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Research Paper :

Performance and evaluation of heat exchanger for hot water generation

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ABSTRACT

A wood based batch type heat exchanger based on natural draft gasifier system has been developed at College of Technology and Engineering (CTAE), Udaipur (Rajasthan). The system was designed to produce 180 litre of hot water per batch for thermal application. 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 performance of the system was evaluated in terms of heat exchanger efficiency, benefit cost ratio and pay back period.

Key words : Heat exchanger, Hot water generation, Benefit cost ratio, Pay back period.

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.

Biomass gasification is the process in which solid biomass materials are converted by a series of thermo chemical reactions, to a combustible gas called producer gas, liquids (tar and oils) and solid (char and ash). The reactions are carried out in the reactor called as gasifier.

Biomass based natural draft gasifier system can be used for various purposes *viz.*, institutional cooking, hot water generation, steam generation for process in a variety of traditional industries in the developing country and other thermal applications such as par-boiling, pottery making etc.

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 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.

The system design consists of a natural draft gasifier, shell and tube type flue gas water heat exchanger as major components.

The study was attempted with the following objectives to design and develop producer gas operated heat exchanger, to test and evaluate the performance of the developed system and to assess techno-economical feasibility of the developed system.

METHODOLOGY

The system was designed to generate hot water with following design consideration:

Design data

- Operating pressure (P) = 1 bar
- Temperature gradient (Δt) = 70 ^{0}C
- Specific heat of water (C_p) = 1 kcal kg^{-1} $^0C^{-1}$
- Heat exchanger efficiency = 40 %
- Capacity of water = 180 litre per batch

Gasifier data:

- Heat produced by gasifier (Rated) = 20000 kcal h^{-1}
- Specific gasification rate = 150 kg h^{-1}-m^{-2}
- Calorific value of producer gas = 1100 kcal m^{-3} or 4.6 MJ m^{-3}
- Gas output from wood chip = 2.2 m^3 kg^{-1}

Calculated data

- Gasifier efficiency = 70.36 per cent

The gasifier is available to supply the heat 20000 kcal h^{-1}, but by calculating gasifier efficiency actual heat available is (Q_h)= 20000 x 0.70 = 14000 kcal h^{-1}

The 14000 kcal h^{-1} heat is available, therefore the quantity of hot water generated with temperature gradient 70 ^{0}C.

Q = m x C_p x Δt

14000 = m x 1 x (97-27) m = 200 lit.

Dimensions of heat exchanger for hot water generation:

The inner diameter of the shell was 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 was to be increased, in this connection number of tubes which hold water inside it, were placed across the shell.

The inner diameter of the tube = 40 mm

No. of tubes (n) = 24

The 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 minimum time and it can be used for continuous operation.

d_o = outside diameter of shell, 910 mm

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

$V_2 = A \times h$

$$= \frac{\pi}{4} \times [d_o^2 - d_i^2] \times h$$

$$0.16 = \frac{3.14}{4} \times [0.91^2 - 0.75^2] \times h$$

h = 0.767 m

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) Hence heat required to generate hot water with temperature gradient 70 ^{0}C is

$Q_r = m \times C_p \times \Delta t$

= 180 x 1 x (97-27)

= 12600 kcal h^{-1}.

The detailed specification, dimensions and material of heat exchanger are shown in Table 1 and the diagram of heat exchanger with natural draft gasifier as shown in Fig.1.

Performance of heat exchanger with natural draft gasifier:

The performance of the system has been tested with woodchips. Parameters related to the gasifier namely the feed stock consumption rate; the temperature inside the reactor at predetermined locations and other operating difficulties were recorded. For the producer gas, temperature of the gas and temperature of flame produced were recorded with respect to time from beginning of experiment to the completion. The time required to produce the producer gas was also recorded. The feed material is characterized in terms of physical and chemical properties, which included physical properties (size fraction of wood, moisture content) and chemical properties (proximate analysis, volatiles, fixed carbon, ash content, calorific value of biomass). The gross calorific value of the biomass was determined by bomb calorimeter method.

