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Research title:

THERMO-ECONOMIC ANALYSIS OF STEAM PLANTS: CASE STUDY (KHARTOUM NORTH POWER STATION)

تحليل حراري – اقتصادي للمحطات البخارية

دراسة حالة محطة الخرطوم شمال الحرارية

A project submitted in partial fulfillment of the degree of B.Eng. (honor) in Mechanical engineering (power)

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الأية

قال تعالى : (إن في خلق السموات والأرض و إختلاف الليل والنهار والفلك التي تجري في البحر بما ينفع الناس وما أنزل الله من السماء من ماء فأحيا به الأرض بعد موتها وبث فيها من كل دابة وتصريف الرياح و السحاب المسخر بين السماء والأرض لأيات لقوم يعقلون). صدق الله العظيم (البقرة 164)

Dedication

To our parents who gives us first light in our life,

To our friends who gives us a company,

To our colleagues whom draw with us future steps,

To our Islamic movement which learn us the value of the life.

Acknowledgement

First of all we would like to submit our best greeting to our supervisor Dr.ABDAALAH MOKHTAR for his acceptance to supervise our research and for his directions during preparing this research. Also our full respect and appreciation to Eng. ABUBKR AHMED for his support. Finally, a lot of thanks to Khartoum North Power Station Directorate which gives us permeations to apply this research and analysis in the station and have been supplying us by all data we needed throughout the research.

Abstract

The power industries, especially thermal power plants, have large energy consumptions, which play an important role in energy conversion. In this study, the energy and economic analysis of Khartoum North power plant is presented. The primary Objectives of this research are to analyze the system components separately and to identify and quantify the energy. In addition, the effect of operation condition change will be presented. The study founded that increasing the mass flow rate of steam entering the boiler from 8.67kg/s to 10kg/s will increase the efficiency about 7.26% and increase power about 1.7MW and will effect in the fuel flow rate and increase the cost of fuel about 9$/hr.

Since the efficiency of the plant is fundamentally limited by the ratio of the temperatures of the steam at turbine input and output, efficiency improvements require use of higher temperature, and therefore higher pressure steam throughout the study find that increasing the temperature at the outlet of the boiler from 811k to 850k will increase the efficiency about 2.13% and the power out of the turbine will increase about 0.5MW also will rise the cost of fuel 8$/hr.

المستخلص

تستهدف محطات القدرة الحرارية كميات كبيرة من الطاقة تختص هذه الدراسة بتحليل حراري إقتصادي لمحطة الخرطوم شمال الحرارية والهدف الأساسي من الدراسة هو معرفة تأثير تغير ظروف التشغيل على أداء المحطة. حيث وجد أن زيادة معدل التدفق الكتلي من (8.67 kg/s – 10 kg/s) يزيد قيمة الكفاءة بنسبة 7.26% والقدرة الناتجة بمقدار MW1.7 وترتفع تكلفة الوقود في الساعة 9 دولار .

بما إن الكفاءة الحرارية تعتمد على درجة الحرارة والضغط عند مدخل ومخرج التوربينة فتحسين الكفاءة يكون برفع درجة الحرارة و كذلك الضغط الداخل للتوربينة . ولذلك وجد أنه عندما ترتفع درجة الحرارة عند مدخل التوربينة من 811 كلفن إلى 850 كلفن ستزيد الكفاءة بمقدار 2.13% وستزيد القدرة الناتجة بمقدار .5 ميغاوات وسترتفع تكلفة الوقود في الساعة بمقدار 8 دولار .

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LIST OF SYMBOLS

Qin	Amount of heat addition (KJ/Kg)
Wnet	Net work (KJ/Kg)
Hth	Thermal efficiency
Qout	Amount of heat rejection (KJ/Kg)
Wout	The outlet work (KJ/Kg)
Win	The inlet work (KJ/Kg)
Tl	Lower temperature (K)
T_H	Higher temperature (K)
FO	Fuel oil
Hin	Enthalpy at the inlet (KJ/Kg)
Hout	Enthalpy at the outlet (KJ/Kg)
$\dot{m}$	Mass flow rate (Kg/s)
P	Pressure (bar)

LIST OF ABBREIVIATION

KNPS	Khartoum north power station
KNPSP(3)	Khartoum north power station phase 3

CHAPTER ONE

INTRDUCTION

1.1 Background

Energy production of today's world calls for continuous efforts of efficiency improvement to comply with the arising awareness of the deleterious environmental impacts caused by traditional energy production methods, on the one hand, as well as to survive the growing economic challenges imposed by the advance of technology on the other hand. The augmentations in combustion efficiency and pollutant reduction have become the main concerns of combustion researchers in academic societies and of industrial manufacturers. In the combustion process, a reaction between the fuel and the oxidizer occurs to release heat (thermal energy) and consequently generate electricity. Current researchers focus on increasing combustion performance while reducing the emission of these pollutants. The most important factor driving the increasing focus on combustion performance is energy savings because the anticipated global energy demand is expected to rise by 58% between 2001 and 2025. Figure 1.1 shows the world's energy production by source [2]. From this Figure, we readily observe that the world's three main sources of energy are coal, natural gas and oil; each of which depends upon combustion. In the foreseeable future, these energy sources are expected to continue their domination. Although between 2001 and 2025 the global production of renewable energy is expected to rise by 8%, the expected annual growth of energy demand will rise by 1.9% [3, 4].

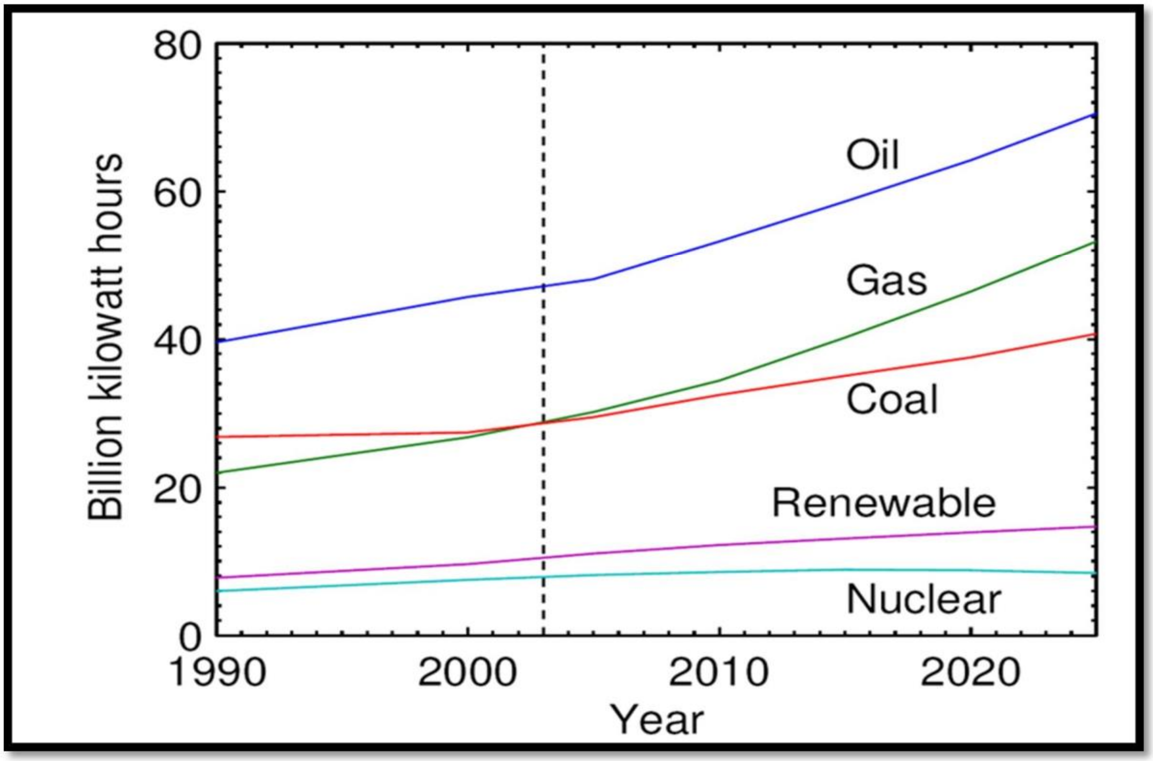


Figure 1.1: World energy productions by sources [1].

1.2 Problem statement

Current research and development was focused in analyzing, optimizing and evaluating thermal power plant. There are many methods and approaches to evaluate the power plant and decrease the cost of produce energy, one of which is thermal economic analysis. Analysis in the light of second law of thermodynamics to determine the actual efficiency and evaluate the performance of the plant with the lower production cost.

1.2 Objective of study

1. To Study Khartoum north power station steam cycle.
2. To Study the effect of boiler temperature and the mass flow rate on efficiency, power turbine and fuel cost.
3. Matlab and Excel programs used to evaluate the performance of the power plant.

1.4 Scope

Thermal economic analysis of the effect of the change in the temperature and mass flow in the boiler of (KNPS) phase 3 unit 6.

1.5 Significance of Research

It is important to ensure that the plant is operating on the maximum achievable efficiency. What motivates this work is the fact that it is not uncommon to find a plant running with an actual efficiency way below the nominal, or the optimum, efficiency due to the lack of real time tracking of changes in equipment performance, which means the incurrence of significant opportunity costs that could have been avoided.

1.6 Methodology:

1- An Excel and Matlab based static simulation model of Khartoum north Power station (KNPS) to be built and tested. The model, will be based on the first and second laws of thermodynamics (Energy and Mass Balance,), as well as the principles of engineering economic analysis.

2- The actual performance of (KNPS) to be evaluated by collecting the actual performance data and using the model to estimate the efficiency and all the key performance indicators.

3-Two main parameter will be proposed, modeled and evaluated to compare with the actual performance.

