# CHAPTER I

# Introduction

## 1-1 Thermal generation:

The theory of thermal power station or working of thermal power station is very simple. The power plant cycle (simple) is stating when the water enter the boiler and because the boiler is in higher level from the condenser we need to lift the water from the condenser level to the boiler level for this mission we use pump which lift the water to the boiler, after that the Boiler mission is to heat the water till it change from liquid state to steam the steam which come from the boiler is used to rotate the turbine shaft.

Investigations on the increasing of efficiency of Steam Turbine cycle have been carried out by many Research centers of universities and turbine production Concerns already for a few dozen of years. In the case of thermodynamic cycles with applied steam turbines, the investigations have dealt with steam pressure and temperature.

In these research we are study the influence of the regenerative a closed feed water heaters on effect in efficiency of steam power plant stations can be determined by means of the incremental energy efficiency of total system the presented method proves energy Avery high efficiency of the regenerative preheating of the feed water (the analysis of the influence of feed water heaters on investment expenditures of the plant, would be more difficult by normal method (calculation).

In fossil power generating plants, a boiler is utilized to produce steam and the expanded steam is then used to drive turbine and routed generators. A portion of the steam at different stages of the turbine is extracted to the feed water heater to pre-heat the water before it goes into the boiler. As the heat energy from the extraction steam is transferred to the feed water, the steam is condensed and collected at the bottom of the heater, during normal operation; the condensed liquid in the heater is directed to the downstream lower pressure heater whereinteracts with the feed water.

Feed water heater are of two types open heaters and closed heaters ,In an open heater the extracted steam is allowed to mix with feed water and both leave the heater at a common temperature. in a closed heater the fluids are kept separate and are not allowed to mix together closed heaters are shell and tubes heat exchangers where the feed water flows through the tubes and the extracted steam condenses outside the tubes in the shell the heat released by condensation is transferred through the walls of the tubes.

**1-2Types of thermal energy:**

Almost all coal( like in Sudan Garri-4 ),nuclear, geothermal, solar thermal electric, and waste incineration plants, as well as many natural gas power plants are thermal. Natural gas is frequently combusted in gas turbines as well as boilers. The waste heat from a gas turbine, in the form of hot exhaust gas, can be used to raise steam, by passing this gas through a Heat Recovery Steam Generator (HRSG) the steam is then used to drive a steam turbine in a combined cycle plant that improves overall efficiency. Power plants burning coal, fuel oil, or natural gas are often called *fossil-fuel power plants*. Some biomass-fueled thermal power plants have appeared also. Non-nuclear thermal power plants, particularly fossil-fueled plants, which do not use co-generation, are sometimes referred to as conventional power plants.

Commercial electric utility power stations are usually constructed on a large scale and designed for continuous operation. Virtually all Electric power plants use phase electrical to produce alternating current (AC) electric power at a frequency of 50 Hz or 60 Hz. Large companies or institutions may have their own power plants to supply heating or electricity to their facilities, especially if steam is created anyway for other purposes. Steam-driven power plants have been used to drive most ships in most of the 20th century until recently.

## 1-3Open Feed water Heaters:

An open feed water heater is basically a mixing chamber, where the steam extracted from the turbine mixes with the water exiting the pump. In an ideal condition, the water leaves the heater as a saturated liquid at the heater pressure, and can also bring the feed water to saturated state. One of the feed water heaters is a contact-type open heater, known as Deaerator others being closed heaters It is used for the purpose of the Deaerating the feed water [1].

Advantages andDisadvantages of Open Feed water Heaters in chapter three.

## 1.4 Closed Feed water Heaters:

Closed Feed water Heaters, Closed feed water heaters are shell-and-tube type recuperates in which feed water temperature increases as the extracted steam condenses on the outside of the tubes carrying the feed water. The two streams can be at different pressures since the two streams do not mix.

The level of the condensed water in the heater is important to the efficiency of heat transfer and must be wisely determined and tightly controlled.

Advantages andDisadvantages of closed Feed water Heaters in chapter three.

**1-5Efficiency of Thermal Power Station or Plant:**

Table (1.1) Efficiency of Thermal Power Station or Plant

| Installed plantCapacity | Average overall thermalEfficiency |
|---|---|
| Upto 1MW | 4% |
| 1MW to 10MW | 12% |
| 10MW to 50MW | 16% |
| 50MW to 100MW | 24% |
| above 100MW | 27% |

Overall efficiency of steam power plant is defined as the ratio of heat equivalent of electrical output to the heat of combustion of coal. The overall efficiency of a thermal power station or plant varies from 20% to 26% and it depends upon plant capacity.

**1-6Problem statement:**

- Lower generation efficiency.
- Increase of vibration turbine shaft.

**1-7Objectives:**

- Increase efficiency of generation.
- Decrease (reduction) vibration in the shaft of the turbine.
- Reduction quantity of the fuel so increase the operation life of plant.

**1-8Methodology:**

Method that was flowed in collection of data based on multiple visits to Garri-4 of the thermal power plant to identify the fuel cycles, starting from the coal or sponge coke production from the refinery that burned in the boiler.

**1-8-1 there are multiple ways to collect information like:**

- Interview (this technique give fuel information by the engineers and more detailed responses).
- Follow - up interviews (face- to face or phone and email).
- Observation.

**1-9Scope:**

The scope of which is the study of the influence of high pressure heat exchanger (HP) and how to raise the efficiency of generation, and the theory of batch work.

**1-10 Important of research:**

Lies the importance of research to increase the generation efficiency (output increase from the turbine to the electric generator) cheap and safe manner and thus supply the national grid power capacity for sustained, stable and thus reducing the DC-stop from factories, homes and hospitals and thus help in the progress and development of Sudan.

**1-11lay out:**

Increase the generation efficiency of the introduction of the heat exchanger where the uniforms of high pressure(HP) will increase efficiency and increase electricity output of the generator.

**1-12The research plan shown in the figure below:**

Table (2.1) The research plan

| Activity Time | November | | December | January | | February | March | | April | | May | | June | | July | August | September |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 30% | 70% | 100% | 40% | 60% | 100% | 50% | 100% | 50% | 100% | 50% | 100% | 50% | 100% | 40% | 60% | 100% |
| Introduction and plan of scientific research | | | | | | | | | | | | | | | | | |
| Previous studies | | | | | | | | | | | | | | | | | |
| Theoretical studies | | | | | | | | | | | | | | | | | |
| Case study | | | | | | | | | | | | | | | | | |
| Results & analysis | | | | | | | | | | | | | | | | | |
| Conclusion & recommendations | | | | | | | | | | | | | | | | | |
| Printing &delvery | | | | | | | | | | | | | | | | | |

# CHAPTER II

# Preview Studies

**2-1** Increase the Thermal Efficiency In K.R.C power station, Prof: Sabir Mohammed Salieh, August 2009.

Problem statement: lower efficiency in K.R.C Power Station

Objectives: Increase The Thermal Efficiency In K.R.C Power Station

Conclusion: As we can see, we can save a big amount of money just by increasing the temperature by 1C or decreasing the pressuer or increasing the inlet pressuer or we can do those entire things.

Recommendation: From the context of the study, the methodology followed and results obtained the following recommendations could drawn:

Make a maintenance check to the pressure and temperature equipment and calibrated it, and use standard measurement devices, and use fresh water and add chemical substance to the heat transfer surface always clane.

***2-2***Blow down process effect on boiler efficiency to increase output power of generating ,D.TawfeegGamalalden , August 2010.

**Problem statement:** Reduce blow down losses and losses in heat energy.

***Objectives:*** Study the boiler parts, Understand the losses which effect on boiler efficiency; Study blow down process effect on boiler efficiency.

**Conclusion:**

During the blow down process water is discharged from the boiler to avoid the negative impacts of dissolved solids or impurities on boiler efficiencyandmaintenance. However boiler blows down wastes energy because the blow down liquid is at about the same temperature as the steam produced.

Much of this heat can be recovered by routing the blow down liquid hrough a heat exchanger that preheats the boiler's makeup water. Boiler blow down heat recovery project at KNPS will save almost 11498.7 kg annually about 32.946% in fuel used for blow down about 0.01130258 % from total fuel consumed in the station.

**Recommendation:**

More co-operations with thermal power station would be to make the student dealing with it easier toincrease generating efficiency

**2-3Effect of maintenance on burner efficiency:**

Prof.Sabir Mohammed Salieh , August 2008.

**Problem statement:** A decrease in the efficiency of the boiler.

***Objectives:*** Study types of burners; Study the combustion system at bahry power station; Study the maintenance and the effect of it on the boiler.

**Conclusion:**

The use of HFO, although it is cheaper, but it increases the total cost due to the requirement for heating at the pumping due to the high viscosity. This process increases the total cost.

Schedule of daily maintenance allows the burner, which was conducted by the maintenance to be in standby for 8 hours. And back to service when other burner is maintained.

Notes from the values obtained before and after maintenance engineers in bahry power station are committed to the schedule of maintenance which reduces the possibility of breakdowns.

We also calculated the efficiency of the burner before and after the maintenance.

The efficiency before maintenance = 88.3%

The efficiency after maintenance =90.4%

**Recommendation:** Continue to raise the efficiency of thermal generation to raise the efficiency of the turbine.[2]

**2-4The Usage of solid fuel in power plant (sponge coke):**

Prof.Sabir Mohammed Salieh , August 2009.

**Problem statement:** Study effect of solid fuel to increase the efficiency of the boiler; Study reducing the emissions of the combustion were been carried out.

***Objectives:*** Study the possible methods to how reduce the emissions in the power plant; Effect of heat balance and calculations.

**Conclusion:**

From the previous study it was been noted that the system used in Garri 4 has Avery high reliability that it can function above 89% during the season, in addition to the low prices of sponge coke which reduces the running cost.

The system has Avery good characteristics in reducing the emissions of the combustion hence it counts as “environment friend ".

**Recommendation:**

Finally it is recommended that NEC should try establishing same stations because of the properties listed above.[3]

**2-5Effect of Turbine Back Pressure of on steam cycle Efficiency.**

Dr.TawfeegGamalalden, August 2012.

Problem **statement:**

This study aims at tracking the effect of turbine back pressure (vacuum) on cycle efficiency of phase at Khartoum north power station.

The study included collecting data and readings of the turbine and condenser conditions for phase, calculating the unit efficiency and finding the relationships between the efficiency &the load, the efficiency & the vacuum under constant load. Also the research inspected the causes of change in vacuum, the effect of this change in the operation conditions in the case of the rise or the drop in vacuum and the actions in response to these changes. The analysis of these data shows that any increase in condenser pressure (and this causes back pressure turbine) is followed by a decrease in the efficiency of the unit.

**Objectives:**

The purpose of this research:

- To study the effect of the turbine back pressure on the cycle efficiency.
- To determine all factors this may cause any change in back pressure (vacuum).
- To show the results and the consequences on the cycle operation when any changes in vacuum occur.

**Conclusion:**

1/

| Heat added(Q) | WORK | Efficiency | Power out put |
|---|---|---|---|
| 2083.86 | 836.56kj/kg | 40.14% | 52.548MW |

2/

| Heat added(Q) | Work | Efficiency | Power out put |
|---|---|---|---|
| 2089.6 9kJ/kg | 837.92kJ/kg | 40.097% | 50.7647MW |

3/

| Heat added(Q) | Work | Efficiency | Power out put |
|---|---|---|---|
| 2096.14 kJ/kg | 79064 kJ/kg | 37.71% | 48.822MW |

**Recommendation:**

- In order to improve the cycle efficiency we recommend that using vacuum pump beside the air ejector in phase .will help in the adjustment of the back pressure when any change occur.
- To avoid the manual response when any alarm is launched , we advise the plant to install condenser pressure control system which will actuate any errors in the vacuum value immediately and automatically .

## 2-6 Relationship of previous studies with our study:

In this section we discussed previous studies in the field of increasing the efficiency of different power stations in many ways and their aim to increase the efficiency of the generation which is related to our study of the impact of high pressure heat exchangers and their effect on increasing thermal efficiency and the relationship of these studies with our research is to increase the efficiency of generation.

We also note that in the first study, the increase in temperature was simple and efficient. In our study, the heat is increased in a somewhat larger quantity. In the second study, the water was eliminated. The uniform was treated as a chemical. This is a loss and cost. The effect of fuel type coal in the increase efficiency only and the fifth study aims to increase efficiency through the pressure from the turbine and our study is treated for all previous studies as it increases thermal efficiency and thus increases the efficiency of generating less cost and faster time.

# CHAPTER III

# Theoretical

## 3-1 preface:

Is a device that extracts thermal energy from pressurized steam and uses it to do mechanical work on a rotating output shaft. Its modern manifestation was invented by Sir Charles Parsons in 1884.

Because the turbine generates rotary motion, it is particularly suited to be used to drive an electrical generator – about 90% of all electricity generation in the United States (1996) is by use of steam turbines. The steam turbine is a form of heat engine that derives much of its improvement in thermodynamic efficiency from the use of multiple stages in the expansion of the steam, which results in a closer approach to the ideal reversible expansion process [9].

Thermodynamic cycles can be divided into two general categories: power cycles, which produce a net power output, and refrigeration and heat pump cycles, which consume a net power input. The thermodynamic power cycles can be categorized as gas cycles and vapor cycles. In gas cycles, the working fluid remains in the gas phase throughout the entire cycle. In vapor cycles, the working fluid exits as vapor phase during one part of the cycle and as liquid phase during another part of the cycle [2].

Steam power plants run vapor power cycles with water as the working fluid. This section introduces the ideal cycle for vapor power cycle - Ideal Rankin cycle - Ideal Reheat Rankin - cycle Rankin cycle-Regeneration Cycle - the Ideal Cycle for Vapor Power Cycle Vapor power plants generate electrical power by using fuels like coal, oil or natural gas The schematic of a vapor power plant is shown below. The entire power plant can be broken down into four major subsystems.

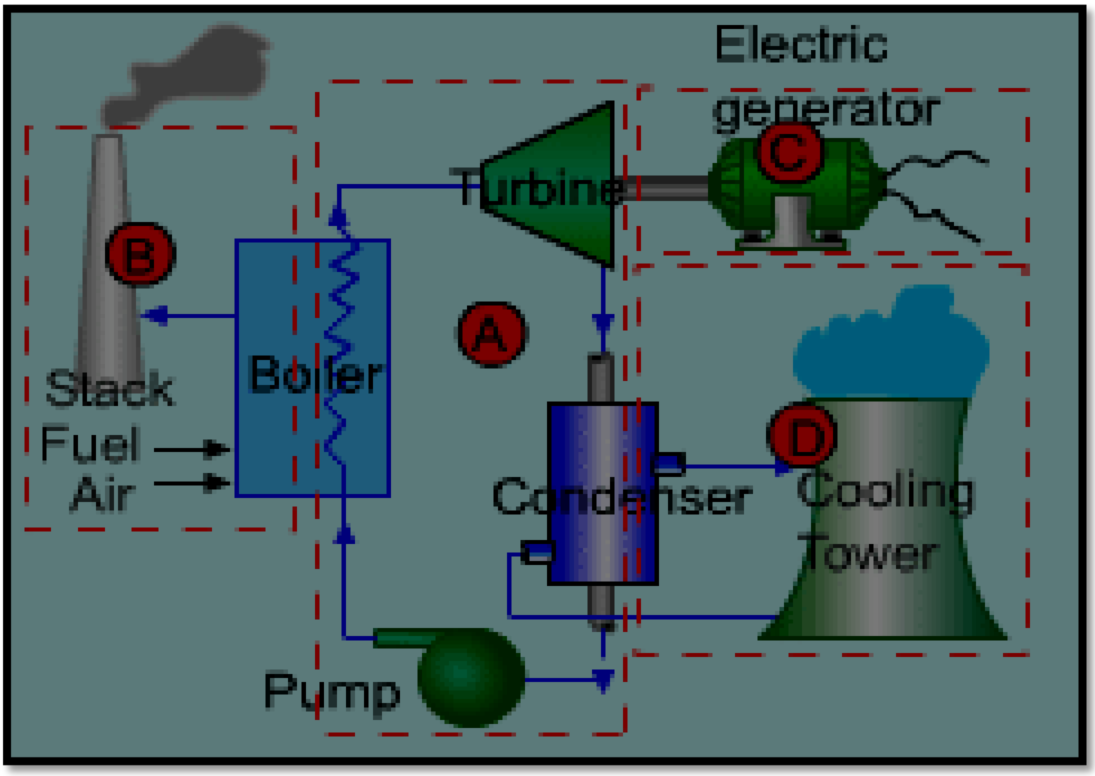



**Fig (3.1) Schematic of a Vapor Power Plant**

- Subsystem A: Energy conversion from heat to work.
- Subsystem B: Energy source and waste removal required to vaporize the water.
- Subsystem C: Electric generator.
- Subsystem D: Cooling water system.

The thermodynamic cycle in subsystem A is called the Rankin cycle. Subsystem A consists of a boiler, turbine, condenser and a pump. Fuel, burned in the boiler, heats the water to generate superheated steam (subsystem B). This steam is used to run the turbine which powers the generator. Electrical energy is generated when the generator windings rotate in a strong magnetic field (subsystem C). After the steam leaves the turbine, it is cooled to its liquid state in the condenser by transferring heat to the cooling water system (subsystem D). The liquid is pressurized by the pump prior to going back to the boiler.

All four components associated with the ideal Rankin cycle are steady-flow devices, and thus all four processes that make up the Rankin cycle can be analyzed as steady-flow process. The kinetic and potential energy changes of water are small relative to the heat and work terms, are thus neglected. Energy analyses of the four components are given below [2].