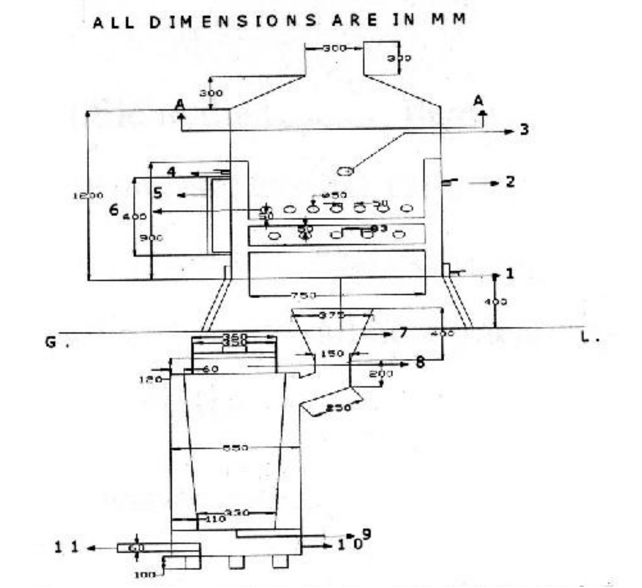
The performance of the gasifier with heat exchanger system was analyzed under the following headings:

– Temperature profile in the reactor, flame temperature and gas temperature.

– Specific gasification rate, gasifier efficiency and combustion efficiency.

Table 1: Detailed specification, dimensions and material of heat exchanger

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



1. Hot Water Outlet
2. Water Intlet
3. Pressure Gauge
4. Steam Outlet
5. Water Level Indicator
6. Tubes
7. Burner
8. Feeding
9. Grate
10. Ash Port
11. Air Vent (Inlet)

Fig. 1 : Schematic diagram of Natural Draft Gaslfier with Heat Exchanger System

– Feed stock consumption rate, heat exchanger efficiency, heat utilization efficiency, log mean temperature difference, overall heat transfer coefficient and effectiveness.

Specific gasification rate (SGR):

The specific gasification rate was calculated by the following equation:

$$\text{Specific gasification rate} = \frac{\text{Feed input}}{\text{Area of grate x Time of operation}}$$

$$\text{Area of grate} = \left(\frac{\pi}{4} \times d^2\right)$$

d =diameter of grate, m

Gasifier efficiency (η_g):

The gasifier efficiency of the system was calculated as follows:

$$\eta_g = \frac{\text{Energy output}}{\text{Energy input}} \times 100$$

Energy input:

Energy input (Q_i) = F x H_F

where,

F = Feed stock consumption rate

H_F = Heating value of fuel

Energy output:

The energy outputs (Q_o) consists of components as outlined below:

Gas energy output (Q_g) = G x CV

where,

G = Gas production rate

CV = Calorific value of gas

Sensible heat in gas=G x ρ_g x C_{pgas} x dt_{gas}

where,

ρ_g = Density of producer gas, kg m^3

C_{pgas} = Specific heat of producer gas, MJ kg^{-1} $^0C^{-1}$

dt_{gas} = Gas temperature difference with ambient, ^0C

Energy output =Gas energy output + Sensible heat in gas.

Combustion efficiency (η_c):

It is the ratio of heat output to the heat input. It was calculated by the following equation.

$$\eta_c = \frac{\text{Heat output}}{\text{Heat input}} \times 100$$

Feed stock consumption rate (FCR):

The consumption rate of feedstock was calculated by the following equation:

$$FCR = \frac{Q_r}{\eta_g \times \eta_{he} \times CV}$$

FCR = feed stock consumption rate, kg

Q_r = heat required, kcal h^{-1}

η_g = gasifier efficiency, %

η_{he} = heat exchanger efficiency, %

CV = calorific value of wood, kcal kg^{-1}

Heat exchanger efficiency (η):

The heat exchanger efficiency of the system was calculated by the following equation:

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

where,

η = Heat exchanger efficiency, %

M_w = Mass of the hot water generated, kg
Cp_w = Specific heat of the water, kcal kg^{-1} ^{0}C^{-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

Heat utilization efficiency:

It was calculated by the following equation:

$$\text{Heat utilization efficiency} = \frac{\text{heat utilized}}{\text{heat produced}} \times 100$$

Economic analysis of biomass gasifier cum burner system:

For the success and commercialization of any new technology, it is essential to know whether the technology is economically viable or not. Three different economic indicators namely net present worth, benefit cost ratio and payback period were used.