CHAPTER TWO

LITREATURE REVIEW & THEORATICAL APPROCH

2.1 Preface

A power plant is playing very important role in engineering field (also referred to as a generating station, power station, powerhouse, or generating plant) is an industrial facility for the generation of electric power. Most power stations contain one or more generators, a rotating machine that converts mechanical power into electrical power. The relative motion between a magnetic field and a conductor creates an electrical current. The energy source harnessed to turn the generator varies widely. Most power stations in the world burn fossil fuels such as coal, oil, and natural gas to generate electricity. Others use nuclear power, but there cleaner renewable sources such as solar, wind, wave and hydroelectric[6,7,8].A turbo machinery fired thermal power plants are producing most electric energy in the world; this type of plants operate on a deferent cycle and modes as a follow. The Brayton cycle was first proposed by George Brayton for use in the reciprocating oil-burning engine that he developed around 1870[1]. Today, it is used for gas turbines only where both the compression and expansion processes take place in rotating machinery. Gas turbines usually operate on an open cycle, Fresh air at ambient conditions is drawn into the compressor, where its temperature and pressure are raised. The high pressure air proceeds into the combustion chamber, where the fuel is burned at constant pressure. The resulting high-temperature gases then enter the turbine, where they expand to the atmospheric pressure while producing power. The exhaust gases leaving the turbine are thrown out (not recalculated), the cycle to be classified as an open cycle. The open gas-turbine cycle described above can be modeled as a closed cycle, by utilizing the air standard assumptions. Here the compression and expansion processes remain the same, but the combustion process is replaced by a constant-pressure heat-addition process from an external source, and the exhaust process is replaced by a constant pressure heat-rejection process to the ambient air. The processes taking place in power-generating systems are sufficiently complicated that idealizations are required to develop thermodynamic models. Such modeling is an important initial step in engineering design. They also provide relatively simple settings in which to discuss the functions and benefits of features intended to improve overall performance. The vast majority of electrical generating plants are variations of vapor power plants in which water is the working fluid. The basic components of a simplified fossil-fuel vapor power plant. To facilitate thermodynamic analysis, the overall plant can be broken down into the four major subsystems [9]. The continued quest for higher thermal efficiencies has resulted in rather innovative modifications to conventional power plants. The binary vapor cycle discussed later is one such modification. A more popular modification involves a gas power cycle topping a vapor power cycle, which is called the combined cycle power plant, or just the combined cycle. The combine cycle of greatest interest is the gas-turbine (Brayton) cycle topping a steam turbine (Rankine) cycle, which has a higher thermal efficiency than either of the cycles executed individually Gas-turbine cycles typically operate at considerably higher temperature than steam cycle.

2.2 Thermodynamic analysis:

It is also can be called energy and mass balance. Thermodynamic analysis is to study the theoretical thermodynamic effect of various variables (such as temperature, pressure and mass flow rate) on the system power output, thermal efficiency, secondary law efficiency, irreversibility and availability [5].

2.2.1 Energy analysis:

Energy analysis is used to determine the temperature profile in the plant. We need the properties of each point of the cycle to do the energy analysis which is done usually through the physical modeling. The major portion of this modeling consists of the application of the mass and energy balance equations [6].

2.2.2 Energy efficiency concept:

The basis for understanding the concept of energy efficiency is energy flow, from primary energy contained in energy carriers to the useful energy consumed through various activities of the society. Energy efficiency is all about tackling energy losses. Losses occur in processes of energy transformation, transmission, and distribution as well as in the final uses of energy. While reducing losses in the first three activities is mainly a matter of technology, the latest should be tackled by both technical and non-technical measures. Often unnecessary uses of energy could be avoided by better organization, better energy management and changes in consumers' behavior and increasingly so by changing lifestyle, which is the most difficult part.

Energy efficiency has to be considered as a continuous process that does not include only one-time actions to avoid excessive use of energy and to minimize energy losses, but also includes monitoring and controlling energy consumption with the aim of achieving continuous minimal energy consumption level. Avoiding excessive and unnecessary use of energy through regulation (e.g. building codes and minimal standards) and policies that stimulate behavior changes, Reducing energy losses by implementing energy efficiency improvement measures and new technologies monitoring energy consumption in order to improve knowledge on energy consumption patterns and their consequences (e.g. smart metering and real-time pricing) and Managing energy consumption by improving operational and maintenance practices. To ensure continuity of energy efficiency improvements, energy consumption has to be managed as any other activity. Actually, energy management can be denoted as a framework for ensuring continuous avoidance of excessive energy use and reduction of energy losses supported by a body of knowledge and adequate measuring. It should not only consider techno-economic features of energy consumption but should make energy efficiency an ongoing social process. It also rests on the fact that energy has to be priced in a manner that more accurately reflects its actual costs, which include, inter alia impacts on the environment, health and geopolitics, and that consumers have to be made aware of these consequences of energy use. These main pillars for achieving energy efficiency improvements have to be taken into account in the policy making process - "avoiding" and stimulation of "reducing" shall be a main driver in design of policy instruments, while for "monitoring" and "managing" implementing capacities with appropriate capabilities and supporting infrastructure shall be ensured [7].

2.3Efficiency laws

Efficiency is the (often measurable) ability to avoid wasting materials, energy, efforts, money, and time in doing something or in producing a desired result. In a more general sense, it is the ability to do things well, successfully, and without waste. In more mathematical or scientific terms, it is a measure of the extent to which input is well used for an intended task or function (output). It often specifically comprises the capability of a specific application of effort to produce a specific outcome with a minimum amount or quantity of waste, expense, or unnecessary effort. Specifically this text present most efficiencies uses in power plant analysis.

2.3.1 Thermal efficiency:

The fraction of the heat input that is converted to network output is a measure of the performance of a heat engine and is called the thermal efficiency (ηth). For heat engines, the desired output is the network output, and the required input is the amount of heat supplied to the working fluid. Then the thermal efficiency of a heat engine can be expressed as:

$$\eta th = \frac{Wnet}{Qin} \quad \text{(2-1)}$$

Since ($W_{net} = W_{out} - W_{in}$) It can also be expressed as:

$$\eta_{th} = 1 - Q_{out}/Q_{in} \qquad (2\text{-}2)$$

2.3.2 Carnot efficiency

The hypothetical heat engine that operates on the reversible manner cycle is called the Carnot heat engine. The thermal efficiency of any heat engine, reversible or irreversible, is given by equation (2-2). Where Q heat is rate transferred to the heat engine from a high temperature reservoir at T_H , and Q_{OUT} is rate heat rejected to a low temperature reservoir at T_l . For reversible heat engines, the heat transfer ratio in the above relation can be replaced by the ratio of the absolute temperatures of the two reservoirs. Then the efficiency of a Carnot engine, or any reversible heat engine, becomes

$$\eta_{th} = 1 - T_l/T_H \qquad (2\text{-}3)$$

2.3.3 Regenerative cycle

In the Rankine cycle it is observed that the condensate which is fairly at low temperature has an irreversible mixing with hot boiler water and this results in decrease of cycle efficiency.

Methods are, therefore, adopted to heat the feed water from the hot well of condenser irreversibly by interchange of heat within the system and thus improving the cycle efficiency. This heating method is called regenerative feed heat and the cycle is called regenerative cycle [8].

2.3.3.1 Open Feed water Heaters

An open (or direct-contact) feed water heater is basically a mixing chamber, where the steam extracted from the turbine mixes with the feed water exiting the pump. Ideally, the mixture leaves the heater as a saturated liquid at the heater pressure. The schematic of a steam power plant with one open feed water heater (also called single-stage regenerative cycle).

2.3.3.2 Closed Feed water Heaters

Another type of feed water heater frequently used in steam power plants is the closed feed water heater, in which heat is transferred from the extracted steam to the feed water without any mixing taking place. The two streams now can be at different pressures, since they do not mix.

2.4 Economic model:

Mathematical models are effective tools for analyzing systems or processes. They can be used to develop a new system or to evaluate the performance of an existing one. Mathematical modelling is widely applied to the solution of engineering problems. Modelling usually describes a system using a set of variables and equations and sets up relationships among the variables. Mathematical models are found to be very useful in solving problems related to process energy efficiency and can be utilized for both static and dynamic systems [7].

Due to finite natural resources and world increasing energy demand by developing countries, it becomes increasingly important to recognize the mechanisms that degrade energy and resources and to develop systematic approaches for improving the design of energy systems and reducing the impact on the environment. The second law of thermodynamics combined with economics represents very powerful tool for the systematic study and optimization of energy systems. This combination forms the basis of the relatively new field of thermo economic. Moreover, the economic model takes into account the costs of the component including the amortization and maintenance and the cost of the fuel combustion.

Differently from the literature in this paper the thermos-economic analysis of an operating thermal power cycle is conducted with the actual operating data taken from the power plant. Also, the calculation of energy and mass balance of each component are carried out and improvement suggestion are made [9].

The fuel cost is 90% of the real cost of producing energy in Khartoum north power station and the price of one ton of the fuel is 100$ dollars [25].

Fuel flow = Load / (43 x Efficiency) ……………………………(2.4)

Fuel Cost (fo) = FO flow (kg/s) x FO Price ($/t)

= FO flow (t/h) x 3,6 x FO price($/) ………..….(2.5)

So,

FO Cost ($/h) = Price ($/t) x Load (MW) / (43 x Efficiency)……. (2.6)

FO Cost ($/h) = Price ($/t) x3,6 /43 x Load/Efficiency

=,0 84 *price *Load / Efficiency ………………… (2.7)

2.5 Exergy analysis

Exergy is composed of two important parts. The first one is the physical exergy and the second one is the chemical exergy. The kinetic and potential parts of exergy are negligible. Exergy is defined as the maximum theoretical useful work that can be obtained as a system interacts with an equilibrium state. The chemical exergy is associated with the departure of the chemical composition of a system from its chemical equilibrium. The chemical exergy is an important part of exergy in combustion process**.**

Exergy analysis is a method that's uses the conservation of mass and energy principles together with the second law of thermodynamics for the analysis, design and improvement of energy and other systems [10]. Also, the exergy can play an important issue developing strategies and in providing guidelines for more effective use of energy in the existing power plants [11] and unlike energy, exergy is a measure of the quality of energy that can be considered to evaluate and optimize the system [12].

