WASTE HEAT RECOVERY FROM STACK GASES IN A CEMENT PLANT

Ahmed Ullah[1], [*]Asim Mushtaq[2], Rizwan Ahmed Qamar[1], Zaeem Uddin Ali[1]
[1]Chemical Engineering Department, [2]Polymer and Petrochemical Engineering Department
NED University of Engineering & Technology, Karachi, Sindh, Pakistan
Authors e-mail address: *engrasimmushtaq@yahoo.com

ABSTRACT: *Cement is a fine powder which sets following a couple of hours when blended with water, and after that solidifies in a couple of days into a robust and solid material. The Portland cement is most commonly used in the creation of concrete. Concrete is a composite material encompassing of cement, aggregate (gravel and sand) and water. The goal of this research is to recover the waste heat in cement plant is to recoup vitality, decrease generation cost and to make the procedure natural well disposed. The process depends on the Rankine cycle to change over heat into mechanical work. A waste heat recovery (WHR) plant requires a cooling tower which ought to be constantly accessible to supply the cold water to the condenser. A forced draft cooling tower is regularly introduced for this purpose. Further uses of a cooling tower in waste heat recuperation plant are to cool down the core, stator windings and furthermore to give cold water to the radiator; this is utilized to cool down generator heat exchanger. To cool down circulation oil for lubrication of bearings and furthermore for cooling of the boiler feed pump. The procedure of transformation of waste heat to power is relevant to each mega industry, bringing about a high measure of hot effluent gases can utilize this modest wellspring of age with exceedingly positive outcomes.*

Key Words: Cement; Waste heat; Stack gases; Recovery; Designing

1. INTRODUCTION

Cement is mostly used to tie fine sand and coarse aggregates together in cement. Cement is a hydraulic fastener; it solidifies when water is included. There are twenty-seven kinds of regular cement which can be gathered into five general classifications and three quality classes: normal, high and exceptionally high. Likewise, some extraordinary cement exists like sulfate opposing concrete, low heat concrete and calcium aluminate cement [1, 2].

History & Development of cement

It is dubious where it was first found that a mix of hydrated non-water driven lime with pozzolan produces a hydraulic blend, yet the Ancient Macedonians first utilized concrete produced using such blends and after three centuries on a huge scale by Roman engineers. They utilized both characteristic pozzolans (trass or pumice) and synthetic pozzolans (ground block or stoneware) in these cement [3, 4]. Numerous superb instances of structures produced still using these cement, eminently the tremendous vault of the Pantheon in Rome and the enormous Baths of Caracalla. The immense arrangement of Roman aqueducts passages additionally utilized hydraulic cement. Albeit any preservation of this learning in abstract sources from the Middle Ages is obscure, medieval artisans and some military experts kept up a functioning concord of employing water driven concrete in structures, like; harbors, trenches, strongholds, and shipbuilding offices. The specialized learning of making hydraulic cement was formalized later by French and British designers in the eighteenth century [5, 6].

Present day hydraulic cement started to be created from the beginning of the Industrial Revolution (around 1800), driven by three primary needs. Hydraulic cement render (stucco) for completing block structures in wet atmospheres. Pressure-driven mortars for stone work development of harbor works, in contact with ocean water and improvement of solid cement [1, 2].

Portland cement

Cement is prepared by heating limestone with different materials in small amounts at 1450 °C in a kiln, known as calcination, in which an atom of carbon dioxide is freed from the limestone (calcium carbonate) to form quicklime or calcium oxide, then mixed with different materials that have been unified in the blend. The consequent hard substance termed as 'clinker', is then crushed with a little amount of gypsum into a powder to make 'Ordinary Portland Cement', the most commonly used cement. Portland cement is an essential part of solid and most non-claim to fame mortar. As a constructing material, concrete can be thrown a fit as a fiddle wanted once solidified it can turn into an auxiliary component. Portland cement might be grey or white. Portland cement mixes are frequently reachable as between ground blends from concrete makers, yet comparative definitions are regularly likewise mixing starting from the first stage at the concrete blending plant [3, 5].

Portland blast furnace cement contains up to 70% ground granulated impact heater slag, with the rest Portland clinker and a little gypsum. All synthesis produces extremely high quality, yet as slag content is expanded, early quality is decreased, while sulfate obstruction increments and warmth development lessens. They are utilized as a financial option in contrast to Portland sulfate-opposing and low-heat cement [7].

Portland fly slag cement contains up to 35% fly cinder. The fly ash is pozzolanic, with the goal that extreme quality is kept up. Since fly fiery debris expansion permits a lower solid water content, early quality can in like manner be kept up. Where excessive quality shabby fly ash is available, this can be an economic option in contrast to ordinary Portland cement.

Portland pozzolan concrete incorporates fly ash cement, since ash is a pozzolan, yet also integrates bonds formed using other characteristic or fake pozzolans. In nations where the volcanic powder is accessible in Italy, Chile, Mexico and Philippines these concretes are most commonly recognized structure being used [5, 8].

Portland silica smolders cement growth of silica smoke can yield astoundingly high potentials, and cement consist of 5–20% silica rage are at times delivered. Be that as it may, silica fume is all the more typically added to Portland cement at the concrete blender.

Masonry cement is utilized for planning bricklaying mortars and stuccos, and must not be utilized in concrete. These are proposed to deliver precise cement with brickwork squares. Costly concretes. It contains, notwithstanding Portland clinker, far-reaching clinkers (as a rule sulfoaluminate clinkers), and are intended to counterbalance the impacts of drying shrinkage that is regularly experienced with water driven bonds. This permits huge floor sections (up to 60 m square) to be set up without contraction joints. White mixed concretes might be made utilizing white clinker and advantageous white materials, for example, high-virtue metakaolin [6, 9].

Colour cement is utilized for decorative purposes. In certain principles, the expansion of shades to create "colored Portland concrete" is permitted. In various gauges (for example ASTM), shades are not allowable constituents of Portland cement and sold as "mixed hydraulic cement ". In all respects finely ground bonds are produced using blends of cement with sand or with slag or other pozzolan type minerals that are amazingly finely ground together. Such concretes can have indistinguishable physical qualities from a typical bond [3, 10].

Pozzolan-lime cement is blends of ground pozzolan and lime are the concretes utilized by the Romans, and can be found in Roman structures as yet standing. They create quality gradually. However, their ultimate strength can be exceptionally high. The hydration items that produce quality are equivalent to those created by Portland cement [11, 12].

Slag-lime cements ground granulated impact heater slag isn't water driven without anyone else, however, is " activated " by the expansion of soluble bases, most monetarily utilizing lime. They are like pozzolan lime cement in their properties. Just granulated slag is viable as a bond segment.

Calcium aluminate cement is hydraulic cement made basically from bauxite and limestone. The dynamic fixings are monocalcium aluminate $CaAl_2O_4$ and mayenite $Ca_{12}Al_{14}O_{33}$ in Cement chemist notation. Quality structures by hydration to calcium aluminate hydrates, they are well-adjusted for use in refractory cement.

Calcium sulfoaluminate cement is produced using clinkers that incorporate ye'elimite (Ca_4 $(AlO_2)6SO_4$ or C_4A_3S in Cement scientific expert's documentation) as an essential stage. They are utilized in broad cement, in ultra-high early quality concretes, and in "low-vitality" concretes. Hydration produces ettringite, and specific physical properties, (for example, development or quick response) are gotten by the change of the accessibility of calcium and sulfate particles. Their utilization as a low-vitality option in contrast to Portland cement has been spearheaded in China, where a few million tons for each year are delivered. Vitality necessities are lower as a result of the lower furnace temperatures required for response, and the lower measure of limestone (which must be endo thermical de carbonated) in the blend. Also, the lower limestone substance and lower fuel utilization prompt a CO_2 discharge around a large portion of that related with Portland clinker. Nonetheless, SO_2 emanations are generally essentially higher [7, 8].

Natural cement relates to specific concretes of the pre-Portland period, created by consuming argillaceous lime stones at moderate temperatures. The level of clay segments in the limestone (around 30–35%) is to such an extent that a lot of belite (the low-early quality, high-late quality mineral in Portland cement) are framed without the development of extreme measures of free lime. Similarly, as with any characteristic material, such cement has profoundly factor properties. Geopolymer cement is produced using blends of water-soluble alkali metal silicates and alumino silicate mineral powders, for example, fly cinder and metakaolin [5].

World Wide Production

In 2018, the world generation of hydraulic cement was 3,300 million tons. The best three makers were China with 1800, the USA with 63.5 and India with 220, million tons for a joined aggregate of over a large portion of the world collective by the world's three most populated states. For the world capability to distribute cement in 2018, the circumstance was relative with the best three states representing under a large portion of the world complete limit. Lafarge holds its top position regarding worldwide concrete offers of 141.2 million tons and turnover of 15,884 million euros, in front of Holcim with cement offers of 136.7 million tons and a turnover of 15,691 million euros. Heidelberg Cement stays third, in front of Cemex, Italcementi and BuzziUnicem. Holcim, anyway has the lead as far as the worldwide bond limit at 212 million tons, 11 million tons higher than Lafarge [13-16].

2. METHODOLOGY

Waste heat recovery is an essential procedure to recoup any heat lost all through the entire creation process. This procedure is a substitute source of sustainable power energy. WHR plant, otherwise called co-generation power plant, takes up any conceivable heat vitality that can be recouped and changed over into electrical vitality. The motivation behind WHR is to recuperate vitality, lessen generation cost and to make the procedure natural well-disposed [17, 18]. The procedure depends on the Rankine cycle to change over heat into mechanical work.

