International Journal of Scientific Research in Multidisciplinary Studies
Vol.5, Issue.1, pp.01-08, January (2019)

Research Paper
E-ISSN: 2454-9312
P-ISSN: 2454-6143

Low Pressure Steam from Waste Heat of Updraft Gasifier

R N Singh [1]*, Abhishek David[2] and V K Aharwal[3]

[1]School of Energy and Environment Studies, Devi AhilyaVishwaVidhyalaya, Indore, India
[2]Mechanical Engineering department of Karunya University Coimbatore, Tamil Nadu, India
[3]School of Energy and Environment Studies, Devi AhilyaVishwaVidhyalaya, Indore, India, India

**Corresponding Author: rnsingh.seema@gmail.com*

Available online at: www.isroset.org

Received: 28/Aug/2018, Accepted: 23/Sep/2018, Online: 31/Jan/2019

Abstract- Waste heat of producer gas generated from a force-updraft gasifier is utilized for steam generation. Generally Producer gas released from gasifier comes under medium temperature waste heat. This gas has temperatures ranging up to 350-450°C depending upon the design of the gasifier, type of biomass, biomass flow rate est. Theoretically, it is possible to reduce the producer gas temperature up to room temperature (25-30°C). The producer gas temperature does not help to increase the energy content of gas. Thus to harness the heat of producer gas a pipe to pipe counter flow heat exchanger was designed, developed and used for waste heat recovery of gas. Hot producer gas flows in inner pipe and water flows in annulus of heat exchanger, in counter current manner. Low pressure steam was generated due to heat transfer between water and hot producer gas. Various parameters such as heat transfer coefficient of producer gas, water, surface temperature of producer gas carrying pipe of heat exchanger, mass flow rate of steam est. are calculated theoretically at mean outlet temperature of producer gas and results are compared with practical values of parameters obtained during gasifier run. On an average about 3.5 L/h water is converted into low pressure steam at an atmospheric pressure from waste heat of producer gas.

Keywords*— Updraft gasifier, Biomass, heat exchanger, waste heat, Low pressure steam*

1. INTRODUCTION

In the present scenario energy crises is a severe problem across the globe. In order to obtain better economy, cost effective energy saving is one of the most vital issues to protect all ready degraded environments. Therefore, it is essential to empathize more and more on waste heat recovery in the existing setup by making significant and sincere effort [1].

Basically waste heat is heat that is generated due to fuel combustion or chemical reaction. It is normally released into the environment, even though it may still be reused. These waste heat, which is rejected from a process has sufficiently higher temperature than ambient air and permits the recovery of energy for some useful purpose in an economical manner [2]. The waste heat available for recovery is categorized on basis of temperature as, high-, medium and low waste heat. Producer gas released from gasifier comes under medium temperature waste heat. This gas has temperatures ranging from 300 to 450°C or more depending upon the design of the gasifier, type of biomass, biomass flow rate. Theoretically it is possible to reduce the producer gas temperature below 25°C [3].

Waste heat generated by different sources were used by different research for different purposes such as Amador, 2008 [4], used waste heat of a 60 kW gasifier driven by coconut shell biomass as a fuel to dry pulverized kernel of coconut. Jain et al. 2013 [5] used waste heat generated from air conditioning systems to heat the feed water of a boiler. They observed that efficiency of boiler could be increased from 76.33% to 76.53% and fuel cost could be reduction from Rs. 8, 04,000 to Rs. 8, 01,934 per day.

Aharwal and Singh, 2018 [6] studied computational fluid dynamics simulation of horizontal biomass gasifier and found that superficial gas and mass fraction of biomass has a strong influence on the outlet Producer gas temperature and gas velocity. Producer gas temperature and H_2 and CO distributions in producer gas indicate that reactions in the instantaneous gasification model occur very fast and finish very quickly. It was also reported that these parameters affect the gas temperature.

Cengel, 2007 [7] worked on waste heat recovery steam generator (WHRSG) in Sponge Iron Plant. He was able to recover about 150 kW of waste heat which was used to run fuel feeding system, combustion chamber, fans, blowers, and auxiliary power in the plant.

