Increasing Efficiency of Boiler using Scaph

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Abstract :- The shell and tube heat exchanger is used in wide variety of industrial application particularly in heating, air conditioning and refrigeration industry. In most case fluid is liquid on the tube side exchanging heat with gas, usually air. The current study focused on the base tube there by giving excellent heat transfer. Steam coil air pre-heater is type heat exchanger. The equipment is particularly used to heat the atmospheric air to required process temperature by mean of saturated steam. Steam flows inside the tube while air passes over tube. It is generally used for heating the combustion air for all type high capacity boilers, recovery boiler and dryers etc. where in winter season temperature goes below 10^{0}C consistently. In this dissertation, we have fixed the design methodology of design of SCAPH by using the data of old system, cross check with exact site feedback and by using the same methodology design the new SCAPH thermal design for project.

Keywords :- *air pre-heater, saturated steam, tubes, SCAPH.*

I. INTRODUCTION

A. Introduction To Heat Exchangers

The technology of heating and cooling of systems is one of the most basic areas of mechanical engineering. Wherever steam is used, or wherever hot or cold fluids are required we will find a heat exchanger. They are used to heat and cool homes, offices, markets, shopping malls, cars, trucks, trailers, aero-planes, and other transportation systems. They are used to process foods, paper, petroleum, and in many other industrial process. They are found is superconductors, fusion power labs, spacecraft, and advanced computer systems. The list of applications, in both low and high tech industries, is practically endless. In our basic study of thermodynamics and heat transfer, we studied the form of control volume energy balance and its application too many engineering problems, including to a basic heat exchanger problem. In this module, we will extend heat exchanger analysis to include the convection rate equation, and demonstrate the methodology for predicting heat exchanger performance that include both design and performance rating problems. [5]

B. Introduction To Air Pre-Heater

Air pre-heater is a heat transfer surface in which air temperature is raised by transferring heat from other media such as flue gas. Air pre-heater is a heat recovery equipment, which improves the efficiency of boiler. The fuel consumption is reduced to an extent 5 %, depending on the duty. In Air pre-heater the combustion air is preheated before admitting the air to combustion zone. The air preheating can be heated up to 200 deg C max, depending on type of Combustion equipment. [7]

C. Introduction To Scaph

Steam Coil Air Pre Heater (SCAPH) is a tube type heat exchanger. This equipment is used to heat atmospheric air to the required process temperature by means of saturated steam. Steam flow Inside the tube while air passes over the finned tubes. It is generally used for heating process air in Sugar mills, Chemical & allied industries. SCAPH find extensive use with all types of High Capacity Boilers, Recovery Boilers, and Dryers etc. Steam coil air pre-heaters are used to heat air entering the air heater recuperative or regenerative type, in order to raise the average cold end temperature to prevent acid dew point corrosion. This type of equipment is normally incorporated into design of a boiler unit for low load operation and startup operation particularly in those areas with low ambient air temperatures. They are desirable in that the main air heaters, recuperative or regenerative, have corrosion sections that are more readily maintained this type of air heater uses extended surface, normally referred to as fins, to reduce the overall size of this air pre-heater. It is generally located in the duct between the FD and the main air pre-heater. In those areas that have extremely low ambient air temperatures, it is common to have this ahead of the FD fan that could pre heat cold winter air uoto 40 degrees F. Many types of heat exchangers are used in industrial waste heat recovery units such as cross flow, rotary, run around coil & especially tube heat exchangers which has high performance & low operating cost. The tube heat exchangers is used to recover heat from flue gas of the boiler or furnace & transfer this energy to increase the temperature of combustion air (air pre-heater) or boiler feed water (economizer). Generally acid dew point temperature of bagasse fired flue gas is in between

140^0 C to 150^0 C. This temperature is calculated by bulk mean temperature of flue gas and ambient air. As the ambient temperature falls down there is possibility that overall bulk mean temperature may fall below 145^0 C. At that temperature SO_3 and H_2O present in the flue gas start to reacts with each other. To increase the efficiency of the boiler we are introducing SCAPH system before air pre-heater. In SCAPH as name it indicated that the atmospheric air is heated by system. In cogeneration plant and sugar industry low pressure system is already extracted from turbine for next process. Some amount of this low pressure steam is used in SCAPH system to heat atmospheric air.

