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Parametric analysis of steam flashing in a power plant using waste heat of cement factory.

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Abstract

Currently India is producing 350 million tons of cement and so there is a more potential to generate the power through waste heat recovery. A case study has been conducted at a cement factory, Telangana, India with cogeneration plant having flashing technology. The high pressure water is flashed into wet steam at two pressure levels (high pressure flashing and low pressure flashing) to increase the power generation. The hot water from the flashing chamber is used for the regeneration of the cycle and the steam is supplied to the turbine at the relevant location. In the current work, the optimum values for the high pressure flashing and the lower pressure flashing are searched and developed for the maximum heat recovery and also higher output from cogeneration plant. The identified key operational parameters are steam generating pressure, limit to high pressure flashing, limit to low pressure flashing and flash mass ratio.

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Keywords: *Cogeneration, steam flash, heat recovery, thermodynamics*

1. Introduction

India has a great potential in cogeneration field to meet the increasing demand of power. Cogeneration is a thermo dynamically efficient use of fuel. In separate production of electricity, some energy must be discarded as waste heat, but in cogeneration this thermal energy is put in use. Cogeneration currently accounts for around 9 % of global power generation. Karellas et al., [1] compared energetically and exergetically two different WHR methods: a water steam-Rankine cycle and an organic Rankine cycle (ORC).A parametric study proved that the water steam technology is more efficient than ORC in exhaust gases temperature higher than 310^0C.Madlool et al., [2] conducted

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exergy analysis for cement industries. The exergy losses due to irreversibility from kiln are higher than other units in cement production plant. Saneipoor et al., [3] examined the performance of a new Maronch Heat Engine (MHE) Compressed air the working fluid is installed to recover the waste heat. Ankur Kapil et al., [4] conducted a case study on energy consumptions for the site and a new cogeneration targeting method and benefits of optimizing steam levels for reducing the overall energy consumption has been proposed.

Liu et al., [5] proposed that the thermal efficiency of the raw material preheating and decomposition process unit has the greatest impact on the thermal efficiency of the whole process, followed by the clinker cooling and clinker calcination process. Adem atmaca and Recep yumrutas [6]. A detailed analysis has been carried out which includes the thermodynamic and exergo economic methodology on a cement plant and formulations developed. Emad Benhelal et al., [7] proposed a new pyro processing unit in a cement factory. Decomposition reactions have been separated from other reactions which results in pure carbon dioxide production. Tahsin engine and vedat ari [8] conducted an energy audit on cement production. It is mentioned that the average specific energy consumption is about 2.95Gj per ton of cement produced for well-equipped advanced kilns. Shaleen khurana et al., [9] selected a steam cycle to recover the heat from the streams using a waste heat recovery system generator and it is estimated that about 4.4Mw of electricity can be generated. It is 30% of the electricity requirement of the plant. Pradeep Varma and Srinivas [10] proposed a low steam pressure for power generation at 176 °C, 330 °C and 420 °C heat recovery gas temperature.

Tianhong pan et al., [11] proposed a statistical model to optimize the six fans subjected to different climatic conditions are also incorporated. Jiangfeng wang et al., [12] carried out exergy analysis on single flash steam cycle, dual pressure steam cycle, Organic Rankine Cycle and Kalina cycle in a cement plant subjected to same operational conditions. Compared with other cogeneration systems in cement plant, the Kalina cycle can achieve the best performance from the view point of exergy efficiency, and the ORC shows the lowest exergy efficiency under the same condition. The literature review shows that there no much work done on steam flashing technology in the power generation using waste heat recovery. Therefore the current work is focused on the finding the best operational conditions for the high pressure flashing and low pressure flashing in a cogeneration plant applied to a cement factory.

Nomenclature

h	enthalpy(kJ/kg)	M_g	mass of gas
m	mass flow rate (kg/s)	M_s	mass of steam
p	pressure(bar)	m_{gaqc}	mass of gas in AQC boiler(Nm^3/hr)
t	temperature (^0C)	m_{gph}	mass of gas in PH boiller (Nm^3/hr)
T	temperature (K)		
W	work done		
Q	heat supplied		
SH	super heater		
EVA	evaporator		
ECO	economiser		
HPF	high pressure flasher		
LPF	low pressure flasher		
ESP	electro static precipitator		
MW	molecular weight		

Subscripts

AQC	Air Quenched Cooler boiler
PH	Pre Heater boiler

2. Methodology

The following are the assumptions made in the cogeneration plant for thermodynamic evaluation.

