Palestine Polytechnic University

Collage of Engineering & Technology
Mechanical Engineering Department

Bachelor's Thesis

Graduation Project

Educational Model of Power Plant

Project Team

Amer M. Thawabtah **Yassen M. Atbesheh** **Eyad R. Jarayseh**

Project Supervisor

Eng. Zuheir Wazwaz

Hebron-Palestine

May-2015

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According to the orientation of the supervisor on the project and the examined committee is by the agreement of staffers all, sending in this project to the mechanical engineering department are in the college of the engineering and technology by the requirement of the department for the step of the bachelor's degree.

Project Supervisor Signature

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Committee Signature

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Department head Signature ……………………..

Dedication

We dedicate this simple work:

To our parents

To our brothers

To our friends

To our nation

To any person working hard …

Acknowledgment

First and for most we should offer our thanks, obedience and gratitude to Allah.

Our appreciation to:

Our supervisor. Eng. Zuhair Wazwaz

Palestine Polytechnic University

College of Engineering & Technology

Deanship of Graduate Studies & Scientific Research

Mechanical Engineering Department

Anyone who helped us

Abstract

Energy sources such as natural gas or coal can be used to perform work. The work obtained by burning the sources, then the thermal energy resulted from burning gas can be converted to mechanical or electrical energy. These processes governed by thermodynamic cycles. The educational model of power plant by using thermodynamic Rankine cycle.

The gas burned, the water evaporated in the boiler. The steam enters the turbine with high pressure and superheated, then steam rotates the turbine blades to produce work at turbine shaft with no problems. The shaft is connected with DC generator to produce an electrical power. The exhausted steam from the turbine exhaust enters condenser which is fitting with that exhaust. The condensed steam can be reused by feed it to the boiler. Sensors are used in this system for more accuracy measurements.

ملخص

يتوفر العديد من مصادر الطاقه التي يمكن استغلالها في انتاج اشكال اخرى من الطاقه. الغاز الطبيعي يمكن حرقه واستغلال الطاقه الحراريه الناتجه منه لانتاج طاقه تكون على شكل اخر.

يقوم المبدأ الأساسي للنظام على حرق الغاز الطبيعي الذي يمكن استغلال الطاقه الحراريه الناتجه منه في رفع درجة حرارة الماء الموجود داخل البويلر حتى نحصل على بخار. يكون ضغط البخار مرتفع نوعا ما، ينتقل البخار داخل انبوب نحاسي الي التوربين، ثم يقوم ضغط البخار بتحريك شفرات التوربين الذي يكون موصول مع عمود (Shaft). تحول الطاقه الحراريه الي ميكانيكيه على العمود يمكن استغلالها في انتاج طاقه كهربائيه من خلال وصل مولد مع التوربين بشكل مباشر او باستخدام البكرات. ايضا يمكن اعادة استخدام البخار الخارج من التوربين من خلال وصل مخرج البخار مع مكثف، يتم استخدام الماء الناتج من تكثف البخار وضخه داخل البويلر باستخدام مضخه يدويه او كهربائيه.

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CHAPTER ONE

INTRODUCTION

Contents:

1.1 Introduction

The energy resources available in nature such as natural gas, petroleum, and coal can't be used directly for most of the applications. These resources have to be transformed into a useful form such as heat or electricity before their use. For example, natural gas must first be burned or combusted to generate heat which is then used to produce steam for electricity generation. The conversion of heat energy to mechanical or other forms of energy is governed by a series of thermodynamic processes. Thermodynamic cycle is a series of thermodynamic processes that used in power plants.

A station thermal power is a power plant in which the prime mover is steam driven. Water is heated, turns into steam and spins a steam turbine which drives an electrical generator. After it passes through the turbine, the steam is condensed in a condenser and recycled to where it was heated; this is known as a Rankine cycle. The greatest variation in the design of thermal power stations is due to the different fossil fuel resources generally used to heat the water. Some prefer to use the term energy center because such facilities convert forms of heat energy into electrical energy. Certain thermal power plants also are designed to produce heat energy for industrial purposes of district heating, or desalination of water, in addition to generating electrical power. Globally, fossil fueled thermal power plants produce a large part of man-made CO2 emissions to the atmosphere, and efforts to reduce these are varied and widespread.

Almost all coal, 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 can be used to raise steam, 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. Large companies or institutions may have their own power plants to supply heating or electricity to their facilities, especially if the steam is created anyway for other purposes. Steam-driven power plants have been used in various large ships, but are now usually used in large naval ships. Shipboard power plants usually directly couple the turbine to the ship's propellers through gearboxes.

As seen in the Fig.1.1, the schematic of simple power plant cycle operation

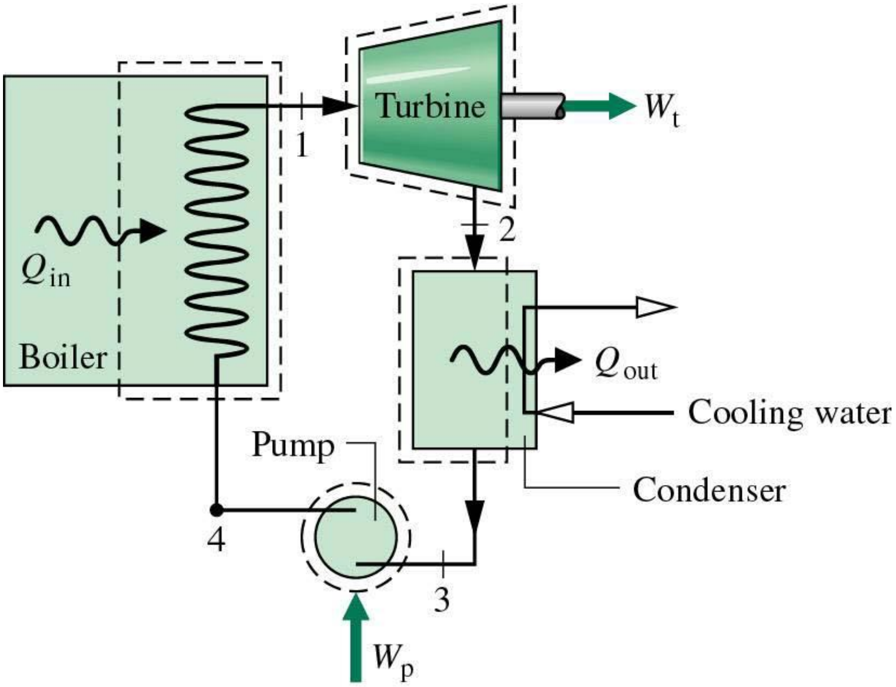


Fig.1.1: Schematic of the simple power plant operation by Rankin cycle

In this project, the cooling tower and stack neglected because the amount of the exhausted steam and burned gas are small.

1.2 Objectives of the Project

The main purpose of this project is to establish and build an educational model of power plant by using Rankine cycle, so the one who is interesting how power plant works, can make experiments by using that model to understand the principle of working.

The importance of this project can be summarized in the following points:

1. Educational model of power plant.
2. Rankine cycle analysis.
3. Helps to understand the energy conversion.
4. Review some of power plant improvements.

1.3 Literature Review

Power plant is an assembly of a steam, where the electricity is generated by different mechanical and electrical equipment with different processes. The basic components of the power plants are steam turbine, steam condenser, feed water pump and boiler or steam generator.

1.4 Budget Estimation

Table 1-1: Budget estimation

No.	Name of Parts	Cost (NIS)
1.	Steam Turbine (TS-532)	1350
2.	Sensors	480
3.	Digital Output Screen (LCD's)	830
4.	Boiler with Components	580
5.	Feed Water Pump with Components	370
6.	Generator	60
7.	Indicators	95
8.	Belt	25
9.	Other Components	727

1.5 Project Scope

1.5.1 Chapter One: Introduction

This chapter, gives an introduction about the project, it clarifies the system as a practical idea and the table time.

1.5.2 Chapter Two: Rankine cycle analysis and improvements

This chapter includes the analysis of the Rankine cycle that used in the steam power plants, and the possible improvements of the cycle.

1.5.3 Chapter Three: The main components of the project

This chapter descriptions of the main components of the steam power plants, which they are micro steam turbine, boiler, steam condenser and feed water pump.

1.5.4 Chapter Four: The secondary components of the project

This chapter describes the secondary components that used between all the relevant system components, they are sensors, gauges, etc.

1.6 Table Time

The time schedule shows the stages of developing in our work and the process of project growth for the first semester and the second semester.

Table 1-2 Project Time-Schedule for First Semester

Week Process	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Collecting data and literature	■	■	■	■												
Analyzing of data				■	■	■	■	■								
Calculations								■	■	■	■	■				
Searching on the steam turbine												■	■	■		
Writing the documentation							■	■	■	■	■	■	■	■	■	
Final presentation																■

Table 1.3 Project time-schedule for second semester

Week Process	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Buying the steam turbine	■	■	■													
Buying electronic parts			■	■	■	■	■	■								
Assembling the project							■	■	■	■						
Check the project part and perform the initial experiment										■	■	■				
Perform final experiment												■	■	■		
Writing the documentation								■	■	■	■	■	■	■	■	
Final presentation																■

CHAPTER TWO

Rankine Cycle and Improvements

Contents:

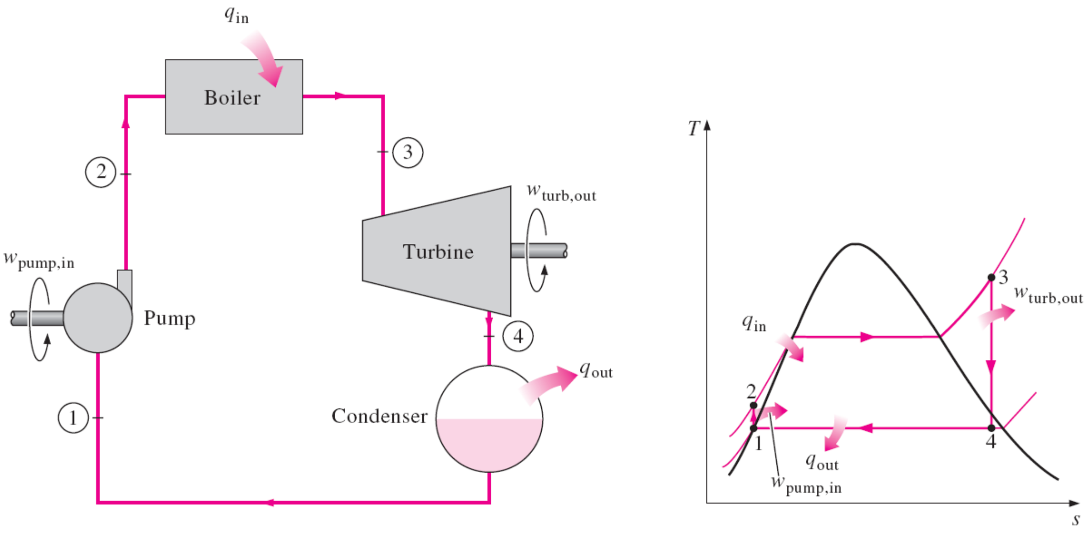
2.1 Introduction

The Rankine Cycle is a thermodynamic cycle which converts heat into work. The heat is supplied externally to a closed loop. Rankine cycle is the one used in steam power plants. The most common fluid used in this cycle is water, but other fluids can also be used.

2.2 The Simple Rankine Cycle

Rankine cycle is ideal cycle for vapor power plants, which it does not involve any internal irreversibility, the Fig.2.1 Shows the ideal Rankine cycle which it consist of the following processes:

1) **Process 1-2:** Isentropic compression of the working fluid in the pump.
2) **Process 2-3:** Heat addition to working fluid at constant pressure in boiler.
3) **Process 3-4:** Isentropic expansion of in the working fluid in turbine from boiler pressure to condenser pressure.
4) **Process 4-1:** Heat rejection from the working fluid at constant pressure in the condenser.



(a) (b)

Fig.2.1: (a) The simple Rankine cycle; (b) Temperature-enthalpy diagram

According to the Fig.2.1 which explains the way of operating the cycle by using the schematic and T-s diagram:

Water enters the pump at state 1 as saturated liquid and is compressed isentropically to the operating pressure of the boiler. The water temperature increases somewhat during this isentropic compression process due to a slight decrease in the specific volume of water. Water enters the boiler as a compressed liquid at state 2 and will leave it as a superheated vapor at state 3, when enters as superheated it will enters turbine, where it expands isentropically and produces work by rotating the shaft connecting to electric generator. The pressure and temperature of steam drop during this process to the values at state 4, where steam enters the condenser. At this state, steam is usually a saturated liquid-vapor mixture with a high quality [1].

Steam is condensed at constant pressure in the condenser, which is basically a large heat exchanger, by rejecting heat to a cooling medium such as a river and lake. Steam leaves the condenser as saturated liquid and enters the pump, completing cycle.

But also, in the actual cycle the irreversibilities which result from two main reasons, sources heat losses and friction of fluid in the components of the cycle (pump, turbine, condenser and boiler). These two sources effects on the performance of the cycle as shown in Fig. 2.2 by means the performance of the components decrease and cycle efficiency .