Although sufficient work has been reported for recovery of waste heat from different sources and its application, however no work/ very less work was reported on generation of low pressure steam using waste heat of producer gas, even though numbers of gasifier works in the field commercially [8]. Thus work was initiated on small capacity updraft gasifier available at School of Energy and Environmental Studies (SEES), DAVV, Indore.

2. METHODS AND MATERIALS

Earlier work done at School of Energy and Environmental Studies (SEES) on updraft gasifier indicate that producer gas temperature depends on flow rate of gas and it reaches some times as high as up to 650ºC linearly at the end of gasifier run [3]. Mean temperature of producer gas released from gasifier is about 300ºC and the surface temperature of pipe carrying producer gas is up to 390ºC [9]. Hence it looked convincing to generate low pressure steam by using waste heat of producer gas.

2.1. Design and Development of Heat Exchanger

To harness the heat of producer gas, a pipe to pipe counter flow heat exchanger was designed, developed and used for waste heat recovery of gas. Hot producer gas flows in inner pipe and water flows in annulus of heat exchanger, in counter current manner (Fig. 1&2). Developed heat exchanger has two different diameter pipes. Internal pipe have 7.5 cm dia. with 0.5 cm thick mild steel, and outer pipe have 10.5 cm dia. with 0.8 cm thick mild steel. The length of both pipes was maintained as 100 cm.

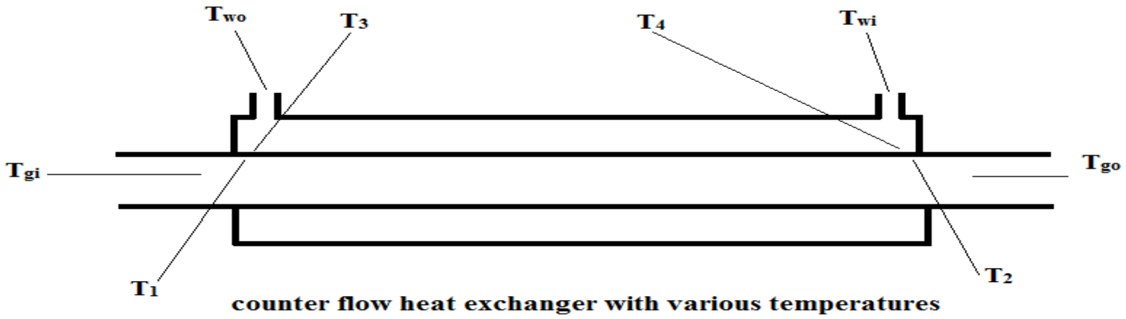


Fig. 1: Schematic of developed heat exchanger

2.2 Theoretical Analysis: Considering the temperature of producer gas released from gasifier as 300ºC, properties of gas such as density, dynamic viscosity, thermal conductivity, prandlt number etc were calculated theoretically taking standard composition of producer gas on w/w basis. The governing equations of heat transfer from producer gas to water, resulting in steam formation at ideal conditions can be given as:

$M_g C_{Pg} (T_{gi} – T_{go}) = h_g A_i(T_{gi}– T_1) = h_g A_i(T_{go} – T_2) = h_w A_a(T_3– T_{wo}) = h_w A_a(T_4– T_{wi}) = M_w C_{PW}(T_{wo} – T_{wi}) + M_w \lambda_w$

Fig. 2: Photograph of gasifier-cyclone assembly along heat exchange

Where,

M_g = mass flow rate of producer gas in pipe at a given velocity.

M_w = mass flow rate of water flowing through pipe annulus and steam generation.