Exergy can be defined as the amount of obtainable work for a system when reaches to state of thermodynamic equilibrium with the surrounding through reversible processes [13]. The main goal of exergy analysis is to quantitatively detect and evaluate the thermodynamic inefficiencies of the process under consideration [13-15].

Many researches have carried out the exergy analysis for power plant. Rosen and Dincer performed a study of industrial steam heating process through exergy analysis. The result suggest that exergy analysis should be used as the central tool in process optimization when the use of the large quantities of the steam in energy centers is contemplated [16]. Ahmadi et Al. carried out energy, exergy and exergoeconomic analysis of a steam power plant in Iran. They also considered the effect of the load variation and ambient temperature in order to find the exergy destruction in each component of the cycle [15]. Dincer and al-muslim analyzed a Rankine cycle reheat steam power plant to study the energy and exergy efficiencies at different operating conditions with varying boiler temperature, boiler pressure mass fraction power generation systems and work output from the cycle [17] .Lior proposed a concept about future power generation systems and the role of exergy analysis in their development. He focused on exergy analysis which would be essential in the conception and development of such processes. Finally, he discussed about which kind of development is essential for the power generation units in the coming century. The results indicated that exergy analysis will help the designer to come up with a good decision on how to improve the system performance. In recent decades, thermodynamis and exergoeconmics have been increasingly utilized by researchers, combining thermodynamics with economics. Many such studies have been reported, especially for power generation [18].

Woudstra et Al. applied three different HRSG system design for the application of exergy analysis tools for the evaluating of alternative designs of combined cycle plants and carried out exergy destruction calculation for each component [19].

Petrackopulu et Al. analyzed a combined cycle power plant using both conventional and advanced exergetic analysis methods. Besides the classic exergy efficiency analysis, they also concluded the exergy analysis by splitting the exergy destruction term into avoidable, unavoidable, endogenous and exogenous parts [20]. Bagdanavicius et Al. carried out exergy, energy and exergoeconmic analysis of four community energy supply systems including combind cycle power plant using natural gas and found that CCPP is the most exergy efficient system with the lowest exergy costs of electricity and heat produced [21]. Kaviri et Al. analyzed the effect of mass flow rate and inlet gas temperature on the efficiency of the cycle. They find that, increasing the inlet temperature affect the efficiency positively until 6501c but after that point increasing the inlet temperature has a negative effect on the efficiency [22].

Sanjay and Prased compared the energy and exergy efficiencies of the combustion turbine based combined cycle and the intercooled combustion turbine. According to their study, thanks the intercooler the rational efficiency increase by 3.13% [23]. Sanjay has investigated the effect of variation of cycle parameters on rational efficiency and component exergy destruction of the plant. According to the paper, the most effective parameter on the cycle performance is turbine inlet temperature [23]. M.N. Lakhoua, M. Harrabi and M. Lakhoua analyzed that The performance of a thermal power plant will begin to decline as the thermal power plant begins to age. A good performance program will be able to identify these losses of the degradation of the heat rate. A more accurate knowledge of TPP heat rates can improve economic dispatching costs and ensure that profits are maintained on a daily basis [22].

Although exergy and exergoeconomic analyses are so important and indispensable in power generation, they cannot find the optimal design parameter in such systems. Therefore, using the optimization procedure with respect to thermodynamic law as well as thermo-economics is essential. In fact objectives in this regard involved in the design optimization process are as follows: thermodynamic (e.g. maximum efficiency, minimum fuel consumption, minimum irreversibility and so on), economic (e.g. minimum cost per unit of time, maximum profit per unit of production) [11].

2.6 Thermal power plant components:

From equation (2.2) the efficiency is depends on the Qin and Wnet.

$$\mathrm{Wnet} = \mathrm{Wout} - \mathrm{Win} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2.1)$$

2.6.1 Boiler:

Boilers are pressure vessels designed to heat water or produce steam, which can then be used to provide space heating and/or service water heating to a building. In most commercial building heating applications, the heating source in the boiler is a natural gas fired burner. Oil fired burners and electric resistance heaters can be used as well. Steam is preferred over hot water in some applications, including absorption cooling, kitchens, laundries, sterilizers, and steam driven equipment.

Both gas and oil fired boilers use controlled combustion of the fuel to heat water. The key boiler components involved in this process are the burner, combustion chamber, heat exchanger, and controls.

The burner mixes the fuel and oxygen together and, with the assistance of an ignition device, provides a platform for combustion. This combustion takes place in the combustion chamber, and the heat that it generates is transferred to the water through the heat exchanger. Controls regulate the ignition, burner firing rate, fuel supply, air supply, exhaust draft, water temperature, steam pressure, and boiler pressure.

Hot water produced by a boiler is pumped through pipes and delivered to equipment throughout the building, which can include hot water coils in air handling units, service hot water heating equipment, and terminal units. Steam boilers produce steam that flows through pipes from areas of high pressure to areas of low pressure, unaided by an external energy source such as a pump. Steam utilized for heating can be directly utilized by steam using equipment or can provide heat through a heat exchanger that supplies hot water to the equipment.

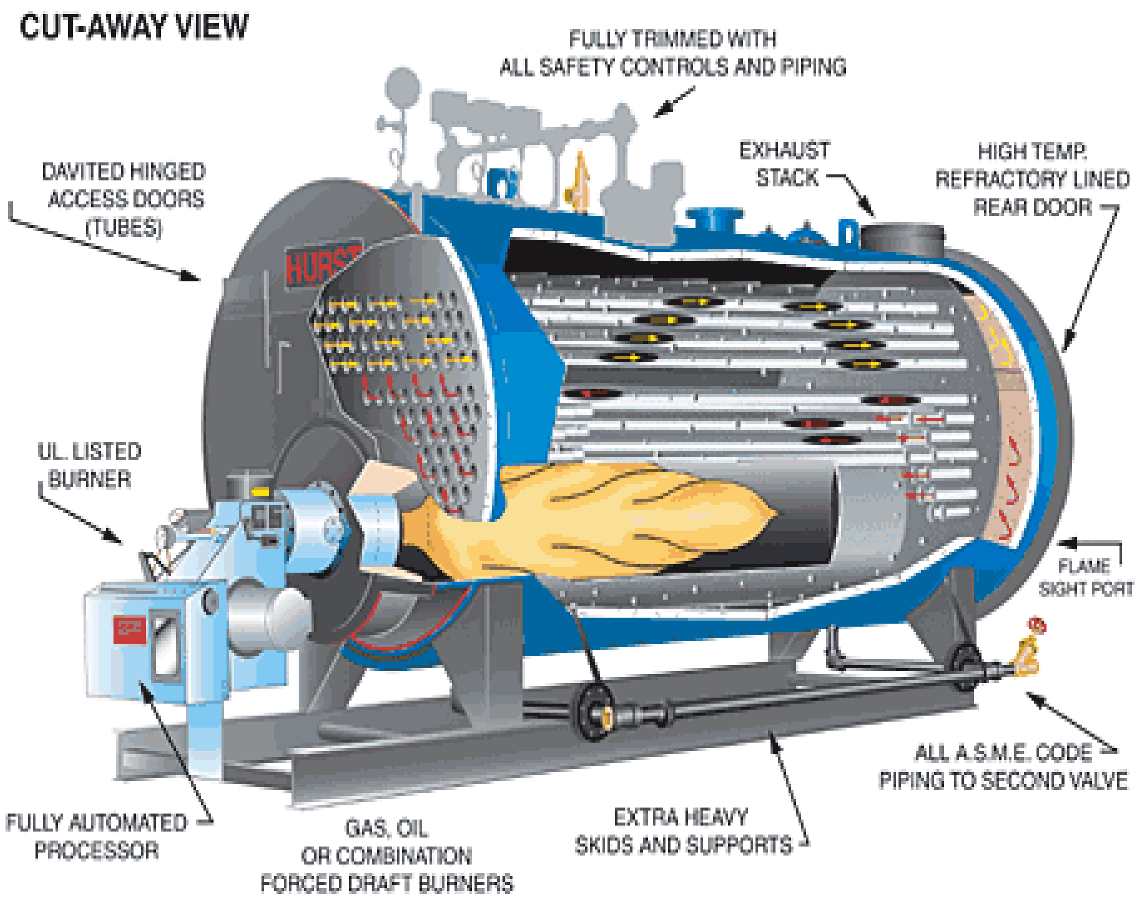


Figure 2.1: Firetube Boiler

2.6.2 Condenser:

The function of condenser is to condense the exhausted steam from turbine into water, it is an important equipment that create a certain vacuum at the steam exhausting port of turbine. Condenser is composed of condenser upper part, condenser lower part, front water chamber, rear water chamber, condensate water accumulator, spring supporting base and steam extraction pipe etc. The single-shell condenser adopts cooling-water double inlet and outlet surface welding structure. The laryngeal and LP casing are connected as one part; the base adopts spring support which can compensate the heat expansion of condenser in vertical direction. The side of rear water chamber at the bottom of condenser arranged with expansion joint which can compensate differential value of vertical heat expansion between condenser lower part and cooling pipe, and reduce the stress and pressure between condenser cooling pipe and welding part among pipes.

Assume fully adiabatic heat exchanging.

