DEDICATION

This project is dedicated to my guardian Mr. Akumah, and to all those who know that nothing is impossible, difficult certainly, improbable most likely, but never impossible.

CERTIFICATION

This is to certify that this project work "Equipment Design of a Boiler to Generate 130t/hr Steam" was carried out by Letitia AK. Tuekpe of the Department of Chemical Engineering, School of Engineering and Engineering Technology, Federal University of Technology, Minna, Niger State.

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ABSTRACT

The basic aim of this project is to design a boiler to generate 130 t/hr of steam for deodorizing shea butter and to serve as utility in other plant processes.

The design included, energy and material balances for the plant, design of boiler components such as furnace, slagscreens, superheater, economizer and air heater was carried out.

The volume of the furnace which is equivalent to the volume of the boiler was calculated to be 384m^3 and its depth was 5m. The number of tubes and their diameters were specified.

The cost of the boiler determined by the factorial method was £1,5451 930.1 whose equivalent in Naira is ₦259,000,000.

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CHAPTER FIVE

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5.1 CONCLUSION 31

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2.3.5 STEAM DRUM.

Supercritical recirculating boilers are provided with large cylindrical pressure vessel or stream drum in which the separated steam is separated from the two phase mixtures living the boiler tubes. The drum can be given large, with diameters ranging from 1m to several meters and with length approaching 30m. Thick plates that have been rolled into cylinders with hemispherical heads manufacture them.

The primary function of the is to house the equipment necessary to separate the steam cool surface in the boiler, and the separated liquid for recirculation to the furnace circuits

2.4 CLASSIFICATION OF BOILERS:

Steam boilers can be classified according to their uses, steam pressure, circulating methods, fuel, firing methods, methods of removing slag and boiler layout forms.

2.4.1 CLASSIFICATON BY USE

i) Utility boiler

ii) Industrial boiler

iii) Marine boiler

2.4.2 CLASSIFICATION BY STEAM -WATER CIRCULATION

i) Natural circulation boiler

ii) Forced multiple circulation boilers.

iii) Once through boiler

iv) Combine circulation boiler.

2.3.3 CLASSIFICATION BY PRESSURE

- Low and middle pressure boiler (<10MPa).
- Higher pressure boiler (10-14MPa).
- Super high-pressure boiler (>17mpa).
- Super critical pressure boiler(>22.1mpa)

2.4.4 CLASSIFICATION BY FUEL OR HEAT SOURCE

i) Solid fuel fired boiler

ii) Fuel oil fired boiler

iii) Gas fired boiler

iv) Water heat boiler.

2.4.5 CLASSIFICATION BY FIRING METHOD

- Boiler with stoker
- Boiler with burners

$= H^w{}_1 + H_ph$ - (3.35)

$= 41242 + 266$

$H^w av = 45108$ KJ/kg

Also, $H^w av = H^w{}_1 + H_2 + H_3 + H_4 + H_5 + H_6$. - (3.36.)

Dividing through by H^wav gives.

$100 = h_1 + h_2 + h_3 + h_4 + h_5 + h_6$.

$nb = 100 - (h_1 + h_2 + h_3 + h_4 + h_5 + h_6)$. - (3.37)

Where nb = efficiency of boiler

h_2 = relative heat loss with waste gases

h_3 = relative heat loss by incomplete combustion

h_4 = relative heat loss with unburnt carbon

h_5 = relative heat loss by cooling through lining

h_6 = physical heat of removal slag.

Now H_2 = (1wg - & wg 1 ca) $(1\text{-}0.01h_4)$ - (3.3.8)

Let $h_3 = 0.5\%$ H in

$h_4 = 0\%$

$h_5 = 0.7\%$

neglect h_6 for the fuel oil.

$$h_2 = \frac{H_2}{H^w av} \text{ - (3.3.9)}$$

Now, fuel consumption rate

$$B = \frac{1}{H^w av\ nb} [Wsh\ (iss - ifw) + Wrh\ (irhe - irhi) + Wbw(isw - ifw)] \quad \text{- (3.310)}$$

Assume waste gas temperature = 160^0C = iwg, 1 g = 3153 KJ/kg

Assume cold air temperature Tca = 30^0C 1ca = 440KJ/kg

α wg = 1.21

$\therefore H_2 = [3153 - 1.2(440)]\ (1 - 0.001h_4)$

$= 2620.6$ KJ/kg

$$\therefore H_6 = \frac{2620.6}{45108} \times 100 = 5.81\% \approx 5.8\%$$

$\therefore$ Boiler efficiency nb = $100 - (h2 + h_3 + h_4 + h_5 + h_6)$

$= 100 - (5.81 + 0.5 + 0 + 0.7 + 0)$

$= 92.99 \approx 93\%$.

Q out = [36.11 (3332 - 730.2) 0 0.3611 (1116.3 - 730.2)]

= 93950.998 + 139.42071

= 94008.25

Fuel consumption from equation (3.3.10)

$$B = \frac{1}{45108(5.8)} [36.11\,(332 - 730.2) + 0.3611\,(116.3 - 730.2)]$$

$= 2.451 kg/s.$

$\therefore$ Q in = 36.11 x 41,242

= 101084.14 KJ/kg

Q_3 = 0.5% Q in = 0.005 (101084.14) = 5050.4207KJ/kg

Q_2 = 5.8% Q in = 0.058 (101084.14) = 5862.8801 KJ/kg

Q_5 = 0.7% Q in = 0.005 (101084.14) = 707.58898

$\therefore$ 101084.14 = 94008.25 + 5862.8801 + 5050.4207 + 707.58898

101084.14 = 101084.14

TABLE 3.2: SUMMARY OF MATERIAL BALANCE

COMPONENT [mw]	FUEL OIL FROM STORAGE	FUEL OIL TO BOILER Kg	kgmo1	COMBUSTION AIR Kgmo1	kg	BOILER FEED WATER kg	STEAM PRODUCTS kg	ATOMIZING STEAM Kg	Kgmo1	COMBUSTION PRODUCTS. Kgmo1	kg	FLUE GASES Kg
C [12]	BATCH	2.1213	0.1767									
H [1]		0.3107	0.3107									
N_2 [28]		7.1079×10^{-3}	2.5385×10^{-4}	0.04554	1.27512.					0.04576	1.281	1.281
0_2 [23]		7.353×10^{-4}	2.2978×10^{-6}	0.0121	0.3872.					0.00121	0.0887	0.387
S [32.1]		7.1079×10^{-3}	2.2214×10^{-4}									
CO_2 [44]										0.17677	7.7782.	7.7782
CO [28]												
NO [30]										2.5385×10^{-4}	7.6156×10^{-3}	7.6156×10^{-3}
SO_2 [641]										2.22142×10^{-4}	0.0142.	0.0142.
H_20 [18]				0.00121	0.02178	36.11	36.11	0.2451	0.0136	0.18	3.38	3.38
Ash		3.9216×10^{-3}								3.9216×10^{-3}		3.1×10^{-3}
Total		2.451	na.	**0.5585**	**1.6841**	**36.11**	**36.11**	**0.2451**	**0.0136**	**0.4042**	**12.51**	**12.51.**

$$Kg = 10 \frac{0.78 + 1.6 \times 0.1227}{(10 \times 0.1 \times 3.81 \times 0.2644)^{0.5}} \quad 1 - 0.37 \times \frac{1373}{1000}$$

$= 4.4441/(m .MPa)$

$$K_s = 0.3\,(2 - 1.1)\,(1.6 \times \frac{1373}{1000} - 0.5)\,\frac{86 \times 55}{12.68}$$

$= 3.1271/m . MPa)$

The flame emissivity, $a_{fl} = 0.55[1\text{-}e^{-(4.444 \times 0.2464 + 3.127) \times 0.1 \times 3.81}]$

$+ (1 - 0.55) \times [1\text{-}e^{-(4.444 \times 0.2464 + 3.127) \times 0.1 \times 3.81}] = 0.5957$

