Technologies for Biomass Utilization

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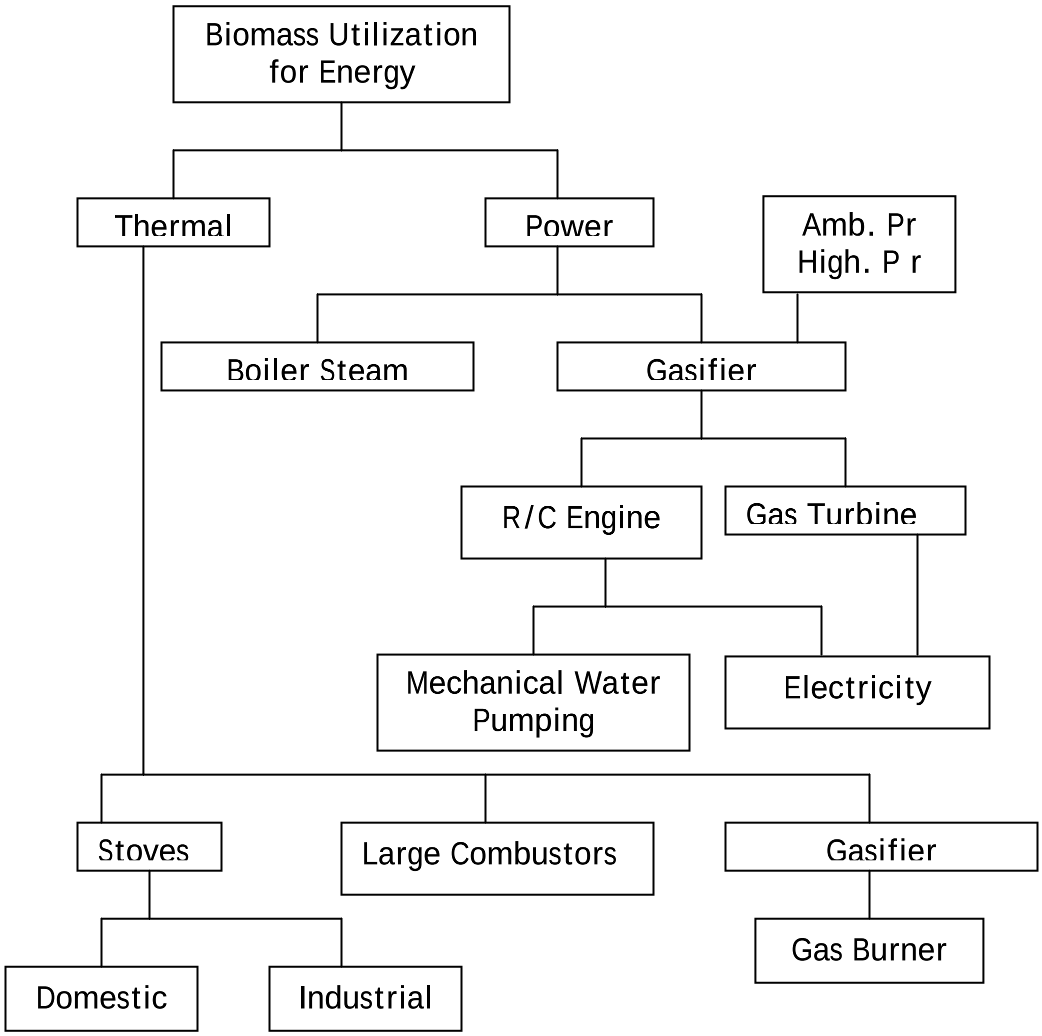
Technologies for Biomass Utilisation

- **Biomass utilisation strategy**
- **Applications to be serviced**
- **Biomass classification and properties Gasification?**
- **Combustion vs. Gasification**
- **Woody biomass gasifier (thermal and electric)**
- **Pulverised fuel gasifier (thermal and electric)**
- **Engine operation**
- **Technologies available**

Biomass Utilisation Strategy



Applications

Thermal (Diesel/Electricity Replacement)

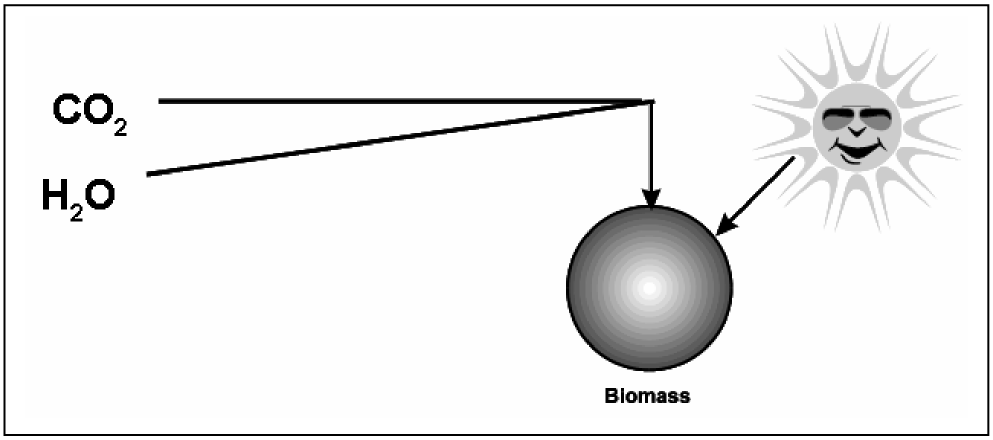
- Drying⇒50 to 150 °C(with/without clean up)
- Hot water/cooking ⇒100 to 500 °C
- Non ferrous melting ⇒ ~ 1200 °C
- Ceramic industry ⇒ ~ 1350 °C

Mechanical/Electrical Power

- Water pumping 2.0, 3.7 kW, upto 100 kW
- Rural electrification 3.7 to 100 kWe

Industrial electricity servicing upto 5 MWe

Varieties of biomass / Waste

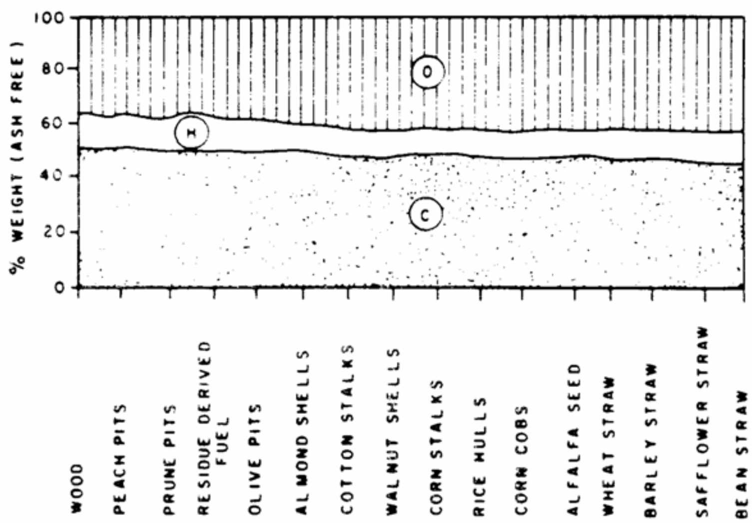


- Biomass is stored solar energy.
- There is inadequate recognition of this for the construction of economically viable, renewable and clean technologies.
- Biomass can be classified as woody and non-woody.
- Woody biomass is essentially the solid stalk of the main trunk and branches in trees/plants. It is a structural element in the living material. It is dense and has little ash.
- Even agricultural residues which may consist of whole plants or branches of plants can be woody, like cotton stalk and mulberry stalk. Weeds like Juliflora Prosopis, Lantana camera, usually found in tropical climates can also be treated as woody biomass.

Bio-resource classification

WOODY	**PULVERISABLE**
Branches of wood	Rice husk, Rice straw
Some agricultural wastes	Saw dust
Cotton sticks	Sugarcane trash
Mulberry sticks	Bagasse
Lantana Camara, Prosopis Julifora	Coir pith, Peanut shells
Density > 250 - 300 kg/m3	< 250 - 300 kg/m3
Ash < 2 %	~ 6 - 20 %

Ultimate Analysis of Wood and Coal (32).



Ultimate Analysis of Biomass Fuel Tested at the University of California, Davis.

Even though woody and non-woody classification is important, it is useful to recognise that the composition is nearly same over a number of species.

<u>Composition of Biomass:</u> $CH_n\ O_m\ N_p$

Material	n	m	p
Rice husk	1.78	0.56	0.007
Saw dust	1.65	0.69	-
Paper	1.60	0.65	0.005
Rice straw	1.56	0.50	0.008
Douglas fir, Beech, poplar	1.45	0.60	0.002
Pine bark, Red wood	1.33	0.60	0.002

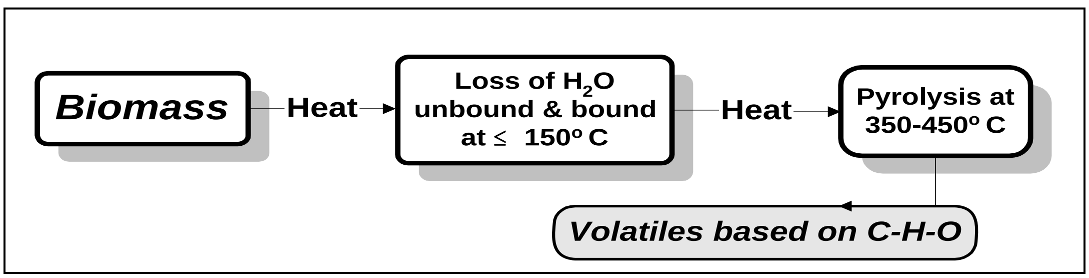
Structurally, biomass is composed of about 50% cellulose, 25% hemicellulose and 25% lignin. Cellulose and hemicellulose break down easier than lignin, thermally as well as bacterially.

Biomass as Volatiles + Carbon + Ash:

When biomass is heated, it begins to loose moisture, unbound first and bound later.