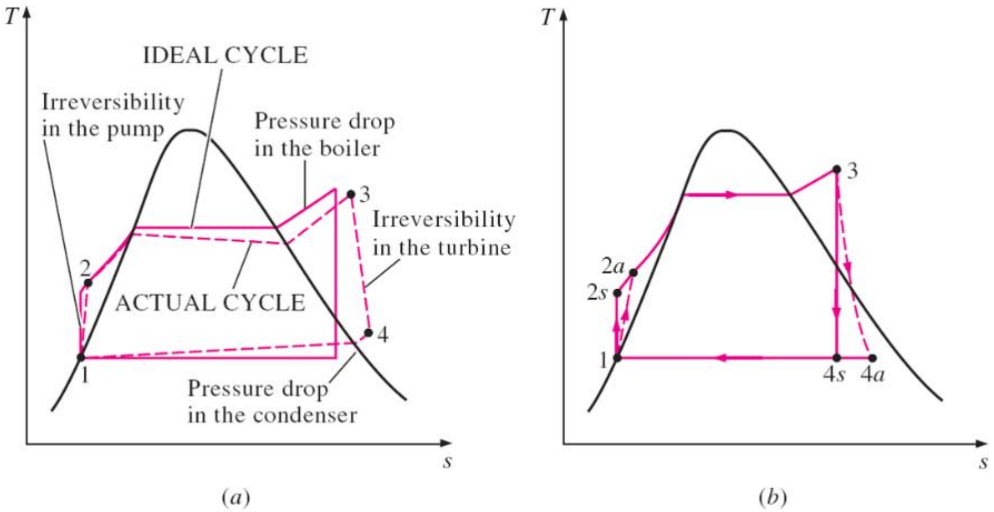


Fig. 2.2: (a) Deviation between ideal and actual Rankine cycle; (b) The effect of pump and turbine irreversibilities on the ideal Rankine cycle

The heat losses results from flow the steam through the various components, so increasing the amount of heat transferred to the steam in the boiler to compensate the losses and obtaining the same amount of the net work output.

The other main source is fluid friction which causes pressure drop in boiler, condenser and pipes between various components. The water pumped pressure must increase that mean the pressure inlet to boiler will increase and some of pressure drops in pipe will be compensated that tends to increase somewhat pressure to turbine inlet, that requires a larger pump and larger work input to pump.(see Fig.2.2)

2.3 Analysis of the Power Cycle

In the Rankine cycle system the main four components (turbine, boiler, condenser, pump) which these devices steady-flow, so the analysis of all processes can be done under steady-flow process. The potential and kinetic energy changes in the steam small so are neglected, so:

$$(q_{in} - q_{out}) + (w_{in} - w_{out}) = (h_{in} - h_{out}) \tag{2.1}$$

When the pump and the turbine assumed to be isentropic (process 1-2). The conservation energy of each one as following:

Pump work (q=0)

$$w_{p,in} = h_2 - h_1 \tag{2.2}$$

Where $h_1$the enthalpy of liquid at condenser pressure P_4, and h_2 is the enthalpy of liquid at state 2.

Now, in the process (2-3) for constant heat addition in the boiler where it dose not involve work, boiler (w=0) as follows:

$$q_{in} = h_3 - h_2 \tag{2.3}$$

For the process (3-4) Isentropic expansion in turbine which, turbine (q=0) as follows:

$$w_{T,out} = h_3 - h_4 \tag{2.4}$$

For last process (4-1) when Heat rejection in condenser and the condenser does not involve any work, condenser (w=0) as below:

$$q_{out} = h_4 - h_1 \tag{2.5}$$

Finally, the thermal efficiency of the Rankine cycle can be determined by the ratio of the area enclosed by cycle on T-s diagram to the area under the heat addition process, another way shown as follows:

$$w_{net} = w_{T,out} - w_{P,in} \tag{2.6}$$

$$\mu_{th} = \frac{w_{net}}{q_{in}} = 1 - \frac{q_{out}}{q_{in}} \tag{2.7}$$

But there's a little change in the liquid density or specific volume due to increase in pressure because pump handles water which is incompressible that causes increasing pressure. For reversible adiabatic compression we using general property relation, we get

$$Tds = dh - vdP$$

$$dh = vdp$$

After integration we get the final equation as follows:

$$h_{f1} - h_{f4} = v(P_3 - P_4) \tag{2.8}$$

For small quantity of $(h_{f1} - h_{f4})$ of pump compared with turbine work $w_{T,out}$ and at low pressure of boiler, is usually neglected. Then the equation of Rankine cycle efficiency became as below:

$$\mu_{th} = \frac{h_2 - h_3}{h_2 - h_{f1}} \tag{2.9}$$

For the actual Rankine cycle, the pump requires larger work input, but turbine produces small amount of the work due to the irreversibilities. However, from Fig2.2b where 2a and 4a are the actual exit states of the pump and turbine and so the 2s and 4s for isentropic, depend on that the deviation of pump and turbine showing as below:

$$\mu_P = \frac{h_{2s} - h_1}{h_{2a} - h_1} \tag{2.10}$$

$$\mu_T = \frac{h_3 - h_{4a}}{h_3 - h_{4s}} \tag{2.11}$$

2.4 Possible Improvements of the Thermal Efficiency

Most of electric power in the world is produced by steam power plants, and even small increases in the thermal efficiency can result in large savings of money and fuel consumptions.

The methods to improve the thermal efficiency of the power cycle is the same

- Increasing the average temperature (T_{avg}) at which heat is supplied in boiler.
- Decreasing the average temperature (T_{avg}) at which heat is rejected in condenser.

To accomplish that's, below discussed three ways:

1) Superheating the Steam to High Temperatures

By superheating the steam to high temperatures, the (T_{avg}) at which heat is added to the steam can be increased without increasing the boiler pressure. The effect of superheating the steam on the performance of power vapor power cycle is shown in Fig.2.3. Superheating to higher temperatures decreases the moistures content of the steam at the turbine exit and that ensures longer life of turbine blades, which is desirable.

The temperature is limited by metallurgical considerations. Presently the highest steam temperature allowed at the turbine inlet is about 620℃

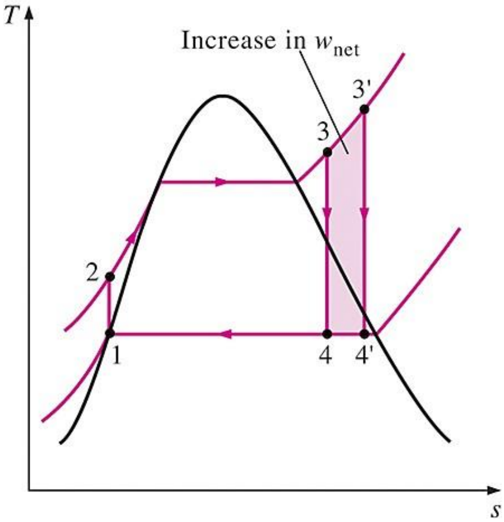


Fig.2.3: The effect of superheating the steam to higher temperature on Rankine cycle

2) Increasing the Boiler Pressure

An increasing in the operating pressure of the boiler automatically increasing in the temperature. That causing to increase the average temperature at which heat is added to the steam, which tends to increase in the thermal efficiency of cycle. The effect of increasing the boiler pressure on the cycle performance is shown in the Fig.2.4 .When the pressure increased, the cycle will shift to the left and the moisture content of the steam will increase but that not recommend for the turbine because it erodes the turbine blades and decreases the efficiency at the final stage.This side effect can be corrected by reheating the steam.

3) Reducing the Condenser Pressure

Reducing in the operating pressure at the condenser inlet will decrease the temperature of the steam, and that temperature at which heat is rejected, since the steam exits as a saturated mixture in the condenser at the saturated temperature corresponding to the pressure inside. The effect is shown in Fig.2.5.The inlet turbine remaining the same, but the input heat which represents under colored area from (2-2') increase relatively small. Decreasing pressure of condenser from (4-4') that affects to increase in the net work output, the thermal efficiency increased.

To take the advantage of the increased efficiencies at low pressures, the condensers of steam power plants usually operates well below the atmospheric pressure. There is a lower limit to this pressure depending on the temperature of the cooling medium. Lowering the condenser pressure increases the moisture content of the steam at the final stages of the turbine

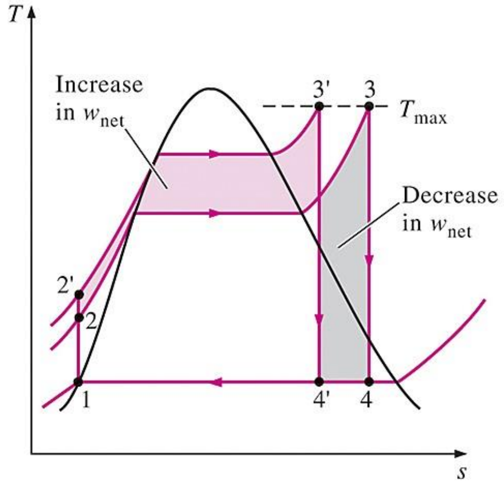


Fig.2.4: The effect of increasing the boiler pressure on the Rankine cycle

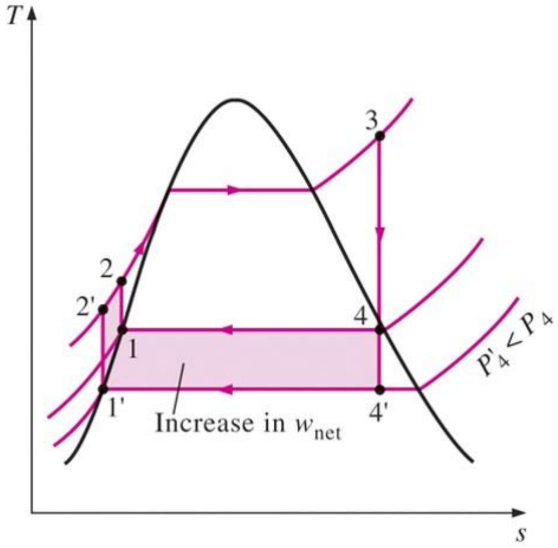
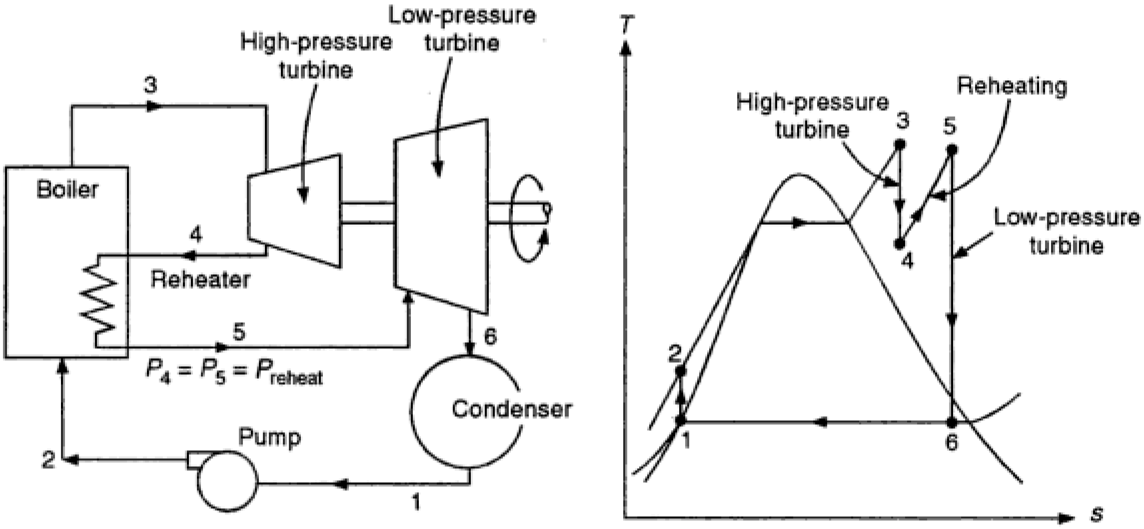


Fig.2.5: The effect of lowering the condenser pressure on the Rankine cycle

2.5 The Reheat Rankine Cycle

The reheat cycle has been used to solve the problem of excessive moisture at the final stages of the turbine. This will allow the temperature in a constant boiler pressure to be increased, in order to improve boiler efficiency.

The optimal way of increasing boiler pressure but not increase in the moisture content in the exiting vapor is to reheat the vapor after it exits from a first-stage turbine and redirect this reheated vapor into a second turbine. The schematic diagram of the reheat Rankine cycle shown in the Fig.2.6. This differs from the basic Rankine cycle that takes place into two stages [2].



(a) (b)

Fig.2.6: (a) The schematic of reheat cycle. (b) T-s diagram for reheating

Also the Rankine cycle consist the following processes:

In the first stage with high pressure turbine, the steam expanded isentropically to an intermediate pressure and sent back to the boiler where it is reheated at constant pressure, usually to the inlet temperature of the first turbine stage. In the second stage, the steam expands isentropically, through a low-pressure turbine to the condenser pressure. According to the Fig.2.6b

$$q_{in} = q_{primary} + q_{reheat}$$

$$q_{in} = (h_3 - h_2) + (h_5 - h_4) \ (KJ/Kg) \tag{2.12}$$

$$w_{turb,out} = w_{turb,1} + w_{turb,2}$$

$$w_{turb,out} = (h_3 - h_4) + (h_5 - h_6)\ \ (KJ/Kg) \tag{2.13}$$

As the number of stages increase, the expansion and reheat processes approach an isothermal process at the maximum temperature.

