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Effects of the Boiler Outlet Pressure on the Performance of a Cogeneration Rankine Cycle

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Abstract : This article presents a study that aims to achieve an increase in the efficiency of the Rankine cycle with cogeneration by studying the influence of the variation of the turbine inlet pressure after leaving the boiler, taking into account the maximum and minimum pressures that could actually occur. For this purpose, a spreadsheet with thermodynamic tables was used to determine the thermodynamic states and to create case studies to analyze the behavior of the power developed by the turbine and the cycle utilization factor. An exegetic study of the cycle was also made with the variation of the mentioned parameter in order to find the levels of exergy destroyed by component at the moment of varying the input parameter. Once all the corresponding calculations had been made, it was observed that as we increased the value of the turbine inlet pressure, both the utilization factor and the power delivered by the turbine increased, on the other hand, the heat input to the boiler decreased as the boiler outlet pressure increased. From this it is possible to draw several conclusions and among these it stands out as the work and the utilization factor increases with pressure, it is possible to make a Rankine cycle with cogeneration more efficient if we manage to control the output pressures of the boiler.
Keywords: Cogeneration, Exergy, Exergy destroyed, Utilization factor, spreadsheet, cycle Rankine, efficiency.

1.Introduction

The study on how to improve steam power cycles for electric power production is becoming increasingly important. To carry out these studies where large numbers of variables are handled, programmed spreadsheets are needed to facilitate this task. However, once we understand the importance of the use of programs that facilitate the study of cycles and numerical methods, we should say why we should study power

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cycles, the study of these cycles is of great importance due to the fact that fossil fuels are becoming less and less available and the need to create electrical energy from other types of fuels arises[1], as is the case of R. E. Barber on the use of solar energy and its conversion to mechanical energy[2,3] from these power cycles, The use of sea waves for conversion to electrical energy[4,5].

But with these power cycles there are also drawbacks, as an example we have the simple Rankine cycle which wastes heat on the condenser which still has high quality energy that can be used by a process heater and be used for productions such as steel making, oil refining, among others[6] this is how the Rankine cycle with cogeneration was born, which is the object of study in this article, from the engineering point of view it is more economical to use the useful work potential or (Exergy) to produce electrical energy while covering the heat requirements of certain industrial processes, we can also use it for the production of ethanol[7].

Other studies and improvements in the Rankine cycle with cogeneration focused on the use of these cycles for domestic applications without high demands on energy or work with all types of fuels for operation and these advances were called the domestic Rankine cycle[8-10]. Similarly, in recent years special attention has been paid to the use of renewable energy, but some negative features of these sources (low power density and unpredictable availability) cause significant difficulties in economic recovery. For this reason, incentives are offered in many countries to promote energy conversion plants powered by these sources. Such incent can influence not only the design of new plants, but also their operating straivestegy[11-13]. In addition, thermo-economic studies have also been very helpful in realizing that it was necessary to start looking for different options to further increase the efficiency of the power cycles taking into account all the parameters that influence[14].

Considering the great importance of looking for improvements in power cycles, this article will show the results of a study of a Rankine cycle with cogeneration, which by means of a parameter variation shows us that this increase in efficiency or utilization factor is possible, in accordance with the above the main objective of the research is to provide a cumin to achieve an increase in the efficiency of an electric power plant by means of a steam power cycle using a Rankine cycle with cogeneration with mathematical demonstrations of variations simulating real operating conditions, the results obtained are in line with the power and factor equations found in the literature[6].

2. Materials and Methods

Next, a description will be made of the process carried out by a Rankine cycle with cogeneration, its components and their function in the cycle, as well as the fundamental equations that govern the calculation of the outstanding parameters of the cycle, such as net power, heat of entry to the cycle and others.

