

# TWO-STAGE GASIFICATION OF WOOD WITH PREHEATED AIR SUPPLY: A PROMISING TECHNIQUE FOR PRODUCING GAS OF LOW TAR CONTENT

**S. C. Bhattacharya and Animesh Dutta**

Energy Program, Asian Institute of technology, P O Box 4, Klong Luang, Pathumthani 12120, Thailand  
Tel: +662 524 5403, Fax: +662 524 5439, Email: [bhatta@ait.ac.th](mailto:bhatta@ait.ac.th)

**Abstract** - This paper presents the results of an experimental study on two-stage gasification of wood with preheated air. Very clean gas having a tar content of about 10 mg/Nm<sup>3</sup> or lower could be obtained from such gasification. For a given primary airflow rate, increase in the secondary airflow rate of the two-stage gasifier resulted in a decrease in tar content and CO<sub>2</sub> concentration while the concentration of CO and H<sub>2</sub> increased.

## 1. INTRODUCTION

A fixed-bed downdraft gasifier coupled to an internal combustion engine is known to be one of the very few practical alternatives for producing electricity from biomass on the range of 100-300 kW<sub>e</sub> (Solantausta and Kurkela, 1995). The main problems of gasifier-engine systems are caused by tar associated with the gas (Brewer et al., 1993; Parikh et al., 1993). Rapid deterioration of lubricating oil and consequent wear of engine has been mentioned in numerous publications (Parikh et al., 1993; Kuapp et al., 1984; Blomquist et al., 1982; Bohr, 1982; Kutz et al., 1983; Parikh, 1987). Thus, the tar content of the final cleaned and cooled gas for use in internal combustion engines must be very low.

As pointed out by Bhattacharya et. al (1998), different authors have suggested different desirable levels of tar of gas for engine applications; this ranges from 10 to 100 mg/Nm<sup>3</sup> (Brown et al., 1987; Bridgewater, 1995; Stassen, 1993).

Tar content of the producer gas to be used in engines is normally reduced by employing an elaborate gas cleaning/scrubbing system. Tar content of the cleaned gas found in practical gasifier systems is often in the range of 70 to 80 mg/Nm<sup>3</sup> (Coovattanachai, 1989; Karuppaswamy et al., 1993); this level of tar content is high enough to warrant a regular and rigorous maintenance schedule of producer gas powered engines. Also, besides being expensive and bulky, the gas cleaning system produces waste water which contain carcinogenic substances and may need further treatment before disposal (Guigon et al., 1989; Bridgewater, 1995).

In recent years, some attempts have been made to develop gasifier designs that drastically reduce tar production. A two-stage straw gasification process is being developed in the Technical University of Denmark (Nikolaisen, 1992; Hounmann, 1993; Houmoller, 1997). Tar content of this gasifier was reported to be only 35 mg/Nm<sup>3</sup>.

Two-stage gasification of biomass has been studied at the Asian Institute of Technology located at Bangkok, Thailand. Earlier studies showed that under certain conditions raw gas of tar

content about 50 mg/Nm<sup>3</sup> could be obtained from two-stage wood gasification (Bui et al., 1994). In a recent study, tar content of gas obtained from a system consisting of a charcoal gasifier coupled with a two-stage wood gasifier was found to be in the range of 19-34 mg/Nm<sup>3</sup> (Bhattacharya et al., 1998).

This paper presents results of an experimental study on two-stage gasification with preheated air aimed towards further reducing tar content of the final gas.

## 2. MATERIALS AND METHODS

### 2.1 Gasification System

A two-stage gasifier in which preheated air was supplied in two-stages was designed, fabricated and tested (Figure 1). The gasifier essentially consisted of four sections assembled together using suitable flanges and gaskets.

The top section consisted of three parts; an upper cylindrical fuel storage part, a middle conical fuel storage part and a lower cylindrical storage/reactor part. Near the bottom end of the lower cylindrical part, four tubes of diameter 10 mm were provided at equal intervals around the perimeter for first-stage (i.e. primary) air supply. An ignition port was provided at the same level as the first-stage air supply.

The second section of the gasifier was a mild steel cylinder of height 550 mm, with four 10 mm diameter tubes attached radially at an axial distance of 460 mm from the first-stage air supply ports; these tubes were used for second-stage (i.e. secondary) air supply.

The third section of the gasifier was also a mild steel cylinder and had a grate attached at a distance of 260 mm below its top flange. The part of the third section below the grate served as a gas solid separator.