Net present worth (NPW):

The mathematical statement for net present worth can be written as:

$$NPW = \sum_{t=1}^{t=n} \frac{B_t - C_t}{(1+i)^t}$$

where,
C_t = Cost in each year
B_t = Benefit in each year
t = 1, 2, 3................n
i = discount rate

Benefit cost ratio:

The mathematical benefit-cost ratio can be expressed as:

$$\text{Benefit-cost ratio} = \frac{\sum_{t=1}^{t=n} \frac{B_t}{(1+i)^t}}{\sum_{t=1}^{t=n} \frac{C_t}{(1+i)^t}}$$

where,
C_t = Cost in each year
B_t = Benefit in each year
t = 1, 2, 3................n
i = discount rate

Payback period:

The pay back period is the length of time from the beginning of the project until the net value of the incremental production stream reaches the total amount of the capital investment. It shows the length of time between cumulative net cash outflow recovered in the form of yearly net cash inflow.

RESULTS AND DISCUSSION

The feed material is characterized in terms of physical and chemical properties, which included physical properties (size fraction of wood, moisture content) and chemical properties (proximate analysis, volatiles, fixed carbon, ash content, calorific value of biomass) as shown in Table 2. The gross calorific value of the biomass was determined by bomb calorimeter method. 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 was increasing from 25.53 to 41.26% due to continuous working as well as regular contact of water with heated surface of heat exchanger.

Table 2 : Physical properties and proximate composition of wood chips

Moisture content, % (w. b.) (Average)	Proximate composition, %			Feed stock (Babul wood)
	Fixed carbon (Average)	Volatile matter (Average)	Ash content (Average)	Calorific value, kcal kg^{-1} (by bomb calorimeter method)
14.75	19.78	77.56	2.66	3700

Table 3: Calculated data after experimentation

Specific gasification rate	117.64 kg h^{-1}-m^{-2}
Gasifier efficiency	70.36 per cent
Combustion efficiency	55 per cent
Feed stock consumption rate	12 kg
Heat exchanger efficiency	35.56 per cent
Heat utilization efficiency	90 per cent

Table 4 : Temperature of hot water with respective time for four batches in the fifth day

Time, min	Temperature of hot water, (^{0}C)			
	Batch I	Batch II	Batch III	Batch IV
10	32	39	51	54
20	43	49	66.4	69
30	54	64	78	79.8
40	63.8	75	89.8	93
50	72.7	89	97.7	97.4
60	81.8	97		
70	88.9			
80	96.8			

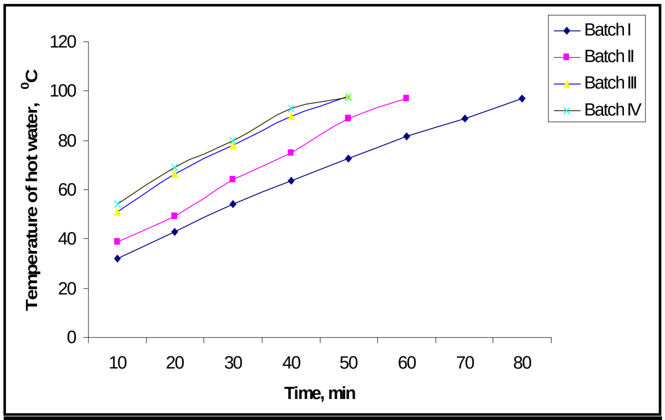


Fig. 2: Variation of temperature of hot water for four batches in the day

Table 5 : Exhaust temperature and time (for four batches in the fifth day)