2.1 Process description

The Rankine cycle with cogeneration is a steam power cycle consisting of a boiler which supplies the exergy to the system by means of heat (inlet heat), once the mass flow exits the boiler there is a throttling valve which can divide the flow by carrying a part for a process heater when needed, if continuous flow is not necessary until a steam expanding turbine is encountered, before the turbine expands all the steam, it is extracted and directed to the process heater which uses the useful energy of the steam for a process that requires heat; the other part of the flow continues the expansion, once it leaves the turbine the flow is met with a condenser which removes the heat from the turbine until it completely saturates it to a pump which will increase the pressure of the saturated liquid to be in a mixing chamber with the extraction of the steam to go to the process heater; the flows are mixed and led to the boiler to continue with the thermodynamic cycle as shown in the figure 1.

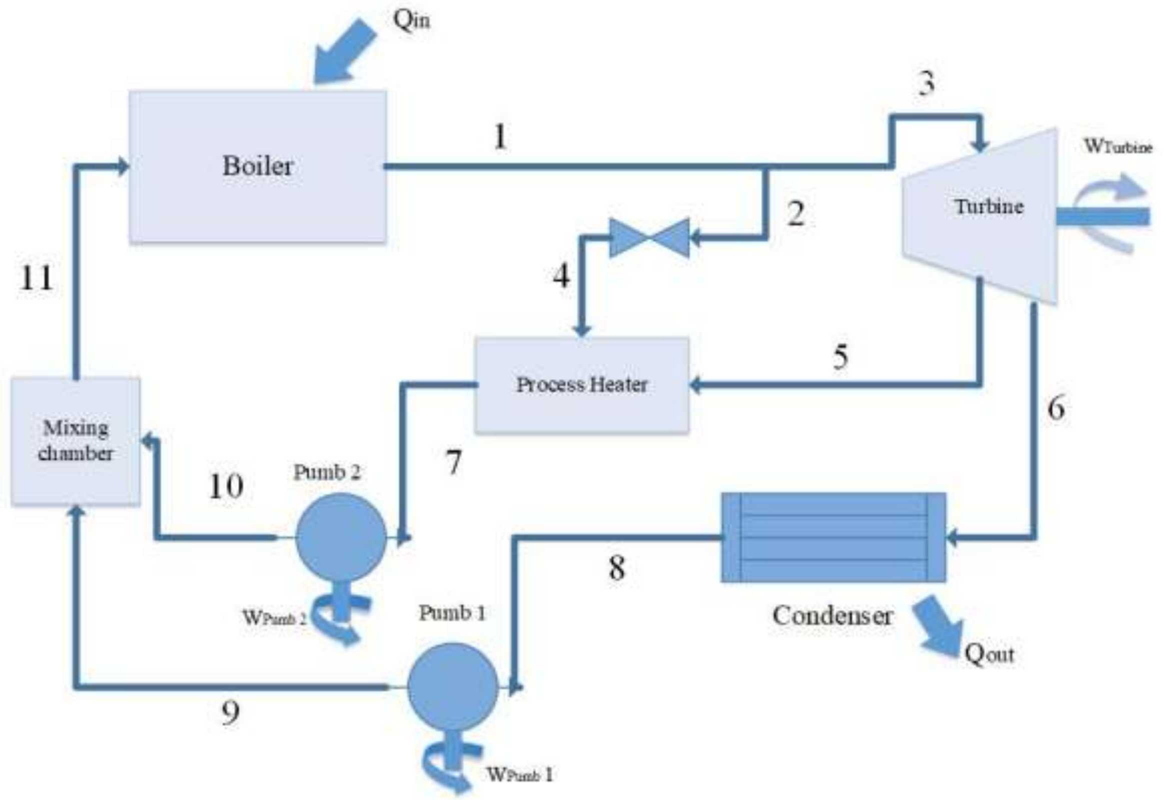

Figure 1. Cogeneration Rankine cycle.

A programmed spreadsheet was used which includes the data corresponding to enthalpy and entropy of the thermodynamic tables found in the literature, in order to facilitate the calculation of the thermodynamic states in each of the points of the Rankine cycle with cogeneration, to then proceed to calculate the data corresponding to turbine work, net work, input and output heat, utilization factor, to observe and discuss the behavior of the utilization factor vs. the pressure change at the turbine inlet, as well as the behavior of the power developed by the turbine when the inlet pressure is increased while maintaining the other parameters constant and to make the corresponding exegetical balances for the purpose of observing and discussing the results on the exergy destroyed by each component.