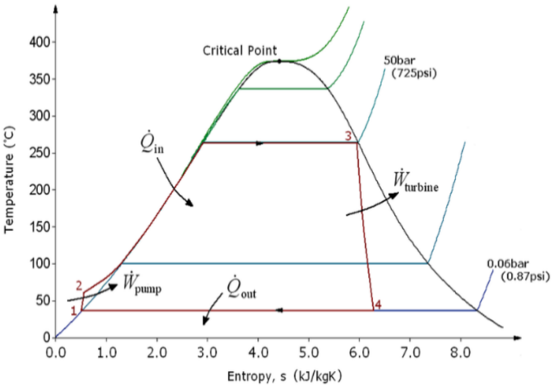

Figure 1: Temperature entropy profile

There are four stages in the Rankine cycle. These stages are illustrious by numbers in the TS (temp-entropy) in Figure 1. Procedure 1-2 the working liquid is siphoned from low to high pressure. As the liquid is fluid at this stage, the siphon requires little info-energy. Procedure 2-3 the high-pressure fluid enters a boiler where it is heated at steady pressure by an external heat source to turn into a dry saturated vapor. Procedure 3-4 the dry saturated vapor extends over a turbine, producing power. This reduction the pressure of the vapor and temperature, some condensation may happen. Procedure 4-1 the wet vapor at that point enters a condenser where it is condensed at a steady pressure to turn into a saturated fluid [12, 19].

In an ideal Rankine cycle, the turbine and pump would be isentropic, create no entropy and thus augment the system yield. Systems 1-2 and 3-4 would be addressed by vertical lines on the T-S outline and even more eagerly resemble that of the Carnot cycle. The Rankine cycle showed up here thwarts the vapor ending up in the superheat district after the augmentation in the turbine, which diminishes the imperativeness emptied by the condensers [12, 19].

Boilers

In a cement plant, every manufacturing line has two boilers, SP (suspension pre-radiator) kettle on the pre-heater side and an AQC (air extinguishing cooling) evaporator on the cooler side. The measure of heat recuperated from the boilers is reliant upon the limit of boilers, which itself is subject to the structure component of the creation procedure. For instance, in 'Lucky Cement Ltd.' the creation lines are planned at low weight framework (1.25 MPa) so, the AQC kettle's ability (14.5 tons/hr) is practically twofold the limit of the SP boiler (6.25 tons/hr) [20, 21].

Water Treatment

Water is the most basic necessity for steam generation. To realize that a boiler takes in water as feed and produces steam which is utilized to give fundamental heat vitality to the procedure. The proficiency, sturdiness of the boiler and recuperation rate of heat from the boiler are, for the most part, reliant on the nature of water provided to the boilers. For these real, undeniable reasons, the water treatment plant is a significant advance before steam generation. Its points of interest are reduced support cost, high recuperation rate, high productivity and in general benefit. Steam from both the boilers (AQC and SP) enter the WHR plant in various streams through isolated pipelines. Every pipeline has a valve. A fumes steam line is likewise introduced for crisis cases. Every one of the streams associates into the main header with jet valve. Steam from the main header moves towards the steam turbine, which is a shaft power generator more often than not with a limit differing from 10 MW to 12MW from three creation lines [21, 22]

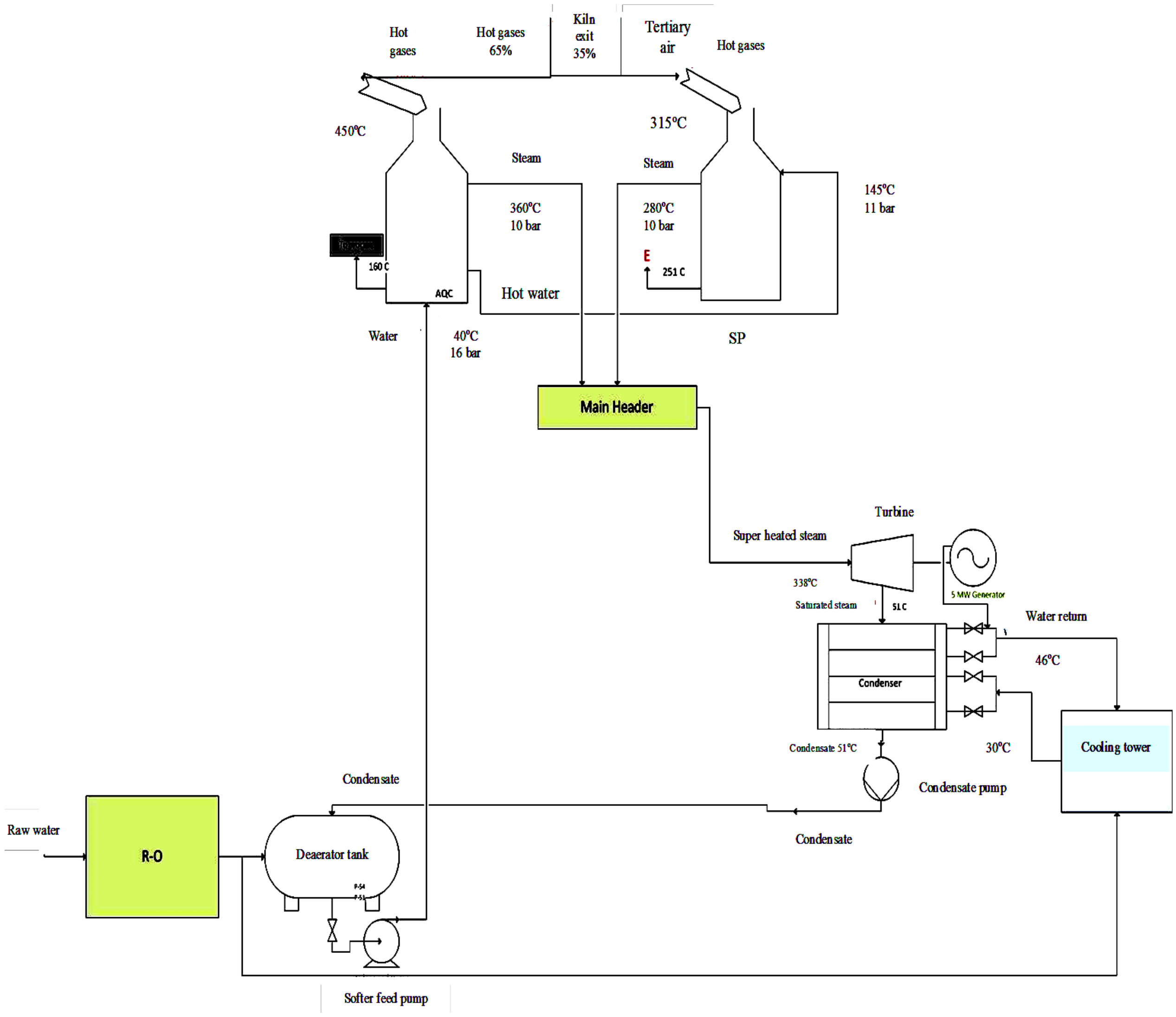

Figure 2: Process flow diagram of the waste heat recovery plant

A solitary creation line is fit for delivering around 14.5 tons/hr of steam, producing 3-4 MW power. The steam turbine deals with mechanical oil frameworks. Steam from the turbine is then sent to condenser which changes over it into the water which can be additionally utilized. Water to this condenser originates from cooling tower. A WHR plant requires a cooling tower which ought to be constantly accessible to supply the cold water to the condenser. A forced draft cooling tower is ordinarily introduced for this reason.

Further applications of a cooling tower in waste heat recovery plant are to cool down the core, stator windings and also to provide cold water to the radiator; this is used to cool down generator heat exchanger. To cool down circulation oil for lubrication of bearings and also for cooling of the boiler feed pump. A simple process flow diagram with all the parameters is shown in Figure 2 [23, 24].

Further utilizations of a cooling tower in waste heat recuperation plant are to cool down the core, stator windings and furthermore to give cold water to the radiator, this is utilized to cool off generator heat exchanger. To cool down flow oil for lubrication of bearings and furthermore for cooling of boiler feed pump. A straightforward procedure stream outline with every one of the parameters is indicated Figure 2 [15, 24].

3. RESULT AND DISCUSSION

3.1. Material Balance

Air Quenching Cooling (AQC) Boiler

Figure 3 shown the air quenching cooling boiler.