$Q_{out}=Q_{cond}=\dot{m}*c_p*(T_{cond,out} - T_{cond,in})$ ……………………… (2.8)

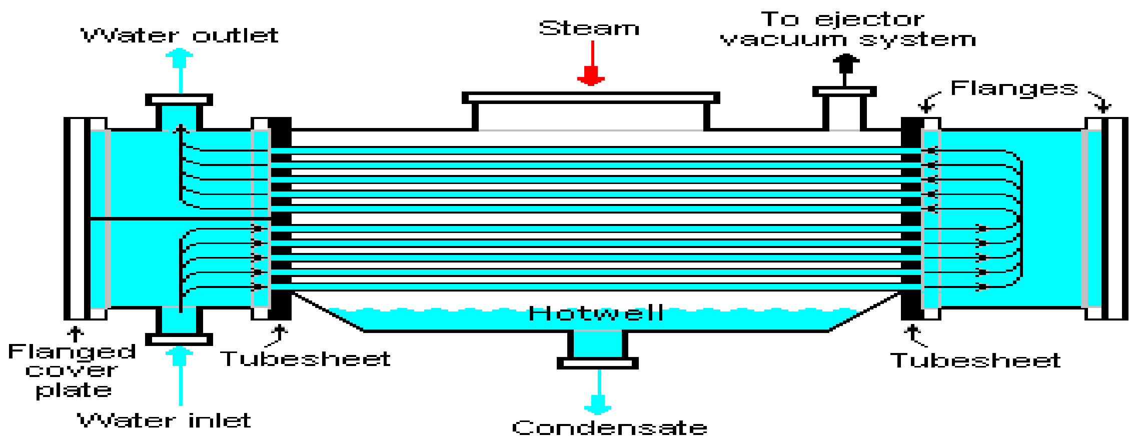


Figure 2.2: condenser

2.6.3 Turbine:

The steam turbine is a prime mover which drives other machines to rotate by converting heat potential energy of steam to mechanical energy. In order to ensure safe and economic operation of steam turbine, several accessory equipment’s shall be provided, which shall be connected by pipelines and valves to form steam turbine set. This steam turbine drives the generator to form the steam turbine generator set. Steam with relatively high pressure and temperature enters into the steam turbine through the main throttle valve and the control valve. Under the action of differential pressure between the inlet and outlet of steam turbine, steam flows towards the exhaust and the pressure temperature is decreasing, converting some electric hydraulic eat potential energy into mechanical energy. For the electric hydraulic eat economy consideration, when steam flows to different levels, certain volume of steam will be extracted out as regeneration system to heat condensation water and feed water. The condensing equipment is used to further reduce the pressure and temperature of exhaust steam, so as to improve efficiency of the unit which is equipped with regenerative electric hydraulic eating equipment to increase economy.

Assume fully adiabatic expansion flow and neglect mechanical transport and generator losses the power in turbine will be the different between the power out and power inter the turbine.

$\text{Wout}=\text{Wturbine} = \text{Hin} - \text{Hout}$ …………. (2.9)

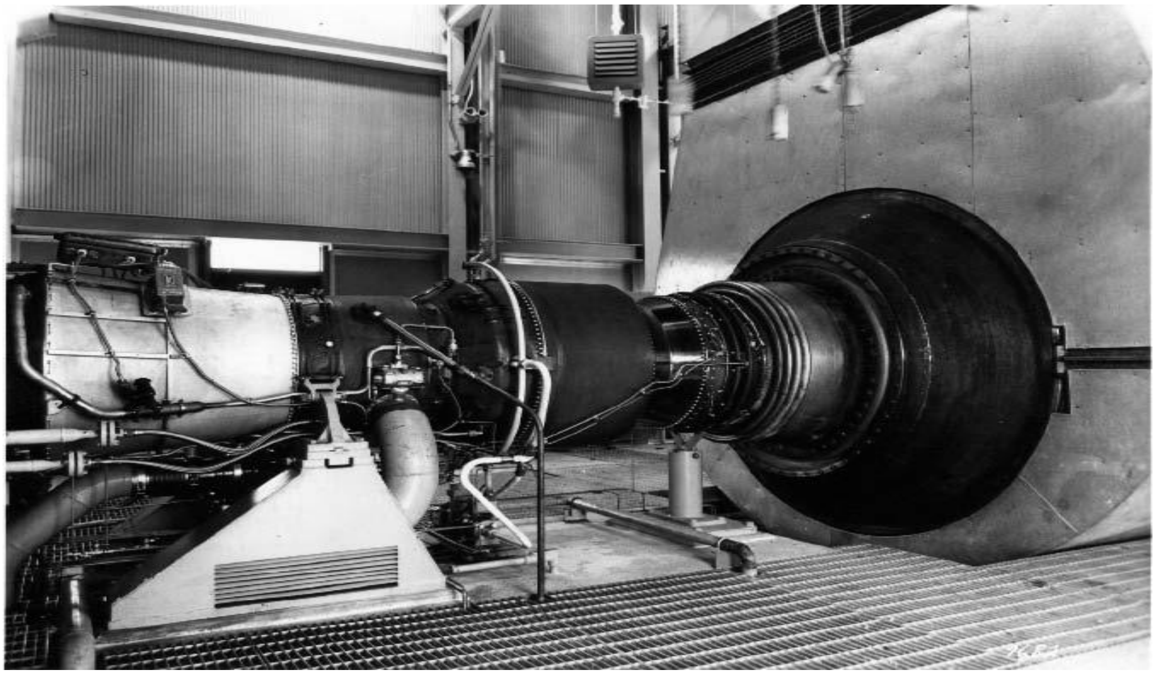


Figure 2.3: Turbine

2.6.4 Cooling tower:

The industrial mechanical draft cooling tower, applied for the axial flow fan, to suck cold airflow, which exchanges heat at the opposite direction with hot circle-water from spray nozzles of distribution system. Following is the principle: pump hot water needed onto the cooling tower top; then uniformly spray the water onto fillings through nozzles in the water distribution system so that hot water drops down from the fillings. At that moment, the suction force caused by the running fan lift the unsaturated air up to the filling area. The air flows up through the clearance of the fillings and exchange heat with hot water. The heat will be transferred to the outside of the cooling tower so that the water temperature in the tower could fall down.

2.6.5 Heater

2.6.5.1 HP Heater:

HP heater is vertical surface cooling type. Water side of each heater is equipped with safety valve to prevent the over pressure caused by the heat expansion under the situation of closing of the inlet and outlet valve at the water side. Steam side of heater is equipped with safety valve to protect the shell when pipes are broken. According to HEI standard, its minimum volume can pass 10% feed water flow with maximum load, or the water flow volume when one heater pipe is broken, take the larger one between the two. Temperature change rate of HP feed water is ≤4℃/min and does not affect the safety and life span of HP heater.

HP heater is composed of: water chamber, tube bank, shell etc Water chamber is composed of: man hole, feed water inlet valve, feed water outlet valve, air vent valve (water discharging valve is on tube plate), split-arranged diaphragms etc. tube bank is composed of: tube plate, water discharging valve of water chamber, air vent valve at shell side, heat exchange tube, diaphragm, deflecting baffle, draw bar, air extraction pipe, inner and outer shell of superheated steam section etc.

Shell is composed of: pedestal, steam inlet pipe, safety valve interface, drain outlet valve, emergency drainage outlet valve, continuous air vent valve, level gauge interface, balance vessel interface, interface of liquid level switch measuring tube, pressure gauge interface, spare ports etc.

2.6.5.2 LP HEATER

LP heater is important auxiliary equipment in steam turbine regenerative system; it extracts some of steam that has done work from steam turbine to heat main condensate water.

Water chamber is mainly composed of water chamber shell, water chamber end cover, inlet and outlet water pipes of main condensate water. Shell body is composed of top part, shell, cover head, connection pipe of water level alarm, connection pipe of level gauge, connection pipe of pressure differential former and connection pipe of safety valve.

CHAPTER THREE

METHDOLOGY

3.1 Environment description

Khartoum north power station is located at the north side of Khartoum. It consists of six units, these units are: units 1 and 2 which been constructed in 1983 by an England company so both of the units generate around 60 MW. Units 3 and 4 which generate 120 MW and they were also constructed by a British company in 1994. Finally, the units 5 and 6 generate 200 MW and they were a gift from the Chinese government [24].

Figure 3.1: illustrates the location of (KNPS)

3.2 Excel model

By excel model we can estimate the performance of the plant and comparing the performance with various changes in the plant. The model use the temperature, pressure and mass flow to determine the enthalpy at all component of the schematic diagram in figure (3.4). All the equations of the thermodynamic analysis and energy balance and economic equations are defined in excel to calculate the required output (efficiency, output work and fuel cost) which is shown in figure (3.2) below.