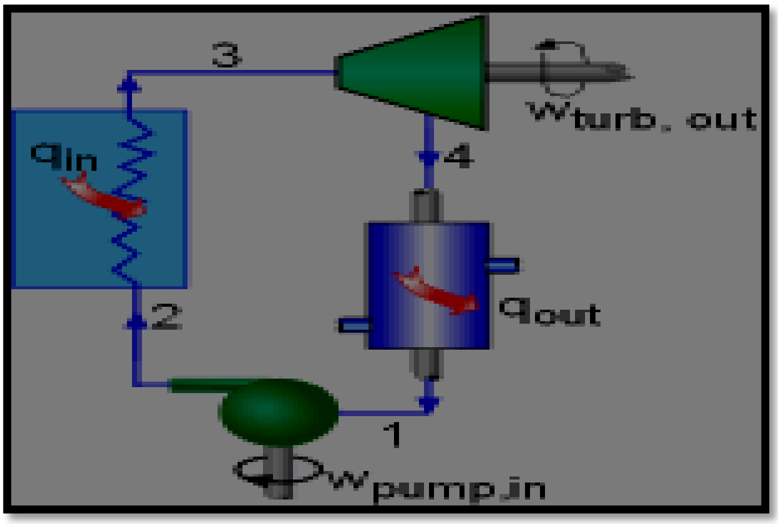



**Fig (3.2) Schematic of a Vapor Power Plant**

Pump (process 1-2): Pump pressurized the liquid water from the condenser and going back to the boiler. Assuming no heat transfer with the surroundings, the energy balance in the pump is :

$$w_{pump,in} = h_2 - h_1 \rightarrow (1,3)$$

Boiler (process 2-3): Liquid water enters the boiler and is heated to superheated state in the boiler. The energy balance in the boiler is :

$$q_{in} = h_3 - h_2 \rightarrow (2,3)$$

Turbine (process 3-4): Steam from the boiler, which has an elevated temperature and pressure, expands through the turbine to produce work and then is discharged to the condenser with relatively low pressure. Neglecting heat transfer with the surroundings, the energy balance in the turbine is :

$$\boldsymbol{w_{turbine,out} = h_3 - h_4} \rightarrow \mathbf{(3,3)}$$

Condenser (process 4-1): Steam from the turbine is condensed to liquid water in the condenser. The energy balance in the condenser is:

$$\boldsymbol{q_{out} = h_4 - h_1} \rightarrow \mathbf{(4,3)}$$

For the whole cycle, the energy balance can be obtained by summarizing the four energy equations above. It yields,

$$\boldsymbol{(q_{in} - q_{out}) - (w_{turbine,out} - w_{pump,in}) = 0} \rightarrow \mathbf{(5,3)}$$

The thermal efficiency of the Rankine cycle is determined from

$$\boldsymbol{\eta_{th} = \frac{w_{net,out}}{q_{in}} = 1 - \frac{q_{out}}{q_{in}}} \rightarrow \mathbf{(6,3)}$$

where the net work output from the cycle is

$$\boldsymbol{w_{net,out} = (w_{turbine,out} - w_{pump,in})} \rightarrow \mathbf{(7,3)}$$

The Rankine cycle is an ideal cycle if water passes through the four components without irreversibility and pressure drops. The ideal Rankine cycle consists of the following four processes, as shown on the T-s diagram on the below [2]:

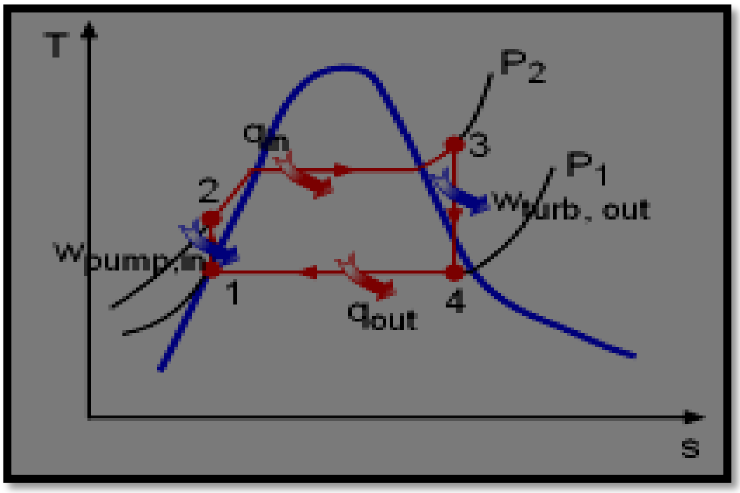



**Fig (3.3) Schematic of a Vapor Power Plant**

- 1-2: Isentropic compression in a pump.
- 2-3: Constant pressure heat addition in a boiler.
- 3-4: Isentropic expansion in a turbine.
- 4-1: Constant pressure heat rejection in a condenser.

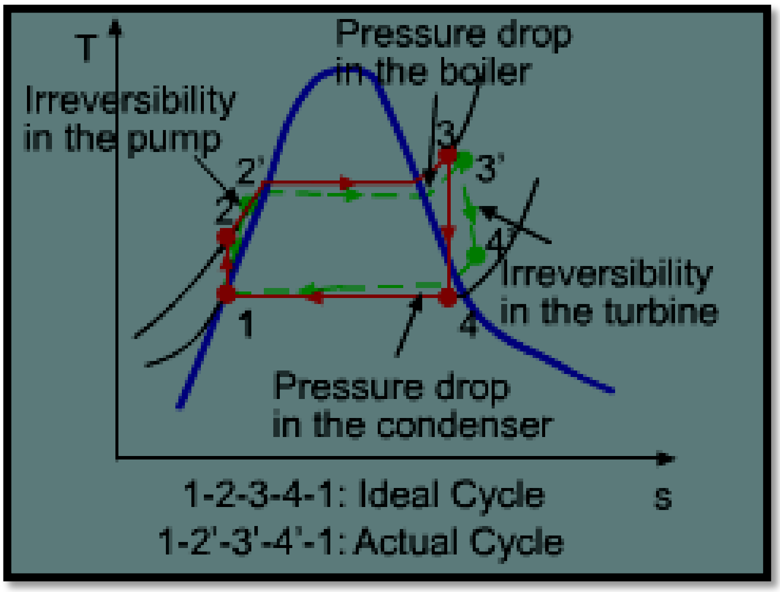
**3-2 Actual Vapor Power Cycle:**

The actual vapor power cycle differs from the ideal Rankine cycle as a result of irreversibility's in various components. The two common sources of irreversiblities are the friction and undesired heat loss to the surroundings. Fluid friction causes pressure drops in the boiler, the condenser, and the connecting pipes. To compensate for these pressure drops, the water needs to be pumped to a higher pressure. Heat loss from steam to surroundings takes place when steam flows through the connecting pipes and the various components. To maintain the same work output, more heat needs to be transferred to the steam in the boiler. The deviation of actual pumps and turbines from the isentropic ones can be accounted for by utilizing adiabatic efficiencies:

$$\eta_{pump} = \frac{w_s}{w_a} = \frac{h_{2s}-h_1}{h_{2a}-h_1} \rightarrow (8.3)$$

$$\eta_{turbine} = \frac{w_a}{w_s} = \frac{h_3-h_{4a}}{h_3-h_{4s}} \rightarrow (9,3)$$

Where the subscript a means the actual value and subscript s means the isentropic value.




**(3.4) Deviation of Actual Vapor Cycle from**

Methods of Increasing the Efficiency of the Rankine Cycle:

There are three ways to increase the efficiency of the simple ideal Rankine cycle.

**1. Decreasing the condenser pressure:**

The effect of lowering the condenser pressure on the Rankine cycle efficiency is illustrated on a T-s diagram on the left. Steam exits as a saturated mixture in the condenser at the saturation temperature corresponding to the pressure in the condenser. So lower the pressure in the condenser, lower the temperature of the steam, which is the heat rejection temperature. The blue area is the net work increases due to the decreasing of the condenser pressure [5].

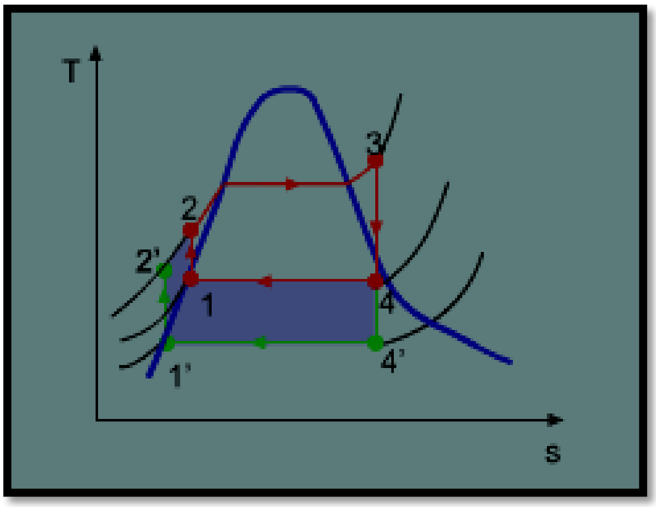



**Fig (3.5) the Effect of Lowing the Condenser Pressure**

**2. Superheating the steam to a high temperature:**

The effect of superheating the steam to a high temperature on the Rankine cycle efficiency is illustrated on a T-s diagram on the left. By superheating the stream to a high temperature (from state 3 to state 3'), the average steam temperature during heat addition can be increased. The black area is the net work increased due to superheating the steam to a high temperature [5].

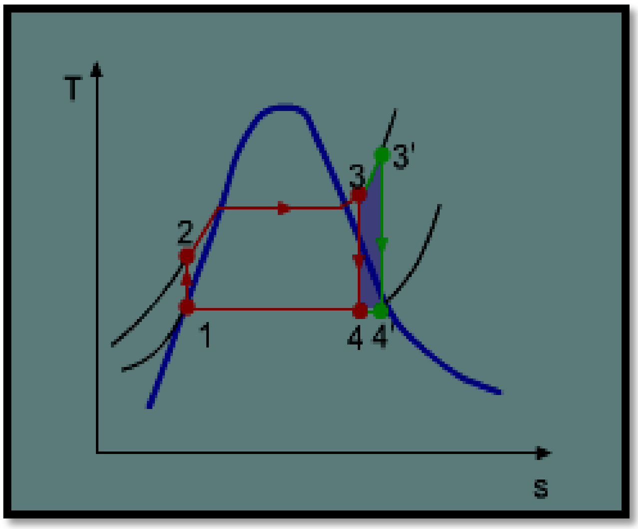



**Fig (3.6) the Effect of Superheating the Steam to a higher temperature.**

### 3. Increasing the boiler pressure:

The effect of increasing the boiler pressure on the Rankine cycle efficiency is illustrated on a T-s diagram on the left. If the operating pressure of the boiler is increased, (process 2-3 to process 2'-3'), then the boiling temperature of the steam raises automatically. For a fixed inlet turbine temperature, the blue area is the net work increased and the gray area is the net work decreased. Also, the moisture content of the steam increases from state 4 to state 4', which is an undesirable side effect. This side effect can be corrected by reheating the steam, and results in the reheat Rankinecycle[5].

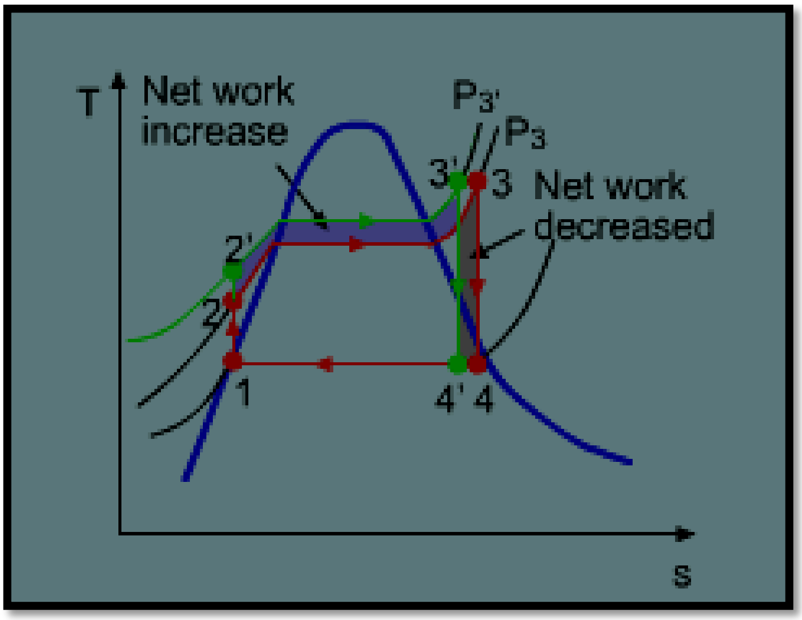


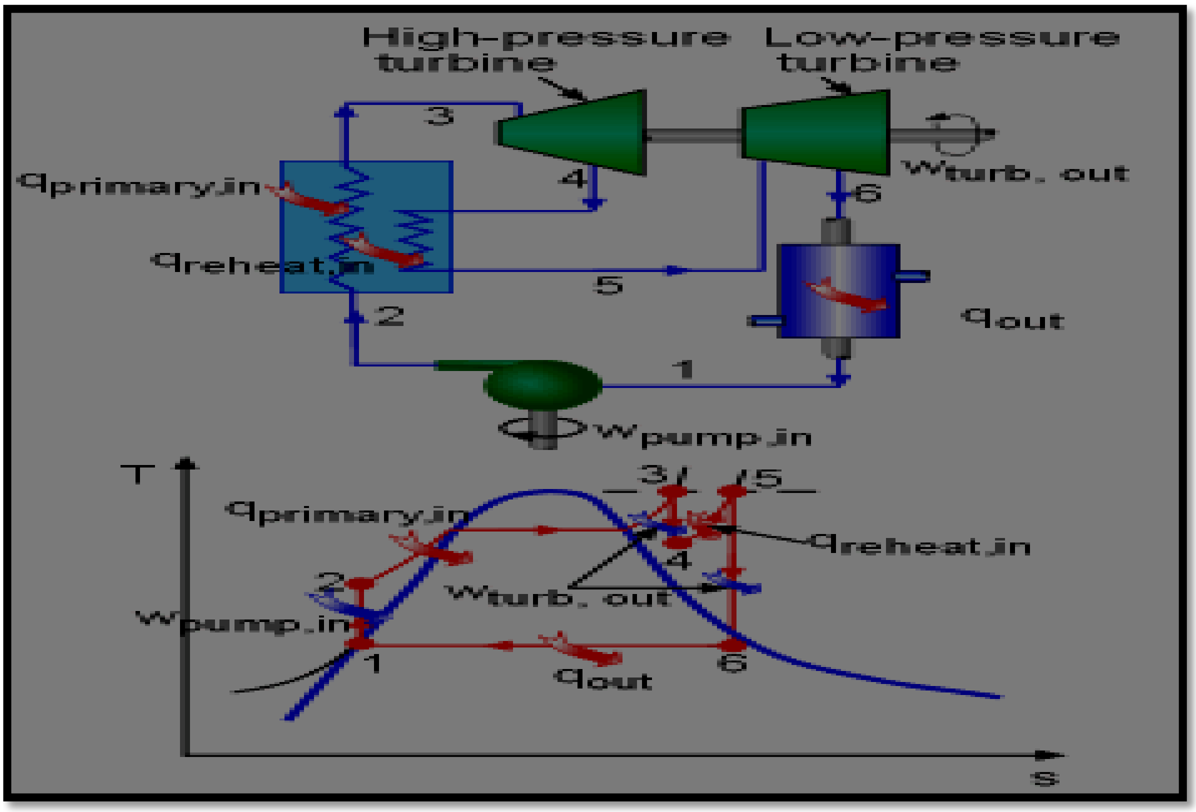

**Fig (3.7) the Effect of Increase the Boiler Pressure**

## 3-4 The Ideal Reheat Rankine Cycle:

The above section states that increasing the boiler pressure can increase the thermal efficiency of the Rankine cycle, but it also increases the moisture content at the exit of the turbine to an unacceptable level. To correct this side effect, the simple Rankine cycle is modified with a reheat process. The schematic of an ideal reheat Rankine cycle is shown on the left with its T-s diagram. In this reheat cycle, steam is expanded isentropically to an intermediate pressure in a high-pressure turbine (stage I) and sent back to the boiler, where it is reheated at constant pressure to the inlet temperature of the high-pressure turbine. Then the steam is sent to a low-pressure turbine and expands to the condenser pressure (stage II) . The total heat input and total work output is

$$q_{in} = q_{primary} + q_{reheat} = (h_3 - h_2) + (h_5 - h_4) \rightarrow (10.3)$$

$$w_{total,out} = q_{turbine,I} + q_{turbine,II} = (h_3 - h_4) + (h_5 - h_6) \rightarrow (11.3)$$




**fig(3.8) Schematic and T-s Diagram of an Ideal Reheat Rankine Cycle**

When the number of the reheat stages increases, the expansion and reheat processes approach an isothermal process at the maximum temperature. But using more than two stages is not practical[8].

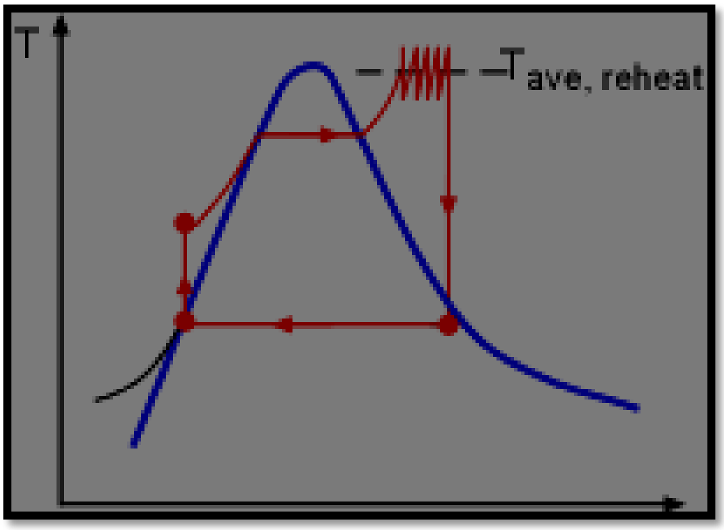



**Fig (3.9) Multistage Reheat Approaching**

**An Isothermal Process**

**3-5 Regeneration cycle:**

The focus of this Search is **Regeneration cycle**. In a simple Rankin cycle, heat is added to the cycle during process 2-2'-3 (see the T-s diagram blow). During this first stage (process 2-2'), the temperature of the water is low. That reduces the average temperature during heat addition (process 2-2'-3). To remedy this shortcoming, increasing the temperature of the feed water (water leaving the pump and entering the boiler) can be considered. This is accomplished by extracting stream from the turbine to heat the feed water. This process is called regeneration and the heat exchanger where heat is transferred from steam to feed water is called a regenerator, or a feed water heater. There are actually two main types of feed water heaters. If the steam mixes with the compressed water from the pump, it is an open feed water heater. If the steam does not mix with the compressed water from the pump, it is a closed feed water heater[2].

