



# Design of a Simple Model of S. P. P. to Study the Effect of Increasing the Boiler Pressure on the Efficiency of the Model

A. S. A. Elmaryami\*  
Hafied M. B. Khalid  
Abdulssalam M. Abdulssalam  
Alaa A. Abdulssalam  
Mohamed M. Alssafi  
Abdullateef S. Abdullateef  
Ziadan A. Mohamed

Department of Mechanical Engineering, Bright Star University [BSU], El-Brega - Libya

\*Corresponding Author: [damer604@yahoo.com](mailto:damer604@yahoo.com)

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## Research Article

### Abstract

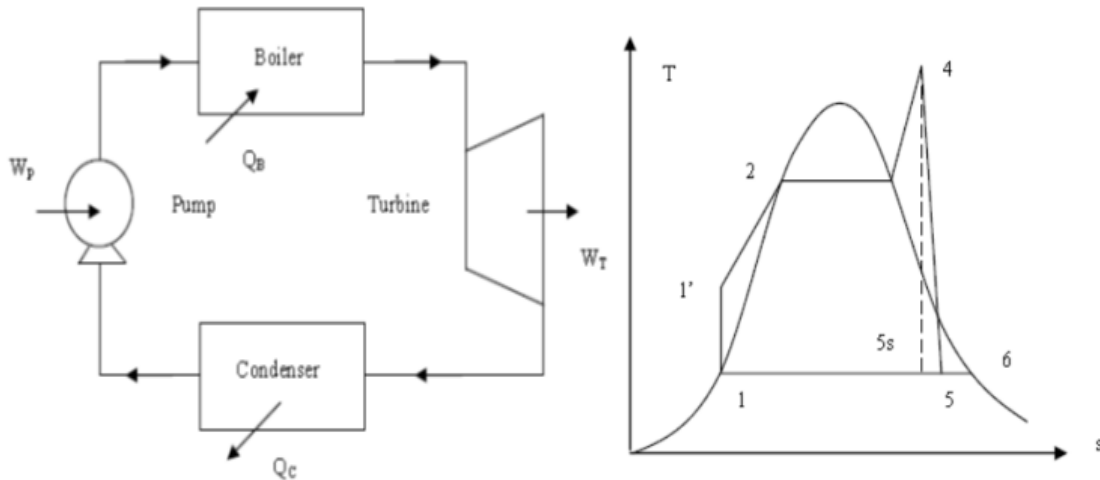
The Rankine cycle is one example of vapor power cycles. One important application of it is in steam power plants. In this paper, a simple model of the steam power plant is designed to study the effect of increasing boiler's pressures (3, 4, 5, and 6 bar respectively) on the efficiency and the dryness fraction of the Model. Properties of the important points in the cycle were calculated consequently the losses in the pump, the losses in the condenser, expansion of the working fluid through the turbine, and the heat transfer to the working fluid through the boiler were determined. From the results, it was found that with the increasing of the boiler's operating pressure the thermal efficiency of the model cycle increases due to a substantial increase in network. Thus net-effect is marked increases in the thermal efficiency of the cycle on account of these measures.

**Keywords:** Rankine cycle; Model of steam power plant; Thermodynamic performance; Energy analysis.

### 1. Introduction

The Rankine cycle is an important area of thermodynamics. One vital application of the cycle is in steam power plants. The performance of a steam power plant is measured by its thermal efficiency, which needs values at important points of the cycle. A simple steam power plant is shown in Fig.1.1. The T-s diagram of the cycle is shown in Fig.1.2. Processes in the Rankine cycle can be briefly explained as follow. For more details, see [1-2] or any other engineering thermodynamics textbooks. Water enters the pump as a saturated liquid at  $T_1$  and pumped is entropically to  $T_2'$  at  $P_2$ . The water is then preheated to  $T_2$  before entering the boiler where it is

converted into superheated steam at  $P_4$  and  $T_4$ . For an ideal cycle, we assume there is no pressure loss in the heat exchanger (boiler and condenser) so  $P_2 = P_3 = P_4$  and  $P_1 = P_6$ . The steam enters the turbine which develops power and then flows to the condenser where the pressure and the temperature decrease. In Figure 2, the water which exits from the turbine is a mixture of saturated liquid and vapor. However, it can be saturated vapor or superheated steam, depends on the condenser's pressure. Ideally, the steam is expanded isentropically (shown as 4–5s). In practice, there is a loss so the actual process is shown as 4–5



**Fig.1.A simple steam power plant Fig.2. T - s diagram for the cycle**

In the steam boiler industrial sector, pressure and temperature of the water tube are the two main factors affecting the safety and efficiency of a steam boiler. Explosions may be occurring because of a sudden drop in pressure without a corresponding drop in temperature. The theory of axisymmetric has been utilized since the water-tube is cylindrical in shape. In axisymmetric theory, a three-dimensional cylindrical problem like a water tube can be reduced to two dimensional. Then two-dimensional rectangular elements meshing for the profile cross-section along the water tube in  $r$  and  $z$  axes were implemented in a computerized simulation using ANSYS 10 to find out the steady-state temperature distribution of the water tube [3].