The fourth or bottom section of the gasifier was an ashpit attached to the bottom of the third part.

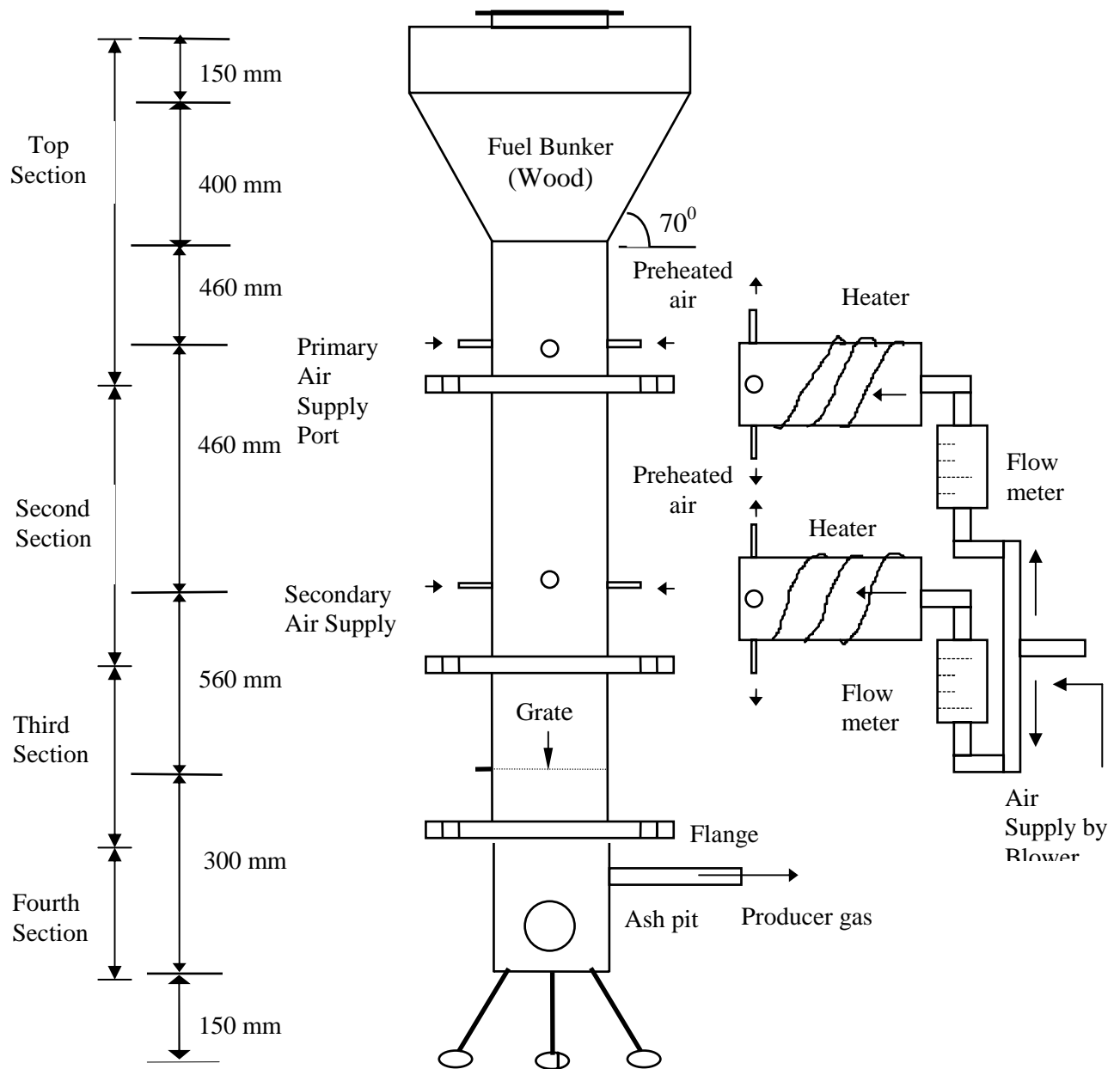


Figure 1. Two-stage wood gasification with preheater

The cylindrical parts of the gasifier (sections 2-4 and lower cylindrical part of section 1) were made from a mild steel cylinder of inner diameter 250 mm. The inner surface of these cylindrical parts of the gasifier unit was insulated with a 50-mm thick layer of fire clay so that the effective inner diameter of the gasifier was 150 mm.

Air from a central blower was supplied to each gasifier stage through a control valve and a rotameter. Produced gas left the gasifier through a pipe connected to the ashpit.