The bottom surface area of the furnace ($31.5m^2$) is covered with refractory bricks; its angular coefficient, $x = 1.0$ and its coefficient of fouling,

$\zeta = 0.1$; for the exit surface area of the furnace ($29.08m^2$), $x = 1.0$ and

$\zeta = 0.55$; for the other water walls ($302.26m^2$),

$\zeta = 0.55$ (Table 8.10) and $x = 0.99$ (Fig 8.25): therefore the average value of the coefficient Ψ_{ef} is equal

$$\Psi_{ef} = \frac{0.99 \times 302.26 \times 0.55 + (31.5 \times 0.1 + 29.08 \times 0.55) \times 1.0}{362.84} = 0.5063$$

The coefficient of thermal radiation of the furnace, a_F, is calculated from tables as

$$a_F = \frac{1}{1 + \left(\frac{1}{0.5957} - 1\right)^{0.5063}} = 0.7443$$

The average heat capacity of the gases in the temperature interval of $T_a - T_{gFe}$ can be obtained from tables

$VC = H_u - I_{Fe}$ $44{,}416 - 22{,}300$ $= 23.45kJ/ (kg.^0C)$

Burners are arranged horizontally, and the average relative level, $X_b = 0.239$. The coefficient M, can be obtained

$M = 0.54 - 0.2 \times 0.239 = 0.4922$

The calculated flue gas temperature at the furnace outlet [Eq. (8.37)]:

$$T_{gFe} = \frac{2316}{0.4922 \left(\frac{5.67 \times 10^{-11} \times 0.5063 \times 362.84 \times 0.7443 \times 2316^3}{0.9925 \times 2.451 \times 23.45}\right)^{0.6}} - 273$$

$= 1110^0C$

The discrepancy between the calculated T_{gFe} and the assumed T_{gFe} is 10^0C; it is smaller than the allowable discrepancy of $\pm 100^0C$. Therefore, we consider T_{gFe} to be equal to 1110^0C, and need not calculated it again; the corresponding flue gas enthalpy can be found from Table 8.13 as $I_{Fe} = 22524kJ/kg$.

The quantity of heat transferred in the furnace

$Hr = 0.9925\,(44{,}416 - 22{,}524) = 21{,}728$ KJ/kg

$$x\left[1 - 0.37\frac{1040 + 273}{1000}\right]0.2464$$

$= 2.124\ 1/(\text{m. MPa})$

The emissivity of the gases

$$A_g = 1 - e^{-2.124 \times 0.1 \times 1.17} = 0.22$$

Th absolute temperature of the ashy tube wall, since the working fluid is steam - water mixture at 4.41 MPa and its saturated temperature is 256.2^0C, can be found using $T_{aw} = 256.2 + 80 + 273 = 609.2K$.

The radiant heat transfer coefficient of the space, h_r can be determined by

$$h_r = 5.1 \times 10^{-11} \times 0.22 \times 1348^3 \left(\frac{1 - \left(\frac{609.2}{1348}\right)^{3.6}}{1 - \left(\frac{609.2}{1348}\right)} \right)$$

$+ 0.04729\ \text{kW}/(\text{m}^2 . \text{K})$

The heat transfer coefficient from the gas to the tub wall, h_0

$$H0 = 1.0(49.9 + 47.29) = 97.19\ \text{W}/(\text{m}^2 . \text{K})$$

4.15 GEOMETRIC CONSTRUCTION PARAMETERS OF SUPER HEATER

For a 130t/hr boiler capacity:

The superheater consists of 24 rows of tubes with outside diameter A = 38mm

Thickness = 3.5mm

Tubes are arranged in an in-line form, $S_1 = S_2 = 84$mm.

Total number of serpentine tubes, n= 146

Number of tubes per row, n = 73

Total heating surface, A = $641m^2$.

Parallel - flow heating surface Ap = $68m^2$.

The flow area for flue gases, Ag = $13.13m^2$.

The flow area for superheated steam, Ass = $0.11m^2$.

The depth of empty room before superheater, $L_R = 0.65$m

The depth of superheater tube bundle L=1.725m.

HEAT TRANSFER CALCULATIONS

From the preceding calculations and the given data, we know the flue gas parameters at the inlet are $T_{gSSi} = 1040^0C$and $I_{gSSi} = 20{,}964$KH/kg; the working fluid parameters at the inlet are $T_{SSi} = 256.230C$ and $I_{SSi} = 2798.6$KJ/kg (saturated temperature

The absolute temperature of the ashy tube wall

$$T_{aw} = \frac{450 + 256.23}{2} + \left[2.6 + \frac{1}{1.365}\right] \frac{2.451(7460.3 + 398.3) + 273}{641} = 726.3K$$

The effective thickness of the radiating layer, S

$$S = 0.9 \times 0.038 \quad \frac{4 \times 0.084 \times 0.084}{\pi \times 0.038^2} \quad -1 = 0.1787m$$

The effective coefficient of absorption, k

$$K = k_g r = 10 \quad \frac{0.78 + 1.6 \times 0.12}{10 \times 0.1 \times 0.1787 \times 0.2406)^{0.5}} \quad -0.1$$

$$\times \left[1 - 0.37 \frac{697 + 273}{1000}\right] 0.2406$$

$= 7.09$ 1/m (m . MPa)

The emissivity of the gases [q. (8.74)]:

$$a_g = 1 - e^{-7.09 \times 0.1 \times 0.1787} = 0.119$$

The radiant heat transfer coefficient of the space, h_r

$$h_r = 5.1 \times 10\text{-}11 \times 0.119 \times 1141 \times 5^3 \left(\frac{1 - \left(\frac{726.3}{1141.511}\right)^{3.6}}{1 - \left(\frac{726.3}{1141.511}\right)} \right)$$

$= 0.01986$ KW/(m^2 . K)

Considering the empty room before the superheater, the corrected radiant heat transfer coefficient will be

$$h_r = 0.01986 \left[1 + 0.3 \left[\frac{1040 + 273}{1000}\right]^{0.25} \left[\frac{0.65\ 0}{1.725}\right]^{07}\right] = 0.0258 \text{ KW/(m}^2\text{.K)}$$

The heat transfer coefficient from the gas to the tube wall, h_o

$$h_o = 1.0(74.67 + 25.80) = 100.47 \text{ W/(m}^2 \text{ . K)}$$

The overall heat transfer coefficient, U

$$U = \frac{0.6}{\frac{1}{100.47} + \frac{1}{1365}} = 56.18 \text{W/(m2 . K)} = 0.05618 \text{ KW/(m}^2 \text{ . K)}$$

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EQUIPMENT DESIGN OF A BOILER TO GENERATE 130 T/HR OF STEAM

BY

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CHAPTER ONE

1.0 GENERAL INTRODUCTION

Boilers are generally classified under heat exchangers and fired heaters. A boiler is a device in which steam is generated. Generally then, it must consist of a water container and a heating device. The heating can be from combustible fuel, electricity or nuclear energy.

Fossil fuel fired boilers are perhaps some of the most complex pieces of heat exchange equipment currently supplied - stretching materials and design technologies to their limits. Their basic function is to convert water to steam for electricity generation, and process applications. However, they are also being called upon to burn on a variety fuels, dispose of refuse, enhance oil recovery, recover waster heat and reduce pollution. Many possible trades off can be made in the design of boilers to accommodate local and worldwide variations in application: fuel, reliability, efficiency, environmental protection, customer preferences and a variety of economic and political factors. As a result many different approaches to water - tube boiler design have evolved over the past 150 years to meet the diverse needs. Operating pressures, cycling requirements, unit sizes, steam - water circulation options, fuel firing methods and heat transfer surface arrangements vary widely, even while many of the fundamentally technologies remain common to all designs.

1.1 DESIGN STATEMENT

This project's objective is to design a once - through boiler to generate 130t/hr. of steam, for the deodorization of shea butter and also for use as utility in the oil (vegetable) refining plant.

