Development of a Small Downdraft Biomass Gasifier for Developing Countries

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Abstract

Biomass gasification has been receiving increasing attention as a potential renewable energy source for the last few decades. This project involved designing, developing and testing a small downdraft biomass gasifier JRB-1 (6-7 kW) at Durham University, UK which could be a feasible solution for the supply of green energy in developing countries. The gasifier was built of stainless steel pipes, sheets and other fittings and tested for wood chips and pellets. The composition, moisture content and consumption of biomass feedstock (3.1 kg/hr for wood chips, 2.9 kg/hr for pellets), temperature inside the reaction zone (950-1150 $^{o}\mathrm{C}$*), primary air flow rate (0.0015* $\mathrm{m^3/s}$*) and exit temperature of the producer gas (180-220* $^{o}\mathrm{C}$*) was measured. The main constituents of syngas included Nitrogen (50-56%), Carbon monoxide (19-22%), Hydrogen (12-19%), Carbon dioxide (10-12%) and a small amount of Methane (1-2%). These results were used in Engineering Equation Solver (EES) software to obtain the lower calorific value of syngas (4424-5007* $\mathrm{kJ/m^3}$*) and cold gas efficiency (62.5-69.4%) of the gasifier, which were found close to the calculated values. Again the thermal efficiency was calculated as 90.1-92.4%. Being comparatively easy to build, downdraft gasifiers like JRB-1 are likely to be the most appropriate technology for developing countries as a source of decentralized power supply and for development in agricultural sector.*

Keywords: Biomass gasification, syngas, emission, renewable energy

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1. Introduction

One of the greatest achievement of man since the beginning of civilization has been the discovery and control of various forms of energy. Energy is a strategic input necessary for socio-economic development. Worldwide, 80% of all energy used by human comes from fossil fuels. Massive exploitation is leading to the exhaustion of theses resources and imposes a real threat to the environment mainly it would seem through global warming. Therefore scientists all over the world are trying to tap the sources of energy that are inexhaustible, cheap, absolutely pollution free and specially suited to remote places.

Of the renewable sources of energy, one of the promising is biomass especially for developing countries. One of the attractive technologies for alternative fuel from biomass is gasification which has been commercially applied for more than a century for the production of both fuels and chemicals. The equipment used in the gasification process is commonly referred to as gasifier. This project intended to design, develop and test a small downdraft biomass gasifier JRB-1 at Durham University, which was fuelled by wood chips and pellets. This was actually a modified version of Fluidyne gasifier suitable for developing countries.

2. Gasification

Gasification is a process of converting carbonaceous materials (biomass/coal) through incomplete combustion at temperatures of more than 1000 $^\circ C$ to combustible gases consisting of Carbon monoxide, Hydrogen, Carbon dioxide and small amounts of Methane etc. This gas mixture is commonly known as a producer gas or syngas while the reactor is termed as gasifier. Biomass gasification is considered as a potential renewable energy source for developing country due to:

- Capable of reducing wood consumption up to 50%
- Environmentally sound technology, reduce greenhouse gas emission
- Reduce dependency on fossil fuels
- Good use of domestic resources and boosts agriculture
- Comparatively easy technology
- Distributed generation (DG) or Island power systems

2.1. Gasification versus combustion

There is a significant difference between gasification and combustion processes.

- Gasification is not an incineration process like combustion; rather it is a conversion technology.
- Combustion processes usually take place with excess of air whereas gasification processes are conducted with limited amounts of air (35% of Stoichiometric conditions or less).
- The combustion processes usually produce CO_2, H_2O, SO_2, NO, NO_2, HCl whereas biomass gasification processes produce CO, H_2, H_2O, CO_2, N_2, NH_3, CH_4, H_2S, HCl, COS, HCN etc.
- Emission of S, NOx and particulate materials are remarkably reduced in the gasification. Moreover furan and dioxin are not formed during gasification processes as combustion.

2.2. Types of gasifier

Gasifiers can be classified according to:

(i) Method of heat introduced in the gasifier
  - (a) Direct-Fired Gasifier
  - (b) Indirect-Fired Gasifier

(ii) Basic reactor principles
  - (a) Fixed-Bed Gasifier

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(x) Updraft or Counter Current Gasifier
(y) Downdraft or Co-current Gasifier
(1) Imbert Type (Throated)
(2) Open Core Type (Throatless)
(z) Cross-draft Gasifier
(b) Fluidized-Bed Gasifier
(c) Entrained Flow Gasifier
(d) Plasma Gasifier
(iii) Gasifying media: Air/Steam/Oxygen/mixture of these.
(iv) Application of the producer gas
(a) Heat Gasifier
(b) Power Gasifier

2.3. Downdraft gasifier

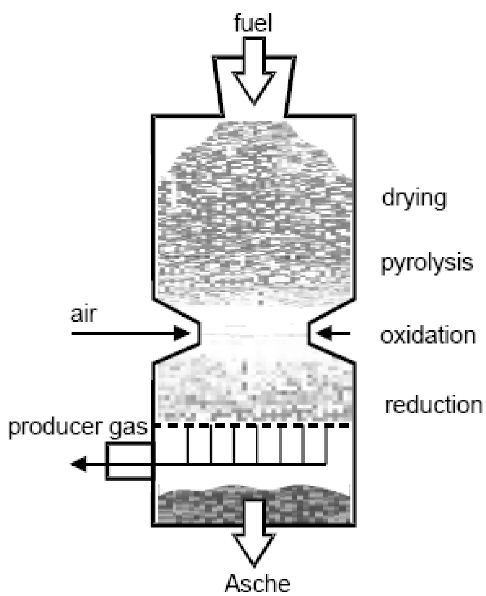

Fig. 1. Downdraft Gasifier

2.3.1. Features

- Aimed to solve the tar entrancement problem found in other types of gasifier to make it suitable for engine applications.
- Primary gasification air is introduced at or above the oxidation zone and producer gas removed from bottom of the gasifier
- Fuel and gas move in the same direction (co-current)
- On their way down acid & tarry distillation products pass through glowing bed of charcoal and converted to permanent gases.
- Depending on the temperature and residence time more or less complete breakdown of tar is achieved

2.3.2. Advantages

- Possibility of producing tar free gas
- Flexible adaptation of gas production to load
- Less environmental objection for condensate.
- Fuel conversion rates could attain over 95%

2.3.3. Disadvantages

- Major drawback is the inability to operate on a number of unprocessed fuels particularly fluffy, low density materials give rise flow problems and excessive pressure drop. Moreover solid fuels must be palletized, briquetted before use.
- Minor drawbacks are somewhat lower efficiency.