II. INTRODUCTION TO SS ENGINEERS

They are internationally renowned original equipment manufacturer of complete sugar plants, co-generations plants and industrial boiler. Their highly esteemed and satisfied clientele will attest to our turnkey capabilities, right from requirement analysis to post commissioning services. Building on our core competencies of total technical expertise and vast practical experience, S.S. engineers is today at the forefront of innovative, affordable, efficient, and most modern sugar technology. It is leading engineering industry of India engaged in the manufacture of complete sugar plants. SS engineers incorporated in 1980, with single handed effort, modest investment and full dedication has grown today into a large organization. Founder Mr. Bhad, after completing his graduation in engineering 1972, joined M/s. walchandnagar industries Ltd. Engaged in design of various sugar machineries. Later he joined the consultancy winged enveloping a very sound knowledge bank in sugar machinery since 30 year long.

He ventured in consultancy services of his own in the later part of his career. SS engineers offers most innovative, convenient and profitable “Single Window” solution from design and manufacture to erection and commissioning of complete sugar plants, Co-generation plants, industrial boiler, by-products, electrical systems and instrumentation etc. from small equipment like fibrizer and mills up to a complete plant. SS engineers have carved the niche for them during the last 25 years. The consultancy services banked by years of hands on expertise in the industry, along with the rich knowledge bank have benefited their clients for over 2 decades. Today with a team of 100 engineers, headed by technocrats of high repute, three most modern workshops and the engineering expertise achieved at micro level, SS engineers is in the forefront of the Indian Sugar Industry, providing complete Sugar Solutions to its customers in India and abroad.

A. Clients

Bajaj Hindustan Ltd.
Indian Sugar Manufacturing Co.
Siddhanath Sugar Mfg. Co. Maharashtra
Upper Ganges Sugar & Ind. & Ltd. Uttar Pradesh
Seena Sugars Mfg. Co. Maharashtra
Bhalkeshwar Sugar Ltd. Karnataka
Jaywant Sugar Ltd. Maharashtra
Dynamic Sugar Pvt. Ltd. Uttar Pradesh
IPL Sugar And Allied Industries Ltd.
Bhausaheb Birajdar SSK Ltd. Maharashtra
Tata Chemicals Ltd. Maharashtra

B. Products

Complete sugar plants
Milling tenders
Industrial boilers
Heat exchangers
Co generations
Diffuser
Boiling house equipment
Centrifugal machines
Turbo generator
Electrical equipment
Instrumentation and automation

C. Achievements

Complete sugar plants- 20 Nos. (1000 TCD to 10000 TCD)
Co-generation plants- 21 Nos. (6 MW to 50 MW)
Boilers- 75 Nos. (20 TPH, 45 ata, 440^0 to 150 TPH, 110 ata, 540^0 C)
Mills- 250 Nos. (20”× 40” to 50” × 100”)

III. LITERAURE REVIEW

A. Heat Exchanger Types

(a) concentric-tube parallel flow
(b) concentric-tube counter-flow
(c) shell-and-tube and
(d) Cross flow

Heat exchangers are typically classified according to flow arrangement and type of construction. In this introductory treatment, we will consider three types that are representative of a wide variety of exchangers used in industrial practice. The simplest heat exchanger is one for which the hot and cold fluids flow in the same or opposite direction in a concentric-tube (or double-pipe) construction.

In the parallel-flow arrangement of figure 3.1a, the hot and cold fluids enter at same end, flow in the same direction, and leave at same end. In the counter flow arrangement, figure 3.1b, the fluids enter at opposite ends, flow in opposite directions, and leave at opposite ends. A common configuration for power plant and large industrial applications is the shell-and-tube heat exchanger, shown in figure 3.1c. This exchanger has one shell with multiple tubes, but the flow makes one pass through the shell. Baffles are usually installed to increase the convection coefficient of the shell side by inducing turbulence and a cross-flow velocity component. The cross-flow heat exchanger, figure 3.1d is constructed with a stack of thin plates bonded to a series of parallel tubes. The plates function as fins to enhance convection heat transfer and to ensure cross-flow over the tubes. Usually it is a gas that flows over the fin surfaces and the tubes, while a liquid flows in the tube. Such exchangers are used for air conditioner and refrigeration heat rejection application.[1]