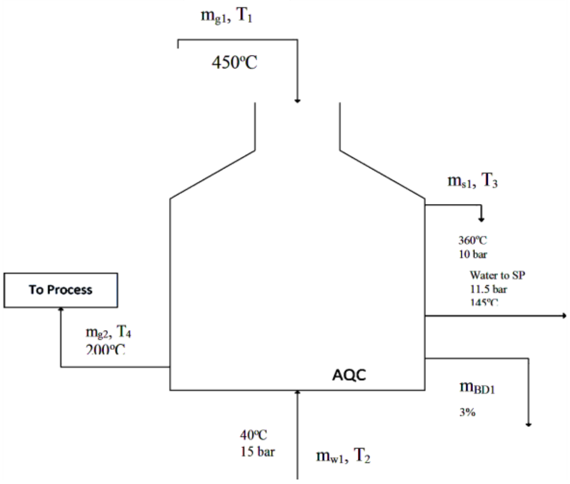

Figure 3: Air Quenching Cooling (AQC) Boiler

M_{exit}= Mass of gases at kiln exit= 50 kg/sec

Hot gases to the clinker cooler (65%) = 32.5 kg/sec

Fresh air blow in the cooler = 2.814kg/sec

mg= Mass flow of gases to cyclone separator
= 35.3144 kg/sec

mg1 = Inlet mass flow of hot gases to the AQC boiler = 33.195536 kg/sec

T1= Temperature of hot gases in = 450 ^{o}C

T2= Temperature of water flowing in= 40 ^{o}C

mg2 = Outlet mass flow of hot gases from AQC boiler (to process) 33.195536 kg/sec

T3= Temperature of steam at boiler exit = 360 ^{o}C

T4= Temperature of hot gases out = 200 ^{o}C

Tsat= Saturation temperature of water (11.5 bar)
= 186 ^{o}C = 459 K

Lam=Latent heat of vaporization= 1986 kj/kg

Cpg=Avg Heat capacity of mixture of hot gases
= 1.09 Kj/Kg.^{o}C

Cpw= Heat capacity of inlet water= 4.175 Kj/Kg^{o}C

mw1=Inlet mass flow of water

mw2= Mass flow of hot water to SP boiler
= 1.2437 kg/sec

cpw2=Average heat capacity of water to SP boiler (145 ^{o}C) = 4.2954 Kj/Kg^{o}C

Cps = Average heat capacity of steam = 2.45

mg1*Cpg*(T1-T4)=Q=mw*cpw*(Tsat-T2)+(mw*Lam)+mw2*cpw*(175-T2)+mbd*Cpw2*(175-T2)+mw*Cpw*(T3-Tsat) (1)

mw =quantity of water being converted to steam =mw1-mw2

mg1*Cpg*(T1-T4) =Q= (mw1*cpw*(Tsat-T2)-mw2*Cpw(Tsat-T2))+(mw1*Lam-mw2*Lam)+mw2*cp2*(145-T2)+mbd*cpw2*(145-T2)+(mw1*Cps*(T3-Tsat)-mw2*Cps*(T3-Tsat)) (2)

mw1= (mg1*cpg*(T1-T4))+(mw2Cpw(Tsat-T2))+(mw2*Lam-(mw2*cpw2*(145-T2)+(mw2*Cps*(T3-Tsat))/(cpw*(Tsat-T2)+Lam+0.03Cpw2(145-T2)+Cps*(T3-Tsat)) (3)

L.H.S= 12243.12856

R.H.S= 3035.38051

13872.2= 2964.613mw1

mw1= 4.033474064 kg/sec

mw= 2.789774064 kg/sec

Blow down= 0.12100422 kg/sec

ms1= Mass flow of steam= 2.789774064 kg/s
= 10.0431866 tonns/hr

Q= Heat given by gases = mg1*Cpg*(T1-T4)
= 9045.7835Kj/sec

Suspension Pre-heater (SP) boiler

Figure 4 shows the suspension pre-heater boiler.

M_{exit}= Mass of gases at kiln exit= 50 kg/sec

Hot gases to the preheater (35%) = 17.5 kg/sec

Tertiary air to the SP= 24.503 kg/sec

mg= Mass flow of gas to the cyclone separator
= 42.003 kg/sec

mg3 = Inlet mass flow of hot gases to the boiler
= 39.48282 kg/sec

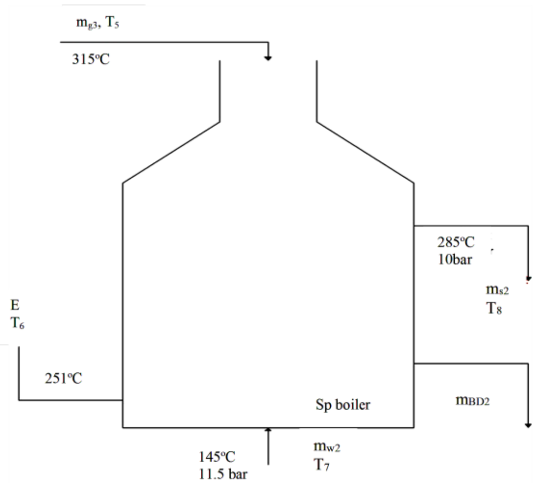

Figure 4: Suspension pre-heater boiler

T5= Temperature of hot gases in = 315 ^{o}C

T7= Temperature of water flowing in= 145 ^{o}C

E = Exhaust hot gases from the boiler
= 39.48282 kg/sec
T8= Temperature of steam at boiler exit = 285 ^{o}C
T6= Temperature of hot gases out = 251 ^{o}C
Tsat= Saturation temperature of water (11 bar)
= 184 ^{o}C
ƛs=Latent heat of vaporization = 2000 kj/kg
Cpg= Avg Heat capacity of mixture of hot gases
= 1.0692 Kj/Kg^{o}C
Cpw= Heat capacity of water= 4.35 Kj/Kg^{o}C
mw2=Inlet mass flow of water
Cpbd= Avg heat capacity of blowdown water
= 4.3 Kj/Kg^{o}C
Cps=mg3*Cpg*(T5-T6) =Q=mw2*cpw*(Tsat-T7)
+mw2*ƛs+mbd2*Cpbd(165-T7)+mw2*Cps* (T8-Tsat)
(4)
mw2=mg3*cpg*(T5-T6)/(cpw*(Tsat-T7)+ƛs+0.03
Cpbd(165-T7)+Cps*(T8-Tsat) (5)
mw2= 1.243773446 kg/s
Blow down = 0.037313203 kg/s
ms2= Mass flow of steam= 1.206460243 kg/sec
= 4.343256874 tons/hr

Material balance on Condenser:
Figure 5 shows the material balance of condenser.

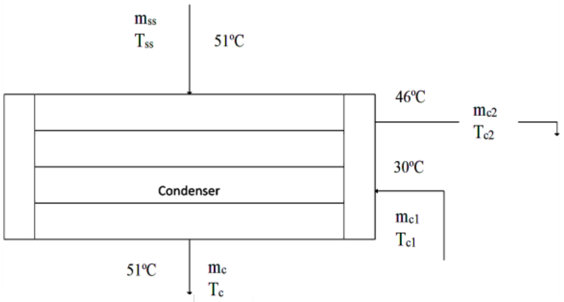

Figure 5: Mass flow in condensor

mss= Mass flow of saturated steam to condenser
= 3.995 kg/sec =31640.4lb/hr
mc= Mass flow of condensate= 3.95505 kg/sec
Tss= Temperature of saturated steam in= 51 ^{o}C
Tc= Temperature of condensate= 51 ^{o}C
Tc1= Temperature of water from cooling tower
= 30 ^{o}C
Tc2= Temperature of water to cooling tower
= 46 ^{o}C
hfg= Latent heat of vapourization = 2387 KJ/kg
Heat capacity of water (hot) = 4.178 KJ/Kg^{o}C
Heat capacity of water (cold) = 4.18 KJ/Kg^{o}C
Cpw= Avg. heat capacity of water
= 4.179 Kj/Kg^{o}C
mc1=Mass flow of cold water from cooling tower
mss(hfg+Cpc(Tss-Tc))=Q=mc1*cpw2*(Tc2-Tc1)
(6)
Q=9536.065kJ/se c= 32538388.83btu/hr

3.2. Energy Balance

Air Quenching Cooling (AQC) Boiler

Figure 6 shows the air quenching cooling boiler.

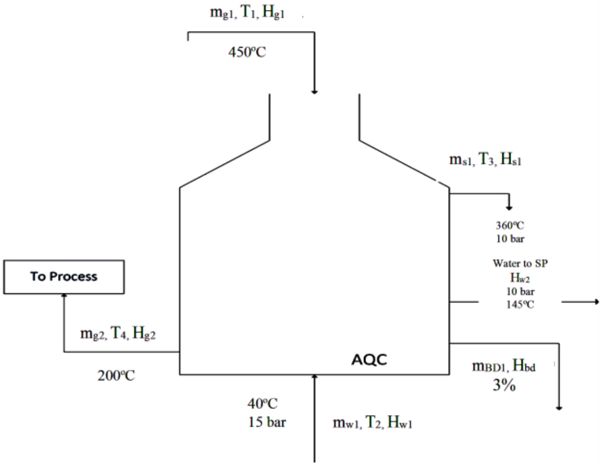

Figure 6: Air Quenching Cooling (AQC) boiler

Mass flow rate of inlet gases=mg1 = 33.195 kg/sec
Mass flow of water at inlet= mw1 = 4.033 kg/sec
Mass flow of steam out = ms1 = 2.789 kg/sec
Mass flow of water to SP=mw2 = 1.2437 kg/sec
Blow down of water=mbd1 = 0.12099 kg/sec
Cpg= Heat capacity of mixture of hot gases in
= 1.1177KJ/Kg ^{o}C
T1= Temperature of hot gases in = 450 ^{o}C
Enthalpy of hot gasses= Hg1 = 502.96KJ/kg
T4= Temperature of hot gases out = 200 ^{o}C
Heat capacity of mixture of hot gases at out let
= 1.0452 KJ/kg
Enthalpy of hot gasses at out let= Hg2
= 209.04 KJ/kg
Enthalpy of blow down water (145^{o}C) = Hbd
= 611.15 KJ/kg
Enthalpy of water in=Hw = 168.86 kJ/kg
T3= Temperature of steam at boiler exit = 360 ^{o}C
Enthalpy of water out to SP=Hw2= 611.15 KJ/Kg
Energy given by gas = energy taken by water
ΔH= ΣmH(out) -ΣmH(in) =0
mg1(Hg2-Hg1)=mw1*Hw1-ms1*Hs1-mbd*Hbd-
mw2*Hw2 (7)
L.H.S= -9756.840375
R.H.S= (4971.73-(3.398*Hs1)-126.32-1364.3)
HS1= 3443.46449 kJ/kg

Suspension Pre-heater (SP) Boiler:
Figure 7 shows the suspension pre-heater boiler.