T_{gi} = temperature of producer gas at inlet

T_{go} = temperature of producer gas at outlet

T_1 = temperature of inner surface of pipe at gas inlet

T_2 = temperature of inner surface of pipe at gas outlet

T_3 = temperature of outer surface of inner pipe at gas inlet

T_4 = temperature of outer surface of inner pipe at gas outlet

T_{wi} = temperature of water inlet (25ºC)

T_{wo} = temperature of water outlet before steam generation (100ºC)

h_g= heat transfer coefficient of producer gas flowing from inner pipe in force convection

h_w= heat transfer coefficient of hot water flowing in pipe annulus

A_i= longitudinal curved surface area of inner pipe ($0.2186 m^2$)

A_a= annular longitudinal curved surface area ($0.0723 m^2$)

C_{Pg}= 1.45 kJ /kg°k

C_{PW}= 4.18 kJ /kg°k

λ_w = 2256.9 kJ/kg

Heat transfer coefficient of producer gas and heat transfer coefficient of hot water can be calculated theoretically.

2.3 Theoretical Calculation of Heat Transfer Coefficient of Producer Gas

Based upon the previous work done on Updraft gasifier at SEES [3], the average velocity of producer gas released from existing gasifier is taken as 7.75 m/s and velocity of producer gas in developed heat exchanger using continuity theorem was calculated as 7.84m/s. Now to calculate Reynolds number of producer gas flowing through internal pipe of heat exchanger, 7.84 m/s velocity was taken.

$R_e = \rho * v * D / \mu = 1.3*7.84*6.96*10^{-2} / 2.558*10^{-5} = 27570.37$

The other properties of producer gas such as density and viscosity were calculated as per the method suggested by Kaupp, Goss, 1984 [10], considering standard composition of producer gas on w/w basis (19.5% CO, 9% CO_2, 15% H_2, 2.5% CH_4, 52.5 % N_2 and remaining water). Further considering Reynolds number range between 3000 to 5 x 10^6, and temperature difference of gas and pipe inner surface, heat transfer coefficient of producer gas could be calculated using "Petukhov Equation" [7]. Nusselt number (Nu) = $(f/8)*R_e*Pr / [1.07 + 12.7*(f/8)^{.5}*(Pr^{2/3} - 1)]$

Where,

f =friction coefficient

Re =Reynolds Number

Pr = Prandlt number (which is 0.7226 at 300ºC, from steam table)

$f = (0.079 \ln Re - 1.64)^{-2}$

$f = (0.079 \ln 27570.37 - 1.64)^{-2}$

f = 0.0241

$f/8 = 3.0125 * 10^{-3}$

Therefore, Nusselt number (Nu) = $(f/8)*R_e*Pr / [1.07 + 12.7*(f/8)^{.5}*(Pr^{2/3} - 1)]$

$Nu = (3.0125*10^{-3})*27570.37*0.7226 / [1.07 + 12.7*(3.0125 * 10^{-3})^{.5} * (0.7226^{2/3} - 1)]$

Nu = 64.239

This Nusselt number could be also correlated with heat transfer coefficient i.e.

$Nu = h*D/K_f$

Where, h is heat transfer coefficient, D is the characteristic length and K_f is the thermal conductivity.

Therefore heat transfer coefficient of producer gas (h) $=64.239 * 0.0677 / 6.96 *10^{-2}$

h = 62.5 W/ m^2°k

2.4 Theoretical Heat Transfer Coefficient of Water Flowing Through Pipe Annulus

According to Cengal, 2007, the Nusselt number of any fluid, flowing through pipe or pipe annulus gaining heat from constant heat flux from pipe surface is constant and can be represented as:

Nu = 4.364

$Nu = h*D/K_f$

Here, D is the annulus diameter of pipe and k is thermal conductivity of water flowing at a mean temperature of 50ºC.

Thus, heat transfer coefficient of water flowing in counter direction of gas in pipe annulus can be given as:
$h = 4.364*0.649 / 2.3 * 10^{-2}$

$h = 123.15 W/ m^2 °k$

Similarly using governing equations of heat transfer from producer gas to water, mass flow rate of steam generated (M_w) was calculated at different temperature of water outlet before steam generation (100ºC) and same is shown in Table 1.