B. Air Heater Corrosion

There are two modes by which the corrosion failures are initiated. The flue gas contains water vapor, which is due to moisture and hydrogen in fuel and moisture in air. This water vapor condenses on cool surfaces of Air Pre-heater. The temperature of the Air pre-heater tubes will be closer to ambient temperature at air inlet section. This is where the water droplets form. The sweating of the tubes here promotes corrosion spots. The ash in flue gas also deposits at this point and leads to choking of tubes. With fuels containing sulfur, the acid formation takes place and corrosion is accelerated. The air pre-heater failure in oil fired boilers would be faster as compared to coal fired boilers. With high moisture fuels such as lignite, wood, bagasse the tube failures are common. It is better to design the air pre-heater with multiple blocks so that the cold end block can be replaced when necessary. If the air-preheater is of a single block, the replacement cost and down time cost for replacement of tubes will be high. [10]

- *Effects of Air Pre-Heater Failure*

In the event of tube failure, the heat gain from Air pre-heater will not be available for furnace heat transfer. In order to compensate for this loss the fuel consumption would go up. As the failures increase, beyond a limit the combustion airflow to the furnace would start coming down, as the combustion airflow goes to chimney directly. This leads to poor combustion of fuel. The unburnt in ash and flue gas will go up. The furnace draft cannot be maintained. Further the steam generation would come down. Generally at this stage only, the failure is realized by many.

C. Arrangement of Heat Transfer Surface (Furnace-Equipped Boiler)

According to second law of thermodynamic heat transfer cannot occur from a lower temperature level to a higher one. That's why the flue gas temperature has to be higher than the temperature of heat absorption fluid (working fluid). The temperature of flue gas leaving the furnace is 800-1400^{0}C and it cools to 150-200^0 C in the air pre-heater. The arrangement of heat transfer surfaces have an effect on durability of material, fouling of material, temperature of steam and final temperature of flue gas.

The evaporator is generally built into the furnace. Moving through the flue gas path in boiler the heating surfaces are found in the sequence: furnace, superheaters (and pre-heaters), economizer and air pre-heater. Table 1 presents an example of changes of stream temperatures in heat exchanger surfaces of a boiler, where the steam pressure about 80-90 bar.

The utilization of tube heat exchanger widely used in variety of applications e.g. in air-conditioning, refrigeration and processing industry. The air flow in compact heat exchangers is known to be very complex. This is because of complex interaction between the air flow and the tube pattern. In typical application of the tube heat exchangers, the air side resistance generally comprises over 90% of total thermal resistance. There, enhance surface were often employed to effectively improve the overall performance of the tube heat exchangers.[9]

D. Fouling Factor

Steam is passed through the tube and gate condensed on the inner surface of tube so scale and impurities gets deposited inside the tube. At the outside of tubes atmospheric air is working fluid. It passes through fine wire mesh before the FD fan and it is already under the pressure as it is just at delivery end FD fan. So no fouling factor for outside fluid considered.

It is important to emphasize that *fouling* or *scaling* is the most common in heat exchanger applications. For instance, scaling is typically associated with inverse solubility salts, such as $CaCO_3$, $CaSO_4$, $Ca_3(PO_4)_2$, $CaSiO_3$, $Ca(OH)_2$, $MG(OH)_2$, $MGSiO_3$, Na_2SO_4, $LiSO_4$, and $LiCo_3$. The characteristics which is termed inverse solubility is that, unlike most inorganic materials, the solubility decrease with temperature. The most important of these compounds is calcium carbonate, $CaCO_3$. Calcium carbonate exists in several forms, but one of the more important is limestone. As water runs through aquifers, running primarily through openings in limestone rock, it becomes saturated with calcium carbonate. This saturated water if pumped from the ground and passed through a heat exchanger, becomes supersaturated as it is heated, so that $CaCO_3$ begins to crystallize on heat exchanger internal passages. Similar results occur when ground water is used in any industrial cooling process. Most of the actual data on fouling resistances or fouling factors is tightly held be a few specialty consulting companies. This data which is commonly available is sparse. An example is shown in Table 2.3 for some typical industrial applications.