Properties of the important points in the cycle can be found from steam tables. However, reading values from a steam table is rather inconvenient particularly when there are many values to be read such in a simulation. Interpolation must often be done since the table only provides values of properties at determined points. Using equations of states for steam is very convenient since values can be computed quickly. Unfortunately, equations of states for steam are very complicated. A program written in MATLAB to assist the teaching of the Rankine cycle using steam has been developed. MATLAB is used since it is widely available. Using this program, a lecturer can easily modify a problem and get the answer quickly. Students can also benefit from the program where they can solve problems and compare the results that they will get manually [4].

Interest exists both for power generation and heat and power cogeneration [5, 6]. Unlike commercially demonstrated large-scale ORC power plants commonly used in geothermal [7], biomass [8], solar [9] and WHR applications [10, 11], micro- or small-scale ORC engines [12].

## 2. Thermal Efficiency of the Cycle

For the calculation of the thermal efficiency, we assume that the mass flow rate of the steam is 1 kg/s. Also, we assume that the pump and the turbine are adiabatic with adiabatic efficiencies of  $\eta_P$  and  $\eta_T$ , respectively. The thermal efficiency of the cycle can be found from:

$$\eta_{th} = \frac{W_N}{Q_B} = \frac{W_T - W_P}{Q_B}$$

where

$W_N$  = net power, kW,

$W_T$  = power developed by the turbine, kW

$W_P$  = power needed by the pump, kW

$Q_B$  = heat absorbed by the boiler, kJ/s or kW

Where,  $W_N$  = net power, kW,  $W_T$  = power developed by the turbine, kW,  $W_P$  = power needed by the pump, kW,  $Q_B$  = heat absorbed by the boiler, kJ/s or kW. Power developed by the turbine is given by  $W_T = h_3 - h_4$ . The power needed by the pump is given by  $W_P = h_2 - h_1$  but this can be approximated as  $v_f (P_2 - P_1)$  since the temperature increase in the pump is quite small. Heat absorbed by the boiler is given by  $Q_B = h_3 - h_2$  and  $Q_C = h_4 - h_1$ . All formulas mentioned here are given in most thermodynamics textbooks; see [1-2], for example.

The designed model of the steam power plant to study the effect of increasing boiler's pressures (3, 4, 5, and 6 bar respectively) on the efficiency and the dryness fraction of the Model shown in Fig. 3.



Fig.3. Designed model of the steam power plant

## 3. Results and Discussions

### 3.1 The boiler pressure 3 bar

#### 3.1.1 State 1:

##### 3.1.1.1 $h_1$ calculation:

$P_1 = P_4 = 100\text{Kpa} = 0.1 \text{ bar}$

$h_1 = h_f$  (at 0.1 bar, saturated liquid)

From the table:  $h_1 = h_f = 191.83 \text{ KJ/Kg}$  and  $v_f = 0.001010 \text{ m}^3/\text{Kg}$

**3.1.2. State 2:**

**3.1.2.1. h<sub>2</sub> calculation:**

$$W_{12} = W_{p,in} = h_2 - h_1 = v_f (P_2 - P_1) = 0.001010(3 \times 10^5 - 10 \times 10^3) = 0.2929 \text{ KJ/Kg}$$

$$0.2929 = h_2 - 191.83$$

$$\text{Thus } h_2 = 192.1229 \text{ KJ/Kg}$$

**3.1.3. State 3:**

**3.1.3.1. h<sub>3</sub> calculation:**

From superheated table at P<sub>3</sub> = 3bar and T<sub>3</sub> = 150 °C

$$h_3 = 2761 \text{ KJ/Kg and } s_3 = 7.0778 \text{ KJ/Kg.}^\circ\text{K}$$

**3.1.4. State 4:**

**3.1.4.1. h<sub>4</sub> calculation:**

$$P_1 = 0.1 \text{ bar, } s_3 = s_4 = 7.0778 \text{ KJ/Kg.}^\circ\text{K}$$

$$\text{At } 0.1 \text{ bar: } s_f 0.6493, s_{fg} = 7.5009 \text{ KJ/Kg.}^\circ\text{K}$$