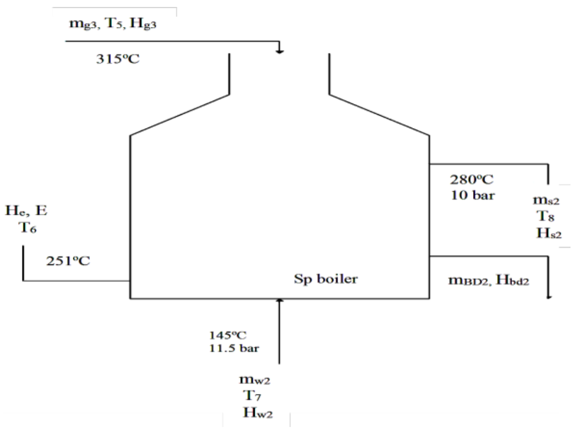

Figure 7: Suspension pre-heater boiler

Mass flow rate of inlet gases=mg3
= 39.48282 kg/sec
Mass flow of water at inlet= mw2 = 1.2437kg/sec
Mass flow of steam out = ms2 = 1.206 kg/sec
Blow down of water = mbd2 = 0.037311kg/sec
Cpg= Average heat capacity of mixture of hot gases = 1.0775KJ/Kg^{o}C
T5= Temperature of hot gases in = 315 ^{o}C
Enthalpy of hot gasses= Hg3 = 339.4125KJ/kg
Enthalpy of water in= Hw2 = 611.159KJ/kg
Enthalpy of blow down water (165^{o}C) = Hbd2
= 697.6 KJ/kg
T6= Temperature of hot gases out = 251 ^{o}C
Heat capacity of mixture of hot gases at out let
= 1.0609KJ/Kg.^{o}C
Enthalpy of hot gasses at out let= He
= 266.2859 KJ/kg
Energy given by hot gasses=Energy taken by water
ΔH= ΣmH(out) -ΣmH(in) =0
mg3*(He-Hg3)=mw2*Hw2-mbd2*Hbd2-ms2*Hs2 (8)
Hs2= 3002.748491 kj/kg

Energy Balance on Main Header

Figure 8 shows the main header of waste recovery heat.

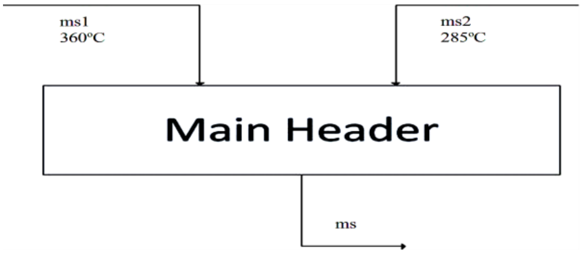

Figure 8: Main header of waste recovery heat

Temperature of steam from AQC=T1 = 360 ^{o}C
Pressure of steam from AQC=P1 = 10 bar
Mass flow rate of steam from AQC=ms1
= 2.789 Kg/sec
Temperature of steam from SP=T2 = 285 ^{o}C
Pressure of steam from SP=P2 = 10 bar
Mass flow rate of steam from SP=ms2
= 1.206 Kg/sec
Total flow rate=msh= 3.995 Kg/sec
Temperature of steam into the main header=T =(steam flow AQC*steam temp AQC) + (steam flow SP*steam temp SP)/(Total flow rate) (9)
Temperature of steam into the main header=T
= 337.359199 ^{o}C

Turbine Energy Balance

Figure 9 shows the energy balance in turbine.

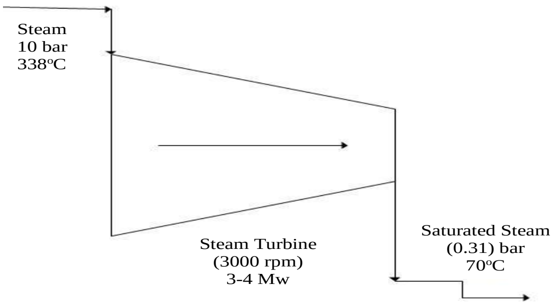

Figure 9: Turbine

Inlet pressure of steam=P1 = 10 bar = 1000 kPa
Inlet temperature of steam=T1= 338 ^{o}C
At the inlet conditions:
H1= 3334 kJ/kg
S1= 7.26 kJ/kg K
Outlet pressure of steam=P2 = 0.11 bar = 11 kPa
Outlet temperature of steam=T2= 51 ^{o}C
At the outlet conditions:
H2v = 2587 kJ/kg
H2L = 199 kJ/kg
S2v= 8.05 kJ/kg K
S2L= 0.716 kJ/kg K
Assuming isentropic process, then,
Entropy at outlet = S' =S1= 7.26 kJ/kg K
Steam with this entropy at 31 kPa is wet,
Calculating vapour fraction xv by using formula;
S2=S2L +xv (S2v-S2L) (10)
Since the process is isentropic so S2=S1=S'
xv = 0.89228252
This is the vapor fraction discharge at outlet:
The enthalpy is H2' (at outlet under constant entropy) is given by: H2'=H2L +xv (Hv-HL)
As isentropic process so, H2=H2'≠H1
H2'= 2329.770657 kJ/kg
So,
(ΔH) s= H2'-H1'
(ΔH) s= H2'-H1 (as H1'=H1)
(ΔH) s= 1004.229343 kJ/kg
Thus, the actual final enthalpy is;
ΔH = η (ΔH) s
Taking η = 85%
ΔH= 853.5949414 kJ/kg
Work done =mass flow rate*enthalpy change
Since,
Mass flow rate =m = 4 kg/sec
W = -3414.379765 kj/sec = -3.414379765 MW
So turbine power recovery is i = 3.414379765 MW

Condenser Energy Balance

Figure 10 shows the condenser of energy balance.

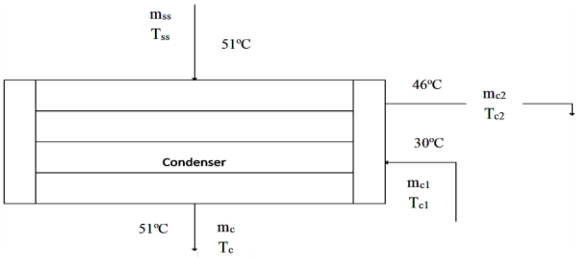

Figure 10: Condensor

mss= Mass flow of saturated steam to condenser
= 3.995 kg/sec =31640.4 lb/hr
mc= Mass flow of condensate= 3.95505 kg/sec
Tss= Temperature of saturated steam in= 51 ^{o}C
Tc= Temperature of condensate= 51 ^{o}C
Tc1= Temperature of water from cooling tower
= 30 ^{o}C
Tc2= Temperature of water to cooling tower
= 46 ^{o}C
hfg= Latent heat of vapourization= 2387 KJ/kg
Heat capacity of water (hot) = 4.178 KJ/Kg^{o}C
Heat capacity of water (cold) = 4.18 KJ/Kg^{o}C
Cpw= Average heat capacity of water

$= 4.179\ KJ/Kg^{o}C$

mc1=Mass flow of cold water from cooling tower

mss(hfg+Cpc(Tss-Tc))=Q=mc1*cpw2*(Tc2-Tc1) (11)

Q= 9536.065 kJ/sec= 32538388.83 btu/hr

3.3. Designing of Equipment

Boiler feed pump

Figure 11 shows the boiler feed pump.

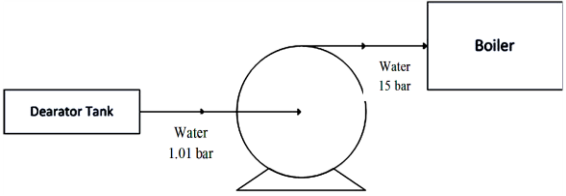

Figure 11: Boiler feed pump

Δz = 30 ft

Length of pipe= 1000 ft

Number of elbows = 10

Number of gate valves = 2

ϵ = 0.00015 (for steel pipe)

Dia of pipe = 3 inch = 0.249999 ft

As the temperature of water is constant;

If inlet temperature $T1= 40\ ^{o}C$

Viscosity of water μ= 0.0005 lb/ft sec

Density of water $\rho= 62.3\ lb/ft^3$

Specific volume $= 0.016051364\ ft^3/lb$

Inlet pressure = p1 = 1 bar = 2116.8 psf

Outlet pressure =p2= 362 psi = 15 bar = 31752 psf

Work done by the pump is given by the equation

W=Δz+Δv^2/2g+pΔv+∑F (12)

For total friction

∑F=total friction + friction due to enlargement +friction due to contraction

For velocity;

Mass flow rate (as calculated in material balance) = mw1= 9.75986 lb/sec= 4.033 kg/sec

Volumetric flow rate Q= mw1/ρ (13)

$Q= 0.156659069\ ft^3/sec = 563.9726485\ ft^3/hr$

Velocity = volumetric flowrate /area

V= 3.191044121 ft/sec

Reynold number:

Re = D*ρ*V/μ (14)

Re= 99400.62676 (turbulent flow)

So, α = 1

ϵ/D = 0.000600002

From moodys chart

f= 0.0055 check

Equivalent length Le:

Le= 83.499666 ft

Total friction=2fv^2(L+Le)/gc*D (15)

Total friction = 15.0884197 ft lbf/lbm

Friction due to enlargement and contraction = kc*v^2/2gc+(v1-v2)^2/2gc (16)

Taking kc = 0.5

Friction due to enlargement and contraction = 0.237367811 ft lbf/lbm

So,

$\sum F= 15.32578751\ ft.lb_f/lbm$

$Work\ done = 521.0111808\ ft.lb_f/lbm$

Power of the pump:

Power=W*Q*ρ/η (17)

η= 70%

Power= 7264.280261 lb/ft sec =13.20778229 hp

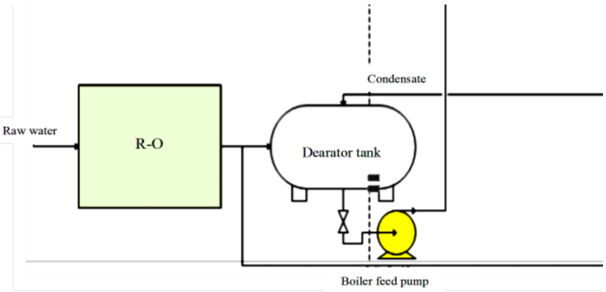

Figure 12: Process diagram of raw water treated

Figure 12 shows the process diagram of raw water treated.