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Table 1. Commercial Installations of Some Downdraft Gasifiers [8]

Country	Fuel	Capacity	Organization/Project
USA	Hogged wood, stumps	1 MW	CLEW
	Wood chips and corn cobs	40 kW	Stwalley Engg.
Denmark	Wood residues	500 kW	Hollesen Engg.
New Zealand	Wood blocks, chips	30 kW	Fluidyne
France	Wood, agriculture residues	100-600 kW	Martezo
UK	Wood chips, hazel nut shells	30 kW	Newcastle University
	Industrial agriculture waste	300 kW	Shawton Engineering
Switzerland	Woody & agriculture waste	50-2500 kW	DASAG
	Wood, wood waste	0.25-4 MW	HTV Energy
India	Woodchips, rice hulls	100 kg/h	Associated Engineering
South Africa	Wood blocks, chips	30-500 kW	SystBM Johnson Gas
Netherlands	Rice husk	150 kW	KARA Energy System
China	Sawdust	200 kW	Huairou wood equipment
	Crops residues	300 kW	Huantai Integrate Gas System

2.4. Processes and reaction chemistry for the downdraft gasifier

As the feedstock proceeds through the different section of a downdraft gasifier the following physical, chemical and thermal processes may take place simultaneously or sequentially depending on the properties of feedstock and the design of the gasifier.

2.4.1. Drying zone or bunker section

Solid feedstock/biomass is introduced into the downdraft gasifier at the top. During feeding of the biomass, a small amount of air leakage is tolerable. Due to the heat transfer from the lower part of the gasifier, drying of biomass takes place in the bunker section.

Moist Feedstock + Heat → Dry Feedstock + H_2O (1)

Part of this water vapour reduces to hydrogen and the rest ends up as moisture in the gas.

2.4.2. Pyrolysis zone

At temperatures above 250 $^\circ C$, pyrolyzing of the biomass feedstock occurs. Wood pyrolysis is a complicated process and details of these reactions are still not well understood. However, we can surmise that large molecules (Cellulose, Hemi-cellulose and Lignin) are broken down into carbon (char) and medium size molecules (Volatiles).

Dry Feedstock + Heat → Char + Volatiles (2)

Up to 200 $^\circ C$, only water is driven off and temperatures in between 200 to 280 $^\circ C$, carbon dioxide, acetic acid and water are evolved. The actual pyrolysis reactions occur between 280 and 500 $^\circ C$ and produce large quantities of tar, gases and some methyl alcohol.

2.4.3. Oxidation or combustion zone

An oxidation/burning zone is formed in the section where air/oxygen is supplied. During the complete combustion processes, carbon dioxide and steam are formed. These combustion reactions are highly exothermic and result in a rapid temperature increase up to 1100-1500 $^\circ C$. The reactions are:

$C + O_2 = CO_2$ (+ 393 MJ/kg mole) (3)

$2H_2 + O_2 = 2H_2O$ (+ 242 MJ/kg mole) (4)

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Instead of generating heat, another important function of the oxidation zone is to convert and oxidize virtually all condensable products coming from the pyrolysis zone. In order to avoid cold spots in the oxidation zone, air inlet velocity and reactor geometry are carefully chosen.

2.4.4. Reaction or reduction zone

The reaction product of the oxidation zone flows downwards into the reduction zone. Here the sensible heat of the gases and charcoal is converted into the chemical energy of the producer gas. Reactions are:

$$C + CO_2 = 2CO \text{ (- 164.9 MJ/kg mole)} \quad (5)$$

$$C + H_2O = CO + H_2 \text{ (- 122.6 MJ/kg mole)} \quad (6)$$

$$CO + H_2O = CO_2 + H_2 \text{ (+ 42.3 MJ/kg mole)} \quad (7)$$

$$C + 2H_2 = CH_4 \text{ (+ 75 MJ/kg mole)} \quad (8)$$

$$CO + 3H_2 = CH_4 + H_2O \text{(-205.9MJ/kg mole)} \quad (9)$$

Generally the temperature of the reduction zone can reach 800-1000 $^\circ C$. The end product of this reduction zone is syngas.

2.5. Efficiency of gasifier

The cold gas efficiency of the gasifier is defined as:

$$\eta_g = \frac{H_g \times Q_g}{H_s \times M_s} \times 100\% \quad (10)$$

If the producer gas is used for direct burning applications, gasification efficiency can be defined as:

$$\eta_{th} = \frac{(H_g \times Q_g) + (Q_g \times \rho_g \times C_p \times \Delta T)}{H_g \times M_g} \times 100\% \quad (11)$$

Cold gas efficiency (η_g) of the gasifier can be varied between 60 and 75% whereas thermal efficiency (η_{th}) can reach up to 95%.

2.6. Properties of producer gas

The performance and suitability for operation of any type of gasifier depends on its producer gas qualities. The following factors affect the producer gas quality:

- Type of gasification system
- Type and composition of the feedstock
- Properties including size and preparation of the feedstock.
- Temperature of the hot zone
- Residence time of the feedstock in the hot zone
- Plant configuration including

  (i) Feed system- dry or slurry
  (ii) Ash or slag removal system
  (iii) Configuration of the grate system
  (iv) Gasifier heating system & heat losses
  (v) Syngas gas cleaning mechanism
  (vi) Producer gas outlet temperature

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Table 2. Composition of Producer Gas from Various Fuels [5]

Fuel	Volume Percentage					Calorific value MJ/m^3
	CO	H_2	CH_4	CO_2	N_2	
Charcoal	28-31	5-10	1-2	1-2	55-60	4.60-5.65
Wood	17-22	16-20	2-3	10-15	50-55	5.00-5.86
Wheat straw pellets	14-17	17-19	2-3	11-14	50-55	4.50
Coconut shells	19-24	10-15	2-3	11-15	50-55	7.20
Pressed sugarcane	15-18	15-18	2-3	12-14	50-55	5.3
Corn cobs	18.6	16.5	6.4	3.6	46	6.29
Rice hulls pelleted	16.1	9.6	0.95	3.6	46	3.25
Cotton stalks cubed	15.7	11.7	3.4	3.6	46	4.32