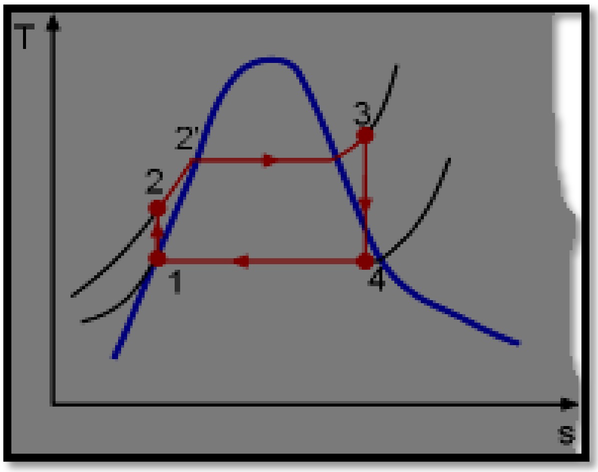



**Fig (3.10) T-s Diagram of Lowering the Condenser Pressure**

The schematic of a steam power plant with one open feed water heater is shown blow. In an ideal regenerative Rankin cycle with an open feed water heater, steam from the boiler (state 5) expands in the turbine to an intermediate pressure (state 6). At this state, some of the steam is extracted and sent to the feed water heater, while the remaining steam in the turbine continues to expand to the condenser pressure (state 7). Saturated water from the condenser (state 1) is pumped to the feed water pressure and send to the feed water heater (state 2). At the feed water heater, the compressed water is mixed with the steam extracted from the turbine (state 6) and exits the feed water heater as saturated water at the heater pressure (state 3). Then the saturated water is pumped to the boiler pressure by a second pump (state 4). The water is heated to a higher temperature in the boiler (state 5) and the cycle repeats again. The T-s diagram of this cycle is shown on the blow[2]

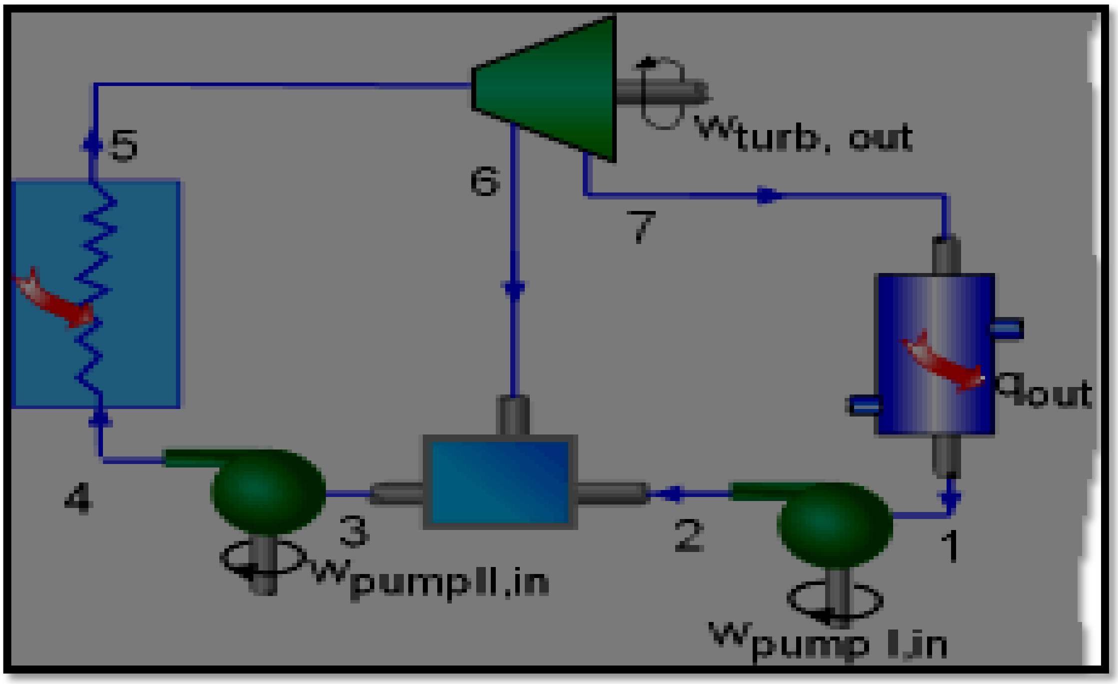



**Fig (3.11) Schematic of a Power Plant Running an Ideal Regenerative Rankin Cycle with One Open Feed water heater**

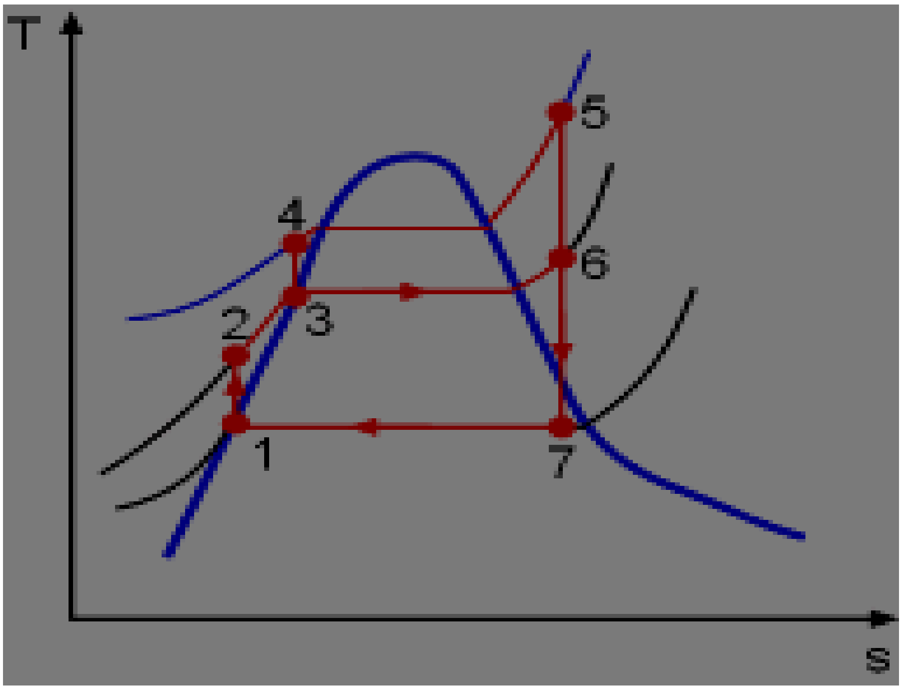



**Fig (3.12) T-S Diagram of an Ideal Regenerative Rankin Cycle with One Open Feed water Heater**

Note that the mass flow rate at each component is different. If 1 kg steam enters the turbine, y kg is extracted to the feed water heater and $(\mathbf{1}-\boldsymbol{y})\boldsymbol{kg}$continues to expand to the condenser pressure. So if the mass flow rate at the boiler is $\boldsymbol{m}^{\cdot}$, then the mass flow rate from other components are[2]:

**Condenser:** $\boldsymbol{m}^{\cdot}(\mathbf{1}-\boldsymbol{y})$ →(12,3)

**Pump I:** $\boldsymbol{m}^{\cdot}(\mathbf{1}-\boldsymbol{y})$→(13.3)

**Feed water Heater:** $\boldsymbol{m}^{\cdot}\boldsymbol{y}+\boldsymbol{m}^{\cdot}(\mathbf{1}-\boldsymbol{y})=\boldsymbol{m}^{\cdot}$ →(14.3)

For convenience, heat and work interactions for regenerative Rankin cycle is expressed per unit mass of steam flowing through the boiler. They are:

**Heat Input:**Qin = h5-h4→(15,3)

**Heat Output:** $q_{out}=\quad(\mathbf{1}-\boldsymbol{y})(\boldsymbol{h}_{\mathbf{1}}-\boldsymbol{h}_{\mathbf{7}})$ → (16,3)

**Work Output:**

$w_{turbine,out}=(\boldsymbol{h}_{\mathbf{5}}-\boldsymbol{h}_{\mathbf{6}})+(\mathbf{1}-\boldsymbol{y})(\boldsymbol{h}_{\mathbf{6}}-\boldsymbol{h}_{\mathbf{7}})$ → (17,3)

**Work input:** $w_{pump,in}=(\mathbf{1}-\boldsymbol{y})(\boldsymbol{h}_{\mathbf{2}}-\boldsymbol{h}_{\mathbf{1}})+(\boldsymbol{h}_{\mathbf{4}}-\boldsymbol{h}_{\mathbf{3}})$ → (18,3)

**The schematic of a steam power plant with one closed feed water heater is shown in blow:**

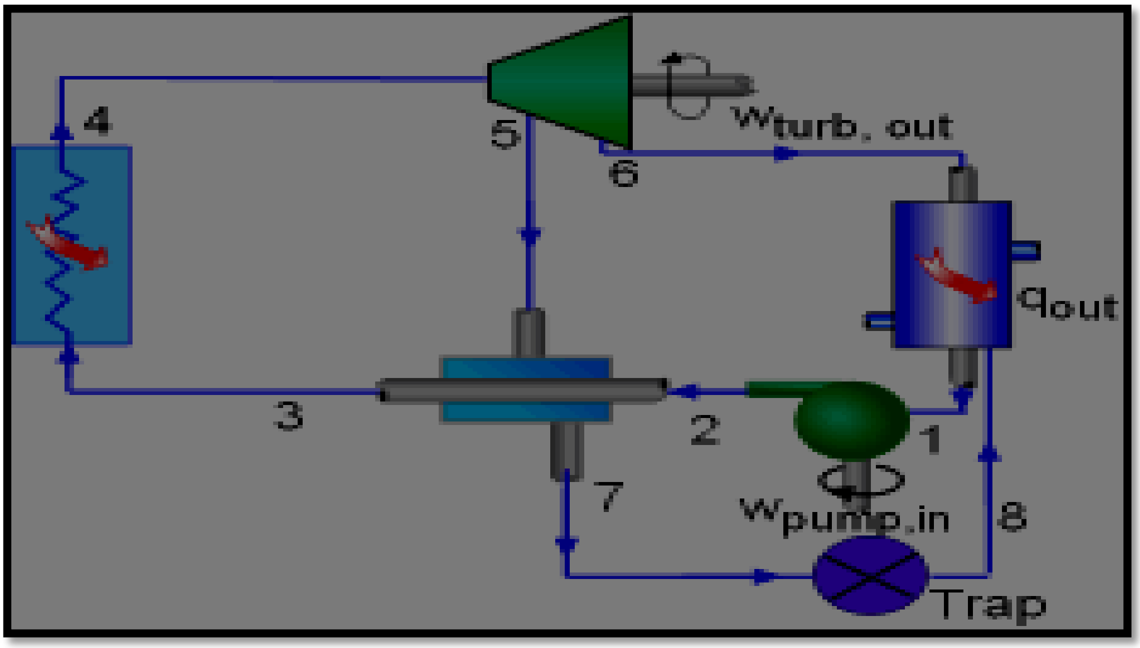



**Fig (3.13) Schematic of a Power Plant Running an Ideal Regenerative Rankine Cycle with One Closed Feedwater Heater:**

In an ideal regenerative Rankine cycle with a closed feedwater, steam from the boiler (state 4) expands in the turbine to an intermediate pressure (state 5). Then some of the steam is extracted at this state and sent to the feedwater heater, while the remaining steam in the turbine continues to expand to the condenser pressure (state 6). The extracted stream (state 5) condenses in the closed feedwater while heating the feedwater from the pump. The heated feedwater (state 3) is send to the boiler and the condensate from the feedwater heater (state 7) is allowed to pass through a trap into a lower pressure heater or condenser (state 8). Another way of removing the condensate from the closed feedwater heater is pump the condensate forward to a higher-pressure point in the cycle. The T-s diagram of this cycle is shown on the blow[2]

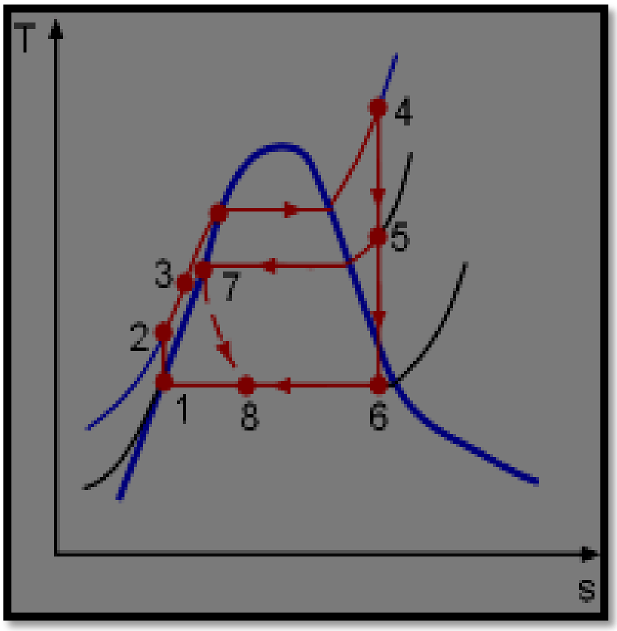



**Fig (3.14)T-S Diagram of an Ideal Regenerative Rankine Cycle with One Closed Feedwater Heater**

Heat and work interactions for regenerative Rankine cycle with one closed feed water heater is expressed per unit mass of water flowing through the boiler. They are:

Heat Input: $q_{in} = h_4 - h_3$ →(19,3)

Heat Output:

$q_{out} = (1-y)(h_1 - h_6) + y(h_8 - h_1)$ → (20,3)

Work Output:

$w_{tu}$

Work input: $w_{pump,in} = (h_2 - h_1)$→(22,3)

The efficiency ratio of the actual efficiency to the ideal efficiency.

In the vapourcycles the efficiency ratio compares the actual cycle efficiency to the rankine cycle efficiency,

$$\text{Efficiency ratio} = \frac{cycle \text{ Efficiency}}{Rankine \text{ Efficiency}} \rightarrow (23.3)$$

The actual expansion process is irreversible & the actual compression of the water is irreversible, the isentropic efficiency of process is defined by:

$$\text{Isentropic efficiency} = \frac{actualwork}{isentropicwork} \text{ for an expansion process} \rightarrow (24{,}3)$$

$$\text{Isentropic efficiency} = \frac{isentropicwork}{actualwork} \text{ for a compression process} \rightarrow (25{,}3)$$

$$workratio = \frac{networkoutput}{grossworkoutput} \rightarrow (26{,}3)$$

Both efficiency and work ratio are criteria of performance, another criteria of performance in steam plant is the specific steam consumption (ssc).it relates the power output to steam flow necessary to produce it. The steam flow indicates the size of plant and its component parts, and the (ssc) is a means where by the relative size of different plants can be compared. The (ssc) is the steam flow required to develop unit power out put[2].

$$ssc = \frac{1}{isentropicwork} \, kJ/kg \rightarrow (27{,}3)$$

**3.6 Advantages Open Feed water Heaters:**

1. Open feed water heaters are simple.
2. Dissolved oxygen and carbon dioxide gases get released from the water and leave along with some vapor, which is condensed back in the vent condenser, and the gases vented out.
3. The presence of dissolved gases like oxygen and carbon dioxide in water makes the water corrosive, as they react with the metal to form iron oxide.
4. The solubility of these gases in water decreases with increase temperature by steam extracted from the turbine.

5. The deareator is usually placed near the middle of the feed water system so that the total pressure difference between the condenser and the boiler is shared equitably between the condensate pump and boiler feed pump[1].

### 3.7 Disadvantages Open Feed water Heaters:

To neutralize the effect of residual dissolved oxygen and carbon dioxide gases in water, sodium sulphite($Na2So3$)or Hydrazine($N2H4$)injected in suitable calculated doses in to the feed water at the suction of the boiler feed pump(BFP).

1. During suction of the BFP, some of the saturated feed water may be flash in vapor due to reduction in pressure casing vapor lock and cavitation problems in the pumps .
2. However, each feed water needs a separate pump which adds to the cost[1].

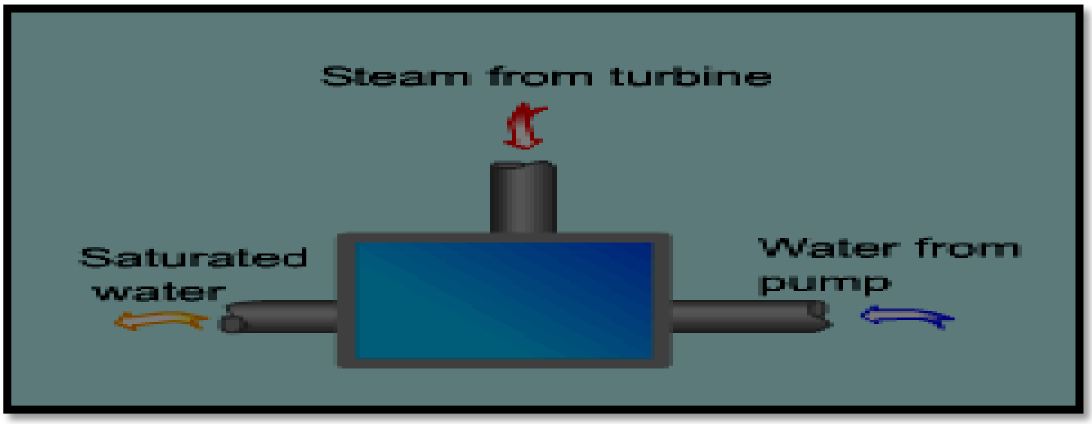



**Fig (3.15) An Open Feed water Heater**

### 3.8Advantages closed Feed Water Heaters:

1. Closed feed water heaters do not require a separate pump for each heater.
1. Since the two streams do not mix in the heater, most power plants use a combination of open and closed feed water heaters.
2. Extremely flexible and robust design.
3. Easy to maintain and repair.
4. Can be designed to be dismantled for cleaning.
5. Very many suppliers world-wide[1].