$$h_4 = h_f + xh_{fg} = 2242.532 \text{ KJ/Kg}$$

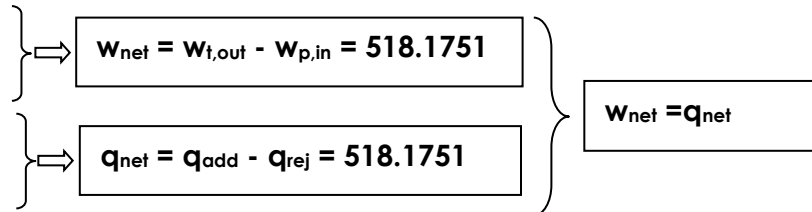
Thus:

$$W_{p,in} = W_{12} = h_2 - h_1 = 0.2929 \text{ KJ/Kg}$$

$$W_{t,out} = h_3 - h_4 = 518.468 \text{ KJ/Kg}$$

$$q_{add} = q_{in} = h_3 - h_2 = 2568.8771 \text{ KJ/Kg}$$

$$q_{rej} = q_{out} = h_4 - h_1 = 2050.702 \text{ KJ/Kg}$$



$$\eta_{th} = 1 - q_{re} / q_{add} \text{ OR } \eta_{th} = W_{net} / q_{add} \text{ OR } \eta_{th} = q_{net} / q_{add} = 0.20 = 20 \%$$

By repeating this process, the effect of increasing the boiler pressure on the model cycle at each pressure (4 bar, 5 bar and 6 bar) can be calculated, the final results shown in Table 1, Fig. 4, and Fig. 5.

**Table 1: The effect of increasing the boiler pressure on the model cycle**

The boiler pressure (bar)	3	4	5	6
<b>w<sub>p,in</sub> (KJ/Kg)</b>	0.2929	0.3939	0.4949	0.5959
<b>w<sub>t,out</sub>(KJ/Kg)</b>	518.468	557.48	587.9914	615.6462
<b>q<sub>add</sub> (KJ/Kg)</b>	2568.8771	2560.5761	2556.3751	2564.3741
<b>q<sub>rej</sub> (KJ/Kg)</b>	2050.702	2003.5	1968.8786	1949.3238
<b>w<sub>net</sub> (KJ/Kg)</b>	518.1751	518.1751	518.4965	615.0503
<b>q<sub>net</sub>(KJ/Kg)</b>	518.1751	518.1751	518.4965	615.0503
<b>X</b>	0.857	0.8373	0.8228	0.81466
<b>η<sub>th</sub></b>	20 %	21.7 %	22.98 %	23.98 %

