate of exergy destruction [kW];

The overall energy efficiency of the power plant, known as thermal efficiency, can be expressed as:

$$\eta = \frac{net\ \ energy\ \ output}{energy\ \ input} \tag{4}$$

Similarly, the exergy efficiency can be expressed as follows:

$$\psi = \frac{net\ \ work\ \ output}{exergy\ \ input} \tag{5}$$

Table 2

Characteristics of steam turbine

Entry pressure	120 MPa
Efficiency turbine (isentropic)	85%
Efficiency turbine (mechanic)	99%
Generator	98%

Table 3

Thermodynamic parameters of the steam cycle

Flow	Mass flow rate [kg/s]	Temperature [°C]	Pressure [MPa]	Enthalpy [kJ/kg]	Entropy [kJ/kg K]
1	5.22	600	12	3608	6.80
2	3.72	389.7	3	3136	6.80
3	1.50	389.7	3	3136	6.80
4	3.72	600	3	3682	7.54
5	3.72	36.17	0.006	2321	7.54
6	3.72	36.17	0.006	151.4	0.5207
7	3.72	36.35	3	154.5	0.5207
8	5.22	233.9	3	1008	2.65
9	5.22	236.2	12	1019	2.65
10	241	8	0.1	33.70	0.1211
11	241	16	0.1	67.19	0.2386

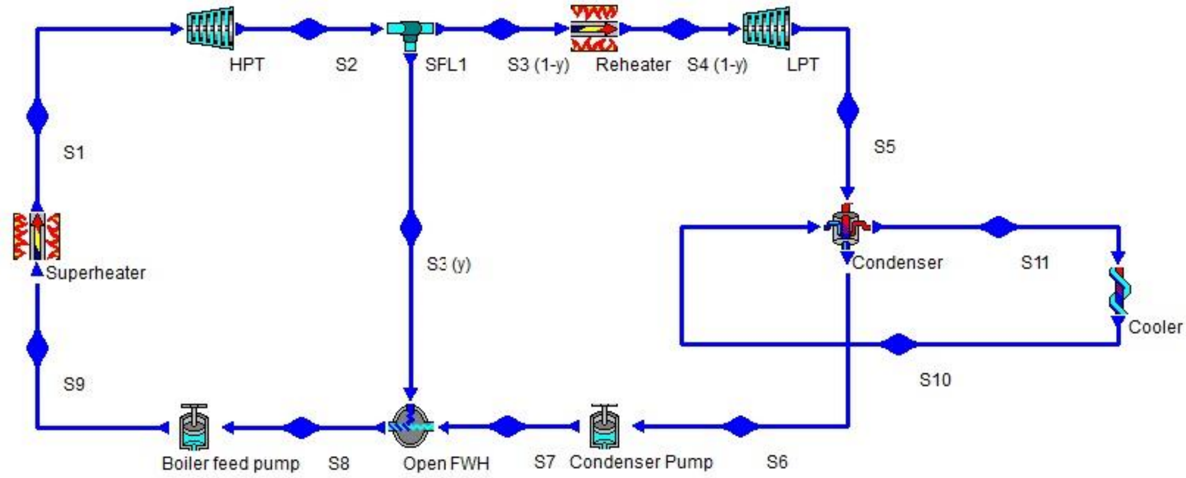

Fig. 1. Schematic representation of the Rankine cycle steam power plant.

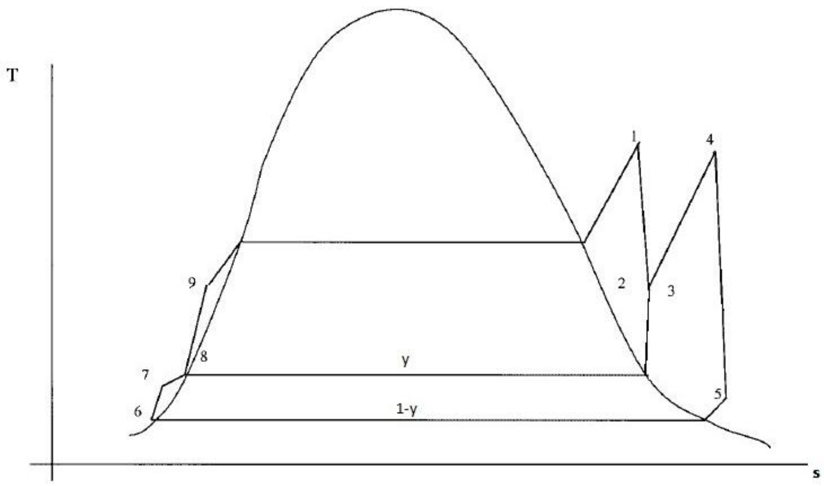

Fig. 2. *T-s* diagram of the Rankine cycle reheat steam power plant.

4. COMPARATIVE RESULTS

The biomass used in the power plant is wheat straw. Therefore, the energy and exergy analysis are performed for this type of fuel (biomass). The biomass composition is given in the Table 1.

The steam power plant using biomass was analysed using the above relations.

A complete set of results for steam cycle is given in

Table 3. This table contains the information needed to establish an evaluation of the general performance of energy and exergy analysis.

The calculated energy and exergy efficiencies are given in Table 4.

Table 4

	Energy efficiency	**Exergy efficiency**
Combustion chamber	98.38%	78.67%
Heat exchanger	87.95%	61.03%
Cycle	48.90%	80.36%
Overall plant	42.31%	38.58%

5. CONCLUSION

The main goal in the thermodynamic modelling of steam power plant is the determination of the most favourable combination of process parameters with regard to efficiency and output.

In this paper it has been found that the traditional approach of energy analysis often is inadequate for indicating how energy can be better used.

The investigation and optimization of the processes can be performed using exergy, rather than energy. Exergy analysis does allow the determination of the losses in the plant and the quality of the energy forms involved. In this paper, an energy and exergy analysis of a steam power plant was performed to study thermodynamic aspects for different system parameters. Process and performance information of steam power plant using biomass was simulated using the MATLAB software. It has been found that exergy efficiency is lower than energy efficiency. The calculated overall energy efficiency was 42.31% while the overall exergy efficiency of the steam power plant was 38.58%.

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