The boiler to be designed consists of a furnace, slag screens, a super heater, an economizer and an air heater.

The characteristic features of the once- through boiler are its circulation ratio which is unity and the fact that there in no distinct boundary between the economizing, evaporating and superheating zones. The advantages claimed with this type of boiler are that the welded construction avoids expansion troubles due to starting up and shutting down. Starting up and shutting down can be accomplished more rapidly. The boiler can be operated at any pressure and temperature over its load range.

1.2 SCOPE OF WORK

This covers the design of the boiler. It includes heat and material balances over boiler components and also the determination of the efficiency of the boiler.

CHATER TWO

2.0 LITERATURE REVIEW

A boiler is a device for generating steam for power, processing and heating purposes, or for producing hot water for heating purposes and hot water supplies. The former is called a steam boiler and the latter is called a hot water boiler. Both boilers work on the same principle and the hot water boiler is easier to design.

Steam boilers are built in a variety of sizes, shapes and forms to fit conditions peculiar to the individual plant and to meet varying requirements. Generally speaking, steam boilers may be classified according to their uses, steam pressures, circulation methods, fuel firing methods, methods of removing slag and boiler layout forms.

2.1 BACKGROUND

Since at least the time of the ancient Greeks and Romans, steam generated from boiling water has been used for a variety of applications to provide heat and power. Initially, boiling water was used for heating applications with an occasional innovative but mostly ornamental power use. It was not until the industrial revolution with the development of practical steam engines such as those of savory and New-comen that steam and boilers became widely used to generate power for transportation and industry. Today, boiler and the steam they produce generate electricity, heat and cool structures, provide energy to chemical processes. Enhance oil recovery, food process, among others.

Boilers are basically enclosed spaces where water can be treated and continuously evaporated to steam. Early designs were little more than empty vessels ("shell or kettle boilers) to which water could be added, heat externally applied and steam removed at a pressure slightly above atmospheric soon designers learnt that large gas - water contact areas were needed to generate increasing quantities of steam at higher efficiencies. This led to boiler designs with the combustion products passing through tubes, which were surrounded by water: "fire - tube" type boilers. Eventually the need for higher pressures and larger capacities led to the introduction of "water tube" type boilers where water and steam passed through the tubes which could more easily withstand the higher pressures.

Since that time, boilers have evolved into very large, complex machines which use the most advanced theoretical analysis and materials. New designs are constantly striving for higher efficiency and lower costs. The largest fossil fuel boiler built today operate at supercritical steam pressures [> 22.1mpa (>3205 psig)] providing 1260kg/s or (10 million lbm/hr) of steam flow at 566^0C. The steam can be reheated once or twice to 566^0C before ultimately being passed to the condenser. These large units produce 1300Mive. Fuels have expanded greatly from gas, oil, coal and wood to include nuclear fission, municipal refuse, oil shale, and biomass, among other. The evolution in the design of fossil fuel fired boilers has been led by extensive innovations in theory, designs and materials over the past 150 years.

2.2 CURRENT PRACTICE

Today's fossil - fired boilers are very diverse in design, depending on the steam use requirements. Sizes range from 0.1 to over 1260kg/s steam flow. Pressures range from a little over 1atm to over the critical pressure. However, regardless of the size or application, fuel or design, all of these units share a number of fundamental key elements upon which the site and application specific design is based. This is especially true for the steam - waterside of the system, which is the focus here.

2.3 MAJOR STEAM-WATER BOILER COMPONENT

The steam water circuitry of a modern high-pressure utility boiler consists of an integrated system of the following:

- i) Enclosure surfaces: (a) Furnace: boiling; (b) Convection pass: Steam cooled or boiling.
- ii) Super heater: Primary and secondary.
- iii) Reheater
- iv) Economizer
- v) Attemperator (steam temperature control)
- vi) Drum.

2.3.1 ENCLOSURE SURFACES

The enclosure surface in a large pulverized - coal boiler is a large enclosed space for the combustion of the fuel and for the cooling of the products of combustion prior to their entry into the tube bundles found in the convection pass. Excessive gas temperatures entering these tubes banks can lead to unacceptable fooling, slugging or elevated metal temperatures. Heat transfer in the enclosure walls is basically, controlled by radiation. The enclosure walls are cooled by boiling water (subcritical) or high - velocity supercritical pressure water. The convection pass enclosure is composed of the horizontal and vertical down gas flow passages, where most of the supper heater, reheated and economizer surfaces are located .The enclosure surface can be water or steam cooled, the heat transfer to the enclosure wall is predominantly controlled by convention. The object of the water or steam cooled wall is to maintain the wall metal temperatures within allowable limits.

The furnace enclosure is usually made of water cool tube in a membrane construction: closely spaced tube with centerlines slightly larger than the tube outside diameter, connected by bar continuously welded to each tube. Furnace enclosure may also be made from tangent tube construction or closely spaced with tight a gas tight seal usually composed of insulation, or refractory or lagging.

2.3.1 SUPER HEATER OR REHEATERS.

Super heaters and reheaters in utility boilers increase the temperature of saturated or near saturated steam in order to increase the thermodynamic efficiency of the power cycle to provide the desired process conditions. In general, they are simple single-heat exchangers with the flowing inside the gas and five gas passing outside the tube generally in cross flow.

The main difference between super heaters and reheaters is operating pressure in a typical recirculating drum boiler, the outlet pressure of the superheater is 18mpa while the reheater inlet pressure is only 4mpa. The volumetric flow rate of the reheater will thus be substantially higher the those of the superheater, though the mass flow rate through the reheater is 10-5% less than the superheater because of the steam extracted from high pressure turbine to preheat the feed water.

2.3.3 ECONOMIZERS

Water preheating to the saturation temperature is done in an economizers are simply counterflow heat exchangers for recovering additional energy from combustion products after the super heaters and reheaters but before the air heater, increasing the water temperature after the final regenerative feed water heater, and minimizing temperature differences between the saturation temperature and the feed water temperature. The tube bundle is typically an arrangement of a parallel horizontal serpentine tube with both inlet and outlet headers as well as the 180^0 bends exposed to the flue gas stream. The water flow is usually counter to the flue gas flow .The tube spacing is set to ensure the highest gas velocities, which do not exceed allowable erosion velocities. The bundles have historically been bare tubes con-figured in an in–line arrangement with appropriate cavities for soot blower equipment replacement Carbon steel is usually used for this pieces of equipment.

2.3.4 STEAM TEMPERATURE CONTROL

The object of steam temperature control system is to maintain the reheated and super heated outlet temperatures within a narrow range, regardless of change in the boiler wad or normal fluctuation in the wide variety if operating variables.

Attemperators are usually installed at the inlet of superheater or sections or between super heater section to control the final super heater outlet metal temperature.

- Boiler with cyclone furnaces
- Boiler with fluidized beds.

2.4.6 CLASSIFICATION BY METHOD OF REMOVING SLAG

(1) Boiler with dry clean furnace

(2) Boiler with slag tap furnace.

2.4.7 CLASSIFICATION BY BOILER LAYOUT FORM.

(1) Tower Shape

(2) Inverted U-Shape

(3) Box Shape Etc

2.5 MAIN CHARACTERISTICS OF STEAM BOILERS

The main characteristics of steam boilers are the rated steam generating, and the superheated steam parameters. The rated steam-generating capacity of a boiler expresses the highest load of the boiler in a stable operation for long periods of time on special fuel and with rated parameters of steam and feed water.

2.6 WORKING PRINCIPLE OF A STEAM BOILER

A boiler consists of two parts: a furnace in which combustion of fuel takes place, and a water steam system through which feed coater passes and is converted into steam by the absorption of heat produced by the combustion, it is necessary to supply a quantity of air and to remove the products of combustion by means of a draft caused by a chimney or draft fans.

In large boilers, the incoming air is preheated in an air heater and the feed water (working fluid) is heated in an economizer by the discharged flue gases. This arrangement improves the boiler efficiency.