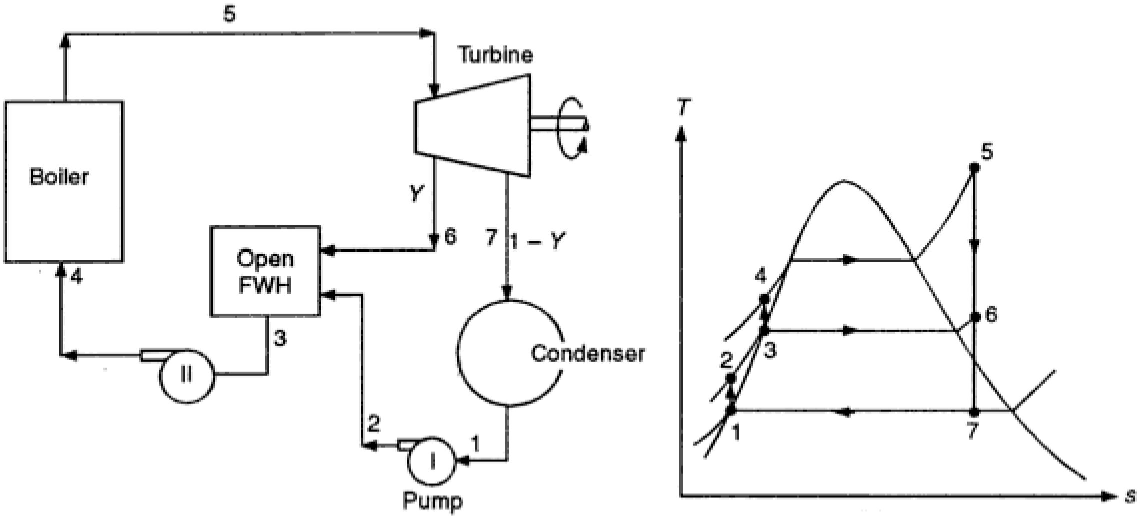
2.6 The Regenerative Rankine Cycle

In the regenerative Rankine cycle, the working fluid, water, after emerging from the condenser possibly as a subcooled liquid is heated by steam tapped from the hot portion of the cycle. This can reduce the energy required to heat the high pressure water to its saturation temperature in the boiler. This would avoid the necessity of condensing all of the steam. The feedwater refers to the water entering the boiler and when the extracted steam and the condenser water are mixed it called a feedwater heater device (FWH). Two types of FWH:

- Open feedwater heater: The condensate water is directly mixed with the steam in a mixing chamber.
- Closed feedwater heater: In this type, not allowed for mixing two streams. Which the water passes through tubes and the steam condenses on the outer surface of the tubes

2.6.1 Open Feedwater Heater

An open feedwater heater is basically a mixing chamber, the steam extracted from the turbine mixes with the feedwater exiting the pump. The mixture leaves the heater as a saturated liquid at the heater pressure. For more clarification, see the Fig.2.7 below. In this cycle, the steam enters the turbine at the boiler pressure (stage 5) and expands partially in the turbine to an intermediate pressure. Steam (Y) at this state is extracted and routed to the feedwater heater. The remaining steam (at stage 7) expands completely to the condenser pressure.



(a) (b)

Fig.2.7: (a) Open feedwater schematic. (b) T-s diagram for open feedwater

In the different components, the mass flow rates of the steam are different. If the mass flow rate through the boiler is $\dot{m}$, it will be $(1-Y)\dot{m}$ (see Fig2.7) through the condenser. Through the boiler, the heat and work are as follows:

$$q_{in} = h_5 - h_4 \tag{2.14}$$

$$q_{out} = (1-Y)(h_7 - h_1) \tag{2.15}$$

$$w_{turb,out} = (1-Y)(h_0 - h_2) + (h_5 - h_0) \tag{2.16}$$

$$w_{pump,in} = (1-Y)w_{pump\ 1,in} + w_{pump\ 2,in} \tag{2.17}$$

Where

$Y = \dot{m}_6/\dot{m}_5$

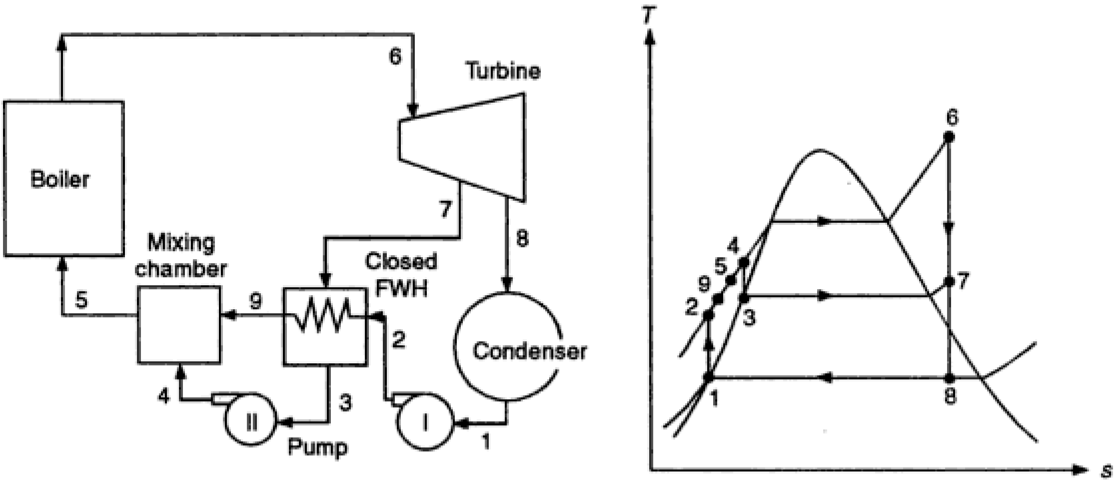
$w_{pump\ 1,in} = v_1(P_2 - P_1)$

$w_{pump\ 2,in} = v_3(P_4 - P_3)$

The thermal efficiency of the Rankine cycle increases as a result of regeneration. When the number of FWH's increased, the efficiency cycle increases. That number is governed by economical considerations.

2.6.2 Closed Feedwater Heater

In closed feedwater heater, the extracted steam and the feedwater can be at different pressure, they don’t mix. In the Fig.2.8 shows the schematic diagram of a steam power plant with one closed feedwater, since we can increase the number of closed feedwater heater. The feedwater heater is heated to the exit temperature of the extracted steam, which leaves the heater below the exit temperature of the extracted steam because a temperature difference of at least a few degrees required for any effective heat transfer to take place. The condensed steam the pumped to heater or to the condenser through a trap or to the feedwater line.



(a) **(b)**

Fig.2.8: (a) Closed feedwater schematic. (b) T-s diagram of the closed feedwater

2.6.3 Comparison Between the Open and Closed Feedwater Heaters

There are many differences between the open and the closed feedwater heaters, below in table.2.1 shows some of these differences.

Table 2-1: Comparisons between open and closed feedwater heaters

No.	Open feedwater heater	Closed feedwater heater
1.	Simple	Complex
2.	Inexpensive	Expensive
3.	Good heat transfer characteristics	Bad heat transfer

2.7 The Cycle Calculations

The working pressure of the boiler is 3 bar absolute. By using superheated and saturated steam tables, the cycle can be calculated as the following:

At boiler pressure $\mathrm{P_3} = 3\mathrm{bar\ abs.}$

From superheated steam tables, the following data can be used:

$\mathrm{h_3} = 2724.9\ (\mathrm{kJ/kg})$

$\mathrm{s_3} = 6.9917\ (\mathrm{kJ/kg.K})$

At condenser pressure $\mathrm{P_1} = 1\mathrm{bar\ abs.}$

Using saturated steam tables:

$\mathrm{T_{sat}} = 99.61\ ℃$

$\mathrm{h_1} = \mathrm{h_f} = 417.51\ \ (\mathrm{kJ/kg})$

$\mathrm{h_{fg}} = 2257.5\ (\mathrm{kJ/kg})$

$\mathrm{v_f} = 0.001043\ \ (\mathrm{m^3/kg})\ \text{ and }\ \mathrm{v_g} = 1.6941\ \ (\mathrm{m^3/kg})$

$\mathrm{s_f} = 1.3028\ \ (\mathrm{kJ/kg.K})\ \ \text{ and }\ \mathrm{s_{fg}} = 6.0562\ \ (\mathrm{kJ/kg.K})$

$h_2 = v(P_2 - P_1) + h_1$

$h_2 = 0.001043 \times 2 \times 10^3 + 417.51 = 419.59\ \ (\mathrm{kJ/kg})$

For superheated steam:

$s_3 = s_4$

$s_4 = s_f + x \times s_{fg}$

$6.9917 = 1.3028 + \mathrm{x}(6.0562)$

$\mathrm{x} = 0.939$

$h_4 = h_f + x \times h_{fg}$

$\mathrm{h}_4 = 417.51 + (0.939) \times (2257.5) = 2516.985\ (\mathrm{kJ/kg})$

$w_{in} = h_2 - h_1$

$\mathrm{w}_{\mathrm{in}} = 419.59 - 417.51 = 2.086\ \ (\mathrm{kJ/kg})$

$q_{in} = h_3 - h_2$

$\mathrm{q}_{\mathrm{in}} = 2724.9 - 419.59 = 2305.31\ \ (\mathrm{kJ/kg})$

$w_{out} = h_3 - h_4$

$\mathrm{w}_{\mathrm{out}} = 2724.9 - 2516.985 = 207.915\ \ (\mathrm{kJ/kg})$

$q_{out} = h_4 - h_1$

$\mathrm{q}_{\mathrm{in}} = 2516.985 - 417.51 = 2099.475\ \ (\mathrm{kJ/kg})$

$w_{net} = w_{out} - w_{in}$

$\mathrm{w}_{\mathrm{net}} = 207.915 - 2.086 = 205.829\ \ (\mathrm{kJ/kg})$

$$\mu = \frac{w_{net}}{q_{in}} \times 100\%$$

$$\mu = \frac{205.829}{2099.475} \times 100\% = 9.8\%$$

CHAPTER THREE

Main Components

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- **3.4.2 Working Principle of the Hand Pump**
- **3.4.3 Pump Components**
- **3.4.4 Design Analysis**

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- **3.5.2 Advantages of Copper Tube**
- **3.5.3 Design Formulas**
- **3.5.4 Design Analysis**

3.1 Steam Turbine

3.1.1 Introduction

The steam turbine is a prime mover in which the potential energy of the steam is transformed into kinetic energy, and later in its turn is transformed into mechanical energy of rotation of turbine shaft. The turbine shaft, directly or with other helping devices or tools, is connected with the driven mechanism.

3.1.2 Impulse Steam Turbine

For impulse steam turbines, the steam enters from nozzle to blades, which blades start moving and making work.

According to the Fig.3.1.1, that shows the diagrammatical of simple impulse turbine. The top portion of the figure exhibits a longitudinal section through the upper half of the turbine , the middle portion shows one set of nozzle which is followed by a ring of moving blades ,while lower part of the diagram indicates approximately changes in pressure and velocity during flow of steam through the turbine . Since the expansion of the steam takes place in one set of the nozzles.

As the steam flows through the nozzle its pressure falls from the steam chest pressure to condenser pressure. Due to this relatively higher ratio of expansion of steam in the nozzles the steam leaves the nozzle with a very high velocity. Refer to the Fig.3.1.1, it is evident that the velocity of the steam leaving the moving blades is a large portion of the maximum velocity of the steam when leaving the nozzle. The loss of energy due to this higher exit velocity is commonly called the "**leaving loss**".

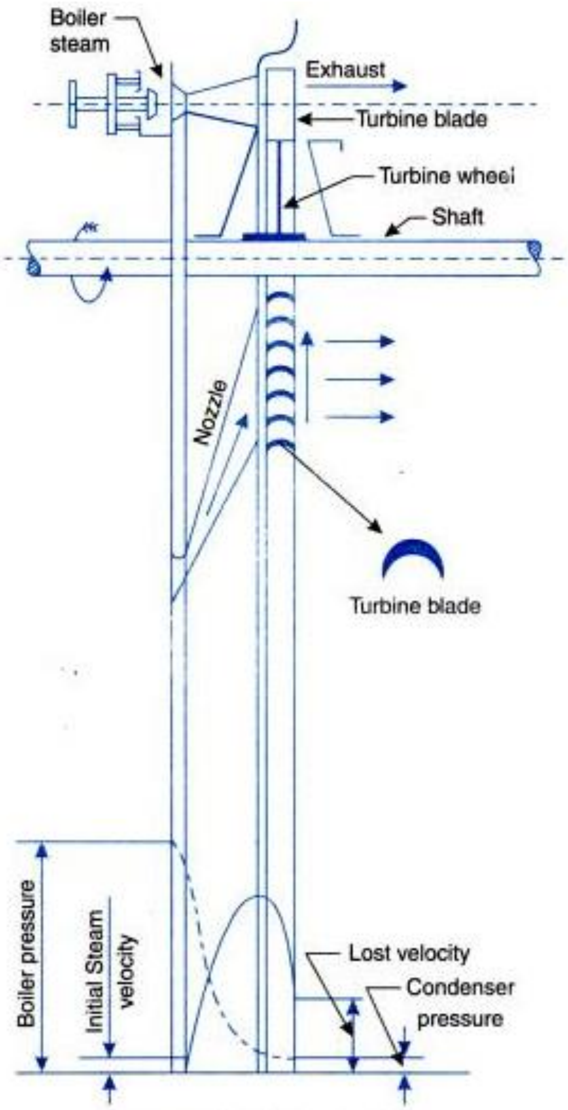


Fig.3.1.1: Diagrammatical of the simple steam impulse turbine

3.1.3 Moving Blades Velocity Diagram

Velocity of impulse steam turbine depends on the angles of inlet and outlet angles. In the Fig.3.1.2 shows the velocity components of blade

Where

C_{bl} = Linear velocity of moving blade (m/s).

