Madras Agric. J., 97 (4-6): 193-198, June 2010
https://doi.org/10.29321/MAJ.10.100379

Comparative Experiment on Tar Removal Methods in Fixed Bed Gasifier

P. Vijayakumary* and P. Venkatachalam
Department of Bioenergy, Agricultural Engineering College and Research Institute
Tamil Nadu Agricultural University, Coimbatore-641 003

Gasification is a thermo chemical transformation of a combustible solid in the presence of gaseous compound to produce producer gas, which is a mixture of Carbon monoxide, Hydrogen, Nitrogen, Carbon dioxide, Methane and traces of other hydrocarbons more commonly known as tar, resulting from an incomplete destruction of volatiles during different stage of transformation in the gasifier. Tar will impose serious limitations in the use of producer gas due to fouling of downstream process equipment, engine wear and high maintenance cost. Tar can be removed from producer gas by chemical and physical methods. Present study was carried out to study the removal of tar from selected biomass through physical method and catalytic cracking method. Catalytic cracking of tar was done with dolomite as tar cracking catalyst was carried out in this study. The selected biomass for the study was wood, arecanut husk and coconut shell. A dry filter with carbonized porous charcoal as bed material was designed and developed with a diameter of 15.5 cm, filter bed height of 60 cm, height of filter 90cm, superficial velocity of 0.06 m/s and residence time of 10 seconds to remove the tar coming after two condensers. By employing the filter, a tar conversion efficiency of 90.5 per cent was achieved. To reduce the tar further, dolomite was used as the catalyst. As the catalyst was added in the gasifier, the temperature gets increased from 675°C to 935 °C and the tar produced gets cracked in the gasifier. A tar conversion efficiency of 96.9% was attained by using dolomite as a catalyst. The mass closure and the energy closure for the gasifier were calculated as 98.04% and 98.55% respectively.

Key words: Gasification, tar, catalytic cracking, filter, dolomite.

Biomass, as a fuel, has been in use for centuries all over the world. In India, biomass energy is being utilised mainly for domestic, commercial and industrial applications. Globally, India is in the fourth position in generating power through biomass and is poised to become a world leader in the utilisation of biomass. Thermo chemical conversion of biomass by pyrolysis and gasification is becoming increasingly important for production of gaseous fuels in commercial and industrial applications as alternative for electric power generation through combustion in diesel engines and gas turbines.

Gasification is a thermo chemical transformation of a combustible solid (coal, wood, straw etc,) in the presence of gaseous compound (O_2, air, CO_2, water vapour etc.). The end result is Producer gas, which is a mixture of Carbon monoxide, Hydrogen, Nitrogen, Carbon dioxide, methane and traces of other hydrocarbons. One of the main problems in biomass gasification is production of tar products along with the gas. Tar will impose serious limitations in the use of producer gas due to fouling of downstream process equipment, engine wear and high maintenance cost. Thus the successful implementation of gasification technology for gas engine/ turbine based power project depends much on the effective and efficient removal/ conversion of tar from the synthesis gas. Tar can be removed from producer gas by chemical and physical methods. Physical removal of tar includes scrubbers, filters and wet electrostatic precipitators. Chemical methods include catalytic and thermal cracking. Catalytic cracking has higher tar conversion efficiency than other methods of tar removal. Present study was carried out to study the removal of tar through physical method and catalytic cracking method.

*Corresponding author

Materials and Methods

In and around Thondamuthur (Coimbatore District), there are large numbers of cottage industries processing arecanut for edible purpose. Regarding processing, nearly 30 units are situated in the Kempanoor road in Thondamuthur. Lots of arecanut husk materials remain as surplus in the processing industries. The best way of proper utilization of these husks was gasification and the gas produced can be utilized for boiling the arecanut. Similarly, in Pollachi there are many cottage