Note that the data in the table is given to only one significant figure. It is standard engineering practice to indicate the precision of a number by the number of significant figures presented, i.e. 0.0001 would indicate a number between 0.00005 and 0.00015. Actually these numbers are not known to this precision. Nevertheless, this data is often the best that is openly available and it is used for heat exchanger design calculations.[1]

IV. CONVENTIONAL METHOD

An air pre-heater (APH) is a general term used to describe any device designed to heat air before another process (for example, combustion in a boiler) with the primary objective of increasing the thermal efficiency of the process. They may be used alone or to replace a recuperative heat system. The purpose of air pre-heater is to recover the heat from the boiler flue gas which increase the thermal efficiency of the boiler by reducing the useful heat lost in the flue gas. As a consequences, the flue gasses are also conveyed to the flue gas stack (or chimney) at a lower temperature, allowing simplified design of conveyance of gases leaving the stack to meet emissions regulations.

A. Disadvantages of conventional methods

- Corrosion takes place in air pre-heater
- Coating of tubes has to be changed frequently.
- Combustion efficiency decreases.

V. WORKING OF SCAPH

SCAPH [Steam Coil Air Pre-Heater] is equipment fitted between F.D. fan and air pre-heater to avoid the acid dew point condensation which occurs at the flue gas side in the air pre-heater due to the low temperature of the atmospheric air. The SCAPH uses the low pressure of the air goes beyond the acid due point temperature. Hence corrosion in air pre-heater can be avoided by using SCAPH.

A. Material Of Construction

Tube is made up of carbon steel having thermal conductivity around 45 to 50 W/mK, this is of quality (BS-3059 1987 CEW) or SA210 grade B. steam and water header is made up by material SA-106 grade B as it is standard material of construction for pipe and header for low pressure and temperature steam.

B. Operating Pressure And Temperature

Operating pressure of the steam is taken between 1 to 5 bar and temperature is taken a saturation temperature at that corresponding pressure is taken as working temperature. F.D. fan deliver the air at ambient temperature and at pressure of 250mm/WC (mm of water column) draft pressure. Generally 25to 35mm/WC pressure drop is allowed in the SCAPH due to its complex geometry.

C. Starting And Stopping Condition

To avoid the overheating of SCAPH care should be taken as before starting the steam inlet, force draft fan or air inlet should be start. For stopping drain valve should be open and care must be taken as the SCAPH should be completely drain.

D. Maintenance Of Graph

In the SCAPH there are no moving parts, therefore there is no need of lubrication, gracing etc. but during shutdown period of plant it should dissemble from the duct and washing from the water jet should be done to remove the unwanted deposition if any from the SCAPH surface area. Good clean surface area helps in better heat transfer.

Actually there is no bypass of SCAPH during the summer season is provided. We can stop the steam flow, so SCAPH becomes idle through it will be inline in duct or we can provide spare duct having the dimension exactly matching the SCAPH. We can replace the spare duct by SCAPH during the summer season. The aim of SCAPH is not to remove any moisture from the air but to heat the ambient air to such level that no acid formation takes place at the flue gas side in the APH.

VI. DESIGN

Design consists of gathering important data of previous systems and applying scientific principles, technical information and imaginations for development of a machine to perform a specific function with maximum economy & efficiency.

➢ *Applications*

- Steady state heat conduction.
- Negligible thermal contact resistance.
- Heat conduction one dimensional.
- Uniform heat exchanged through length of the tube.
- Negligible radiation.

➢ *Given Data*

- Velocity of low pressure steam= 15m/s
- Velocity of air at outlet of FD fan=20m/s

- Air flow rate=5.5m^3/s
- Inlet mean temperature =20^0
- Mass flow rate of steam =0.4028 kg/sec
- Steam pressure=1.4bar
- Steam saturation temperature =130^0C
- Air flow direction=horizontal
- Inlet fouling factor=0.0002 m^2 K/w

A. Calculate Overall Heat Transfer Coefficient (U_o)

$$U_0 = \frac{1}{(do/di) \times (1/hi) + (do/di \times fi) + (do \times \ln do/di / 2\times k_{wall}) + (1/h_0) + f_o}$$

Where,

hi= Inside convective heat transfer coefficient in W/m^2k.

ho= outside convective heat transfer coefficient in W/m^2k.

fi= inside fouling factor in m^2k/w.

fo= outside fouling factor in m^2k/w.

K_{wall}= thermal conductivity of wall in W/mk.