C_1 = absolute velocity of steam entering moving blade (m/s).

C_0 = absolute velocity of steam leaving moving blade (m/s).

C_{w_1} = velocity of whirl at the entrance of moving blade (m/s).

C_{w_0} = velocity of whirl at the exit of moving blade (m/s).

C_{f_1} = velocity of flow at the entrance of moving blade (m/s).

C_{f_0} = velocity of flow at the exit of moving blade (m/s).

C_{r_1} = Relative velocity of steam to moving blade at entrance.

C_{r_0} = Relative velocity of steam to moving blade at exit.

α = Nozzle angle .

Also nozzle angle can be defined angle with the tangent of the wheel at which the steam with velocity C_1 enters.

β = Angle wich the discharging steam makes with the tangent of the wheel at the exit of moving blade

θ = Entrance angle of moving blade .

$\emptyset$ = Exit angle of moving blade .

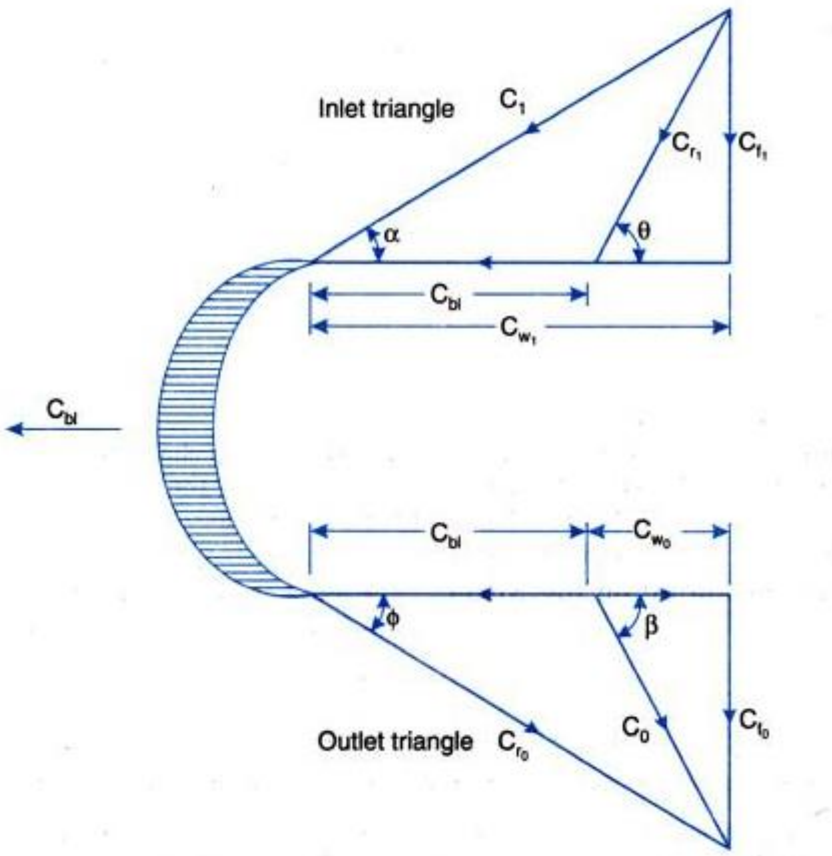


Fig.3.1.2: Moving blade velocity diagram

The steam jet comes out from the nozzle at velocity of (C_1) bumping to the blade at an angle (α). The tangential component of this jet (C_{w_1}) makes work on the blade. The axial component (C_{f_1}) however does no work but let the steam goes through the turbine. While the blades movies with tangential velocity of (C_{bl}), the coming steam jet has a relative velocity (C_{r_1}) which makes an angle (θ) with the wheel tangent. The steam then slips over the blade without any shock at a relative velocity of (C_0) at an angle ($\emptyset$) with the tangent of the blades. The relative velocity at the inlet (C_{r_1}) is the same as the relative velocity at the outlet (C_{r_0}) if there is no frictional loss at the blade. The absolute velocity (C_0) of leaving steam make an angle (β) to the tangent at the wheel.

3.1.4 Advantages of Using Steam Turbine over Steam Engines

There are many advantages of using steam turbine over steam engines, the following some of these advantages:

1) The thermal efficiency of a steam turbine is much higher than that of steam engines.
2) The steam turbine provides a higher output power much than steam engines. The steam turbine can use in large thermal station.
3) The steam turbine doesn't require internal lubrication as there are no friction parts.
4) In a steam turbine there is no loss due to initial condensation of steam.
5) Obtaining high speed range is possible than in case of a steam engine.

3.1.5 The Principle of the Turbine

The type that used simple impulse turbine. It is designed much like the exhaust side of a turbo-charger having the compressed steam enter into the turbine housing tangentially along the blades, which drive the 3/16" hardened stainless steel shaft. The pressure then runs through the blades working its way towards the middle of the rotor and exits out the center through the 1" standard copper exhaust pipe coming out the rear. The 1" copper pipe can then be fitted to any other standard copper fitting to perhaps run to a condenser to convert the steam back into water again and be recycled. As seen in the Fig.3.1.3 the steam turbine.

Its speed reaches approximately 30,000 rpm at 45 psi without load. The efficiency of this type reaches 15%, with low efficiencies, the speed and power decreases and it reaches approximately 8000 rpm and 15 watt.

Fig.3.1.3: Simple impulse steam turbine

3.2 Steam Condenser

3.2.1 Introduction

Condenser is a device in which steam is condensed to water at a pressure less than the atmosphere. Condensation can be done by removing heat from exhaust steam using cooling water. During condensation, the working substance changes its phase from vapor to liquid and rejects latent heat. When the tubes are kept cold by the circulation of water which removes the heat given up by the condensing steam. This heat is called latent heat of vaporization or heat of condensation.

The functions of the condenser are improving the thermal efficiency of the cycle by reducing the turbine exhaust pressure, and supplying the preheated feed water to the boiler [3].

3.2.2 Surface Condenser or Indirect Contact Condenser

In surface condensers, the exhausted steam and water don’t come into direct contact. The cooling water passes through tube and the steam uniformly distributed over cooling water tube for obtaining best works. When the steam contacts the relatively cold tubes, it condenses. This condensing effect is a rapid change in the state from a vapor to liquid.

The air must be prevented from leakage in the condenser for better efficiencies. The leakage of the air can causing the following effects:

1) Increased requirements of the cooling water :

Leakage the air in the condenser lowers the partial pressure of the steam. The saturation temperature of the steam lowered, that increases the potential heat. Increasing in the potential heat requires to increase in the amount of cooling water.

2) Decreasing the thermal efficiency:

Leakage the air in the condenser increases the back pressure on the prime mover. That increases the losses of heat drop, as the heat losses increased the thermal efficiency decreases.

3) Reduced heat transfer :

Leakage the air in the condenser reduces the rate of heat transfer from the steam because the air has poor thermal conductivity, so the surface of the tubes of a surface condenser increased for a given condenser capacity.

4) Corrosion:

The existence of the air in the condenser increases corrosion.

3.2.3 Advantages and Disadvantages of Surface Condensers

Advantages

1) It gives a pure condensate which can be recirculated as feed water to the boiler.
2) By regulating the flow of cooling water, the cooling of condensate can be controlled.
3) By reusing the condensate, which saves the cost of fresh water to be circulated and the cost of its chemical treatment.

Disadvantages

1) Large amounts of cooling water requires.
2) The construction is complicated and requires higher installation costs.

3.2.4 Design Formulas

Speed of the steam output from the nozzle mustn’t become over sound speed. This prevents the nozzle choke, so $V_{sound} = 340\ (m/s)$

$$\dot{m}_s = \rho \times V_{sound} \times A_n \tag{3.2.1}$$

Where

$\dot{m}_s$: Mass flow rate of steam (kg/s)

ρ: Steam density (kg/m^3)

A_N: Nozzle area (m^2)

The required heat rejection from the condenser is:

$$Q_{out} = \dot{m}_s \times q_{out} \tag{3.2.2}$$

Where

$\mathrm{Q_{out}}$: Condenser heat output (Watt)

$\mathrm{q_{out}}$: The cycle work (kJ/kg)

Reynolds number

$$Re = \frac{D \times u}{v} \tag{3.2.3}$$

Where

Re: Reynold number. Dimenssion less

D: Pipe diameter (m)

u = Flow in pipe (m/s)

v: Kinematic viscocity ($\mathrm{m^2/s}$)

Nusselt number

$$Nu_{Turbulent\ flow} = 0.023 \times Re^{0.8} \times Pr^{\mathrm{n}} \tag{3.2.4}$$

$$Nu = \frac{h \times D}{k} \tag{3.2.5}$$

Where

Nu: Nusselt number.

h: Heat transfer coefficient ($\mathrm{W/m^2K}$).

Pr: Prandtl number.

n: 0.3 for cooling and 0.4 for heating.

k: Conductivity (W/m. °C).

The overall heat transfer coefficient

$$Q = U \times A \times \Delta T_m \tag{3.2.6}$$

$$U = \frac{1}{\frac{1}{h_i} + \frac{A_i \ln(r_o/r_i)}{2\pi k L} + \frac{A_i}{A_o}\frac{1}{h_o}} \tag{3.2.7}$$

$$\Delta T_m = \frac{(T_{h2} - T_{c2}) - (T_{h1} - T_{c1})}{\ln[(T_{h2} - T_{c2})/(T_{h1} - T_{c1})]} \tag{3.2.8}$$

Where

U: Overall heat transfer coefficient (W/m^2°C)

ΔT: Mean temperature difference

A_i , A_o: Inner and outer diameters of tube (m^2).

L: Tube length (m).

T_h, T_c: Temperatures for hot and cold fluids (°C or K)

As seen in the Fig 3.2.1, the temperature profile for counterflow in double pipe heat exchanger [4]

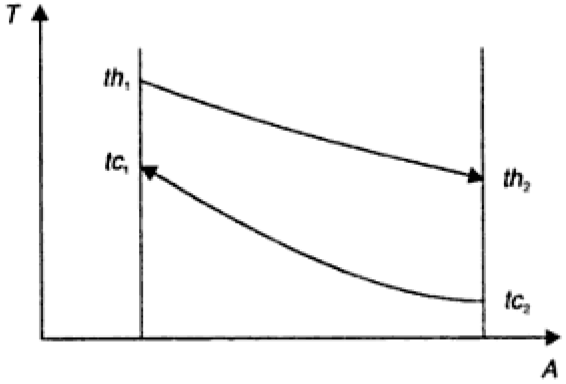


Fig.3.2.1: Counterflow double pipe heat exchanger

3.2.5 Design Analysis

$$\dot{m}_s = \rho \times V_{sound} \times A_n$$

$\dot{\mathrm{m}}_{\mathrm{s}} = 1.13 \times 340 \times 4.4533 \times 10^{-6} = 1.7 \times 10^{-3}\ \mathrm{kg}/s$

$Q_{out} = \dot{m}_s \times q_{out}$

$\mathrm{Q_{out}} = 1.7 \times 10^{-3}\ \times 2099.5 \times 10^{3} = 3570\ \mathrm{W}$

For water, assume flow speed $1\ \mathrm{m/s}$ and $\mathrm{Pr} = 1.8$ and $\mathrm{k} = 0.66$

$\mathrm{D_i} = 0.0061\ \mathrm{m}$ and $\mathrm{D_o} = 0.012\ \mathrm{m}$

Find $\mathrm{h_o}$

$$Re = \frac{D_o \times u}{v}$$

$$\mathrm{Re} = \frac{0.012 \times 1}{0.478 \times 10^{-6}} = 25104$$

When $2500 < \mathrm{Re} < 1.25 \times 10^{5}$ the Nusselt number is

$$Nu_{Turbulent\ flow} = 0.023 \times Re^{0.8} \times Pr^{\mathrm{n}}$$

$$\mathrm{Nu_{Turbulent\ flow}} = 0.023 \times 25104^{0.8} \times 1.8^{0.3} = 90.78$$

$$Nu = \frac{h_o \times D_o}{k}$$

$$\mathrm{h_o} = \frac{90.78 \times 0.66}{0.012} = 4993\ \mathrm{W/m^2.K}$$

Find $\mathrm{h_i}$

$$Re = \frac{D_i \times u}{v}$$

$$\mathrm{Re} = \frac{0.0061 \times 1}{0.478 \times 10^{-6}} = 12761.5$$

$$\mathrm{Nu_{Turbulent\ flow}} = 0.023 \times 12761.5^{0.8} \times 1.8^{0.3} = 52.7$$

$$\mathrm{h_i} = \frac{52.7 \times 0.66}{0.0061} = 5704.5\ \mathrm{W/m^2.K}$$

When

$\mathrm{T_{h1}} = 100\ ^{\circ}\mathrm{C}$, $\mathrm{T_{h2}} = 70\ ^{\circ}\mathrm{C}$, $\mathrm{T_{c1}} = 50\ ^{\circ}\mathrm{C}$, $\mathrm{T_{c2}} = 25\ ^{\circ}\mathrm{C}$ and K for copper $= 401\ (\mathrm{W/m.K})$

$$\Delta T_m = \frac{(T_{h2} - T_{c2}) - (T_{h1} - T_{c1})}{\ln[(T_{h2} - T_{c2})/(T_{h1} - T_{c1})]}$$

$$\Delta T_m = \frac{(70 - 25) - (100 - 50)}{\ln[(70 - 25)/(100 - 50)]} = 47.45\ ^\circ\mathrm{C}$$

$$\frac{1}{\mathrm{h_i} \times \mathrm{r_i}} = 0.058$$

$$\frac{1}{h_o \times r_o} = 0.033$$

$$\frac{1}{\frac{\mathrm{K}}{\ln(\mathrm{r_o}/\mathrm{r_i})}} = 0.0017$$

$$Q = U \times A \times \Delta T_m$$

$$3570 = \frac{2\pi \times \mathrm{L} \times 47.45}{0.058 + 0.033 + 0.0017}$$

L = 1.77 m the length of double pipe heat exchanger.

