Sudan University of Science and Technology

College of Engineering

School of Mechanical Engineering

Power Department

Relation between exhaust gases and efficiency in Khartoum north power station

العلاقة بين غازات العادم والكفاءة في محطة بحري الحرارية

Thesis submitted in partial fulfillment for the requirement of the Degree of B.Sc. (Honors) in Mechanical Engineering

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الآية

(وَيَسْأَلُونَكَ عَنِ الرُّوحِ ۖ قُلِ الرُّوحُ مِنْ أَمْرِ رَبِّي وَمَا أُوتِيتُم مِّنَ الْعِلْمِ إِلَّا قَلِيلًا)

الأسراء (85)

كلمة شكر

لابد لنا ونحن نخطو خطواتنا الأخيرة في الحياة الجامعية من وقفة نعود إلى أعوام قضيناها في رحاب الجامعة

مع أساتذتنا الكرام الذين قدموا لنا الكثير باذلين بذلك جهودا كبيرة في بناء جيل الغد لتبعث الأمة من جديد

وقبل أن نمضي تقدم أسمى آيات الشكر والامتنان والتقدير والمحبة

إلى الذين حملوا أقدس رسالة في الحياة..

إلى الذين مهدوا لنا طريق العلم والمعرفة...

إلى جميع أساتذتنا الأفاضل.......

"كن عالما ... فإن لم تستطع فكن متعلما ، فإن لم تستطع فأحب العلماء ،فإن لم تستطع فلا تبغضهم"

ونخص بالتقدير والشكر :

الدكتور توفيق أحمد جمال الدين

الذي نقول له بشراك قول رسول الله صلى الله عليه وسلم:

"إن الحوت في البحر ، والطير في السماء ، ليصلون على معلم الناس الخير "

الذي علمنا التفاؤل والمضي إلى الأمام، إلى من رعانا وحافظ علينا، إلى من وقف إلى جانبنا عندما ضللنا الطريق.....

وكذلك نشكر كل من ساعد على إتمام هذا **البحث** وقدم لنا العون ومد لنا يد المساعدة وزودنا بالمعلومات اللازمة لإتمام هذا **البحث** ونخص بالذكر:

المهندس : زهير محمد اشيخ دفع الله

الذين كانوا عونا لنا في بحثنا هذا ونورا يضيء الظلمة التي كانت تقف أحيانا في طريقنا.

إلى من زرعوا التفاؤل في دربنا وقدموا لنا المساعدات والتسهيلات والأفكار والمعلومات، ربما دون يشعروا

بدورهم بذلك فلهم منا كل الشكروالتقدي

الأهداء

إلى الينبوع الذي لا يمل العطاء إلى من حاكت سعادتي بخيوط منسوجة من قلبها إلى

والدتي العزيزة .

إلى من سعى وشقى لأنعم بالراحة والهناء الذي لم يبخل بشئ من أجل دفعي في طريق النجاح

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إلى من حبهم يجري في عروقي ويلهج بذكراهم فؤادي إلى أخواتي وأخواني

دمتم لي خير سند

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Abstract

Energy saving is one of the key issues, not only from the viewpoint of fuel consumption but also for the protection of global environment. A rotary regenerator Air pre-heater in thermal power stations is a heat transfer surface in which air temperature is raised by transferring heat from other media which is flue gas here .Hot air is necessary for rapid combustion in the furnace. So an essential boiler accessory which serves this purpose is air pre-heater. The air pre-heater are not essential for operation of steam generator, but they are used where a study of cost indicates that money can be saved or efficient combustion can be obtained by their use. The decision for its adoption can be made when the financial advantages is weighed against the capital cost of heater in the present search we have taken up the operation and performance analysis of face 2 Air pre-heater of Khartoum North Thermal Power. In analysis of performance boiler efficiency and heat gain from air pre-heater has been studied, and also effect of pre-air heater in boiler, air side efficiency, gas side efficiency, X ratio has been calculated.

المستخلص

تعتبر المحافظة على الطاقة أحدى القضاية الأساسية ليس فقط من حيث أستهلاك الوقود بل أيضاً من حيث حماية النظام البيئي العالمي. يعتبر مسخن الهواء الدوار في محطات التوليد الحراري هو عبارة عن جهاز يقوم بعملية تبادل الحرارة بحيث ترتفع درجة حرارة الهواء عن طريق أنتقال الحرارة أليه من وسط اخر وفي هذه الحالة يمثل الغازات . يعتبر الهواء الساخن ضروري للاحتراق السريع في الغلاية .لذلك هو من الملحقات الاساسية التي تقوم بهذه الوظيفة ، لايعتبر السخان جزء أساسي لكي تتم عملية توليد البخار لكن يتم أستخدامه عندما يكون العائد الما دي من وراء استخدامه مجزي أو انه يقوم بزيادة الكفاءة ويتم أتخاذ قرار أستخدامه عندما ترجح كفة المردود المادي على كفة التكلفة الكلية لأنشاء السخان . يقوم هذا البحث على عملية تشغيل وتحليل الأداء لسخان الوحدة الثانية لمحطة بحري الحرارية .في تتحليل الاداء درست كفاء الغلاية والحرارة المستفادة بواسة السخان المبدئي للهواء وأيضاء دراسة أثر السخان المبدئي للهواء على كفاءة الغلاية عن طريق دراسة كفاءة جزء الهواء و أيضاء كفاءة جزء الغازات لحساب كفاءة السخان الكلية .

Chapter one

(Introduction)

1-1 Introduction

Electricity generation is the process of generating electric power from sources of primary energy. It is one of the most important blessings that science has given to mankind. It has also become a part of modern life and one cannot think of a world without it. Electricity has many uses in our day to day life it is used for lighting rooms, working fans and so on. Also In factories, large machines are worked with the help of electricity.

Thermal power plants generate more than 80% of the total electricity produced in the world. Fossil fuel, viz. coal. Fuel oil and natural gas are the energy source, and steam is the working fluid. Steam is also required in many industries for process heat. To meet the dual need of power and process heat, cogeneration plants are often installed

Thermal power station it use as a base load power plant because it is usually provides a continuous supply of electricity throughout the year with some minimum power generation requirement, So air preheater and economizer are designed to increasing the thermal efficiency by uses exhaust gases At a certain limit, exhaust gases temperature must be above partial pressure of dew point temperature to avoid condensation at stack. [1].

This process saves a lot of energy, Energy saving is one of the key issues, not only from the viewpoint of fuel consumption but also for the protection of global environment. A rotary air preheater is a sizeable porous disk, fabricated from some materials having a fairly high heat capacity, which rotates between two side-by-side ducts; one for the cold gas; the other for the hot stream.

The Khartoum North Power Station of Sudan is located at northeast of North Khartoum Industrial Area in Khartoum suburb to provide power for national public, industrial and civil use, the installed gross capacity of the plant is 386 MW.

1.2 research problem

Generally high fuel consumption in thermal power station and especially in steam power station is motivation to decrease fuel consumption by using heat in exhaust gases.

1-3 objectives

1-3-1 Effect of rotary air heater on thermal power station.

1-3-2 Improve heat recovery from exhaust gases to increase air temperature.

1-4 Methodology

1.4.1 Theoretical study of steam power station and main component will do by use text book and web site to take background for research.

1-4-2 Conduct several visits to Khartoum north power station to gathering data concerning thermal power station heat recovery steam generator, then the fuel consumption at full load and partial load will be calculated and collect another readings.

Chapter tow

(Literature Review)

2.1. INTRODUCTION

A steam generator or Boiler generates steam at the desired rate at the desired pressure and temperature by burning fuel in its furnace. Steam generators are used to both fossil-fuel and nuclear-fuel electric generating power stations. [3]

2.1.1 Boiler definition

Boiler or steam generator is a closed vessel in which water under pressure is transformed into steam by the application of heat.

2.1.2 Steam produced is used for

- Generating power in steam turbine.
- Heating residual and industrial building.
- Performing certain process in the sugar mills, chemicals and textile industries.

2.2. Classifications of boilers

2.2.1 Boiler tube content

- Fire tube boiler.
- Water tube boiler.

2.2.2 Water circulation

- Forced circulation.
- Natural circulation boilers.

2.2.3 Boiler pressure

- High pressure boiler
- Low pressure boilers

2.2.4 Draft

- Natural draft (gas density).
- Forced draft. (F.D fan).
- Induced draft. (Induced fan).
- Balanced draft (F.D. fan& induced fan) .

2.3 Water tube boiler

The water-tube boiler, where water flows through the tubes and flue gases flow outside them, puts the pressure in the tubes and the relatively small diameter drums, which are capable of withstanding extreme pressures of the modern steam generator. [2]

2.3.1 Heat Absorption in Water-Tube Boilers

In a water-tube boiler, feed water is heated in three kinds of heat-exchangers, economizer, evaporator (down-comer-riser circuit) and super-heaters.

Feed water from the high pressure heater enters the economizer where it is heated by the outgoing flue gases till it is saturated liquid at that pressure and then it is fed to the drum. Saturated water falls through the down comer into the bottom header and moves up through the riser where water is partially boiled back into the drum. Saturated steam from the drum goes to the super heaters for being heated to the desired temperature. [2]

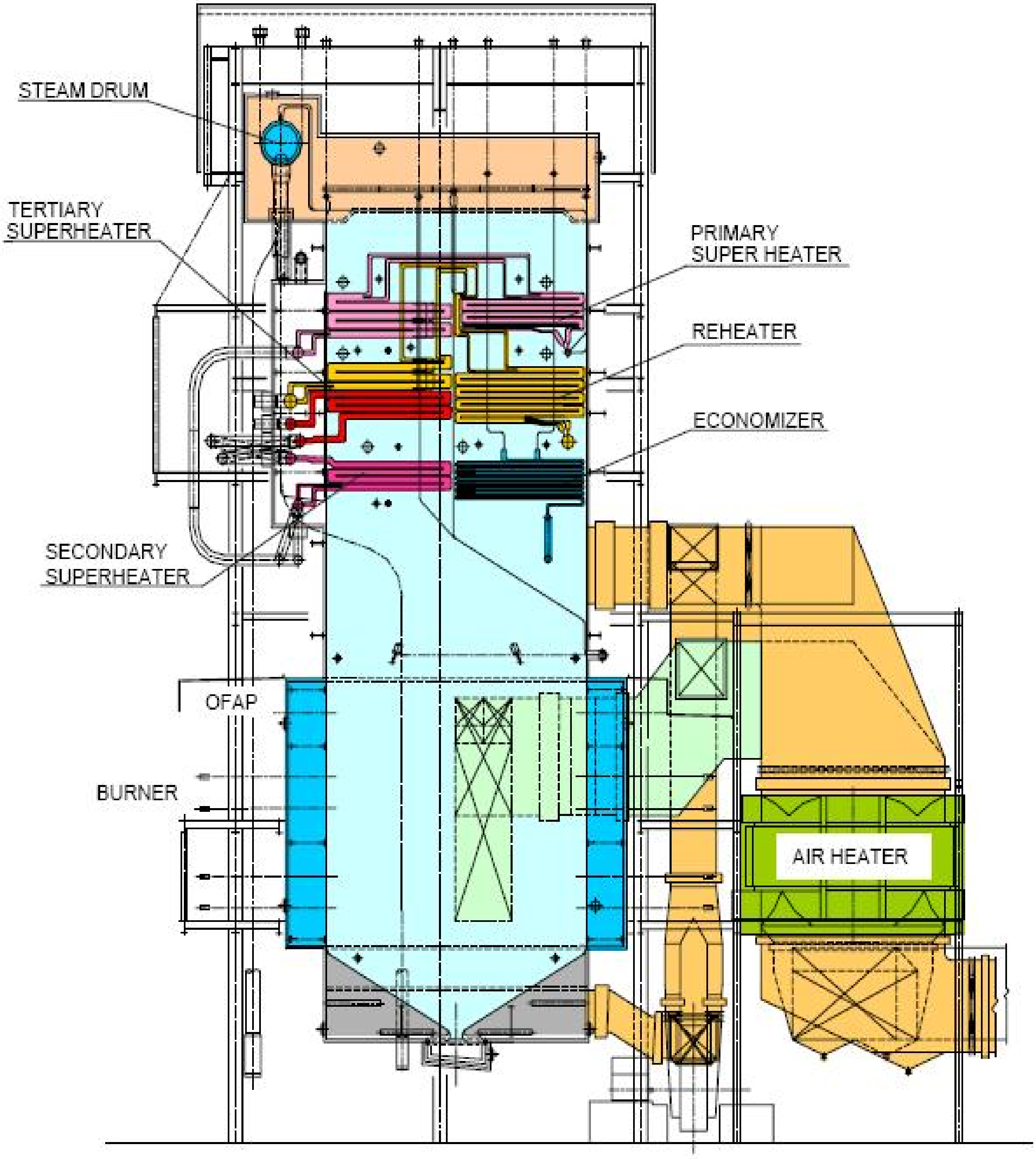


Fig (2-1) Water tube boiler

2.4. Steam Generator component design

2.4.1. Furnace

The furnace serves as an enclosure for the combustion process, and walls are formed by water-filled tubes that contain the upward flow of water and steam. [3]

2.4.2. Drum

The drum encloses the steam-water interface in a boiler, and provides a convenient point for addition of chemicals and removal of dissolved solids from the feed water steam system. The drum also contains equipment for removal of liquid from the steam as the steam leaves the drum and enters the connecting links to the primary super heater. [2]

2.4.2.1 Circulation

The flow of water and steam within the boiler circuit is called circulation.