Two air preheater units as shown in Figure 1 were used to preheat air supply to the two gasifier stages. Each preheater unit consisted of a 3 inch diameter galvanized iron pipe with three electrical heaters in the form of copper tubes (2000W, 2m long) having internal insulated heating wire wound around it. A ceramic wool layer of 25-mm thickness was used to insulate each preheater unit to reduce the heat loss from it.

### 2.2 Raw Materials

Wood in the form of bars of nearly square section were cut into chips of cubic shape with sides in the range 10-15 mm. The measured properties of the wood chips as used for gasification without preheating are given in Table 1. The moisture content of the wood increased somewhat during storage, and was 17.3% for experiments on gasification with preheated air.

Table 1. Average Properties of Wood Chips

Apparent density, (kg/m <sup>3</sup> )	879
Bulk density, (kg/m <sup>3</sup> )	417
Moisture content, %	15.4
Volatile matter, %	72.7
Fixed carbon, %	11.6
Ash, %	0.3

### 2.3 Experimental Procedure

The two-stage gasifier initially was loaded with charcoal up to the first-stage air supply level and wood above this level. It can be seen that the two-stage gasifier with preheater involved preheated air supply in two stages, e.g. primary and secondary. To start the system, a suction blower was used to suck in a flame torch held near a port at the same level as the first-stage air supply. When combustion developed well inside the two-stage gasifier and the temperature of the air in the heating units exceeded 200°C, the suction port was closed and preheated air at desired rates was supplied to the two sets of air supply ports; primary and secondary. In order to investigate the effect of air flow rate on its performance, the gasifier was tested for different pairs of primary and secondary air flow rates: 80,80; 80,100; 100,100; 100,120; 120,120; 120,140; 140,140; 140,160; 160,160 l/min.

Two on-line gas analyzers were used to measure the composition of the produced gas. To analyze composition, the gas was passed first through a filter to remove associated particles and then through a condenser to remove tar and condensable vapors;

the cleaned and cooled gas was passed through the gas analyzers after practically steady state operation was achieved.

To measure tar content of the gas, the condensate produced as a result of cooling a known volume of raw producer gas was dried to a constant weight by placing the condensate container in an oven at 105°C (Parikh et al 1993); the residue left after drying was regarded as tar. Initially, a few condensate samples were dried at 105°C as well as 70°C for comparison. In general, tar contents obtained from drying at 105°C were lower by about 11% compared with drying at 70°C. Tar contents reported in this paper are based on drying condensate samples at 105°C.

## 3. RESULTS AND DISCUSSIONS

Temperature distributions inside the gasifier for an air supply rate of 140 l/min to both the stages with and without air preheating are shown in Figure 2. The temperature profiles show that there is a clear increase in temperature throughout the gasifier due to preheating of air. Rise in temperature as a result of preheating was more pronounced a few centimeters below the first-stage air supply level.

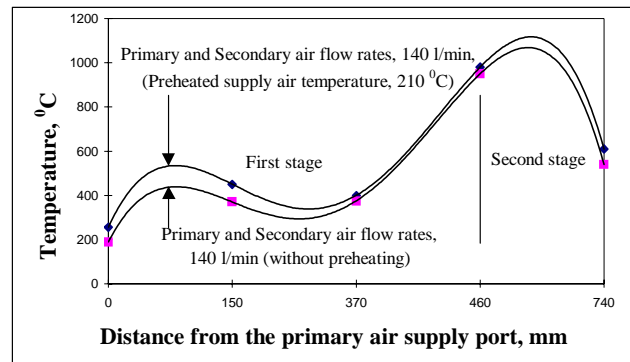


Figure 2. Temperature profile along the gasifier with and without preheating

Table 2 summarizes the results of test runs on gasification of wood with preheated air.

Tar in the producer gas was found to be significantly low in case of preheated air supply (Figure 3). For five of the nine experimental runs shown in Table 2, the measured tar content was below 10 mg/Nm<sup>3</sup>; it should be possible to use gas of such low tar content for trouble free operation of engines directly after filtering and cooling to remove particles and condensable vapours (i.e., without gas scrubbing).

It has been reported by Jonsson (1982) that even a slight increase of temperature above 950°C can significantly reduce tar content of producer gas. The low tar content with air preheating is obviously due to higher temperature levels prevailing inside the gasifier as a result of air preheating.