2.5 Theoretical Effectiveness of Heat Exchanger

Considering at mean inlet temperature of producer gas water is heated up to 100ºC from constant water inlet temperature of 25ºC, theoretical effectiveness of heat exchanger was calculate using method suggested by Cengel, 2007 [7]. Similarly the mean inlet temperature of hot fluid (producer gas) is calculated by taking average of all inlet temperatures i.e. 353.6ºC. Thus effectiveness of heat exchanger (€) would be= $T_{co} – T_{ci} / T_{hi} – T_{ci}$, where ($M_g * C_{Pg} > M_w * C_{PW}$). Therefore € = 100 – 25/353.6 - 25 = 0.228

Table 1: Theoretically calculated value of various parameters at different gas outlet temperature

Sr. No.	Tgo ˚C	Tgi ˚C	ΔT ˚C	T_1 ˚C	T_2 ˚C	Q watt	Mw g/s
1	200	218.35	18.35	143	141.7	1029.72	0.4
2	250	271.2	21.2	184.1	159.3	1189.64	0.46
3	300	325.92	25.92	219.46	189	1454.5	0.56
4	350	380.65	30.65	254.8	218.8	1719.92	0.66
5	400	435.4	35.4	289.0	248.6	1986.47	0.77
6	450	490.12	40.12	325.34	278.34	2251.34	0.87

3. RESULTS AND DISCUSSION

Considering the different calculated parameters, heat exchanger unit was designed and fabricated. The heat exchanger was installed with gasifier setup. To enhance the efficiency of heat exchanger, it was insulated with ceramic blanket.

3.1 Experimental Setup and Measurement

The experimental setup consists of a 5 kW capacity Updraft gasifier, flow measuring device (orifice plate & pitot tube), heat exchanger unit along with inlet and outlet water supply and burner for flaring of gas. Producer gas was obtained from the up draft gasifier. Sun dried fire wood blocks were used for producer gas generation. The characteristic of biomass (moisture content, ash content, volatile matter, fixed carbon, calorific value) was available in hand, which was carried out as per the ASTM standards [11,12]. For recovery of waste heat from producer gas, available temperature at the beginning and end of heat exchanger unit was measured using a K type & J type thermocouple; however surface temperature of producer gas carrying pipe was measured with IR gun. Flow of producer gas was quantify using orifice plate & further rechecked with pitot tube. Pressure gauge was used to measure the pressure of steam. Fuel consumption rate of gasifier was measured by topping method [9].

In order to provide water in heat exchanger drip-needle arrangement was done, and flow of water is adjusted approximately double to that of theoretical flow rate obtained in order to capture the extra waste heat for heating and steam generation of water. As theoretically obtained flow rate was very less and it may increase losses to ambient if insufficient water was provided. Performance of heat exchanger without Insulation and with insulation is shown in Table 2 & 3 respectively.

Performance of heat exchanger without insulation and with insulation was evaluated in term of heat transfer coefficient of producer gas at mean values of gas outlet temperature and mass flow rate of steam at average steam velocity (Fig. 3 & 4). Close look of Figure 3 & 4 and Table 1 indicate that practical value of heat transfer coefficient and mass flow rate of steam are at par with theoretical value.

Critical analysis of Fig. 3 & 4 indicate that heat transfer coefficient and hence heat recovery were lower at temperature less than 350°C and then increase rapidly. Thus due to sudden increase in heat transfer coefficient of producer gas, heat recovery for generating steam also increases to a great extent. Relation between producer gas outlet temperature and surface temperature of producer gas carrying pipe is shown in Fig. 5.

Fig. 5 indicate that at the begging when gas outlet temperature was up to 350ºC, there is not much difference in the surface temperature of gas carrying pipe with producer gas for both condition i.e. Experiment 1 (heat exchanger without Insulation) and Experiment 2 (heat exchanger with insulation). Latter difference started widening specially in heat exchanger without Insulation; however it was almost constant with heat exchanger with Insulation. It may be due to better heat transfer from inner pipe to outer surface just because of insulation. Although it was always lower than the theoretically calculated surface temperature.