- The isentropic efficiency for turbine and pump is taken as 85% and 75% respectively
- The pinch point (pp) temperature is taken as 20°C.
- The terminal temperature difference (ttd) is taken as 25°C.
- The specific heat of flue gas is considered as c_p=1.03kJ/kg k
- The molecular weight (MW) of the flue gases is considered as 29
- The saturation temperature of high pressure is taken as 200.492°C
- The saturation temperature of condenser pressure is taken as 45.81°C
- The mass ratio for flashing (mrf) is considered as 0.25
- The volume of gas available in the PH boiler is 360750 Nm^3/hr
- The volume of gas available in the AQC boiler is 191600 Nm^3/hr

Waste heat recoveries cement plant whose capacity is 4000 TPD has been selected for case study which is located in Telagana, India. The schematic flow diagram of the plant is shown in figure 1. The working fluid passed through feed pump is sent into air quenched cooler (AQC) boiler and preheated (PH) boiler. The mass, m_{11} is saturated water, supplied to AQC (12), PH (16) boiler and high pressure flusher (HPF) (19). The saturated water to AQC is vaporized (13) and superheated (14) in later stages. The saturated water (16) is evaporated (17) and superheated (18) in PH boiler. The saturated water (19) after flashing enters to HPF where the steam and water are separated. High pressure flashed steam (21) is supplied to the flash steam turbine at appropriate place. The saturated water (20) is passed through a flashing valve enters into the low pressure flusher (LPF) where water is flashed again. The flashed steam (24) is supplied to flash steam turbine. The two streams of superheated vapour from AQC boiler and PH boiler are mixed and expanded through turbine to generate power. The rest of the preheated working fluid is separated into saturated vapour and saturated water. The saturated vapour from two flash chambers is supplied to turbine to generate more power. The turbine exhaust is condensed in the condenser, and passes through condensing pump to be mixed with saturated water from the low pressure flasher.

The mass and energy balance formulae are developed from the schematic and temperature-entropy diagram.
Drawings:

- Schematic flow diagram of cogeneration plant in a cement factory.
- Temperature-entropy diagram of cogeneration cycle.
- Heat recovery plot between hot fluid and cold fluid in (a) PH boiler and (b) AQC boiler Drawings.