2.7. Fuels for the gasifier

Common biomass feedstocks for the gasifiers are charcoal, wood and wood waste and agriculture residues (coconut shells, coconut husks, straw, maize cobs, rice husks, pressed sugarcane etc.) All these fuels differ in physical, chemical and morphological properties. The most important fuel properties are

(a) Energy content of the fuel
(b) Moisture content
(c) Volatile matter content of the fuel
(d) Dust content
(e) Tar content
(f) Ash and slagging characteristics
(g) Reactivity & density of the fuel
(h) Fuel particle size and distribution

Table 3: Gasification Characteristics of Various Fuels for Downdraft Gasifiers [5]

Fuel	Treatment, Bulk density, Moisture	Tar (g/ m^3)	Ash (%)	Slagging
Alfalfa straw	Cubed, 298 kg/ m^3, m.c. =7.9%	2.33	6	No slagging
Coconut shell	Crushed, 435 kg/ m^3, m.c. =11.8%	3	0.8	No slagging
Rice hulls	Pelleted, 679 kg/ m^3, m.c. =8.6%	4.32	14.9	Severe slagging
Sugarcane	Cut 2-5 cm, 52 kg/ m^3	0.88	6.0	Minor slagging
Wheat straw	Cubed, 395 kg/ m^3, m.c. =9.6%	---	9.3	Severe slagging
Wood blocks	5 cm cube, 256 kg/ m^3, m.c.=5.4%	3.24	0.2	No slagging
Wood chips	166 kg/ m^3, m.c. =10.8%	6.24	6.26	Severe slagging

3. Design and development of the downdraft gasifier

This project involved designing, developing and testing a small biomass gasifier named JRB-1 at Durham University capable of running on wood chips or wood pellets. The first step was to find a feasible design, which could be taken as the basis for the gasifier construction. It was also decided that, at this stage, syngas would be burnt in a simple burner rather than feeding it to an engine. After a few technical considerations, it was decided to develop approximately 6-7 kW capacity downdraft gasifier based on the 'Fluidyne Gasifier' model with modifications.

3.1. Development of model of the gasifier

At the beginning of the project, it was decided that the main body of the gasifier would be divided into 3 pieces of pipe for easy fabrication of the internal parts. These three sections would be top cylinder (fuel chamber), middle cylinder (reaction chamber) and bottom cylinder (ash chamber). For reliability, longer life and future experimentation, the gasifier was decided to be built with stainless steel.

Depending on the available materials and the original Fluidyne model, drawings for different parts and the full gasifier were developed with SolidWorks drawing package

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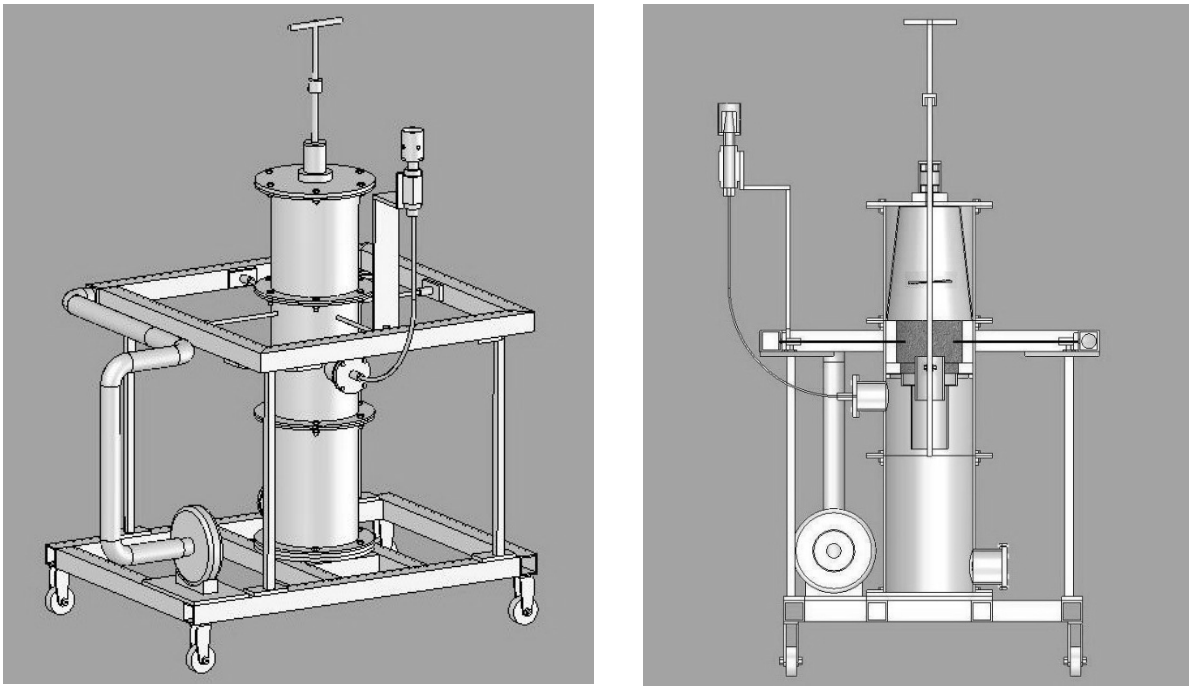

Fig. 2. Schematic and cross-sectional view of the planned JRB-1 gasifier

After developing SolidWorks model of gasifier, materials were collected for fabrication. This included stainless steel tubes/pipes, sheets, flanges; stainless steel straight fittings, copper gaskets, steel and braze metals, Gate valve and high temperature bearings etc.

Non-metal items included high temperature sealing materials/gaskets, thermal resistant cement (Refractory Castable 160 LC cement, service temperature 1600 $^{\circ}C$), insulating tape etc.

Electrical equipment included an air supply fan with duct and control system, thermocouples and gas velocity measuring speed-gun.

3.2. Manufacture of different parts and assembly

At the beginning of the construction, all the pipes/tubes and sheet metals were fabricated according to the drawings. The gasifier was sectionalized into the following parts:

3.2.1. Top part or fuel chamber

The top cylinder was made of 6.3 mm thick, 219 mm outer diameter and 272 mm length stainless pipe. It contained bunker and pyrolysis zones. Biomass feedstock dried here due to the convective and radiation heat transfer from the lower parts of the gasifier. A conical tube of 2.5 mm thick stainless steel was placed inside to avoid 'fuel bridging'. The capacity of the fuel chamber was approximately 5 kg of wood chips/pellets.