NPSHa calculation:

Inlet pipe dia = 0.249999 ft

Velocity = 3.191044121 ft/sec

Head Loss = 4flv^2/2gd m

Head Loss = 1.162785781 ft = 0.35450786 m

Vapour Pressure @ $38\ ^{o}C$ = 154.176 Pa

NPSHA = 33.76029698 ft = 10.29277347 m

Air Quenching Cooler (AQC) Boiler Economizer designing

Figure 13 show the economizer of air quenching cooler AQC boiler.

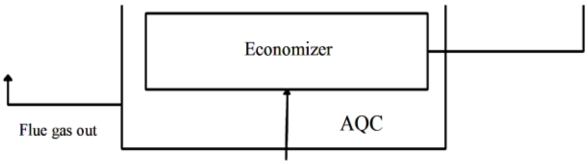

Figure 13: Economizer designing

Mass of water =mw= 4.1275 kg/ sec = 32689.8 lb/hr

Mass flow of gasses to AQC=mg= 33.195 kg/sec = 262908.3 lb/hr

cp of inlet gasses=cpg= 0.241 btu/lb ^{o}F

Inlet temperature of gasses to economizer= 276 ^{o}C

Outlet temperature of gasses from economizer = 200 ^{o}C

cp of water = cpw = 4.175 kj/kg ^{o}C

Inlet temperature of water =Tin = 40 ^{o}C = 104 ^{o}F

For economizer;

mg*cpg*ΔTg=mw*cpw*ΔTw (18)

Tout= temperature of water at outlet

Tout= 40 ^{o}C = 328.139 ^{o}F

Average temperature of water=Tin+Tout/2 (19)

Average temperature of water = 216.0695 ^{o}F

Specific volume (V) = $0.01674\ ft^3/lb$

Inner dia of tube = 2.5 inch = 0.208333333 ft

Velocity=V=0.05*(mw*sp.vol)/di^2 (20)

Velocity = 4.377818016 ft/sec

Tube side heat transfer coefficient=hi

hi= (150+1.55Tavg)*v^0.8/di^0.2

hi= 1315.458842 btu/ft^2 hr F

F=0.101

At 40 ^{o}C

$\rho= 62.16\ lb/ft^3$

cp= 0.9983 btu/lb ^{o}F

μ= 2.1538 lb/fthr

K= 0.335 btu/hrft F
Nu= hidi/12k
Nu= 68.17261826
Reynold number =Re=15.2*W*di/μ (22)
Re= 48062.8192
Pr= μcp/k (23)
P r= 6.418324

Shell side heat transfer coefficient=h0

G=12*wg/NwL(ST-d) (24)
G= 12619.5984
hc=0.9*G^0.6*F/d^0.4
hc =16.91775386 btu/ft^{2} hr F
Shell side heat transfer cofficient=h0
h0=hc+hN

For gas temperature less than 800 ^{o}F hn is very small and can be neglected.
h0=hc

For economizer:

U=over all heat transfer coefficient
U=0.9*h0
U= 15.22597847 btu/ft^{2} hr ^{o}F
At 373 ^{o}F
cp= 0.25156 btu/lb ^{o}F
μ= 0.0594 lb/ft.hr
K= 0.02 btu/hr.ft ^{o}F
d= 3 inch
Nu=hcd/12k
Nu= 211.4719232
Reynold number =Re=G*d/12 μ (25)
Re= 53112.78788
Pr= μcp/k
Pr=0.7471332
Over all heat transfer coefficient = U
= 15.22597847 btu/ft^{2} hr F
LMTD=(T1-t2)-(T2-t1)/Ln(T1-t2)/(T2-t1) (26)
Inlet temperature of gasses=T1 = 528.8 ^{o}F
Outlet temperature of gasses=T2 = 392 ^{o}F
Inlet temperature of water t1 = 104 ^{o}F
Outlet temperature of water=t2 = 329 ^{o}F
LMTD = 241.2184888 ^{o}F
Q=UAΔT (27)
A=Q/UΔT
Q=mgcpΔT (28)
Q= 8667771.161 btu/hr
A= 2359.99799 ft^{2}

Evaporator designing

Figure 14 shows the evaporator for designing.

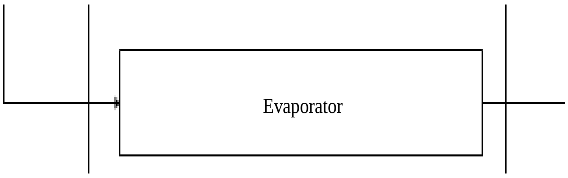

Figure 14: Evaporator

Using carbon steel tube:
Outer dia =do = 3 inch
Inner dia =di = 2.5 inch
Number of tubes wide =Nw = 24
Length of tube =L= 12.5 ft
Tube spacing= 4 inch^{2}
Flow rate of flue gasses=mg= 33.1955 kg/sec
= 262908.36 lb/hr
Temperature of inlet gas to evaporator=T1
= 370 ^{o}C= 698 ^{o}F
Temperature of inlet gas from evaporator=T2
= 276 ^{o}C = 528.8 ^{o}F
Steam pressure= 11bar
Feed water temperature=Tw= 164.52 ^{o}C
= 328.139^{o}F
Fouling factor on steam and gas side=ffi=ffo
= 0.001 ft^{2} hr ^{o}F/Btu
Assume heat loss from casing= 1%
Average gas temperature=Tavg= 613.4 ^{o}F= 596 K
= 1073.44 R
At pressure of steam=10.5 bar
Steam temperature inside tubes =Ts= 455.08^{o}C
= 360 ^{o}F
Tube wall temperature= 370 ^{o}F (assume) = 830 R
Film temperature=tf= 491.7 ^{o}F

Properties of gas at film temperature

cp= 0.26148 btu/lb ^{o}F
μ= 0.06468 lb/ft.hr
k= 0.02314 btu/hr.ft ^{o}F
cp at average gas temperature = 0.2648 btu/lb ^{o}F
Duty Q= mcpΔT (29)
Duty Q= 11661594.34 Btu/hr= 11.67M Btu /hr
Mass velocity =G= 12*mg/NwL (ST-d)
ST=4 (30)
Mass velocity =G= 10516.3344 lb/hr ft^{2}
Reynold number =Re= G*d/12 μ
Reynold number = Re = 40647.55102
Nu= 0.229(Re^0.632)
Nu= 187.3894832
Convective heat transfer coefficient=hc
= Nu*12*(k/d) (31)
hc = 17.34477057 btu/ft^{2} hr ^{o}F
Beam length=L= (1.08*ST*SL-0.785d^2)/d
SL= 4 (32)
L= 3.405 inch= 0.086m
Partial pressure of tri atomic gasses at Tavg
Pco$_{2}$ = 0.1136
PW = 0.0418
pso$_{2}$ = 0.0016

For engineering estimate we add partial pressure of CO$_{2}$ and SO$_{2}$

Pc= 0.1152
K=((0.8+1.6*pw)*(1-0.38Tg/1000)*(Pc+Pw))/((Pc+Pw)*L) ^0.5 (33)
K= 0.90600612
ϵg=0.9*(1-exp^-Lk) (34)
ϵg= 0.06746
Non luminous heat transfer coefficient =hN
=σϵg(Tg^4-To^4)/(Tg-To) (35)
σ= 0.173*10^ (-8) = 1.73E-09
hN= 0.409070062 Btu/ft^{2} hr ^{o}F
Here Km= 25 Btu/ft.hr ^{o}F
Boiling heat transfer coefficient =hb
= 2000 Btu/ft^{2} hr
1/U= 1/ (hN+hc) +ff0+ (ffi*d/di) +d/ (di*hi) +d/ (24*Km) ln d/di (36)
1/U= 0.060037449
U= 16.65627079 Btu/ft^{2} hr ^{o}F
LMTD=((T1-Ts)-(T2-Ts))/ln(T1-Ts)/(T2-Ts) (37)
LMTD= 243.6876989 ^{o}F
Q=UAΔT

$A=Q/U\Delta T$

$A= 2873.07227\ ft^2$

$A=\prod dNLNd/12$ Nd= 14 (rowsdeep) (38)

$A= 3297\ ft^2$ (actual area)

Gas density ρ=PM/RT (average. molecular weight of gasses) = 29.819

Gas density $\rho= 0.038071688\ lb/ft^3$

f= Re^-0.15*x

x=0.044+(0.08*(SL/do)/(ST/d0-1)^ (0.43+1.13*d0/SL)

x= 0.47806136

f= 0.097303505

ΔPg= 9.3exp-10*G^2*Nd*f/ρ (39)

$\Delta Pg= 3.680154957\ inch^2$

q= average heat flux on tube inner dia

q= U*(Tavg-Ts)*d0/di

$q= 5064.838821\ Btu/ft^2\ hr$

Temperature drop across fouling layer= q*ffo

Temperature drop across fouling layer = 5.064838821 °F

Temperature drop across film coefficient= q/hb

Temperature drop across film coefficient = 2.53241941 °F

Temperature drop across tube wall = 0.0004*di*q/do

Temperature drop across tube wall = 1.688279607 °F

Adding all temperature drop = 9.285537838 °F

Hence tube outer wall temperature = Ts+total temperature drop

Hence tube outer wall temperature = 369.2855378 °F

This is close to assume value = 370 °F

Super heater designing

Figure 15 shows the super heater design.