3.3 Boiler

3.3.1 Introduction

A boiler is an enclosed vessel that provides a means for combustion heat to be transferred into water until it becomes heated water or steam. The hot water or steam under pressure is then usable for transferring the heat to a process. Water is a useful and cheap medium for transferring heat to a process. In other word, a boiler is a pressure vessel with burner or other energy source used to convert thermal energy from one form to another. Example, burn gas to generate steam.

3.3.2 Gas Boiler

A gas boiler is a boiler that uses gas as its fuel source. Natural gas is becoming an important energy for heating and natural gas became one of important heating energy for gas boiler. A vertical boiler used for obtaining a steam by burning natural gas in a combustion chamber.

As seen in the Fig.3.2.1, a vertical boiler with the mountings

Fig 3.2.1: Boiler

A very important characteristic of gaseous fuels is the ignition speed. It depends on the percentage of gas in the air-gas mix.

3.3.3 Boiler Mountings

Boiler mountings are the machine components that are mounted over the body of the boiler itself for the safety of the boiler and for complete control of the process of steam generation. The following mountings fitted to the boiler:

1) **Pressure Gauge:** It indicates the pressure of the steam in the boiler.
2) **Steam Stop Valve:** It regulates the flow of the steam from the boiler to the steam pipe or from one steam pipe to the other. (see Fig.3.3.2)

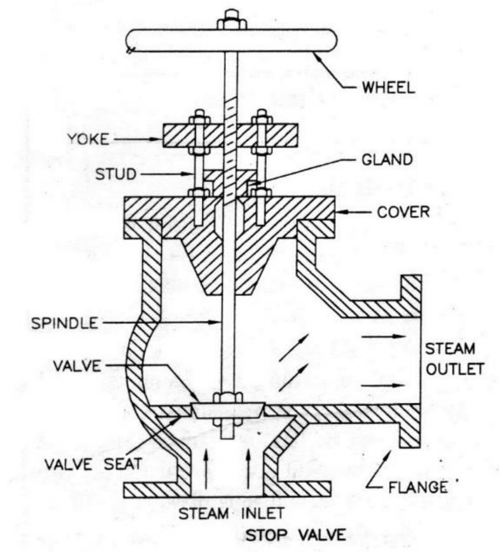


Fig.3.3.2: Steam stop valve

3) **Water Level Indicator:** It indicates the water level inside the boiler vessel. Which the maximum pressure inside it 5 bar.

4) **Two Springs Loaded Safety Valves**: It prevents increasing the steam pressure in the boiler to keep boiler from damage. One of them open when the pressure reaches 4 bar and the second one can be adapted, and it adapted up to 3 bar as experiment requirements.

5) **Temperature Sensors**: It indicates the temperature of the steam in the boiler and in all relevant system.

The boiler system comprises of feed water system, steam system and fuel system. The feed water system provides water to the boiler and regulates it automatically to meet the steam demand. Various valves provide access for maintenance and repair. The steam system collects and controls the steam produced in the boiler.

Steam is directed through a piping system to the point of use. Throughout the system, steam pressure is regulated using valves and checked with steam pressure gauges. The fuel system includes all equipment used to provide fuel to generate the necessary heat. The equipment required in the fuel system depends on the type of fuel used in the system.

3.3.4 Design Formulas

Mass flow rate exits from the boiler

$$m = \frac{\Delta V}{v_f} \tag{3.3.1}$$

$$\dot{m} = \frac{m}{\Delta t} \tag{3.3.2}$$

Where

m: Mass of water (kg)

ΔV: Volume of water (L)

Δt: Time

v_f: Specific volume of water (m^3/kg)

The velocity of steam exits from the boiler

$$v = \frac{\dot{m}}{\rho \times A} \tag{3.3.3}$$

Where

A: Steam output area (m^2)

ρ: Density of steam

Mass Balance

$$m_{in} - m_{out} = m_2 - m_1 = -m_e \quad (3.3.4)$$

Where

m_1: The volume of water in the boiler before evaporating

m_2: The volume of water in the boiler after evaporating

Energy balance

$$E_{in} - E_{out} = \Delta E_{system}$$

$$Q_{in} - (m_e \times h_e) = (m_2 \times u_2) - (m_1 \times u_1) \quad (3.3.5)$$

$$Q_{in} = h_3 - h_2 \quad (3.3.6)$$

Combining the mass and energy balances gives:

$$Q_{in} = (m_1 - m_2)h_e + (m_2u_2 - m_1u_1) \quad (3.3.7)$$

The quality determination:

$$v_2 = \frac{V}{m_2} \quad (3.3.8)$$

$$x_2 = \frac{v_2 - v_f}{v_{fg}} \quad (3.3.9)$$

The internal energy determination at the final state

$$u_2 = v_f + \left(x_2 \times u_{fg}\right) \quad (3.3.10)$$

Stresses

Referring to the Fig.3.3.3, when the value of the $P_o = 0$ then the stresses in pressurized vessel can be calculated as the following [5]:

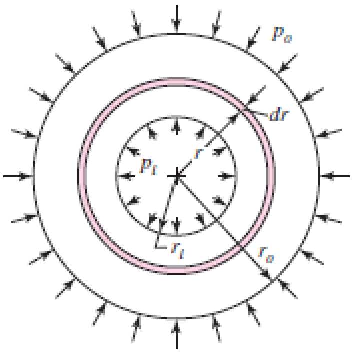
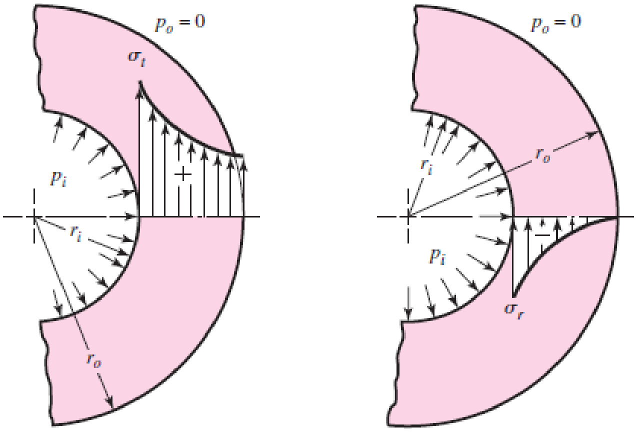


Fig.3.3.3: A cylinder subjected to both internal and external pressure

$$\sigma_t = \left(\frac{r_i^2 \times P_i}{r_o^2 - r_i^2}\right) \times \left(1 + \frac{r_o^2}{r_i^2}\right) \tag{3.3.11}$$

$$\sigma_r = \left(\frac{r_i^2 \times P_i}{r_o^2 - r_i^2}\right) \times \left(1 - \frac{r_o^2}{r_i^2}\right) \tag{3.3.12}$$

According to the Fig.3.3.4, the longitudinal stresses exist when the end reactions to the internal pressure are taken by the pressure vessel itself. This stress is found to be:



(*a*) Tangential stress distribution

(*b*) Radial stress distribution

Fig.3.3.4: Distribution of stresses in thick-walled cylinder subjected to internal pressure.

$$\sigma_l = \frac{r_i^2 \times P_i}{r_o^2 - r_i^2} \tag{3.3.13}$$

Assume $\sigma_t = \sigma_1$, $\sigma_r = \sigma_2$ and $\sigma_l = \sigma_3$

$$\acute{\sigma}_m = \frac{[(\sigma_1 - \sigma_2)^2 + (\sigma_2 - \sigma_3)^2 + (\sigma_3 - \sigma_1)^2]^{1/2}}{2} \tag{3.3.14}$$

Where

σ_t: The tangential stress (MPa)

σ_r: The radial stress (MPa)

σ_l: The longitudinal stress (MPa)

P_i: The internal pressure (Pa)

P_o: The external pressure (Pa)

r_o: The outside radius (m)

r_i: The inside radius (m)

$\acute{\sigma}_m$: *Mechanical stress*

Thermal stress

$$\acute{\sigma}_{th} = \alpha \times \Delta T \times E \tag{3.3.15}$$

$$\acute{\sigma}_{total} = \acute{\sigma}_m + \acute{\sigma}_{th} \tag{3.3.16}$$

Where

$\acute{\sigma}_{th}$: Thermal stress

α: The coefficient of thermal expansion

ΔT: Temperature change (°C)

E: Modulus of elasticity (GPa)

Factor of safety

$$n = \frac{\delta_y}{\acute{\sigma}_{total}} \tag{3.3.17}$$

Where

δ_y: Yield strength

Boiler Insulation

The boiler insulation is very important to reduce heat losses and increase the efficiency of the boiler. (See Fig 3.3.5)

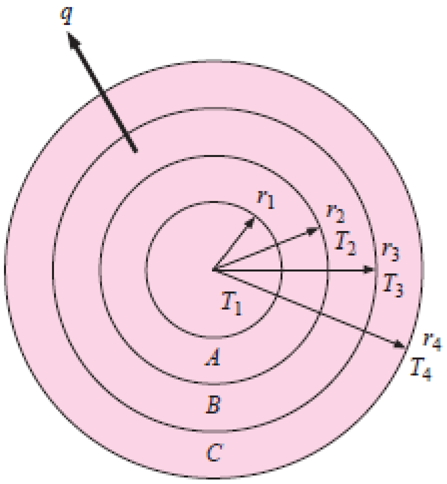


Fig.3.3.5: One dimensional heat flow through multiple cylindrical sections

The heat lose through multiple sections can be calculated as the following:

$$q = \frac{2\pi l(T_1 - T_4)}{\frac{ln(r_2/r_1)}{k_A} + \frac{ln(r_3/r_2)}{k_B} + \frac{ln(r_4/r_3)}{k_C}} \tag{3.3.18}$$

Where

k: Thermal conductivity of materials

l: Length of the cylinder (m)

r_1 , r_2: Inside and outside radius (m)

r_3: The outside radius + rockwool thickness (m)

r_4: The outside radius + rockwool thickness + stainless steel thickness (m)

3.3.5 Data Analysis

The boiler working pressure $P = 3\text{ bar} = 300\text{kPa}$, $m_1 = 2.6$ L and $m_2 = 1.9$ L