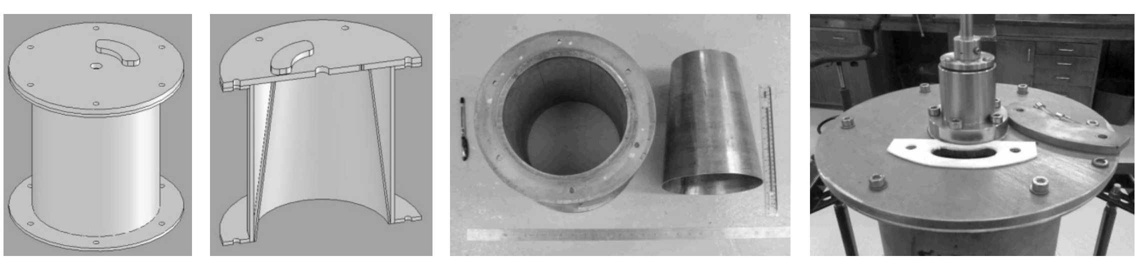

Fig.3. Schematic, cross sectional & manufactured view of top part

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3.2.2. Middle part or reaction chamber

The reaction chamber is the heart of the gasifier where the producer gas is produced. It contains the oxidation zone and the throat section of the gasifier. Fuels flow down by gravity. The middle cylinder was made of 6.3 mm thick, 219.1 mm outer diameter and 320 mm long stainless steel pipe. Inside this chamber there was a slab of thermal resistant concrete to provide insulation in hot zone. There were 4 holes in middle of the slab for the air supply nozzles. Two flanges were mounted at the top and bottom be attached to other chambers.

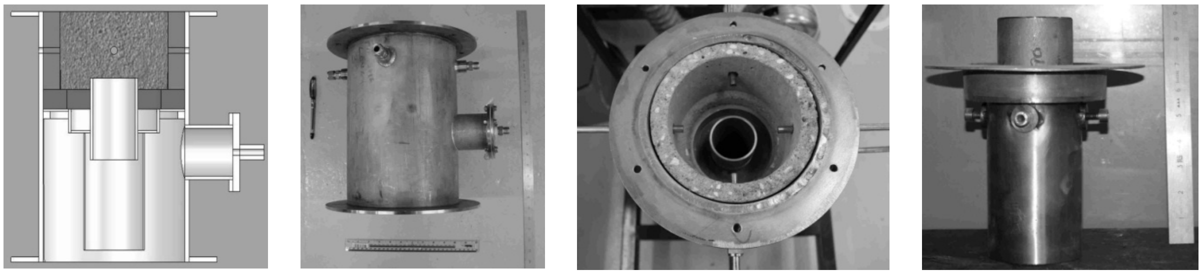

Fig.4. Cross sectional & manufactured view of middle part & throat section

Generally, two methods were applied to obtain an even high temperature distribution. Firstly, reducing the cross sectional area at a certain height ('throat' concept) and spreading the air inlet nozzles over the reduced cross sectional area. The throat section was made of two concentric stainless steel pipes of 70 & 88 mm diameter along with annular plates. The whole assembly seemed like a 'pocket' and gave the facility to change the depth of the throat pipe to modify the distance between the nozzles and the top of the reduction zone in the simplest way. The gas outlet pipe was made of 70mm stainless steel pipe.

3.2.3. Bottom cylinder or ash chamber

The lower cylinder contained the ash zone where the ash resulting from the gasification process of the biomass was stored and occasionally removed. The ash from the reaction chamber could fall down freely through the grate. The bottom chamber was made of 219.1 mm diameter and 325 mm long cylinder.

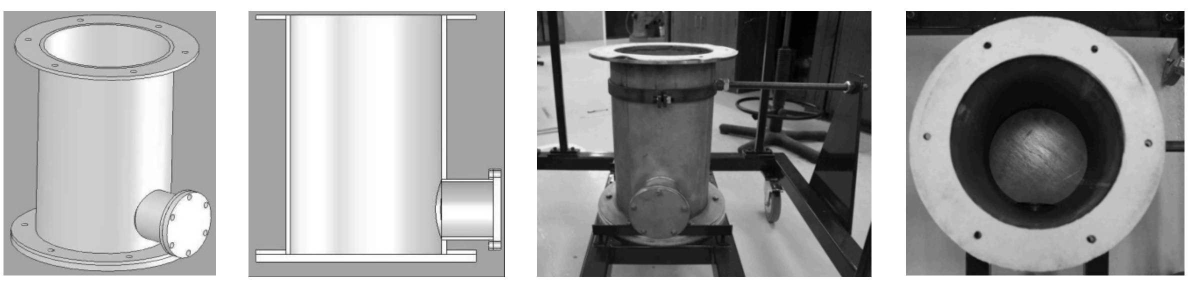

Fig.5. Schematic, cross sectional & manufactured view of bottom part

3.2.4. Stirrer and grate

Because of the fact that fuels often produce bridges, it is often required to use a stirrer. A moveable grate at the bottom is generally considered necessary. This makes it possible to stir the glowing charcoal bed in the reduction zone and thus helps to prevent blockages which can lead to obstruction of gas flow. In our gasifier, stirrer and grate were mounted on a single stainless steel rod (15 mm diameter) inserted from the top of the gasifier. The rod was occasionally rotated with a removable T-shaped handle.

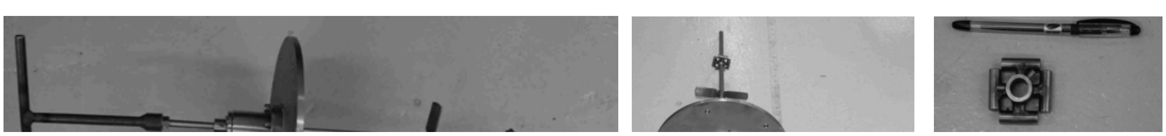

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Fig.6. Stirrer and moveable grate connected with top cover plate

3.2.5. Air supply system

Primary air in the oxidation zone was supplied by 4 air inlet nozzles (7 mm inner diameter) placed in the middle of the reaction chamber. These nozzles were connected to the square shape primary air inlet manifold placed around the middle cylinder. The manifold was constructed from 50x50x4 mm square mild steel pipes. Air was supplied to the manifold from a variable speed SAVT metal case centrifugal fan (Model: SAVT-100L, 230V, 85W and 0.60A, nominal speed 2550 rpm, maximum air volume 0.065 m^3/s at 40 $^\circ C$).