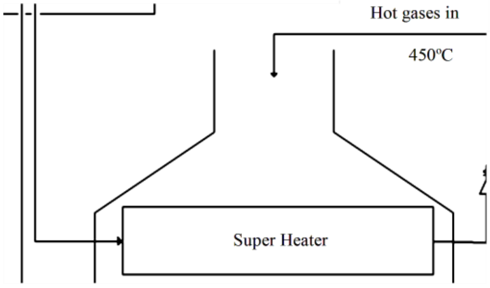

Figure 15: Super heater

Outer dia =do= 3 inch

Inner dia =di= 2.5 inch

Steam in =W= 21960.3384 lb/hr

Outlet temperature of steam =Ts= 360 °C= 680 °F

Steam inlet temperature = 182.22 °C = 360 °F

Average temperature = 520 °F

C@166psia and 520 °F= 0.2847

Tube side heat transfer coefficient hi= 2.44*w^0.8*C/di^1.8 (40)

$hi= 397.005479\ Btu/ft^2\ hr\ ^oF$

Outside gas heat transfer coefficient=h0= hc+hN

Flue gasses =Mg = 262908.36 lb/hr

Gas inlet temperature =T1 = 450 °C= 842 °F

Gas outlet temperature=T2 = 370 °C= 698 °F

Average steam temperature = 520 °F

Number of tube wide =Nw = 20

Length of tube = 12.5 ft

Transverse pitch= 4 inch

Longitudinal pitch= 3.5inch

Mass velocity =G= 12*mg/NwL (ST-d) ST=4 (41)

$\text{Mass velocity} =G= 12619.60128\ lb/ft^2\ hr$

Film temperature= tf=Average steam temperature +gas inlet temperature /2 = 681 °F

Apply correction factor (FN for 60°) angle of attack

FN= 0.94

hc= 0.9*G^0.6*f/do^0.4 (f= 0.1125) (42)

$hc= 18.84403534\ Btu/ft^2\ hr.\ ^oF$

$hc= 17.71339322\ Btu/ft^2\ hr.\ ^oF$

Because the gas temperature is not high, the hN value will be low so,

U=h0=hc

$h0=hc = 17.71339322\ Btu/ft^2\ hr.\ ^oF$

$U= 17.71339322\ Btu/ft^2\ hr.\ ^oF$

At film temperature,

cp= 0.2681 btu/lb °F

μ= 0.0735 lb/ft.hr

k= 0.0269 btu/hr.ft °F

Reynold number =Re= G*d/12 μ

Reynold number = 42923.81388

Nu= hd/12k

Nu= 164.6226136

Pr=μcp/k

Pr= 0.732540892

Cp at average gas temperature =cpg = 0.26911 btu/lb °F

Q= mg*cpg*ΔT (43)

Q= 10188182.7 Btu/hr

ΔTLMTD=(T1-Ts)-(T2-Ts)/ln((T1-Ts)/(T2-Ts)) (44)

ΔTLMTD = 239.3094095 °F

Q= UAΔTLMTD

A= Q/UΔTLMTD

$A= 2403.450519\ ft^2$

Suspension Pre-heater (SP) Boiler

Evaporator designing

Using carbon steel tubes

Outer dia =do= 2.5 inch

Inner dia =di= 2 inch

Number of tubes wide =Nw = 24

Length of tube =L= 10 ft

$\text{Tube spacing} = 4\ inch^2$

Flow rate of flue gasses=mg = 39.48282 kg/sec = 312703.9344 lb/hr

Temperature of inlet gas to evaporator=T1= 288 °C = 550.4 °F

Temperature of outlet gas from evaporator=T2 = 251 °C= 483.8 °F

Steam pressure= 10.5 bar

Feed water temperature=Tw= 185 °C= 365 °F

Fouling factor on steam and gas side=ffi=ffo = $0.001\ ft^2\ hr\ ^oF/Btu$

Assume heat loss from casing= 1%

Average gas temperature=Tavg= 517.1 °F = 542.65 K = 977.1 R

At pressure of steam = 11 bar

Steam temperature inside tubes= Ts = 457.08 K = 362.744 °F

Tube wall temperature= 370 °F (assume) = 830 R

Film temperature=tf= 443.55 °F

Properties of gas at film temperature

cp= 0.2512 btu/lb °F

μ= 0.06008 lb/ft.hr

k= 0.02101 btu/hr.ft °F

cp at average gas temperature = 0.2648 btu/lb ^{o}F

Duty Q= mcpΔT

Duty Q= 5459599.057 Btu/hr = 11.67 M Btu /hr

Mass velocity =G= 12*mg/NwL (ST-d) ST= 4

Mass velocity =G= 10423.46448 lb/hr ft^{2}

Reynold number =Re=G*d/12 μ

Reynold number =Re= 36144.39248

Nu= 0.229(Re^0.632)

Nu= 173.9872203

Convective heat transfer coefficient= hc = Nu*1 2*(k/d) (45)

hc= 17.5462632 btu/ft^{2} hr ^{o}F

Beam length=L= (1.08*ST*SL-0.785d^2)/d SL= 4 (46)

L= 4.9495 inch= 0.086 m

Partial pressure of tri atomic gasses at Tavg

P_{co2} = 0.0697

PW = 0.0257

P_{so2} = 0.00102

For engineering estimate we add partial pressure of CO_2 and SO_2

Pc = 0.07072

K= ((0.8+1.6*pw)*(1-0.38Tg/1000)*(Pc+Pw))/ ((Pc+Pw)*L) ^0.5

K= 0.890619701

ϵg= 0.9*(1-exp^-Lk)

ϵg= 0.0666

Non luminous heat transfer coefficient = hN = σϵg (Tg^4-To^4)/ (Tg-To) (47)

σ=0.173*10^ (-8) = 1.73E-09

hN = 0.342219774 Btu/ft^{2} hr ^{o}F

Here, Km= 25 Btu/ft.hr ^{o}F

Boiling heat transfer coefficient = 2000 Btu/ft^{2} hr

1/U= 1/ (hN+hc) +ff0+ (ffi*d/di) +d/ (di*hi) +d/ (24*Km) ln d/di (48)

1/U= 0.059706654

U= 16.7485519 Btu/ft^{2} hr ^{o}F

LMTD= ((T1-Ts)-(T2-Ts))/ln (T1-Ts)/ (T2-Ts)

LMTD= 151.9308734 ^{o}F

Q=UAΔT

A=Q/UΔT

A= 2145.544133 ft^{2}

A=∏dNLNd/12 Nd= 13.6658862 (15 rows deep)

A= 2355 ft^{2} (actual area)

Gas density ρ= PM/RT (average. molecular weight of gasses) = 29.81

Gas density ρ= 0.041811295 lb/ft^{3}

f= Re^-0.15*x (49)

x= 0.044+ (0.08*(SL/do)/ (ST/d0-1) ^ (0.43+1.13*d0/SL)

x= 0.272710241

f= 0.056493087

ΔPg= 9.3exp-10*G^2*Nd*f/ρ (50)

ΔPg= 1.86572066 inch^{2}

q=average heat flux on tube inner dia

q=U*(Tavg-Ts)*d0/di (51)

q= 3231.549347 Btu/ft^{2} hr

Temperature drop across fouling layer= q*ffo

Temperature drop across fouling layer
= 3.231549347 ^{o}F

Temperature drop across film coefficient= q/hb

Temperature drop across film coefficient
= 1.615774673 ^{o}F

Temperature drop across tube wall
= 0.0004*di*q/do

Temperature drop across tube wall
= 1.034095791 ^{o}F

Adding all temperature drop= 5.881419811 ^{o}F

Hence, tube outer wall temperature =
Ts+total temperature drop

Hence tube outer wall temperature
= 368.6254198 ^{o}F

This is close to assume value = 370 ^{o}F

Super heater 2 designing

Outer dia =do = 2.5 inch

Inner dia =di = 2 inch

Steam in =W= 10667.448 lb/hr

Outlet temperature of steam =Ts = 285 ^{o}C = 545 ^{o}F

Steam inlet temperature = 182.22 ^{o}C = 359.996 ^{o}F

Average temperature = 452.498 ^{o}F

C @ 160psia and 452.5 ^{o}F = 0.2881

Tube side heat transfer coefficient hi= 2.44*w^0.8*C/di^1.8 (52)

hi= 336.9205648 Btu/ft^{2} hr ^{o}F

Outside gas heat transfer coefficient=h0= hc+hN

Flue gasses =Mg = 312703.9344 lb/hr

Gas inlet temperature =T1 = 315 ^{o}C = 599 ^{o}F

Gas outlet temperature=T2 = 288 ^{o}C= 550.4 ^{o}F

Average gas temperature = 574.7 ^{o}F

Average steam temperature = 452.498 ^{o}F

Number of tube wide =Nw = 20

Length of tube = 12.5 ft

Transverse pitch = 4 inch

Longitudinal pitch= 3.5 inch

Mass velocity =G= 12*mg/NwL(ST-d) ST= 4

Mass velocity =G= 10006.5259 lb/ft^{2} hr

Film temperature= tf= (Average steam temperature +gas inlet temperature) /2 = 525.749 ^{o}F