Table 2. Performance of Two-Stage Gasifier with Preheated Supply Air at Both Stages

Primary air supply (l/min)	Secondary air supply (lit/min)	Primary air temp. (°C)	Sec. air temp (°C)	CO vol. (%)	CO <sub>2</sub> vol. (%)	H <sub>2</sub> vol. (%)	Tar content (mg/Nm <sup>3</sup> )	
							With preheating	Without preheating
80	80	263	282	13.5	18.3	12.8	87.1	90
80	100	264	260	15.8	17.3	15.0	32.12	-
100	100	295	295	16.4	15.8	14.8	20.96	40.81
100	120	290	268	17.2	14.6	14.6	10.59	-
120	120	250	250	16.8	14.3	14.7	8.54	17.74
120	140	220	220	16.7	15.4	14.9	4.63	-
140	140	210	210	16.3	15.5	14.9	3.88	28.23
160	160	185	185	17.3	14.9	16.7	5.1	30.81
140	160	200	182	17.6	14.2	16.3	8.1	35

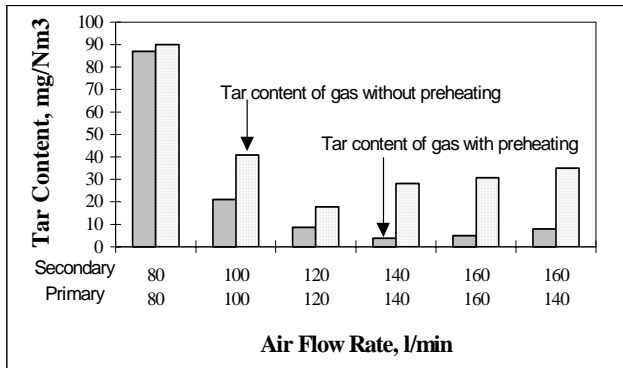


Figure 3. Comparison of Tar Content with and without preheating air supply rates

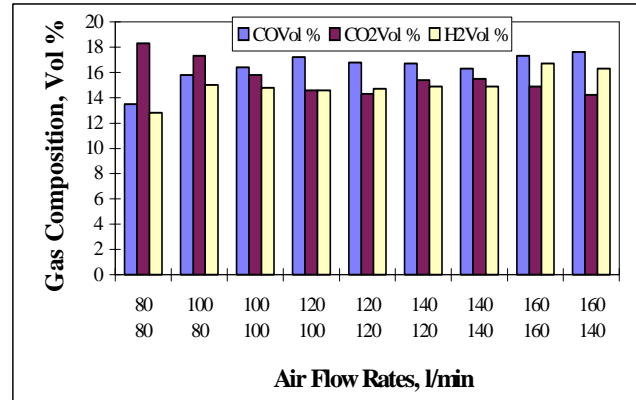


Figure 4. Effect of Air Flow Rates on Gas Composition

As pointed out earlier, moisture content of wood (17.3%) used with air preheating was slightly higher compared with that of wood (15.4%) used in case of no preheating. As a result, concentration of H<sub>2</sub> and CO<sub>2</sub> was found higher while that of CO was lower in case of gasification with preheated air compared with gasification with ambient air. High H<sub>2</sub> concentration at higher moisture content is obviously due to water gas reaction between steam and char producing H<sub>2</sub> and CO as well as the water gas shift reaction in which H<sub>2</sub> and CO<sub>2</sub> are produced at the expense of CO and steam. The higher CO<sub>2</sub> content is due to the shift reaction at higher moisture content of biomass. Similar results were also reported by Parikh (1985); Walawender et al. (1987) and Bhattacharya et al. (1998).

#### 4. CONCLUDING REMARKS

In case of two-stage gasification of wood with preheated air, tar content of the producer gas decreased as the air flow rate increased. For five of the nine experimental runs with preheated air, the tar content of the raw gas was found below 10 mg/Nm<sup>3</sup>, a value that meets the stringent requirement of gas quality required for running engines. Rise in temperature as a result of preheating was more pronounced a few centimeters below the first stage air supply level.

**Acknowledgment:** The authors acknowledge the support provided by the Swedish International Development Cooperation Agency (Sida) within the framework of the regional research and dissemination program, Renewable Energy Technologies in Asia.

#### REFERENCES

- Bhattacharya S.C., Siddique A.H.M. and Pham H.L. (1998). A Study on Wood Gasification for Low-Tar Gas Production, Accepted for Publication, *Energy, The International Journal*.
- Blomquist U. and Bohr E. (1982). Application of Engines to Generator Gas Operation, *GENGAS*, T.B. Reed (Ed.), pp. 199-229. Tipi Workshop Books, Allenspark, Colorado.