Table 2: Performance of heat exchanger without Insulation

S.No.	T_{gi} (°C)	T_{go} (°C)	T_1 (°C)	T_2 (°C)	V_g (m/s)	V_s (m/s)	p_s (bar)	T_s (°C)
1	207	201	107.3	64.8	7.84	5.7	1	96
2	267	264	110.6	70	7.84	6.2	1	99
3	302	290	107.2	80.7	7.84	6.8	1	100
4	330	322	161.2	90.1	7.84	7.1	1	101
5	361	335	175.4	95.8	7.84	7.3	1	101
6	420	362	199	97	7.84	7.75	1	100
7	421	367	213	95	7.84	8.15	1	98
8	455	370	228	104	7.84	8.3	1	100
9	478	385	215	112	7.84	8.41	1	99
10	496	384	240	106	7.84	8.52	1	100
11	573	418	278	111	7.84	8.7	1	102
12	647	555	242	116	7.84	8.9	1	103
13	623	460	246	118.3	7.84	10.1	1	102
14	626	452	240	117	7.84	15.5	1	102

Table 3: Performance of heat exchanger with Insulation

S. No.	T_{gi} (°C)	T_{go} (°C)	T_1 (°C)	T_2 (°C)	V_g (m/s)	V_s (m/s)	p_s (bar)	T_s (°C)
1	203	196	106	62	7.84	4.8	1	95
2	213	204	108.2	67.8	7.84	5.3	1	98
3	258	251	110.3	71.2	7.84	5.8	1	97
4	296	280	113	76.8	7.84	6.2	1	99
5	310	301	121	82	7.84	6.4	1	100
6	336	328	158.7	91	7.84	6.9	1	101
7	365	337	165.3	93	7.84	7.74	1	98
8	426	361	201	98	7.84	7.98	1	99
9	436	369	216	101	7.84	8.21	1	101
10	452	373	225	105	7.84	8.43	1	102
11	488	381	237	107	7.84	8.62	1	102
12	550	408	265	112	7.84	8.8	1	103
13	578	423	273	113.8	7.84	9.2	1	103
14	623	453	281	119	7.84	9.5	1	102
15	630	462	283	121	7.84	12.5	1	103