After leaving the economizer, the working fluid enters the furnace water wall tubes through a drum or distribution header and is heated and partially evaporated there. Then saturated steam is collected in a drum or a header. For common power plant boilers, saturated steam is further superheated to the required temperature in steam superheaters, while for reheat cycle power plant boilers, steam has to be reheated in reheaters.

The boiler consists of two vertical shafts connected at the top by a horizontal gas duct. The left shaft serves s the boiler furnace. Water walls, formed by tubular panels, are arranged around the entire perimeter of the furnace chamber and are heated directly by the radiant heat of the flame. The reheater, economizer and air heater are arranged in the right shaft while the superheater is located in the horizontal gas duct. These heating surfaces receive heat by convection and are called convective heating surfaces.

There are three major flow systems in a boiler: the combustion products flow systems, the steam water flow system and the air flow system.

The combustion products flow system: As fuel is infected with air into the furnace, it is burned and forms the high temperature combustion products (flue gases) which serve as a heat transfer agent on the heating surfaces. Flue gases give up part of their heat by radiation to the water walls and leave the furnace at a safe temperature (1000-1200^{0}C, depending on the type of fuel which will not cause slugging and fouling of the subsequent convective heating surfaces. After that, the flue gas pass through the external surfaces of the slug screen, superheaters, reheater, economizer, air heater. e.t.c, successively and give up heat mainly by convection to these convective heating surfaces. Down stream of the air heater, the flue ash collector, as induced draft fan, and are ejected through the chimney into the atmosphere.

Steam-water flow system: feed water is passed through the feed-water pump into the economizer and is heated to a temperature below the saturation point. Water then flows into the drum and is distributed through the unheated down corners and headers to water to flow downwards upwards from the water is also into the drum. In the drum, steam is separated from the steam - water mixture and discharged by the water walls. In superheaters, saturated steam is heated to the required parameters and flow to the high - pressure turbine. In order to improve the power plant efficiency, part of the exhaust steam of the high turbine is returned to the re-heater for re-heating and then flows to the inlet of the reheat turbine.

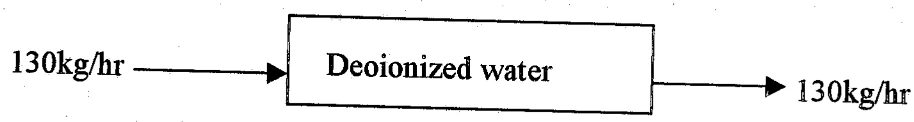
The air flow system: cold air (30 - 60^{0}C) is pressed by the Greed draft far into the inlet of an air heater and flows across its tubes to the desired hot-air temperature (200 - 400^{0}C, depending on the kind of fuel) at the outlet of the air heater with pulverized coal combustion, the hot air is separated into two flows. The primary air is used for drying the fuel and transporting the fuel dust through the burners into the furnace. The secondary air is directed through the burners into the furnace. During burning, fuel leaves fly ash which is mostly carried off by the flue gas and is collected in a fly ash collector arranged upstream of the induced draft fan. The collected ash is removed y means of ash removal devices, part of the ash falls to the bottom of the boiler furnace and is removed continuously by the ash - handling system.

CHAPTER THREE

MATERIAL AND ENERGY BALANCE

MATERIAL BALANCE FOR WATER

Deionized water tank



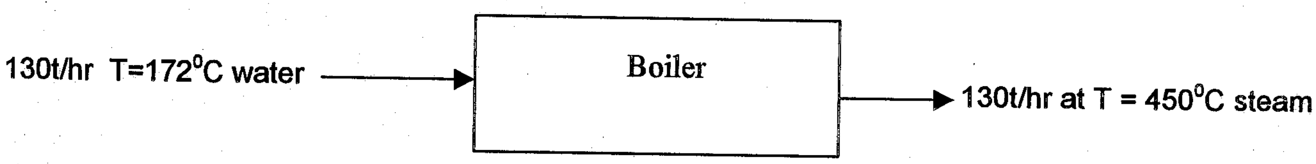
There is a constant volume of water in the tank. Per second and there are no losses except water goes out.

Thus H_20 in to the tank = water out of the tank

130kg/hr = 130t/hr

3.1.1 MATERIAL BALANCE FOR WATER AROUND THE BOILER

H_20 in Boiler

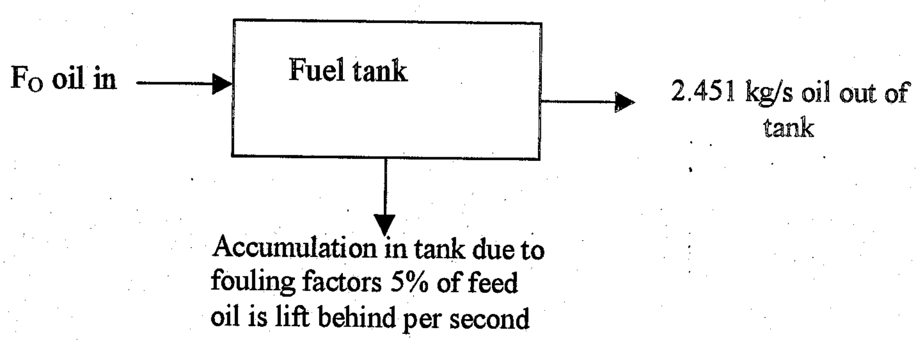


Water from the water storage tank at 130 t/hr enters the Boiler and there are no losses or conversion accumulations or consumption. Thus,

Material in per hour	=	Material out per hour
130t/hr	=	130 t/hr steam
at temperatures of 172°C	=	at temperature of 450°C

3.2 MATERIAL BALANCE FOR FUEL OIL

3.2.1 MATERIAL AROUND FUEL TANK



$\therefore$ $F_O = 0.05F0 + 2.451$

$F_O - 0.05F0 = 2.451$

$F_O\ (1\text{-}0.05) = 2.451$

$F_O\ (0.95) = 2.451$

$F_O = 2.58$ kg/s

3.3 ENERGY BALANCE

3.3.1 STOICHIOMETRIC BALANCES OF FUEL COMBUSTION REACTION.

Ultimate Analysis of fuel oil as fired:

Component	% weight
Carbon (C^w)	86.55
Hydrogen (H^w)	12.66
Oxygen (O^w)	0.03
Nitrogen (N^w)	0.29
Sulphur (S^w)	0.29
Moisture (W^w)	0
Ash (A^w)	0.16
	100

Lower heating value = 41,242 KJ/kg ($H,^w$)

The physical heat of oil before burning Hph = 266 KJ/kg

Auxiliary Calculations:

The theoretical volume of air required (at normal state) for combustion of 1kg of fuel oil is calculated as, $V^0 = 0.0889\ (C^w + 0.3755^w) + 0.265\ H+ - 0.0330^w = 11.063m^3/kg$.

The theoretical volume of RO_2 (at normal state) in the combustion products of fuel oil is:

$$VRO_2 = 1.866\ \frac{C^W + 0.375S^W}{100} = 1.617m^3/kg$$

Theoretical volume of water (at normal state) in the combustion products of 1kg of fuel oil is:

$$V^0H_20 = 0.111H^W + 0.0124W^w + 0.0161V^0 = 1.5855m^3/kg.$$

Theoretical volume of N_2 (at normal state) in the combustion products of 1kg fuel oil is

$$V^0N_2 = 0.79V^0 + \frac{0.8N^w}{100}$$

$$= 0.79(11.063) + \frac{0.8\ (0.29)}{100}$$

$$= 8.742m^3/kg$$

Standard air is defined as

79% Nitrogen

21% Oxygen,

containing 0.013kg of moisture pre kg of air.

The ratio of oxygen to nitrogen is:

21.79 = 1:3.76

Volume of dry air = V^0 - V^0 H_20

= 11.063 - 1.5855

Vdg = 9.4775

Typically, the ratio of actual to theoretical air is 1.1

∴ 3.76 of nitrogen requires 3.76 x 1.1 x X of oxygen.