- Bohr E. (1982). Practical Operating Experience. *GENGAS*, T.B. Reed (Ed.) pp. 262-271.
- Brewer M.K., Brown R.C., Anderson I.C., Hall R.B. (1993). Performance of a Downdraft Biomass Gasifier Coupled to an Internal Combustion Engine. *Energy from Biomass and Wastes – XVI*, Institute of Gas Technology, Chicago, Illinois.
- Brage Claes, Qizhaung Yu and Krister Sjöström (1996). Characteristics of Evaluation of Tar from Wood Pyrolysis in a Fixed-Bed Reactor. *Fuel*, Vol. 75, No 2, pp.213-219.
- Brown M.D., E.G. Baker and L.K. Mudge (1987). Evaluation of processes for removal of particulates, tars, and oil from biomass gasifier product gases. *Energy from Biomass and Wastes X*, Elsevier Applied Science Publishers and Institute of Gas Technology, Chicago.
- Bridgewater, A.V (1995). The Technical and Economic Feasibility of Biomass Gasification for Power Generation. *Fuel*, Vol. 74, No. 5, pp. 631-653.
- Bui, T., Loof, R., Bhattacharya S.C. (1994). Multistage Reactor for Thermal Gasification of Wood. *Energy*, Vol. 19, No. 4, pp. 397-404.
- Coovattanachai, N. (1989). Performance of Small Steam Engine Operating on Wood and Rice Husk, pp. 91-23, 18, 241.
- Guigon, P. and Large, J.F. (1989). Gas Purification: A Review of the Available Methods of Gas Cleaning. *Pyrolysis and Gasification*, Ferrero, G.L. et al (Ed.), Elsevier Applied Science, London.
- Houmoller (1997). Fluid bed pyrolysis and gasification of biomass. <http://www.sh.dk/~cbt/>
- Hounmann H.J. (1993). Wood Chips for Energy Production. *Technology-Environment-Economy*, pp. 40-41, The Center of Biomass Technology, Danish Energy Agency.
- Jonsson O. (1982). Thermal Cracking of Tars and Hydrocarbons by addition of steam and oxygen in the cracking zone. *Fundamental of Thermo-chemical Biomass Conversion*, Overend, R.P (Ed.) pp. 733-745, Elsevier, London.
- Karuppaswamy M., Gnanavel R., Kumar S., Haridasan T. M., (1993). *Recent Advances in Biomass Gasification and Combustion*, Interline Publishing, Bangalore, India.
- Kaupp A. (1984). *Gasification of Rice Hulls*, GTZ/GATE, P.O. Box 5180, D-6236 Eschborn 1, Germany.
- Kaupp A., and Gross J.R., (1981). State of the Art Report for Small Scale (to 50 kW) Gas Producer Engine Systems, Final Report to the USDA/FS on contract #53-319R-0-141, University of California, Davis, CA, NTIS #PB85-102002.
- Kaupp A., and Gross J.R., (1984). *Small Scale Gas Producer Engine Systems*, p. 278, Deutsches Zentrum für Entwicklungstechnologie-GATE, Federal Republic of Germany.
- Kutz L.J., Barret J.R., Richey G.B., Jacko R.B. (1983). Downdraft Channel Gasifier Operation and Particulate Emissions. *Transactions ASAE*, Vol. 26, No. 6, pp. 1614-1618.
- Nikolaisen L. (1992). *Straw for Energy Production*, The Center of Biomass Technology, Denmark.
- Parikh P.P., Shashikantha and Kamat P.P (1993). Wear and Maintenance of Biomass-Based Producer-Gas Dual-Fuel Engine-- Effect of Tars and particulates. *Energy from Biomass and Wastes – XVI*, Institute of Gas Technology, Chicago, Illinois.
- Parikh P.P. (1985). *State of Art: Report on Gasification of Biomass*, Indian Institute of Technology, Bombay, India.
- Parikh P.P., Paul A., Bhave A.G. and Uma R. (1987). Tar in Producer Gas, Why and How Much. *Energy from Biomass and Wastes X*, Klass, D.L. (Ed.) Institute of Gas Technology, Chicago, Illinois.
- Stassen, H.E., (1993). *UNDP/WB Small Scale Biomass Gasifier Monitoring Report*, Vol. I, Biomass Technology Group, University of Twente, The Netherlands.
- Solantausta Y. and Kurkela E. (1995). *Feasibility of Electricity Production from Biomass by Gasification Systems*, VTT Energy, Technical Research Center of Finland.