The properties of the water and steam at 300 kPa from appendix table (A-5) as the following:

$$v_f = 0.001073\ \text{m}^3/\text{kg}$$

$$u_f = 561.11\ \text{kJ/kg}$$

$$u_{fg} = 1982.1\ \text{kJ/kg}$$

$$h_g = 1982.1\ \text{kJ/kg}$$

$$m = \frac{\Delta V}{v_f} = \frac{0.7}{0.001073} = 0.65\ \text{kg}$$

$$\dot{m} = \frac{m}{\Delta t} = \frac{0.65}{30\ \times 60\ \text{s}} = 0.36 \times 10^{-3}\ \text{kg/s}$$

$$v_2 = \frac{V}{m_2} = \frac{0.006}{1.9} = 0.003\ \text{m}^3/\text{kg}$$

$$x_2 = \frac{v_2 - v_f}{v_{fg}} = \frac{0.003 - 0.001073}{0.6058 - 0.001073} = 0.003$$

$$u_2 = u_f + x_2 \times u_{fg} = 567.05\ \text{kJ/kg}$$

$$u_{1@100\ \text{kPa}} = 417.9\ \text{kJ/kg}$$

$$Q_{in} - (m_e \times h_e) = (m_2 \times u_2) - (m_1 \times u_1)$$

$$Q_{in} = 1898.3\ \text{kJ/kg}$$

Stresses Calculations

For $P_{max} = 4\ \text{kPa}$, thickness of boiler wall $t = 1.24\ \text{mm}$ and the outside diameter $D_o = 0.16\ \text{m}$ and inside diameter $D_i = 0.1587\ \text{m}$, also the radius of inside and outside are $r_o = 0.08\ \text{m}$ and $D_i = 0.0793\ \text{m}$

$$\sigma_t = \left(\frac{r_i^2 \times P_i}{r_o^2 - r_i^2}\right) \times \left(1 + \frac{r_o^2}{r_i^2}\right)$$

$$\sigma_t = \left(\frac{0.0793^2 \times 4 \times 10^5}{0.08^2 - 0.0793^2}\right) \times \left(1 + \frac{0.08^2}{0.0793^2}\right) = 53.081\ \text{MPa}$$

$$\sigma_r = \left(\frac{r_i^2 \times P_i}{r_o^2 - r_i^2}\right) \times \left(1 - \frac{r_o^2}{r_i^2}\right)$$

$$\sigma_r = \left(\frac{0.0793^2 \times 4 \times 10^5}{0.08^2 - 0.0793^2}\right) \times \left(1 - \frac{0.08^2}{0.0793^2}\right) = -0.3971\ \text{MPa}$$

$$\sigma_l = \frac{r_i^2 \times P_i}{r_o^2 - r_i^2}$$

$$\sigma_l = \left(\frac{0.0793^2 \times 4 \times 10^5}{0.08^2 - 0.0793^2}\right) = 25.4556\ \text{MPa}$$

$$\acute{\sigma}_m = \frac{[(\sigma_1 - \sigma_2)^2 + (\sigma_2 - \sigma_3)^2 + (\sigma_3 - \sigma_1)^2]^{1/2}}{2}$$

$$\acute{\sigma}_m = \frac{[(53.081 + 0.3971)^2 + (-0.3971 - 25.4556)^2 + (25.4556 - 53.081)^2]^{1/2}}{2}$$

$$\acute{\sigma}_m = 56.32\ \text{MPa}$$

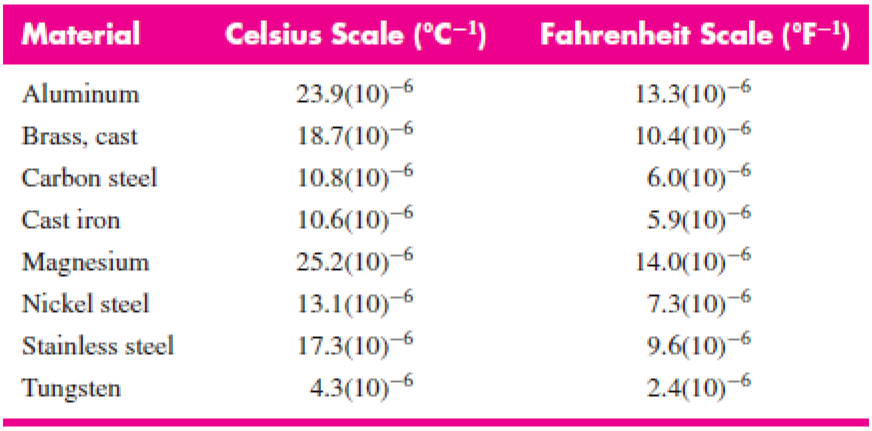
$$\acute{\sigma}_{th} = \alpha \times \Delta T \times E$$

From appendix A table A-5

$$E = 207 \times 10^9\ \text{Pa}$$

$$\Delta T = 133.4 - 25 = 108.4℃$$

From the table 3.1 thermal expansion coefficient for carbon steel $\alpha = 10.8 \times 10^{-6}$



Material	Celsius Scale (°C^{-1})	Fahrenheit Scale (°F^{-1})
Aluminum	$23.9(10)^{-6}$	$13.3(10)^{-6}$
Brass, cast	$18.7(10)^{-6}$	$10.4(10)^{-6}$
Carbon steel	$10.8(10)^{-6}$	$6.0(10)^{-6}$
Cast iron	$10.6(10)^{-6}$	$5.9(10)^{-6}$
Magnesium	$25.2(10)^{-6}$	$14.0(10)^{-6}$
Nickel steel	$13.1(10)^{-6}$	$7.3(10)^{-6}$
Stainless steel	$17.3(10)^{-6}$	$9.6(10)^{-6}$
Tungsten	$4.3(10)^{-6}$	$2.4(10)^{-6}$

Table 3.1: Thermal expansion coefficients

$\acute{\sigma}_{\mathrm{th}} = 242.339\ \mathrm{MPa}$

$\acute{\sigma}_{total} = \acute{\sigma}_{m} + \acute{\sigma}_{th}$

$\acute{\sigma}_{\mathrm{total}} = 278.659\ \mathrm{MPa}$

The 1018 (CD) is used as boiler material. Using table A-20

$\delta_{\mathrm{y}} = 440\ \mathrm{MPa}$

$$n = \frac{\delta_y}{\acute{\sigma}_{total}}$$

$n = 1.578$

So the boiler is safe to use

Insulation

According to the Fig.3.3.5, the value of each radius is

$\mathrm{r}_1 = 0.08\ \mathrm{m}$

$\mathrm{r}_2 = 0.08124\ \mathrm{m}$

$\mathrm{r}_3 = 0.08124 + 0.015 = 0.09624\ \mathrm{m}$

$\mathrm{r}_4 = 0.09624 + 0.09724\ \mathrm{m}$

$\mathrm{k_A = 45\ W/m.K}$

$\mathrm{k_B = 0.48\ W/m.K}$

$\mathrm{k_C = 16\ W/m.K}$

$\Delta \mathrm{T = 133.4 - 25}$

$$q = \frac{2\pi l(T_1 - T_4)}{\frac{\ln(r_2/r_1)}{k_A} + \frac{\ln(r_3/r_2)}{k_B} + \frac{\ln(r_4/r_3)}{k_C}}$$

$\mathrm{q = 82.32\ Watt}$

The heat losses from the boiler is $\mathrm{q = 82.32\ W}$

3.4 Hand Pump

3.4.1 Introduction

Hand pumps are manually operated pumps, they use human power and mechanical advantage to move fluids or air from one place to another. They are widely used in every country in the world for a variety of industrial, marine, irrigation and leisure activities. There are many different types of hand pump available, mainly operating on a piston, diaphragm or rotary vane principle with a check valve on the entry and exit ports to the chamber operating in opposing directions. Most hand pumps have plungers or reciprocating pistons, and are positive displacement.

3.4.2 Working Principle of the Hand Pump

The simple hand pump works by using input and output ports, check valves, cylinder, piston, seal and handle, see Fig.4.4.1. The working principle of the pump as the following:

1) Suction: The fluid entrance in the pump by input port when the handle move clockwise (backward), the piston in the intake stroke.

2) Discharge: The fluid exits from the pump by output port when the handle move counter - clockwise (inward), the piston in the exhaust stroke.

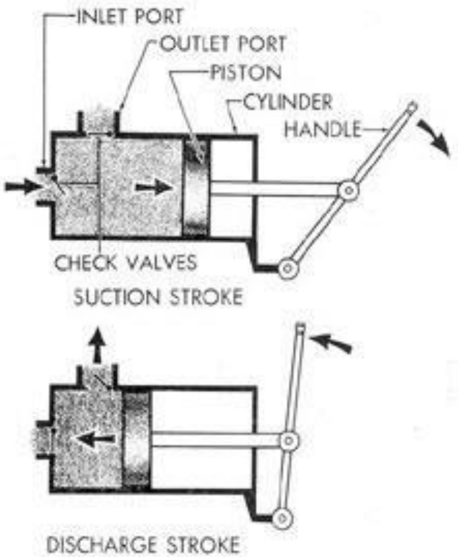


Fig.4.4.1: The simple hand pump

3.4.3 Pump Components

As shown in the Fig.4.4.1 the components of the simple hand pump, which contains:

1) **Body and Cylinder**: The body and cylinder connected with each other by welding. The diameter of the cylinder is 1.5" and the length of the cylinder is 12cm, the type of material for the cylinder and body is brass to prevent corrosion.
2) **Piston**: The type of material used for the piston is aluminum, the length of the piston is 5cm and the diameter of the piston is less than 1.5" so to maintain the clearance distance.
3) **Ring**: The purpose of using ring is to prevent leakage.
4) **Oneway Valve**: The purpose of using oneway valve or (check valve) is to make liquid passing in on direction and prevents return of fluid. The diameter of the check valve is 0.5".
5) **Lever**: The type of the material used is steel. The purpose of using lever is to moving the piston to make suction and discharge.

3.4.4 Design Analysis :

The mass flow rate of the hand pump can be find as the following:

$$\dot{m}_{pump} = \frac{\pi}{4} d^2 \times N \times l \times \mu_o \qquad (3.4.1)$$

$$\mu_o = \mu_v \times \mu_m \qquad (3.4.2)$$

$$\mu_v = \frac{Q_a}{Q_{th}} \qquad (3.4.3)$$

$$\mu_m = \frac{T_{th}}{T_a} \qquad (3.4.1)$$

Where

N: Number of moving lever (suction and dischrage)

d: Piston diameter. (m)

l: Cylinder length. (m)

μ_o: Overall efficiency

μ_v: Volumetric efficiency

μ_m: Mechanical efficiency

Q_{th}: Theoritical flow rate

Q_a: Actual flow rate

T_{th}: Theoritical tourq

T_a: Actual tourq

3.5 Tube

3.5.1 Introduction

Copper tubing is most often used for supply of hot and cold tap water, and as refrigerant line in HVAC systems. There are two basic types of copper tubing, soft copper and rigid copper. Copper tubing is joined using flare connection, compression connection, or solder. Copper offers a high level of corrosion resistance, but is becoming very costly.

3.5.2 Advantages of Copper Tube

Strong, corrosion resistant, copper tube is the leading choice of modern contractors for plumbing, heating and cooling installations in all kinds of residential and commercial buildings. There are seven primary reasons for this [6]:

1) Economical.

The combination of easy handling, forming and joining permits savings in installation time, material and overall costs. Long term performance and reliability mean fewer callbacks, and that makes copper the ideal cost-effective tubing material.

2) Lightweight.

Copper tube does not require the heavy thickness of ferrous or threaded pipe of the same internal diameter. This means copper costs less to transport, handles more easily and, when installed, takes less space.

3) Formable.

Because copper tube can be bent and formed, it is frequently possible to eliminate elbows and joints. Smooth bends permit the tube to follow contours and corners of almost any angle.

4) Easy to join.

Copper tube can be joined with capillary fittings. These fittings save material and make smooth, neat, strong and leak-proof joints. No extra thickness or weight is necessary to compensate for material removed by threading.

5) Safe.

Copper tube will not burn or support combustion and decompose to toxic gases. Therefore, it will not carry fire through floors, walls and ceilings.

6) Resists corrosion.

Excellent resistance to corrosion and scaling assures long, trouble-free service, which means satisfied customers.

3.5.3 Design Formulas

1) Tank to pump and boiler:

$$V_{disp.} = \frac{\pi}{4} \times {d_P}^2 \times l \tag{3.5.1}$$

$$N = \frac{V}{V_{disp}} \tag{3.5.2}$$

$$Q = \frac{V}{t} \tag{3.5.3}$$

$$Q = v \times A \tag{3.5.4}$$

$$A = \frac{\pi}{4} \times D^2 \tag{3.5.5}$$

Where

V_{disp}: Pump volumetric diplacement (l)

d_P: Piston pump diameter (m)

l: Strok diameter (m)

N: The required number of moving piston

Q: Flow rate (l/s)

v: Water speed in the tube (m/s)

A: Tube area (m)

D: Tube diameter (m)

2) Tube between boiler and turbine

$$\dot{m} = \rho \times v \times A \tag{3.5.6}$$

Other equations, listed in last sections.

Where

$\dot{\mathrm{m}}$: Boiler flow rate $(\mathrm{m}^3/\mathrm{s})$

ρ: Steam density $(\mathrm{kg}^3/\mathrm{m}^3)$

v: Steam speed in tube (m/s)

3.5.4 Design Analysis

1) Tube between the tank, pump and boiler

$$V_{disp.} = \frac{\pi}{4} \times {d_P}^2 \times l$$

The piston diameter $= 0.03675$ (m) and the stroke length $= 0.05$ (m)

$$\mathrm{V_{disp.}} = \frac{\pi}{4} \times (0.03675)^2 \times 0.05 = 0.00053\ (\mathrm{m}^3) = 0.053(\,\mathrm{l})$$

Assume the volume of the water used in the boiler = 2.5 (l), the number requires to achive that volume is:

$$\mathrm{N} = \frac{2.5}{0.053} = 47 \text{ times}$$

Assume the time requires to move the piston in one round $= 3$ (s), so the time requires for $\mathrm{N} = 47$ is $\mathrm{t} = 3 \times 47 = 141$ (s)

$$\mathrm{Q} = \frac{2.5}{141} = 0.017\ (\mathrm{l}) = 0.000017\ (\mathrm{m}^3)$$

Assume the speed of water in tube $\mathrm{v} = 1\ (\mathrm{m/s})$

$0.000017 = 1 \times \mathrm{A}$

$\mathrm{A} = 0.000017\ (\mathrm{m}^2)$

$0.000017 = \frac{\pi}{4} \times \mathrm{D}^2$

$\mathrm{D} = 0.005\ (\mathrm{m}) = 0.204\ (\mathrm{in})$

The type used is K

According to table of dimenssion and charactarestics of copper tube K type in appendix A table 2a.