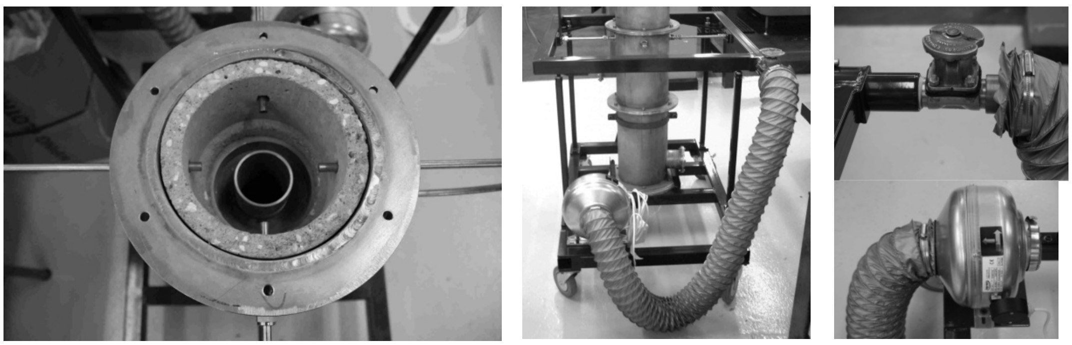

Fig.7. Air inlet nozzles, air supply system, gate valve and centrifugal fan

3.2.6. Other accessories and assembling

A gradually bending stainless steel pipe was connected to gas outlet and the other end was attached to a simple burner. For every flange joint, top and bottom cover plates, and fuel feeding channel a high temperature ceramic paper gasket (2 mm) was used. Again insulation material (Webbing tape, TW G3) was placed on the main body. Finally the gasifier was placed on a trolley so that it could be easily moved to a suitable place for testing. After assembling the final shape of the JRB-1 gasifier became as follows.

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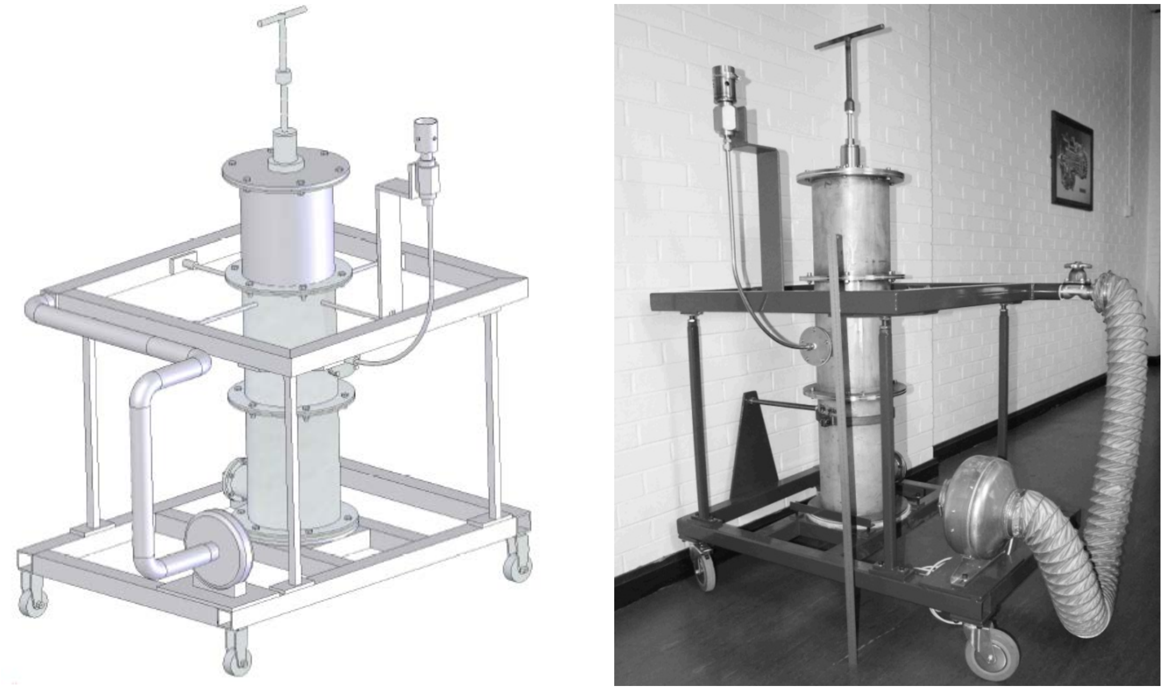

Fig.8. Schematic and final manufactured form of the JRB-1 gasifier

4. Operation and Testing of Gasifier

4.1. Operating procedure

The JRB-1 gasifier was operated and tested in the following steps:

(i) Before starting, all the parts (flanges attachment, fittings) of the gasifier were properly tightened and it was placed on open space.
(ii) The electrical fan for primary air supply was kept switched off.
(iii) The top cover of the gasifier was opened.
(iv) A thin layer of charcoal was placed near the throat (pocket area) of the oxidation zone and some was wetted with fire lighter (liquid) to initiate the combustion.
(v) The charcoal bed was ignited with a torch and fan was switched on to supply sufficient air/oxygen to initiate the combustion.
(vi) The top cover plate was closed and tightened.
(vii) Then the gasifier was loaded with biomass through fuel feeding hole.
(viii) During the second run, gasifier was loaded first and ignition was initiated from the down side through the ash hole. Finally an ignition port was cut to initiate combustion.
(ix) The primary air supply was full at the beginning and then maintained around 35% of the stoichiometric condition to ensure the partial combustion of the biomass using a fan-controller, gate valve and air flow meter.
(x) After 5 minutes, the producer gas in the form of thick white smoke came out through the burner.
(xi) The producer gas was ignited with a firing-torch at the burner.
(xii) A yellowish-red flame was observed and continued to ignite for more than 90 minutes.
(xiii) To stop the gasifier, first the fan was switched-off then the gate valve in the air supply channel was closed to completely stop the primary air supply.
(xiv) The gasifier was ultimately stopped after closing the air supply and left in an open space until it cooled down and all gases came out of the gasifier (more than 6 hours).