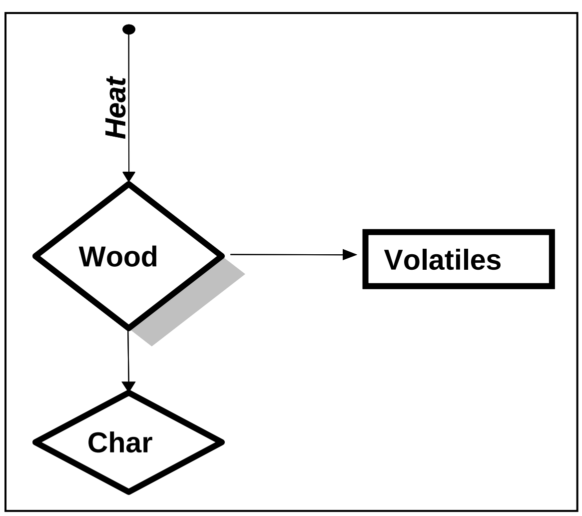
Bulk Densities of Common Pulverised Fuels

Fuel (sun dry)	Ash (%)	Bulk Density (kg/m3)
Saw dust (< 3 mm)	< 1.0	300 - 350
Rice husk	20	100 - 130
Rice husk pulverised (< 2 mm)	20	380 - 400
Sugar cane trash (chaff cut)	6	50 - 60
Sugar cane trash (pulverised, < 4 mm)	6	70 - 90
Ground nut shell	3.5	120 -140
Ground nut shell (pulverised, < 2 mm)	3.5	330 - 360

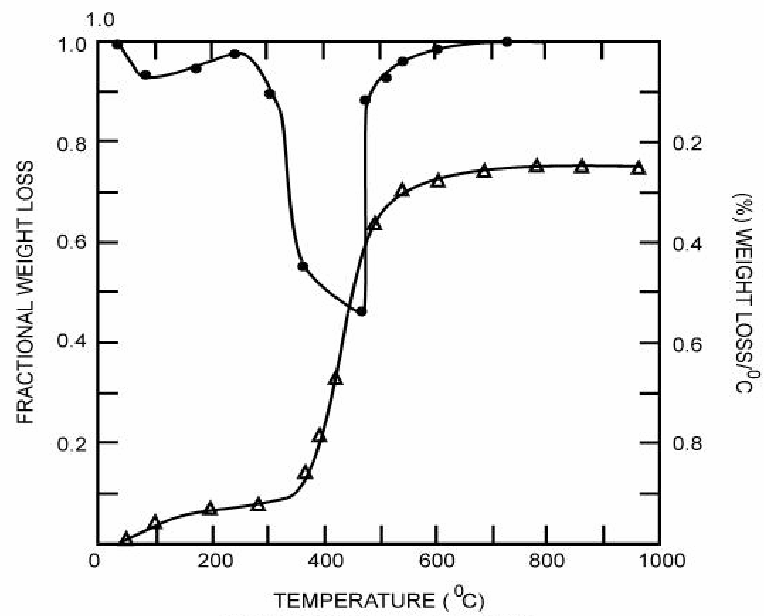


Most Hydrogen will be lost during this process. What will be left behind is called char, consisting of mostly carbon, but some hydrogen and oxygen are also left behind. Typical composition of char could be CH0.1o0.06N0.002.

These can be represented as follows

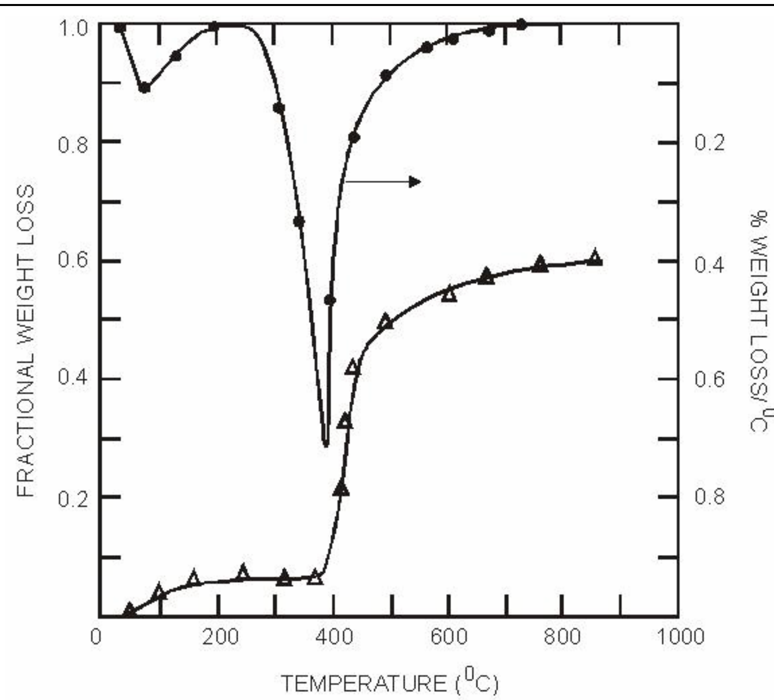


To understand what happens to the weight of a sample of wood when it is heated, one conducts an experiment called Thermogravimetric analysis. A sample is placed in a fine quartz balance and heated at a specific heating rate. The weight of sample with temperature is measured.



THERMOGRAM OF BAGASSE

Source: Thermochemical charactoisation for biomass residues, Grover P D, IIT Delhi, "94



THERMOGRAM OF RICE HUSK

Source: Thermochemical charactoisation for biomass residues, Grover P D, IIT Delhi, "94

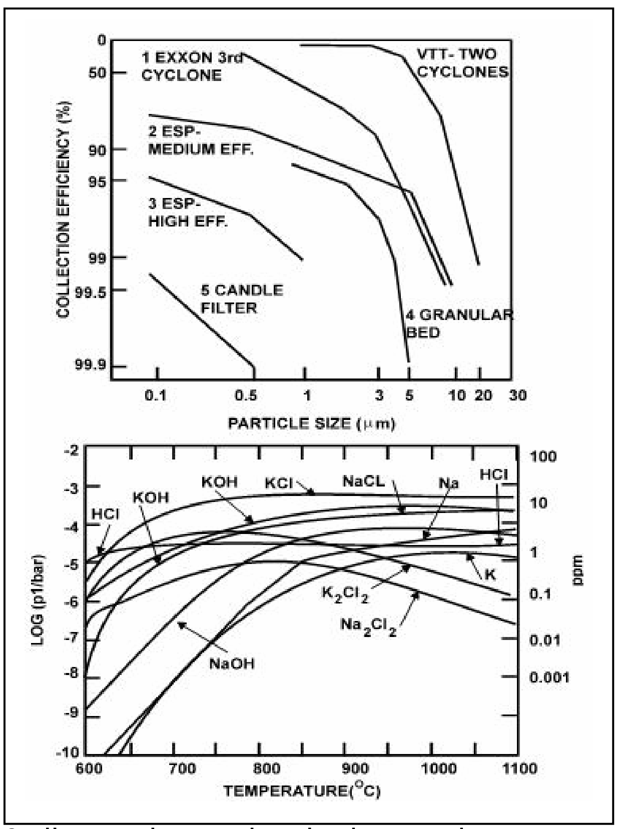
Typical fraction of volatiles, fixed carbon and ash in selected biomass fuel is as follows

Biomass	Volatiles	Fixed Carbon	Ash
Bagasse	75	17	08
Rice husk	60	20	20
Corn cob	80	16	04
Wood	75	24	01

A Comparison of these with coal is as follows

Component	Agro Residues	Wood	Coal
Volatile	60 – 75	75 - 80	20 - 30
Fixed Carbon	20 - 30	17 - 24	50 - 70
Ash	03 - 20	< 1	05 - 40

Notice that Coal has much smaller fraction of volatiles



Sodium and potassium in the gas phase

Figure indicates the amount of sodium & potassium salts at equilibrium atvarious temperatures.

For temperatures below 500-600 C, one can reduce the amount of these components.

Temperatures below 300C are considered most acceptable from the view of sodium salts.

Source: Development of simplified IGCC-processes for bio fuels, Kourkela E. et , Bioresource technology 46 `93, 37-47

Calorific Value

The Calorific Value of all biomass is obtained from Bomb calorimeter experiments and is represented by

Lower Cal value (MJ/kg) = (18.0 - 20 fw) (1 - fash), (for fw < 50 %)

Where fw moisture fraction in dry wood

fash = ash fraction in dry wood

Typically sun dry wood has 10 % moisture. The ash fraction is about 0.5 %. Thus the calorific value of sun dry wood is 15.8 MJ/kg.

The calorific value in relation to other fossil fuels is as below

Fuel	*Cal Value (MJ/kg)*
Biomass (wood)	*16 - 18*
Coal (5 % Ash)	*35 - 37*
Coal (40 % Ash)	*20 - 22*
Diesel / gasoline	*42 - 44*

Notice that the calorific value of biomass is roughly same as coal with 40% ash. In many countries the coal available has this kind of calorific value (including India). This has implications on the use of renewable source of energy as fuel instead of coal in manners not realised by most users far away from the pithead of coal. Notice also that the Calorific value of fuel oil is about two and half times that of biomass.

The Power of a Combustor

$$\text{Power (kW)} = \frac{\text{(fuel) kg/hr * Cal Value (MJ/kg)}}{3600}$$

This is approximately expressed (for most of the biomass) as

Power (kW) = 4.5 X fuel (kg/hr)

A 10 kg/hr of biomass burning system delivers a thermal power of 45 kW

Air-to-fuel ratio

The amount of air needed to completely burn the fuel to CO_2 and H_2O is known as stoichiometric ratio. The amount required for converting carbon to carbon dioxide, hydrogen to water constitute the amount of air required. If the fuel has some oxygen in its structure then the amount of air required is smaller.

For a typical hydrocarbon we have

$$CH_n + \left(1+\frac{n}{4}\right)\left(O_2+\frac{79}{21}N_2\right) \rightarrow CO_2 + \frac{n}{2} H_2O + \left(1+\frac{n}{4}\right) N_2$$

A hydrocarbon fuel leads to stoichiometric ratio (S)

$$S = \left\{(32+3.7628)\left(\mathbf{1}+\frac{\mathbf{n}}{\mathbf{4}}\right)\right\} \Big/ (12+n)$$

is 14.4 for n = 1.8 and 17.1 for n = 4

These are the typical values for diesel/gasoline and methane, [n = 4]

If we take a typical biomass

$$CH_{1.4}O_{0.6}\,N_{0.002} + 1.05\left(O_2+\frac{79}{21}N_2\right) \rightarrow CO_2 + 0.7\,H_2O + 3.952\,N_2$$

We get s = 6.3

In general

$$CH_nO_m\,N_p + \left[O_2+\frac{79}{21}N_2\right]\left[1+\frac{n}{4}-\frac{m}{2}\right] \rightarrow CO_2 + \frac{n}{2} H_2O + \left[1+\frac{n}{4}-\frac{m}{2}-\frac{p}{2}\right] N_2$$

$$\frac{A}{F} = \frac{(32+3.7628)\left[1+\frac{n}{4}-\frac{m}{2}\right]}{12+n+16m}$$

	n	m	Ash (%wt)	(A/F) stoichiometry
Rice husk	1.78	0.56	20.0	5.60
Saw dust	1.65	0.69	0.80	5.90
Paper	1.60	0.65	6.00	5.75
Rice straw	1.56	0.50	20.0	5.80
Douglas fir	1.45	0.60	0.80	6.30
Beech, Poplar, Red wood	1.33	0.60	0.20	6.00
Pine bark	1.33	0.60	2.90	5.85

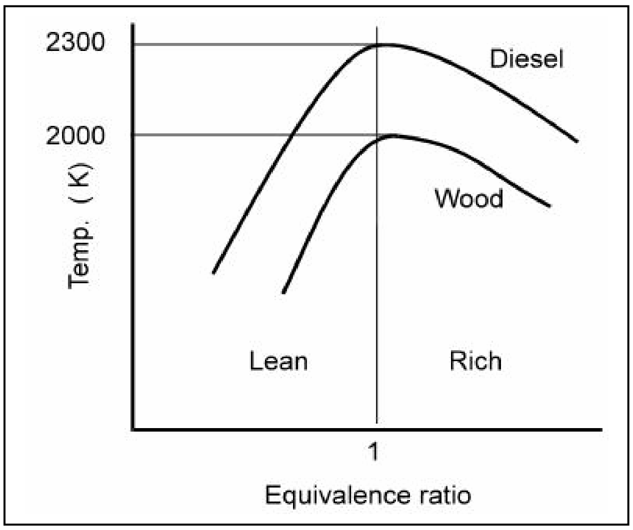
Depending on the mixture ratio (air-to-fuel), whether it is more or less than the stoichiometric value, one has lean or rich operating conditions.