### 3.9Disadvantages closed Feed Water Heaters:

1. Require large plot (footprint) area- often need extra space to remove the bundle.
2. Compared with open feed water heaters, closed feed water heaters are more complex, and thus more expensive[1].

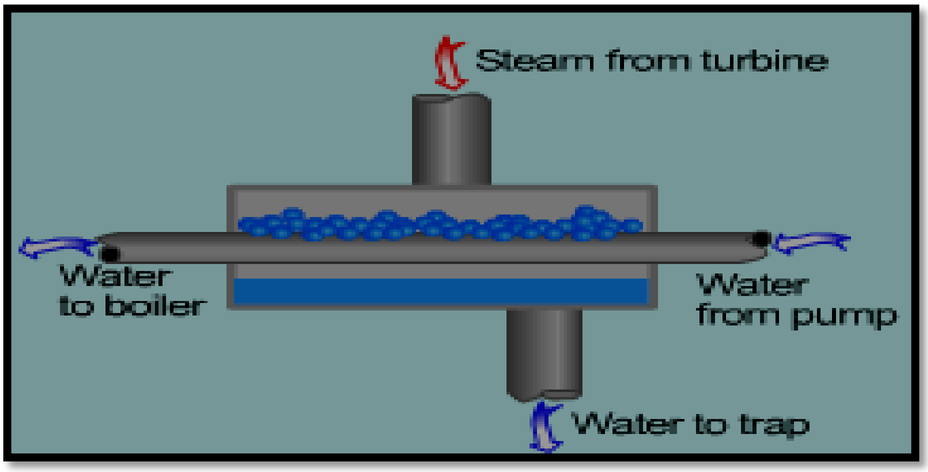



**Fig (3.16) Closed Feed water heater.**

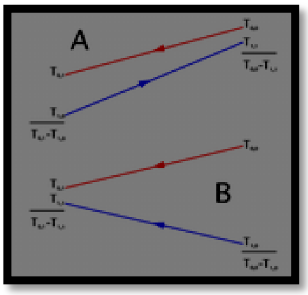
## 3-10Theoretical Turbine efficiency :

To maximize turbine efficiency the steam is expanded, doing work, in a number of stages. These stages are characterized by how the energy is extracted from them and are known as either impulse or reaction turbines. Most steam turbines use a mixture of the reaction and impulse designs: each stage behaves as either one or the other, but the overall turbine uses both. Typically, lower pressure sections are reaction type and higher pressure stages are impulse type[3].

## 3-11A heat exchanger:

Is a device used to transfer heat between a solid object and a fluid, or between two or more fluids. The fluids may be separated by a solid wall to prevent mixing or they may be in direct contact. They are widely used in space heating, refrigeration, air conditioning, power stations, chemical plants, petrochemical plants, petroleum refineries, natural-gas processing, and sewage treatment. The classic example of a heat exchanger is found in an internal combustion engine in which a circulating fluid known as engine coolant flows through radiator coils and air flows past the coils, which cools the coolant and heats the incoming air. Another example is the heat sink, which is a passive heat exchanger that transfers the heat generated by an electronic or a mechanical device to a fluid medium, often air or a liquid coolant[6].

### 3-11-1 Flow arrangement:-




Countercurrent (A) and parallel (B) flows

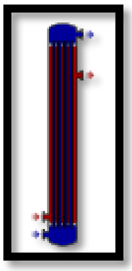
- 

Fig. 3.17: Shell and tube heat exchanger, single pass (1–1 parallel flow)

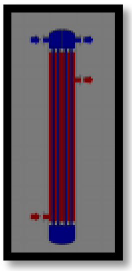
- 

Fig. 3.18: Shell and tube heat exchanger, 2-pass tube side (1–2 crossflow)

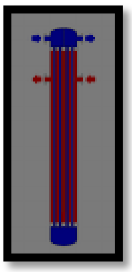
- 

Fig. 3.19: Shell and tube heat exchanger, 2-pass shell side, 2-pass tube side (2-2 countercurrent)

There are three primary classifications of heat exchangers according to their flow arrangement. In *parallel-flow* heat exchangers, the two fluids enter the exchanger at the same end, and travel in parallel to one another to the other side. In *counter-flow* heat exchangers the fluids enter the exchanger from opposite ends. The counter current design is the most efficient, in that it can transfer the most heat from the heat (transfer) medium per unit mass due to the fact that the average temperature difference along any unit length is *higher*. See countercurrent exchange. In a *cross-flow* heat exchanger, the fluids travel roughly perpendicular to one another through the exchanger[6].

For efficiency, heat exchangers are designed to maximize the surface area of the wall between the two fluids, while minimizing resistance to fluid flow through the exchanger. The exchanger's performance can also be affected by the addition of fins or corrugations in one or both directions, which increase surface area and may channel fluid flow or induce turbulence.

The driving temperature across the heat transfer surface varies with position, but an appropriate mean temperature can be defined. In most simple systems this is the "log mean temperature difference" (LMTD)[6].

**3-11-2 Types:**

Double pipe heat exchangers are the simplest exchangers used in industries. On one hand, these heat exchangers are cheap for both design and maintenance, making them a good choice for small industries. On the other hand, their low efficiency coupled with the high space occupied in large scales, has led modern industries to use more efficient heat exchangers like shell and tube or plate. However, since double pipe heat exchangers are simple, they are used to teach heat exchanger design basics to students as the fundamental rules for all heat exchangers are the same. To start the design of a double pipe heat exchanger, the first step is to calculate the heat duty of the heat exchanger. It must be noted that for easier design, it's better to ignore heat loss to the environment for initial design[6].

### 3-11-2-1 Shell and tube heat exchanger:

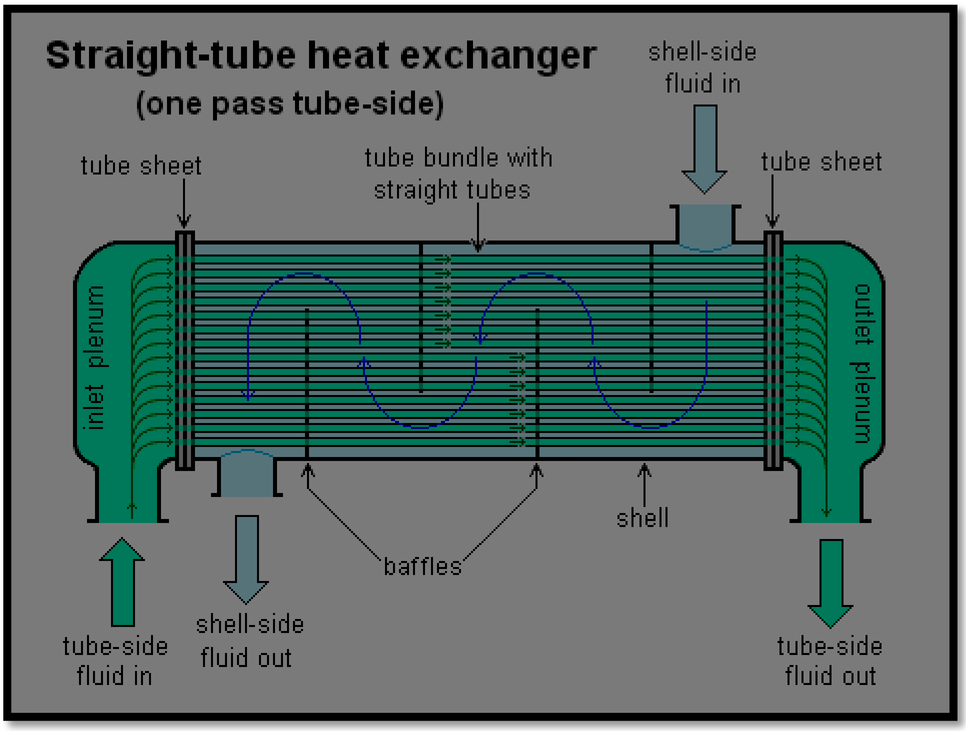



**Fig3.20 A shell and tube heat exchanger**

Shell and tube heat exchangers consist of series of tubes. One set of these tubes contains the fluid that must be either heated or cooled. The second fluid runs over the tubes that are being heated or cooled so that it can either provide the heat or absorb the heat required. A set of tubes is called the tube bundle and can be made up of several types of tubes plain, longitudinally finned, etc. Shell and tube heat exchangers are typically used for high-pressure applications (with pressures greater than 30 bar and temperatures greater than 260 °C). This is because the shell and tube heat exchangers are robust due to their shape[6].

### 3-11-2-2 Plate heat exchangers:

**Plate heat exchanger :**

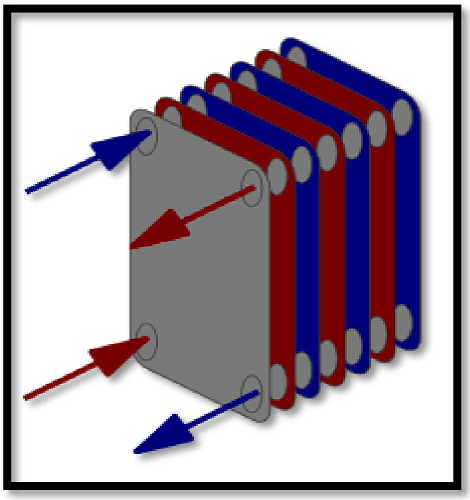


**Fig3.21 Conceptual diagram of a plate and frame heat exchanger.**

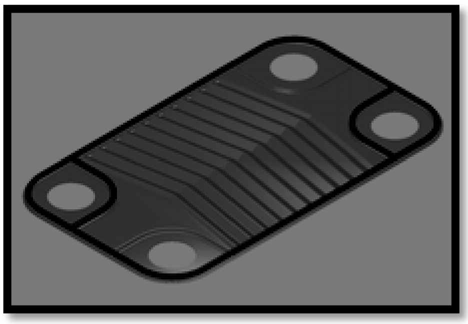


**Fig3.22A single plate heat exchanger.**

**3.23An interchangeable plate heat exchanger applied to the system of a swimming pool.**

**3-12Advantages of plate heat exchangers:**

- High heat transfer efficiency especially in gas treatment
- Larger heat transfer area
- Approximately 5 times lighter in weight than that of shell and tube heat exchanger.
- Able to withstand high pressure[6]

**3-13Disadvantages of plate heat exchangers:**

- Might cause clogging as the pathways are very narrow
- Difficult to clean the pathways
- Aluminum alloys are susceptible to Mercury Liquid Embrittlement Failure[6]

**3-14Phase-change heat exchangers:**

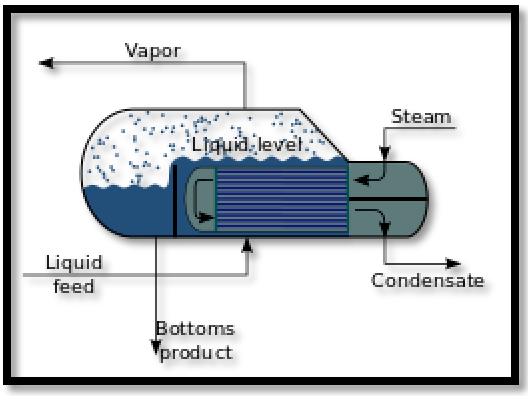



**Fig 3.23 Typical kettle reboiler used for industrial distillation towers.**

## 3-15Direct contact heat exchangers:

Direct contact heat exchangers involve heat transfer between hot and cold streams of two phases in the absence of a separating wall. Thus such heat exchangers can be classified as:

- Gas – liquid
- Immiscible liquid – liquid
- Solid-liquid or solid – gas

Most direct contact heat exchangers fall under the Gas – Liquid category, where heat is transferred between a gas and liquid in the form of drops, films or sprays.

Such types of heat exchangers are used predominantly in air conditioning, humidification, industrial hot water heating, water cooling and condensing plants[6].

## 3-16Theory and Application:

Two fluids, of different starting temperatures, flow through the heat exchanger. One flows through the tubes (the tube side) and the other flows outside the tubes but inside the shell (the shell side). Heat is transferred from one fluid to the other through the tube walls, either from tube side to shell side or vice versa. The fluids can be either liquids or gases on either the shell or the tube side. In order to transfer heat efficiently, a large heat transfer area should be used, leading to the use of many tubes. In this way, waste heat can be put to use. This is an efficient way to conserve energy[7].

Heat exchangers with only one phase (liquid or gas) on each side can be called one-phase or single-phase heat exchangers. Two-phase heat exchangers can be used to heat a liquid to boil it into a gas (vapor), sometimes called boilers, or cool a vapor to condense it into a liquid (called condensers), with the phase change usually occurring on the shell side. Boilers in steam engine locomotives are typically large, usually cylindrically-shaped shell-and-tube heat exchangers. In large power plants with steam-driven turbines, shell-and-tube surface condensers are used to condense the exhaust steam exiting the turbine into condensate water which is recycled back to be turned into steam in the steam generator [7].

**3-17 steam condenser:**

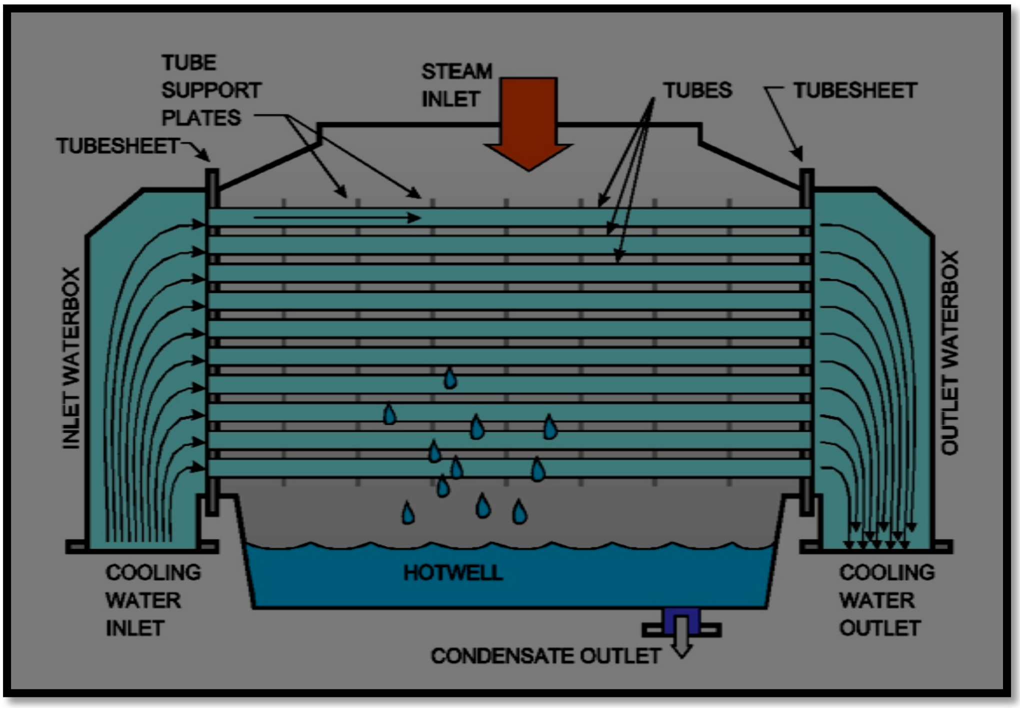



**Fig3.24 explain condenser**

**Any steam condenser does the task to fulfill mainly two objectives as given below:**

(1)The first objective is to create a low back pressure (vacuum) at the turbine exhaust so as to obtain the maximum possible energy conversion from the high pressure and high temperature steam and thus to increase the efficiency of the power plant.

(2)The secondary objective is to condense the exhaust steam coming from the turbine and therefore recover the high-quality feed water for the reuse in the cycle of operation.

When a condenser is introduced in a plant with steam turbine the work obtained per kg of steam is increased in comparison to the non-condensing turbine. Thermal efficiency of a condensing unit is therefore higher than that of non-condensing unit for the same mass of steam [1].

**3-18 equation used inConclusion**:

The equationused for conclusion :

$Wfwin \times Hfwin + Qfwin = Wfwo \times Hfwo$ →(28,3)[1]

As :

W ≡ the flow rate , kg/h.

H ≡ the Enthalpy for steam kj/kg .