industries making coir from coconut byproducts. They are using coconut husk leaving coconut shell as a waste. Coconut has high energy value and can be used to produce energy through gasification. Hence arecanut husk and coconut shell were selected for his study. The selected biomass was studied for their proximate and ultimate composition. The proximate analysis was done to determine fixed carbon, volatile matter and ash content of the material. ASTM standards D3172-73 (ASTM, 1977) through D3173-75 and modified procedures for volatiles were used (Grover, 1989 and Sirisomboon, 1991). The ultimate analysis gives elemental carbon, hydrogen, oxygen, sulphur and nitrogen of the sample.The ultimate analysis of feedstock was carried out using a Carlo Ebra Elemental analy-ser (EA 1108) coupled with an auto sampler (AS-200) and Data Processor (DP 200-PRC) following the procedure suggested by ASTM D3174-76 standards (Grover, 1989).

After the characterization of selected biomass, the tar produced during gasification of each biomass was quantified.To quantify the tar from the selected biomass a fixed bed gasifier test setup

Table 1. Elemental Composition and Calorific value of selected biomass

Biomass	Elemental composition				Calorific value, MJ/Kg
	C, %	H_2, %	N_2,%	O_2, %	
Wood chip	51.30	5.62	0.45	42.63	17.01
Arecanut husk	45.48	4.80	0.35	49.37	15.40
Coconut shell	52.46	5.38	0.10	42.06	17.92

was made which consists of four main units: a) a downdraft fixed bed gasifier, b) a Sampling train, c) a digital Temperature indicator d) a vacuum pump and e) a gas flow meter. The height of the gasifier was fixed as 1.2 m, in order to accommodate grate, to provide space for ash collection at the bottom, and to allow free board. The performance of the gasifier was evaluated in terms of temperature profile of the reactor chromel-alumel thermocouples at 3 different zones, pyrolysis, oxidation and reduction zones, biomass consumption rate calculated by mounting the gasifier on a platform scale and

Table 2. Composition of wood gas
weight of wood taken: 2 kg

Time, mins.	Gas Composition, %						
	CO	CO_2	H_2	CH_4	O_2	N_2	HC, ppm
10	9.65	13.25	10.83	2.85	3.20	59.96	2550
20	11.30	12.95	12.25	2.88	1.40	58.92	2950
30	13.85	12.73	12.85	3.15	1.25	55.9	2650
40	13.57	12.35	12.90	3.30	0.95	56.66	2730
50	12.65	12.15	12.87	3.43	1.15	57.62	1250
60	11.20	12.10	12.70	3.45	1.35	59.10	1020
Average	12.11	2.6	12.40	3.17	1.55	57.96	2192

Table 3. Composition of arecanut husk gas
weight of arecanut husk taken: 2 kg

Time, mins.	Gas Composition, %						
	CO	CO_2	H_2	CH_4	O_2	N_2	HC, ppm
10	5.35	14.80	9.85	0.90	1.37	67.51	2230
20	8.76	13.89	11.80	1.95	1.93	61.42	2500
30	9.75	13.25	12.10	2.78	1.58	60.31	2335
40	12.53	12.50	13.26	2.76	1.42	57.26	2710
50	13.29	12.30	13.11	2.98	1.90	56.09	3255
60	13.25	11.45	12.25	2.85	1.85	58.09	2650
Average	10.49	13.10	12.10	2.37	1.68	60.10	2613

measuring the weight loss in the gasifier for one hour, measuring the flame temperature gas burning in the developed burner using thermocouple (chromel - alumel) with temperature indicator and analysing the producer gas leaving the gasifier using gas chromatography.

