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Research Paper :

Design and development of producer gas operated heat exchanger

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ABSTRACT

Hot water is used in many industries where the hot water is used as a working fluid such as yarn bleaching, jetropa boiling, small agro processing industries, dairy industries and for community cooking purpose etc. Looking to this heat exchanger, operated on wood fired natural draft gasifier was designed and developed for hot water generation at the Department of Renewable Energy sources, College of Technology and Engineering, Udaipur. The system was designed to produce 180 litre of hot water per batch for thermal application. The temperature of water reached from 27 to 97.9^{0}C within a period of 80 minute. The exhaust temperature ranged from 81.7 to 113^{0}C. The flame temperature was measured between 312 to 532^{0}C. The average efficiency of the heat exchanger system worked out to around 25.65 per cent for single trial in a day and 35.56 per cent for four batches in a day. The design of heat exchanger and system description are presented in this paper. In the economic consideration, benefit cost ratio, pay back period were found as 1.92 and 7.5 months, respectively.

Key words : Natural draft gasifier, Heat exchanger, Thermal application

Energy is a key input for technological, industrial, social and economical development of a nation. However, a large number of consumers in domestic, agricultural, commercial and industrial sectors are faced with a situation of energy availability that is characterized by inadequate quantity, poor quality, un-affordability, un-sustainability and negative environmental consequences. The challenge for the country is ensuring affordable- clean energy for all in a sustainable manner.

Rapid industrialization in India has resulted in an ever-increasing demand for process heat and steam. Most of these industries are in the metallurgical and food processing sectors and have to use petro-fuels like furnace oil, light diesel oil (LDO) or diesel to meet their energy demands. However, due to uncertain supplies and high cost of these fuels, there is an urgent need for other sources of energy.

A heat exchanger is a device that is used to transfer heat between two or more fluids that are at different temperatures. Heat exchanger is an essential element in a wide range of system. The most commonly used type of heat exchanger is the shell and tube type heat exchanger applicable for a wide range of operating temperatures and pressures. One fluid flows through the tubes and second fluid flows within the space between the tubes.

The shell and tube type heat exchanger was designed for hot water generation. Hot water is used as a working fluid in many industries for different processes such as yarn bleaching, jetropa boiling, rose boiling, etc. and for small scale industries like agro processing industries, dairy industries. It can be used in hostels, hospital and big hotels, institutions and for community cooking etc.

METHODOLOGY

The designed heat exchanger was fabricated at workshop and tested in the month of June-July 2007 at the Department of Renewable Energy Sources, College of Technology and Engineering, Udaipur. The location of the area is 24^0 38' N – latitude, 73^0 44' E – longitude and at an altitude of 582.5 m above mean sea level.

Design of heat exchanger system for hot water generation:

The heat exchanger was designed for hot water generation. This heat exchanger operated on natural draft gasifier.

The system was designed to generate hot water with following assumptions:

Design data:

- Operating pressure (P) = 1 atmospheric
- Temperature gradient (Δt) = 70^{0}C
- Specific heat of water (C_p) = 1 kcal kg^{-1} ^{0}C^{-1}
- Capacity of water = 180 litre per batch

The heat exchanger designed for 180 litre of hot water.

Dimensions of hot water generator:

The inner diameter of the shell is kept twice of gasifier burner which accumulates secondary air for complete combustion of producer gas. The diameter of the gasifier burner is 375 mm.

d_i = inside diameter of shell, 750 mm

For efficient utilization of heat produced by producer gas, the water contact area to be increased. To achieve this, number of tubes holding water were placed across the shell.

The inner diameter of the tube = 40 mm

No. of tubes (n) = 24

Quantity of water inside the tubes calculated by using following formula :

$$\mathbf{V = \pi \times r^2 \times h}$$

$$= \pi \times \left(\frac{d}{2}\right)^2 \times h$$

$$= \pi \times \frac{d^2}{4} \times h$$

The height h, here has been taken as length of tubes.

Quantity of water inside the tubes, V_1 = 19.82 lit ~ 20 lit.