Apply correction factor (FN for 60°) angle of attack

FN= 0.94

hc= 0.9*G^0.6*f/do^0.4 f= 0.1095

hc= 17.16526923 Btu/ft^{2} hr ^{o}F

hc= 16.13535307 Btu/ft^{2} hr ^{o}F

Because the gas temperature is not high, the hN value will be low. So,

U=h0=hc

h0=hc= 16.13535307 Btu/ft^{2} hr.^{o}F

U= 16.13535307 Btu/ft^{2} hr. ^{o}F

At film temperature

cp= 0.2647 btu/lb ^{o}F

μ= 0.069 lb/ft.hr

k= 0.025 btu/hr,ft ^{o}F

Reynold number =Re=G*d/12 μ

Reynold number = 30212.94052

Nu= hd/12k

Nu= 134.4612756

Pr= μcp/k

pr= 0.730572

Cp at average gas temperature =cpg
= 0.2662 Btu/lb ^{o}F

Q= mg*cpg*ΔT

Q= 4045550.865 Btu/hr

ΔTLMTD= (T1-Ts)-(T2-Ts)/ln ((T1-Ts)/ (T2-Ts))

ΔTLMTD = 108.2430469 ^{o}F

Q= UAΔTLMTD

A= Q/UΔTLMTD

A= 2316.323346 ft^{2}

Condensate pump

Figure 16 shows the condensate pump.

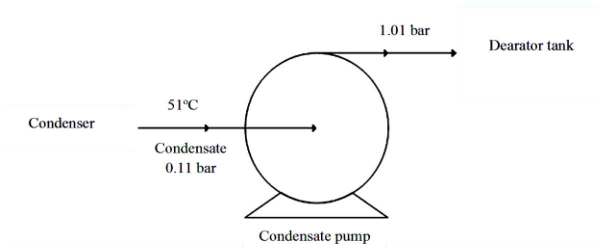

Figure 16: Condensate pump

Δz = 20 ft
Length of pipe = 40 ft
Number of elbows = 6
Number of gate valves = 2
ϵ = 0.00015 (for steel pipe)
Dia of pipe = 1.5 inch = 0.125 ft
Inlet pressure=P1= 0.11 bar = 232.848 psf
Outlet pressure=P2= 1.01 bar = 2137.968 psf
As the temperature of water is constant;
If inlet temperature T1= 51 ^oC
Viscosity of water μ= 0.000403 lb/ft sec
Density of water ρ= 61.65 lb/ft^3
Specific volume=v= 0.0162206 ft^3/lb
Work done by the pump is given by the equation

$W= \Delta z+\Delta v^2/2g +\Delta pv+\sum F$ (53)

Velocity is negligible assuming the fluid is in compressible therefore the equation becomes

$W= \Delta z+\Delta pv+\sum F$ (54)

For total friction

$\sum F$= total friction + friction due to enlargement +friction due to contraction

Mass flow rate (as calculated in material balance):
Mass = 3.995 kg/sec = 3.95505 kg/sec (final)
= 9.571221 lb/sec
Volumetric flow rate Q= mw1/ρ (55)
Volumetric flow rate Q= 0.155250949 ft^3/sec
Velocity =volumetric flow rate /area
V = 12.6493453 ft/sec
Reynold number;
$Re = D*\rho*V/\mu$
Re= 241883.4173 (turbulent flow)
So; α = 1
ϵ/D= 0.0012
From moodys chart:
f= 0.0053
Equivalent length = 25.75 ft
Total friction = $2fv^2(L+Le)/gc* D$ (56)
Total friction = 27.72826192

Friction due to enlargement and contraction = $kc*v^2/2gc + (v1-v2)^2/2gc$ (57)

Taking kc= 0.5
Friction due to enlargement and contraction
= 3.729858032
So,
$\sum F$= 31.45811995
Work done = 82.36030973 $kg \cdot m^2 \cdot s^{-2}$
Power of the pump = $W*Q*\rho/\eta$ (58)
η= 70%
Power= 1126.126752 lb/ft sec = 2.047503185 hp

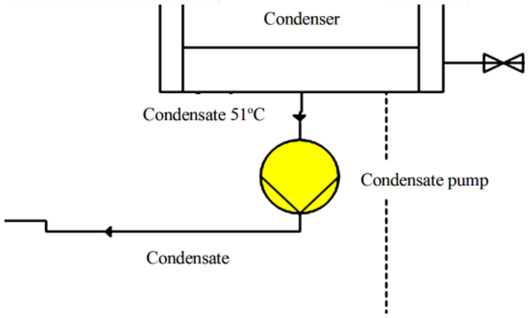

Figure 17: Net positive suction head for condensate

Figure 17 shows the net positive suction head for condensate. NPSHa calculation:
Inlet pipe dia = 0.125 ft
Velocity = 12.6493453 ft/sec
Head Loss = $4flv^2/2gd$ m (59)
Head Loss = 2.108613074 ft = 0.64286984 m
= 13.43031706 Psf
Vapour Pressure @ 36 ^oC = 5.9472 KPa
= 124.2440953 psf
NPSHA = 5.946139848 ft= 1.812847515 m

Condenser Design

Figure 18 show the condenser designing parameters.

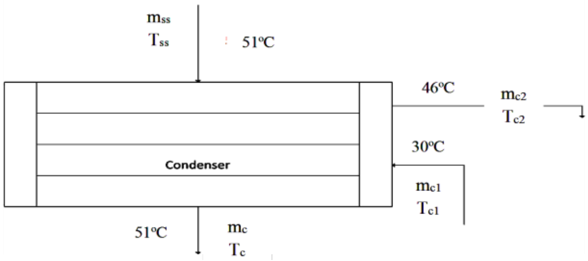

Figure 18: Condenser parameters

Saturated Steam= m s= 14382.00 tons/day
= 13806.72 kg/hr = 30374.78 lb/hr
Temperature; Ts = 51 ^oC =123.8 ^oF
Specific Heat = Cp =1.871 KJ/kg°C
Water (condensate) = 4382.00 tons/day
= 13806.72 kg/hr = 30374.784 lb/hr
Temperature; Ts = 51 ^oC = 123.8 ^oF
Specific Heat = Cp = 4.181 KJ/kg°C
Latent heat of vaporization of steam at 51^{o}C
= 1027.201896 Btu/lb
λ= 2387 KJ/kg
Pressure = 11 kPa
Heat Duty= 9536.1kW
Water vapours= I = 3.995 kg/sec = 14382 kg/hr
= 31640.4 lb/hr
Outer Diameter = 7/8 inch; 18 BWG
Cleanliness factor; Ccl = 85 % = 0.85
Maximum Steam Loading = 8 lb/hr ft^2
Water velocity; v= 7.5 fps
Length of tube; L = 26 ft
Number of passes; n = 2
CL = 1.0(8 Loading)
CT = 1.1 (86 ^oF)
Ct = 263
Overall coefficient (design)
UD =Ccl CT CL Ct (v) ½ (60)
UD = 648.95 Btu/hr.ft^2.^oF

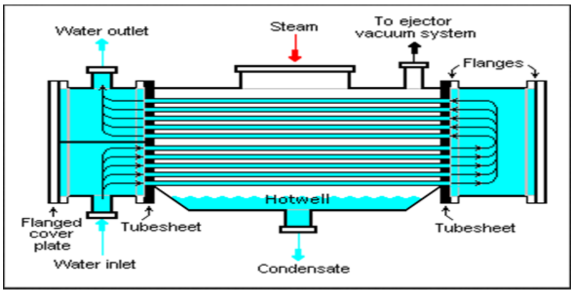

Figure 19: Overall coefficient of condensate

Figure 19 shows the overall coefficient of condensate to cleaning.

Overall coefficient (clean)

$U_c = C_t$ (v) 1/2

$U_c = 720.26$ Btu/hr.ft^2.^{o}F

Area of Condenser:

A =water vapors / steam loading

$A = 3796.848$ ft^2

Outlet water temperature:

T2 = TS - (Ts - t1)/ antilog (0.000279 UD Lna" /v a't) (61)

For 7/8 in O.D and 18 BWG:

a" = 0.229 ft^2/ft

I.D = 0.777 in

a't = 0.475 in^2

T2 = 114.42 °F = 46 °C

Rate of Circulation:

Go = ms λ / (T2 - T1)* 500

Go = 2195.86 gpm

Water out:

m = S8 = 500*Go

m = S8 = 1097929 lb/hr = 498459.6035 kg/hr

Tube side pressure drop:

ΔPt = 0.0067 v 1.84 / d1.16

ΔPt = 0.3658 psi

Number of tubes:

Nt= A/La"

Nt= 638

Turbine designing

Reaction type (impulse-reaction) of 2-stage.