The tar and particle sampling system consisted of a pair of condensers with impinger bottles and a filter. The gas was first passed through a pair of condensers in an ice bath to cool the gas and remove most of the tar and moisture. At the end of the run the moisture recovered was measured and the condenser was rinsed with acetone to collect the tar completely. Residual moisture and tar was

Table 4. Composition of coconut shell gas
weight of coconut shell taken: 2kg

Time, mins.	Gas Composition, %						
	CO	CO_2	H_2	CH_4	O_2	N_2	HC, ppm
10	8.76	14.27	9.85	2.12	1.90	63.10	2125
20	9.75	13.30	10.75	2.56	1.40	62.24	2310
30	11.25	12.70	14.35	2.28	1.25	58.17	2575
40	12.65	12.58	14.80	3.10	0.95	55.92	2420
50	12.20	12.43	13.75	1.90	1.15	58.57	1980
60	11.29	11.78	14.10	2.10	1.35	59.38	1250
Average	10.98	12.84	12.93	2.34	1.55	59.53	2110

removed after cooling condenser. The total gas flow was measured with a gas flow meter fitted at the exit of the sampling train and the gas was flared. A single-phase vacuum pump of 0.25 HP working at 1420 rpm was used to suck the gas from the gasifier through the tar sampling train and a wet type gas flow meter of 3 litre capacity was used to measure the volume of producer gas coming at the gas outlet of the sampling train.

The parameters optimized for the production of clean producer gas were the superficial velocity and residence time of gas in the dry filter. A dry filter with carbonized porous charcoal as bed material was designed and developed with a diameter of 15.5 cm, filter bed height of 60 cm, height of filter 90cm,

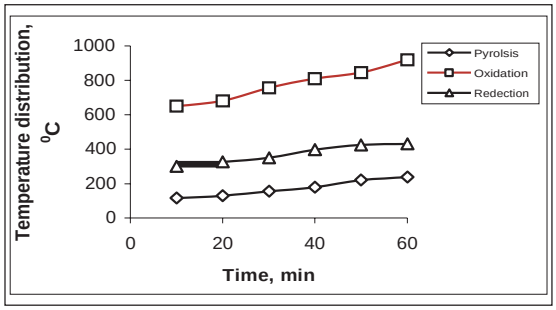

Fig.1 Temperature across the reactor during gasification of wood

superficial velocity of 0.06 m/s and residence time of 10 seconds to remove the tar coming after two condensers.Toproduce cleaner producer gas, Dolomite was used as the catalyst. Samples were ground and sieved to 10/20 mesh with an average

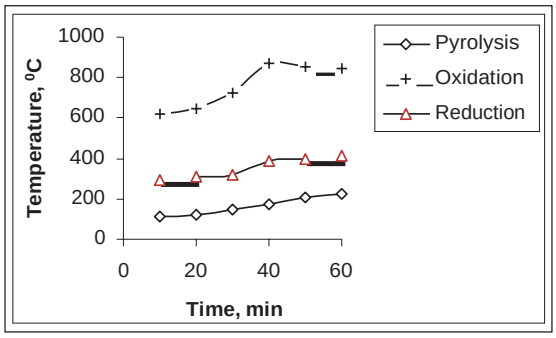

Fig.2 Temperature across the reactor during gasification of arecanut husk

diameter of 1.45mm. The dolomite stones prior to each experiment were calcined in situ at the experiment temperature for approximately 8 hours in a nitrogen atmosphere. The calcinating process was considered to be complete when the content of carbon dioxide in the exit gas was below 0.2 (vol%). The temperature of the reactor was between 700 and 900°C. The pressure was slightly above atmospheric. The wood feed rate was 1.7 kg/h. Air was used as the gasifying agent. Above the grate a bed of charcoal was placed for a height of 10 cm. Above the charcoal bed, catalyst was distributed evenly. Biomass was then fed above the catalyst bed. The catalyst load was fixed as 80g/kg of DS (Vassilatos 1990).