Q ≡ heat add kj/kwh

$totalheatrate = totalheatrateofdesign - heatrateofHPH1,$→(29,3) [2]

$Totalofheatrateofdesign = \frac{Fs \times Hs - Fw \times Hw}{output}$ →(30,3) [3]

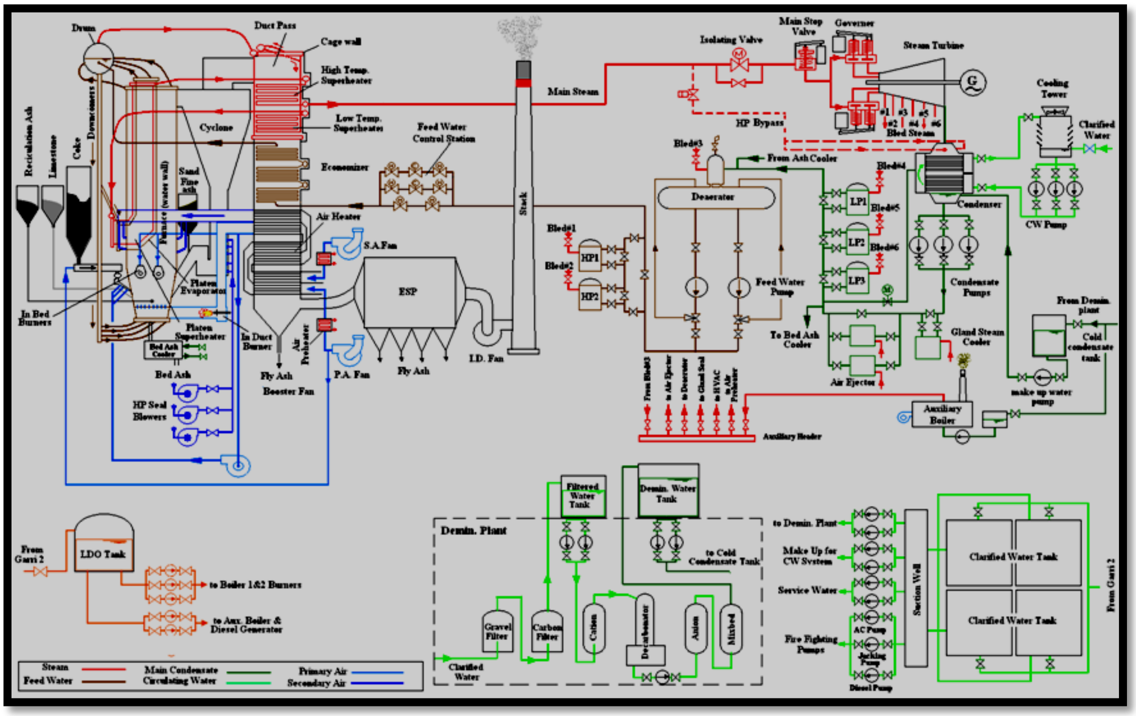
## 3-19 Methods used in calculations:

We have written in this chapter about the theoretical side of the research and we will address the mathematical aspect and efficiency calculations using mathematical equations and thermo dynamic laws in studying the effect of high pressure heat exchangers in efficiency and also we will find them through the programs of MATLAB.

# CHAPTER IV

# Case study

### The sketch below represents GARRI4 THERMAL POWER PLANT




### 4-1 preface:

Garri4 is a sponge coke fired power plant. It is a first power plant in the Middle East which used a solid fuel.

Khartoum refinery produces 256 tone/year of sponge coke as a byproduct. This coke can be used to generate electric power. So NEC decided to build Garri4 power plant which used this coke as a solid fuel.

Garri4 is a steam power plant, it works with regeneration cycle. It consists of two steam turbines each one generate 55 MW. Each turbine has a boiler to supply superheated steam to the turbine. This boiler known as a Circulating Fluidized Bed Boilers (CFB Boilers) [3].

**4-2 Location of Garri4:**

Garri4 located at the east from garri2 near phase II of Khartoum Refinery which produces sponge coke. This location has the following advantages:

1. It is near Khartoum refinery to supply sponge cock.
2. It is near garri2 to connect garri4 substations with garri2 and national grid, also supply garri4 with LDO and water from garri2 [3].

**4-3 Layout of Garri4 Power Station:**

- Two CFB boilers
- Main power building which contain two steam turbines with generators and auxiliary equipments.
- Substation
- Clarified water tank
- Composite pump house.
- Demineralization plant.
- Waste water treatment plant.
- Cooling towers.
- Circulating water pumps house.
- LDO storage tank and pump house.
- Sponge coke shed.
- Convey system.
- Auxiliary boiler and emergency generator house.
- Administration building.
- Workshop.

### 4.3.1CycloneFulatizationBed Boiler:

The function of CFB boiler is to generate superheated steam with proper pressure, temperature and flow rate to operate steam turbine and generate electric power [3].

The boiler has two fans which supply air for combustion to six burners to make initial combustion and help the coke to be burned when it is feed to the boiler. Combusted gases with heat energy heat the boiler feed water and generate steam and send it to the turbine. Exhaust gases filtered from ash before it flows to the atmosphere through stack [3].

**The diagram for water &steam:**

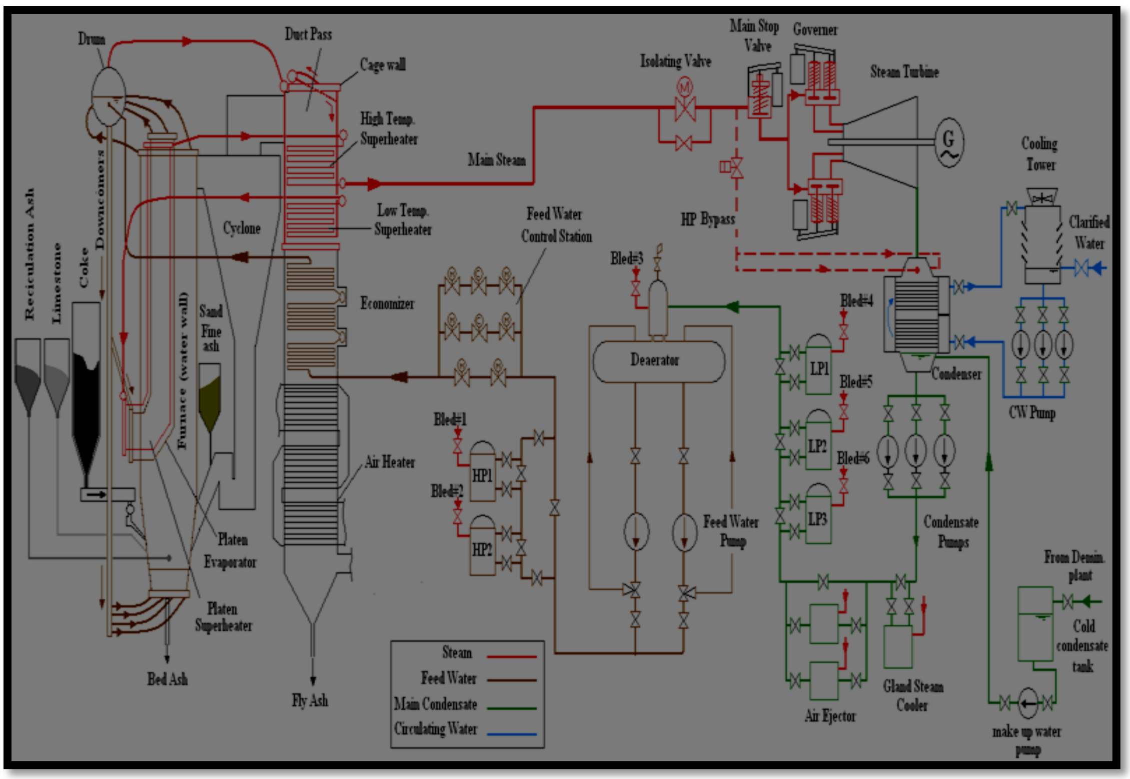



**Fig (4.1): water &steam cycle**

### 4.3.2Sponge coke feeding system:

Four material feeding devices are fitted at the lower part of furnace's front wall along width.

After the fuel enters into conveying belt, it drops down to material Returning devices by gravitation. Three material distributing airs fitted at theLower part of material feeding device blow the fuel into furnace to combust.

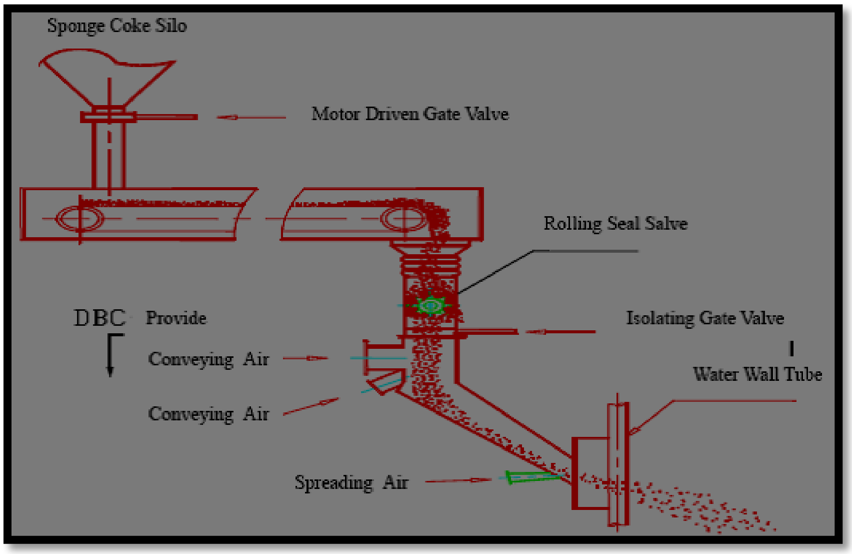



**Fig (4.2): Coke Feeder**

## 4.4 Steam Turbine and its systems:

The steam turbine takes the steam as the working medium; it is the prime mover transforming heating energy of the steam into mechanical energy, it has advantages such as big power, high rotating speed, and higher efficiency, stable operation and long useful time [3].

## 4.5 Brief working principle of impulse steam turbine:

In turbine, the steam according with requirements expands and accelerates in nozzle (static blade), steam pressure drops, speed increases, which transforms the heat energy of steam into kinetic energy; when high-speed steam flow at nozzle (static blade) outlet flows through moving blade, because of the change of steam flow direction, it generates the impulse force to moving blade, and drives rotor to rotate and do work, transforming the kinetic energy of steam into the mechanical energy of rotating shaft [3].

**4.6 Main technical parameter of turbine unit:**

Type: N55—8.83/535

Unit type: High temperature, HP, no re-heating, impulse condensing type steam turbine

Unit operating type: Unit system operation

Rotating direction: clockwise direction seen from turbine head to generator [3].

**Manufacturer Shanghai steam turbine factory Data Below in the table:**

**Table (4.1) Manufacturer Shanghai steam turbine factory Data**

| | |
|---|---|
| Rated power | 55MW |
| Maximum power | 62MW |
| Rated pressure of main steam | 8.83± 0.49MPa (a) |
| Rated temperature of main steam | 535 ºC 510+− |
| Exhaust steam pressure: | 11.80 kPa |
| Rated main steam flow | 219.5t/h |
| Maximum main steam flow | 252T/H |
| Rotating speed | 3000r/min |
| Cooling water temperature | 33ºC （ max.38 ºC ） |
| Feed water temperature | 234 ºC |
| Heat consumption | 9823.8kJ/kWh |
| Steam consumption | 3.987 Kg/KWh |
| Rated steam flow | 219.5 t/h |
| Rated steam flow | 219.5 t/h |
| Flow path stages | 19 stages in total |
| One governing stage adds | 18 pressure stages |
| HP heaters and LP heaters | 2,3 |

**4.7 Turbine structure:**

Steam turbine components can be classified in to three groups:

1/Static parts: including casing, nozzle, static blade, diaphragm, blade carrier, steam seal, bearing, etc;

a- Casing
b- Bearing
c- Turbine gland
d- Nozzle area, diaphragm and blade carrier
e- LP casing spray
f- Turning gear
g- Main stop valve
h- Governing valve

2/ Rotating parts: including moving blade and rotor (impeller, main shaft), coupling, etc;

3/ Auxiliary equipments: including main stop valve, control valve, governing system, main oil pump, auxiliary oil pump and lubricant devices, etc.

**4.8 Steam Turbine Systems:**

**1 .Main Steam and High Pressure Bypass System**

The main steam system of this unit is unit system. The main steam came from the boiler enters into main check valve (with strainer) through electric isolation valve, and it comes out from the steam guiding pipe at the back of the main check valve, and enters into four governing valves through steam guiding pipe, and then enters into nozzle group of the front casing, after its expansion and doing work in the turbine, the steam is discharged into condenser and it becomes condensate water [3].

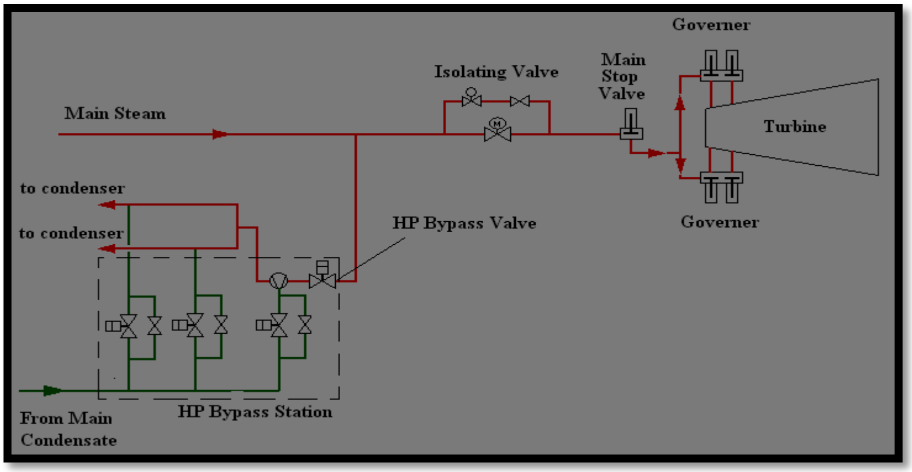



**Fig. (4.3) Main Steam and High Pressure Bypass System**

## 2. Main Condensate Systems:

* Flow process: Condenser→ Condensate Extraction Pumps→ Gland Steam Cooler →Air→Ejector→Lp→ LP Heater3 → LP Heater2 → LP Heater1 →Deaerator.

Condensate water enters into deaerator after lifting pressure by condensate water pump and then through gland seal heater and three stages LP, a part of the condensate water enters into boiler slag cooler through the outlet of the gland seal heater, and then returns to deaerator.

Every condenser has a make-up tank which receives demineralized water from demin. Plant and pump it to the condenser to fill the system during initial start up and make up the system during operation [3].

*** Description of system components:**

### 1/ Condenser:

The function of condenser equipment is to increase the ideal enthalpy of steam in turbine and improve the circulating thermal efficiency of unit. Another function is to condense the exhausted steam from turbine into water and recycle working medium, and then sent into boiler as feed water over again [3].

**Basic Components of Condenser:**

1- Condenser shell
2- Water chamber
3- Tube plate and tube support plate
4- Hot well

**2/ Condensate Extraction Pump:**

The function of condensate pump is to extract the condensate in hot well of condenser uninterruptedly.

**3/ Gland Steam Cooler:**

The function of gland steam cooler is to absorb heat from gland steam and heat up the main condensate to improve the thermal efficiency of the cycle.

**Gland steam cooler structure:**

- One set of gland steam cooler with 100% capacity pipe types is supplied and the pipes adopt stainless steel. This will ensure the gland seal system not leak steam to outside.
- Two motor-driven exhaust fans with 100% capacity are supplied to discharge [3].

**4/ Air Ejector:**

After Auxiliary steam uses in ejectors to make a vacuum in the condenser, it has a heat energy which could be used to heat the main condensate and improve the thermal efficiency of the cycle. After that, condensate steam flows to the condenser.

**5/ Low Pressure Heaters:**

LP heater (LP heater) is vertical channel type, 4 pipes, U-shaped surface heat exchanger; it is mainly made up of water chamber, tube bank and shell body and connected by flanges and bolts. Water chamber take welded-steel structure, feed-water inflow/outflow port and air vent port are installed in water chamber, which is divided to three parts and formed feed-water path. Tube bank is the core part of heater, U-shaped pipe and pipe disk are curling connected, and supported by several support disks in case that hot steam goes into tube bank to make pipe vibrate. Pipe disk and shell body flange are connected by bolts; when water chamber is open, tube bank and shell body will not separate. LP heater could bear high vacuum extraction steam and changes of reactance force and thermal stress of connecting pipes [3].

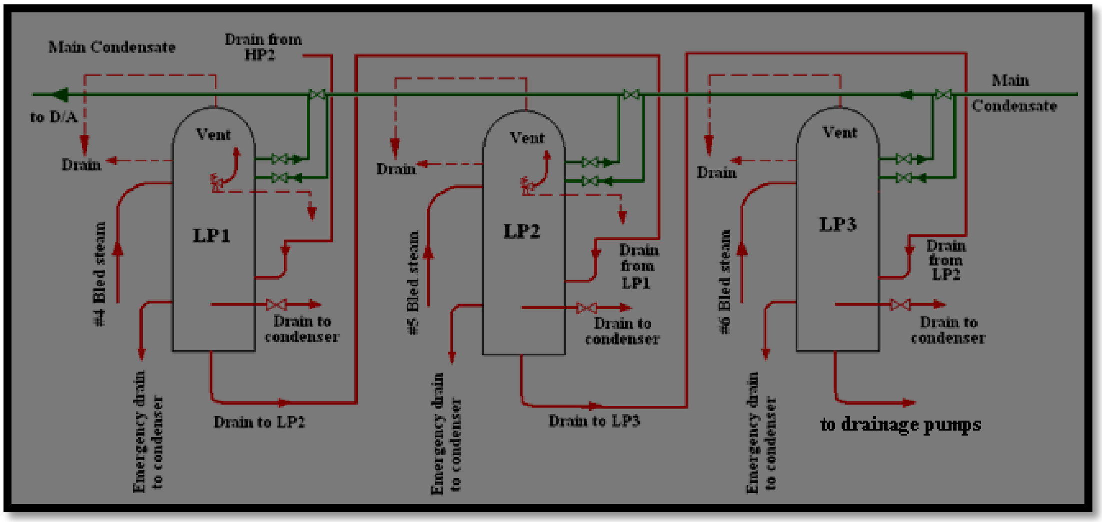



**Fig. (4.4): Low pressure heaters**

**6/ Deaerator:**

The main function of spiral membrane deaerator is to decrease the oxygen content of boiler feed water to meet the standard requirements to ensure that boiler, steam turbine unit and metal parts of system do not have excessive oxidation corrosion under high temperature condition. Thermal deaerator is the commonly used deoxidization equipment of boiler at present.

Be side deoxidization, the deaerator is an open type heater to heat up the main condensate. Also, deaerator is the highest vessel in the cycle to make enough positive suction head to feed water pumps. Deaerator also is a water storage tank which supply water under different loads [3].

**There are many advantages** to deaerating water prior to boiler input, but they all boil down to reduced cost operations.

Water is heated

- deaeration nozzles and warm up nozzles.