For the operation of the program it was necessary to enter initial data of the cycle, the turbine inlet pressure (Press.1) was varied from 3Mpa to 10Mpa for study purposes to observe how the pressure in question influences the utilization factor of the cycle. The following input values have been chosen, it should be noted that the numbers following the input data correspond to the thermodynamic states found in figure 1.

Table 1. Input data for the cycle

Tem. 1	Pres. 5	Pres. 6	Ext 4.	Ext 5.	$\dot{m}$	η pump	η turbine
500°C	0.5Mpa	0.005	10%	70%	15 kg/s	80%	80%

2.2 Fundamental equations

For a plant with cogeneration, there is a hot spotlight with an input heat (1), in this case a boiler, a cold spotlight with output heat or condenser (2), and an output acquired by the passage of steam between the blades of a turbine (3),

$$\dot{Q}_{in} = \dot{Q}_{boiler} = \dot{m}_{11}(h_1 - h_{11}) \quad (1)$$

$$\dot{Q}_{out} = \dot{Q}_{condenser} = \dot{m}_6(h_6 - h_8) \quad (2)$$

$$\dot{W}_{out} = \dot{W}_{Turbine} = \dot{m}_3(h_3 - h_5) + \dot{m}_6(h_5 - h_6) \quad (3)$$

This power is used for the power consumed by the pumps in operation and we can determine a net power (4) that will be

$$\dot{W}_{net} = \dot{W}_{Turbine} - \dot{W}_{pump\ 1} - \dot{W}_{pump\ 2} \quad (4)$$

Where,

$$\dot{W}_{pump1} = \dot{m}_6(h_9 - h_8) \text{ , y} \quad (5)$$

$$\dot{W}_{pump2} = \dot{m}_7(h_{10} - h_7). \quad (6)$$

As it is a Rankine cycle with cogeneration, the need arises to determine the total energy use including both the net power delivered by the plant and the heat used in the process heater and a utilization factor (7) was reached given by

$$\in_u = \frac{\dot{W}_{net} + \dot{Q}_p}{\dot{Q}_{in}} \quad (7)$$

where,

$$\dot{Q}_p = 1 - \frac{\dot{Q}_{out}}{\dot{Q}_{in}}. \quad (8)$$

For the calculation of the destroyed exergy, the exergy balance sheet (9) for systems with stationary flow given by

$$\sum \left(1 - \frac{T_0}{T_k}\right) \dot{Q}_k - \dot{W} + \sum_{in} \dot{m}\psi - \sum_{out} \dot{m}\psi - \dot{X}_{destruida} = 0. \quad (9)$$

This equation was used for each component studied to determine the exergy destroyed by component when the boiler outlet pressure varied.

3. Results and Discussion

To analyze the turbine power performance and utilization factor, the turbine inlet pressure was varied for different boiler outlet temperatures at 400, 500 and 600°C as shown in Figure 2.