Tar conversion was calculated according to the following formula:

$$\text{Tar conversion},\% = \left[1 - \frac{\text{Tar produced from experiment}}{\text{Tar produced from the reference experiment at 700°C}}\right] \times 100$$

Mass and energy balance is a good indicator of the system performance. Mass balance takes into account the input such as feed stock and air and output such as producer gas, charcoal, ash, tar, etc to test the accuracy of calculations of material flow into and out of the system and is indicated by calculating closure. The closure is defined as the ratio of output to input. The mass balance was

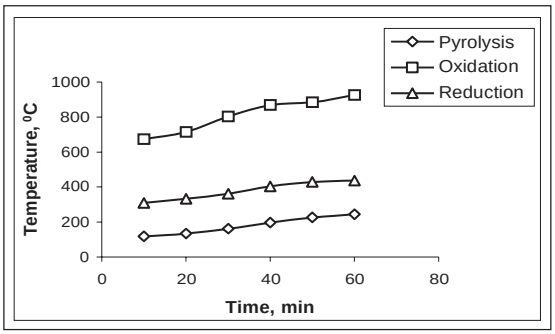

Fig. 3 Temperature across the reactor during gasification of coconut shell

calculated for the best operating condition and closure was worked out to assess the gasifier system perform-ance (Coovattanachai, 1989). Energy balance was arrived at by considering the energy content of the feedstock and energy in the output gas, char, ash, tar along with heat loss from the gasifier reactor.

Results and Discussion

The bulk density of wood, arecanut husk and coconut shell were found to be 425.2, 118.3 and 540 kg/m^3 respectively. The true density of wood, arecanut husk and coconut shell were found to be 795.4, 172.8 and 938 kg/m^3 respectively. Arecanut

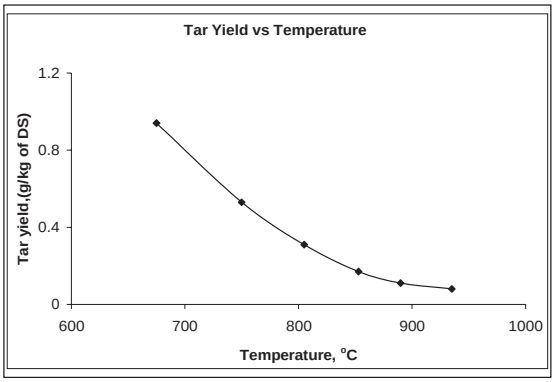

Fig.4. Tar yield vs temperature during cracking of tar using dolomite

husk has high ash content of 0.3% when compared to wood and coconut shell of 0.19% and 0.15% respectively. Fixed carbon content was high for arecanut than wood and coconut shell and hence the volatile matter of arecanut husk was low when compared to wood and coconut shell.

The elemental composition of the wood, arecanut husk and coconut shell were presented in Table 1.

The gasifier was tested with wood, arecanut and coconut shell for determining the performance. The performance of the gasifier was analyzed under the following headings i) Gas composition and ii) Temperature profile in the reactor,flame temperature iii) Biomass consumption rate. The gas composition of gasification of wood was presented in Table 2. The CO content of producer gas gets increased at the initial stage and stabilized after 30minutes and then shows a slight decrease with a mean value of 12.10%. The carbon dioxide content decreased from 13.25% to 12.10% with a mean value of 12.60%.

Table 5. Characterization of tar from wood chips

Weight of wood chips taken: 1.7kg ; Moisture content of wood: 5.16%

Time, (mins.)	Moisture content, %	Viscosity, (cSt)	Density, (g/c.c)	pH	Weight of collected tar (g)	Weight of filtered tar (g)	Weight of water(g)	Weight of filtered tar/weight of collected tar	Air flow rate, (m^3/h)
10		12.43	1.08	2.67	79.11	13.64	65.47	0.172	
20		12.49	1.103		56.60	11.67	44.93	0.206	
30	30.16	12.49	1.114	2.5	46.22	9.63	36.59	0.208	
40		12.52	1.121	2.56	58.33	12.28	46.05	0.210	3
50		12.62	1.296		57.77	13.92	43.85	0.241	
60		12.62	1.293	2.65	43.39	10.33	33.06	0.238	
				2.54					
				2.51					
Average		12.53	1.17	2.57	56.90	11.91	44.99	0.213	