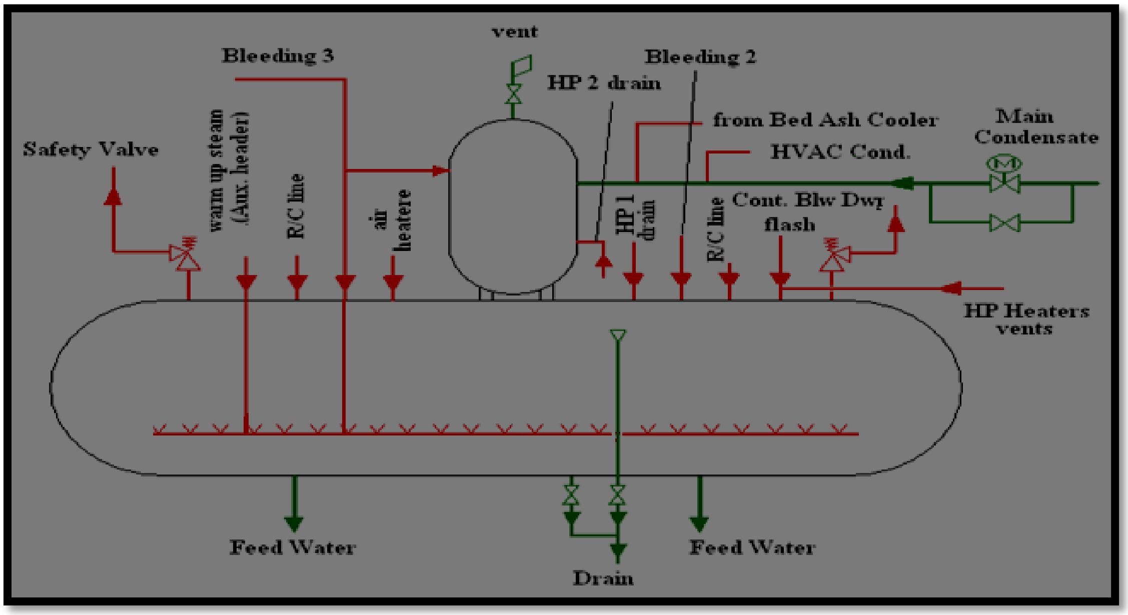



**Fig. (4.5): Deaerator**

## 3. Feed Water System:

*** Flow process:Deaerator → Feed Water Pump→ HP Heater 2→ HP Heater 1→ Feed water control station →boiler .**

After the heating and deaeration of the condensate water in the deaerator, it is sent to boiler through HP heaters by feed water pump, under the failure condition, the bypass electric valve near the HP heater can send the water into the boiler directly [3].

* **Description of system components:**

### 1/ Feed Water Pump:

Feed water pump receive water from deaerator and pressure it to steam drum with sufficient pressure and flow through high pressure heaters and control station.

This pump is a multi-stage horizontal type radial split centrifugal pump driven by variable speed electric motor. It contains five impellers, pump case, shaft, stage casing, two mechanical seals, two bearings, suction pipe, discharge pipe, recirculation line, coupling, base plate and other components.

**2/ High and low Pressure Heaters:**

Work principle of heaters: feed water goes into water chamber through water intake pipe, firstly flows through drainage cold section, and then flows through steam condensing section and superheated steam section, and finally flows through water chamber and goes out from water outlet pipes. Heating steam goes into heater from right-lower part, firstly across superheated steam section, and then across water condensing section and drainage section, and finally be leaded out from water outlet pipes from left-lower part. In addition, drainage water of superior stage flows through upper guide apparatus and goes into heater, drainage water guide apparatus is divided into two fluids: expanding steam and drainage water, among them, expanding steam directly goes into steam condensing section, but drainage water cross guide slot from top to down and flow to drainage water cold section [3].

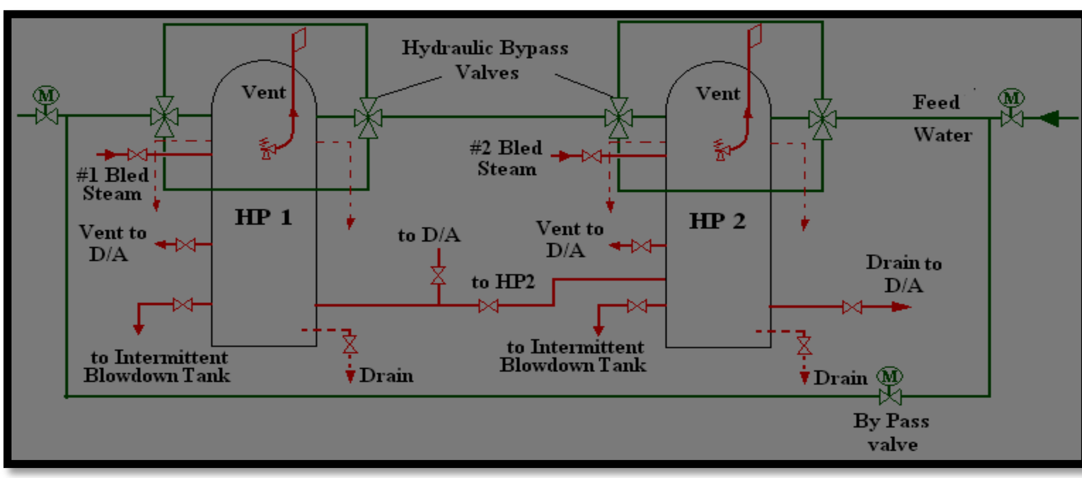



**Fig. (4.6): High pressure heaters**

**3. Bleeding Steam System:**

The function of this system is to supply steam with different pressures and temperatures to low pressure and high pressure heaters, deaerator and auxiliary equipments in the plant.

- First stage extraction is extracted from the back of 3# diaphragm, and connects with 1# HP heater.
- Second stage extraction is extracted from the back of 5# diaphragm, and connects with 2# HP heater.
- Third stage extraction is extracted from the back of 9# diaphragm and is divided into two parts, and one part is connected with deaerator the other part is connected with non-governing auxiliary extraction.
- Forth stage extraction is extracted from the back of 11# diaphragm, and connect with 1# LP heater.
- Fifth stage extraction is extracted from the back of 14# diaphragm, and connects with 2# LP heater.
- Sixth stage extraction is extracted from the back of 16# diaphragm, and connects with 3# LP heater.

**4. Gland Steam Systems:**

This system supply steam to gland seal to prevent steam from leaking from turbine high pressure side and prevent air from entering to turbine from vacuum side.

Steam from Auxiliary header flows through electric valve to chamber 2 of the two gland seals of the turbine. After doing the sealing, gland steam flows to gland steam cooler and cooled down by main condensate water and back to the condenser.

uringdeaeration to near the temperature of the boiler water, thus minimizing the risk of thermal shock damage to a high value boiler system.

The deaerating process removes noncondensible gases (oxygen and carbon-dioxide) which tend to act as insulators inhibiting the transfer of heat within the boiler.

Removal of corrosive oxygen and carbon-dioxide controls corrosion within the boiler and piping, extending the life expectancy of the system and reducing maintenance cost.

Higher temperature feedwater reduces the drop in boiler operating pressure which can occur when cold water is added.

Recycling of steam from vents and flash steam from traps that would otherwise be vented to the atmosphere can result in appreciable energy savings.

Mechanical deaeration by feedwaterdeaerators can cut the amount of chemical consumables used for water conditioning for a continuing operating cost saving [3].

**Deaerator Components**

- Deaeration Tower.
- Water Tank.
- Safety valves and vent valve.

## 4-9How to Monitor Feed water Heater Performance to Ensure Optimum Heat Rate:

Many power plant operators have begun replacing outdated level instrumentation with newer technologies to accurately control feedwater heater levels and decrease their plant's heat rate. However, assurance of proper performance can only be determined with a feedback reporting system in place.

There are three primary parameters that you can use to monitor individual heater performance. The following definitions and diagram highlight these parameters [3].

- **Feedwater Temperature Rise** is the difference between the feedwater outlet temperature and the feedwater inlet temperature. A properly performing heater should meet the manufacturer's design specifications, provided the level controls are up to the task.

- **Terminal Temperature Difference (TTD)** provides feedback on the feedwater heater's performance relative to heat transfer. TTD is defined as the saturation temperature of the extraction steam minus the feedwater outlet temperature. An increase in TTD indicates a reduction in heat transfer, while a decrease indicates an improvement. Typical ranges for TTD on a high-pressure heater with and without a desuperheating zone are -3° F to -5° F and 0° F, respectively. The TTD for low-pressure heaters is typically around 5° F. Steam tables and an accurate pressure reading are required to complete this calculation.

- **Drain Cooler Approach (DCA)** is a method used to adjust feedwater heater levels based on the temperature difference between the drain cooler outlet and the feedwater inlet. A typical value for DCA is 10° F. An increasing DCA temperature difference indicates the level is decreasing and a decreasing DCA temperature indicates a rise in level.

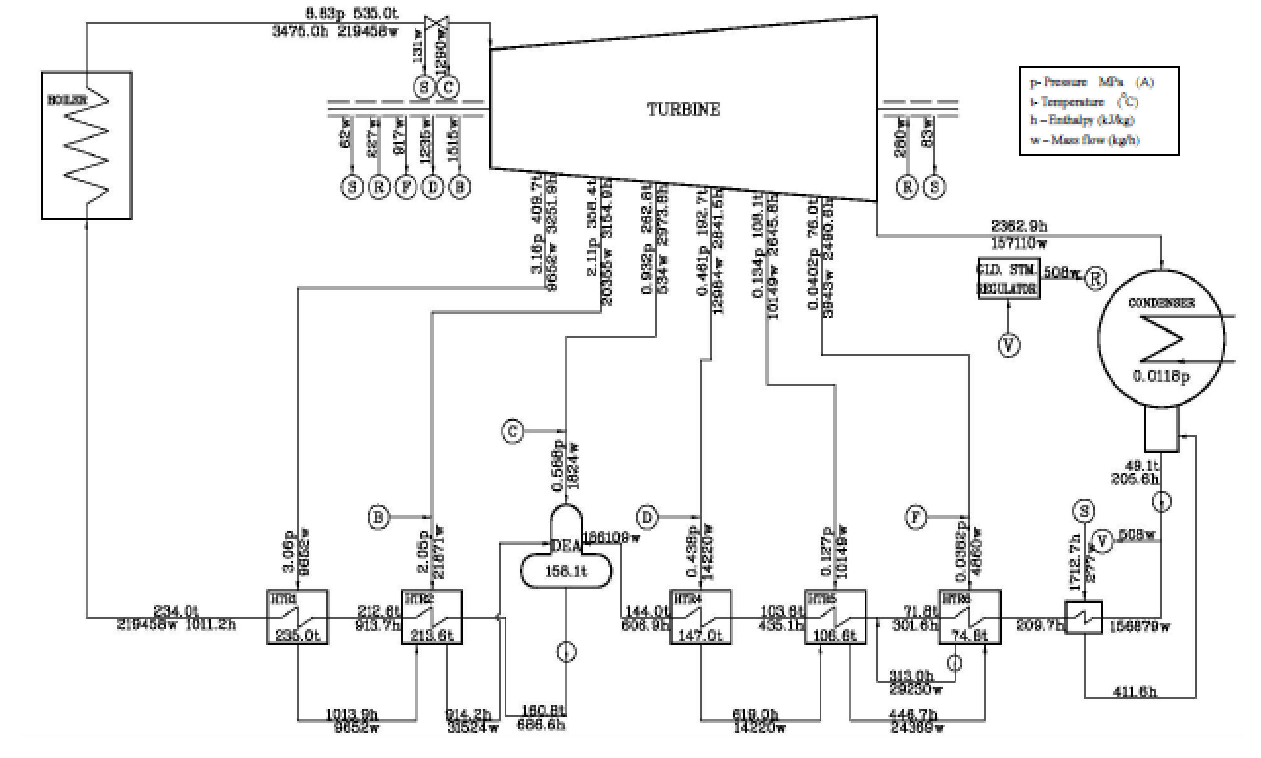
**4-10Calculation:**

## First:

(For load 55 MW):

HPH 1#:

From chapter three equation number [1]




Block diagram 5. Heat and Mass Balance of the Steam Turbine at the performance guarantee condition (55MW)

**Fig(4.7)**

From fig(4.7) :

Qsw = 21397155 Kj/h.

From chapter three equation number [3]

$$= \frac{219458 \times 3475 - 219458 \times 1011.2}{55 \times 10^3} = 9830.9 Kj/Kwh$$

Total heat rate of design = 9830.9 Kj /Kwh

From chapter three equation number [2]

Total HPH 1# =

9830.9 – (-389.0391) =

10219.9391Kj/Kwh

Effecicncywith out HPH 1# =

Efficincy with HPH 1# =

Effect of HPH 1# =

36.6 – 35.22= 1.4 %

## Second:

HPH 2#:

From chapter three equation number [1]

219458 * 686.6 + Qsw = 219458 * 913.7

Qsw = 49838911.8 Kj/h

Heat rate = $\frac{Qs}{55 \times 10^3}$= 906.16 Kj / Kwh

From chapter three equation number [2]

9683.23 + 906.16 = 10589.39903 Kj/Kwh

Efficincywithout  HPH 2# =3600 / 1058.39903 =0.339 OR 33.9%

Efficincy with HPH 2 = 3600 / 9683.237 =37.1%

Effect of HPH 2# =37.1 – 33.9 = 3.2%

The total of effect of two HPH in the efficincy is =Effect of HPH1 + Effect of HPH2 =3.2 + 1.4 = 4.6 %

So:

Total efficincy with all heaters = 37.1 %

Total efficincywith out heaters =  35.7 + 33.9 / 2 = 34.2 %.

## Secondcalculation(actual) :

Data used in actualcalculationin table below:

**Table (4.2) Data used in actual calculation**

| Number | Main pressure | Main temperature | The Enthalpy |
|---|---|---|---|
| 1.form main steam | 7.5 MPA | 535C | 3480.5KJ/Kg |
| 2.from HP ( 2# ) | Inlet Temperature | Out let temperature | The Enthalpy kj/kg |
| Data | 160c | 185c | 670 (inlet)<br>763(out let)<br>From steam Table. |
| 3.from HP ( 1# ) | 185c | 218c | 931(out let) |

Main flow of steam = Main flow of water = 230*$10^3$ kg/hour

(For load 55 MW):

HPH 2# :

From table (4.8) :

Qsw = 3864×$10^4$Kj/h

Heat rate =Qsw / Wout =

From chapter three equation number [3]

$$= \frac{230 \times 10^3 \times 3480.5 - 230 \times 10^3 \times 931}{55 \times 10^3}$$

Total heat rate of actual = 10661.545 Kj /Kwh

Total HPH 1# =

From chapter three equation number [2]

10661.545 – (-702.245) =11363.7904 Kj/Kwh

Efficiencywithout HPH 1# =

$$\frac{3600}{11363.7904}$$

= 0.316 OR 31.6%

Efficincy with HPH 1# =

$$=\frac{3600}{10661.545}$$

0.337 OR 33.7%

Effect of HPH 1# =

33.7 – 31.6 = 2.1 %

## Second:

HPH 1# :

From chapter three equation number [1]

$230\times10^3\times 670 + Qsw = 230\times10^3\times 763$

$Qsw = 2139\times10^4 Kj/h$

Heat rate $=\frac{Qs}{55\times10^3} = 388.90$ Kj / Kwh

From chapter three equation number [2]Type equation here.

1066.545 + 388.909 = 11050.545 Kj/Kwh

Efficincywithout HPH 2# =

$\frac{3600}{11050.454} =$

0.325 OR 32.5%

Efficincy with HPH 2 =

$\frac{3600}{1066.545} =$

33.7%

Effect of HPH 2# =

33.7 – 32.5 = 1.2

The total of effect of two HPH in the efficincy is =

Effect of HPH1 + Effect of HPH2 =

1.2 + 2.1 = 3.3 %

So:

Total efficiency with all heaters = 33.7 %

Total efficiencywith out HP heaters = $\frac{31.6 + 32.5}{2}$= 32.05%.