B. Calculation Of Heat Carried By Air (Qair)

Air volume flow rate =5.5 m^3/s

Density of air ϱ_a= 1.20 kg/m^3

Therefore mass flow rate of air required,

$m_a = 5.5\times1.20$

m_a = 6.60 kg/s

we know,

$Q_{air} = m_a \times C_p \times \Delta T$

Q_{air}= 6.60×1.007×30

Q_{air}= 188.386 KJ/s

C. Calculate Number Of Tubes

As per the velocity of saturated steam 15-25 m/s we have take 15m/s by reference.

$A= (\pi/4) \times d^2$

V_s= 15 m/s

Outer diameter of tube= 19.05 mm

14SWG=2.03mm

Inner diameter=outer diameter-2×2.03

=19.05-2×2.03

$di = 14.99\times10^{-3}$

So Internal Area of tube

$A_i = (\pi/4) \times 14.99\times10^{-3}$

$A_i = 1.764 \times 10^{-4}\ m^2$

Mass flow rate of steam $m_{steam} = \varrho_s \times A_i \times V_s \times N$

$0.4028 = 1.345 \times 1.764\times10^{-4} \times 15 \times N$

N= 108.73

Take N = 371

D. Calculate Inside Heat Transfer Coefficient (Hi)

Actual velocity of steam is,

$m_{steam} = \varrho \times A_i \times V_{act} \times N$
$0.2428 = 1.353 \times V_{act} \times 240$
V_{act} = 4.3963 m/s.
Now,
Reynolds no. for steam,
$Re = (\varrho V_{act} di)/\mu$
$Re = (1.496 \times 43963 \times 14.99\times10^{-3})$
Re = 6936.92

Nusselts no. can be calculated by
As per the table 7.1 Page no. 436 Yunis Cengel book,
For Re = (4000 to 40000)
$Nu = 0.193\ Re^{(0.618)} \times Pr^{(1/3)}$
$Nu = 0.193\ (6936.92)^{(0.618)} \times (1.01)^{(1/3)}$
Nu = 45.7956

We know that,
Nu = (hi × di)/k
$hi = (45.7956 \times 0.0288)/\ (14.99 \times 10^{-3})$
$hi = 87.9863\ W/m^2k$

E. Calculate Wall Resistance (Rw)

(1/hi) = 0.0113454

$(1/hi) \times (do/di) = 0.0144\ m^2K/w$

We have

$(do/di) \times fi = 2.5 \times 10^{-4}\ m^2k/w$

Rw = (do×((ln(do/di)))

$Rw = 4.57 \times 10^{-5}\ m^2k/w$

From the specification of F.D. fan outlet velocity of air i.e. inlet to SCAPH is 20 m/s.
Re = (ϱvdo)/μ
$Re = (1.092 \times 20 \times 19.05 \times 10^{-3})\ /\ (1.963 \times 10^{-3})$
= 21194.70

For Re = 21194.70 Nusselt no. is,
$Nu = 0.193 \times Re^{(0.618)} \times pr^{(0.3)}$
$Nu = 0.193 \times (21193.70)^{(0.618)} \times (0.7228)^{(0.3)}$
Nu = 81.77
We know,
ho = (Nu × k)/do
$ho = 117.18\ W/m^2k$

F. Calculate Log Mean Temperature Difference (Lmtd)

LMTD = (ΔT1-ΔT2)/ (lnΔT1/ΔT2)
ΔT1 = 130-50
$= 80^0C$
ΔT2 = 130-20
$= 110^0C$
$LMTD = 96.77^0C$

G. Calculate Overall Heat Transfer Coefficient (U_o)

$$U_0 = \frac{1}{(do/di) \times (1/hi) + (do/di \times fi) + (do \times \ln do/di / 2 \times k_{wall}) + (1/h_0) + f_o}$$

$Uo = 42.97\ W/m^2k$

H. Heat Transfer Area (A)
Q = Uo × A × LMTD
$199.386 \times 10^3 = 42.97 \times A \times 96.77$
$A = 47.94\ m^2$

I. Calculation of Length Of The Tube

A = π × do × L × N
L = 47.94/ (π×0.01905×371)
L = 2.16 m

Quality of product = 2

For single product L = 1.08m

VII. MATERIAL COST

Vendors total cost of SCAPH = Total weight × 220

= 4244 × 220

= 933680

Vendors total cost of SCAPH = 933680

Total saving cost = total cost for SCAPH – In house total cost of SCAPH

= 933680 – 491704.64

= 441975.36 Rs.