$\mathrm{D} = 0.305$ in the standard size is $\mathrm{D} = {}^{1}/_{4}$

2) Between boiler and turbine

The inlet diameter of tube from the boiler to the turbine is standard which is $\mathrm{D} = {}^{3}/_{16}$ and this value obtained from the company that produced the turbine.

CHAPTER FOUR

Secondary Components

Contents:

4 The Secondary Components

4.1 Pressure Gauge

Pressure gauge or barometer is a device used to measure the pressure of the water, steam, etc. The pressure gauge used to measure pressure in the boiler pressure range 0 to 10 bar. Also, the pressure in all relevant system is opened to the atm.

Fig.4.1: Pressure gauge

4.2 RPM Sensor

It used to measure turbine speed and display reading by digital display screen (Tachometer). Its reading value between 60-9999 rpm.

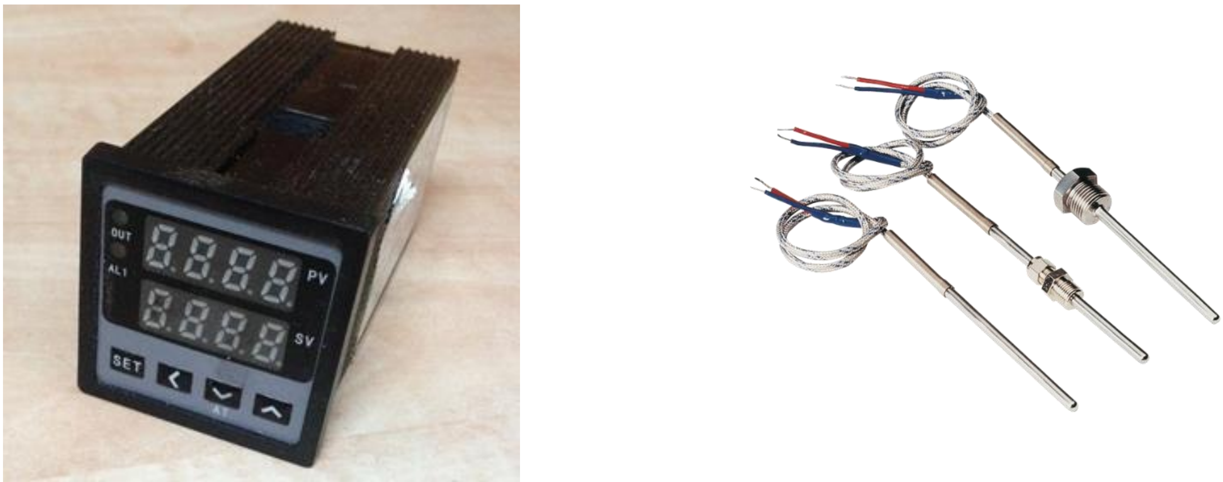
Fig.4.2: Rpm sensor with digital display screen

4.3 Temperature Sensors

Thermocouple J-type sensor in boiler, which require digital indicator. A thermocouple is a sensor for measuring temperature. It consists of two dissimilar metals, joined together at one end. When the junction of the two metals is heated or cooled a voltage is produced that can be correlated back to the temperature. The thermocouple alloys are commonly available as wire.

Technical specification for J-type sensor:

1) Temperature range 0^o: to 750^o C
2) Alloy combination : +lead (Iron Fe) and –lead(Copper-Nickel Cu-Ni)
3) Standard limits of error above 0^oC : greater of 2.2^oC or 0.4%



(a) **(b)**

Fig.4.3: a) Digital indicator. b) Thermocouple sensor

4.4 Voltage Indicator

Voltage indicator is a device that indicates the output volt from the generator by connection wires.

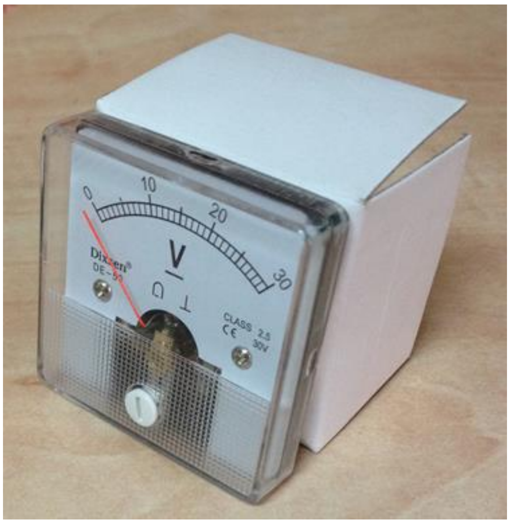


Fig.4.4: Mechanical volt indicator

4.5 Ampere Indicator

Ampere indicator is a device indicates the output ampere from the generator by connection wires.

Fig.4.5: Mechanical ampere indicator

4.6 Switch

It used to switch between the temperature sensors, which provides different values by the same digital indicator.

Fig.4.6: Switch

4.7 DC Generator

Generator is a device that directly convert mechanical energy into electrical energy by incorporating a miniature permanent-magnet generator. The mechanical input power could be derived from intermittent movements, which might be associated with the random motion of a limb. Linear permanent-magnet generators systems which are capable of extracting and storing energy from both reciprocating and intermittent motion.

The output power of the turbine between 10 -15 watt, the required generator power is near the power of the turbine but the available one is less than the required type. Its speed approximately reaches 4500 rpm. The speed reduction between the turbine and generator is 1.5 that achieved by two pulleys, the turbine pulley is 25 mm and the generator pulley 37.5 mm.

Fig. 4.7: DC generator

4.8 Lamps

Lamps used to prove the working of cycle by converting the thermal and mechanical power into electrical power.

Fig 4.8: Lamps

CHAPTER Five

Experiment Procedure and Results

Contents:

5.1 Purpose of the Experiment

The aim of this experiment is to understand the Rankine cycle system with the details of each component, conduct the experiment and gather data analyze the system with obtained data.

5.2 Components of the System

Fig.5.1 illustrates the whole components of the system. Each component explained in last chapters

Fig.5.1:Project components

1) Boiler

As shown in the Fig.5.2 the boiler with its components. The boiler contains two relief valves, one of them open when the pressure reaches 4 bar abs and the other one can be adapted up to 8 bar.

Fig.5.2: Boiler

2) **Steam Turbine**

The steam turbine, shown in the Fig.5.3 which consists the following major components:

1. The housing and base is CNC'd from Aluminum 6061-T6.
2. The turbine blades and nozzle are machined from solid brass.
3. The steam exhaust is 1" copper pipe.

Fig.5.3:Steam turbine

3) Condenser

The condenser, shown in the Fig.5.4, is counter flow double pipe condenser.

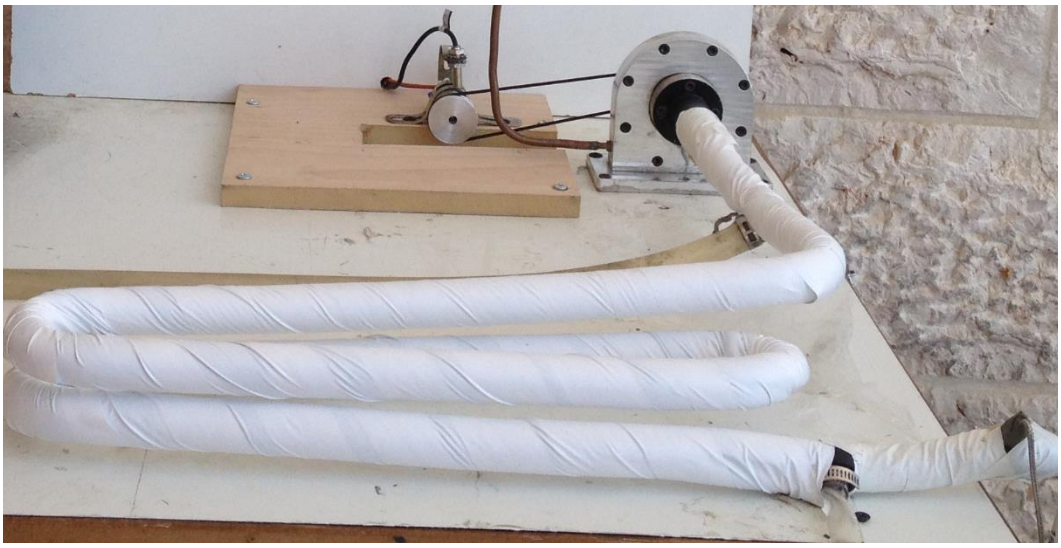


Fig.5.4: Surface and double pipe heat exchanger

4) Feed Pump

The feed pump, shown in the Fig.5.5, is simple hand pump. It can be work when the boiler pressure is 1 bar abs.

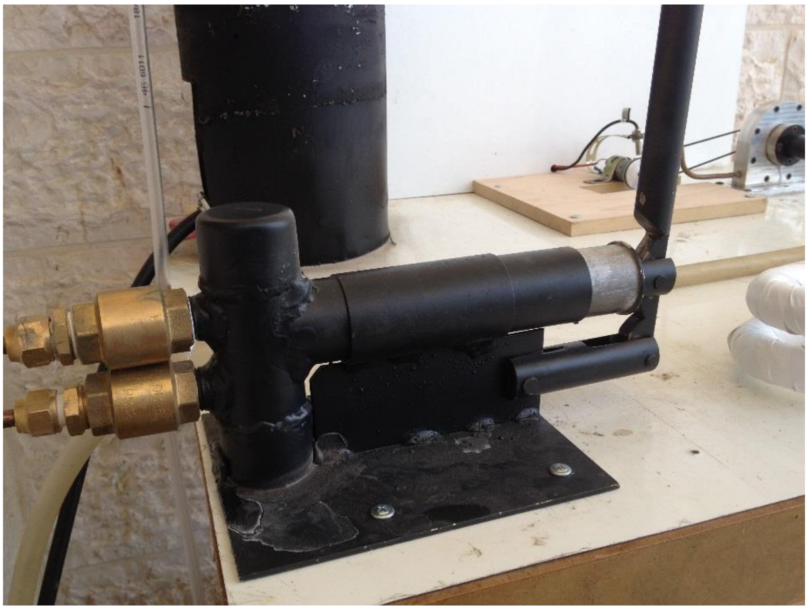


Fig.5.5: Simple hand pump

5.3 Experiment Procedure

Follow these steps to operate Rankine cycle system:

1. Fill the boiler with 3 liters of water.
2. Close the steam admission valve.
3. Open fuel source.
4. Increase or decrease the amount of gas as required.
5. Turn digital screens on, to obtain experiment values.
6. Wait until pressure in the boiler reaches 3 bar. Open the admission valve to drop pressure to 2 bar then close the valve.
7. Repeat the process above.
8. When pressure reaches 3 bar again, open the valve slowly without decreasing pressure too much.
9. Write the temperature readings in system components, switch between readings using switch.

10. Open the load switch (lamp) and write the output readings
11. Repeat the process for accurate readings.
12. Finish the experiment by close gas valve and open the steam admission valve till the turbine stops.

5.4 Calculations

In this experiment we calculate the efficiency of the cycle and the relationship between the volt and RPM. Below shows the data collected :

The lamp resistance is 1 ohm

$T_{sat,\ actua}$ (℃)	Pressure (bar gauge)	T_1 (℃)	T_2 (℃)	T_3 (℃)	T_4 (℃)	T_{in} (℃)	Volt (v)	Rpm	Water flow rate (l/min)
133.6	2	131.8	96.3	41.8	58.9	23.1	2.02	2384	1.2
133.6	2	131.8	96.1	42.1	60.1	22.9	1.05	1512	1.2
138.6	2.5	137.5	97.2	43.1	36.9	23	3.87	3647	1.2
138.6	2.5	137.6	97.2	42.9	62.7	23	2.1	2813	1.2
140.6	2.7	141.7	96.8	41.2	68.1	39.7	2.51	2712	3
143.6	3	142.8	98	43.3	71.2	42.4	1.45	1932	3

Where

T_1: Steam temperature in the boiler

T_2: Temperature after turbine

T_3: Condensed steam temperature

T_4: Temperature out from condenser

T_{in}: Temperature of water enters to the condenser

According to saturated steam tables and using interpolations, we obtain the following data: where $h_1 = h_{f@\ 1\ bar} = 417.51$ (kJ/kg)

Pressure (bar gauge)	h_1	h_2	h_3	h_4 (kJ/kg)
2	417.5	419.59	1426.9	1318.26
2	417.5	419.59	1426.9	1316.38
2.5	417.5	420.11	1442.69	1326.75
2.5	417.5	420.11	1442.69	1326.75
2.7	417.5	420.32	1449.006	1322.98
3	417.5	420.63	1458.48	1334.30

Pressure (bar gauge)	q_{in}	w_{out}	q_{out}	$w_{net} = w_{out}$	μ_{cycle} (%)
2	1007.3	108.6	900	108.63	10.7
2	1007.3	110.5	898	110.52	10.9
2.5	1022.5	115.9	909.	115.93	11.3
2.5	1022.5	115.9	909	115.93	11.3
2.7	1028.6	126.02	905	126.02	12.2
3	1037.8	124.1	916	124.17	11.9

CHAPTER SIX

CONCLUSIONS RECOMMENDATIONS AND PROBLEMS

Contents:

6.1 Conclusion

The efficiency of the cycle is approximately 10% and this efficiency is low because the losses in the system components, the working pressures are low which approximately 2 bar and this cycle is basic not improved cycle.