During the testing of the gasifier the following measurements were taken:

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(a) Primary air velocity & volumetric flow rate of syngas was measured by VELOCICALC Air Velocity instrument. The average air velocity of primary air during the experiment was found in between 6.35 and 8.75 m/s at the gas outlet pipe of ID16 mm. Therefore, volumetric air flow rate was in between 0.00127 and 0.0017 m^3/s. The best result was obtained at 0.0015 m^3/s of air flow rate.
(b) Average solid biomass fuel consumption was measured using digital weight machine. The biomass feedstock was dried in the BINDER electrical oven.
(c) Temperature in the reaction zone and gas outlet zone were measured with the help of a K-type thermocouple and Autoranging multimeter. Throughout our testing, the temperature of the hot zone was found up to 1160 ^{o}C. The producer gas temperature at the generator exit was 180-230 ^{o}C.

4.2. Safety issues during testing

Since the gasifier produced syngas containing toxic and flammable carbon monoxide, methane, hydrogen etc., and the temperature in the oxidation zone was more than 1100 $^{\circ}C$, a number of safety measures were taken to avoid toxic, fire and explosion hazards.

a. Before starting, every joint and fitting was properly tightened to avoid leakage.
b. Tests were carried out in open space and the combustion products were exhausted to the atmosphere.
c. Biomass feedstocks were handled with hand gloves.
d. Safety glass, rigid sole footwear and insulated hand gloves were used during testing.
e. A standard first aid box and fire extinguishing equipment (CO_2/dry powder) were kept ready for emergencies.
f. After testing, the gasifier was cooled down for a 6 hours period and all the gas was ventilated in open air and the ash was disposed of in the waste bin.

4.3. Fuel tested

The downdraft biomass gasifier was tested for two types of fuels i.e. wood chips and wood pellets. The fuels were processed before loading into the fuel chamber. Both wood chips and pellet were supplied by BTL Woodshed Limited, Bp Auckland; Durham.

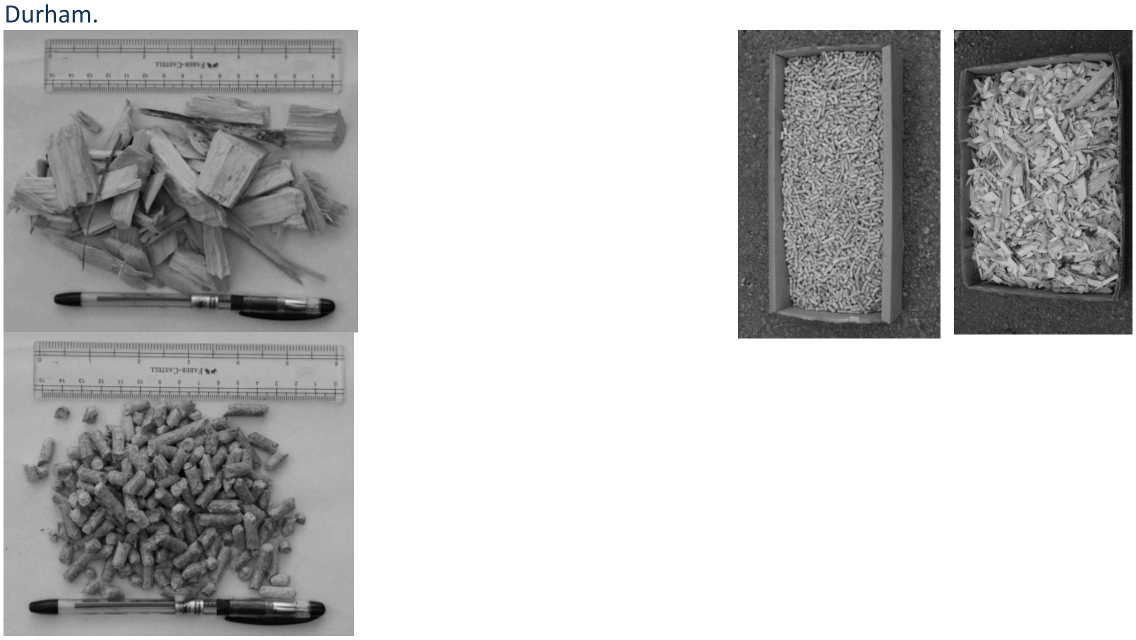

Fig.9. Wood chips and wood pellets tested in the JRB-1 gasifier

The average size of the woodchips was 30-70mm and wood pellets were 15-30mm with 6mm in diameter. Wood chips/pellets were naturally dried for 2 days and electrical oven dried at 105 $^{\circ}C$ for 3-4 hours.

Table 4: Average Properties of the Fuel Used in the JRB-1 Gasifier

Properties	Wood chips	Wood pellets	Reference

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Apparent density (kg/m^3)	280-550	600-700	[4], [5]
Ultimate Analysis (dry basis) Carbon (weight, %) Hydrogen (weight, %) Oxygen (weight, %)	 46-54 4-6 38-43	 41-48 6-8 42-46	 [4], [5] [4], [5] [4], [5]
Proximate Analysis (wet basis) Moisture content (%) Volatile matter (%) Fixed carbon (%) Ash (%)	 7.36 65-75 15-20 0.338	 8.55 80-85 6-10 0.574	 Laboratory Testing [4], [5] [4], [5] Laboratory Testing

5. Result and Discussion

The gasifier was first fired on 10th July 2009 using wood chips as fuel. Next few days, it was tested for wood pellets and chips and performance in different conditions was observed. Based on these, few modifications were conducted in design. During the first run, unstable flame and tar came out through the burner. The reasons identified were the low temperature in the oxidation zone, short residence time of the tarry vapours due to high gas velocity in the hot zone and wet wood chips. Therefore the gas outlet pipe was replaced with a larger bore (OD=34 mm) stainless steel pipe. Another important modification was made in the burner to reduce gas velocity. Finally the hot parts of the gasifier were insulated with webbing tape (TW G3) to reduce heat loss and an ignition port was made close to the reaction zone. With these modifications it was possible to obtain up to 1160 $^{\circ}C$ temperature in the hot zone and stable flame was observed for 91 minutes.