Where X is the number of moles of added oxygen required to oxidize carbon, hydrogen and sulphur in fuel to $C0_2$, H_20 and $S0_2$ respectively.

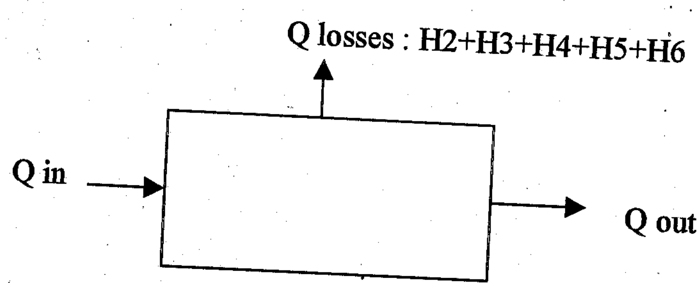
For atomizing steam assume that 0.1kg of steam is used for 1kg of fuel oil.

The summary of material balance for steam and fuel oil is given in table 3.3.

3.3.2 ENERGY BALNCE AROUND THE PLANT

The energy balance for the boiler is given by the equation,

Q in = Q out + losses - (3.3.1)



Q in = BLHV - (3.5.2)

Where Q in = Energy entering boiler KJ/kg

B = Fuel flow rate kg/s

LHV = Lower heating value of fuel.

Q out = Wsh (iss - ifw) + Wrh (irhi) + Wbw (isw - ifw)

Where,

Wsh = Flow rate of working fluid in superheater, kg/s

Wrh = Flow rate of working fluid in reheater. kg/s

Wbw = blow water rate (Assume Wbw = i/wsh) . (kg/s)

iss = enthalpy of superheated steam

ifw = enthalpy of feed water.

irhe = enthalpy of reheated outlet

irhi = enthalpy of reheated inlet

isw = enthalpy of saturated water.

Now the available heat of fuel, $H^{w}av$

CHAPTER FOUR

4.0 DETAILED EQUIPMENT DESIGN

BASIS 130T/hr = 36.11kg/s

4.1.0 OPERATIONG CONDITIONS OF THE WATER-TUBE ONCE - THROUH BOILER

PARAMETER	SYMBOL	UNIT	VALUE
Feed water temperature	Tfw	0^0C	172^0C
Feed water pressure	Pfw	MPa	4.7MPa
Superheated steam temperature	Tss	^0C	450^0C
Superheated steam pressure	Pss	mpa	3.92MPa
Waste gas temperature	Twg	^0C	160^0C
Hot air temperature	Tha	^0C	200^0C

4.1.1. DESIGN OF THE COMPONENT OF THE BOILER

4.1.2 DESIGN OF THE FURNACE

The basic design requirements for designing the furnace of a large capacity boiler includes sufficient furnace volume for burning the fuel completely, sufficient heating surfaces for cooling the combustion product to a state temperature. The type of furnace used in any boiler depends on the fuel fired and the firing rate needed. For this design the fuel to be fired is fuel oil therefore, a furnace with burners is to be used.

For once through boiler operation at low load, the feed water flow is not sufficient to provide necessary mass flux for a sufficient number of even small tubes in vertical arrangements, therefore a water wall with meandering sectionalized riser or down corners and inclined tubes are used. The inclined tubes are usually have a diameter of about 38mm and 50mm pitching.

4.13 DESIGN GEOMETRIC PARAMETERS OF THE FURNACE.

Heat retention co-efficient $\phi = 1\text{-}(hs/nb + hs)$

$$= \frac{0.7}{0.7193}$$

$$= 1 - 0.004470561$$

$$= 0.9925$$

Furnace volume:

The furnace volume is obtained by selecting a heat release rate per unit furnace volume, q_v, from tables, for this work, Let $q_v = 263kw/m^3$

$$\therefore V_f = \frac{B H_1^w}{q_f} = \frac{2.451 \times 41{,}242}{263}$$

$$= 284m^3$$

Furnace Cross Sectional Area

Select q_v (heat release per unit cross sectional furnace area).

$q_f = 3260KW/m^3$

$$\therefore A_f = \frac{BH_1^W}{qf} = \frac{2.451 \times 41{,}242}{3260}$$

$$= 31m^2$$

Assume furnace width a = 6.2m

$$\therefore \text{furnace depth} = \frac{A_f}{a} = \frac{31}{6.2} = 5m$$

The outside diameter of the water wall tubes , d=60mm with tube wall thickness = 3mm.

Center line of the riser to the furnace wall e = 0.5 spacing of water wall tubes = 64mm.

Total number of risers n = 348

Total surface Area of furnace walls Aw = 362.84m2 (including bottom surface area of furnace = 31.5m2, which is covered with refractory brick, the exit surface area of furnace = 29.08)

HEAT TRANSFER CALCULATION OF THE FURNACE

The heat introduced into the furnace by the hot air and the cold air is

$$H_a = (1.1 - 0.05)\ 2945.9 + 0.05 \times 440 = 3115kJ/kg$$

Where the enthalpies of air are obtained from Table 8.13, and α_{Fe} and $\Delta\alpha_F$ are obtained from tables

The useful heat released in the furnace

$$H_u = 41{,}508\ \frac{100 - 0.5}{100} + 3115 = 44{,}416kJ/kg$$

The adiabatic temperature of combustion, T_a, according to H_u and $\alpha_{Fe} = 1.1$, can be found from Table 8.13; $T_a = 2043^0C$.

Assume the flue gas temperature at the furnace outlet is $T_{gFe} = 1100^0C$, its corresponding enthalpy $I_{Fe} = 22{,}300kJ/kg$ (obtained from Table 8.13); T_{gFe} will be checked afterwards.

The effective thickness of the radiating layer:

$$S = \frac{3.6V_F}{A_w} = \frac{3.6 \times 384}{362.84} = 3.81m$$

The effective coefficient of absorption by triatomic gases, k_g, and by shoot particles, k_s [Eqs. (8.23) and (8.29)]:

$H_E = H_r - H_s + H_{ss} = 38{,}389 - 21{,}782 - 1560 - 7460.3$

$= 7586.7$ kJ/kg

The flue gas enthalpy, I_{gEe}, and temperature, T_{gEe}, can be determined from tables

$$7586.7 = 0.9925\,(13{,}473.7 - I_{gEe} + 0.02 \times 440)\ \text{kJ/kg}$$

Therefore, $I_{gEe} = 5838.47$ kJ/kg and $T_{gEe} = 298^0$C (from Tables with I_{gEe} and $\alpha_{Ee} =$ 1.18).

The enthalpy of the working fluid at the exit of the economize

$$i_{Ee} = i_{fw} + \frac{H_E B_r}{(W_{sh} + W_{bw})} = 730.2 + \frac{7586 \times 2.451}{(36.11 + 3.611)} = 1240\ \text{kJ/kg}$$

The exit pressure is 4.41 Mpa; at this pressure, the enthalpy of saturated watr is i_{sw} = 1116.6 kJ/kg and the latent heat of evaporation i_{lg} = 1681.9 kJ/kg; therefore the steam quality at the exit is

$$x = \frac{i_{Ee} - i_{sw}}{i_{lg}}\,100 = \frac{1240 - 1116.6}{1681.9}\,100 = 7.33\%$$

The exit temperature of the working fluid is equal to the saturated temperature, $T_{Ee} = 256.23^0$C.

The average velocity of water

$$V = \frac{(36.11 + 3.611) - 0.00117}{0.0387} = 1.1\text{m/s}$$

The flow system is counter-flow; therefore the mean temperature difference is

$$\Delta T_c = \frac{(697 - 256.23)\ \ (298 - 172)}{\ln\left[\dfrac{697 - 256.23}{298 - 172}\right]} = 251.3^0\text{C}$$

The average gas temperature,

$$T_g = (697 + 298) / 2 = 497.5^0\text{C}$$

The averages flue gas velocity

$$V = \frac{2.451 \times 13.856}{10.206}\left[1 + \frac{497.5}{273}\right] = 9.93\ \text{m/s}$$

Because n > 10, from tables $c_n = 1.0$; $\phi = (2.34\ \ 1) / (2.73 - 1) = 0.775$, from $c_s = 0.34 \times \phi^{0.1} = 0.34 \times 0.775^{0.1} = 0.33$.