The H_2 content of gas fluctuated between 10.83% and 12.90% with a mean value of 12.40%. The methane content increased with time with an average value of 3.17%. The gas composition of gasification of arecanut husk was presented in Table 3. the CO content of producer gas increased with respect to time. Stability was attained after 30 minutes. The average value of CO content was 10.49%. The carbon dioxide content decreased from 14.80 % to 11.45 % with a mean value of 13.1%. The H_2 content of gas fluctuated between 9.85 % and 13.26 % with a mean value of 12.10 %. The methane content increased with time with an average value of 2.37%. During the gasification of of coconut shell,

Table 6. Characterization of tar from arecanut husk

Weight of arecanut husk taken: 1.7 kg; Moisture content of arecanut husk: 3.04%

Time, (mins.)	Moisture content, %	Viscosity, (cSt)	Density, (g/c.c)	pH	Weight of collected tar (g)	Weight of filtered tar (g)	Weight of water(g)	Weight of filtered tar/weight of collected tar	Air flow rate, (m^3/h)
10		12.43	1.22	3.6	51.53	12.24	39.29	0.238	
20		12.43	1.138	3.83	52.32	8.24	44.08	0.157	
30	31.34	12.43	1.11	4.34	44.91	7.22	37.69	0.161	
40		12.43	1.11	4.92	44.83	7.14	37.84	0.159	3
50		12.43	1.14	5.11	48.43	7.25	41.18	0.150	
60		12.52	1.33	5.12	28.12	5.87	22.25	0.209	
Average		12.45	1.17	4.49	45.02	7.99	37.06	0.179	

the CO content gets stabilized after 30 minutes. The CO content fluctuated between 8.76 and 12.65 % with a mean value of 10.98%. The CO_2 content gets decreased with respect to time from 14.27% to 11.78% with an average of 12.84%. The H_2 content fluctuated between 9.85 and 14.80% with a mean value of 12.93%. The CH_4 content fluctuated between 1.90 and 3.10 with an average value of 2.34%. Table 4. Comparing the performance of arecanut and wood in the gasifier it is seen that the CO content was less by nearly 1.6%, CO_2 was more by about 0.5%, H_2 was nearly same, CH_4 content was less by 0.8 % and HC was more by 421ppm. This result indicated clearly that arecanut is on par with wood as a gasifier feedstock as for as gas quality and hydrocarbon are concerned. Comparing the performance of coconut shell and wood in the gasifier it is seen that the CO content was less by nearly 1.1%, CO_2 was more by about 0.2%, H_2 was more by 0.5%, CH_4 content was nearly same and HC was less by 82ppm. This result indicated clearly that coconut husk was on par with wood as a gasifier feedstock as for as gas quality was concerned.

Figure 1, 2 and 3 give the temperature distribution across the reactor while gasifying 2 kg each of wood,

Table 7. Characterization of tar from coconut shell

Weight of coconut shell taken: 1.7 kg; Moisture content of coconut shell: 5.37%

Time, (mins.)	Moisture content, %	Viscosity, (cSt)	Density, (g/c.c)	pH	Weight of collected tar (g)	Weight of filtered tar (g)	Weight of water(g)	Weight of filtered tar/weight of collected tar	Air flow rate, (m^3/h)
10		12.49	1.11	2.55	50.04	12.93	37.11	0.258	
20		12.49	1.119	2.43	50.38	13.12	37.26	0.260	
30		12.49	1.106	2.37	37.51	9.62	27.89	0.256	
40	30.97	12.49	1.103	2.41	49.80	12.48	37.32	0.251	3
50		12.43	1.090	2.61	36.84	8.75	28.09	0.238	
60		12.43	1.024	2.48	48.15	9.26	38.89	0.192	
Average		12.47	1.09	2.48	45.45	11.03	34.43	0.243	

arecanut husk and coconut shell.When wood was gasified, the temperature developed at the pyrolysis zone was ranging from 115 to 238°C. The temperature at the oxidation zone was ranging from