Adequate circulation must be provided to carry away the heat from the furnace. If circulation is caused by density difference, the boiler is said to have natural circulation. If it is caused by a pump, it has forced or controlled circulation; the down comer, which is insulated, is outside the furnace, and the riser is inside it.

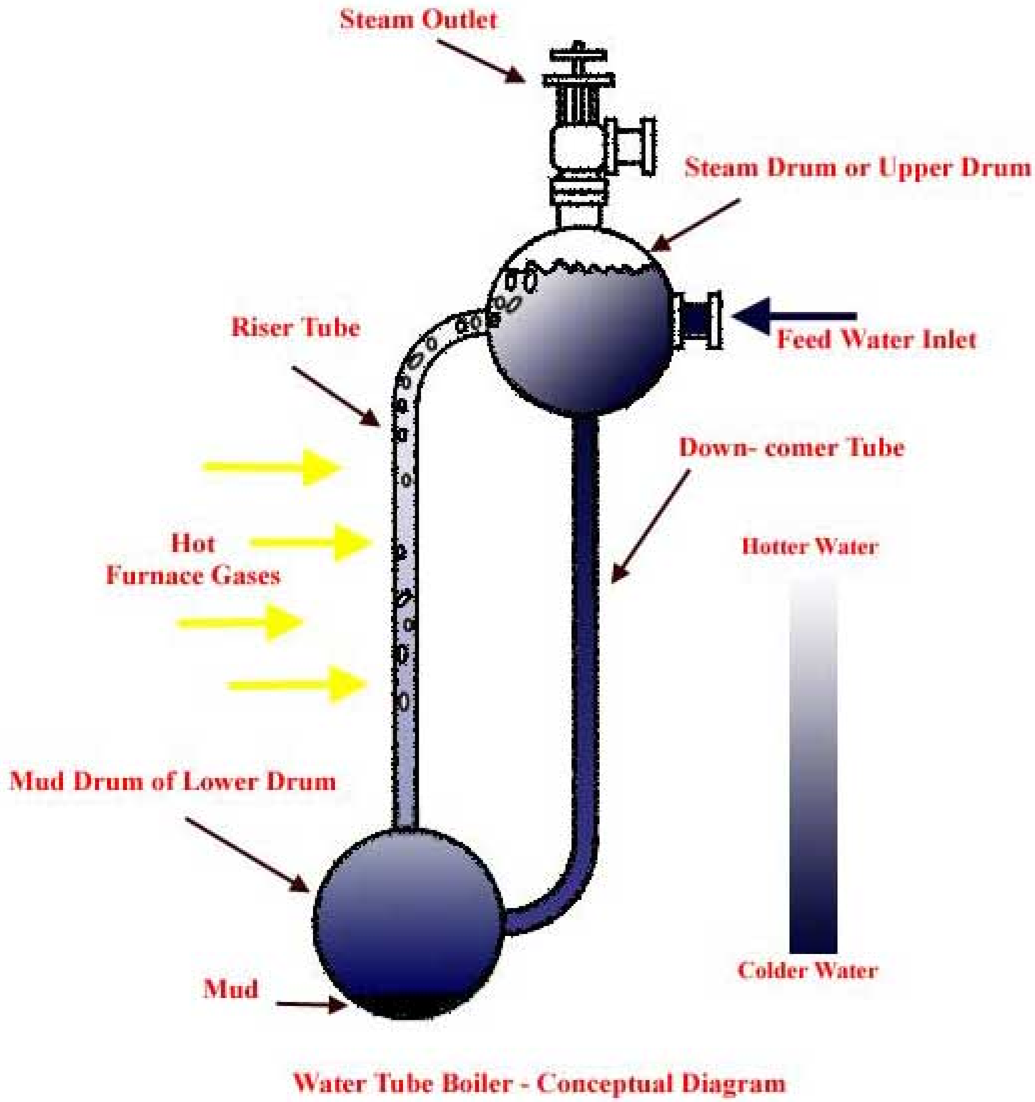


Fig (2-2) Natural circulation in a down comer-riser circuit

Nearly saturated water is falls by gravity from the drum through the down comer into the bottom header. From the header water flows up along the Riser where it partially boils with the formation of bubbles and then back into the steam drum. The density of steam-water mixture in the riser is less than that of saturated water in the down comer, and as a result of this density difference a circulation current is set up within the down comer- riser circuit.

The feed water from the economizer enters the drum and saturated steam is taken out of the drum to the super heater. [2]

2.4.3 Boiler Circulating Pumps

Boilers may be designed with natural circulation through the furnace water walls or forced circulation with boiler circulating pumps. Natural circulation systems must be designed with low flow resistance in the water circuit which consists of the drum, down comers, lower headers, furnace, water walls, upper headers, and connecting links back to the drum. The forced circulation design allows the use of smaller diameter tubing in the furnace walls, since the higher pressure drop in the smaller tubing can be offset through pump circulation. The smaller diameter also allows thinner tube walls. [3]

2.4.4 Super heater

The super heater is a heat exchanger in which heat is transferred to the saturated steam to increase its temperature; it raises the overall cycle efficiency. In addition, it reduces the moisture content in the last stages of the turbine and thus increases the turbine internal efficiency.

Super heaters are commonly classified as either convective super heaters, radiant super heaters or combined super heaters, depending on how heat is transferred from the gases to steam. Super heaters are located in the convective zone of the furnace, usually ahead of the economizer.

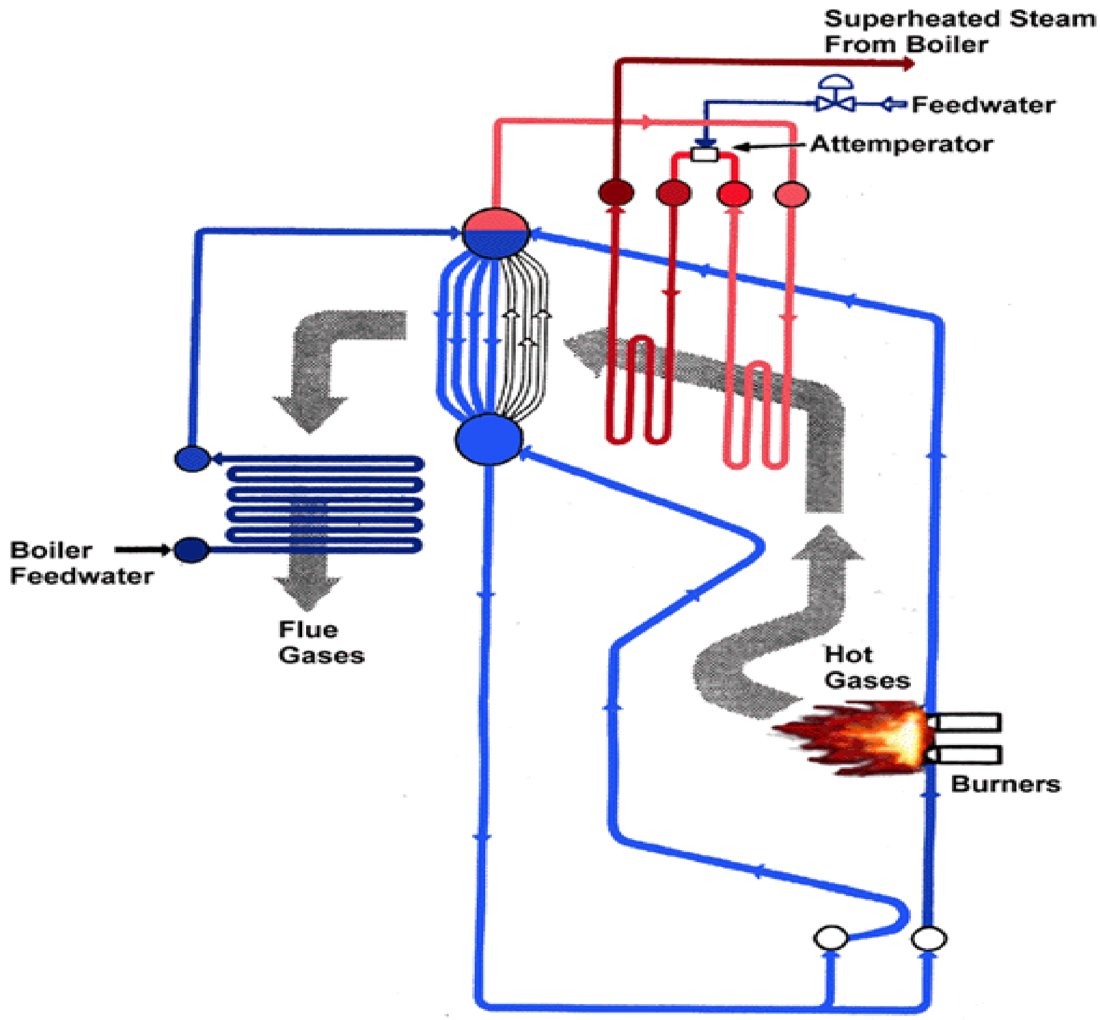


Fig (2-3) Super heater

2.4.5. Re-heater

Like the super heater, the re-heater heat transfer surface may be composed of either radiant or convective surface. Radiant re-heater surface can be either radiant wall heat transfer surface or pendant heat transfer surface. A radiant wall re-heater can be mounted on the front and/or side walls of the upper furnace. [3]

2.4.6. Economizer

An economizer is a heat exchanger which raises the temperature of the feed water leaving the highest pressure feed-water heater to about the saturation temperature corresponding to the boiler pressure. This is done by the hot flue gases exiting the last super-heater or re-heater at a temperature varying from ($370℃$ to$540℃$) by utilizing these gases in heating feed water, higher efficiency and better economy were achieved, and hence the heat exchanger was called "economizer". [2]