Total Cost Of Saving For Scaph Is Rs 441975.36

ISSN No:-2456-2165

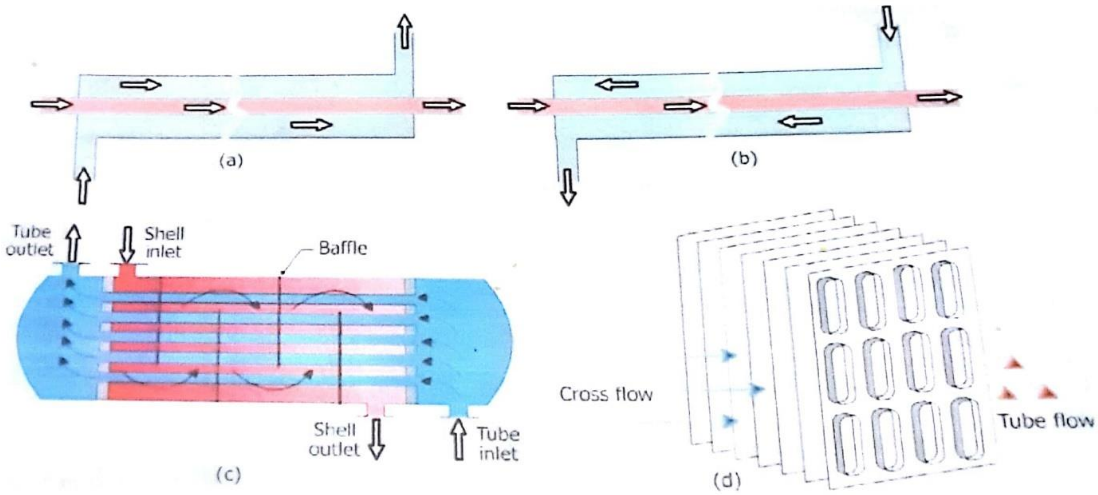

Fig 1:- (a) concentric –tube parallel-flow; (b) concentric-tube counter-flow; (c) shell-and-tube; and (d) cross flow.