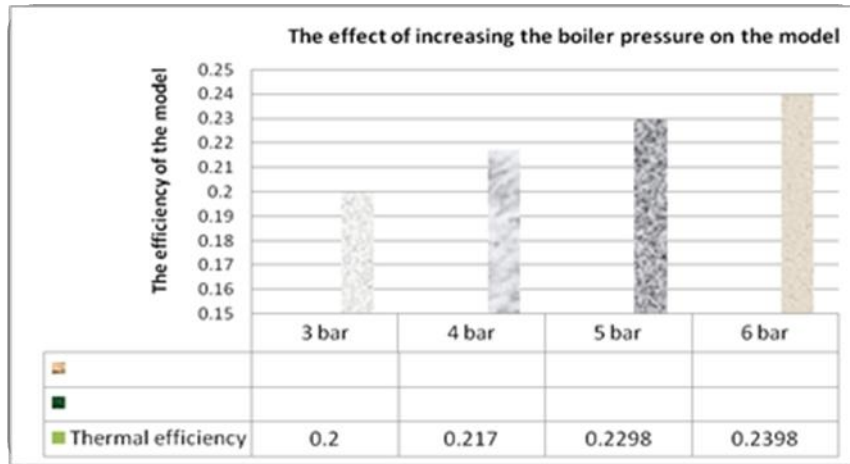


Fig.4. Effect of increasing the boiler pressure on the efficiency of the model

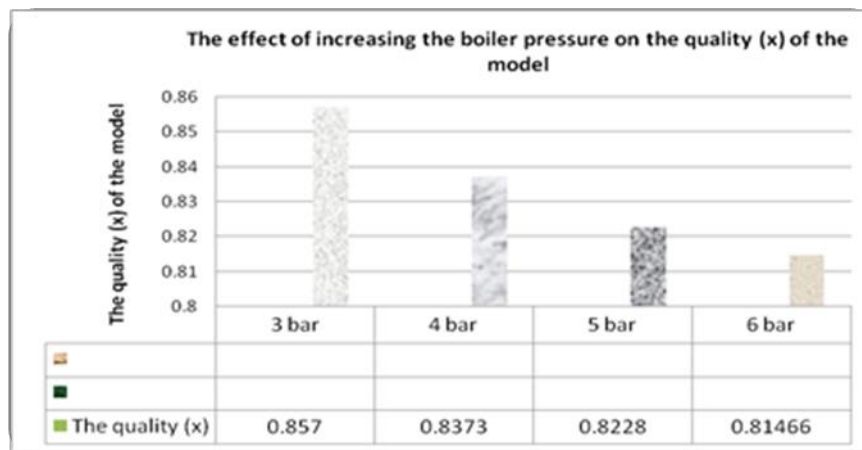


Fig.5. Effect of increasing the boiler pressure on the quality (x) of the model

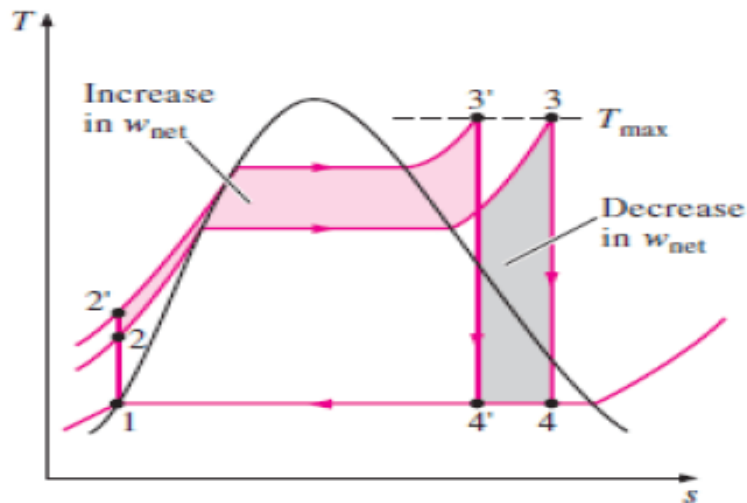
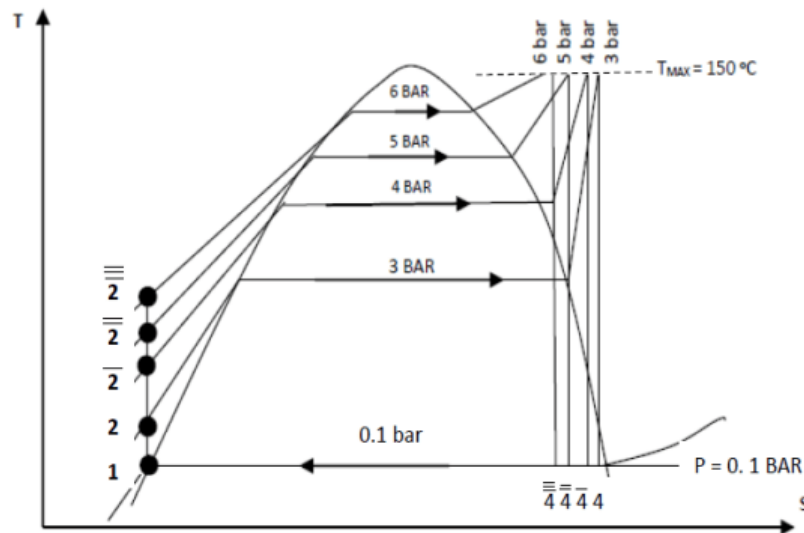


Fig.6. T - S diagram showing the effect of increasing the boiler pressures on the quality and the efficiency of the model



**Fig.7. T - S diagram showing the effect of increasing the four boiler pressures (3, 4, 5, and 6 bar) on the quality and the efficiency of the model**

#### 4. Conclusion

The results of this investigation show that:

- Increasing the boiler's operating pressure thermal efficiency of the model cycle increases.
- Increasing the boiler's operating pressure the quality (x): the dryness fraction of the model decreases.

From the obtained results, it was found that with the increasing of the boiler's operating pressure the thermal efficiency of the model cycle increases due to a substantial increase in network. Thus net-effect is marked increases in the thermal efficiency of the cycle on account of these measures while the dryness fraction (the quality) decreases as shown in Fig. 6 and Fig. 7.

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**Conflict of Interest:** The authors declare no conflict of interest.

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