These are described by a quantity called the equivalence ratio (f) which is the ratio of the air-to-fuel at stoichiometry to the actual value.

$$f = \left\{ (A/F)_{Stoichiometry} / (A/F) \right\}$$

f < 1 lean and f > 1 rich conditions

The flame temperature



Measured values of flame temperature for wood combustion in actual systems is generally around 10000C (1273 K) and rarely exceeds 14000C (1673 K). The difference is because in most practical wood burning conditions, the air-to-fuel ratio matching with the stoichiometric value is difficult due to varying fuel wood size and operating procedure.

However, if the fuel is pulverised, air-to-fuel ratio properly maintained, and heat losses are minimised, one can get a flame temperature as high as 14000C, typical temperatures quoted for large liquid fuel burner operations.

Fuel	Energy MJ/kg	Max.Flame Temperature, K
Petroleum fuel	40 - 44	1800 - 1900
Wood	14 - 17	1300 - 1700
Rice husk, other shells with high ash	10 - 13	1000 - 1300

Gasification? Combustion vs. Gasification

What is Gasification?

Sub-stoichiometric combustion of fuel with oxidant; it is not simply pyrolysis of the fuel elements; it is stoichiometric combustion (oxidation) + reduction reaction leading to typical products - Hydrogen, Carbon monoxide, Methane, Carbon dioxide, some HHC, water vapour and rest Nitrogen - in proportions depending on the feed stock and reactant used.

Most biomass + Air = 20% ± 2 H_2, 20% ± 2 CO, 2% CH_4, 12% ± 2 CO_2, 8% ± 2 H_2O, rest N_2.

Most biomass with water vapour with added heat from external sources → 55-65 % H_2, 25 - 30 % CO, rest HHC.

Combustion

$CH_{1.4}\,O_{0.74}\,N_{0.005} + 0.98\,(O_2 + 79/21\,N_2) \rightarrow CO_2 + 0.7\,H2O + 3.69\,N_2$,

$A/F = 5.25$

Gasification

$CH_{1.4}\,O_{0.74}\,N_{0.005} + 0.337\,(O_2 + 79/21\,N_2)$

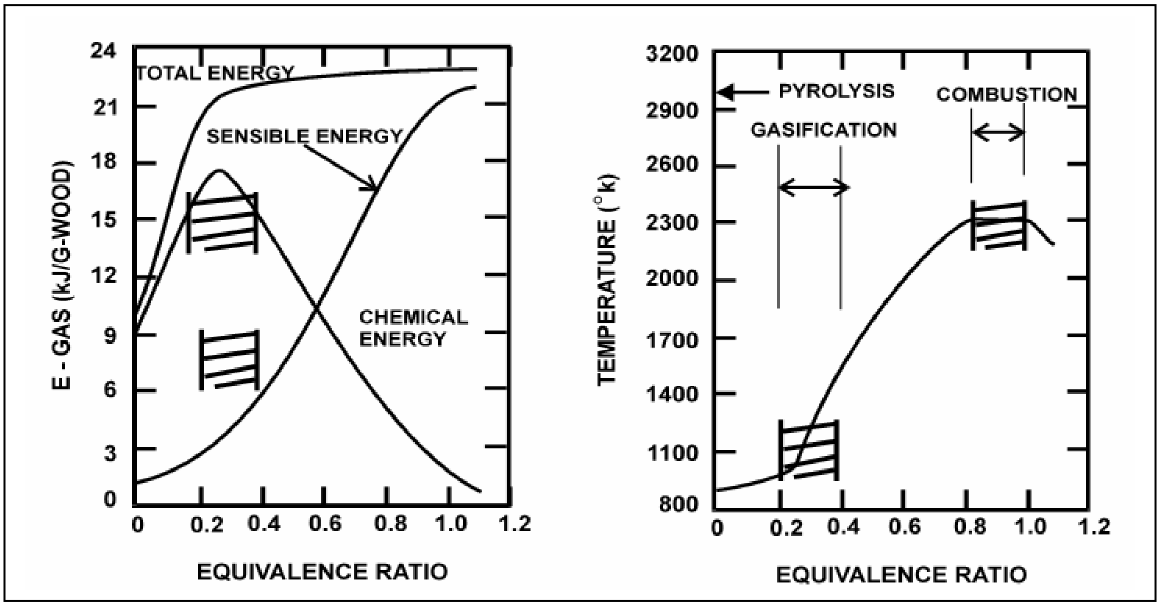
$\rightarrow 0.57\,CO + 0.485\,H_2 + 0.028\,CH_4 + 0.343\,CO_2 + 0.157\,H_2O + 1.27\,N_2 + 0.028\,C$

$- \rightarrow 2.857\,(0.2\,CO + 0.17\,H_2 + 0.01\,CH_4 + 0.12\,CO_2 + 0.055\,H_2O + 0.445\,N_2 + 0.01\,C)$

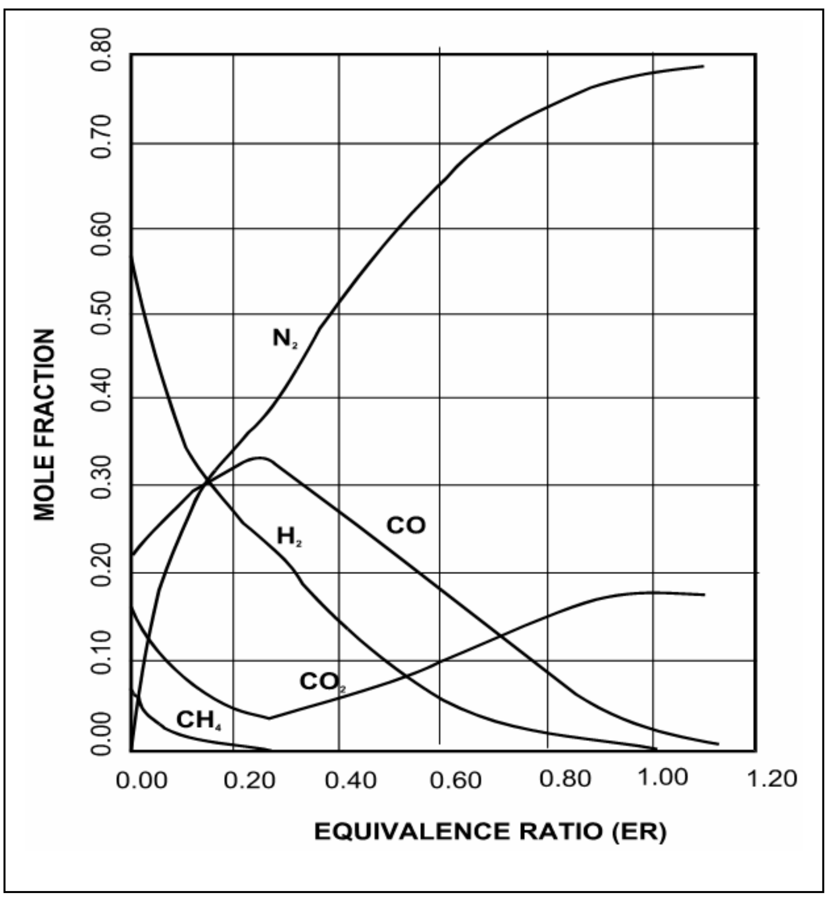
$\rightarrow 0.157\,H_2O + 0.028\,C + 2.7\,(0.211\,CO + 0.18\,H_2 + 0.0105\,CH_4 + 0.1275\,CO_2 + 0.471\,N_2)$

$A/F \cong 1.805$; Hot gas/Fuel = 2.805; Cold gas/Fuel $\cong 2.62$

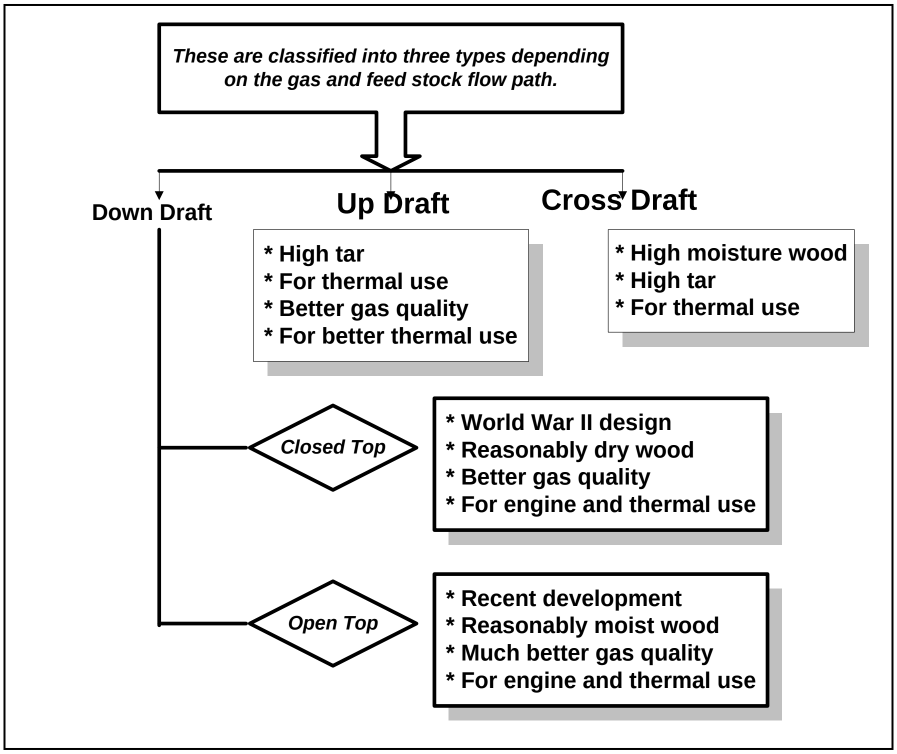
The products of combustion, CO_2 and H_2O pass through a reduction zone made of hot char bed, to convert CO_2 and H_2O into CO and H_2 and in part, CH_4. The net effect is reduction in air consumed.