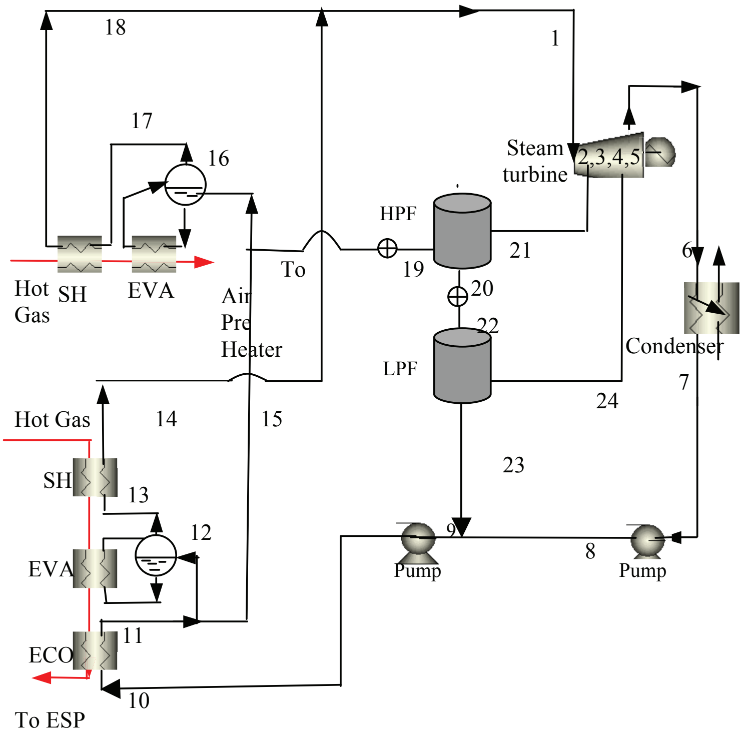

Fig.1. Schematic flow diagram of cogeneration plant in a cement factory

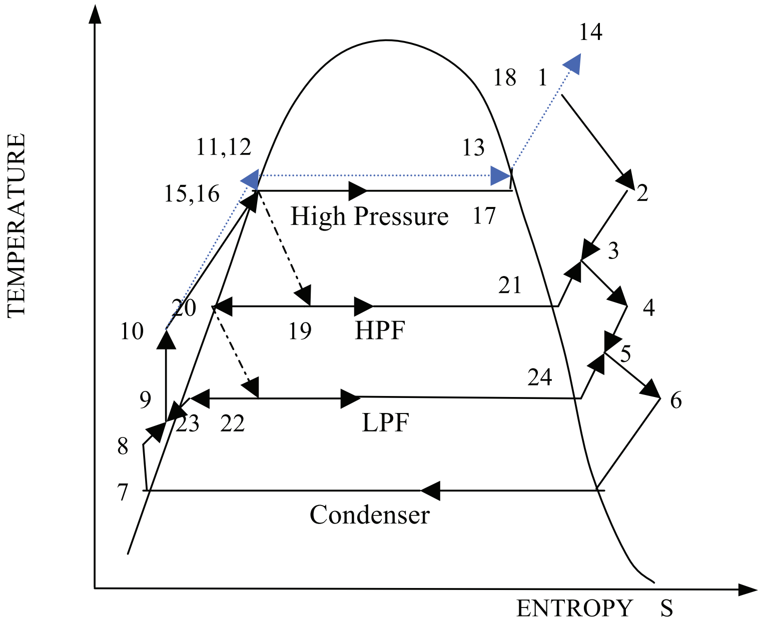

Fig.2. Temperature-entropy diagram of cogeneration cycle

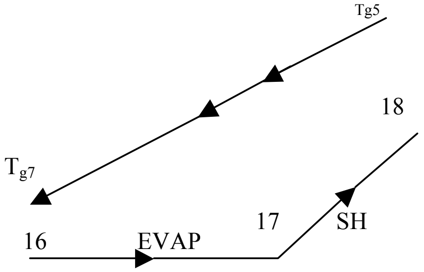

Fig.3(a) Pre heater Boiler

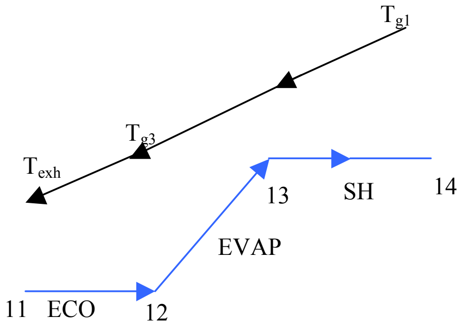

Fig.3(b) Air Quenched Cooler Boiler

2.1 Thermodynamic mass and energy balance formulae

Mass balance

$$M_{gaqc}=\left(\frac{m_{gaqc}\times MW}{22.4\times 3600}\right) \tag{1}$$

$$M_{gph}=\left(\frac{m_{gph}\times MW}{22.4\times 3600}\right) \tag{2}$$

$$M_{sph}=\frac{\left(M_{gph}\times c_{pg}\times(T_{g5}-T_{g7}\right)}{h_{18}-h_{16}} \tag{3}$$

$$M_{s\ aqc}=\frac{\left(M_{gaqc}\times c_{pg}\times(T_{g3}-T_{g5}\right)}{h_{14}-h_{12}} \tag{4}$$

$$m_1=M_{sph}+M_{saqc} \tag{5}$$

$$m_3=m_2+m_{21} \tag{6}$$

$$m_5=m_4+m_{24} \tag{7}$$

$$m_9=m_8+m_{23}$$

$$m_{19}=m_{10}\times mrf \tag{8}$$

Energy balance

$$Q_{\sup ply}=m_{10}\times\left(h_1-h_{10}\right) \tag{9}$$

The net power from the cogeneration plant

$$W_{net}=W_t-W_p=m_1\left(h_1-h_2\right)+m_3\left(h_3-h_4\right)+m_5\left(h_5-h_6\right)-m_7\left(h_8-h_7\right)-m_9\left(h_{10}-h_9\right) \tag{10}$$

The cycle thermal efficiency $\eta_1=\left(\frac{W_{net}}{Q_{\sup ply}}\right)\times 100$ (11)

3. Results and Discussions

To identify the efficient operational conditions, performance characteristics of existing cogeneration plant have been plotted. Fig.4 shows that the maximum power is resulted at 0.5 temperature ratio for both low pressure flasher (LPF) and high pressure flasher (HPF). The power output is gradually decreasing down as the LPF ratio and HPF ratio is increased. The amount of flashed steam depends on the pressure before the flash tank and final pressure in the flashing tank. The lower the pressure in the flashing tank the higher is the amount of steam , but on the other side, low pressure steam generates less power [12].