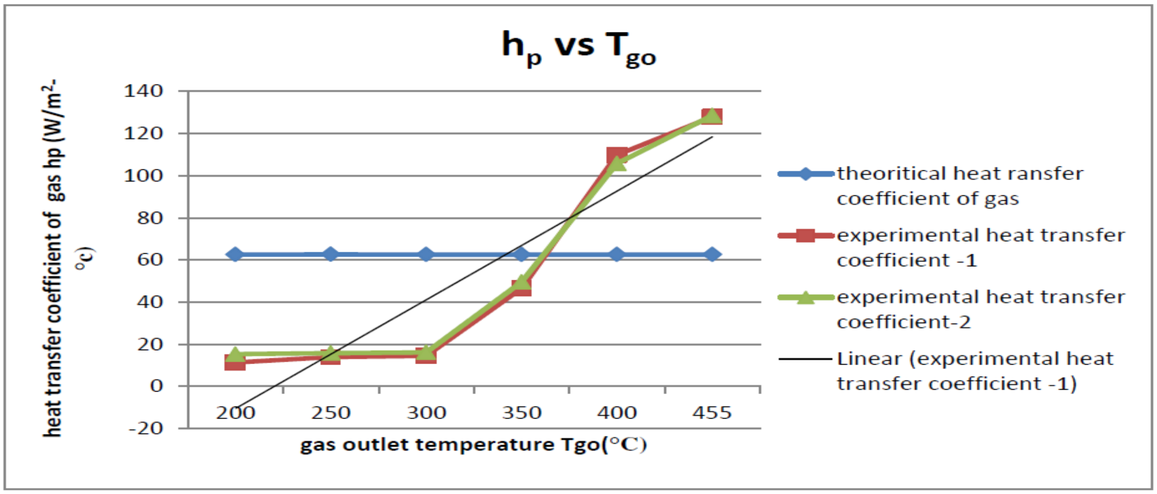
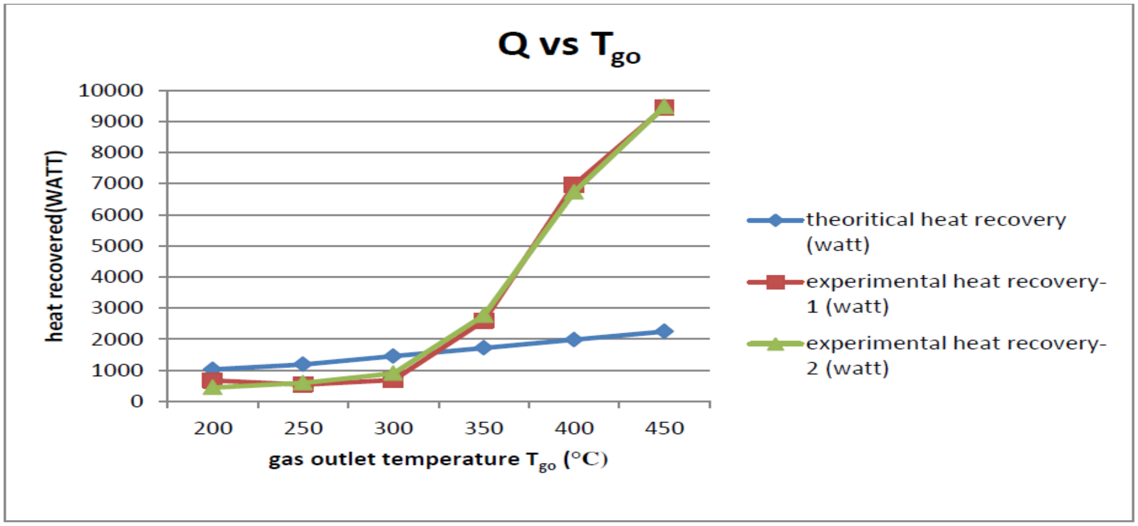


Fig.3 Heat transfer coefficient of producer gas at average gas outlet temperatures



.