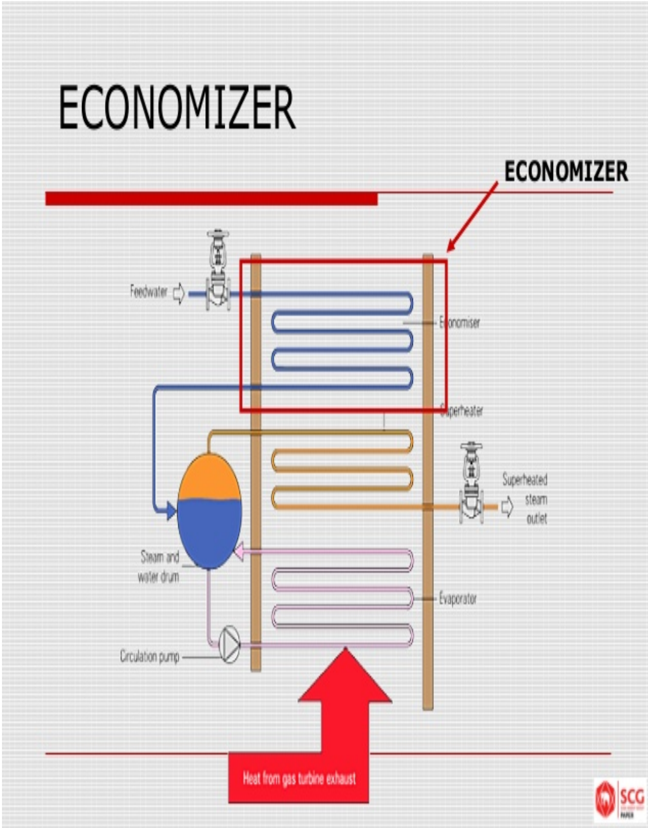

ECONOMIZER
ECONOMIZER
Feedwater
Superheater
Superheated
steam
outlet
Steam and
water drum
Evaporator
Circulation pump
Heat from gas turbine exhaust
SCG

Fig (2-4) Economizer

2.4.7. Air Heater

The rotary regenerative air heater design using either rotating heat transfer surface or rotating air distribution hoods predominates for utility air heating applications. The air heater arrangement may consist of one, two, three, or four air heaters, depending on the size of the unit and the degree of fuel flexibility desired. [3]

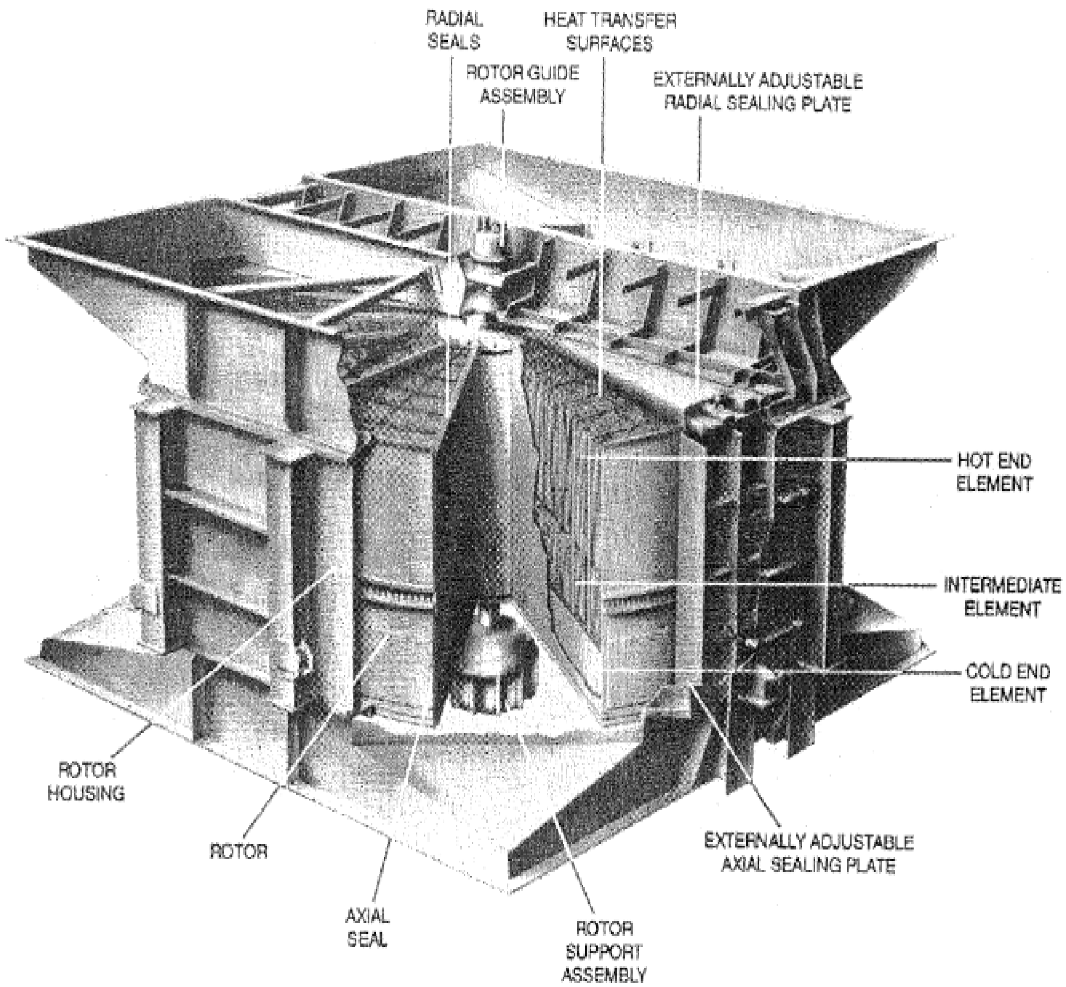


Fig (2-5) rotary Air Preheat

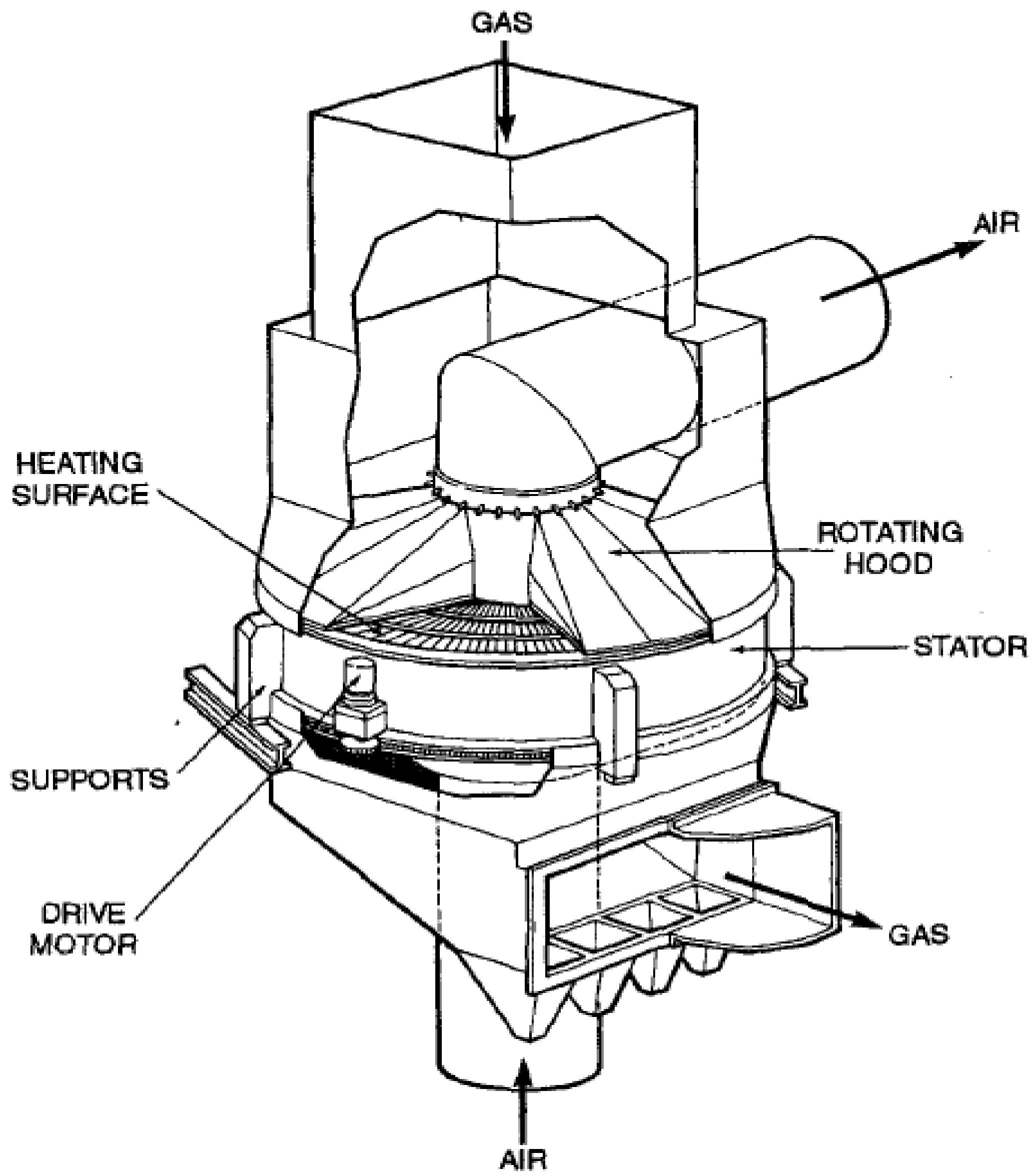


Fig (2-6) rotating air distribution hoods heater

2.4.8. Air Preheat Coils

Air preheat coils are installed upstream from the regenerative air heater. Although their use increases the boiler efficiency, their primary purpose is to prevent corrosion of the regenerative air heater by increasing heat transfer surface temperatures. The increased heat transfer surface temperatures are less likely to cause condensation of acids from the flue gas stream. The design and operation of the air preheat system are based on maintaining an average cold end temperature (ACET) in the regenerative air heater. [3]

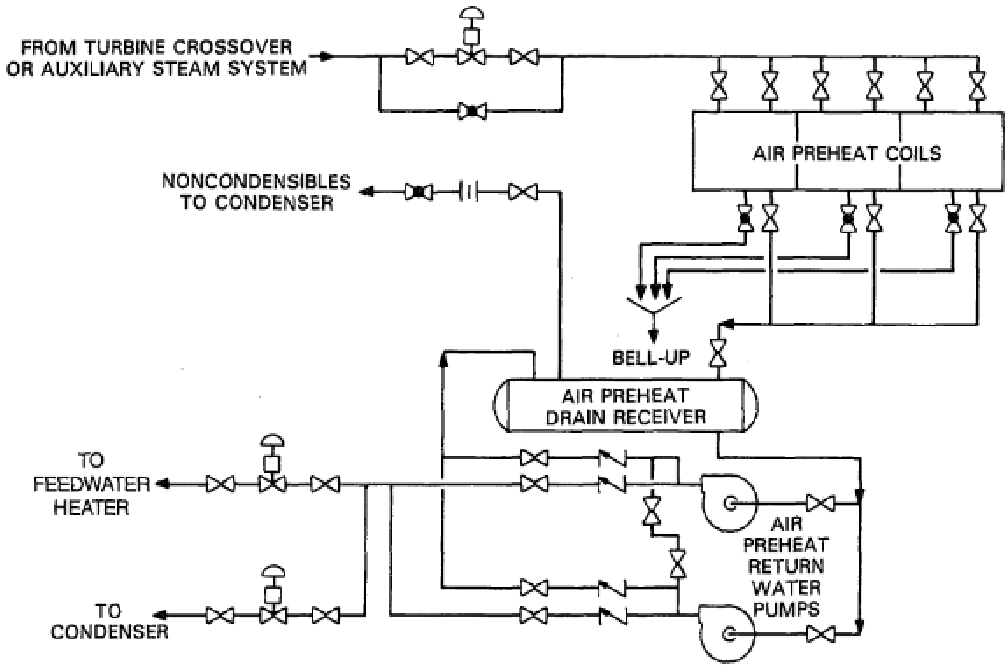


Fig (2-7) Steam air preheating coils flow diagram

2.4.9. Soot Blowers

Soot blowers are used for removal of ash deposits from the fireside of heat transfer surfaces. Several types of soot blowers are used in utility steam generators; Air heater soot blowers are typically found in the flue gas side of the air heater on both the inlet and the outlet. Selection of the air heater soot blower depends on the size of the air heater.