The absolute temperature of the ashy tube wall, $T_{aw} = (172 + 265.23) / 2 + 60 + 273 = 547.2$ K.

The convective heat transfer coefficient, h_c

and enthalpy at 4.41Mpa); and the working fluid parameters at the outlet are $T_{SSe} = 450^0C$ and $I_{SSe} = 3322KJ/kg$.

The quantity of convective heat transfer that must be absorbed by the steam to satisfy the heat balance equation on the steam side,

$$Hb = \frac{36.11}{2.451}(3322 - 2798.6) - 38.3 = 7460.3 \text{ KJ/kg}$$

The flue gas parameters at the outlet of the superheater can be obtained from

$$7460.3 = 0.9925(20{,}964 - I_{gSSe} + 0.06 \times 440) \text{ KJ/kg}$$

Therefore I_{gSSE} = 13,473.7 KJ/kg and its corresponding temperature is T_{gSSE} = 697)C (from tables)

The mean temperature difference for counterflow

$$\Delta T_c = \frac{(1040 - 450) - (697 - 256.23)}{\ln\left[\frac{1040 - 450}{697 - 256.23}\right]} = 511.94^0C$$

Since $T_1 = 1040 - 697 = 343^0C$, $T_2 = 45 - 256.23 = 193.77^0C$, $P = 193.77/(1040 - 256.23) = 0.2472$, $R = 343/193.77 = 1.77$, and $A = 68/641 = 0.106$, from tables we may obtain $\psi = 0.998$. Therefore the actual mean temperature difference $\Delta T = \psi\Delta T_c = 0.998 \times 511.94 = 509.4^0C$. The average specific volume of steam, V = 0.06469m3/kg (for P = 4.16 Mpa and Tss = 353^{0}C). The average steam velocity in the superheater.

$$V = \frac{36.11 \times 0.06469}{0.11} = 21.24\text{m/s}$$

The heat transfer coefficient from the wall to the steam, h_i

$$h_i = 6.61 \times 10^{-3}\frac{(21.24 \times 15.458)^{0.8}}{0.031^{0.2}} = 1.365 \text{ KW/ }(m^2.^0C)$$

Th average gas temperature, Tg = (1040 + 697)/2 = 868.5^{0}C. The average flue gas velocity:

$$V = \frac{2.451 \times 13.406}{13.13}\left[1 + \frac{868.5}{273}\right] = 10.46\text{m/s}$$

Because n > 10 and S2/d = 2.21 > 2, $c_n = 1.0$ and $c_s = 0.2$

The convective heat transfer coefficient, h_c

$$h_c = 28.96\,(1 - 1.25 \times 10\text{-}4 \times 868.5) \times 10\text{-}3 \times 0.2 \times 1.0 \times \frac{10.46^{0.65}}{0.038^{0.35}}$$

$$= 0.07467 \text{ Kw/}(m^2 . ^0C)$$

The average heat flux of the furnace heating surfaces

$$q_{rF} = \frac{2.451 \times 21{,}728}{359.82} = 148\ kW/m^2$$

The radiant heat absorbed by the slag screens from the furnace

$$H_{rF} = \frac{0.685 \times 0.72 \times 148 \times 29.08}{2.451} = 866kJ/kg$$

In the preceding equation, the ratio of the burner axis height to the furnace outlet center height is equal to 0.8; using this value and Fig. 8.29, we may obtain $\eta h = 0.72$.

The radiant heat absorbed by the superheater

$$H_{rF} = \frac{(1 - x_s)\eta_h q_{rF} A_{Fe}}{B_r} \quad \frac{(1 - 0.685)\ 0.72 \times 148 \times 29.08}{2.451} = 398.3kJ/kg$$

The total radiant heat absorbed by the water walls

$$H_{ww} = H_r - (H_{rF} + H'_{rF}) = 21{,}728 - (866 + 398.3) = 20{,}463.7kJ/kg$$

The heat introduced by hot air and cold air is given by:

$$Ha = (\alpha Fe - \Delta\alpha F)\ Iha + \Delta if \times 1ca$$

$$= (1.1 - 0.05)\ 2945.9 + 0.5 \times 440$$

$$= 3115KJ/kg.$$

Where αfe, $\Delta\alpha f$ are obtained from tables.

The useful heat released by furnace

$$Hu = H^w av \ \frac{100 - 0.5}{100} + 3115$$

$$= 44{,}416KJ/kg$$

The adicebatic temperature of combustion T_a, according to H_u and α_{Fe} can be found from tables $T_a = 2043^0C$.

Assume the gas temperature at the furnace outlet is $T_{gFe} = 1100^0C$ its corresponding enthalpy $1_{fe} = 22{,}300KJ/kg$

The effective thickness of radiating layer:

$$S = \frac{3.6VF}{A_W} = \frac{3.6 \times 384}{362.84} = 3.81m$$

The effective co-efficient of absorption by triatomic gases kg, and by soot ks is given by,

$$Kg = \left[\frac{10 \quad 0.78 + 1.6 \times 0.1227}{(10 \times 0.1 \times 3.81 \times 0.2644)^{0.5}} - 0.1\right] \left[1 - 0.37 \times \frac{1373}{1000}\right]$$

$$4.4441/(m - MPa)$$

$$Ks = 0.3(2 - 1.1)\left[1.6 \times \frac{1373}{1000} - 0.5\right]\frac{86 \times 55}{12.68}$$

$= 3.1271/(m.MPa)$

Flame emissivity

$Afl = M_{alum} + (1 - M)\, ag$

$alum = 1 - e^{-k^{lumps}}$

$ag = 1 - e^{kgps}$.

Where alum = emissivity of the luminous portion of the flame.

M = fraction of luminous portion of the flame, the fuel oil,

M = 0.55

K_{lum} = effective co-efficient of absorption of luminous portion on.

Ks = effective co-efficient of absorption by soot particles.

The co-efficient m is expressed as :

M = A - Bx

Where A & B are emperical co-efficient depending on the kind of fuel used. For fuel oil A = 0.54, B = 0.2.

X = 0.14 for furnace with burners.

$A_{fl} = 0.55\,[1 - e^{-(4.444 \times 0.2464 + 3.127) \times 0.1 \times 3.81}] + (1 - 0.55) \times [1 - e^{-(4.444 \times 0.2464 + 3.127) \times 0.1 \times 3.81)}]$

$= 0.5957.$

4.14 GEOMETRIC CONSTRUCTION PARAMETERS OF SLAG SCREEN

For 130t/hr capacity of steam boiler

The staggered arranged slag screens are formed by the rear water wall tubes. 3 rows of 60mm outside diameter tubes are spaced on 250mm centres; 24 tubes per row ar spaced on 256mm centres,

Total heating surface $A = 73.52m^2$.

Flow area of flue gases $Ag = 21.73m^2$.

Transverse spacing $S_1/d = 256/60 = 427$.

Longitudinal spacing $S_2/d = 250/60 = 4.17$.

$X_s = 0.685$ (fraction of heating surface).

Since the heat transfer coefficient from the wall to the working fluid, h_i, is very large, $1/h_i$ can be neglected; the overall heat transfer coefficient, U, can b obtained from tables, where ψ is selected as $\psi = 0.63$, $U = \psi h_o = 0.63 \times 97.17 = 61.23\ W/(m^2.\ 0C)$.