Fig. 4 Heat recovery from producer gas at average gas outlet temperatures

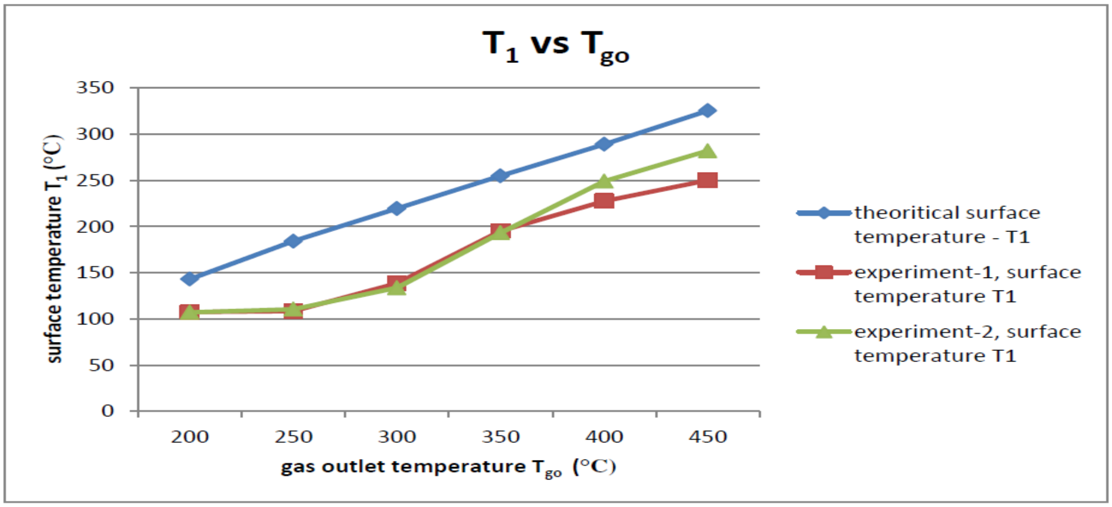


Fig. 5: Surface temperature verses averaged gas outlet temperature

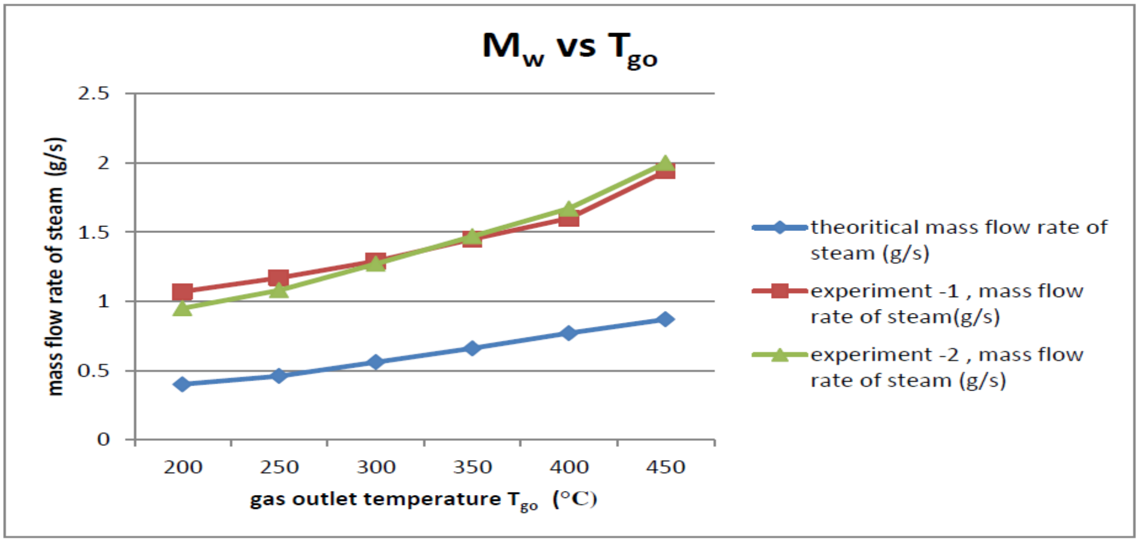


Fig. 6: Mass flow rate of steam at various gas outlet temperatures

Variations of mass flow rate of steam with gas outlet temperatures in shown in Fig.6. As depicted from Fig. 6, mass flow rate of steam generation is considerably higher (almost double), to that of theoretical mass flow rate. The difference in theoretical and experimental mass flow rate is less at the beginning and increase with progress of producer gas temperature. It may be due to increase of gas temperatures, heat transfer coefficient also increases, hence at the end of operation higher mass flow rates of steam was obtained. It may be further noted that towards the end of experiment only charcoal is left in the gasifier reactor which have higher energy content than wood, hence higher gas outlet temperature was received.

Critical analysis of experimental data of gasifier along with heat exchanger reveals that the useful time in which steam generation takes place is approximately 40-50 minutes, although running time of gasifier more than hours. It may be explained as gasifier system took around 15-20 minutes to reach in equilibrium conditions. On an average about 3.5 liter/h water is converted into low pressure steam.

4. CONCLUSION

It can be safely concluded that with introduction of waste heat recovery system efficiency of the gasifier could be increased. The gasifier used for study have capacity about 13kW from which, waste heat recovered was up to 9.5 kW. This figure may increase with higher capacity of gasifier. For small capacity gasifier about 3.5 L/h water is converted into low pressure steam. It was also noted that heat transfer coefficient in pipe heat exchanger increases with progress of gasification due to increase of gas temperatures. Thus at the end of gasification, higher mass flow rates of steam was obtained. The mass flow rates of steam could be made uniform throughout the gasification process except at the beginning of process (as at the beginning whole set up is in atmospheric condition and may take some time to come in equilibrium) by insulting the pipe to pipe heat exchanger with the Cero wool blanket.