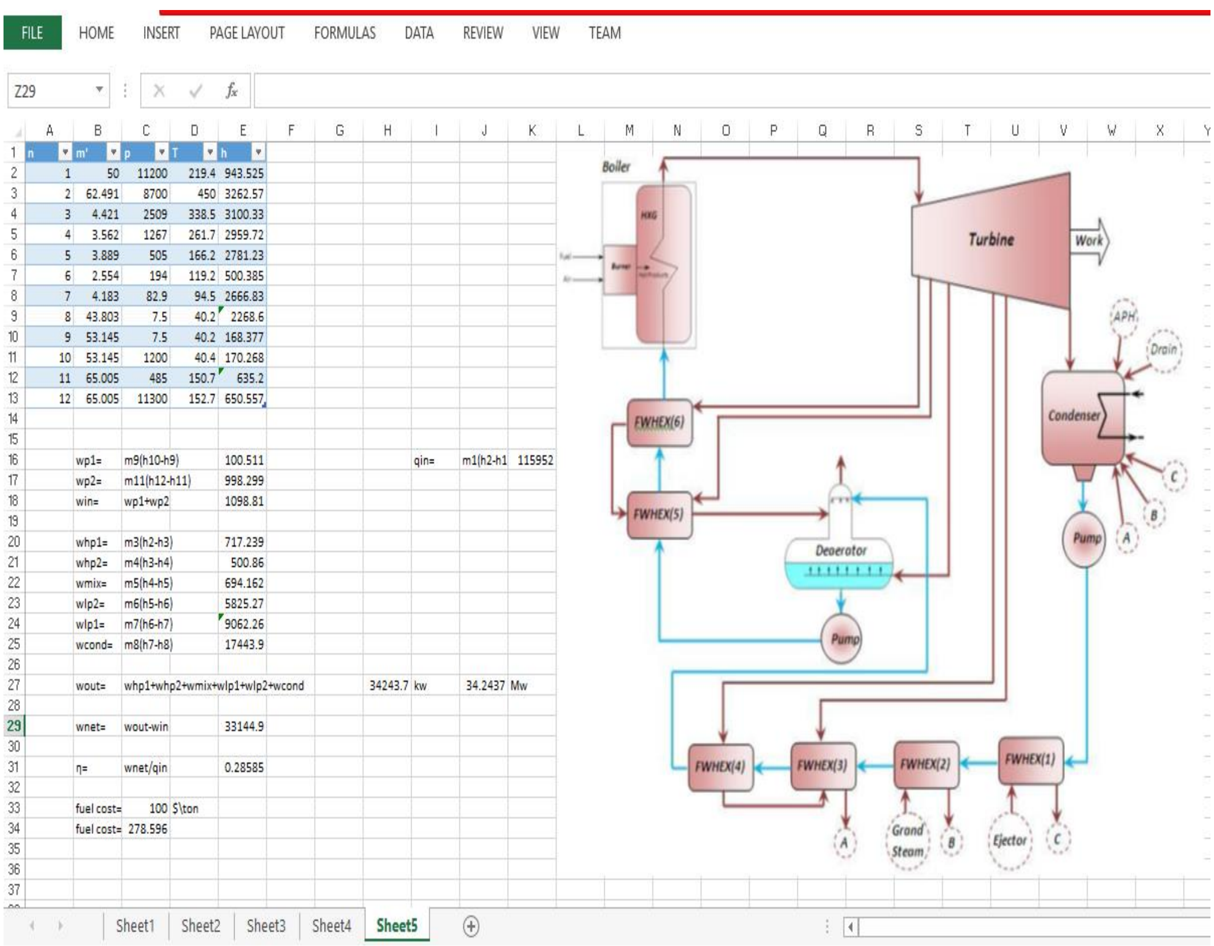


Figure (3.2): excel model

3.3 Matlab model

By matlab model we can estimate the performance of the plant and comparing the performance with various changes in the plant. The model use the temperature, pressure and mass flow to determine the enthalpy at all component of the schematic diagram in figure (3.4). All the equations of the thermodynamic analysis and energy balance and economic equations are defined in excel to calculate the required output (efficiency, output work and fuel cost) which is shown in figure (3.3) below.

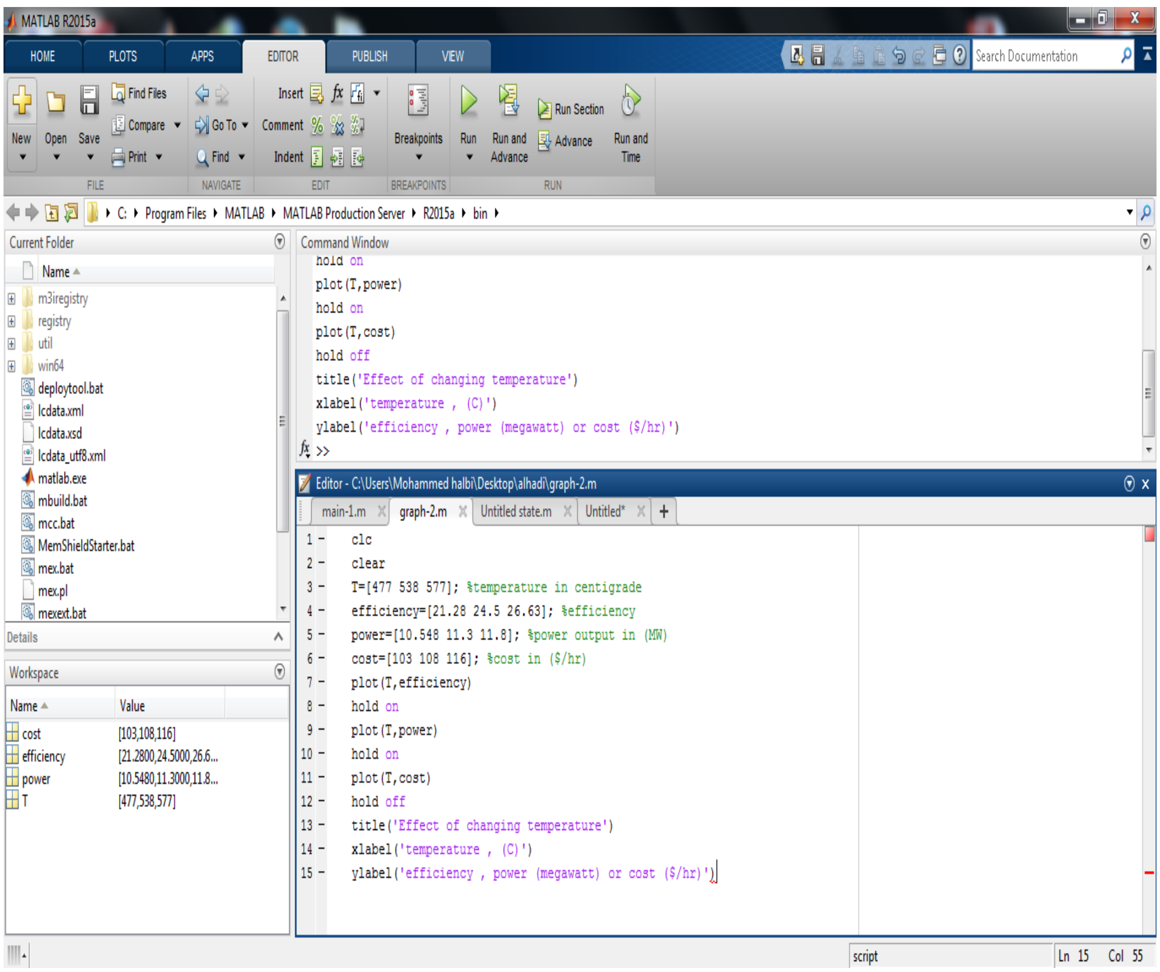
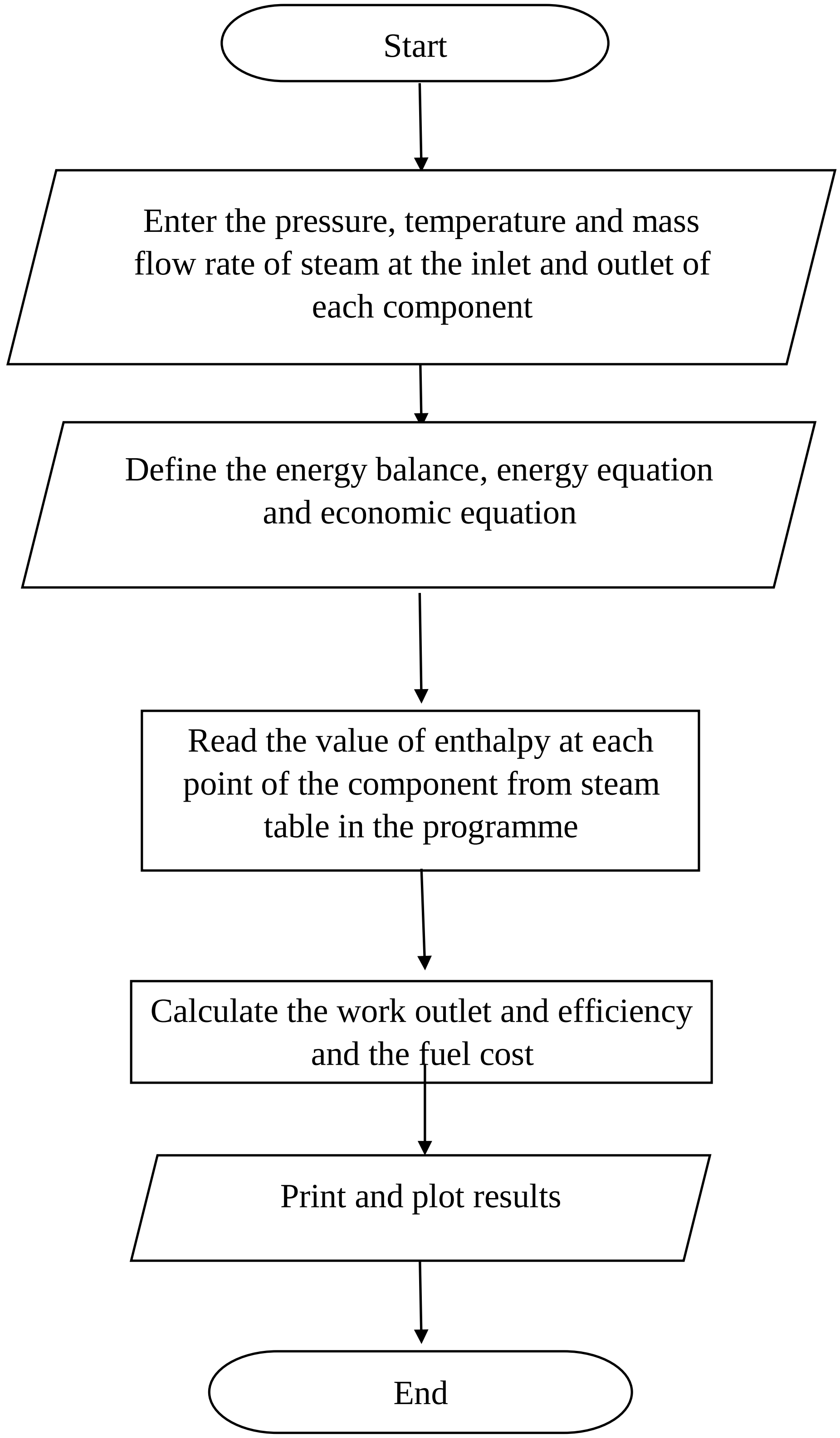


Figure (3.3): Matalab model

3.4 Flow chart for Matlab and Excel models



Plant component	Energy rate(MW)
Boiler	Qb= ṁ* (Hout – Hin)
Pumps	Win= ṁ* (Hout – Hin)
Turbine	Wturbine= ṁ* (Hin-Hout)
Condenser	Qcond= ṁ*(H cond,out – Hcond,in)
efficiency	$\eta th = 1 - Qout/Qin$

Table 3.1 The energy rate for steam cycle power plant components.