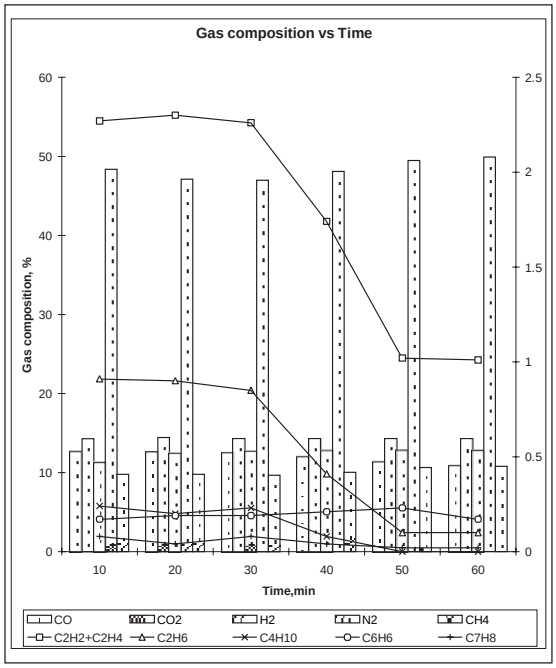

Fig 5. Composition of gas during catalytic cracking of tar

650 to 920°C and that of the reduction zone was ranging from 300 to 430°C and the flame temperature was fluctuating from 640 to 695°C. When arecanut husk was gasified, the temperature developed at the pyrolysis zone was ranging from 112 to 223°C. The temperature at the oxidation zone was fluctuating from 625 to 870°C and that of the reduction zone was ranging from 295 to 412°C. The flame temperature was fluctuating from 635 to 693°C. When coconut shell was gasified, the temperature developed at the pyrolysis zone was ranging from 119 to 226°C. The temperature at the oxidation zone was fluctuating from 675 to 926°C and that of the reduction zone was ranging from 310 to 438°C. The flame temperature was fluctuating from 650 to 724°C.

At an airflow rate of 3 m^3/h, an average value of 71.49 g of tar was collected from 1.7 kg wood chips. An average value of 47.88 g from and 66.14 g from coconut shell was obtained from 1.7 kg each of arecanut husk and coconut shell. The results indicated that for the same air flow rate and gasifier conditions, from the same weight of biomass the tar quantity will be less in coconut shell and arecanut husk when compared to wood. The lower quantity of tar in arecanut husk was due to the low volatile content of arecanut husk when compared to wood and coconut.

Table 8. Tar in the gas when running with optimized parameters

Sl.No.	Weight of Biomass, (kg)	Superficial velocity, m/sec	Retention time in filter, sec.	Tar yield ,g/m^3
1.	1.7	0.06	10	1.67
2.	1.7	0.06	10	1.64
3.	1.7	0.06	10	1.63
Average	1.7	0.06	10	1.65

Table 5, 6 and 7 shows the characteristics of tar collected during the gasification of wood, arecanut husk and coconut shell. Comparing the characteristics of tar from it is seen that quantity of tar was low in coconutshell and arecanut husk compared to wood. The viscosity of tar from these biomass are nearly same in the range 12.45 to 12.56 centistokes. Density of tar is also nearly same in the range of 1.08 to 1.34 g/ c.c. The pH value for wood tar and coconut shell tar are nearly same. But the pH value of arecanut husk tar is found to be high. An average pH value of 4.47 is reported in arecanut husk tar, which is higher than the average value of 2.57 in wood tar and 2.48 in coconut shell tar. The results indicated that the tar from wood and coconut shell tar are highly acidic when compared to the tar from arecanut husk requiring proper selection of materials for gasifier components.

The dry filter system was designed and the dimensions were (i) Diameter of dry filter-15.5 cm, (ii) Filter bed height-60 cm, (iii) Height of filter-90 cm

and (iv) Superficial gas velocity-0.06 m/s, (vi) Residence time - 10 Sec. Table 8 shows the tar content of producer gas at optimized parameters.