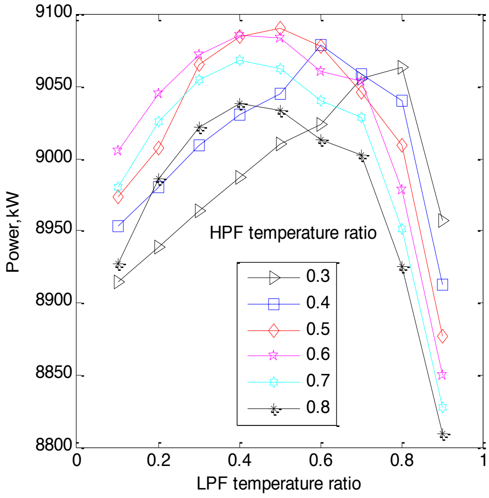

Fig. 4 Effect of LPF and HPF temperature ratios on plant power

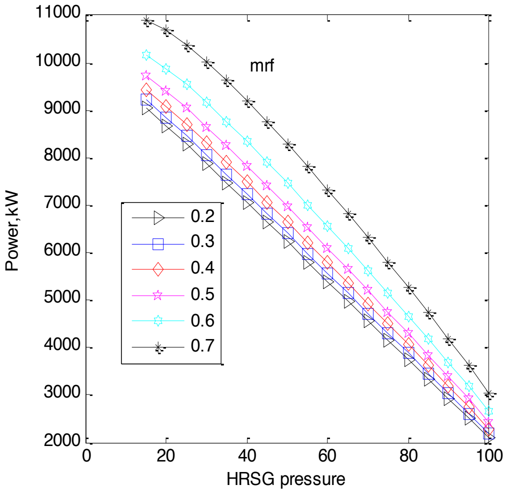

Fig.5 Power output for different HRSG pressure with variation of mrf

Fig.5 shows that the power decreases with increase in HRSG pressure due to drop in heat recovery. If the flashed amount is increased, there will be a more chance of increasing the steam turbine working fluid. Obviously it augments the power from the steam turbine. But the saturated water that is being supplied from AQC boiler to the PH boiler is reduced so it is not possible to use the pre heater gases effectively. The steam from AQC and PH is in superheated condition being mixed before it enters into the turbine so that superheated steam is supplied to the turbine inlet. Saturation temperature of the steam increases with HRSG pressure and steam generation decreases and so low power. From the figure it can depict that the power output is optimum at mrf of 0.2 to 0.3. The recommended HRSG pressure is from 15 to 16 bar.

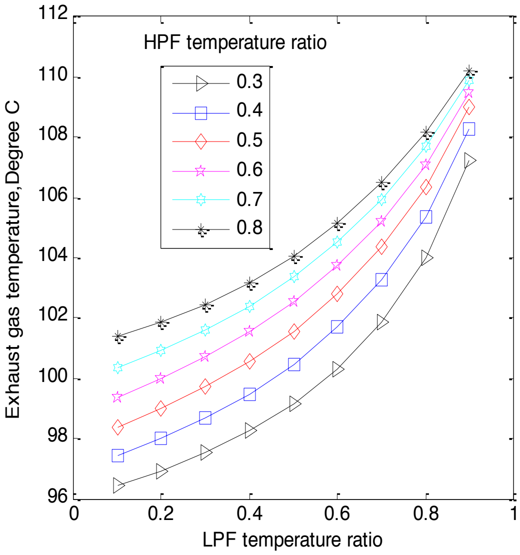

Fig .6 Variation of exhaust gas temperature with LPF temperature ratio and HPF temperature ratio.