For remaining capacity of water, spacing between inner and outer shell is 80 mm to get hot water with in minimum time.

d_o = outer diameter of shell, 910 mm

Volume of water, V_2 = 160 lit = 0.16 m^3

V_2 = A x h

$$= \frac{\pi}{4} \times \left(d_o^2 - d_i^2\right) \times h$$

$$0.16 = \frac{3.14}{4} \times \left(0.91^2 - 0.75^2\right) \times h$$

Height of inner cylinder, h = 767 mm

The total height of system was kept more than that of actual water holding column. Further provision was made to store dry and saturated steam in the system.

Hence, the total water holding capacity, V = V_1 + V_2

= 20 + 160

Total quantity of water inside heat exchanger = 180 lit.

The diameter of exhaust chimney was kept one-third as the diameter of outer shell of heat exchanger.

Diameter of chimney = 30.33 ≈ 30 cm ≈ 300 mm.

(ii) Heat required to generate hot water with temperature gradient 70^0 C is:

Q_r = m x C_p x Δt

= 180 x 1 x (97-20)

= 12600 kcal h^{-1}.

Δt = $t_2 - t_1$

= final temperature hot water– initial temperature of cold water (27 ^{0}C)

(iii)Heat exchanger efficiency of the system is calculated as follows:

$$\eta = \frac{M_w \times Cp_w \times T_w}{FCR \times CV \times T}$$

where,

η = Heat exchanger efficiency, %

M_w = Mass of the hot water generated, kg

Cp_w= Specific heat of the water, kcal kg^{-1} $^0C^{-1}$

T_w = Change in temperature of water, ^{0}C

FCR = Feed stock consumption rate, kg

CV = Calorific value of fuel, kcal kg^{-1}

T = Time of operation, h

All dimensions of heat exchanger are shown in Table 1.

Table 1 : Detailed specification, dimensions and material employed for heat exchanger

Sr. No.	Heat exchanger component	Material specification	Dimensions	Material used
1.	Outer shell	3.0 mm thick	Diameter = 910 mm Height = 1200 mm	MS sheet
2.	Inner shell	4.0 mm thick	Diameter = 750 mm Height = 900 mm	MS sheet
3.	Tubes	3.0 mm thick	Inner diameter = 40 mm No. of tubes = 24	MS pipe
4.	Water level indicator	2.5 mm thick	Height = 600 mm Thickness = 2.5 mm	Glass
5.	Chimney	3.0 mm thick	Diameter = 300 mm Height = 300 mm	MS sheet
6.	Half turn valve	----------	Diameter = 30 mm × 1 Nos.	----------

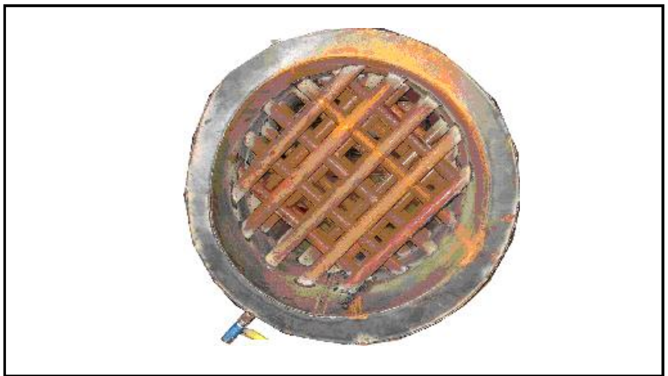

Fig. 1: Assembly of tubes in heat exchanger

RESULTS AND DISCUSSION

Heat exchanger was run continuously for four batches in a day to find out the efficiency of heat exchanger. The efficiency of heat exchanger for four batches went on increasing from 25.53 to 41.26% due to continuous working as well as regular contact of water with heated surface of heat exchanger. It was observed that the hot water temperature increased gradually with time of regular interval of 10 min till 80 min. After that temperature of hot water rise negligible as time increases. For I batch hot water temperature was in the range of 27 to 96.8^{0}C for 80 min. For II, III and IV batch the temperature of hot water reached at 60, 50, 50 minutes, respectively.

Batch I

¦ = $\frac{180 \times 1 \times (96.8-27)}{10 \times 3700 \times 1.33}$

= 25.53 %

Batch II

¦ = $\frac{180 \times 1 \times (97.0-27)}{10 \times 3700 \times 1}$

= 34.05 %

Batch III

¦ = $\frac{180 \times 1 \times (97.7-27)}{10 \times 3700 \times 0.83}$

= 41.43 %

Batch IV

¦ = $\frac{180 \times 1 \times (97.4-27)}{10 \times 3700 \times 0.83}$

= 41.26 %

Average efficiency for four batches in a day = 25.53 + 34.05 + 41.43 + 41.26

= 35.56 %.