## 4−11 Third the programs of MATLAB :

input data:

```
clc
clear
%Conclusion
%The law used for conclusion :
%Wfwin * Hfwin + Qsw = Wfwo * Hfwo
%As :
%W ?the flow rate , kg/h.
%H ?the Enthalpy for steam kj/kg .
%Q ?heat add kj/kwh .
%HPH 1#
Wfwin= 219458
Hfwin= 913.7
Wfwo = 219458
Hfwo = 1011.2
Qsw=(Wfwo  * Hfwo  )-(Wfwin  * Hfwin )
Wout = 55e+03
Heatrate = Qsw / Wout
```

```
Hs = 3475
heatrateofdesign = ((Wfwo* Hs)-( Wfwo *
Hfwo ) )/ Wout
TotalHPH1  =heatrateofdesign - (Heatrate)
EffecicncywithoutHPH1  =3600 /  TotalHPH1
EfficincywithHPH1  =3600 / heatrateofdesign
EffectofHPH1 = EfficincywithHPH1-
EffecicncywithoutHPH1
%Second :
%HPH 2# :
Wfwin2= 219458
Hfwin2=  686.6
Wfwo2= 219458
Hfwo2= 913.7
 Qsw2 =(Wfwo  * Hfwo  )-(Wfwin  * Hfwin )
Wout = 55e+03
 Heatrate2 = Qsw2 / Wout
  Hs2 = 3475
  heatrateofdesign2 = ((Wfwo2* Hs2)-( Wfwo2
* Hfwo2 ) )/ Wout
TotalHPH2  = heatrateofdesign2 -
(Heatrate2)
EffecicncywithoutHPH2  =3600 /  TotalHPH2
EfficincywithHPH2  =3600 /
heatrateofdesign2
EffectofHPH2 = EfficincywithHPH2-
EffecicncywithoutHPH2
ThetotalofeffectoftwoHPHintheefficincyis
=EffectofHPH1 + EffectofHPH2
%Second  Conclusion  ( accual )
%HPH 1#
```

```
Wfwin= 230e+03
Hfwin= 763
Wfwo = 230e+03
Hfwo = 931
Qsw=(Wfwo  * Hfwo  )-(Wfwin  * Hfwin )
Wout = 55e+03
Heatrate = Qsw / Wout
Hs = 3480.5
heatrateofdesign = ((Wfwo* Hs)-( Wfwo *
Hfwo ) )/ Wout
TotalHPH1  =heatrateofdesign - (Heatrate)
EfficincywithHPH1  =3600 /  TotalHPH1
EffectofHPH1 = EfficincywithHPH1-
EffecicncywithoutHPH1
%Second :
%HPH 2# :
Wfwin2= 230e+03
Hfwin2=   670
Wfwo2= 230e+03
Hfwo2=  763
 Qsw2 =(Wfwo  * Hfwo  )-(Wfwin  * Hfwin )
Wout = 55e+03
 Heatrate2 = Qsw2 / Wout
  Hs2 = 3475
  heatrateofdesign2 = ((Wfwo2* Hs2)-( Wfwo2
* Hfwo2 ) )/ Wout
TotalHPH2  = heatrateofdesign2 -
(Heatrate2)
EfficincywithHPH2   =3600 /  TotalHPH2
EffecicncywithoutHPH2 =3600 /
heatrateofdesign2
```

```
EffectofHPH2 = EfficincywithHPH2-
EffecicncywithoutHPH2
ThetotalofeffectoftwoHPHintheefficincyis
=EffectofHPH1 + EffectofHPH2
Totalefficincywithoutheaters = 3600 /
heatrateofdesign2
Totalefficincywithallheaters=
((EffecicncywithoutHPH2+EffecicncywithoutHP
H1)/2).
```

## Output data:

Wfwin = 219458

Hfwin= 913.7000

Wfwo= 219458

Hfwo = 1.0112e+03

Qsw = 21397155

Wout = 55000

Heatrate= 389.0392

Hs = 3475

heatrateofdesign = 9.8309e+03

TotalHPH1 = 9.4419e+03

EffecicncywithHPH1 = 0.3713

EfficincywithoutHPH1 = 0.3562

EffectofHPH1 = 1.51

Wfwin2 = 219458

Hfwin2 = 686.6000

Wfwo2 = 219458

Hfwo2 = 913.7000

Qsw2 = 21397155

Wout= 55000

Heatrate2 = 389.0392

Hs2 = 3475

heatrateofdesign2 = 1.0220e+04

TotalHPH2 = 9.8309e+03

EffecicncywithoutHPH2 = 0.3662

EfficincywithHPH2 = 0.3523

EffectofHPH2 = 1.39

ThetotalofeffectoftwoHPHinthe efficiency is = 2.90

Wfwin= 230000

Hfwin = 763

Wfwo = 230000

Hfwo = 931

Qsw= 38640000

Wout= 55000

Heatrate= 702.5455

Hs = 3.4805e+03

heatrateofdesign = 1.0662e+04

TotalHPH1 = 9959

EfficincywithHPH1 = 0.3615

EffectofHPH1 = 1.98

Wfwin2 = 230000

Hfwin2 = 670

Wfwo2 = 230000

Hfwo2 = 763

Qsw2 = 38640000

Wout = 55000

Heatrate2 = 702.5455

Hs2 = 3475

heatrateofdesign2 = 1.1341e+04

TotalHPH2 = 1.0639e+04

EfficincywithHPH2 = 0.3384

EffecicncywithoutHPH2 = 0.3174

EffectofHPH2 = 2.10

ThetotalofeffectoftwoHPHinthe efficiency is = 1.2

Total efficiency withoutheaters = 0.3174

Total efficiency withallheaters = 0.3494

**Flow charts:**

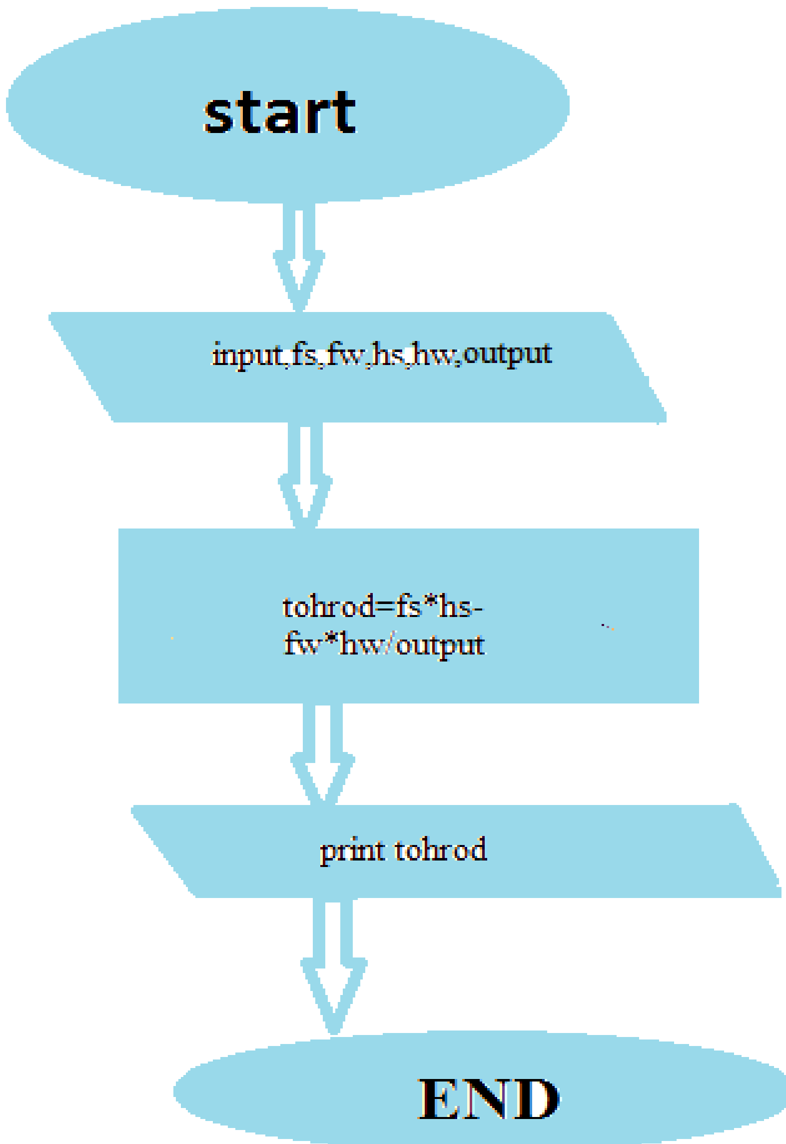



Fig (4.8) Total of heat rate of design .

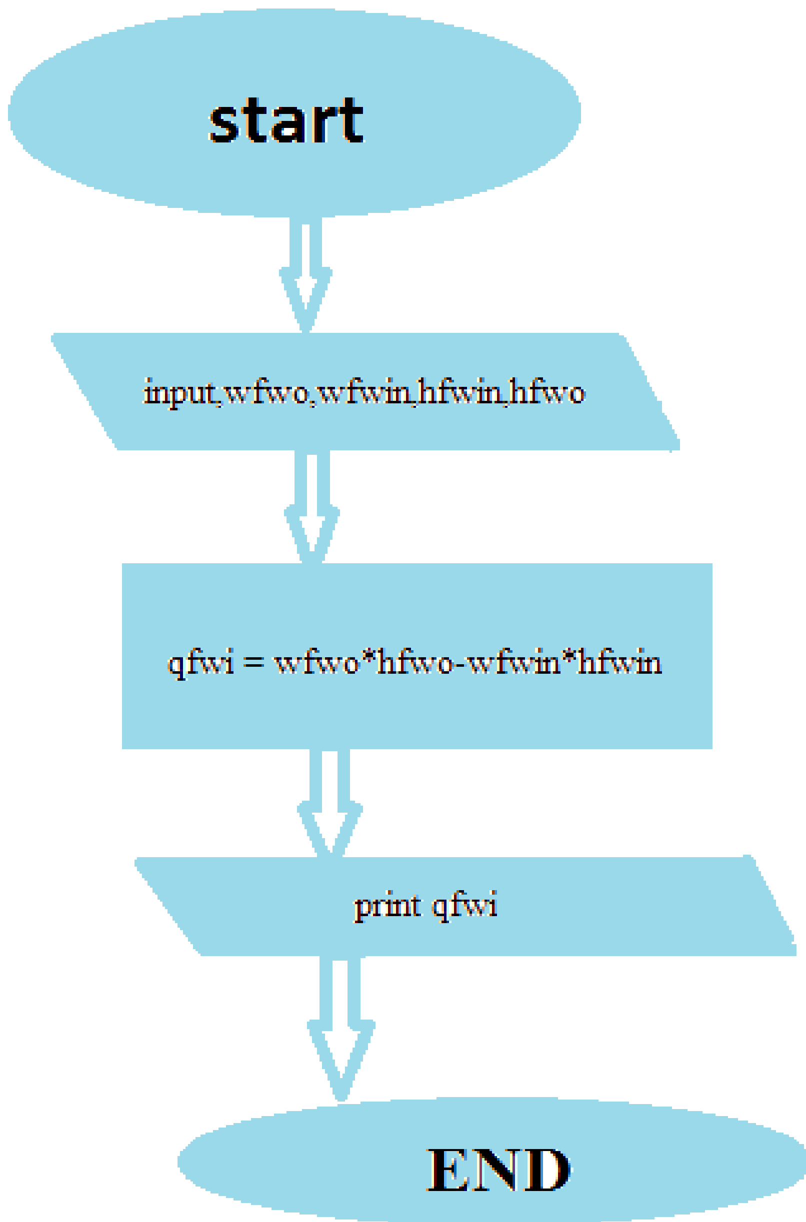



Fig (4.9) quantity of heat addition from feed water

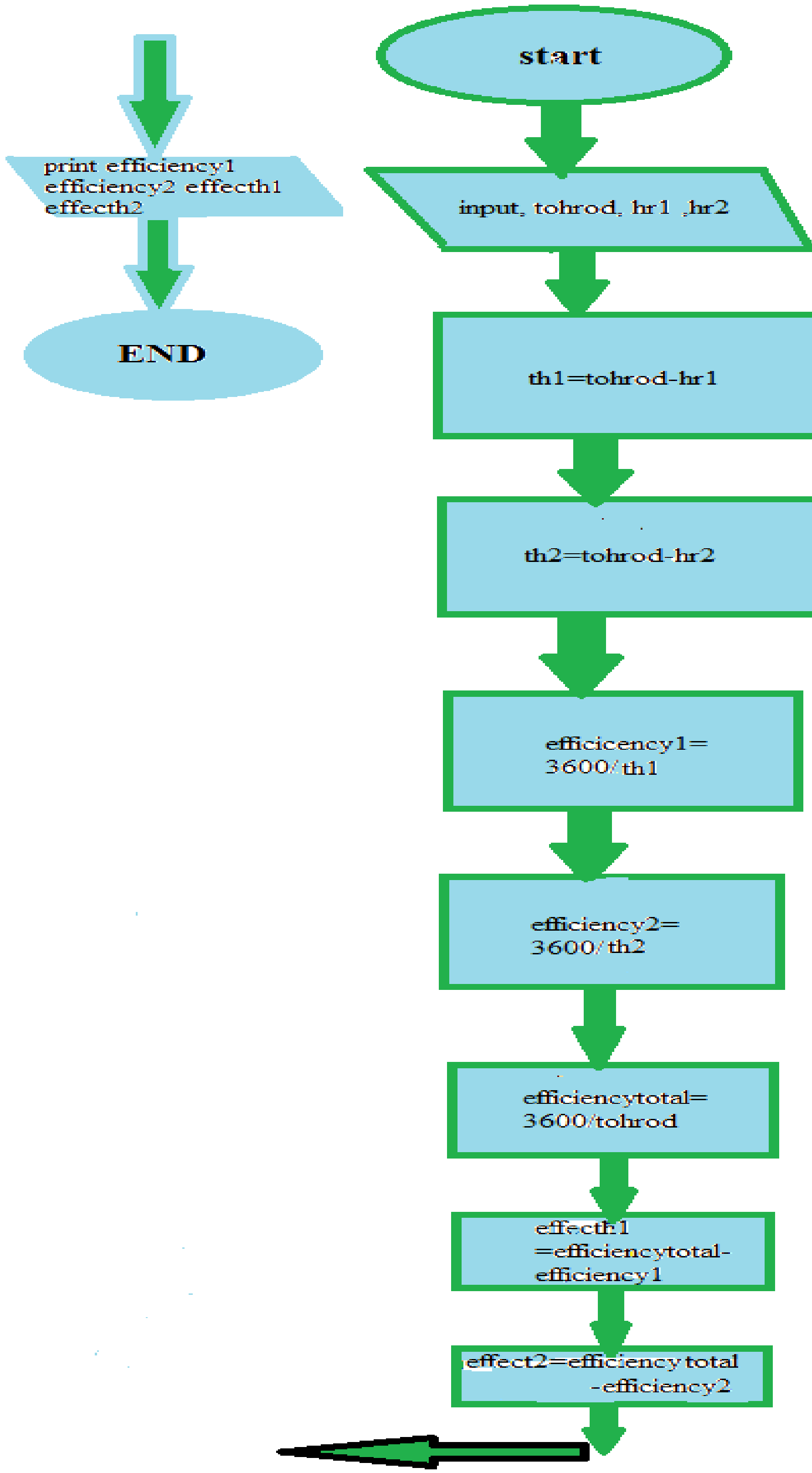



Fig (4.10) effect of high pressure heaters.

# CHAPTER V

# Results and Discussion

## 5.1 Results:

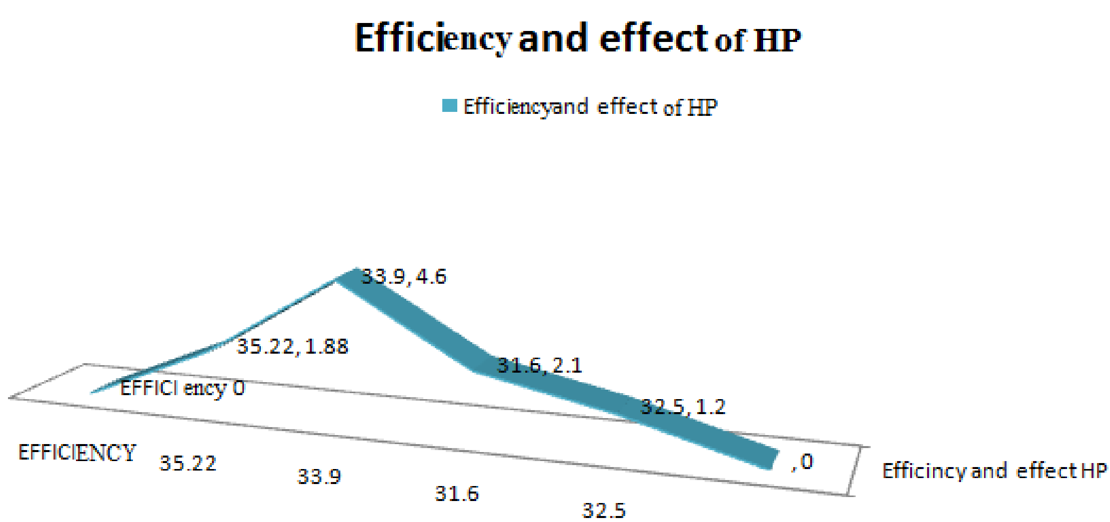
Through the results they created to calculate the effect of high pressure heat exchangers we found that the efficiency of the second heat exchanger is greater in efficiency because it is closer to the place of attrition and the exchangers together have a good efficiency in increasing efficiency and also in the final part of the

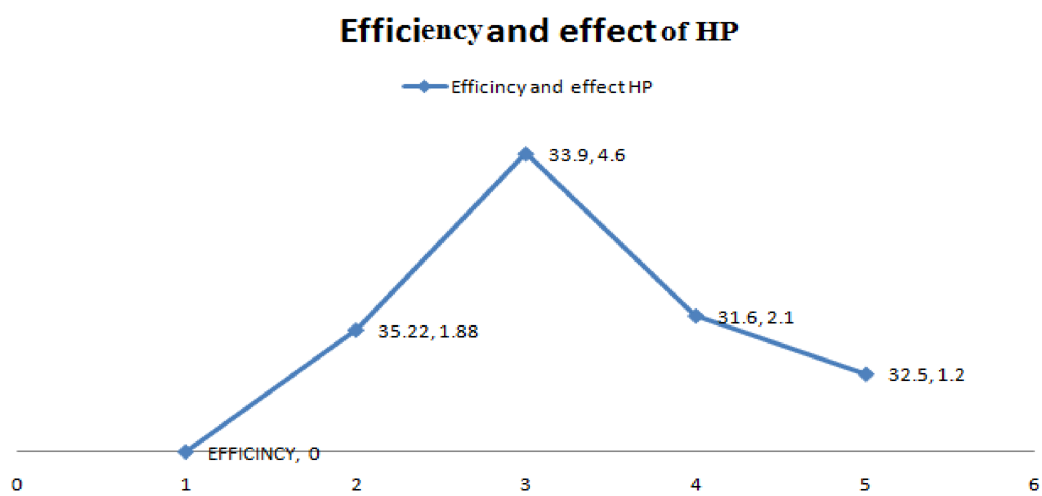
Turbine changes, and the electricity production in that part becomes smaller the regenerative bleeds are not regulated, and therefore, the flow rate of the regenerative steam is determined by the conditions of heat transfer in the regenerative heaters, mainly by the steam temperature (depending on pressure).