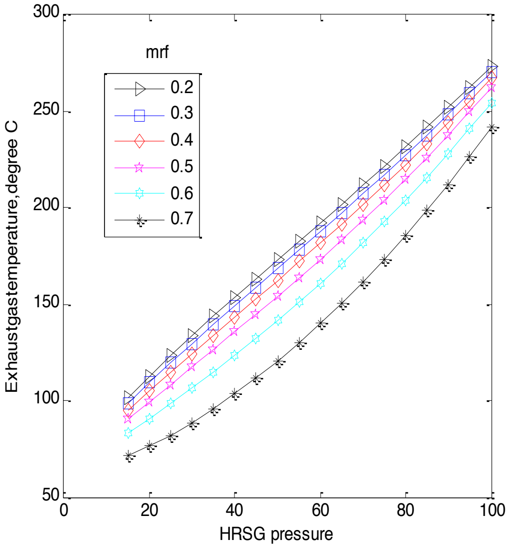

Fig. 7 Parametric analysis of HRSG pressure with exhaust gas temperature

Fig.6 shows the influence of LPF temperature ratio and HPF temperature ratio on exhaust gas temperature from AQC boiler. AQC boiler exhaust temperature is reduced with increase in heat recovery load in PH boiler. From figure the LPF temperature ratio at 0.9 the exhaust gas temperature varying from 106^0C to 110^0C at 0.1 LPF temperature ratio the exhaust gas temperature is varying from 96^0C to 101^0C .At 0.5 HPF and LPF temperature ratio the exhaust gas temperature can be predicted as 101^0C

Fig. 7 shows the role of flash mass ratio with HRSG pressure on exhaust gas temperature. The optimum pressure is around 15 to 17 bar. The mass ratio flash (mrf) value is in between 0.2 to 0.3. The exhaust gas temperature is varying from 100 to 110^0C. So from the graph an inference can be drawn that the HRSG pressure should not exceed 15 to 16 bar with an mrf value of 0.2 to 0.3. For higher mrf values the exhaust gas temperature is very low, so the gas will accumulate in the stack. For higher HRSG pressure the exhaust gas temperature is very high and it is more than the gas temperature of the preheater (PH) exit so it is not possible to use the waste gases that are coming out of the pre heater. The cogeneration plant in one particular application, the gases with 360^0C, can be cooled down to 90^0C where as gases with 340^0C can be cooled down to 230^0C. The pre heater exhaust gas 230^0C is used in the cement plant for drying raw materials, which limits its available heat for power generation .The critical parameters such as steam flow rate and superheat gas outlet temperature are to be optimized for each plant in order to achieve maximum power generation

Table 1 Material flow details from mass and energy balance equations

State	P, bar	t, ^{0}C	m, kg/s	h, kJ/kg
1	15.70	322.52	11.58	3087.13
2	4.61	192.90	11.58	2842
3	4.61	191.34	12.00	2838.6
4	0.92	97.27	12.00	2593.4
5	0.92	97.27	12.33	2595.4
6	0.10	45.91	12.33	2324.7
7	0.10	45.91	12.33	192.5
8	0.92	46.18	12.33	192.69
9	0.92	48.82	15.43	235.70
10	15.70	49.19	15.43	237.80
11	15.70	200.65	15.43	855.9
12	15.70	200.65	4.38	855.9
13	15.70	200.65	4.38	2794.3
14	15.70	335.00	4.38	3114.58
15	15.70	200.65	11.57	855.87
16	15.70	200.65	7.20	855.87
17	15.70	200.65	7.20	2794.3
18	15.70	315.00	7.20	3070.5
19	4.61	148.93	3.86	855.9
20	4.61	148.93	3.44	627.0
21	4.61	148.93	0.42	2744.8
22	0.92	97.37	3.44	627
23	0.92	97.37	3.11	407.2
24	0.92	97.27	0.33	2669.7

Table 1 lists the properties of data of plant shown in Figure 1.evaluated from mass and energy balance formulation. The optimized HP flasher pressure and LP flasher pressure are respectively 4.61 bar and 0.92 bar at 0.5 temperature ratios for both flashers.

Table 2.The performance of double flash cycle

Turbine work(kW)	9119.2
Pump work(kW)	33.03
AQC boiler exhaust temperature (^{0}C)	86.24
Heat input(kW)	43969
Net power output(kW)	9086.2
Thermal efficiency (%)	20.66

Table 2 indicates that efficiency of the plant is low but in case of heat recovery plants efficiency is not the criteria power to be improved by maximizing the heat recovery .The tabulated results are the plant specifications developed at the optimized operation conditions using first law of thermodynamics.

4. Conclusions

A cement factory cogeneration plant, the conventional steam power plant has been replaced by a double flash steam power plant. The results are focused to search the best condition for HRSG pressure, HP flasher, LP flasher and flashing amount. There is a relation between flash mass and exhaust gas temperature. An optimum flash mass ratio can be selected at a minimum flue gas temperature. The current work suggests 0.5 temperature ratio for both HP flasher and LP flasher. The suggested flash mass ratio is 0.25 to result approximately 90^{o}C of exhaust gas temperature at AQC. On overall basis double flashed system proves over conventional plant by increasing heat recovery and so power output.

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