Tar content of gas without cleaning system

= 71.49 g/1.7kg (from Table 2)

= 71.49g/4.13 m^3

= 17.31 g/ m^3

Tar conversion efficiency

= [1–(1.65/17.31)] x 100= 9 0.5%

Tar conversion efficiency of 90.5% was achieved.To reduce the tar content of producer gas further, study on catalytic cracking of tar was carried out. Dolomite was used as the catalyst. Gas composition during catalytic cracking of tar is presented in the Table 9. From the table it is seen that as the temperature increased from 675°C to 935°C, there was a decrease in carbon monoxide yield from 12.60% to 10.87% due to the water-gas shift reaction. Similarly the carbon dioxide yield decreased with increase in temperature due to the same water-gas shift reaction. The hydrogen content after getting stabilized increased with temperature due to the production of hydrogen from cracking of light and heavy hydrocarbons (Fig 4). The tar yield decreased from 0.94 g to 0.08 g when the temperature increased from 675°C to 935°C. From this observation it was clear that the tar yield decreased with increase in temperature (Fig.5).

Tar conversion efficiency

= [1 – (2.14/ 67.80)] x 100 = 96.9 %

Table 9. Composition of wood gas during catalytic cracking of tar (Dry basis)

Weight of wood taken: 1.7 kg

Time, mins.	Temperature, °C	Gas Composition, %										Tar produced (g)
		CO	CO_2	H_2	N_2	CH_4	C_2H_2+C_2H_4	C_2H_6	C_4H10	C_6H_6	C_7H_8	
10	675	12.60	14.28	11.33	48.36	9.76	2.27	0.91	0.18	0.17	0.08	0.94
20	750	12.57	14.42	12.50	47.11	9.77	2.30	0.90	0.14	0.19	0.04	0.53
30	805	12.43	14.29	12.75	46.97	9.65	2.26	0.85	0.17	0.19	0.08	0.31
40	853	11.95	14.27	12.83	48.08	10.02	1.74	0.41	0.05	0.21	0.04	0.17
50	890	11.30	14.25	12.86	49.46	10.63	1.02	0.10	0.00	0.23	0.02	0.11
60	935	10.87	14.20	12.87	49.90	10.79	1.01	0.10	0.00	0.17	0.02	0.08
Total												2.14

Using Dolomite as tar cracking catalyst, the tar conversion efficiency of 96.9 % was obtained. Comparing the effect of catalytic cracking with cleaning of gas with dry filter, the tar conversion efficiency was higher in the case of catalytic tar cracking than by dry cleaning of gas using filter.

The mass closure and the energy closure for the gasifier were calculated as 98.04% and 98.55% respectively.

Conclusion

Tar can be removed from producer gas by chemical and physical methods. Chemical methods include catalytic and thermal cracking. Physical removal of tar includes scrubbers, filters and wet electrostatic precipitators. Catalytic cracking has higher tar conversion efficiency than other methods of tar removal. By using dry filter system a tar conversion efficiency of 90.5% was achieved. But with catalytic cracking method a tar conversion efficiency of 96.9% was attained by using dolomite as a catalyst. The mass closure and the energy closure for the gasifier were calculated as 98.04% and 98.55% respectively.

References

Grover, P.D. 1989. Thermo-chemical characterization of biomass residues for gasification. Biomass research laboratory, chemical engineering department, IIT, New Delhi, vol.1.

Sirisomboon, P. 1991. Estimation of higher heating value of biomass in tropical regions. AMA, **22:** 81-84.

Coovattanachai, N. 1989. Biomass Gasification and Field development by the prince of Songkla University, Thailand, *Biomass* , **18:** 241-271.

Vassilatos, V. 1990. Thermal and Catalytic Cracking of Tar in Biomass Pyrolysis Gas, M.Sc. Thesis Reports submitted to Royal Institute of Technology, Stockholm.

Received: October 9, 2009; Accepted: February 25, 2010