Wall blowers are used for furnace walls. Wall blowers have a very short lance with a nozzle on the tip, the lance rotates as it moves into the furnace, and the nozzle directs the soot blowing medium onto a circular area of the furnace wall. [3]

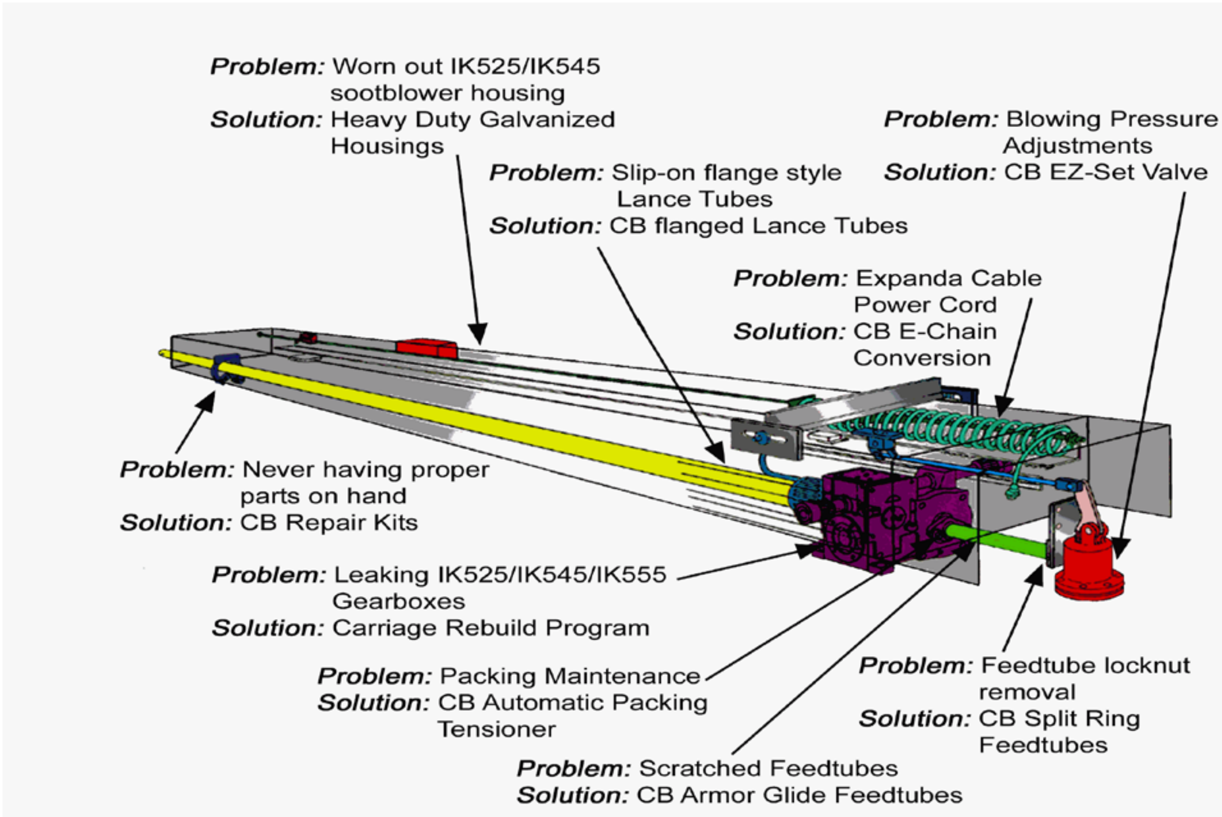


Fig (2-8-1) Soot Blowers

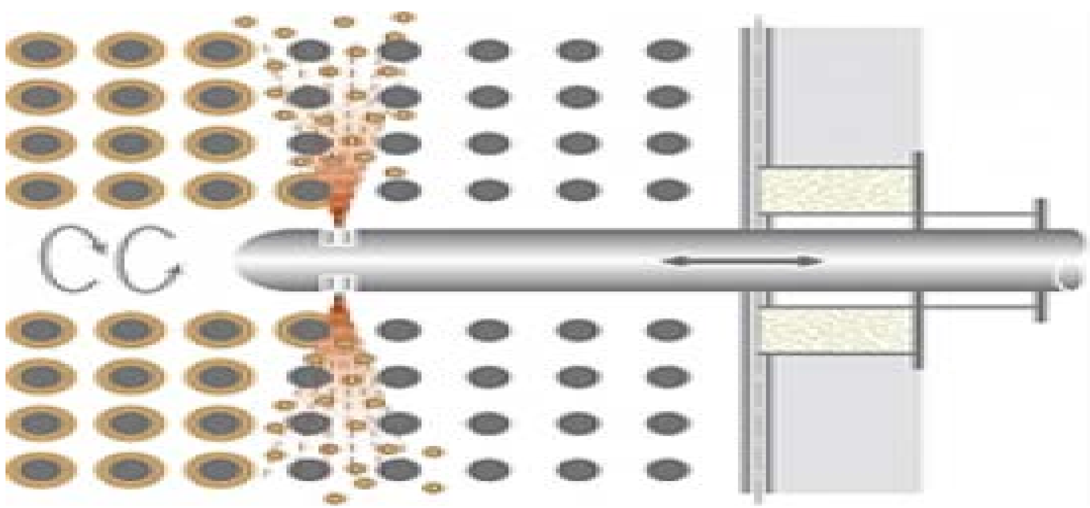


Fig (2-8-2) Soot Blowers

2.4.10. Igniters and Warm-up Burners

Igniters and warm-up burners are necessary for flame initiation and low load stabilization. The type of equipment provided and even the terminology varies depending on the boiler manufacturer.

The warm-up gun is a high heat input gas or oil burner that performs the functions of an igniter. As an example, the heat input of one level of four warm-up guns typically equals or exceeds the heating capacity of all igniters on all elevations, both front and rear, of a comparably sized wall-fired boiler. The igniter itself requires an ignition source.

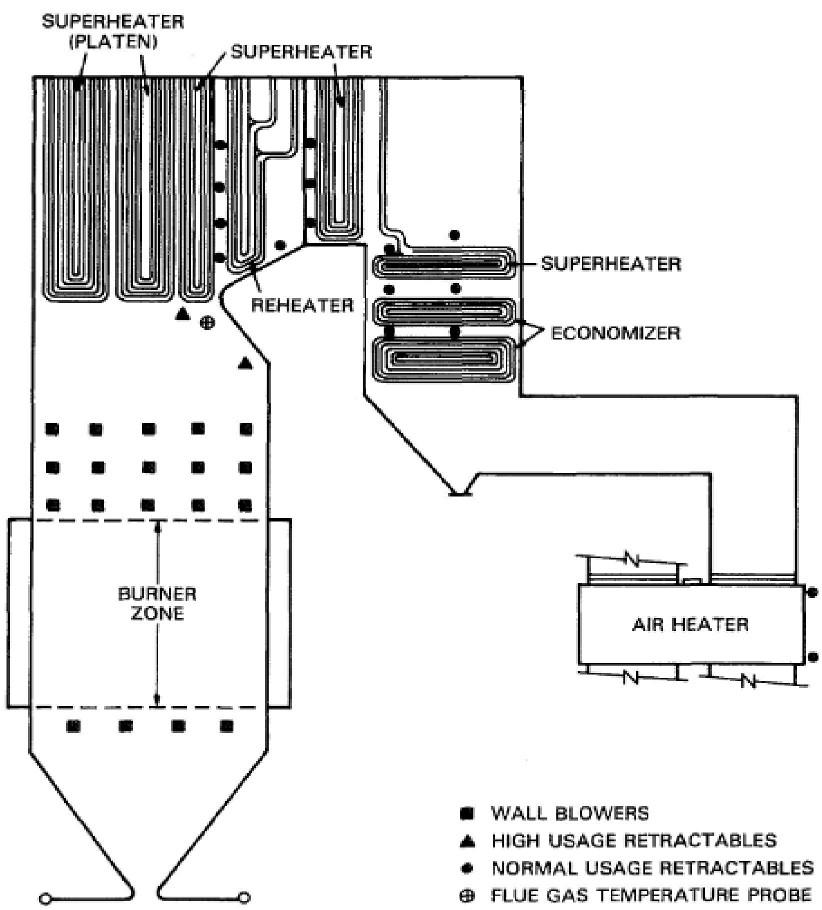


Fig (2-9) soot blower locations.

2.5 Air and Flue Gas System

2.5.1 Air and Flue Gas System Overview

The air-flue gas system of this boiler means to provide the air amount needed for the combustion of boiler fuel continuously and distribute the air amount to send it to the place connecting with the combustion according to the combustion requirement, and to make the dusty gas exhaust to the atmosphere promptly after flowing through each heating surface and gas cleaning devices. Only F.D fan is equipped in the air-flue gas system of the boiler and all the resistances of the gas flue are overcome by the pressure head of the F.D fan, which eliminate the air leakage of the system and improves the combustion strength and boiler efficiency. The F.D fan transmits clean air with low temperature and it is in a good working condition. However, the boiler furnace and air flue work in the normal pressure, so there must be strict sealing for the furnace wall and gas flue; otherwise the gas leakage will result in heat loss and pollute the operation site and even spray flames to hurt the persons. [4]

2.5.2 Working Principle of Air and Flue Gas System

The hot flue gas generated by the fuel combustion transfer the heat to the water wall of the furnace and platen super-heater and then enters the rear vertical flue gas duct, in which the low-temperature super heater and economizer are provided after passing the high-temperature super heater. The flue damper is set behind the economizer and the gas enters the air pre-heater after passing through the damper; a gas shut-down damper is set on the inlet gas flue of the pre-heater and the gas flows to the chimney or exhausts to the atmosphere through the desulfurization system after passing the air pre-heater equipped with bypass gas flue. The unit is equipped with two frequency-conversation ventilators, the outlets of which Converge a main pipe after entering two warm-air pipes. In order to guarantee the cold leg temperature of the air pre-heater, it is possible to use the warm-air pipe to heat the cold air when the ambient temperature is lower than 20oC.

The ventilator sends the air to a 2-compartment air pre-heater, and the hot flue gas of the boiler transfers its heat to the entered air and then enters the two burner bellows set at the front wall and enter the 8 burners respectively. Controlled dampers are set before the air enters each burner [4]

2-6 Literature Review

" P.N.Sapkal"; Presents an approach for the optimization of air pre-heater design with inline & staggered tube arrangement. Air pre-heaters are designed to meet performance requirements with consideration of highly influencing parameters viz. heat transfer, leakage and pressure drop. The performance of tubular air pre-heater is evaluated with the help of CFD analysis for In-line & staggered tube arrangement with the latter being more thermally efficient. [5]

"Thawan Sucharitakul" ; Studies the performance of cross-flow heat exchanger, known as the primary air heater in a 300 MW lignite-fired power plant under particulate, no leakage, and leakage conditions. The leakage values of selected primary air heater were 6.31, 7.37, and 7.65 % when the power plant was run at the manufacturer guaranteed turbine generator capacity of 100, 80, and 60 % respectively. Under these conditions, the gas side efficiency of the selected primary air heater was found to be at the low level of 66.83, 65.44, and 62.12 % and X ratios were 0.92, 0.88, and 0.79 respectively.

“Rakesh Kumar”, here the performance of regenerative air pre heater has been evaluated at off design conditions. To assess the performance at different operating conditions and leakage rate, a regenerator leakage model is proposed. The performance improvements of existing non-performing air pre-heaters are discussed in brief. The performance improvement by improving element profile at cold end of an existing air pre-heater has been presented. With the change in element profile at cold end air side temperature can be increased up to 10℃and gas side temperature can be reduced up to 8.5℃.