Time, min	Exhaust temperature, (°C)			
	Batch I	Batch II	Batch III	Batch IV
10	81.7	88	99	99.3
20	86.4	94	103	101.2
30	91.6	103	109	105.8
40	97.4	107	111	109.6
50	100.8	111	113	110.7
60	109.6	112		
70	112.5			
80	113			

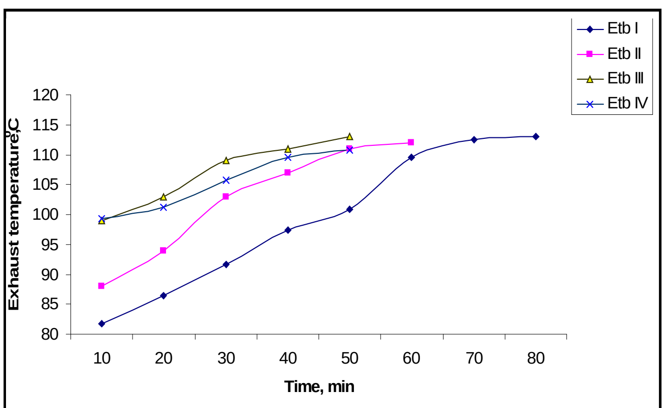


Fig 3. : Variation of exhaust temperature for four batches in the a day

It was observed that the hot water temperature increases 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 °C for 80 min. For II, III and IV batch the temperature of hot water reached at 60, 50, 50

Table 6: Cash flow (Rs.) for hot water generation (compared with light diesel oil)

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	51818.2	96720	87927.3	36109.1
2	57000	47107.4	96720	79933.9	32826.4
3	57000	42824.9	96720	72667.2	29842.2
4	57000	38931.8	96720	66061.1	27129.3
5	57000	35392.5	96720	60055.5	24663.0
6	57000	32175.0	96720	54595.9	22420.9
7	57000	29250.0	96720	49632.7	20382.6
8	57000	26590.9	96720	45120.6	18529.7
9	57000	24173.6	96720	41018.7	16845.2
10	0	0	96720	37289.7	37289.7
Total		328264.4		594302.5	266038.2

Table 7: Economic indicator for hot water generation

Sr. No.	Economic indicator	Value
1.	Net present worth, Rs.	266038.2
2.	B/C ratio	1.81
3.	Pay back period, months	8.7

minute, respectively.

The efficiency of heat exchanger for four batches in the single day was calculated as follows :

Batch I

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

= 25.53 %

Batch II

$$\eta = \frac{180 \times 1 \times (97.0 - 0 - 27)}{10 \times 3700 \times 1}$$

= 34.05%

Batch III

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

= 41.43%

Batch IV

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

= 41.26%

Average efficienty for four batches in a day

= 25.53+ 34.05 + 41.26 = 35.56%

Conclusion:

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. 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 found 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 1.81 and 8.7 months, respectively.

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REFERENCES

ASTM (1977). Annual book of ASTM standards part 26, Gaseous fuels; coal and coke : atmospheric analysis. American Society for Testing Materials, USA, 293-298 and 369-377.

Dubey, Anil and Gangil, Sandip (1998). Coordinators Report. All India Coordinated Research project renewable sources of energy for agriculture and agro-based industries. XIth Annual Workshop, February, 1998.

Khadse, S.D., Vijayaraghavan, N.C. and Sampathrajan, A. (2004). Developed natural draft gasifier for steam generation. Department of Bio Energy Tamil Nadu Agricultural University.

Patil, K.N. and Singh, R. N. (2001). Field evaluation of biomass natural draft gasifier based hot water system. *SESI J.*, **11**(1): 83-90.

Patil, K.N., Ramana, P.V. (1999). Performance evaluation of biomass gasifier based thermal back-up for solar dryer.

Ransing, Pramod (2007). M.E. Thesis, Maharana Pratap University of Agricultural Engineering and Technology, Udaipur, India.

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