3.5 Applied energy and economic analysis on unit (6) power plant

First all details about unit (6) power plant required to applied energy analyzed in previous section (3.1); this part explains main information and all data at specified operation condition to KNPSP(6)power plant as the follow :

3.5.1 Plant Description

The Khartoum North Power Station unit (6) has a total installed power capacity of (100) MW. It is located in Industrial Area district, in Khartoum, Sudan. It started to produce power in the end nineties. The power house consists of two steam turbines units (2x100) MW at 100% load. The unit (6) uses Heavy cocker gas oil. The schematic diagram of one (100) MW unit at 100% load is shown in Figure 3.4

This unit employs regenerative feed water heating system. Feed water heating is carried out in six closed heat exchangers and one open heat exchanger (Daerator). The first closed heat exchanger receives hot stream from outlet of ejector and the second closed heat exchanger receives hot stream from outlet of gland steam system. The extracted steam streams from the turbine are distributed along the other four closed heat exchangers and Daerator as hot streams. Steam is superheated to 538 ℃ and 84.70 bar in the Boiler and fed to the turbine. Exhaust stream at pressure 0.11 bar and it exhausts to a water cooled condenser operates. Then, the cycle starts over again.

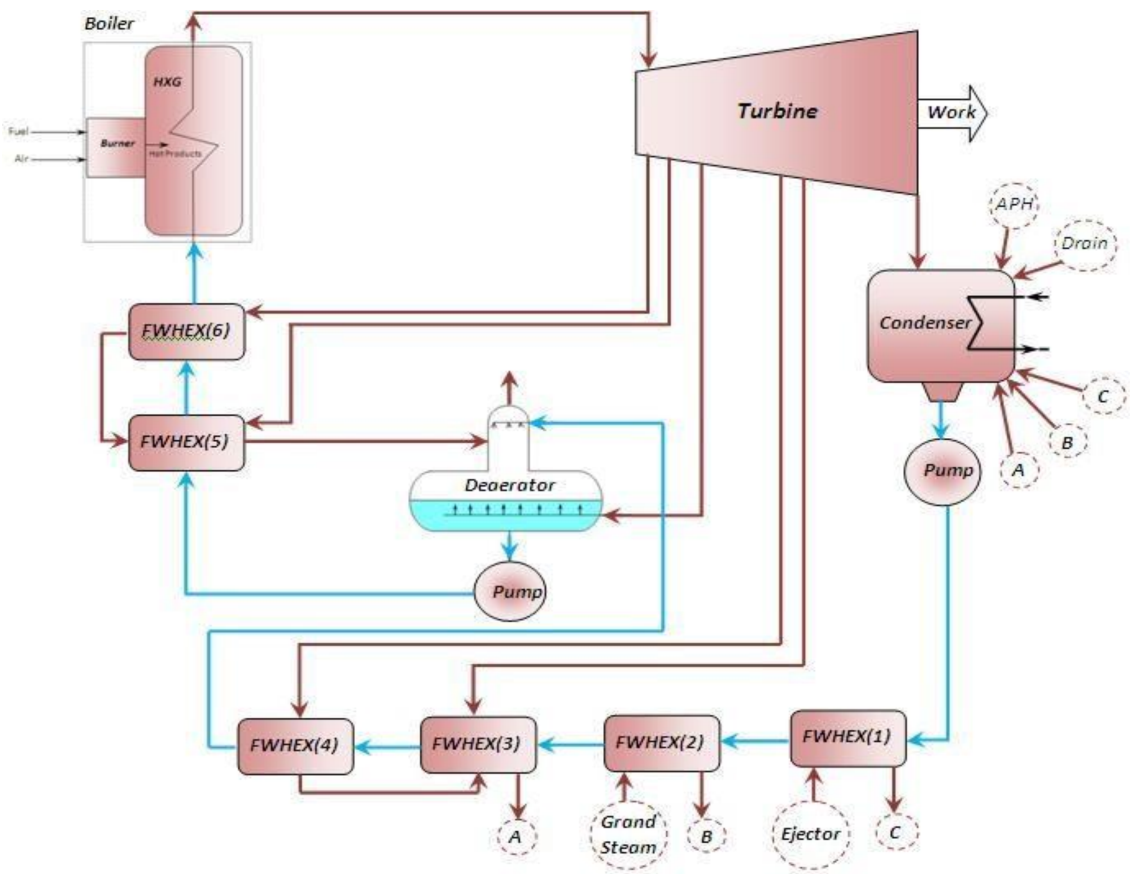


Figure 3.4The schematic diagram of {KNPSP(6)}

3.5.2 Operation data

The main fuel uses in Khartoum North Power Station Phase(6) heavy fuel oil, which is obtained from a nearby oil refinery. The annual fuel consumption 437 TON Properties for the heavy fuel oil obtained are shown in Table 3.2 [25].

Table 3.2: Main data for KNPSP(6)

Parameter	Quantity
Heave fuel oil	890.3 kg/m^3
Fuel oil flow	20T/h
Air flow	261T/h
Air/fuel ratio	13
Feed water flow	286T/h
Steam flow	283T/h
Environment temperature	31C°

Equipment	position	T(K)	P(bar)	$\dot{m}$(kg/s)
turbine	In	811	72.8	8.67
	Out	313	0.11	8
condenser	In	313	0.11	8.67
	Out	313	0.11	8.67
Boiler	In	490	84.7	10.83
	Out	811	72.8	8.67
LPHS	In	313	21	10.83
	Out	433	7	10.79
HPHS	In	433	84.7	10.79
	Out	490	84.7	8.67
Boiler feed pump	In	433	7	8.67
	Out	433	84.7	8.67

Table 3.3: Operation data for actual steam turbine

CHAPTER FOUR

RESULTS AND DISCUSSIONS

This chapter is present all results achieved for Khartoum North Power Station unit (3) Phase (6). The energy and efficiency for the plant of Khartoum North Power Station Phase (6) are calculated according to energy balance.

4.1 First scenario: the change of mass flow rate in the boiler inlet:

Table (4.1) present the effect of changing in a mass flow rate in the boiler at (power turbine, efficiency, fuel cost) in the plant.

Table 4.1: mass flow rate effect

the change / effect type	Actual mass flow rate(kg/s)	Increasing in mass flow rate(kg/s)	Decreasing in mass flow rate(kg/s)
Turbine power(MW)	11.3	13	10.433
Efficiency %	24.5	31.76	20.8
Fuel cost (dollars/hour)	108	117	95.5

The study found that the actual performance for the plant is 24.5% and when increasing the mass flow rate at the inlet of the boiler about (1.23kg/s) the efficiency increase 7.16% and the power of the turbine increased about 1.7 MW this effect in the cost of required fuel and when the mass flow rate decreased about (.67kg/s) the efficiency decreased about 3.7% and decreased the load from 11.3MW to 10.433MW. Increasing the mass flow rate of steam will rise the amount of a kinetic energy of the steam entering the turbine which make the blade of the turbine rotating on a higher speed than the actual one.

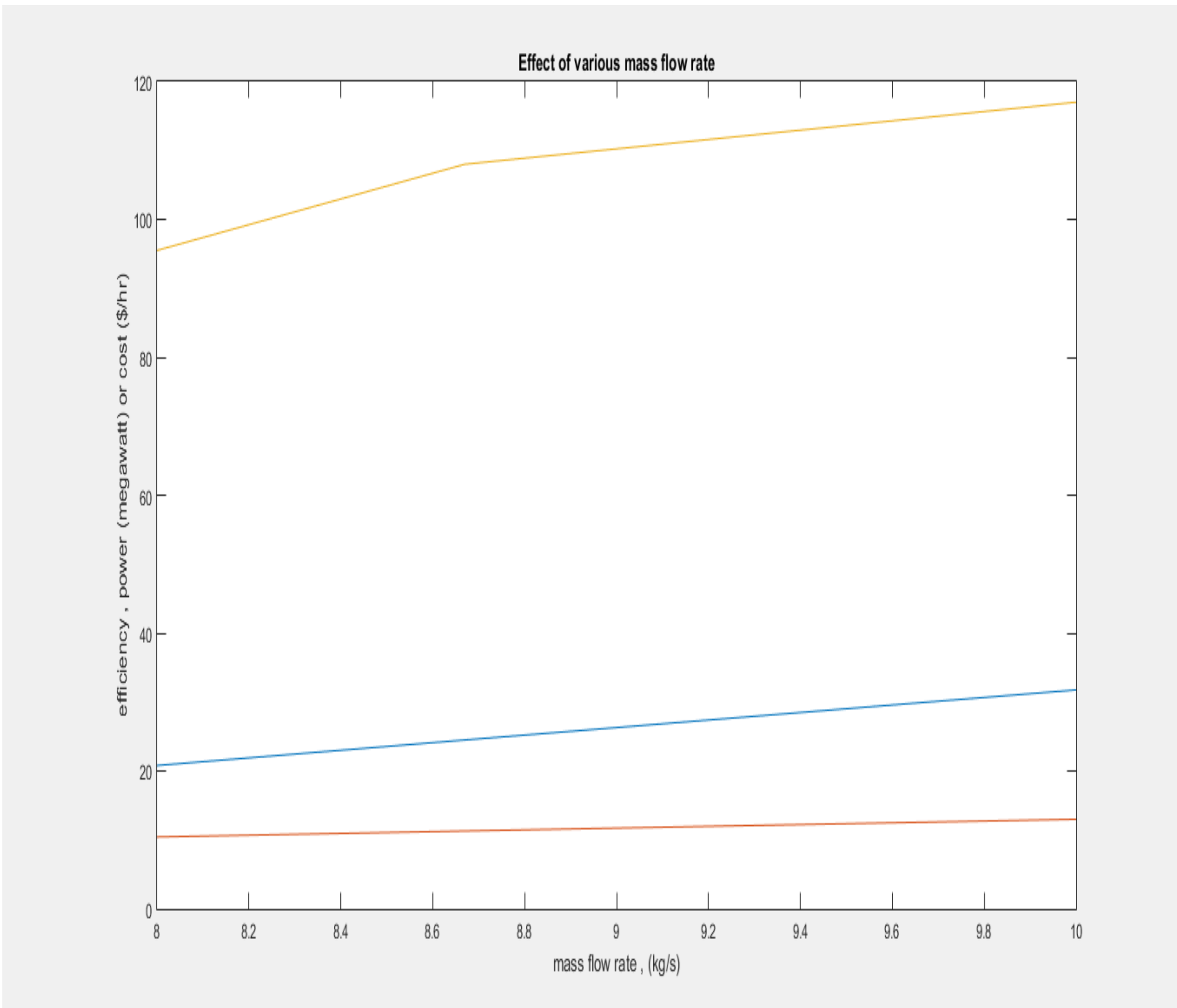


Figure (4.1): The effect of mass flow rate at (efficiency, load and fuel cost)

4.2 Second scenario: the change in temperature in the boiler inlet:

Table (4.2) present the effect of changing in a temperature at the boiler outlet in (power turbine, efficiency, fuel cost) at the power plant cycle.