“Bostjan Drobnic”, et.al. They used a combination of fluid dynamics and a newly developed three-dimensional numerical model for heat transfer as the basis for a theoretical analysis of a rotary air pre-heater. The model enables studies of the flue-gas flow through the pre-heater and the adjoining channels as well as the regenerative heat transfer and the resulting temperature distribution in the matrix of the pre-heater. In MPM they are operating the boiler without air pre-heater, from literature review it is found out that for every 20℃ rise in combustion air the efficiency of the boiler will increase by 1%. Reduction of flue exit temperature will also helps in reduction of harmful gases up to certain extent, also results in lesser coal consumption. [6]

We can be concluded that by providing baffles the rate of heat transfer will be increased. An optimum air side pressure drop is observed, which depicts the installation of medium quantity of air blower, by which energy consumed will be less, from that the overall efficiency of the plant will increase. From incorporating the proposed design in the existing plant, the temperature of the primary air would increase by about 60oC. Then the efficiency of the boiler would increase by 2.7% their by reducing the fuel consumption.

Chapter three
(Methodology)

3.1 Boiler Overview

The characteristics of boiler are as follows: natural circulation and low oxygen and micro positive pressure combustion, single drum, π type open layout, rotary air pre-heater and suspension structure of full steel framework. Oil burner is arranged in front of the wall.

The rectangle-section furnace is in the front of boiler. It adopts membrane water wall. The top and the rear vertical shaft are both covered with super-heater to form roof and back enclosed wall. The platen super-heater is arranged at the top of furnace. Two stages of heating surface (cold and hot section) of the high temperature super heater locate above the arch nose. The low temperature super-heater is arranged above the vertical shaft where a suspension economizer is arranged. Heating surfaces of boiler are suspended to the top plate beam through all kinds of hangers and suspenders.

A rotary air pre-heater is arranged at the back of the boiler back part.

Table（3 －1）Boiler design

Maximum capacity each boiler (BMCR)	67.4	kg/s
Design pressure	110	bar(a)
Operating pressure drum	100	bar(a)
Boiler stop valve pressure	92	bar(a)
Boiler stop valve temperature	515	℃
Feed water inlet temperature at BMCR	220	℃
Flue gas outlet temperature	245	℃

Figure（3 －1）Boiler

Table （3 －2） Boiler performance details

boiler load %		100				
turbine load %		0	100	80	50	30
steam output super heater	Kg/s	67.42	63.8	50.8	32.7	21.7
steam temperature at super heater	℃	510	510	510	503	464
steam pressure at super heater	bar	87	87	87	87	87
fuel consumption	Kg/s	4.352	4.147	3.448	2.335	1.494
air required for combustion	Kg/s	61.603	58.701	48.806	33.982	22.47
Air entering air heater	Kg/s	65.497	62	52.211	37.053	25.01
Flue gas living furnace	Kg/s	65.956	62.849	52.255	36.315	23.96
flue gas entering air heater	Kg/s	65.956	62.849	52.255	36.315	23.96
flue gas leaving air heater	Kg/s	69.844	66.619	55.655	39.387	26.5
atomizing steam flow	Kg/s	0.261	0.249	0.214	0.159	0.125
Pressure of steam before burners	bar	10.9	10.2	7.7	5.8	4.7
Number of burner operating		6	6	6	6	6

Table （3 －3） Heat balance

boiler load %		100				
turbine load %		0	100	80	50	30
Datum ambient	deg c	35	35	35	35	35
Heat to steam	%	89.5	89.49	89.41	89.04	88.5
Heat loss tp dry flue gas	%	3.84	3.84	3.86	4.04	4.28
Heat loss to moisture and combustion to hydrogen	%	5.78	5.78	5.78	5.78	5.78
Heat loss due to moisture in air	%	0.14	0.14	0.14	0.15	0.16

Heat loss due to un-burnt carbon	%					
Heat loss due to radiation	%	0.24	0.25	0.31	0.49	0.78
Un-accounted losses	%	0.5	0.5	0.5	0.5	0.5

3.2 Air and Flue Gas System Overview

The air-flue gas system of this boiler means to provide the air amount needed for the combustion of boiler fuel continuously and distribute the air amount to send it to the place connecting with the combustion according to the combustion requirement, and to make the dusty gas exhaust to the atmosphere promptly after flowing through each heating surface and gas cleaning devices. Only F.D fan is equipped in the air-flue gas system of the boiler and all the resistances of the gas flue are overcome by the pressure head of the F.D fan, which eliminate the air leakage of the system and improves the combustion strength and boiler efficiency. The F.D fan transmits clean air with low temperature and it is in a good working condition. However, the boiler furnace and air flue work in the normal pressure, so there must be strict sealing for the furnace wall and gas flue; otherwise the gas leakage will result in heat loss and pollute the operation site and even spray flames to hurt the persons.

3.3 Working Principle of Air and Flue Gas System

The hot flue gas generated by the fuel combustion transfer the heat to the water wall of the furnace and platen super-heater and then enters the rear vertical flue gas duct, in which the low-temperature super-heater and economizer are provided after passing the high-temperature super-heater. The flue damper is set behind the economizer and the gas enters the air pre-heater after passing through the damper; a gas shut-down damper is set on the inlet gas flue of the pre-heater and the gas flows to the chimney or exhausts to the atmosphere through the de-sulfurization system after passing the air pre-heater equipped with bypass gas flue. The unit is equipped with two frequency-conversation ventilators, the outlets of which converge a main pipe after entering two warm-air pipes. In order to guarantee the cold leg temperature of the air pre-heater, it is possible to use the warm-air pipe to heat the cold air when the ambient temperature is lower than 20oC.

The ventilator sends the air to a 2-compartment air pre-heater, and the hot flue gas of the boiler transfers its heat to the entered air and then enters the two burner bellows set at the front wall and enter the 6 burners respectively. Controlled dampers are set before the air enters each burner.

3.3.1 Air supply System

a. The design scope is from inlet of forced draft fan via forced draft fan to air inlet box of air heater.
b. The function of force air system is to supply cold air that is going to be heated for the purpose of combustion. The system contains equipment and component: Two centrifugal forced draft fans at variable speed with single air inlet, air suction, silencers, discharge dampers, steam air heater, rotary air heater and air duct etc.
c. Each fan when operated alone will be capable of providing 60% of the air required at 100% BMCR. In addition, when both fans are operated simultaneously they will be capable of providing 100% of the air required at100% BMCR. These requirements will be satisfied with a furnace excess air equal to the design excess air or 10%, whichever, the greater and an ambient air temperature of 35°C.

d. In addition to the previously described requirements, the following allowances will be taken into account.
e. Capacity - The fan volume will include an allowance for the increased air heater leakage expected after 12 months of operation and an allowance for the increased boiler seal air leakage expected after 12 months operation, if the forced draught fan provides this.
f. Head - The fan head will not include any allowance for chimney suction.
g. The design capacity and head of the fans will not be less than defined above with both fans operating simultaneously at 100% BMCR with margins 10% on volume and 21% on head.
h. The fan mechanical design temperature will be 50°C.

Figure（3 －2）F D Fan

3.3.2 Hot Air System

The design scope is from the outlet of the air heater to the wind-box of the boiler burners.

The function of hot air system is to supply the hot air demanded by combustion of the boiler, when it starts up and normally operates.

The hot air coming from outlet of air heater will be directly blown into the furnace through the wind-box of the boiler burners. Flow measure devices will be installed in hot air duct to monitor the air flow which will enter furnace.

Table (3 − 4)Air temperature

boiler load %		100				
turbine load %		0	100	80	50	30
steam output super heater	Kg/s	67.42	63.8	50.8	32.7	21.7
Intake to fan	℃	35	35	35	35	35
Intake to steam air heater	℃	41	40	39	37	36
Intake to main air heater	℃	69	72	87	112	131
Outlet to main air heater	℃	287	282	264	240	225

3.3.3 Bypass Air System

The design scope is from the inlet air duct of the air heater to the outlet air duct.

Each boiler is only provided with a single regenerative air heater. When the boiler is out of operation, the air heater inlet and outlet isolated dampers will be closed and the damper in the bypass duct will be opened. The cold air will directly flow into the furnace by bypass air duct without passing the air heater. The bypass air system can prevent air heater from secondary combustion on boiler ignition.

Bypass air system will be designed to allow the boiler to continue to operate at 30% TMCR.

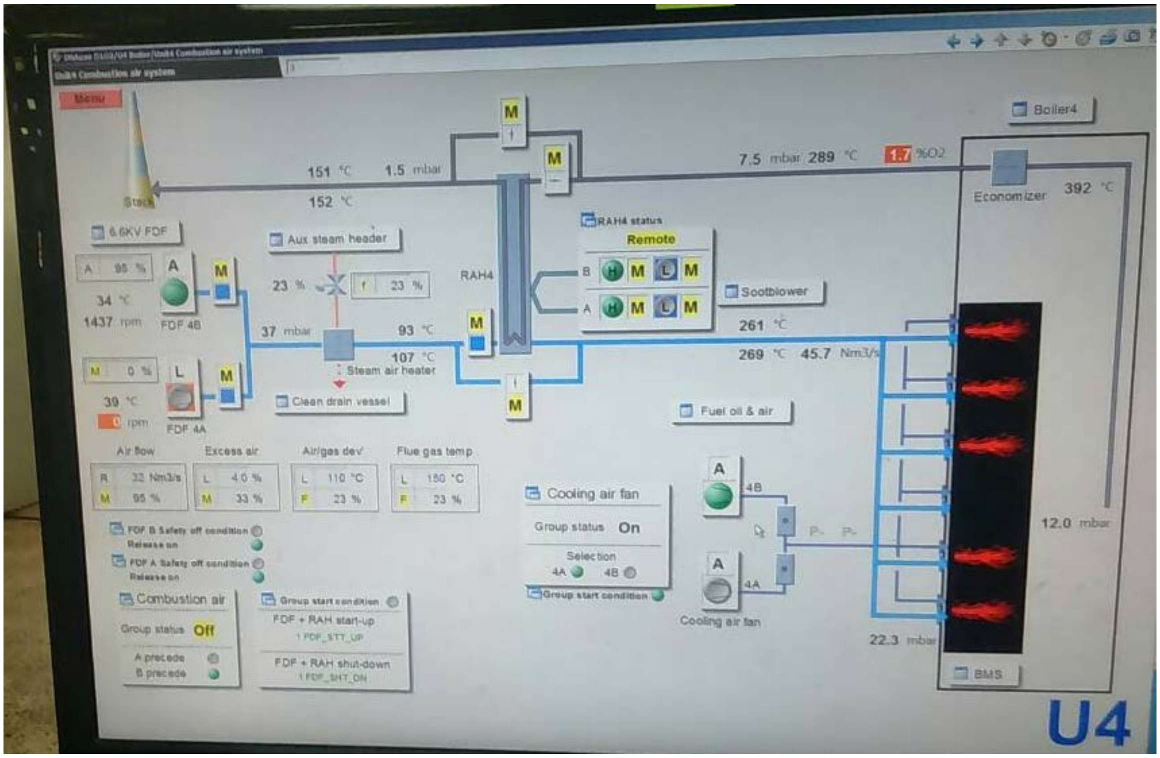
3.4 Flue Gas System

The design scope is from the flue gas outlet of air heater to stack.

The combustion products in the system flow into the atmosphere, which begin in the boiler furnace and go into the stack through the super-heaters, economizer, air heater (at the gas side). The duct material downstream of the air heater will resist flue gas corrosion at low load. This duct will be constructed in acid-resistant steel.

Gas side bypass will be provided by WBC. The gas side bypass can prevent air heater from secondary combustion on boiler ignition.

FGD will be supplied in this contract. A damper will be installed in the flue gas duct .When FGD is in operation, the damper will be closed. Flue gas will flow into FGD through the duct before the damper and then flow into the stack through the duct after the damper.