Also the sensible heat in the first part of combustion is converted into chemical heat in the second part.



How are gasifiers classified?



Woody biomass gasifier (thermal and electric)

Specifications Electrical applications

Combustible gas for use in burners and combustors

Low NOX < 150 ppm @ 3% excess O_2

Low K/Na salts < a few ppb @ 3% excess O_2 in the product gases

Direct use of combustible gas in Reciprocating engines/gas turbines

Low particulates and tar –

Tar < 10 mg/m3 & Particulates < 20 mg/m^3 for turbocharged engines

Gas Composition

Hydrogen	18 - 20 %
Carbon monoxide	18 - 20 %
Methane	1 - 2 %
Carbon dioxide	12 - 14 %
Nitrogen	45 - 48 %
Calorific value	4.5 - 4.8 MJ/m3

Dust and Tar

Before cleaning/cooling

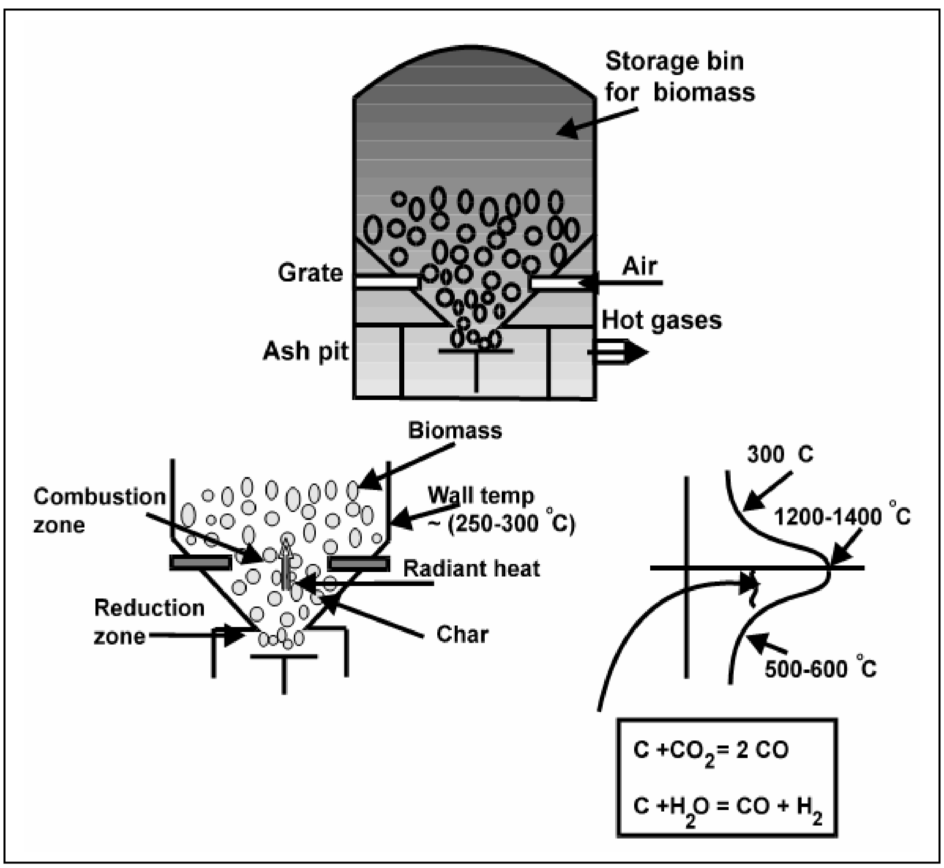
Dust	1000 ppm
Tar	100 - 300 ppm

After cleaning/cooling

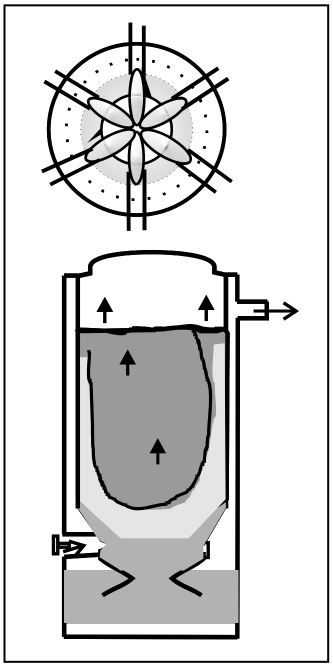
Dust	< 50 ppm (For NA engines)
	< 10 ppm (For TC engines)
Tar	< 30 ppm (For NA engines)
	< 10 ppm (For TC engines)

There are two important kinds of gasifiers, closed top and open top-down draft type.

Closed top design

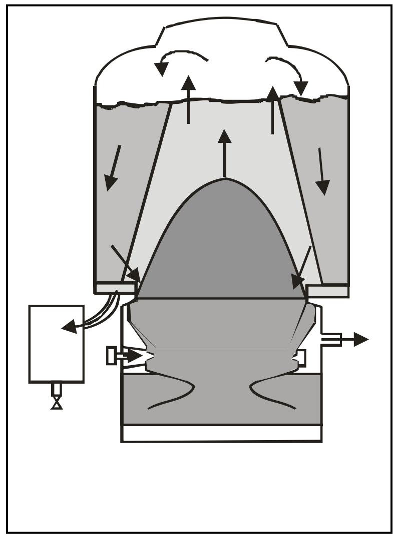


Leakage of Gases having Volatiles; Temp distribution not very favourable



Ordinary Woodgas Generator

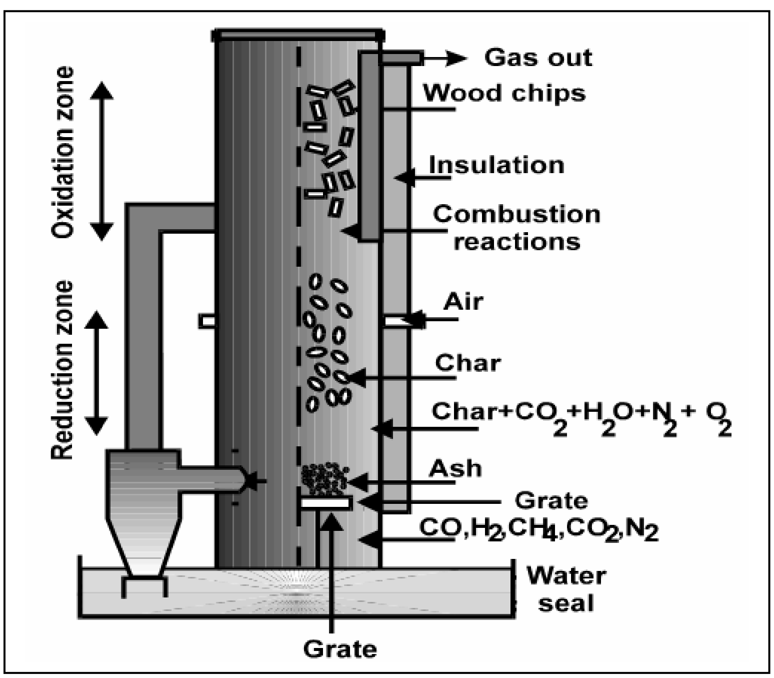
Moisture is not removed. The top region is designed with the view to accommodate a specific amount of wood pieces.



Monorator

Condensation of volatiles and removal can take away the energy. Lateral regions contain blocked material. There are material movement problems. Good for transport applications.

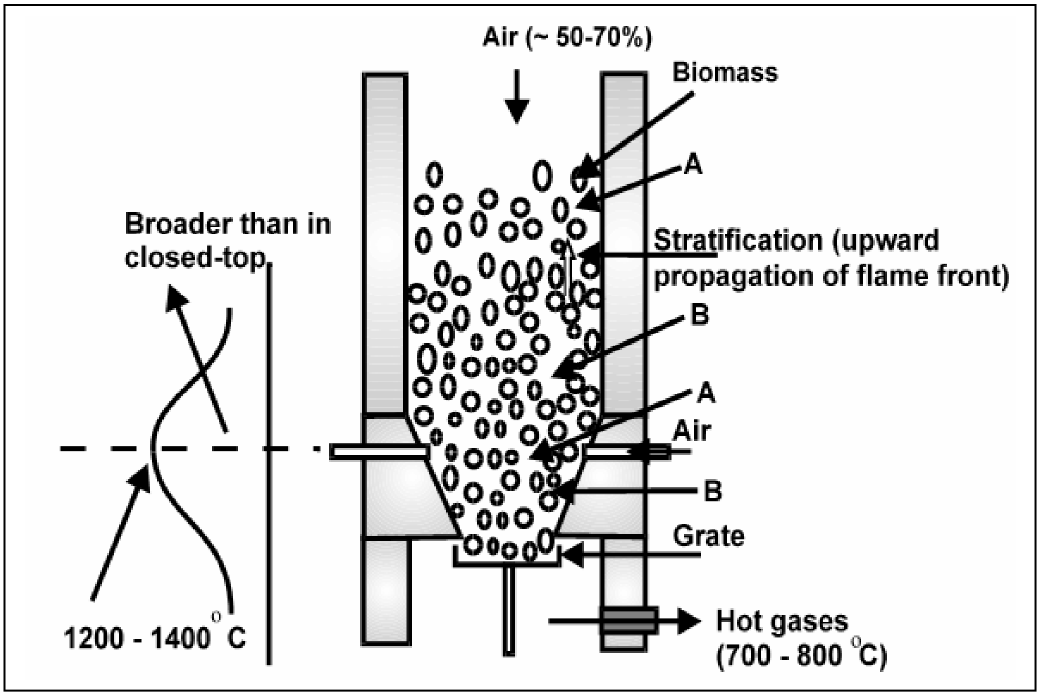
The Modern open top design

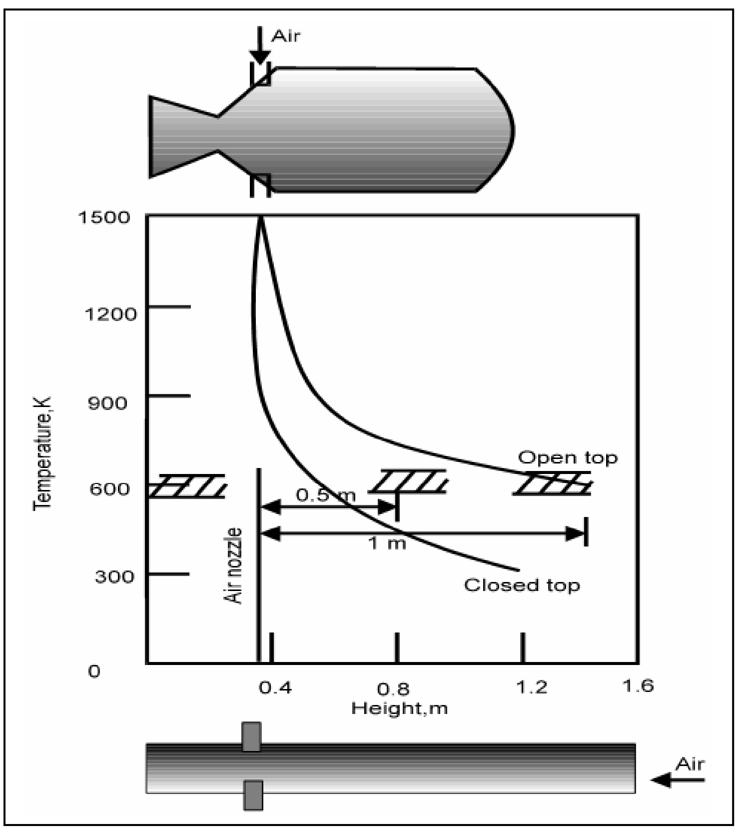


Long life & performance uncompromised,

Lower region ceramic shell; upper region stainless steel shell for low power level systems and entire ceramic shell for high power systems (> 200 kWe).