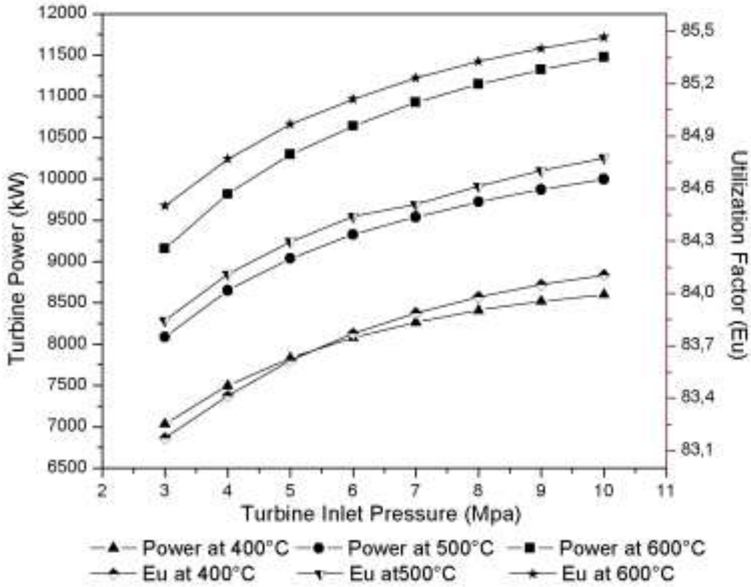

Figure 1. Turbine power and Utilization factor as function of the pressure P1.

In this graph we can see the incremental tendency of the power developed by the turbine turbine and the utilization factor of the cycle as the boiler output pressure increases. At the 3 different temperatures measured, this tendency behaves in the same way, if we also study the equations of turbine power and utilization factor we can confirm this direct proportionality. We can also observe that the boiler output temperature did not influence the incremental trend of both the power developed by the turbine and the utilization factor, but if it did influence the increase in the minimum and maximum values of the power and utilization factor, only in the change from 400 to 500°C at a constant pressure of 6 Mpa the power developed by the turbine increased by 13.41%, and the utilization factor by 6.71%, now we can see how the boiler output temperature influences two very important factors of the cycle.

On the other hand, the same analysis was carried out for the heat input to the cycle provided by the boiler and the utilization factor vs. the turbine input pressure (Press. 1), which was also varied at different boiler output temperatures, from which it was possible to obtain the results shown in figure 3.

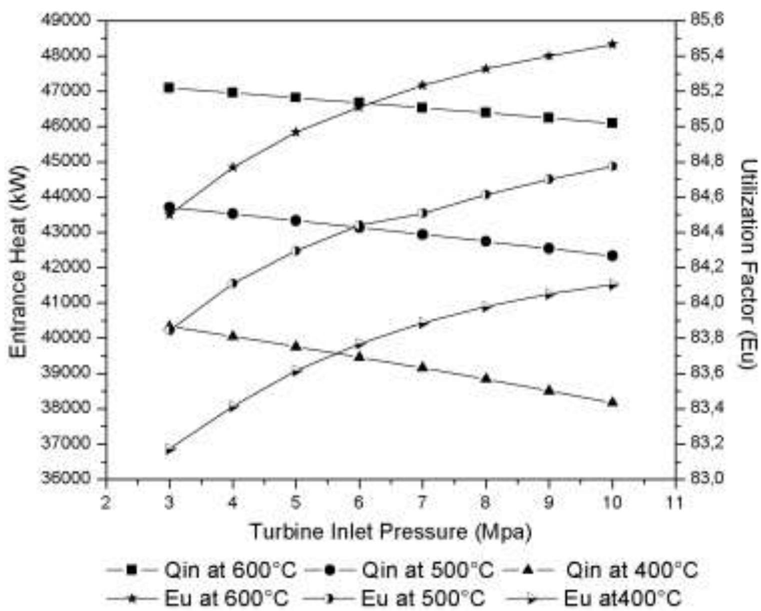

Figure 2. Input heat (Qin) and Utilization factor as function of the pressure P1

In this figure we can already find an inverse proportionality between the heat input to the cycle through the input and the pressure P1, as the pressure increases the pressure P1 the heat of the boiler decreases to keep the cycle running, the factor has the same behavior seen in figure 1, likewise we can corroborate this data through the equations to see that the expected results are congruent with those obtained.

For the exegetical analysis of the main components of the cycle and the determination of the destroyed exergy by component as the inlet pressure p1 is increased or decreased, with the entropy data of each thermodynamic state being taken out of the software, an exergy balance was made for the turbine, boiler, condenser, and process heater which is presented in figure 4.