Table (4.2): effect of changing in temperature

the change / effect type	Actual temperature(K)	Increasing in temperature(K)	Decreasing in temperature(K)
Turbine power(MW)	11.3	11.8	10.548
Efficiency %	24.5	26.23	21.28
Fuel cost (dollars/hour)	108	116	103

The change in the temperature effect at the performance of the plant when temperature increased the efficiency and the load out and fuel cost increased and when the temperature decreased the efficiency and load of the turbine will decreased as shown in the table (4.2).

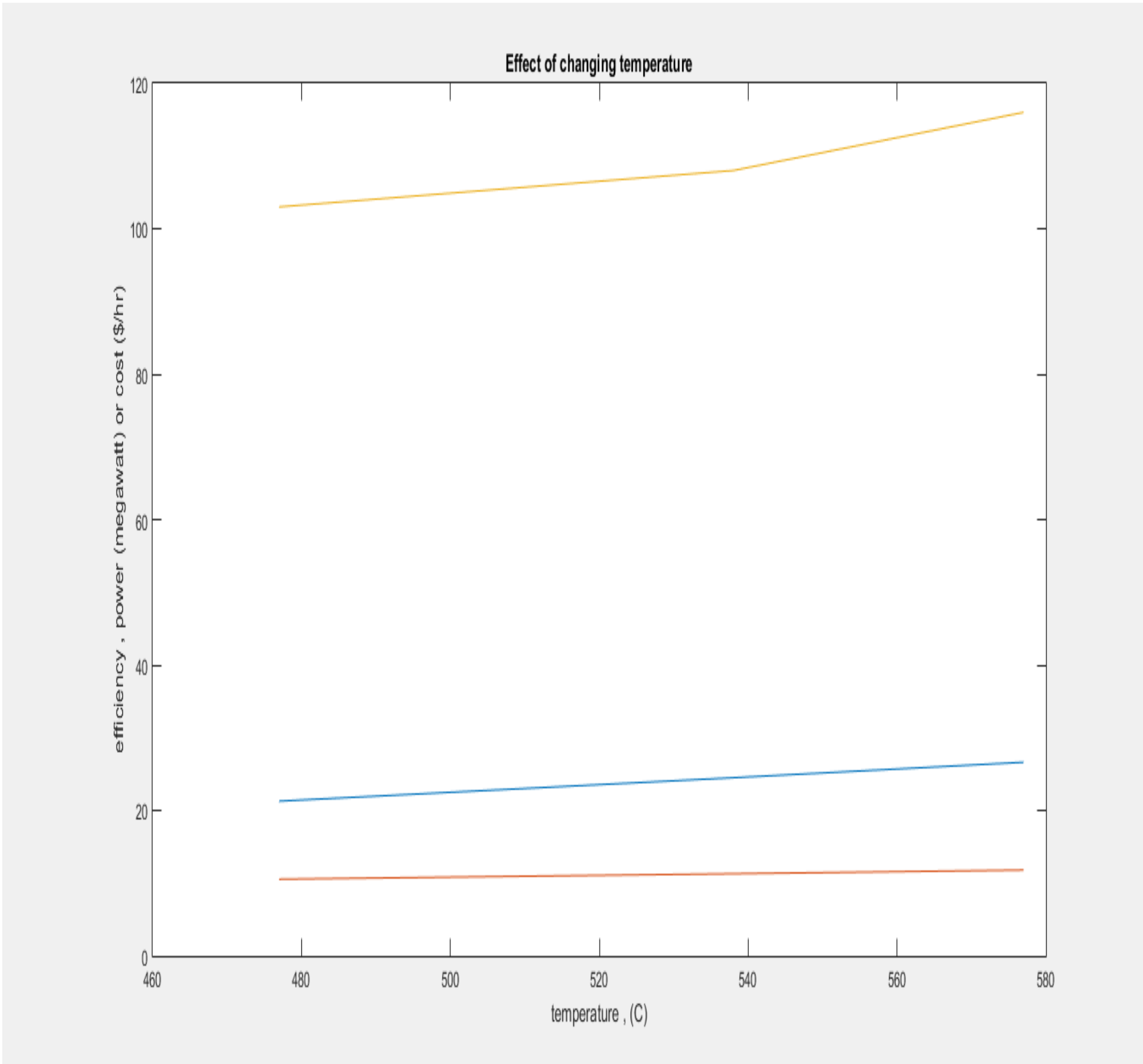


Figure (4.2): The effect of temperature of the boiler

at (efficiency, load and fuel cost)

Figure (4.3) showed the effect of two scenario on the turbine load and comparing between the effect of change and the actual load in turbine of the thermal power plant.

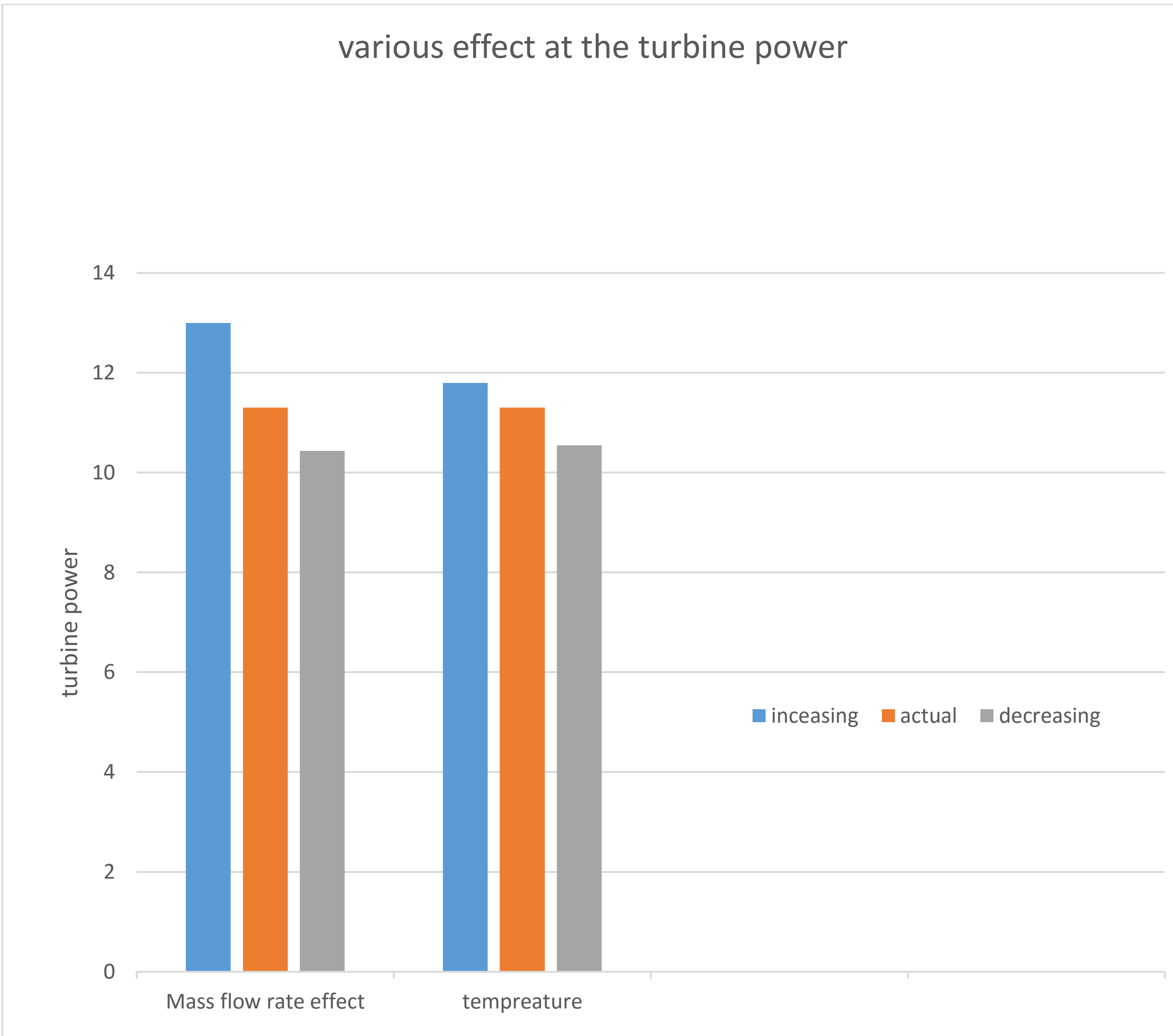


Figure (4.3): effect of various change in the turbine load

Figure (4.4) showed the effect of two scenario on the efficiency and compared to its actual efficiency for the thermal power plant.