Figure（3 －3）Flue gas system

Table（3 －5）Gas temperature

boiler load %		100				
turbine load %		0	100	80	50	30
Furnace exit	℃	1278	1254	1172	1070	1008
2nd super-heater inlet	℃	1236	1214	1130	1026	964
1st super-heater inlet	℃	910	892	822	718	650
Economizer inlet	℃	613	602	554	474	414
Economizer outlet	℃	343	336	306	262	233
Air heater inlet	℃	340	333	304	261	233
Air heater outlet	℃	145	145	145	145	145
Chimney inlet	℃	144	144	144	144	144

Table（3 －6） Flow gas pressure

boiler load %		100				
turbine load %		0	100	80	50	30
Pressure in furnace	m bar g	25.68	23.1	15.24	6.54	2.85
Pressure losses through:						
2st super-heater	m bar g	1	0.91	0.63	0.3	0.13
1st super-heater	m bar g	2.73	2.48	1.71	0.83	0.36
Economizer	m bar g	3.35	3.04	2.1	1.02	0.44

3.5 Boiler equipment

3.5.1 Boiler Washing System

A water washing facility will be provided for cleaning the gas side parts of combustion chamber, super-heater, economizer and air-heaters. The water supply for this facility will be taken from the circulating water header in the pump house. The air heater and boiler wash water will be dosed with sodium carbonate and cleaning agent to be taken from a new storage tank provided under this contract and pumped by a new wash water pump. Air heater wash water will be discharged to the wash water sump that will be common to both boilers.

3.5.2 Air and Flue Gas Equipment

Burner

Six swirling oil burners are arranged in the front wall with three layers and two burners in each layer.

The burner is atomized by superheating steam with pressure about 8.3bar.

3.5.3 Furnace

Furnace is a 8080（deepness）×10320（width）rectangle section with the height 26300mm (from the lower header of rear water wall to central line of roof). The membrane water wall is suspended in the top beam.

3.5.4 Steam coiled air pre-heater

A steam coiled air pre-heater will be installed in FD fans discharge duct. The steam coiled air pre-heater can maintain the cold end metal temperature of air-heater to prevent cold end corrosion. And the steam coiled air pre-heater also can be used to increase the temperature of cold air at low load. The temperature of flue gas in the air heater outlet will be not less than 145 °C to prevent flue gas from corroding the downstream duct of the air heater when the load is above 50%BMCR.

3.6 Air Pre-heater

APH is designed to supply hot air for combustion, so as to further conserve fuels.

Heating elements of heat exchanger are heated or cooled by gas flows through its surface by turns. When hot gas flow and cold gas flow are passing one heat exchange surface, heating elements absorbs heat energy from the hot gas flow and then transfers it to the cold gas flow. Heating exchange process is kind of period; heating elements keep rotating so that the heating exchange process can continue.

Fig (3 – 4) rotary Air Pre-heater

In the interior of APH, flue flows through one side, and air the other side. Rotor of APH rotates slowly through the hot flue and cold air by turns. When the heat exchange elements pass through flue side, certain heat energy carried by flue will transfer to heating elements.

When pass the air side, heat energy carried by heating elements will transfer to air. Thus, APH recycles the heat energy of flue, reduces the exhaust flue temperature, increases the initial temperature of fuel and air, reinforce combustion and improves boiler efficiency.

Rotor is the key part of APH with heating elements. Main radial diaphragm divides rotor into 12 sectors, which are divided into 48 smaller sectors by the main radial diaphragm and secondary radial diaphragm. The circumferential diaphragm between main and secondary radial diaphragms supports the heating elements box.

Weight of rotor and heating elements is supported by bottom spherical roller bearing. The top CARB rolling guide bearing is used to support the radial horizontal weight.

The flue gas and air flow separately pass through the two sides of rotor. The fixed section plate and axial seal plate separately isolates the air and flue gas. Arrangement of gas flow is: flue down; air up.

Shell of rotor is used to seal rotor with transition air and flue duct at top and bottom parts. One side of the transition duct is connected to rotor shell, and the other side to non-metal expansion joint; its height and the interface flange size can be changed with duct arrangement requirements. Outer circumferential seal is set on rotor shell to control the direct air leakage from air to flue and the bypass amount of flue and air.

Rotor shell is connected to the hinge end column of APH and welded as a whole on bottom beam framework. Rotor shell air and flue sides are supported on steel framework by two sets of hinge side columns. This support mode can keep the rotor shell can expand outside freely in hot state.

End column supports the top framework which is equipped with top guide bearing. Two end columns and top structure form a door-shaped framework supported on bottom beam. Bottom spherical rolling thrust bearing supports the rotary elements weight.

And the weight is transferred to two bottom beams through bottom bearing beam plate.

Central drive device is directly connected to rotor center shaft. It consists of main drive motor, standby drive motor, reduction gear box, coupling, drive shaft lock panel and transducer, etc. Besides, it has manual turning gear handle.

Based on design requirements, the startup of driving device must be done by the transducer in order to decrease the startup torque, to protect the gear box and driving mechanism. Strictly prohibit starting up the driving device directly by driving motor.

When carrying out washing low pressure, control the speed of rotor through transducer to make it rotate at low speed.

Static seal pieces of APH are consisted of sector and axial seal plates. Sector plate is arranged along the direction of rotor diameter. The axial seal plate is on end column, connected with upper and lower sector plates forming a closed static seal surface.

Seal pieces are installed on the upper and lower part of axial diaphragms along the radial direction as well as the outer edge along axial direction. These seal are set according to the limit element calculation and field experience of installation commissioning. Thus, air the leakage rate of air pre-heater can be decreased to minimum in normal operation.

Outer circumferential seal is set between the top and bottom outer angle steels and the shell. Bottom circumferential seal is installed in the bottom transition air and flue duct, forming a seal couple with the bottom surface of outer angle steel at bottom. The top annulus seal is welded on the rotor shell plate, forming a seal couple with the edge of top outer angle steel.

Chapter four

(Discussion and analyses)

4.1 Boiler efficiency

$$\textbf{Boiler Efficiency} = \frac{\textbf{Energy output}}{\textbf{Energy input}} \times \mathbf{100\%}$$

$$\text{efficiency} = \frac{\dot{m}_{steam}(\dot{h}_s - h_w)}{\dot{m}_{fuel} * GCV} * 100\%$$

$$\text{GCV} = 43030\ {}^{KJ}/_{Kg}$$

Table (4 − 1) Boiler efficiency

boiler load %	100				
turbine load %	-----	100	80	50	30
steam (kg/s)	67.42	63.8	50.8	32.7	21.7
steam temp °C	510	510	510	503	464
stem pres (bar)	87	87	87	87	87
steam enthalpy	3416	3416	3416	3398.48	3299.168
water temp °C	220	220	220	220	220
water pres (bar)	105	103.5	98.6	92.9	90.2
water enthalpy	946.03	945.983	945.83	945.6	945.57
fuel (kg/s)	4.352	4.147	3.448	2.335	1.494
efficiency (%)	88.924	88.311	84.576	79.829	79.445

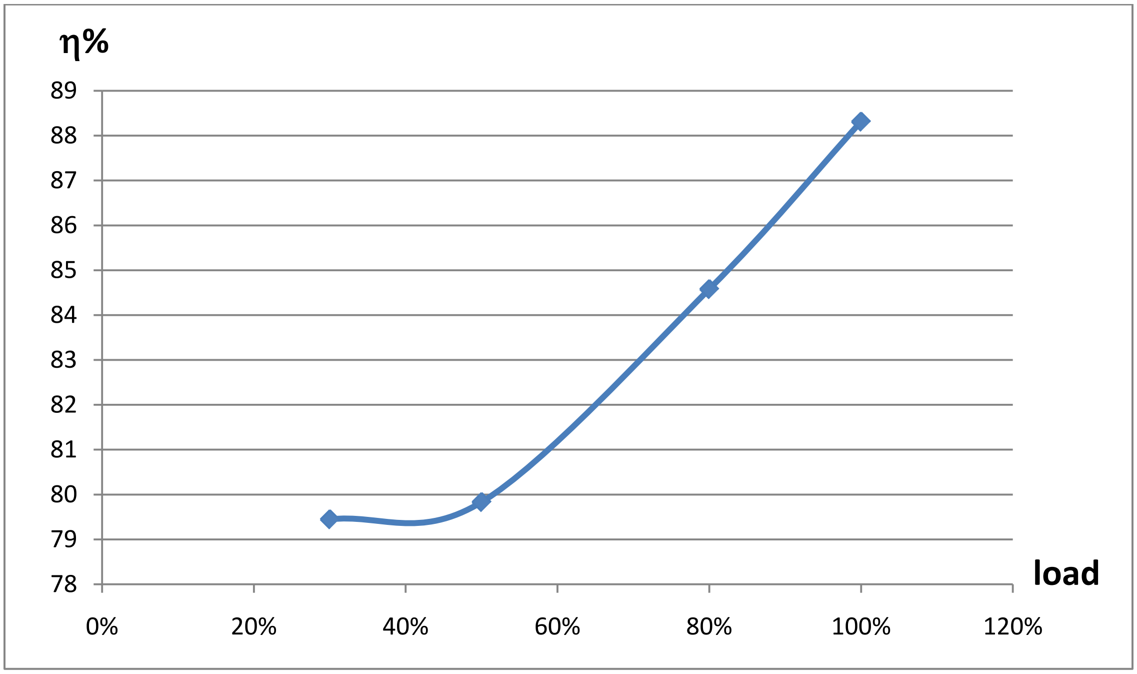


Fig (4 − 1) Boiler efficiency

This graph represents the relation between Boiler efficiency and variation of load. The change in efficiency in all operating conditions 30%, 50%, 80% and 100% depends on the change in the amount of steam and the mass of fuel which it used in the boiler. Because there's no variation in values of steam temperature in loads above 50% so the values of enthalpy are fixed and the mass of fuel which is used in the boiler is a change with the change thus the efficiency changes.

Normally the boiler Efficiency is between 90%- 95% this decrease occurs as a result of lost a Part of heat of burnet fuel due to (Heat lost by exhaust gases, Unburned fuel ,Heat lost by hydrogen, Heat lost by moisture in fuel, Heat lost by moisture of air, Heat lost by walls).

Efficiency reduced to the accumulation of soot on pipes walls of the boiler, which reduces heat transfer.