What happens inside the reactor?





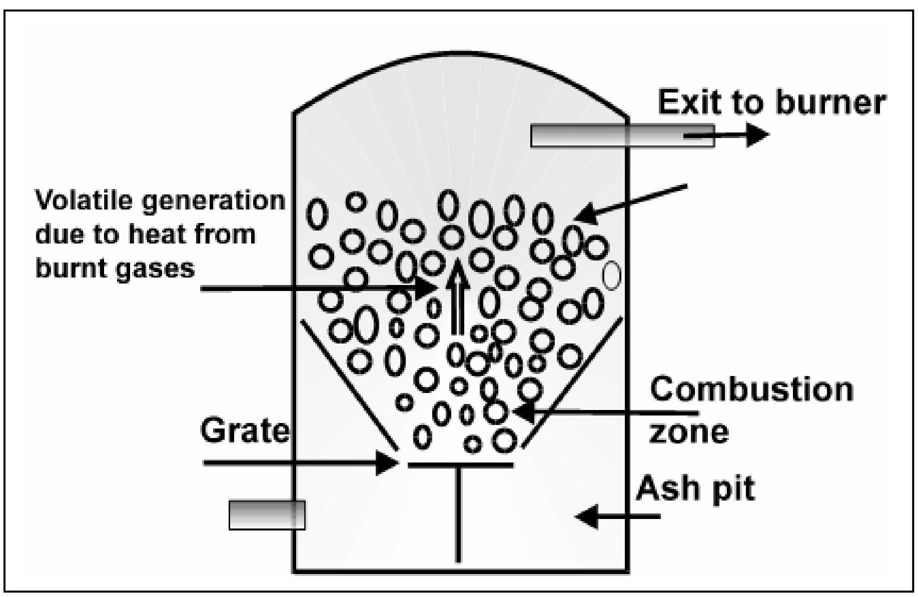
The gases get longer residue time in the high temperature zone for tar cracking $\Rightarrow$ less sticky tar.

Comparison of the fundamental processes

	Closed top	**Open top**
Physical nature of wood chips	Pieces of 20-100 mm size depending on the power	- same -
Top region	Biomass $\xrightarrow{\text{Heat}}$ Volatiles fuel rich operation	Biomass & air $\xrightarrow{\text{Heat}}$ Partial products lean/leaner operation
Uniformity of A/F at a cross section	Non uniform Some very high temp & low temp regions	Relatively far more uniform because of air flow from top
Regions of tar rich zones	Yes	Relatively low

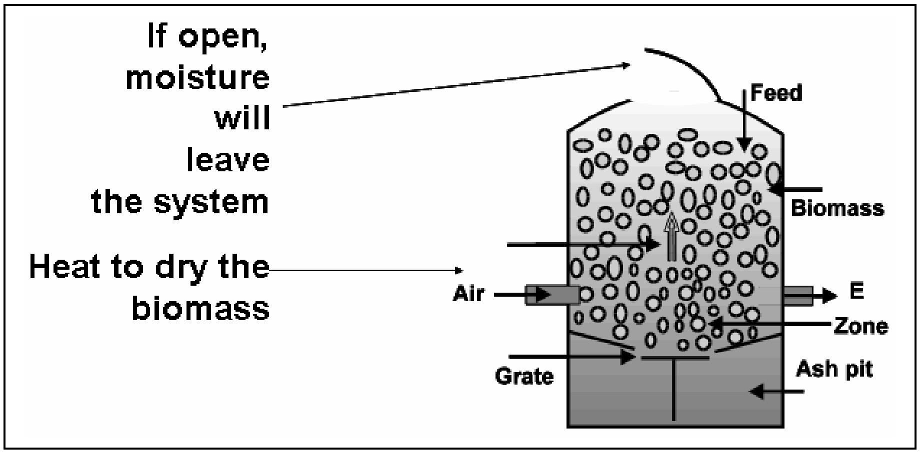
Updraft gasifier

The combustible gases at the exit have a large amount of volatiles. If the combustible gases are cooled to ambient temperature, the tar in the gas condenses and leads to problems of blockage. The gas is fit for direct use in burners. This technique is useful if the downdraft kind cannot be used. It has been used for waste contaminated wood.



Crossdraft gasifier

This technique is of value with biomass having high moisture content. If the top is open, the system can be designed to pump the heat upwards to drive away the moisture and also permit gasification across the feed. The gasifier is again suitable for thermal applications only.



Amongst these three designs it is stated that two are good enough only for thermal applications. One of them (down draft) can be either used for thermal or engine applications.

One of the parameters characterising the quality of a gasifier is called Turn-down ratio. This is the ratio of full to least power at which gasifier can give performance above a minimum. This is typically 3 for many gasifiers.

For different designs it is as below:

Type	Tar	Turn-down ratio
Down draft open top	very little	4
Down draft closed top	little at full load and not too low at lower power	3
Up draft	poor	3
Cross draft	reasonable	2

Pulverized Fuel Gasifier

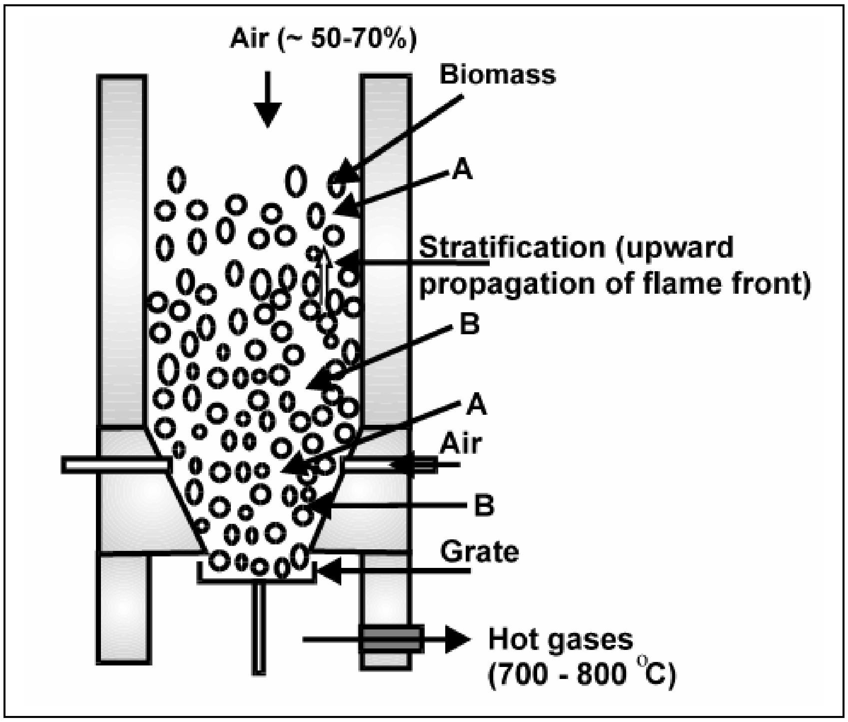
Extend the use of woody biomass gasifier

Fluidised bed gasifier and Circulating fluidised bed system

Why not woody biomass gasifier for pulverized fuels ?

Saw Dust Δp is high/ flow not uniform

$\Rightarrow$ tunnelling



Solution: Briquette the fuel into blocks for use in a standard wood gasifier system.

Rice Husk

Conversion of rice husk char is far too slow compared to flaming $\Rightarrow$ rice char fills up the space; the reactor acts virtually as a pyroliser $\Rightarrow$ tar in the gas is very high $\Rightarrow$10,000 - 20,000 ppm.

- Volume reduction of rice char too small

  $\Rightarrow$ char removal system must be active continuously
- Chinese systems are based on the above principle
- Char conversion ~ 0; residue is quenched with water and discharged. Too high a use of water
- Thermodynamically inefficient $\Rightarrow$ 2 - 2.3 kg/kWhr

➢ Solution: Use rice husk briquettes in a standard wood gasifier with screw ash extraction system.

Fluidised Bed Gasifier

- Fluidisation velocity range small

  ⇒ Power control small

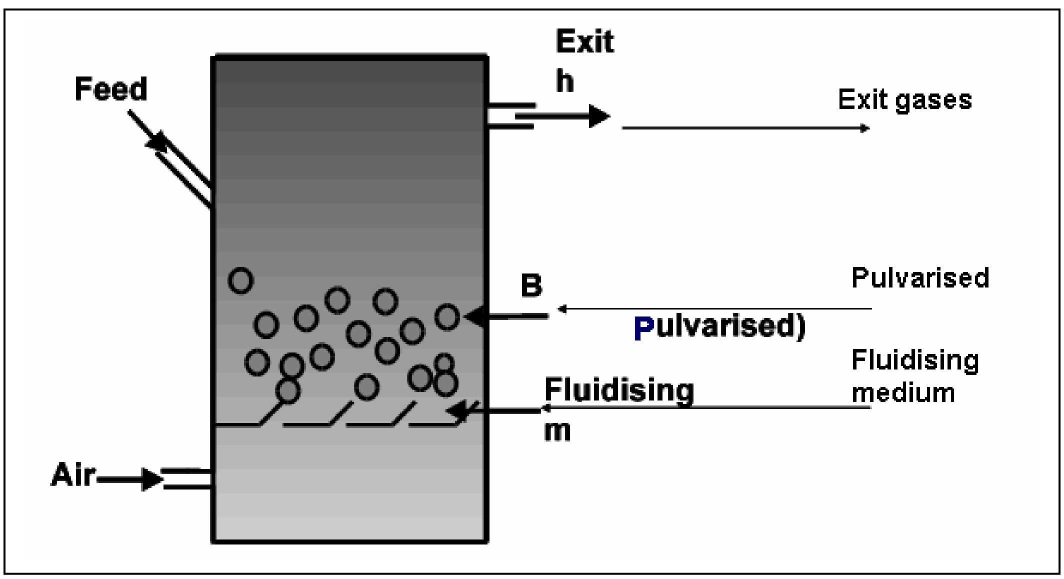
- With varying particle size distribution, small particles will release volatiles with smaller residence time for char conversion