Fig 2:- Air pre-heater tubes corrosion

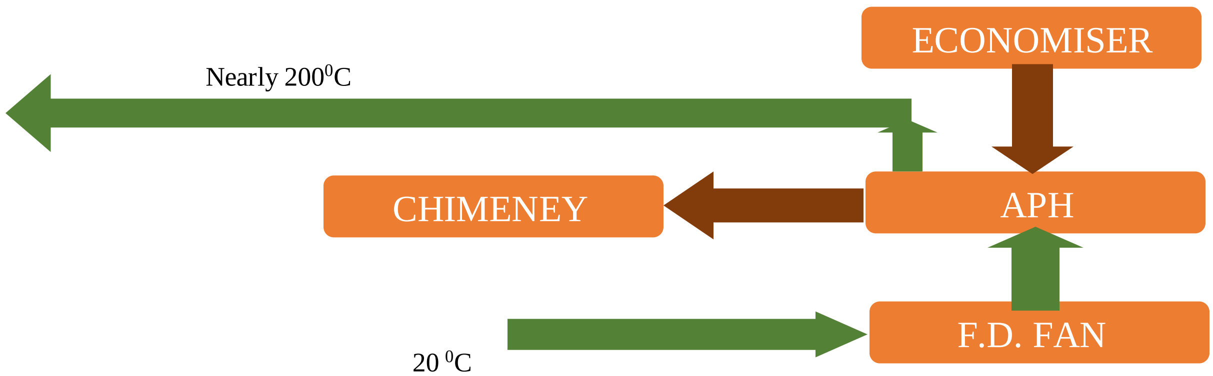

Fig 3:- Conventional air pre-heater method

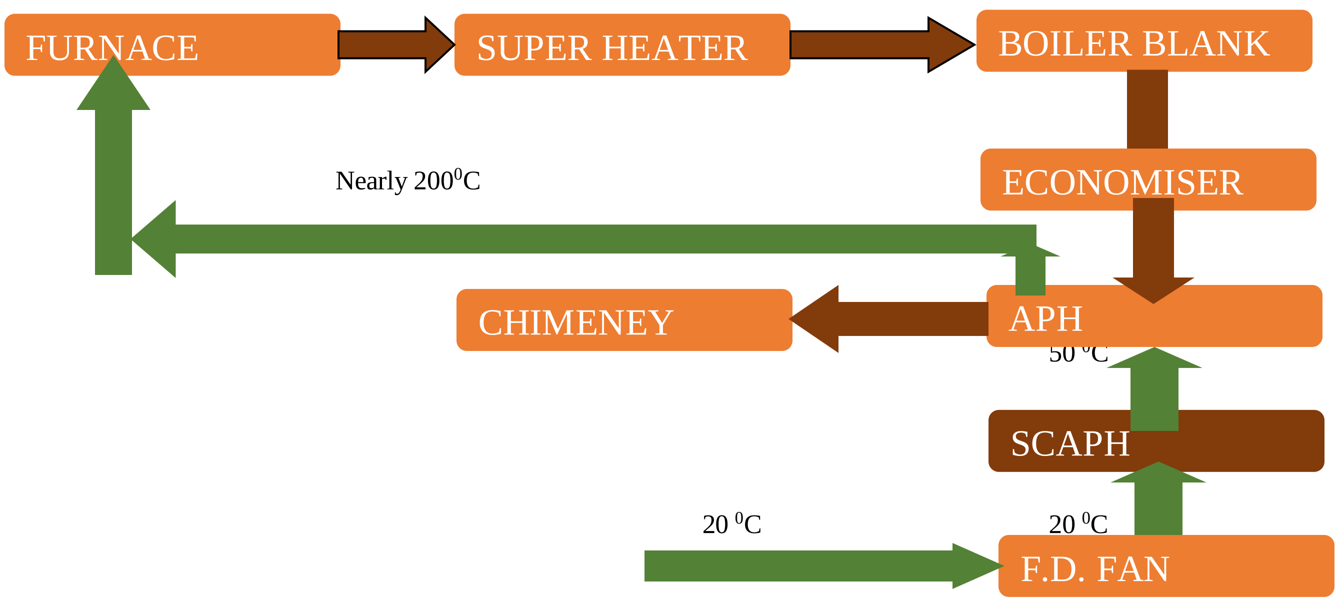

Fig 4:- Working of SCAPH

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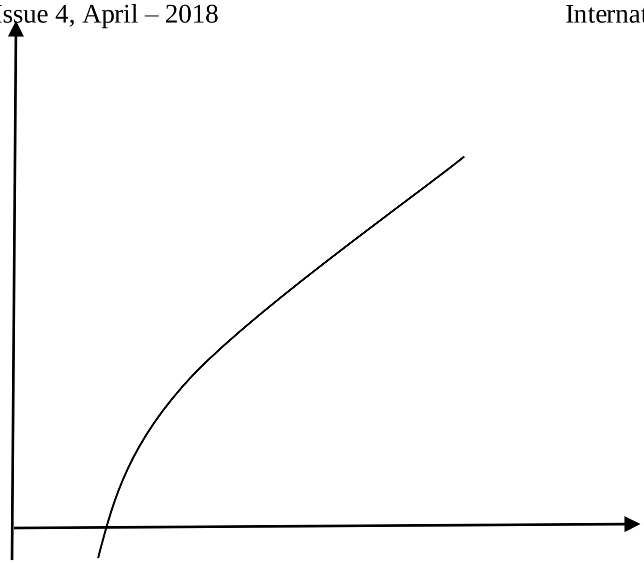