The man temperature difference, $\Delta T = \dfrac{(1110 - 256.2) - (1040 - 256.2)}{\ln\left[\dfrac{1110 - 256.2}{1040 - 256.2}\right]} = 818.3^{0}C$

The quantity of heat transfer calculated by using the heat transfer equation

$$H_t = \frac{61.23 \times 818.3 \times 73.52}{2.451 \times 10^3} = 1502.933 \text{ KJ/kg}$$

Since

$$\frac{H_b - H_t}{H_b} = \frac{1560 - 1502.93}{1560} \times 100 = 3.65\% < \pm 5\%$$

This calculation is acceptable, and the total convective heat absorbed by the working fluid in the slag screen is H_s = 1560 KJ/kg.

HEAT TRANSFER CALCULATIONS OF SLAG SCREENS

The Inlet flue gas temperature is $T_{gsi} = 1110^{0}C$ and I_{gSi} = 22,524kJ/kg. Assume that the exit flue gas temperature, $T_{gSe} = 1040^{0}C$; its corresponding enthalpy is I_{gSe} = 20,964 kJ/kg. In the slag screen duct $\Delta\alpha = 0$.

According to the heat balance equation

H_b = 0.9925 (22,524 – 20,964) = 1560kJ/kg

The average flue gas velocity, *V:*

$$V = \frac{B_r V_g}{Ag}\left(1 + \frac{T}{273}\right) = \frac{2.451 \times 13.068}{21.73}\left(1 + \frac{1075}{273}\right) = 7.28\text{m/s}$$

The coefficient $\phi = (4.27 - 1)/(5.863 - 1) = 0.659$; since $0.1 < \phi \leq 1.7$, this value can be used with to determine c_s:

$c_s = 0.34 \times 0.659^{0.1} = 0.326$

Because $S_1/d = 4.27 \geq 3.0$, and n < 10, therefore is used to calculate c_n:

$$C_n = 4.30.02 - 3.2 = 0.889$$

The calculation of the convective heat transfer co-efficient, h_c

$$h_c = 16.98 \times 10\text{-}3 \times 0.326 \times 0.889 \times \frac{7.28^{0.6}}{0.06^{0.4}} = 0.0499 \text{ kW/(m}^2 \text{ . K)}$$

Th effective thickness of the radiating layer, S

$$S = 0.9 \times 0.06\left[\frac{4 \times 0.256 \times 0.250}{\pi \times 0.06^2} - 1\right] 1.17\text{m}$$

Th effective coefficient of absorption, k, as $\mu_a = 0$,

$$K = k_{er} = 10\left\{\frac{0.78 + 1.6 \times 0.1227}{(10 \times 0.1 \times 1.17 \times 0.2464)^{0.5}} - 0.1\right\}$$

The quantity of heat transfer calculated from the heat transfer equation

$$H_t = \frac{0.05618 \times 509.4 \times 641}{2.451} = 7484.3 \text{ KJ/kg}$$

Since

$$\frac{Hb - Ht}{Hb} = \frac{7460.3 - 7484.3}{7460.3} 100 = -0.32\% < \pm 2\%$$

This calculation is acceptable, and the total convective heat absorbed in the suprheater, H_{ss} = 7460.3 kJ/kg.

4.16 GEOMETRIC CONSTRUCTION PARAMETERS OF ECONOMIZER.

The economizer consists of 56row of 32mm outside diameter tubes (3mm thick)

Tubs are arranged in a staggered form.

$S_1/d = 45/32 = 1.4$

$S_2/d = 75/32 = 2.34$

$S^1{}_2/d = 2.73$.

Total number of serpentine tubes n = 73

Number of tubes per row = 36

Total heating surface Area, A = 1215m^2.

Flow area of flue gases, Ag = 10.206m^2.

Flow Area of water Aw = 0.0387m^2.

Height of economizer tube bundle, L_B = 2.43m

Depth of flue gas duct, b = 2.86m

Width of flu gas duct, a = 5.942m.

HEAT TRANSFR CALCULATIONS OF THE ECONOMIZER

From the calculations for the superheater and the given data, we know that the flue gas parameters at the inlet ar T_{gEi} = 697^{0}C and I_{gEi} = 13,473.7 kJ/kg; the working fluid parameters at the inlet ar $T_{Ei} = T_{fw}$ = 172^{0}C and I_{fw} = 730.2 kJ/kg.

The total quantity of heat that must be absorbed by the working fluid, H_1

$$H_1 = \frac{1}{2.451} [36.11 - 730.2) + 3.611(1116.3 - 730.2)]$$

$$= 38{,}389 \text{ kJ/kg}$$

The quantity of heat that must be absorbed by the working fluid in the economizer, H_E, can be obtained from the following heat balance equation :

$$H_1 = H_r + H_s + H_{ss} + H_E$$

Or

$$h_c = 16.98 \times 10^{-3} \times 0.33 \times 1.0 \times \frac{9.39^{0.6}}{0.032^{0.4}} \quad 0.085 \text{ kW / (m}^2.^\circ\text{C)}$$

The effective thickness of the radiating layer, S

$$S = 0.9 \times 0.032 \left[\frac{4 \times 0.045 \times 0.075}{\pi \times 0.032^2} - 1 \right] = 0.0921 \text{ m}$$

The effective coefficient of absorption, k

$$K = 10 \left[\frac{0.78 + 1.6 \times 0.1166}{(10 \times 0.1 \times 0.092 \times 0.2333)^{0.5}} - 0.1 \right] \left[1 - 0.37 \frac{298 + 273}{1000} \right] 0.2333$$

$= 11.94$ 1/ (m . MPa)

The radiant heat transfer coefficient of the space, h_r

$$h_r = 5.1 \times 10\text{-}11 \times 0.104 \times 770.5^3 \left(\frac{1 - \left(\frac{547.2}{770.5} \right)^{3.6}}{1 - \left(\frac{547.2}{770.5} \right)} \right)$$

$= 0.0059$ kW / (m2 . K)

Considering the influence of the empty room before the economizer, the corrected radiant heat transfer coefficient

$$h_r = 0.0059 \left[1 + 0.3 \left\{ \frac{697 + 273}{1000} \right\}^{0.25} \left(\frac{3.8}{2.43} \right)^{0.07} \right] = 0.0077 \text{ kW / (m}^2 \text{ . K)}$$

The heat transfer coefficient from the gas to the tube wall, h_o

$$Ho = 1.0\,(85 + 707) = 92.7 \text{W / (m}^2\text{.K)}$$

Because the heat transfer coefficient from the wall to the working fluid, h_i, is very large, $1/h_i$ can be neglected in q. (8.51), and the overall heat transfer coefficient, $U = \psi h_o$ $= 0.65 \times 92.7 = 60.25$ W/(m .K) $= 0.06025$ kW / m^2 . K).

The quantity of the heat transfer calculated from the heat transfer equation

$$H_t = \frac{0.06025 \times 251.3 \times 1215}{2.451} \quad 7505.6 \text{ kJ/kg}$$

Since

$$\frac{H_b - H_t}{H_b} = \frac{7686.7 - 7505.6}{7586.7} 100 = 1.07\% < \pm 2\%$$

This calculation is acceptable and the total heat absorption by the economizer, H_E = 7586.7 kJ/kg (obtained from the heat balance equation).

4.17 GEOMETRIC CONSTRUCTION PARAMETERS OF AIR HEATER

The tubular air heater is arranged horizontally, and the air passes through the tubes while the flue gases pass around the outside of the tube.

Width of flue gas duct a = 5.942m

Depth of flue gas duct b = 3.173m

96 rows of 40mm outside diameter tubes (1.5mm thick) are arrange in a staggered form.

$S_1/d = 75/40 = 1.88$

$S_2/d = 46/40 = 1.15$

Number of tubes, n = 7776

Flow area of air, Aa = 2.785m^2

Flow area of flue gases, Ag = 7.665m^2.

Total heating surface Area, A = 2382m^2.