5.1. Biomass fuels consumption

When the gasifier was run on wood pellets, it consumed around 4400 gm of fuel to give a stable flame for 91 minutes (approximately 2.9 kg/hr). On the other hand, when it was loaded with wood chips, fuel consumption was 3.1 kg/hr.

5.2. Producer gas composition

From the moisture content of the biomass feedstock, the composition of producer gas was calculated using the wood gas composition graphs.

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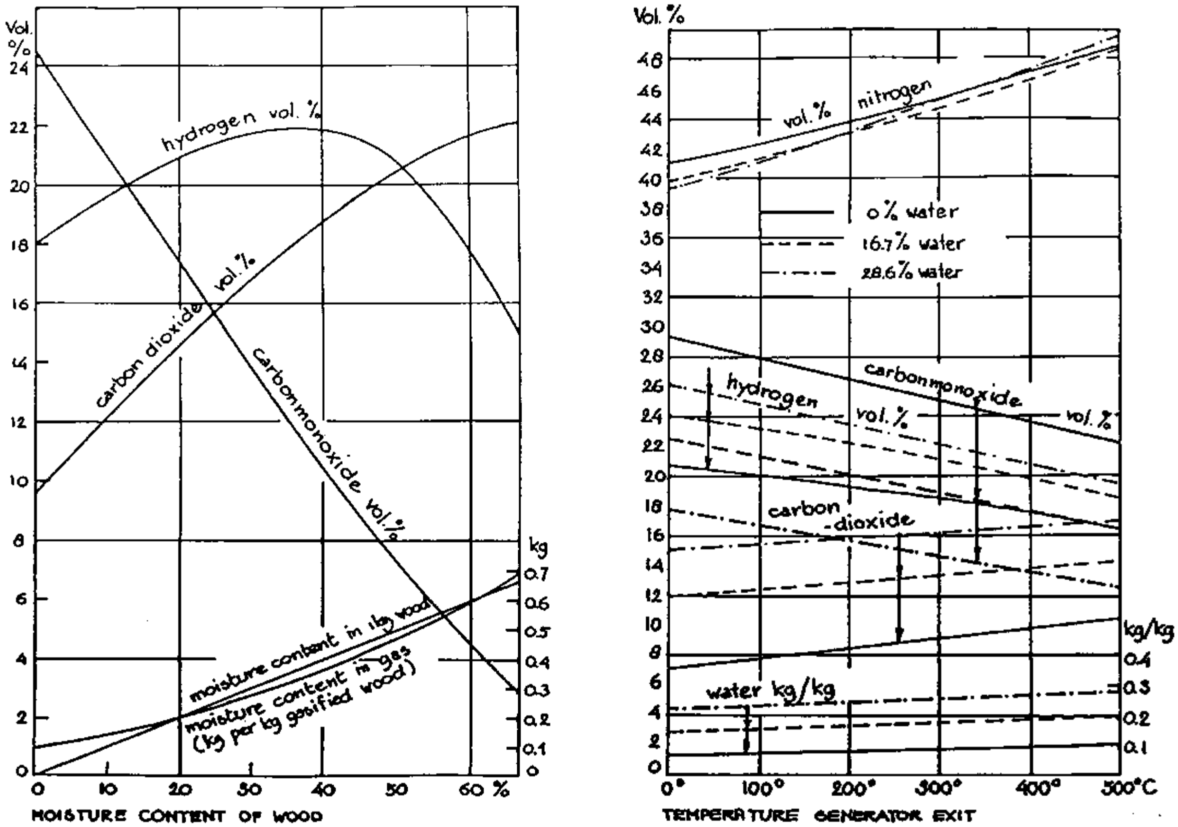

Fig.10. wood gas composition graphs [7]

Table 5: The Composition of Producer Gas (% of Volume)

Fuels	Moisture dry (%)	CO	H_2	CH_4	CO_2	N_2	Moisture in gas (kg/kg of wood)
Wood Chips	7.36	21-22	17-19	1-1.5	10-11	50-55	0.1
Wood Pellets	8.55	19-21	12-19	1-2	11-12	52-56	0.12

Table 7: The Change in Composition of Producer Gas (% of Volume)

Fuels	Temp (^{o}C)	CO	H_2	CH_4	CO_2	N_2	Moisture in gas (kg/kg)
Wood Chips	180-230	23	20	1.5	11	43.7	2
Wood Pellets	220-240	22	20.5	2	11.5	44	2

5.3. Analysis of producer gas using engineering equation solver (EES) software

The producer gas obtained from the different feedstocks was analyzed with a special model of Engineering Equation Solver (EES) software particularly suitable for a stationary model of downdraft gasifier (Felicia Fock and Kirstine Thomsen, 2000, DTU, MEK, Denmark).

5.3.1. Input parameters

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Wood chips: Consumption = 3.1 kg/hr, CH_4=1%, Moisture content=7.36%, Element composition=$CH_{1.586}O_{0.7089}$, Reaction zone temp= 950 ^{o}C, Charcoal=3%, Gas temp=200 ^{o}C.

Wood pellets: Consumption = 2.9 kg/hr, CH_4=2%, Moisture content=8.55%, Element composition=$CH_{1.615}O_{0.664}$, Reaction zone temp= 1150 ^{o}C, Charcoal=3%, Gas temp=220 ^{o}C.