  ⇒ Tar generation much higher to overcome small range fluidisation of velocity, circulating fluidised bed system is developed

  ⇒ Reduces size ⇒ reduces residence time even further ⇒ tar generation significant

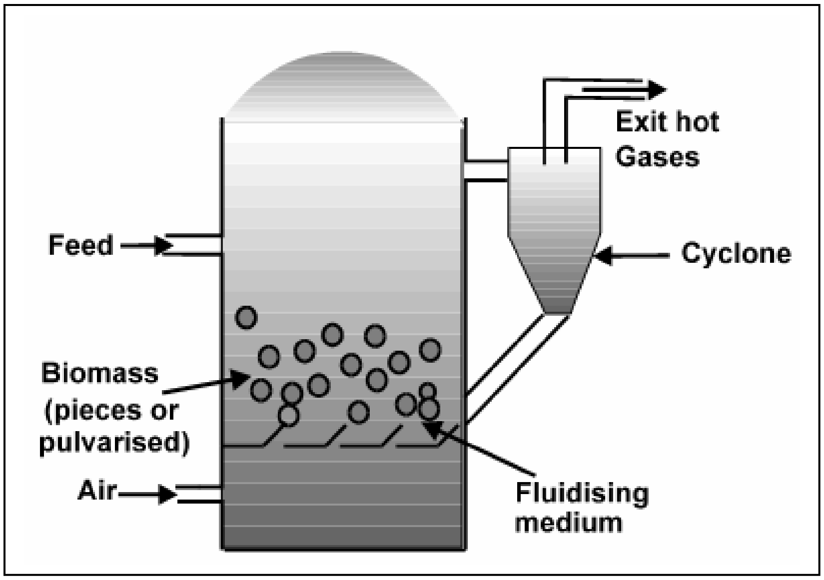
- Path from entry to exit for smaller particle sizes reduces residence time (and therefore more tar)

Fluidised bed combustor/gasifiers



A minimum velocity is needed to keep the medium in fluidised condition. Typically this is between 1-4 m/s.

A fluidising medium like sand is not always needed. The biomass pieces and char may themselves be capable of being fluidised. Fluidised bed combustors have been built for rice husk, bagasse at power levels up to several MW.



In order to reduce the size of the system for the same power level, a circulating fluidised bed reactor is used, particularly at large power levels. Air Velocities as large as 7-10 m/s are used to move the material around. Solid particles, and unconverted species recirculate after the gases exit from a cyclone.

Summary on Gasifiers

i. Gasifiers are devices which convert solid biomass into gaseous fuels for combustion in furnaces or in engines

ii. Gasifiers give a precise control of instantaneous power some thing not possible in combustors (for solid fuel)

iii. Woody biomass gasifiers are of down draft, updraft and crossdraft types ; Downdraft gasifiers can be either closed or open top

iv. For engine applications downdraft gasifier is the most suitable. For engine applications involving variable load/ power demand, open top downdraft gasifiers are most suitable.

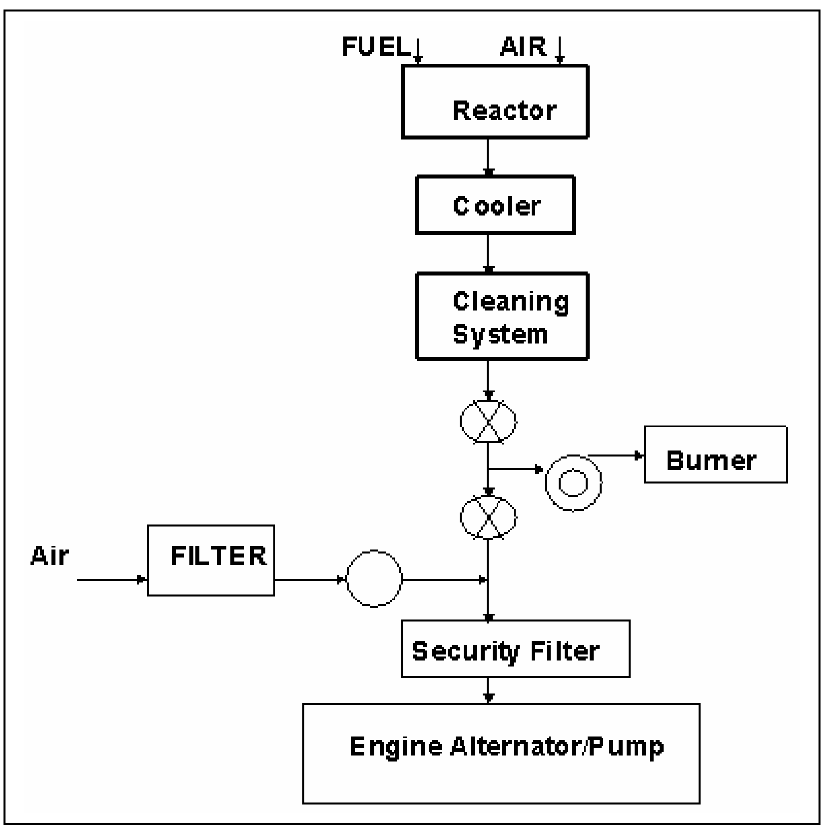
v. Updraft gasifiers may be the most appropriate if the biomass is contaminated, unsized and of a variety of shapes making downdraft gasification difficult. The applications are only thermal.

vi. Crossdraft gasifiers are most appropriate for thermal applications and one can design for higher moisture loadings in biomass.

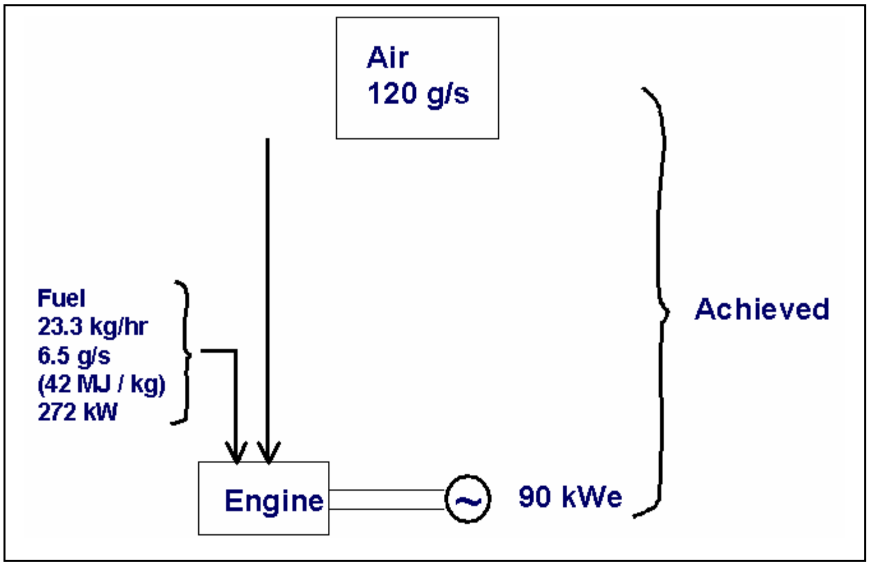
Direct combustion vs. Gasification

Item	**Direct Combustion**	**Gasification**
A/F Control (Instantaneous)	Inadequate (Fuel size, shape, moisture variation)	Good char reduction process permits auto-control
Power control (Instantaneous)	Inadequate	Good
Emission control (NO_X, SO_X, Dioxins)	Possible	Superior
Installed Cost/kW	-	Higher on retrofit; comparable otherwise
Electricity	Economical only at large power levels (~ a few MWs)	Economical even at smaller power levels
Pulverised fuels	Deposition of metal vapours, oxides etc. on inaccessibility parts of boiler	Allows for cooling gas indirectly, eliminating the condensation inaccessibility areas & burning the gas to rigorous standards.

Engine operation in dual fuel mode

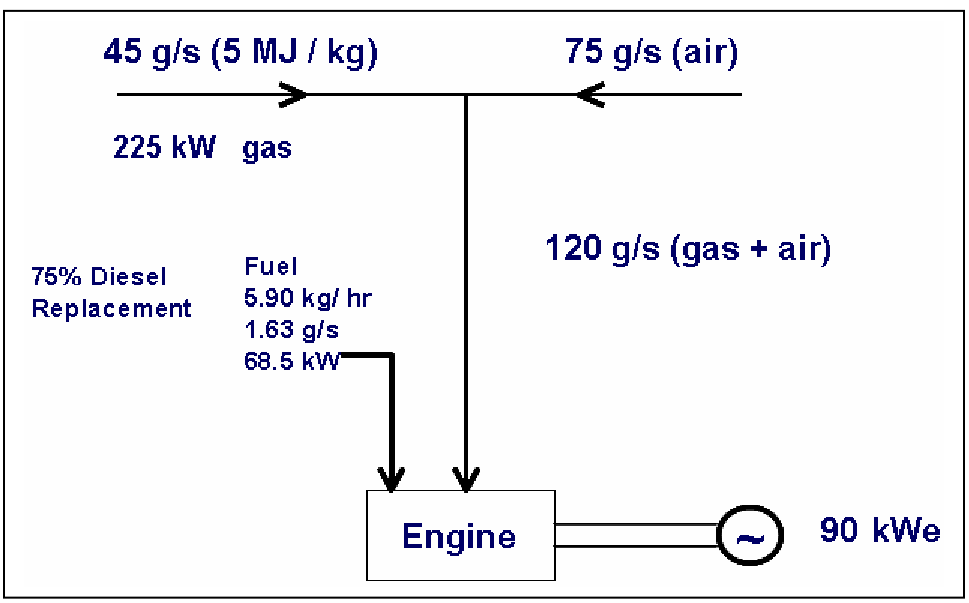


While switching from diesel only mode to dual-fuel mode, reduce the air flow by controlling the air valve. This causes more gas to be drawn in; the diesel governer cuts the diesel to maintain the frequency. One can cut diesel till the system crashes due to the inability to take the load.