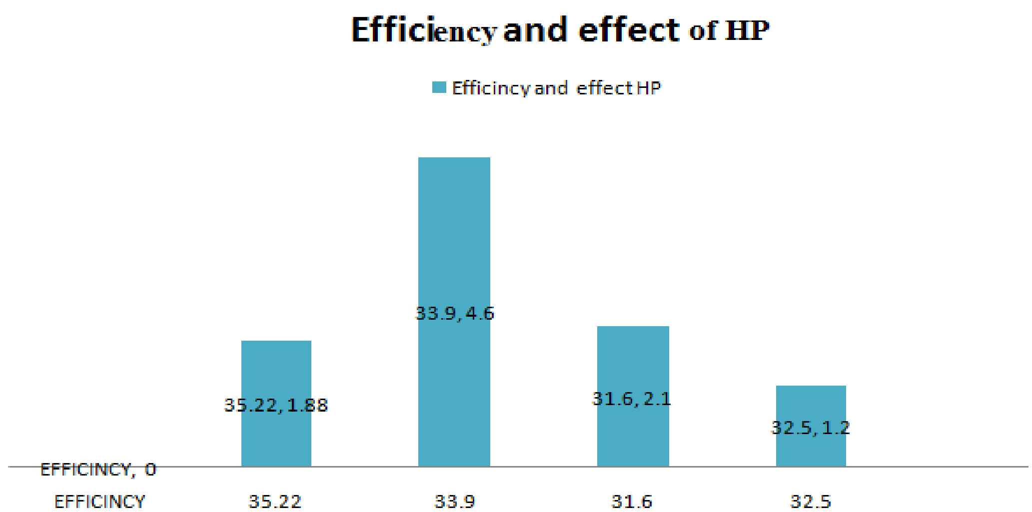
1. The heat demand inside the boiler increases after switching on the regenerative bleed. That increase equals the increase of the internal power of the turbine if the condensate of the bleed steam does not flow to the main condenser.
2. The increase of the demand for chemical energy in the boiler Caused by switching on the regenerative bleed.
3. The temperature of the bled steam in fwh plays a key role on performance of the cycle. It is expressed in an excess temperature ratio as.
4. The condensation power plant can operate at a stabilized load and then the calculation is not difficult.

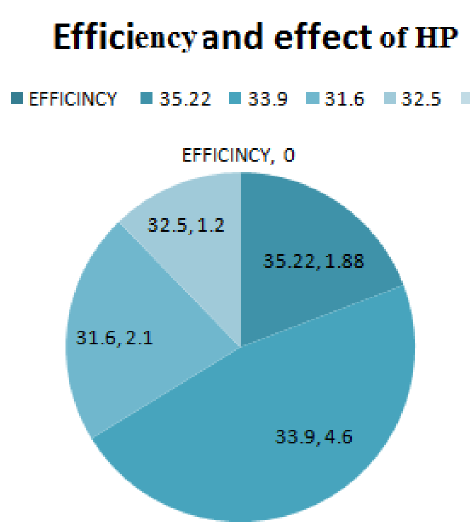
Table (5.1) Theresults

| NO | Heaters | Total efficiency% | Efficiency % | Effect |
|---|---|---|---|---|
| Design | | | | |
| 1 | HPH2 | 36.6 | 33.9 | 2.7 |
| 2 | HPH1 | 36.6 | 35.22 | 1.4 |
| Actual | | | | |
| 1 | HPH2 | 33.7 | 31.6 | 2.1 |
| 2 | HPH1 | 33.7 | 32.5 | 1.2 |




Efficiency and effect of HP
Efficincy and effect HP
33.9, 4.6
35.22, 1.88
31.6, 2.1
32.5, 1.2
EFFICINCY, 0
0
1
2
3
4
5
6


Efficiency and effect of HP
Efficincy and effect HP
33.9, 4.6
35.22, 1.88
31.6, 2.1
32.5, 1.2
EFFICINCY, 0
EFFICINCY
35.22
33.9
31.6
32.5


Efficiency and effect of HP
EFFICINCY
35.22
33.9
31.6
32.5
EFFICINCY, 0
32.5, 1.2
35.22, 1.88
31.6, 2.1
33.9, 4.6

## 5.2 Discussion:

1. •There appears an essential difference between the methods of solution of the problem in the case of a condensation power plant and a steam HP plant, the condensation power plant can operate at a stabilized load and then the calculation is not difficult, In a HP plant the load depends on the demand for useful heat. Therefore, not only does the flow rate of the outlet steam change, but also the flow rate of the bleed steam extracted to feed the peak water heater. The changes of the flow rate of steam cause a change of thepressuredistributioninthesteam bleeds. Theregenerativebleedsarenotregulated, andtherefore,theflow rate ofthe regenerative steam isdeterminedbytheconditionsofheat transfer in theregenerative heaters, mainly by the steam temperature (depending on pressure).
2. If the parameters out of range the Optimization approaches ineffective.
3. Some of the input data and functions required for the thermodynamic and, particularly test.
4. We fined from our result calculation from data actual (during operation Garri4 power plant) influence of high pressure heater1 ,and high pressure heater2 in efficiency of plant .and effect each heater .and we find effect heater2 greater than heater1.it represent ( 2.1) , and heater1 (1.2) percent. And efficiency with high pressure heater2 equal (31.6) percent. And with high pressure heater1 equal (32.5) percent. And total efficiency with all heater equal (33.7) percent.

# CHAPTER VI

## Conclusion and Recommendations

### 6.1 Conclusion:

1. The effects are proportional to the amount of additionally produced electricity. It can be increased by reducing the irreversibility of the feed water heaters (increasing their amount and heat transfer area).
2. The analysis of the influence of feed water heaters on investment expenditures of the plant would be more difficult. When analyzing the power plant the accepted assumption of the parameter P permits acceptance of a constant investment cost of the condenser and water cooling system.
3. The increase of the steam boiler capacity and the change of its operating conditions should be taken into account.
4. The introduction of every regenerative feedwater heater requires an increase of the combustion air heater by means of gaseous combustion products, which increases the combustion temperature and the intensity of NOx formation, the means for the reduction of this formation, should be enhanced.
5. The height of the turbine blades in the turbine stages preceding the considered water heater should be taken into account.
6. This effect improves the internal efficiency of the turbine, because the relative interstage gap losses become smaller..
7. when we talk about ‘n’ fwhs work, a complex thermodynamic analysis of a steam power cycle

### 6.2 Recommendations:

1. We recommended the researcher to built highly program computers to minimize the time loss due to steam regenerative cycle calculation. The soft ware will do all the calculation required.
2. We recommended the researcher to First of all, water level control is important from both heater safety and operation efficiency standpoint, especially in the situation when the optimization strategy calls for a low liquid level set point.
3. We recommended the researcher the General guidelines toward the feed water heater train optimization are proposed.
4. Finally, we recommend that anyone who wants to continue using heat exchangers to raise efficiency by calculating the appropriate level of water within the exchanger.

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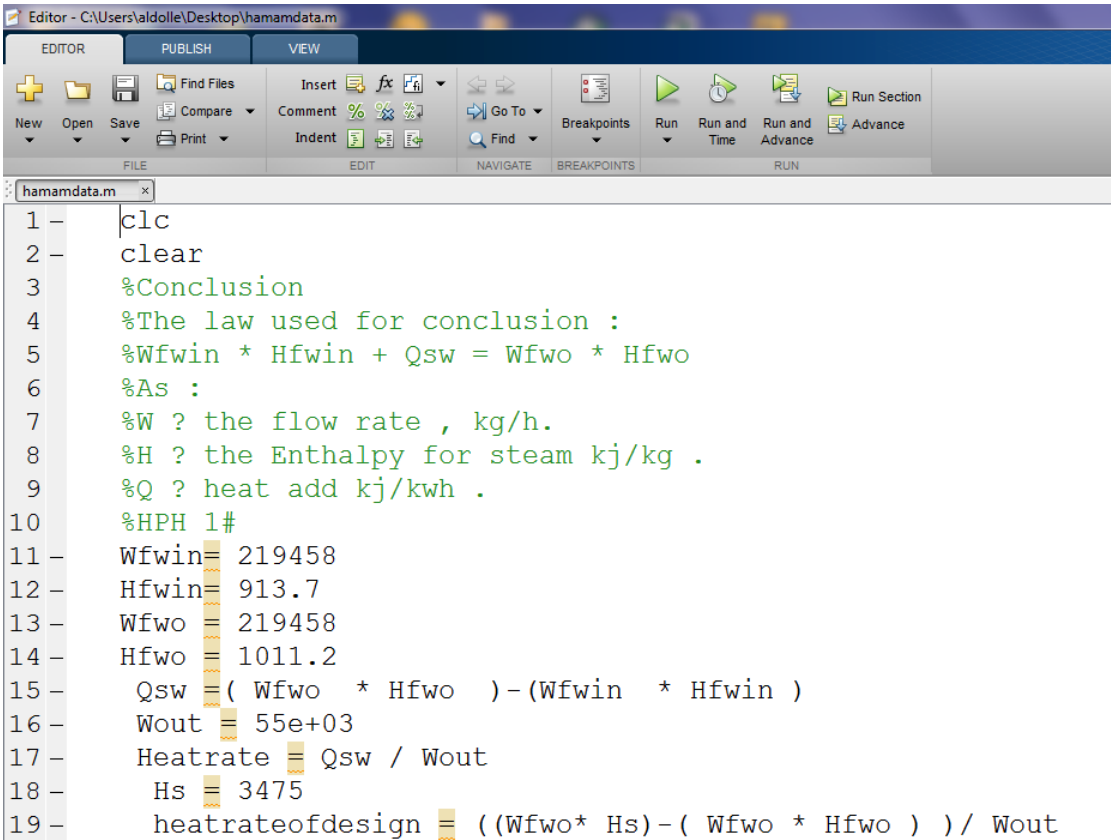
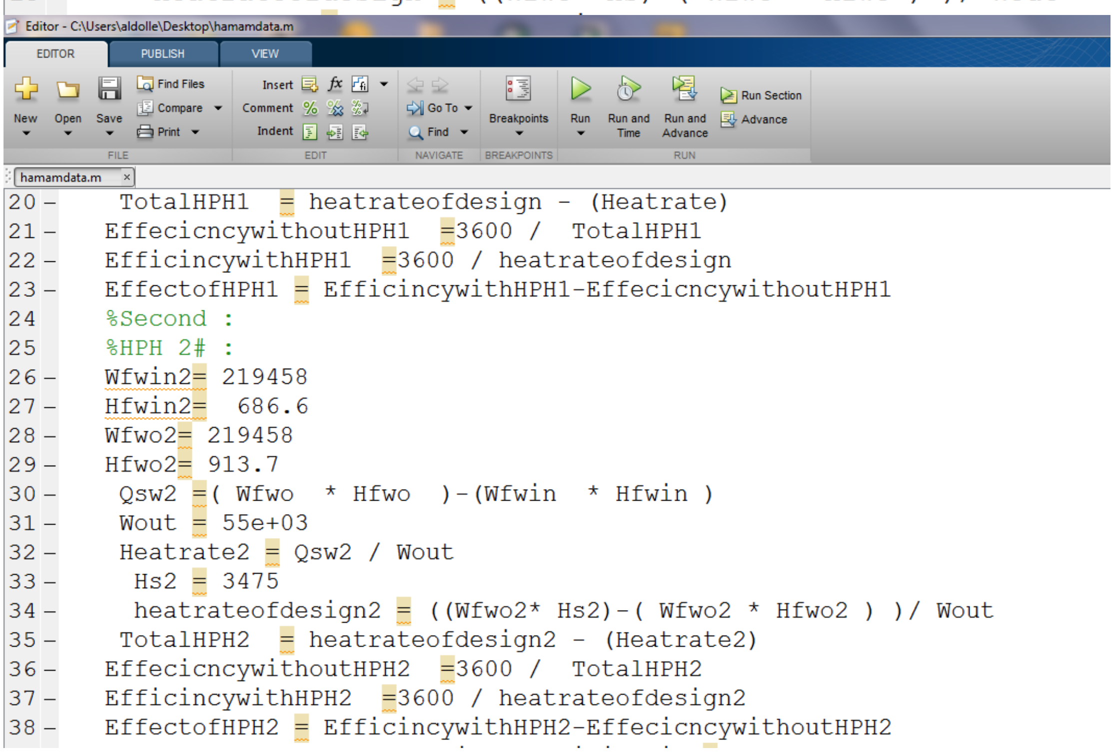
[10] www.pdhengineer.com

# Appendices



```
clc
clear
%Conclusion
%The law used for conclusion :
%Wfwin * Hfwin + Qsw = Wfwo * Hfwo
%As :
%W ? the flow rate , kg/h.
%H ? the Enthalpy for steam kj/kg .
%Q ? heat add kj/kwh .
%HPH 1#
Wfwin= 219458
Hfwin= 913.7
Wfwo = 219458
Hfwo = 1011.2
 Qsw =( Wfwo  * Hfwo  )-(Wfwin  * Hfwin )
 Wout = 55e+03
 Heatrate = Qsw / Wout
  Hs = 3475
  heatrateofdesign = ((Wfwo* Hs)-( Wfwo * Hfwo ) )/ Wout
```



```
 TotalHPH1  = heatrateofdesign - (Heatrate)
EffecicncywithoutHPH1  =3600 /  TotalHPH1
EfficincywithHPH1  =3600 / heatrateofdesign
EffectofHPH1 = EfficincywithHPH1-EffecicncywithoutHPH1
%Second :
%HPH 2# :
Wfwin2= 219458
Hfwin2=  686.6
Wfwo2= 219458
Hfwo2= 913.7
 Qsw2 =( Wfwo  * Hfwo  )-(Wfwin  * Hfwin )
 Wout = 55e+03
 Heatrate2 = Qsw2 / Wout
  Hs2 = 3475
  heatrateofdesign2 = ((Wfwo2* Hs2)-( Wfwo2 * Hfwo2 ) )/ Wout
 TotalHPH2  = heatrateofdesign2 - (Heatrate2)
EffecicncywithoutHPH2  =3600 /  TotalHPH2
EfficincywithHPH2  =3600 / heatrateofdesign2
EffectofHPH2 = EfficincywithHPH2-EffecicncywithoutHPH2
```

```
ThetotalofeffectoftwoHPHintheefficincyis =EffectofHPH1 + EffectofHPH2
%Second  Conclusion  ( accual )
%HPH 1#
Wfwin= 230e+03
Hfwin= 763
Wfwo = 230e+03
Hfwo = 931
 Qsw =( Wfwo  * Hfwo  )-(Wfwin  * Hfwin )
 Wout = 55e+03
 Heatrate = Qsw / Wout
  Hs = 3480.5
  heatrateofdesign = ((Wfwo* Hs)-( Wfwo * Hfwo ) )/ Wout
 TotalHPH1  = heatrateofdesign - (Heatrate)
EffecicncywithoutHPH1  =3600 /  TotalHPH1
EfficincywithHPH1  =3600 / heatrateofdesign
EffectofHPH1 = EfficincywithHPH1-EffecicncywithoutHPH1
%Second :
%HPH 2# :
Wfwin2= 230e+03
```

```
Hfwin2=   670
Wfwo2= 230e+03
Hfwo2=  763
 Qsw2 =( Wfwo  * Hfwo  )-(Wfwin  * Hfwin )
 Wout = 55e+03
 Heatrate2 = Qsw2 / Wout
  Hs2 = 3475
  heatrateofdesign2 = ((Wfwo2* Hs2)-( Wfwo2 * Hfwo2 ) )/ Wout
 TotalHPH2  = heatrateofdesign2 - (Heatrate2)
EffecicncywithoutHPH2  =3600 /  TotalHPH2
EfficincywithHPH2  =3600 / heatrateofdesign2
EffectofHPH2 = EfficincywithHPH2-EffecicncywithoutHPH2
ThetotalofeffectoftwoHPHintheefficincyis =EffectofHPH1 + EffectofHPH2
```

**Turbine unit2**

**Outlet water of high pressure heater**

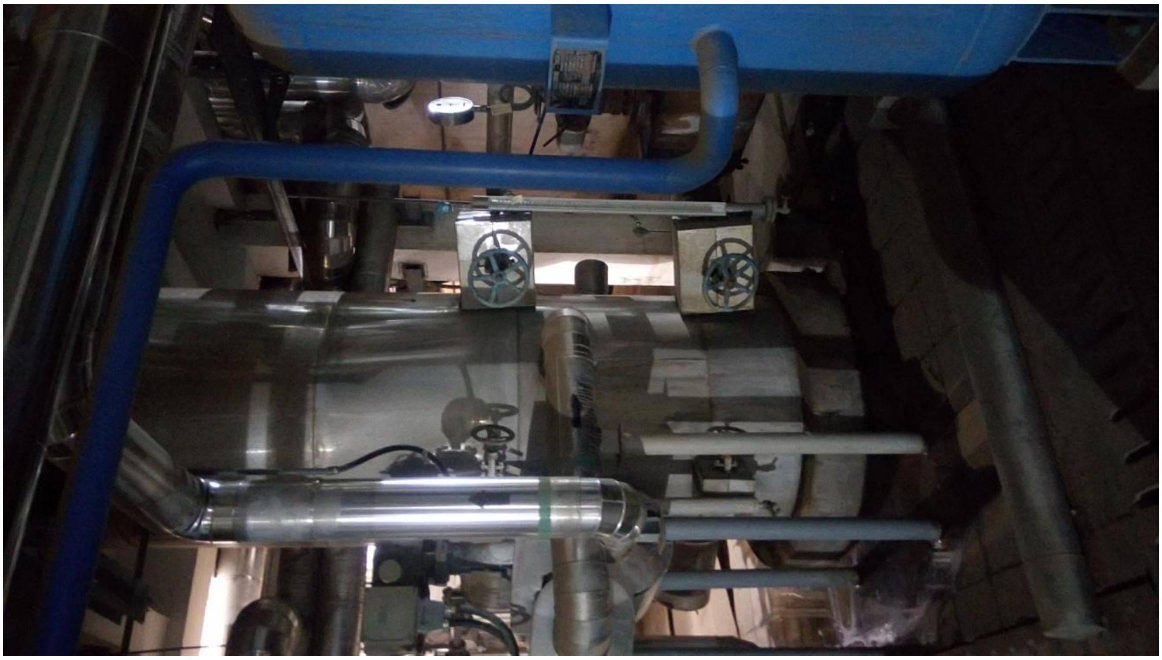
**Extracted**

## High pressures heaters & valve

 v

**safety valve**

**Side water of high pressure heater**



**local level of high pressure heater**

**Control station**