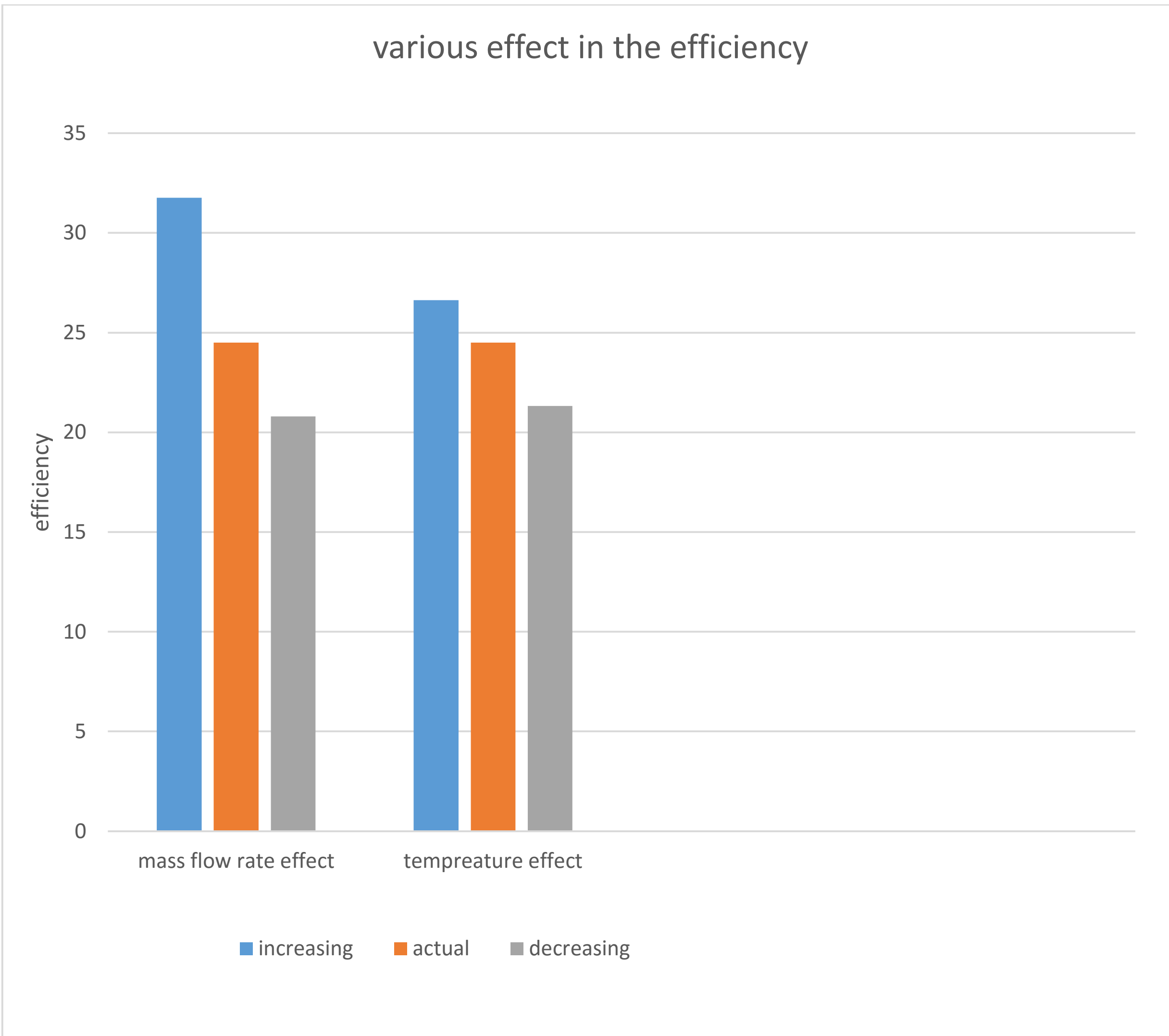


Figure (4.4): effect of various change in the turbine load

Figure (4.5) showed the effect of two scenario on the fuel cost and compared to its actual cost for the thermal power plant.

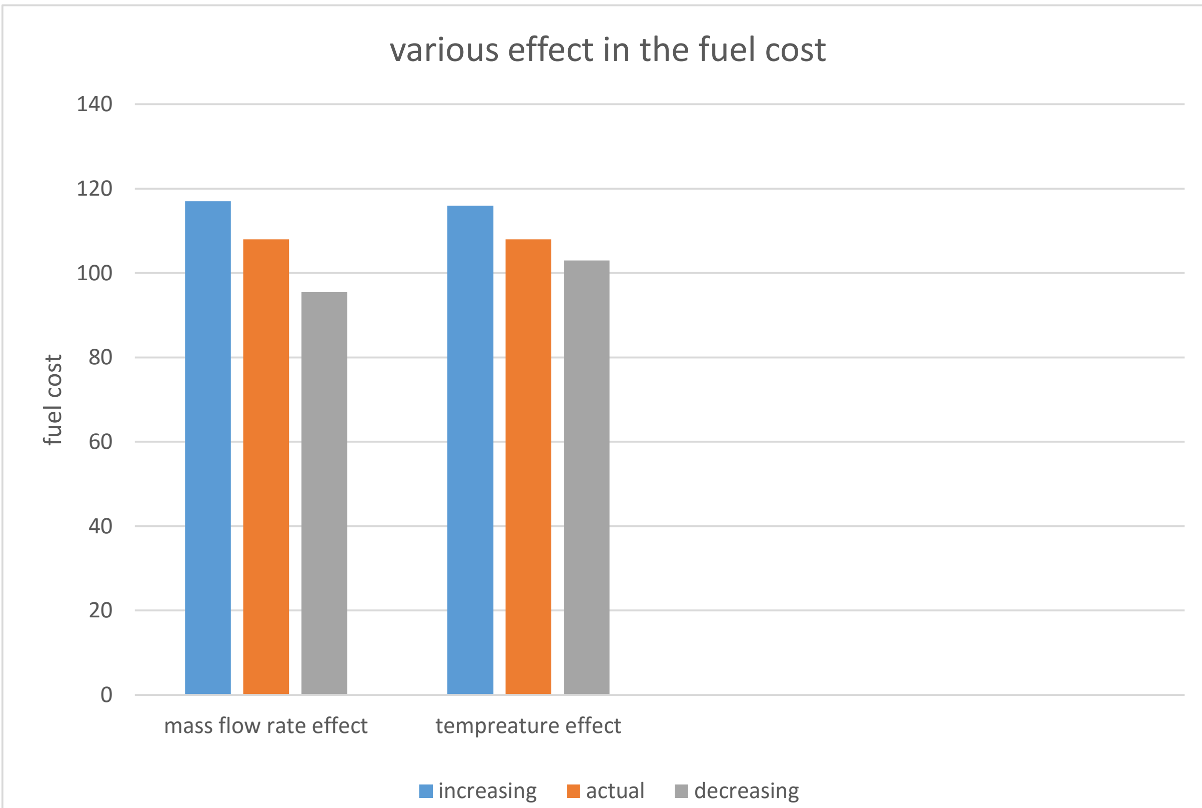


Figure (4.5): effect of various change in the turbine load

The most important things in evaluating the power plant station is to increase the efficiency of the thermal cycle which make the load in the turbine increased and make the power in the shaft produce more energy.

And economically the increasing in power out of turbine will need more fuel and this make the cost of producing energy increased.

CHAPTER FIVE

CONCLUSION

&

RECOMMENDATIONS

5.1 Conclusion

In this study, an energy economic analysis as well as the effect of changing in temperature at the boiler and mass flow rate which enter the turbine for an actual power plant has been presented**.**

The actual efficiency for Khartoum north power station is 24.5% which is very low compared to modern power plants. And one of effective way to increase the efficiency and power of turbine is to rise the temperature in the boiler inlet which increased the required goal (efficiency and load in turbine). This way tested in Khartoum north power station and had increased the efficiency to 26.23% and make the load increased about .5MW.and economically increased the cost of the fuel which needed for one hour in producing energy about 8 dollars cause increasing in the load need more heat in the boiler and this need more mass flow rate of fuel.

The second way is increasing the flow rate of steam entering the turbine and it also tested in Khartoum north power plant and by it had increased the efficiency about 7.26% and the power out of the turbine increased about 1.7MW but also it increased the fuel flow rate which increased the cost of fuel needed.

5.2 Recommendations

1. To judge how good a power plant performance is, should know its actual work. Then selection of a power plant would be built in specified area should be after collection data about average temperature and pressure along year and then simulate the power plant performance in different period along year to get average actual work, irreversibility and second-law efficiency.
2. For power plant complex operation, it is normal to decide what thermal power plant between many are available in the complex should be shared into grid .like this decision sometimes is taken based on availability of the thermal plant where maintenance records and so on. But for economical operation, the lower the power plant irreversibility is the best selection. Thus it is important to know as operating engineer or operation manager the irreversibility of each thermal power plants in the complex to ensure efficient operation decisions are taken.
3. In order to improve the performance of a thermal power plant .it is necessarily to adopt performance monitoring and heat rate improvement. To improve efficiency, the engineer must knew the heat input, the mass of fuel, the fuel analysis and the MW rating generation in order to determine the actual heat rate. After the actual heat rate calculated and understood, losses must be identified and understood.
4. Ensure economical operation.
5. Increase the flow rate of steam which enter the turbine to increase the energy generate.

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APPENDIX

Appendix(1):-

```
%Mass flow rate
clc
clear
m=[8 8.67 10 ]; %mass flow rate in (kg/s)
efficiency=[20.8 24.5 31.76]; %efficiency
power=[10.433 11.3 13]; %power output in (MW)
cost=[95.5 108 117]; %cost in ($/hr)
plot(m,efficiency)
hold on
plot(m,power)
hold on
plot(m,cost)
hold off
title('Effect of various mass flow rate')
xlabel('mass flow rate , (kg/s)')
ylabel('efficiency , power (megawatt) or cost ($/hr)'
```

Appendix(2):-

```
%temperature
clc

clear
T=[477 538 577]; %temperature in centigrade
efficiency=[21.28 24.5 26.63]; %efficiency
power=[10.548 11.3 11.8]; %power output in (MW)
cost=[103 108 116]; %cost in ($/hr)
plot(T,efficiency)
hold on
plot(T,power)
hold on
plot(T,cost)
hold off
title('Effect of changing temperature')
xlabel('temperature , (C)')
ylabel('efficiency , power (megawatt) or cost ($/hr)')
```