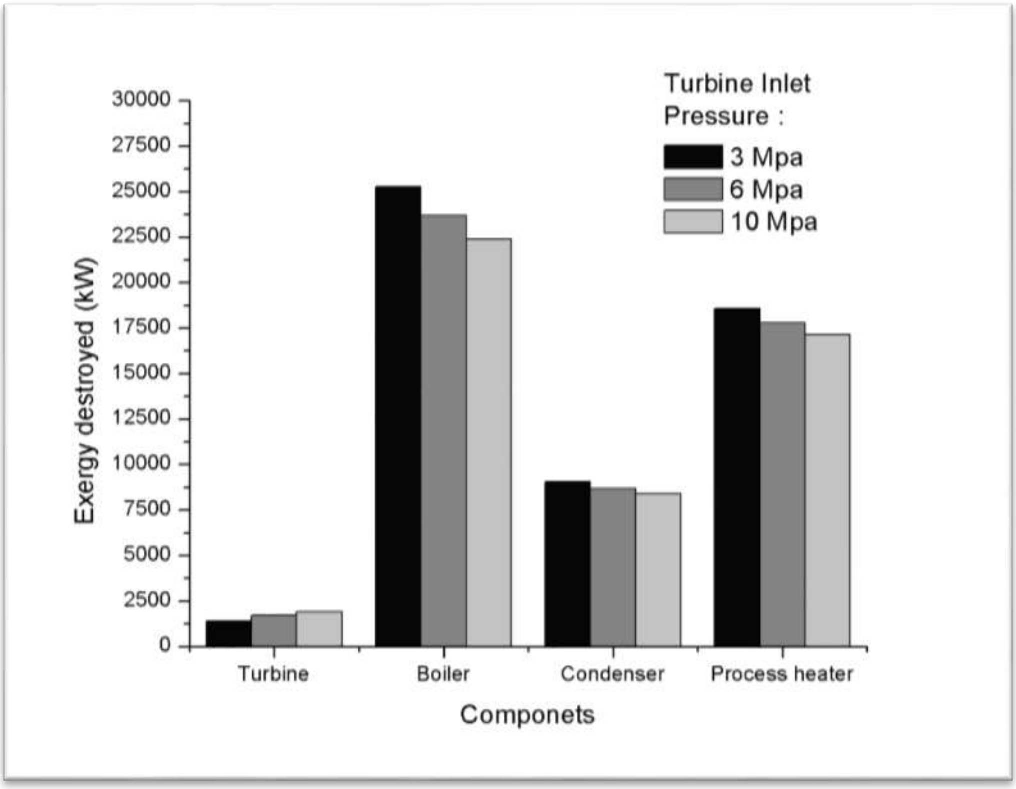

Figure 3. Exergy destroyed by component.

From this figure we can deduce the behaviour of the components of the cycle by varying the output pressure of the boiler P1, as a first part we can see that the turbine in between increases the pressure the turbine destroys more useful energy potential, but on the other hand the boiler does the opposite, Continuing with this analysis we can see that the condenser is the component that destroys more useful energy as is to be assumed because the heat with energy capacity the condenser destroys it and the higher the pressure the less exergy destroys; finally the process heater has a behaviour like that of the boiler and condenser that as we increase the pressure destroys less potential useful energy.

4. Conclusion

In the study that was carried out on the Rankine cycle with cogeneration in search of improving the efficiency of the cycle in general, taking into account the output parameters of the boiler such as pressure and temperature, the results obtained by varying these parameters and their influence on the power developed by the turbine and the utilization factor were demonstrated and discussed; It is clear that, if we want to improve a thermoelectric plant operating with a Rankine cycle with cogeneration, we must consider or take into account what has been proposed and demonstrated in this research as a way to achieve this objective. Likewise, thanks to the exergistic analysis carried out on the cycle in question, we can consider this research to take measures on the components that most destroy useful energy potential (Exergy) in order to have an increasingly more efficient energy generating cycle. As a final point, it can be stated that the objectives of the research on the study of the behaviour of the components of this cycle at the moment of varying a parameter that in this case was the boiler outlet pressure were met.

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