Fig 5:- Graph of draft loss vs. tube thickness

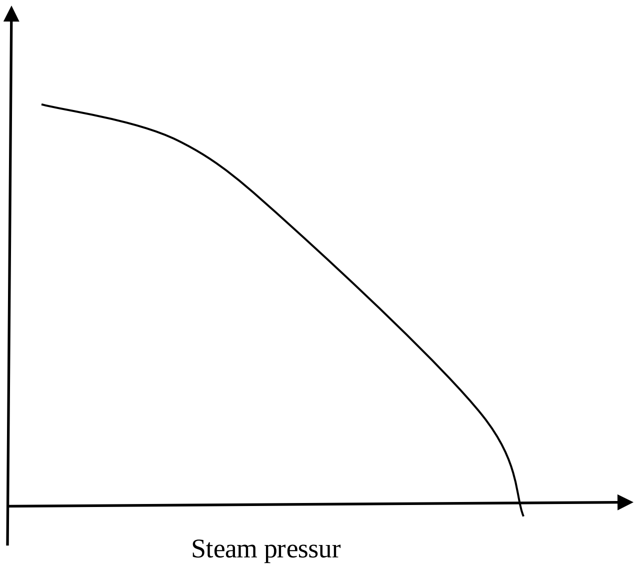

Fig 8.2:- Graph of heat transfer of surface area (A) vs. Steam pressure (P)

Note:- Description of figure is as per topics. For explanation refer the figure number. For example fig. 8.2 means topic number 8 and 8.2 means subtype of it in given topics.

Properties	Unit	Volume
Specific volume (v)	Kg/m^3.	0.668
Density (ϱ)	Kg/m^3	1.496
Dynamic viscosity (μ)	Kg/m-s	1.333×10^{-5}
Prandtl number (Pr)	-	1.01
Thermal conductivity (k)	W/mk	0.0288

Table 1. From Yunis Cengle table A-9, at 130^0 C properties of steam,

Velocity	No. of tubes
14	324
15	347
16	371
17	395

Table 2. No. of tubes corresponds to velocity

Properties	Unit	Value
Density (ϱ)	Kg/m^3	1.092
Dynamic viscosity (μ)	Kg/m-s	1.963×10^{-5}
Prandtl number (Pr)	-	0.7228
Thermal conductivity (k)	W/mk	0.0273

Table 3. properties of air

Sr. No.	Part	Material	Weight	Price Per Kg	Cost
1	Tubes	SA210 GA	1071.344	310	332116.64
2	Miscellaneous part	-	1000	45	45000
3	Manufacturing cost	-	4244	27	114588
In house Cost Of SCAPH In Rs					491704.64

Table. 4 – Material cost

VIII. RESULT AND CONCLUSION

A. Graph of Draft Loss Vs. Tube Thickness

As tube thickness will increase the flowing area becomes less for constant discharge. The velocity of air will increase. As the functional loss increase with increase in flow velocity total draft loss of the system will be increased. So ideally the tube should be selected of low thickness.

B. Graph of heat transfer of surface area (A) vs. Steam pressure (P)

Let, Q=U*A*LMTD

By this equation, for same heat transfer (Q), if LMTD increases, area will decrease. As the steam pressure will increase, the condensation temperature of steam will also increase which results into higher LMTD of the system. But as extraction pressure of turbine increase, it will down the whole system efficiency. As higher pressure and temperature of steam having the condensation with it, Temperature in between 115 to 135 is ideal for SCAPH application.

The designed SCAPH is working satisfactorily on the site and form our calculated area is exactly matching with supplier area; we can conclude that procedure of designing the SCAPH is right. In cost analysis the supplier quoting for SCAPH approximately is 220 Rs per kg i.e. total cost is Rs 933680. But we manufactured in the company the manufacturing cost is Rs 491704.64.

Therefore total cost saving is 933680 – 491704.64 = Rs 441975.36

- It works satisfactorily on the site
- Formation of H_2SO_4 in air pre heater get reduces hence corrosion does not take place.
- Efficiency of air pre-heater increases up to 10%.
- Use of anticorrosive coating on the tube can be avoided.
- It improves the performance of air pre-heater

IX. ACKNOWLEDGMENT

Now a days to improve the overall efficiency, boiler manufacturing is focusing on the design of boiler having high pressure and temperature. As the boiler pressure increases, the more auxiliaries like HP heater, SCAPH, APH, should employ to raise the temperature of fluid like feed water and combustion air comfortable by using the extracted steam and fuel gas as a heating media.

One boiler is consist of many heat exchangers like APH, ECON, super heater, boiler blanks, HP heater, SCAPH, Deaerator etc. some of them are direct contact type some are indirect type some are of cross flow and some are of counter flow etc. Performance of boiler is depends on these heat exchangers. This is a vast scope to improve the design of this heat exchanger. Proper design of these will increase overall efficiency, lesser material cost and proper utilization of all available resources.

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