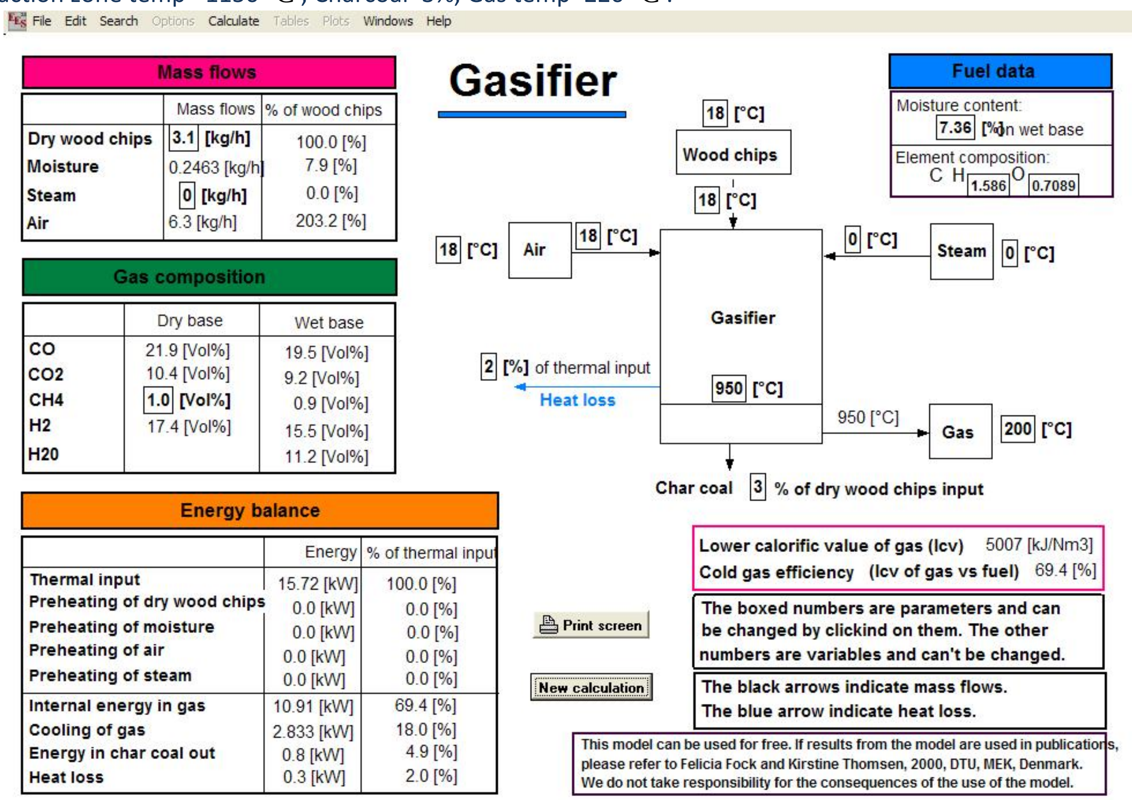

Fig.10. Gasifier performance calculation using EES software

5.3.2. Simulation output

Wood Chips: Lower calorific value of gas (LCV) = 5007 kJ/m^3

Cold gas efficiency (LCV of gas vs. fuel) = 69.4% (At ambient temp=18 ^{o}C)

Wood Pellets: Lower calorific value of gas (LCV) = 4424 kJ/m^3

Cold gas efficiency (LCV of gas vs. fuel) = 62.5% (At ambient temp=20 ^{o}C)

5.4. Cold gas efficiency of the gasifier

From equation (10) & (11), the cold gas and thermal efficiency of the gasifier is defined as:

$$\eta_g = \frac{H_g \times Q_g}{H_s \times M_s} \times 100\% \qquad \eta_{th} = \frac{(H_g \times Q_g) + (Q_g \times \rho_g \times C_p \times \Delta T)}{H_g \times M_g} \times 100\%$$

H_g = LH

Q_g= Vo

H_s= LHV of gasifier fuel; for wood chips13-15000 kJ/kg and wood pellets14-17000 kJ/kg

M_s= Solid fuel consumption; for wood chips 0.000867 kg/s and wood pellets 0.000805 kg/s

ρ_g = Density of producer gas, 1.3 kg/m³ (approx.)

C_p= Specific heat of the producer gas, 1.45 kJ/kg°K (approx.)

ΔT= Temp difference between the gas outlet and fuel inlet, 200 ^{o}C or 473 K (approx.)

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η_g = Overall cold gas efficiency, for wood chips 66.66 % and wood pellets 58.89 %
η_{th}= Thermal efficiency of the gasifier, for wood chips 90.1% and wood pellets 92.4%
P_g = Thermal power of the syngas, Q_g x H_g =0.0015x4424=6.636 kW (approx. for pellets)
P_{th} = Thermal power consumption (full load), P_g / η_{th} =6.636/0.924=7.18 kW

5.5. Limitations of JRB-1gasifier operation

The small JRB-1 downdraft biomass gasifier was developed for testing purpose. Therefore there were number of technical and operational limitations:

- The gasifier was not built for continuous operation and the fuel chamber capacity was approximately 5 kg of biomass to run 1.5 hours of operation. At each refuelling, the top cover needed to be opened and this caused a lot of air leakage and heat loss.
- The design did not include any special fuel feeding hopper. Instead, a simple small fuel feeding hole was used. It was difficult and time consuming to feed the biomass in the reaction zone.
- In first design, there was no ignition port to initiate the combustion in the oxidation zone. Ignition was initiated either from the top or from the bottom.
- Since the stirrer was attached to the top cover plate, opening, fuel feeding and operation process was always very difficult.

5.6. Feasible application of JRB-1 gasifier in developing countries

Biomass gasification using JRB-1 type gasifier could have many potential applications in developing countries, including:

1. Direct thermal application in agro industries. The main advantages of gasifiers in heating applications are the ability to produce higher temperatures than conventional burning systems, better control over heating systems, enhancement of boiler and total efficiency, lower emissions etc. Therefore it could be used as dryer in tea and cardamom industries; tiles, potteries, ceramic industries; to run furnaces in some foundry industries and in metallurgical industries where high temperatures (up to 1000 $^{\circ}C$) is required, to run boiler in rice processing industries etc.
2. Shaft power applications in the agriculture sector, i.e. farm machinery such as harvesters, tractors, grinding machines etc. Another potential field for gasifiers in the agriculture sector is irrigation.
3. Combined Heat and Power (CHP) application, distributed power generation in remote and rural areas.
4. Stand-alone power systems
5. Chemical production

6. Conclusion

Biomass gasification offers one of the most promising renewable energy systems, particularly for agricultural purpose in developing countries. The main focus is on fast growing trees, woody grass and agricultural residues. A more extensive and attractive system could be a downdraft gasifier capable of generating a syngas with sufficiently low tar content for engine applications. The biggest challenge in gasification systems is considered as being the reliable and economical cooling and cleaning technology. The successful JRB-1 gasifier project at Durham University opens a door to ensure effective use of biomass and to reduce emission in agro industries. On the whole, the primary aims of the project were achieved. Finally we can say, being comparatively easy to build using low coast materials, downdraft gasifiers like JRB-1 could be an attractive technology for thermal and power applications in developing countries.

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