HEAT TRANSFR CALCULATIONS OF THE AIR HEATER

From the preceding calculations and given data, we know the flu gas parameters at the inlet of the air heater, T_{gAi} = 298^{0}C and I_{Ai} = = 5838.47 kJ/kg; the inlet cold air temperature, T_{ca} =30^{0}C and the exit hot-air temperature, T_{ha} = 200^{0}C; their enthalpies are I_{ca} = 440kJ/kg and I_{ha} = 2945.9 kJ/kg, respectively.

According to the heat balance equation at the air side, the quantity of heat transfer needed to be absorbed by the air in the air heater is

$$H_b = (1.1 \;\; 0.05 + 0.5 \times 0.03)(2945.9 - 440) = 2668.8 \text{ kJ/kg}$$

The flue gas enthalpy at the exit of the air heater IA can be obtained from tables where the enthalpy of the air leaked into the flue gases is equal to $(I_{ha} + I_{ca})/2$:

$$H_b = 0.9925 \left\{ 5838.47 \;\; I_{Ae} + 0.03 \left[\frac{2945.9 + 440}{2} \right] \right\} = 3200.3 \text{ kJ/kg}$$

The corresponding gas temperature, T_{gAe} = 163^{0}C (Tables). The average temperature of the flue gases, T = (298 + 163)/2 = 230.5^{0}C. The average flue gas velocity

$$V = \frac{2.451 \times 14.36}{7.665}\left[1 + \frac{230.5}{273}\right] = 8.34 \text{ m/s}$$

Because n > 10, cn= 1.0; since $\phi = (1.88\ \ 1) / (2.2\ \ 1) = 0.77$, $c_s = 0.34\ \phi^{0.1} = 0.33$.

The convective heat transfer coefficient, h_c

$$h_c = 16.98 \times 10\text{-}3 \times 0.33 \times 1.0 \times \frac{8.34^{0.6}}{0.040^{0.4}} = 0.07249 \text{ kW/ (m2 . K)}$$

The average air temperature, $T = (30 + 200)/2 = 115^{0}C$. The average air velocity

$$V = \left[\alpha_{Fe}\ \Delta\alpha_f + \frac{\Delta\alpha_{ah}}{2}\right]\frac{B_r V_o}{A_o}\left[\frac{T + 273}{273}\right]$$

$$= \left[1.1 - 0.05 + \frac{0.03}{2}\right]\frac{2.451 \times 11 \times 0.63}{2.785}\left[\frac{115 + 273}{273}\right] = 14.75 \text{ m/s}$$

The heat transfer coefficient from the tube wall to the air, h_i

$$h_i = 3.49(1 - 8.26 \times 10\text{-}4 \times 115) \times 10^{-3}$$

The overall transfer coefficient, U, for = 0.8:

$$U = \frac{0.8}{\frac{1}{72.49} + \frac{1}{53.3}} = 24.57 \text{W/ (m}^2 \text{ . K)} = 0.02457 \text{ kW/ (m}^2 \text{ . K)}$$

According to the flow system of the air hair heater, from Tables, the following parameters can be obtained: $T_1 = 200 - 30 = 170^{0}C$ $T2 = 298 - 163 = 135^{0}C$, $P = 136/(298 - 30) = 0.5132$, and $R = 170/135 = 1.26$; from Fig. 8.34, cur 3, we obtained $\psi = 0.972$.

The mean temperature difference

$$\Delta T = 0.972\ \frac{(163 - 30) - (298 - 200)}{\ln\left[\frac{163 - 30}{298 - 200}\right]} = 110.3^{0}C$$

The quantity of heat transfer calculated from the heat transfer equation

$$H_t = \frac{0.457 \times 110.3 \times 2382}{2.451 \times 10^3} = 2634$$

Since

$$\frac{H_b - H_t}{H_b} = \frac{2668.8 - 2634}{2668.8} 100 = 1.3\% < \pm 2\%$$

This calculation is acceptable, and the total heat absorbed by the air heater, H_A = 2668.8 kJ/kg. Th error of the total heat balance calculation.

$$\Delta H \frac{H^{w}_{av} hb \ (H_r + H_s + H_{ss} + H_E)\left(1 - \frac{h_4}{100}\right)}{H^{w}_{av}} 100$$

$$= \frac{41{,}508 \times 0.9248 - (21{,}728 + 1560 + 7460.3 + 7586.7) \quad 1 - \frac{0}{100}}{41{,}508}$$

$= 0.124\% < \pm 0.5\%$

4.2 COST ESTIMATION OF THE BOILER

Cost estimation is a specialized subject and a profession in its own right. The design engineer, however, needs to be able to make quick rough cost estimation to decide between alternative designs and for project evaluation .

The relation between size and costing is given by the equation 4.2.

$Ce = CS^n$ - Equation 4.2;, where

Ce = purchase equipment cost, E

S = Characteristic size of parameter in units given i.e kg/hr steam.

n = index for type of equipment.

S = 130t/hr of steam = 130,000 kg/hr

C = E50

N = 0.8

The values chosen are standard for the boiler

$Ce = CS^n$

$= 50 \times (130{,}000)^{0.8}$

= 616772.05

∴ Equipment Cost E 616772.05

The base date is in mid 1992 and the prices are thought to be accurate to within ± 25%.

The degree of inflation, however, has to be considered as the price has obviously changed from 1992 to 2000. This is done by using the process engineering index.

Value of index : 1992 = 56

Estimated index in 2000 = 140.

$$2000 \text{ cost} = \text{Cost in } 1992 \times \left[\frac{\text{Cost index of } 2000}{\text{Cost index of } 1992}\right]$$

$$= 616772.05 \left[\frac{140}{56}\right]$$

$$= £1,541,930.1$$

The conversion rate of a pound to a Naira is

₦168 - £1.00

∴ Estimated cost in Naira = 169 x 1541930.1

= 259,000,000

4.3 SAFETY CONSIDERATION

The boiler is fuel oil fired and the products of combustion are carbondioxide, sulphur dioxide, nitrogen oxide, nitrogen and water. Nitrogen is inert and does not undergo reaction in the atmosphere. The other gases are acidic and can combine with oxygen and water of the air to form acids which is corrosive.

A concentration of 5% of CO_2 in the atmosphere may produce shortness of breath and headache. At a concentration of 10% carbon dioxide can produce unconsciousness in and exposed person, who will die from oxygen deficiency unless he is removed to a normal atmosphere or is given resuscitation. Carbon dioxide does not give a warning of its presence.

Soot (ash) which is discharged from the soot blowers also produce a choking feeling in the throat. When inhaled in large quantities it corrodes the lining of the lungs

In this design consideration is given to the standards set by the Environmental Protection Agency to ensure that the emissions are within permissible limits.

Isolation and logging are provided on the outside of the boiler to protect the boiler and protect operating personnel from burns

4.4 MATERIAL OF CONSTRUCTION

The main material for boilers are carbon steels and alloy steels. The latter can contain chromium, tungsten, nickel molybdenum, e.t.c. Most of the alloying elements are expensive but their addition in minor quantities imparts valuable qualities which are unattainable in carbon steel.

The trend to raise temperature of superheated steam to 450^0C and a high order pressure of 6.5 m pa and scale resistance requires the choice of the correct meter of construction. Higher alloy austenite class steel is chosen due to the chromium - nickel - manganese that make up the sturdier. These higher alloy steels have high heat and scale resistance.

CHAPTER FIVE

5.0 CONCLUSION AND RECOMMENDATION

5.1 CONCLUSION

A boiler with the capacity of 130t/hr was designed. The boiler efficiency was calculated to be 93%.

The cost of the boiler was estimated as ₦1,541,930.1 and its equivalent in Naira is 259, 000,000. Within the limits of experimental error the objectives of the project were achieved.

5.2 RECOMMENDATION

From the observations made in the design work, the following suggestions are being made:

1) The steam generated is more than what is required for the deodorization of shea butter, the excess steam should be employed in the other processing units of the refining plant; such as the degumming and the bleaching units.
2) To make the design cost effective, its capacity should be increased.
3) Other facilities such as pumps and attemperators should be included in the design in future design projects of boilers.

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