4-2 Heat gain from air heater:

$$Q_{gain} = \dot{m}_{air} * CP_{air} * \Delta T_{air}$$

$$CP_{air} = 1.005 \ {}^{KJ}/_{Kg.K}$$

Table (4 − 2) Heat gain from air heater

boiler load %	100				
turbine load %	-----	100	80	50	30
air entering air heater (kg/s)	65.497	62	52.211	37.053	25.01
air temp intake to air heater°C	69	72	87	112	131
air temp outlet to air heater °C	287	282	264	240	225
Q gain from air heater (K watt)	14349.74	13185.56	9287.554	4766.498	2362.695

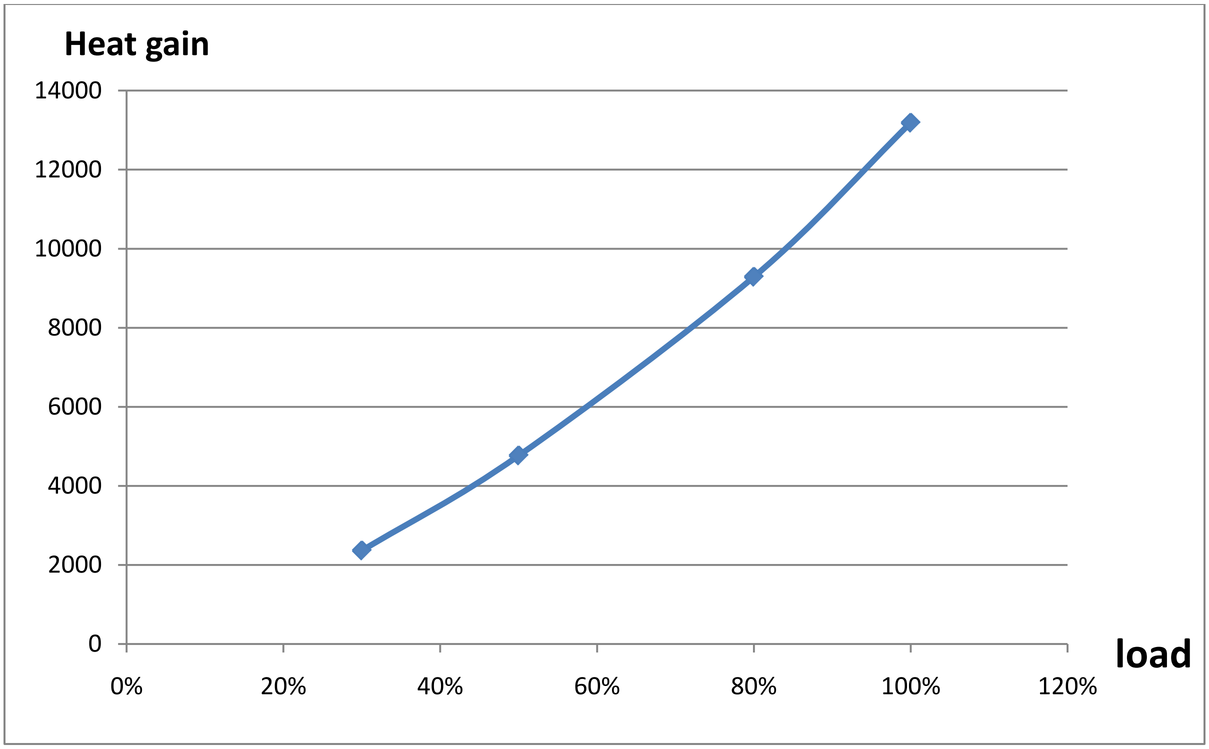


Fig $(4\ -2)$ Heat gain

This graph represents the relation between heat gain by air heater and variation of load. amount of air used in the combustion process rises with an increase in loads Also, the amount of gases produced by burning is therefore the amount of heat returned to the boiler by rotary air heater. At load 30% provides 2362.9kw, 50% provides 4766.498kw, 80% provides 9287.554kw and 100% provides 13185.56kw.

This amount of heat should be added to the boiler by burning an additional amount of fuel if rotary air heater not used, to reach amount of heat required for production steam.

4-3 Effect of air heater in boiler:

Heat added in boiler $Q_{add} = \dot{m}_{fuel} * GCV$

$$\text{Effect} = \frac{Q_{gain}}{Q_{add}} * 100\%$$

Table (4 − 3) Effect of air heater

boiler load %	100				
turbine load %	-----	100	80	50	30
Q gain (K watt)	14349.74	13185.56	9287.554	4766.498	2362.695
Q add in boiler (K watt)	187266.6	178445.4	148367.4	100475.1	64286.82
effect of air heater %	7.662735	7.389128	6.259833	4.743962	3.67524

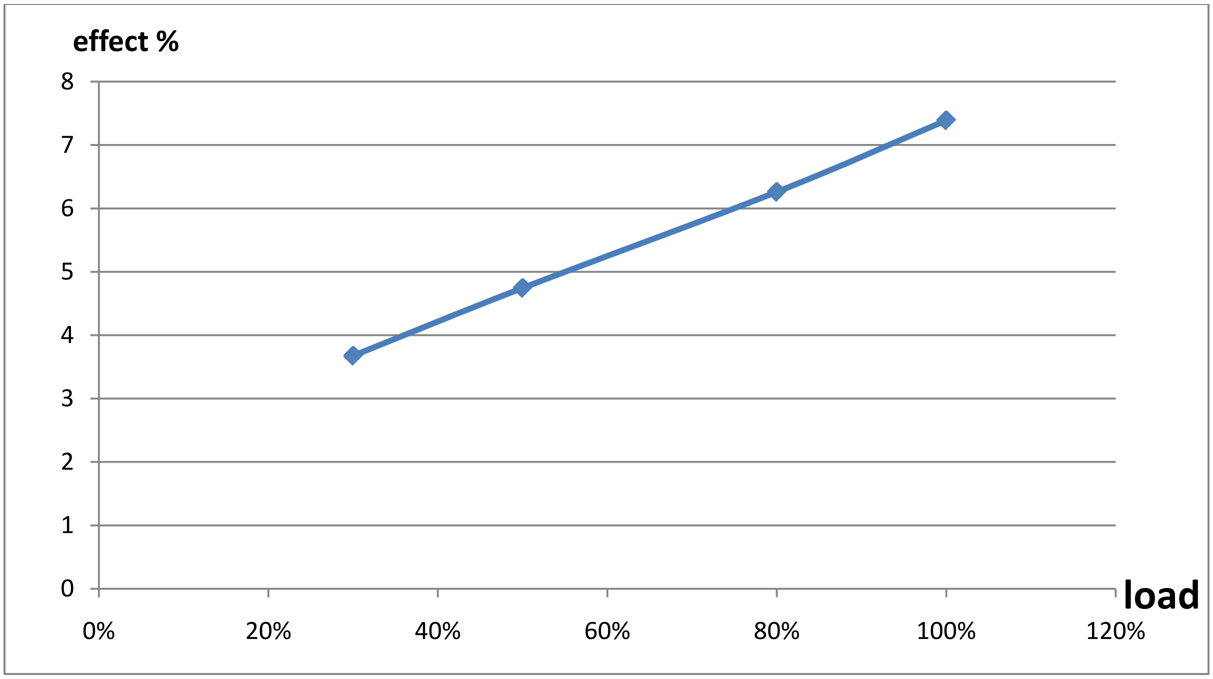


Fig (4 − 3) Effect of air heater

This graph represents the relation between Effect air heater and variation of load. The effect of the air heater on the boiler efficiency is very high as it Reduces the amount of heat that should be added to the boiler at load 30% by 3.67percent , 50% by 4.74 percent, 80% by 6.25 percent and 100% by 7.39 percent This represents a large amount of fuel used.

This heat should be added to the boiler by burning an additional amount of fuel but air heater help to get the heat Required and decrees Quantity of fuel it can be used .

4-4 Cost of fuel saved by rotary air heater:

Cost of fuel = $427_{SDG}/_{ton}$

$$\text{Money saved per year} = \frac{\text{Q gain}}{\text{GCV}} * 365 * \text{Cost of fuel}$$

Table (4 − 4) cost of fuel saved per year

boiler load %	100				
turbine load %	-----	100	80	50	30
Q gain (K watt)	14349.74	13185.56	9287.554	4766.498	2362.695
M fuel Saving(kg/s)	0.333482	0.306427	0.215839	0.110772	0.054908
M fuel Saving (ton) for year	10372.63	9531.11	6713.458	3445.437	1707.861
Money saved per year (SDG)	4356505	4003066	2819652	1447084	717301.7

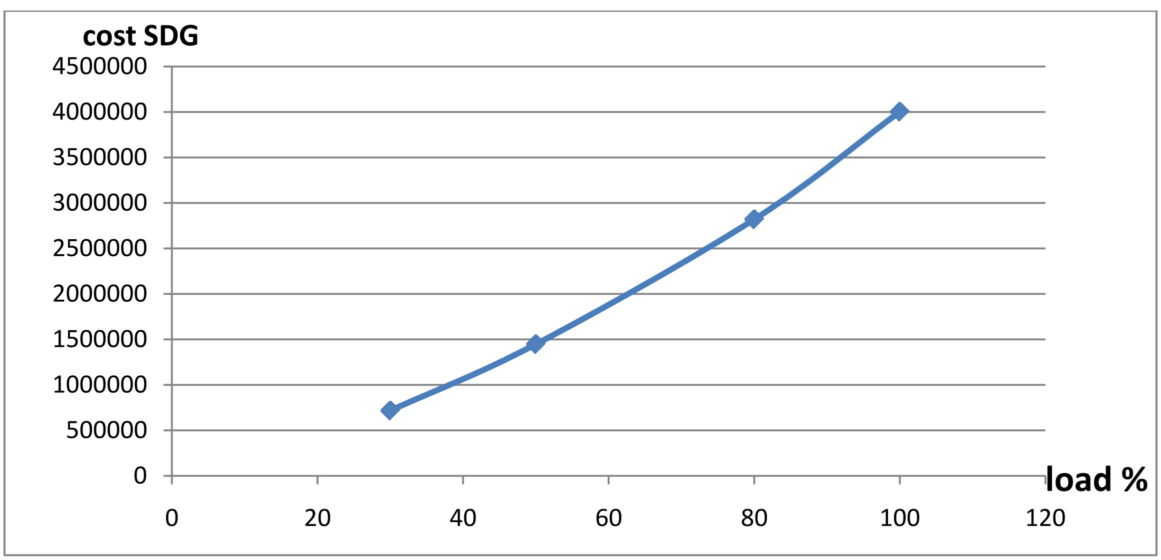


Fig (4 − 4) **cost of fuel saved per year**

This graph represents the relation between cost of fuel saved per year and variation of load. It is clear the amount of money will be saved by using rotary air heater per year is High value And significantly affect on the operational efficiency of the station.

4-5 Rotary air heater parameters:

4-5-1 Air Side Efficiency

$$air\ sid \text{ efficiency} = \left[\frac{T_{al} - T_{ae}}{T_{ge} - T_{ae}}\right] * 100$$

T_{ae} ≡ Temperature of air entering air heater

T_{aL} ≡ Temperature of air leaving air heater

T_{ge} ≡ Temperature of gas entering air heater

T_{gL} ≡ Temperature of gas leaving air heater

4-5-2 Gas Side Efficiency:

$$gas\ sid \text{ efficiency} = \left[\frac{T_{ge} - T_{gl}}{T_{ge} - T_{ae}}\right] * 100$$

4.5.3 X-Ratio:

Ratio of heat capacity of air passing through the air heater to the heat capacity of flue gas passing through the air heater

$$X_{-ratio} = \frac{T_{gas\ in} - T_{gas\ out}}{T_{air\ out} - T_{airin}}$$

Table (4 – 5) Rotary air heater parameters:

boiler load %		100				
turbine load %		0	100	80	50	30
air Intake to main air heater	deg c	69	72	87	112	131
air Outlet to main air heater	deg c	287	282	264	240	225
gas at Air heater inlet	deg c	340	333	304	261	233
gas at Air heater outlet	deg c	145	145	145	145	145
Air Side Efficiency	%	80.442	80.459	81.566	85.906	92.156
gas Side Efficiency	%	71.955	72.030	73.271	77.852	86.274
x-ratio	%	0.8944	0.8952	0.8983	0.9062	0.93617

X-ratio indicates excessive gas weight through the air heater or that Air flow is bypassing the air heater.