Energy input to the blades = Δh

E= Δh= Kinetic Energy supplied to the fixed blades + Kinetic Energy supplied to the moving blades

E= Δh= Δhf + Δhm

$\Delta hm= (Vr2^2 - Vr1^2)/2$

Vb= Vs1 cosα Let α=20

Inlet pressure of steam=P1= 10 bar
= 1000 kPa =145 psi

Inlet temperature of steam=T1= 338 ^{o}C

At the inlet conditions:

H1= 3334 kJ/kg = 1433.361 Btu/lbm

S1= 7.26 kJ/kg K

Outlet pressure of steam=P2 = 0.11 bar = 11 kPa
= 1.6 psi

Outlet temperature of steam=T2= 51 ^{o}C = 124 ^{o}F

At the outlet conditions:

H2v= 2587 kJ/kg = 1112.2 Btu/lbm

H2L= 199 kJ/kg

S2v= 8.05 kJ/kg K

S2L= 0.716 kJ/kg K

M = 3.99 Kg/sec = 8.778 lb/sec

Xv = 0.89

Δh= 401.713 Btu/lbm

Now;

Δhf= Δhm= 200.8565 Btu/lbm

For fixed side (1st stage):

Vs1= 4486.785713 ft/sec

Vb, opt = Vs1Cosα= 4215.783856 ft/sec

$Vr1= (Vs1^2 - Vb^2)^{1/2}$ = 1535.71238 ft/sec

Here γ= 22

For moving side (1st stage):

For same Vb

Vr2= Vb/Cosγ= 4546.888259 ft/sec

$Vs2= (Vr2^2-Vb^2)^{1/2}$= 1703.3377 ft/sec

For fixed side (2nd stage):

Angle increases and for same Vb,

α2 becomes 24

Vb= Vs3Cosα2

Vs3= Vb/Cosα2= 4614.97959 ft/sec

$Vr3= (Vs3^2-Vb^2)^{1/2}$= 1877.552423 ft/sec

For moving blades (2nd stage):

Angle slightly increases again and for same Vb,

γ2 now is 26

Vr4= Vb/Cosγ2= 4694.63681 ft/sec

$Vs4= (Vr4^2-Vb^2)^{1/2}$= 2027.14 ft/sec

F= (m/gc) (Vs1Cos@ - Vb + Vr2Cosγ) (62)

F = 596.6433468 lbf

W= F*Vb

W = 2515319.389 ft. lbf/sec

W = 3410.315052 Kw= 410315052 Mw

Optimum blade speed

VB,opt = Vs1Cosα= 3365.089285 ft/sec

Which gives maximum work:

$Wmax = (m/gc)*(VB^2)$ (63)

Wmax = 3086973.407 ft. lbf/sec

Wmax = 4013.065429 Kw

Fixed blade efficiency

$Nn = Vr4^2-Vs1^2/ (2gc*\Delta h)$ (64)

Nn = 86.82178649 %

Moving blade efficiency

Nb = W/ (mVs1/2gc) +Δh (65)

Nb = 84.16895 %

Overall Efficiency

N = W/Wmax= 0.849803003

N = 84.98030026 %

4. CONCLUSION

The goal was to diminish misfortunes and create influence by using greatest waste heat energy discharge from a cement plant. It has been effectively accomplished through the usage of a few legitimate industrial equipment to utilize energy from waste gases and by the transformation of this vitality to a helpful structure. From this procedure, it is conceivable to create 2064000 KWh of electric power every month. Power is extremely rare and a standout amongst the most costly utilities in businesses. It is a basic and exceedingly requested by both industrial and private division. In this way, by creating a very significant sum and utilizing it back on the plant may help us in preservation of this amazingly important ware. Moreover, this procedure creates control requiring little to no effort by utilizing hot exhaust gases of the plant. Likewise, when the warmth of pipe gases from various segments of the plant is gained up by the water in the boilers procedure, the exhaust stream is nearly cold. Heat given out is appropriately used as opposed to being squandered into the air and in this manner the WHR plant is ecological well-disposed as well. This procedure on across the nation scale can lessen our capacity lack and have an enormous effect.

ACKNOWLEDGEMENT

The authors would like to acknowledge the Department of Chemical Engineering and Department of Polymer and Petrochemical Engineering, NED University of Engineering & Technology, Karachi, Pakistan for supporting in this research work.

REFERENCES

[1] Sui, X., Zhang, Y., Shao, S. and Zhang, S., "Exergetic life cycle assessment of cement production process with waste heat power generation", *Energy Conversion and Management*, **88** 684-692 (2014).

[2] Ishak, S.A. and Hashim, H., "Low carbon measures for cement plant – a review", *Journal of Cleaner Production*, **103** 260-274 (2015).

[3] Li, C., Nie, Z., Cui, S., Gong, X., Wang, Z. and Meng, X., "The life cycle inventory study of cement manufacture in China", *Journal of Cleaner Production*, **72** 204-211 (2014).

[4] Atmaca, A. and Yumrutaş, R., "Thermodynamic and exergoeconomic analysis of a cement plant: Part II – Application", *Energy Conversion and Management*, **79** 799-808 (2014).

[5] Atmaca, A. and Yumrutaş, R., "Analysis of the parameters affecting energy consumption of a rotary kiln in cement industry", *Applied Thermal Engineering*, **66** (1-2): 435-444 (2014).

[6] Atmaca, A. and Yumrutaş, R., "Thermodynamic and exergoeconomic analysis of a cement plant: Part I – Methodology", *Energy Conversion and Management*, **79** 790-798 (2014).

[7] Summerbell, D.L., Barlow, C.Y. and Cullen, J.M., "Potential reduction of carbon emissions by performance improvement: A cement industry case study", *Journal of Cleaner Production*, **135** (1): 1327-1339 (2016).

[8] Broberg Viklund, S. and Johansson, M.T., "Technologies for utilization of industrial excess heat: Potentials for energy recovery and CO2 emission reduction", *Energy Conversion and Management*, **77** 369-379 (2014).

[9] Lombardi, L., Carnevale, E. and Corti, A., "A review of technologies and performances of thermal treatment systems for energy recovery from waste", *Waste Manag*, **37** 26-44 (2015).

[10] Brückner, S., Liu, S., Miró, L., Radspieler, M., Cabeza, L.F. and Lävemann, E., "Industrial waste heat recovery technologies: An economic analysis of heat transformation technologies", *Applied Energy*, **151** 157-167 (2015).

[11] Oluleye, G., Jobson, M., Smith, R. and Perry, S.J., "Evaluating the potential of process sites for waste heat recovery", *Applied Energy*, **161** 627-646 (2016).

[12] Fergani, Z., Touil, D. and Morosuk, T., "Multi-criteria exergy based optimization of an Organic Rankine Cycle for waste heat recovery in the cement industry", *Energy Conversion and Management*, **112** 81-90 (2016).

[13] Salas, D.A., Ramirez, A.D., Rodríguez, C.R., Petroche, D.M., Boero, A.J. and Duque-Rivera, J., "Environmental impacts, life cycle assessment and potential improvement measures for cement production: a literature review", *Journal of Cleaner Production*, **113** 114-122 (2016).

[14] Astrup, T.F., Tonini, D., Turconi, R. and Boldrin, A., "Life cycle assessment of thermal waste-to-energy technologies: review and recommendations", *Waste Manag*, **37** 104-115 (2015).

[15] Gao, T., Shen, L., Shen, M., Liu, L. and Chen, F., "Analysis of material flow and consumption in cement production process", *Journal of Cleaner Production*, **112** 553-565 (2016).

[16] Lu, H., Price, L. and Zhang, Q., "Capturing the invisible resource: Analysis of waste heat potential in Chinese industry", *Applied Energy*, **161** 497-511 (2016).

[17] Le, V.L., Kheiri, A., Feidt, M. and Pelloux-Prayer, S., "Thermodynamic and economic optimizations of a waste heat to power plant driven by a subcritical ORC (Organic Rankine Cycle) using pure or zeotropic working fluid", *Energy*, **78** 622-638 (2014).

[18] Matsuda, K., "Low heat power generation system", *Applied Thermal Engineering*, **70** (2): 1056-1061 (2014).

[19] Jung, H.C., Krumdieck, S. and Vranjes, T., "Feasibility assessment of refinery waste heat-to-power conversion using an organic Rankine cycle", *Energy Conversion and Management*, **77** 396-407 (2014).

[20] Singh, D.V. and Pedersen, E., "A review of waste heat recovery technologies for maritime applications", *Energy Conversion and Management*, **111** 315-328 (2016).

[21] Khaled, M., Ramadan, M., Chahine, K. and Assi, A., "Prototype implementation and experimental analysis of water heating using recovered waste heat of chimneys", *Case Studies in Thermal Engineering*, **5** 127-133 (2015).

[22] Rahman, A., Rasul, M.G., Khan, M.M.K. and Sharma, S., "Recent development on the uses of alternative fuels in cement manufacturing process", *Fuel*, **145** 84-99 (2015).

[23] Miró, L., Gasia, J. and Cabeza, L.F., "Thermal energy storage (TES) for industrial waste heat (IWH) recovery: A review", *Applied Energy*, **179** 284-301 (2016).

[24] Haddad, C., Périlhon, C., Danlos, A., François, M.-X. and Descombes, G., "Some Efficient Solutions to Recover Low and Medium Waste Heat: Competitiveness of the Thermoacoustic Technology", *Energy Procedia*, **50** 1056-1069 (2014).