6.2 Recommendations

1. This project is a prototype. Which simulates the large stations and contains the basic components. The basic cycle effects on the efficiency of cycle, so we recommend that the efficiency can be increase by using one of improvement ways:

    a. Reheat cycle.
    b. Regenerative cycle.

2. Not available gas flow meter makes problem with boiler calculations, so we recommend to use gas flow meter.

6.3 Problems

The problem with this project is affected by environmental conditions because the project is small prototype and the percent of error in sensors reading.

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Appendix

TABLE A–5

Saturated water—Pressure table

		Specific volume, m³/kg		*Internal energy,* kJ/kg			*Enthalpy,* kJ/kg			*Entropy,* kJ/kg · K		
Press., P kPa	Sat. temp., T_{sat} °C	Sat. liquid, v_f	Sat. vapor, v_g	Sat. liquid, u_f	Evap., u_{fg}	Sat. vapor, u_g	Sat. liquid, h_f	Evap., h_{fg}	Sat. vapor, h_g	Sat. liquid, s_f	Evap., s_{fg}	Sat. vapor, s_g
1.0	6.97	0.001000	129.19	29.302	2355.2	2384.5	29.303	2484.4	2513.7	0.1059	8.8690	8.9749
1.5	13.02	0.001001	87.964	54.686	2338.1	2392.8	54.688	2470.1	2524.7	0.1956	8.6314	8.8270
2.0	17.50	0.001001	66.990	73.431	2325.5	2398.9	73.433	2459.5	2532.9	0.2606	8.4621	8.7227
2.5	21.08	0.001002	54.242	88.422	2315.4	2403.8	88.424	2451.0	2539.4	0.3118	8.3302	8.6421
3.0	24.08	0.001003	45.654	100.98	2306.9	2407.9	100.98	2443.9	2544.8	0.3543	8.2222	8.5765
4.0	28.96	0.001004	34.791	121.39	2293.1	2414.5	121.39	2432.3	2553.7	0.4224	8.0510	8.4734
5.0	32.87	0.001005	28.185	137.75	2282.1	2419.8	137.75	2423.0	2560.7	0.4762	7.9176	8.3938
7.5	40.29	0.001008	19.233	168.74	2261.1	2429.8	168.75	2405.3	2574.0	0.5763	7.6738	8.2501
10	45.81	0.001010	14.670	191.79	2245.4	2437.2	191.81	2392.1	2583.9	0.6492	7.4996	8.1488
15	53.97	0.001014	10.020	225.93	2222.1	2448.0	225.94	2372.3	2598.3	0.7549	7.2522	8.0071
20	60.06	0.001017	7.6481	251.40	2204.6	2456.0	251.42	2357.5	2608.9	0.8320	7.0752	7.9073
25	64.96	0.001020	6.2034	271.93	2190.4	2462.4	271.96	2345.5	2617.5	0.8932	6.9370	7.8302
30	69.09	0.001022	5.2287	289.24	2178.5	2467.7	289.27	2335.3	2624.6	0.9441	6.8234	7.7675
40	75.86	0.001026	3.9933	317.58	2158.8	2476.3	317.62	2318.4	2636.1	1.0261	6.6430	7.6691
50	81.32	0.001030	3.2403	340.49	2142.7	2483.2	340.54	2304.7	2645.2	1.0912	6.5019	7.5931
75	91.76	0.001037	2.2172	384.36	2111.8	2496.1	384.44	2278.0	2662.4	1.2132	6.2426	7.4558
100	99.61	0.001043	1.6941	417.40	2088.2	2505.6	417.51	2257.5	2675.0	1.3028	6.0562	7.3589
101.325	99.97	0.001043	1.6734	418.95	2087.0	2506.0	419.06	2256.5	2675.6	1.3069	6.0476	7.3545
125	105.97	0.001048	1.3750	444.23	2068.8	2513.0	444.36	2240.6	2684.9	1.3741	5.9100	7.2841
150	111.35	0.001053	1.1594	466.97	2052.3	2519.2	467.13	2226.0	2693.1	1.4337	5.7894	7.2231
175	116.04	0.001057	1.0037	486.82	2037.7	2524.5	487.01	2213.1	2700.2	1.4850	5.6865	7.1716
200	120.21	0.001061	0.88578	504.50	2024.6	2529.1	504.71	2201.6	2706.3	1.5302	5.5968	7.1270
225	123.97	0.001064	0.79329	520.47	2012.7	2533.2	520.71	2191.0	2711.7	1.5706	5.5171	7.0877
250	127.41	0.001067	0.71873	535.08	2001.8	2536.8	535.35	2181.2	2716.5	1.6072	5.4453	7.0525
275	130.58	0.001070	0.65732	548.57	1991.6	2540.1	548.86	2172.0	2720.9	1.6408	5.3800	7.0207
300	133.52	0.001073	0.60582	561.11	1982.1	2543.2	561.43	2163.5	2724.9	1.6717	5.3200	6.9917
325	136.27	0.001076	0.56199	572.84	1973.1	2545.9	573.19	2155.4	2728.6	1.7005	5.2645	6.9650
350	138.86	0.001079	0.52422	583.89	1964.6	2548.5	584.26	2147.7	2732.0	1.7274	5.2128	6.9402

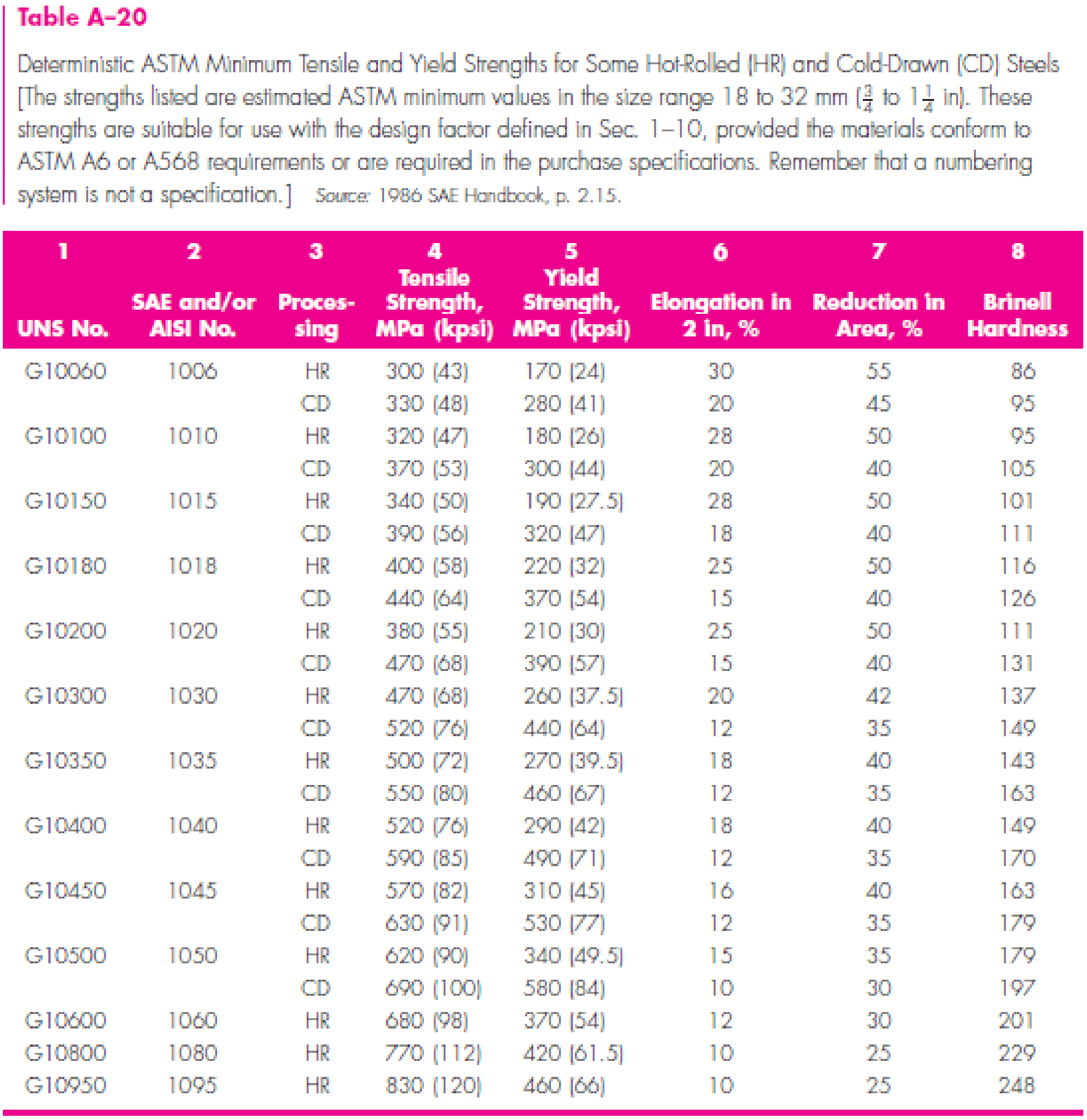

Table A–20

Deterministic ASTM Minimum Tensile and Yield Strengths for Some Hot-Rolled (HR) and Cold-Drawn (CD) Steels [The strengths listed are estimated ASTM minimum values in the size range 18 to 32 mm ($\frac{3}{4}$ to $1\frac{1}{4}$ in). These strengths are suitable for use with the design factor defined in Sec. 1–10, provided the materials conform to ASTM A6 or A568 requirements or are required in the purchase specifications. Remember that a numbering system is not a specification.] *Source:* 1986 SAE Handbook, p. 2.15.

1 UNS No.	2 SAE and/or AISI No.	3 Processing	4 Tensile Strength, MPa (kpsi)	5 Yield Strength, MPa (kpsi)	6 Elongation in 2 in, %	7 Reduction in Area, %	8 Brinell Hardness
G10060	1006	HR	300 (43)	170 (24)	30	55	86
		CD	330 (48)	280 (41)	20	45	95
G10100	1010	HR	320 (47)	180 (26)	28	50	95
		CD	370 (53)	300 (44)	20	40	105
G10150	1015	HR	340 (50)	190 (27.5)	28	50	101
		CD	390 (56)	320 (47)	18	40	111
G10180	1018	HR	400 (58)	220 (32)	25	50	116
		CD	440 (64)	370 (54)	15	40	126
G10200	1020	HR	380 (55)	210 (30)	25	50	111
		CD	470 (68)	390 (57)	15	40	131
G10300	1030	HR	470 (68)	260 (37.5)	20	42	137
		CD	520 (76)	440 (64)	12	35	149
G10350	1035	HR	500 (72)	270 (39.5)	18	40	143
		CD	550 (80)	460 (67)	12	35	163
G10400	1040	HR	520 (76)	290 (42)	18	40	149
		CD	590 (85)	490 (71)	12	35	170
G10450	1045	HR	570 (82)	310 (45)	16	40	163
		CD	630 (91)	530 (77)	12	35	179
G10500	1050	HR	620 (90)	340 (49.5)	15	35	179
		CD	690 (100)	580 (84)	10	30	197
G10600	1060	HR	680 (98)	370 (54)	12	30	201
G10800	1080	HR	770 (112)	420 (61.5)	10	25	229
G10950	1095	HR	830 (120)	460 (66)	10	25	248

Table A–20

Deterministic ASTM Minimum Tensile and Yield Strengths for Some Hot-Rolled (HR) and Cold-Drawn (CD) Steels [The strengths listed are estimated ASTM minimum values in the size range 18 to 32 mm ($\frac{3}{4}$ to $1\frac{1}{4}$ in). These strengths are suitable for use with the design factor defined in Sec. 1–10, provided the materials conform to ASTM A6 or A568 requirements or are required in the purchase specifications. Remember that a numbering system is not a specification.] *Source:* 1986 SAE Handbook, p. 2.15.

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G10060	1006	HR	300 (43)	170 (24)	30	55	86
		CD	330 (48)	280 (41)	20	45	95
G10100	1010	HR	320 (47)	180 (26)	28	50	95
		CD	370 (53)	300 (44)	20	40	105
G10150	1015	HR	340 (50)	190 (27.5)	28	50	101
		CD	390 (56)	320 (47)	18	40	111
G10180	1018	HR	400 (58)	220 (32)	25	50	116
		CD	440 (64)	370 (54)	15	40	126
G10200	1020	HR	380 (55)	210 (30)	25	50	111
		CD	470 (68)	390 (57)	15	40	131
G10300	1030	HR	470 (68)	260 (37.5)	20	42	137
		CD	520 (76)	440 (64)	12	35	149
G10350	1035	HR	500 (72)	270 (39.5)	18	40	143
		CD	550 (80)	460 (67)	12	35	163