REFERENCES

[1]. Amit Kumar Mishra, R N Singh and Pratyush Pingita Mishra, “Effect of Biomass Gasification on Environment” Mesop. Environ. j. Vol.1 (4):39-49, 2015.

[2]. Wen and Lou “Heat recovery from coal gasifier”. Proceedings from the Third Industrial Energy Technology Conference Houston, report no. ESL-IE-81-04-37, Houston-Texas, 1981.

[3]. R N Singh, Mandovra Shashank, and Jai Balwanshi,“Performance evaluation of jacketed cyclone for reduction of tar from producer gas” International Agricultural Engineering Journal Vol. 22 (3) PP: 1-5, 2013.

[4]. Indeewara Amador, “Drying pulverized kernel of coconut for virgin coconut oil extraction from waste heat of a gasifier. Journal of natural science council of Sri Lanka,Wayamba, Sri lanka, 2008.

[5]. Rakesh Jain, Devendra Dandotiya, Abhishek Jain, “Performance Improvement of a Boiler through Waste Heat Recovery from an Air Conditioning Unit”, International Journal of Innovative Research in Science, Engineering and Technology Vol.2 (2) pp: 405-412, 2013.

[6]. V K Aharwal, and R N Singh “Computational Fluid Dynamics Simulation of Horizontal Biomass Gasifier” International Journal of Scientific Research in Multidisciplinary Studies, Vol.4 (2), pp.1-7, 2018.

[7]. Y. A. Cengel, “Heat Mass Transfer” 3rd ed. TMH Publications, Delhi, 1989.

[8]. R N Singh and D Asha (2018), Book Chapter on Thermo-Chemical Conversion of Solid Biomass. In: Low Carbon Energy Supply - Trends, Technology, Management”, published by Springer Nature Singapore pp; 175-202, 2018.

[9]. R N Singh, J B Balwanshi, V K Aharwal and S P Singh, “Experimental Investigation of Horizontal gasifier”, International Journal of Science, Technology and Society Vol. 2 (1&2) PP: 50-55, 2016.

[10]. Kaupp, and J. R. Goss, “Small scale gas producer engine system”. Published by Vieweg fur Technische Zusammenarbeit (GTZ) GmabH, Eschborn. 1984.

[11]. ASTM Standards, American Society for Testing of Material Philadelphia, 1983.
[12]. R N Singh, and K N Patil, "SPRERI method for quick measurement of moisture content of biomass fuels" SESI Journal, 11 (1) pp: 25 – 28, 2001.

AUTHORS PROFILE

Prof. (Dr.) R N Singh has completed his B Tech & M Tech in Agricultural Engineering and Ph.D. in Energy. He has more than 88 research paper and 2 Book chapters in his credit. He is life member of 4 society engaged in Energy & Environment. Guided 4 Ph.D. and more than 50 PG students. 3 Ph.D. research scholars are continuing. He was also member of Executive Council of DAVV and Dean of Faculty of Engineering Science. He has more than 20 year Teaching & Research experience. His area of interest is Bio-fuel, Biomass including biodiesel, bio ethanol and Renewable Energy. He is chief Editor of Progress in Energy & Fuel and Editors of some journals.

Mr. Abhishek David has completed B.E. in Mechanical Engineering from Karunya University Coimbatore (T.N.), M. Tech. in Energy Management from School of Energy and Environmental Studies, DAVV, Indore (M.P.) India. He is working as Assistant professor in Mechanical Engineering department of Karunya University Coimbatore (T.N.) He has 2 year of teaching experience in Medicaps University in Indore (M.P.).

Mr. V K Aharwal has completed B.E. in Electrical Engineering from Vidisha, (M.P.), M. Tech. in Energy Management and pursuing Ph.D. from School of Energy and Environmental Studies, DAVV, Indore (M.P.) India. He is working on horizontal biomass gasifier.

His main research work focuses on biomass gasification, application of biomass gasification output (producer gas) for electricity and thermal generation, CFD simulation of gasification. He has 2 year of teaching experience.