Temperature of hot water with time and exhaust temperature with time for four batches as shown in Fig. 3 and 4.

Fig. 2 : Gasifier with heat exchanger system

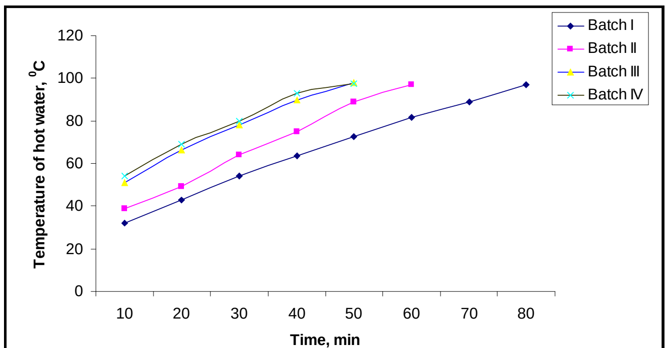

Fig. 3 : Variation of temperature of hot water for four batches in a day

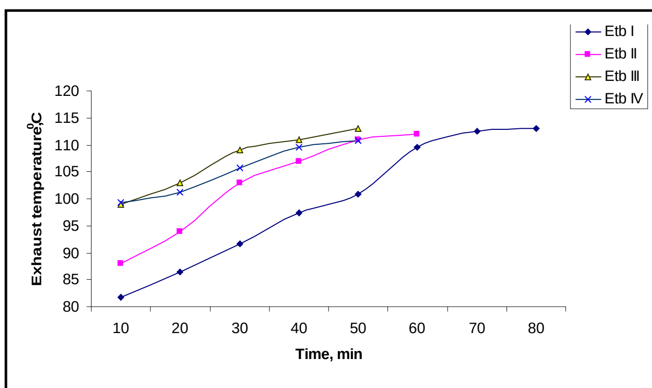

Fig. 4 : Variation of exhaust temperature for four batches in a day

Table 2 : Cash flow (Rs.) for hot water generation (compared with electricity)

Year	Cash outflow	PW of Cash outflow	Cash inflow	PW of cash inflow	NPW
1	2	3	4	5	(5)-(3)
0	87527	-87527			-87527
1	57000	51818.20	102450	93136.36	41318.20
2	57000	47107.40	102450	84669.40	37562.00
3	57000	42824.90	102450	76972.20	34147.30
4	57000	38931.80	102450	69974.70	31043.00
5	57000	35392.50	102450	63613.40	28220.90
6	57000	32175.00	102450	57830.40	25655.30
7	57000	29250.00	102450	52573.00	23323.00
8	57000	26590.90	102450	47793.70	21202.80
9	57000	24173.60	102450	43448.80	19275.20
10	0	0	102450	39498.90	39498.90
Total		328264.40		629510.90	301246.50

Table 3 : Economic indicator for hot water generation

Sr. No.	Economic indicator	Value
1.	Net present worth, Rs.	301246.5
2.	B/C ratio	1.92
3.	Pay back period, months	7.5

The system was compared with the conventional method of hot water *i.e.* electricity. The cash flow (Rs.) for hot water is presented in Table 2, while the various economic indicators are presented in Table 3.

– The time required to boil the water from 27 to 97.9 ^{0}C was 80 minute for single batch in a day.

– When four batches were taken the time required to boil the water was 80 minute for I batch. Subsequently for II, III and IV batch the temperature of hot water reached in 60, 50 and 50 minutes, respectively (Fig. 3).

– The amount of fuel required for the experimentation for I, II, III and IV batch was in a reducing trend of 13, 10, 8 and 8 kg, respectively.

– The average efficiency of heat exchanger was 25.65 per cent for single batch per day.

– When four batches per day were taken the efficiency of heat exchanger came out to be 25.53, 34.05, 41.43 and 41.26 per cent, respectively

– The benefit cost ratio and pay back period for natural draft gasifier with heat exchanger system when compared with electricity were found as 1.92 and 7.5 months, respectively (Table 3).

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