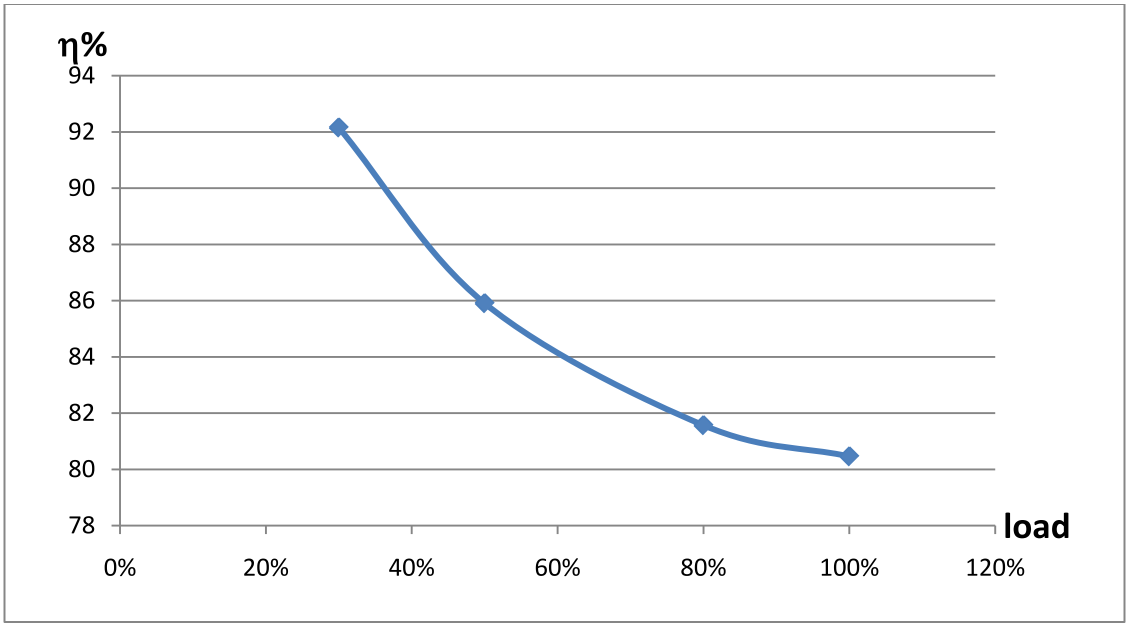


Fig (4 − 5) Rotary air heater Air Side Efficiency

This graph represents the relation between Rotary air heater Air Side Efficiency and variation of load.

We find that the temperature of air entering the rotary air heater in load 30% is 131℃ , 50% is112℃ , 80% is 87℃ and load100% is 72℃ .This values of Temperature are controlled by using steam air heater and it's called set point temperature it use to avoid damage on Rotary air heater Due to the high difference between the flow gases temperature and fresh air temperature. And it can be calculated form equation $\text{set point} = \frac{\text{TaL} + \text{Tae}}{2}$ it always above 110℃ operational design value 178℃ .

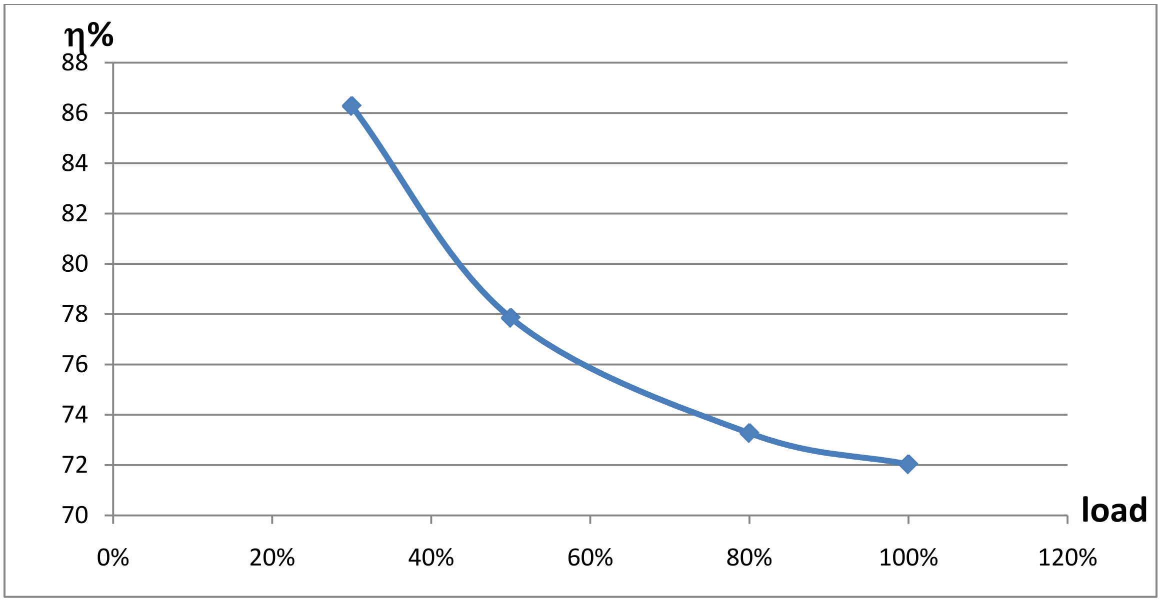


Fig (4 − 6) Rotary air heater Gas Side Efficiency

This graph represents the relation between Rotary air heater Gas Side Efficiency and variation of load. The Temperature of flow gases which exit from Rotary air heater it must be greater than 145. It represents apparatus due point flow gases to avoid condensation of water vapor droplets on the chimney which in turn cause corrosion in stack. Through it is determined value of gas Side Efficiency.

X- Ratio

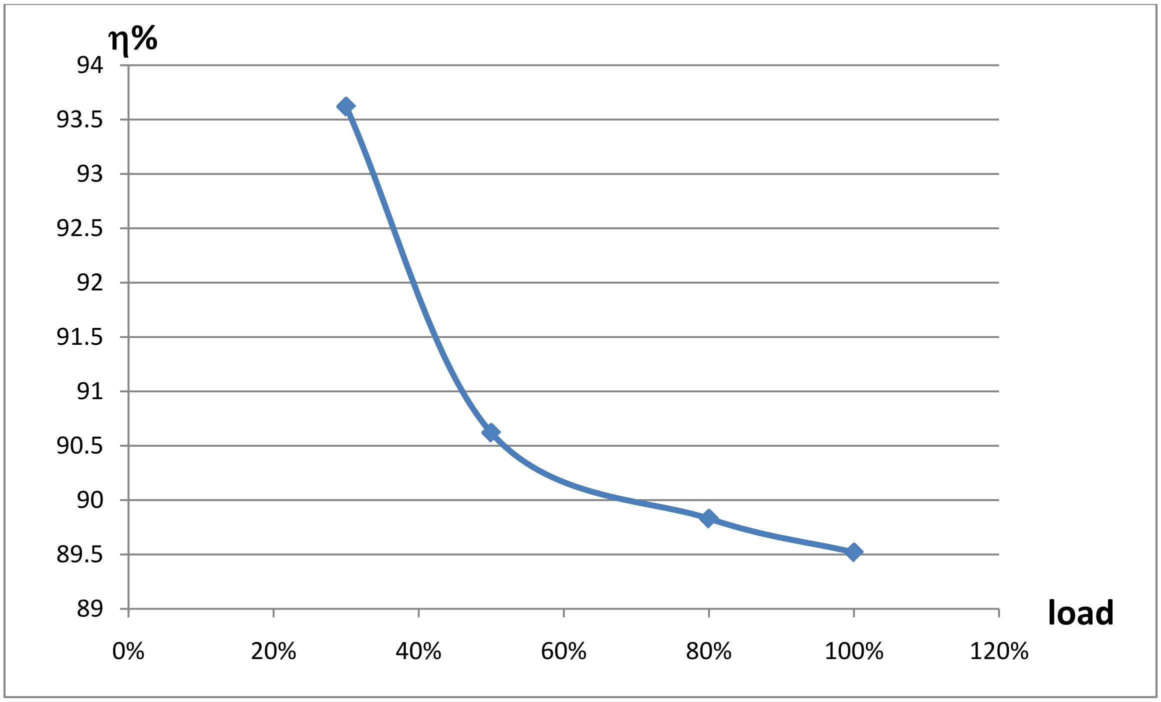


Fig (4 − 7) X-Ratio for Rotary air heater

This graph represents the relation between X-Ratio for Rotary air heater and variation of load. Represent over all Efficiency of rotary air heater it can be calculated by dividing gas side efficiency on air Side efficiency this values depend on several factors (air leakage and quantity of flow gasses through air heater and load).

Chapter five

(conclusion)

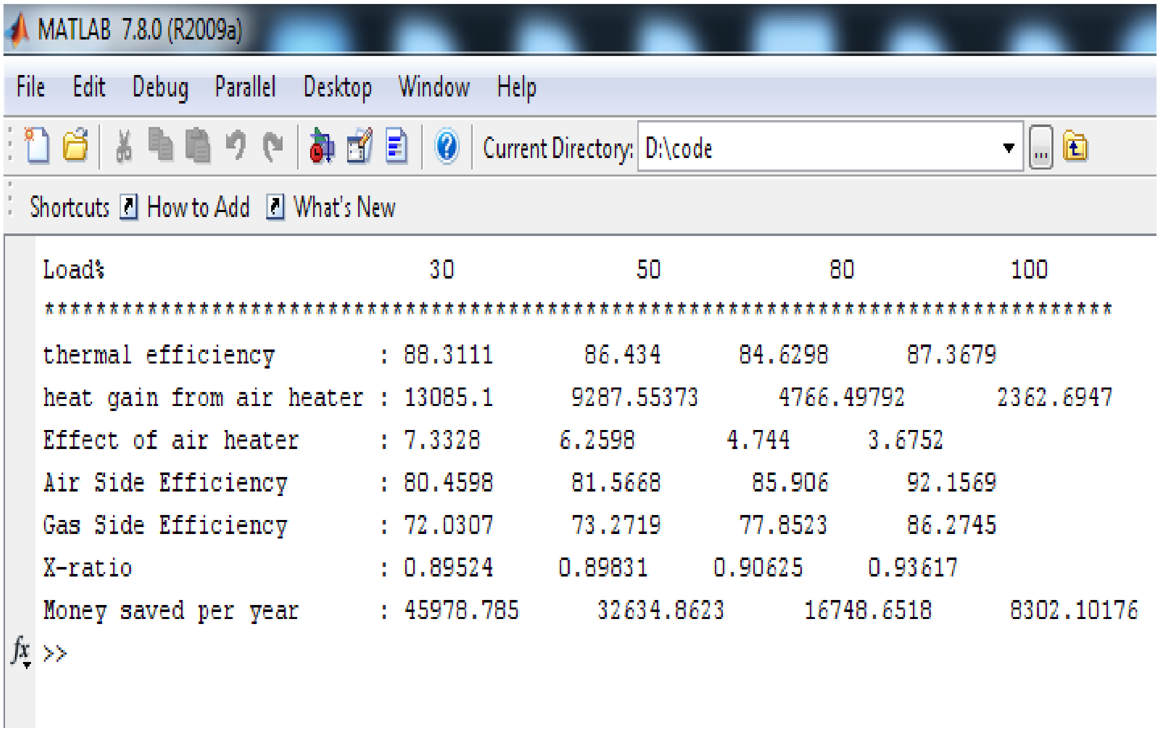
Conclusion

1. The Thermal performance of the air pre-heater is improved
2. The rotary air-heater is essential boiler accessory because it recover large amount of heat by using theses processes raising boiler efficiency and this is what has been proven previously.
3. The rotary air-heater provides a large amount of fuel at load 100% equal economic value of 400306 Sudanese pounds per year.
4. Soot stuck on pipes of super-heaters and economizer and rotary air heater effect on efficiency.
5. The amount of heat returned to the boiler may reach 13185.57 kw and this is a large quantity.

Recommendations

1. doing soot blower every 8 hours to cleaning the soot from pipe get high useful of heat transfer between Air and Exhaust gases in all time to gain a maximum efficiency allowable .
2. recommend the Sudanese thermal power generation company to select design at establishing new steam generation plant include rotary air heater instead of duct air heater.
3. Recommend to do more researches on heat recovery special on apart of air heater to raise the thermal efficiency of plant.

Appendix


MATLAB 7.8.0 (R2009a)
File Edit Debug Parallel Desktop Window Help
Current Directory: D:\code
Shortcuts How to Add What's New
Load% 30 50 80 100
****
thermal efficiency : 88.3111 86.434 84.6298 87.3679
heat gain from air heater : 13085.1 9287.55373 4766.49792 2362.6947
Effect of air heater : 7.3328 6.2598 4.744 3.6752
Air Side Efficiency : 80.4598 81.5668 85.906 92.1569
Gas Side Efficiency : 72.0307 73.2719 77.8523 86.2745
X-ratio : 0.89524 0.89831 0.90625 0.93617
Money saved per year : 45978.785 32634.8623 16748.6518 8302.10176
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