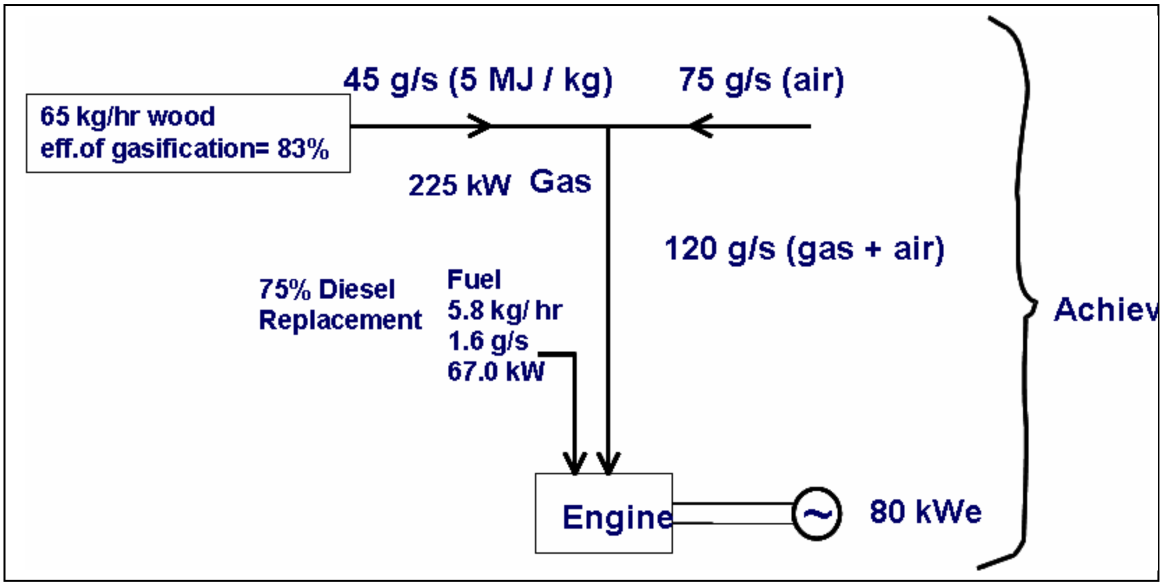


A/F = 17.1 ηov (Overall eff.) = 90/272 = 33%

Diesel alone mode.

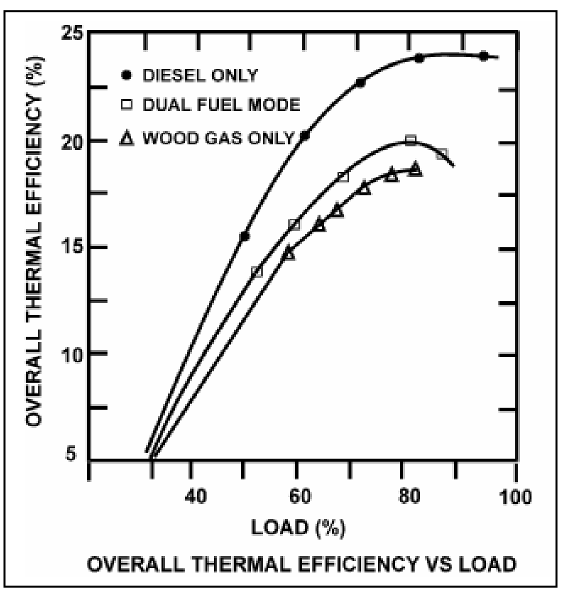


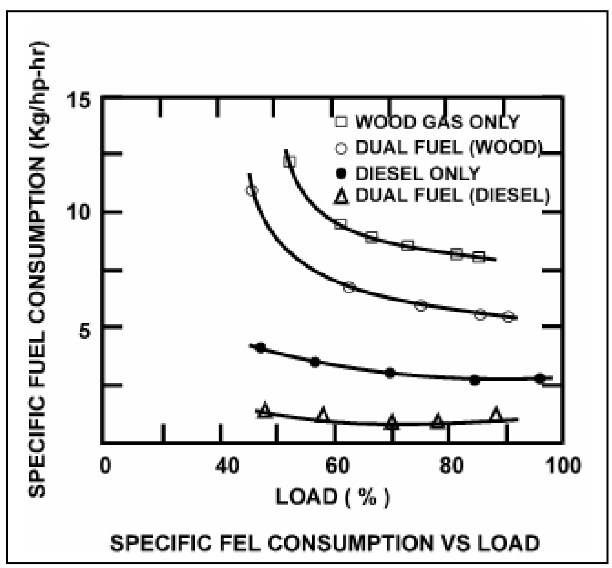
$$\eta_{ov} = \frac{90}{225 + 68.5} = 30.6\%$$



$$\eta_{ov} = \frac{80}{225 + 67} = 27.3\%$$

$$\text{Efficiency (wood + diesel} \Rightarrow \text{electricity)} = \frac{80}{225/0.83 + 67} = 23.6\ \%$$





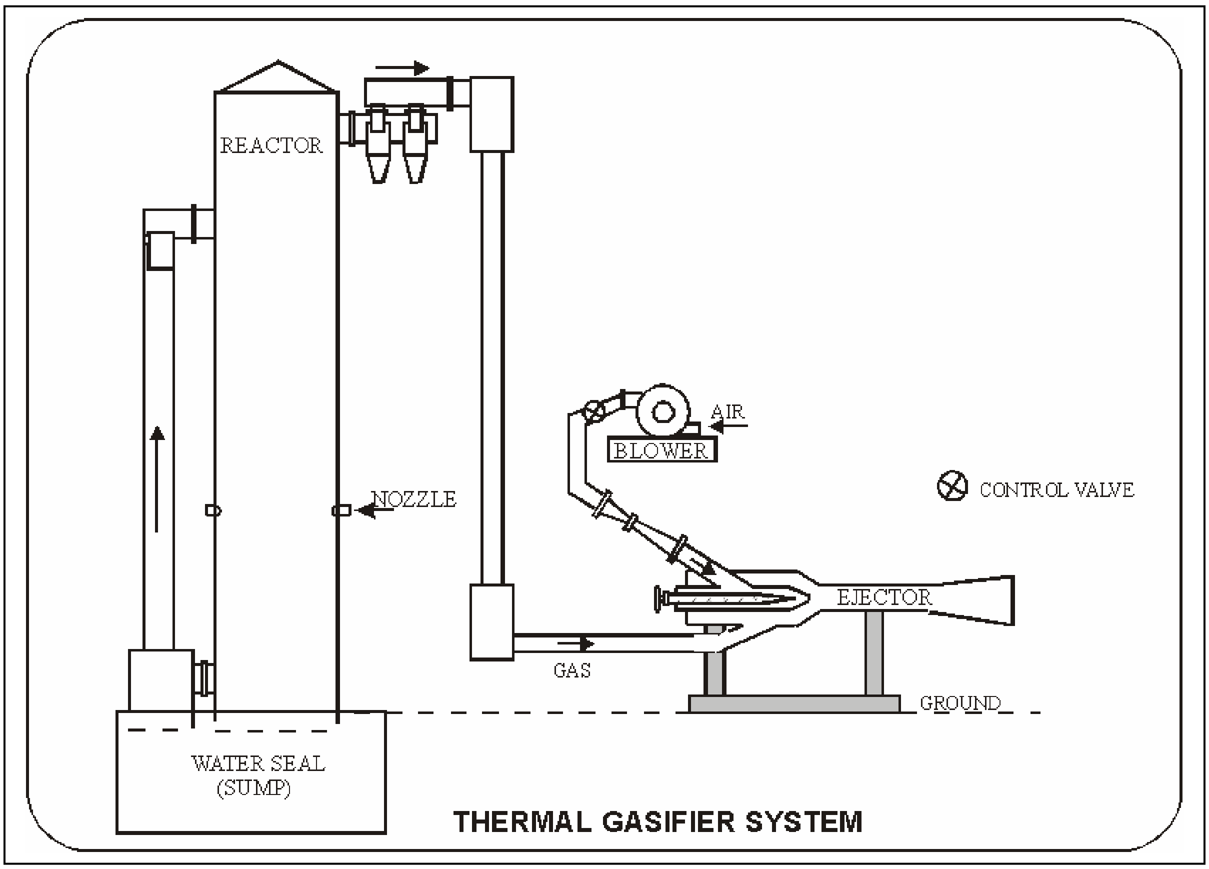
Producer gas engine

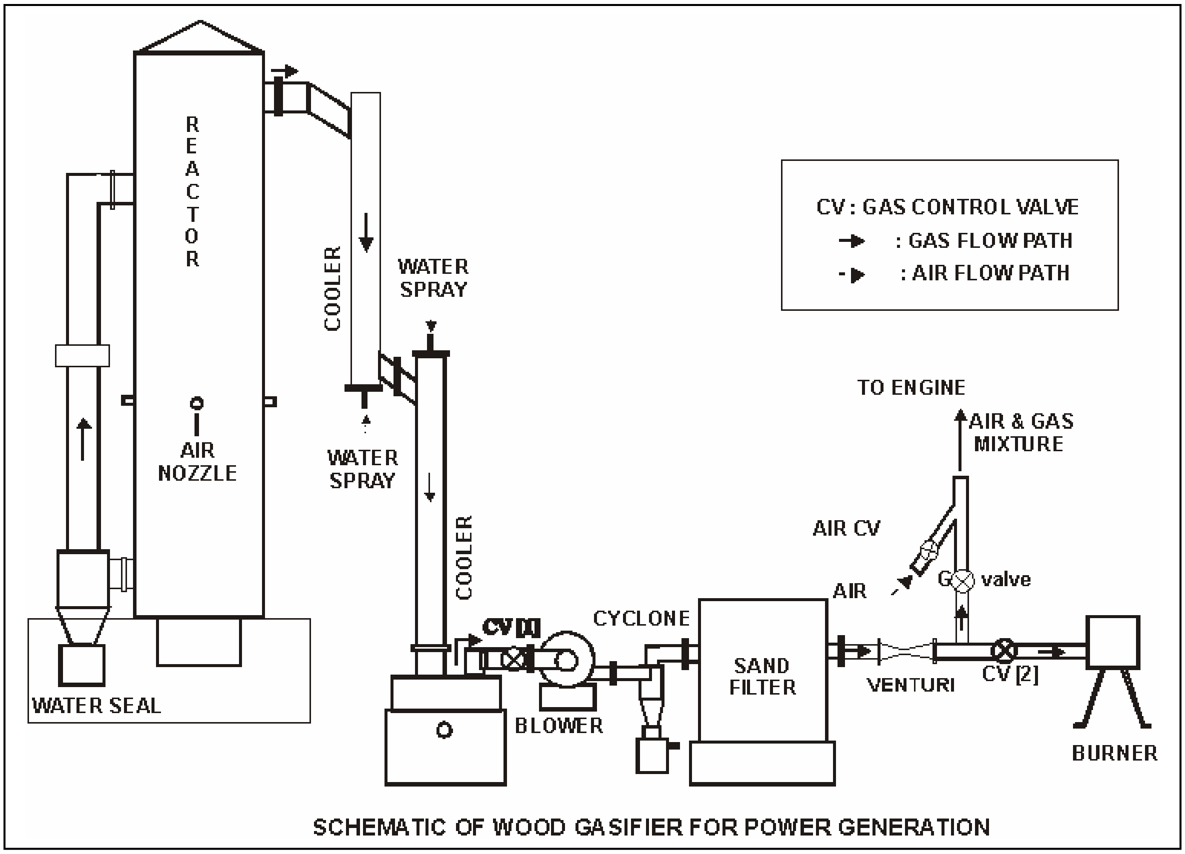
Conversion of a diesel engine to a spark ignition engine:

Three cylinder, model - RB-33 engine coupled to a 25 kVA alternator - 1500 RPM; Kirlosker make; Comp. Ratio 17:1; cylinder vol 3.3 lts

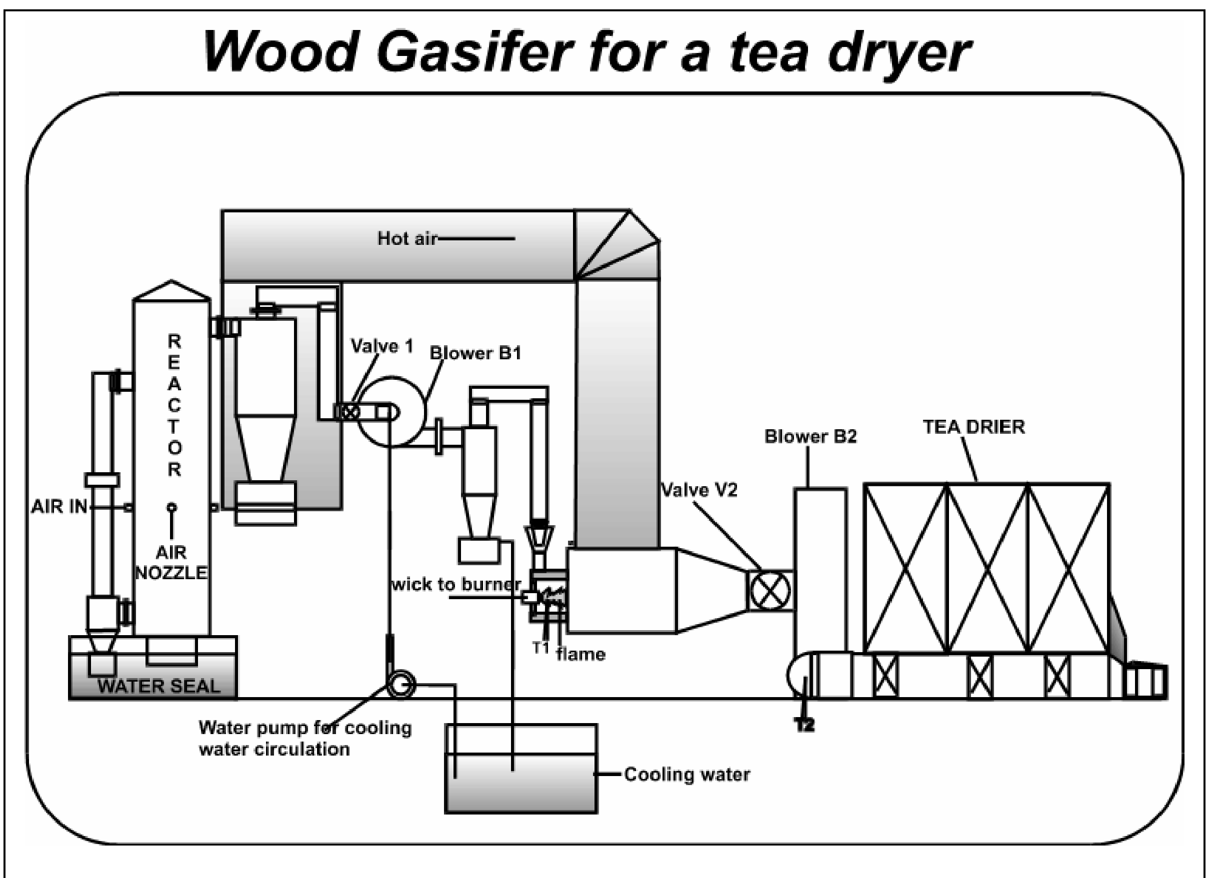
- by adopting a three cylinder battery based electronic ignition system with the provision of advance/retard of ignition timing;
- by incorporating spark plug in place of fuel injectors and retaining the existing comp. ratio of 17:1 without any changes in the combustion chamber;
- Operated with IISc-open top twin air entry woody biomass gasifier, gives an output of 15.4 kWe (28% de-rating from diesel peak power)

(10% de-rating from diesel long life power)





IISc Open top down draft Wood Gasifier - Thermal



Materials for the Systems

Reactor:

Hot zone: Cermaic + Outer MS + Insulation

Top zone: Double shell SS

Recirculating: Ceramic lined SS tubing Duct

Top zone: Double shell SS

Recirculating: Ceramic lined SS tubing Duct

Cooler: SS tubing; Plumbing: PVC

Gas cooling and cleaning system

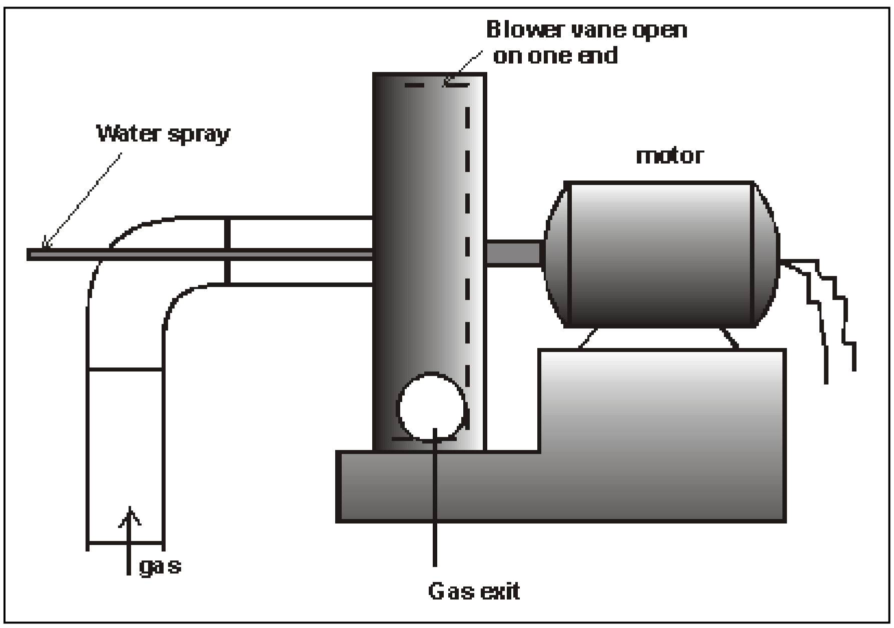
Cooling system :

- There are two techniques - Direct and Indirect. In direct cooling, water at ambient temperature is sprayed into the duct carrying the gas. The other method is to cool via a heat exchanger so that water is not contaminated. The cooling surface required will be very large and the system design for large power levels (even 20 kWe system) will be unwieldy.
- In order to preserve the quality of water to certain extent, one can combine both direct and indirect cooling. Direct cooling also washes the gas off particulates and some tar.
- In some arrangements, liquid ejectors are used to cause good mixing between gas and water and hence have a very short section for cooling. The disadvantage with this technique is the need for large pressure drop across the cooling system ~ as much as 300-500 mm (water gauge).
- Typical pressure drop across cooling system is between 10-50 mm wg.

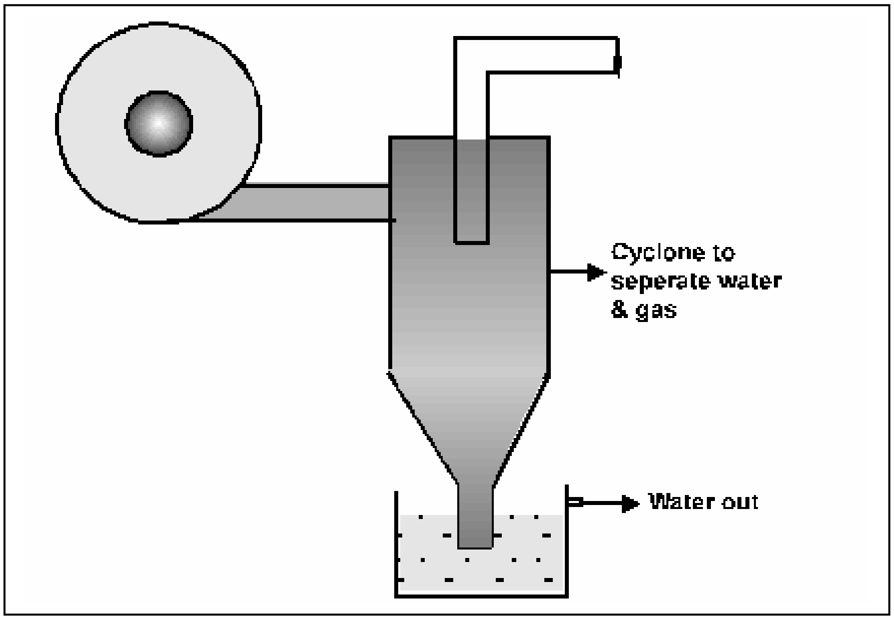
Cleaning System:

- The cleaning system is expected to reduce the particulate content in the gas.
- Cyclones are well known for reducing the particulate content. They are passive and work with moderate pressure drop ~ 20-50 mm wg.

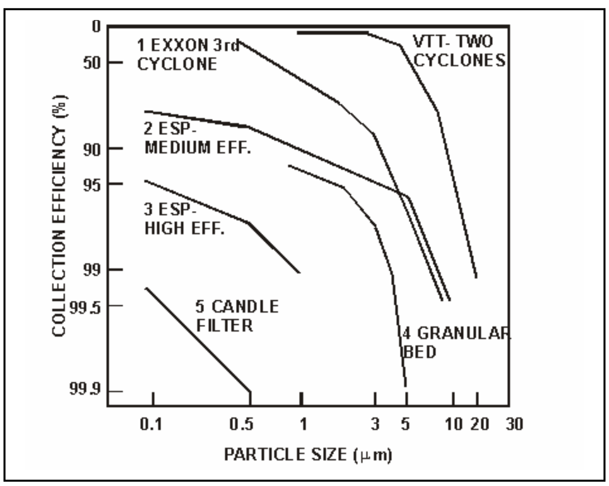
- For large power levels (therefore flow rates) cyclones are to be replaced by multi-clones. At the same flow rate, dividing the flow into several cyclones and maintaining the same velocity of the inlet of the cyclone, several smaller cyclones remove more fine dust.
- Sand beds of varying particle sizes offer an excellent particulate collection system. They are a positive method of eliminating fine dust. Some tar is also collected by the bed. Typical pressure drops ~ 20-50 mm wg.
- A novel method adopted is to take the gas through a blower and introduce a water spray at the centre (at IISc.).

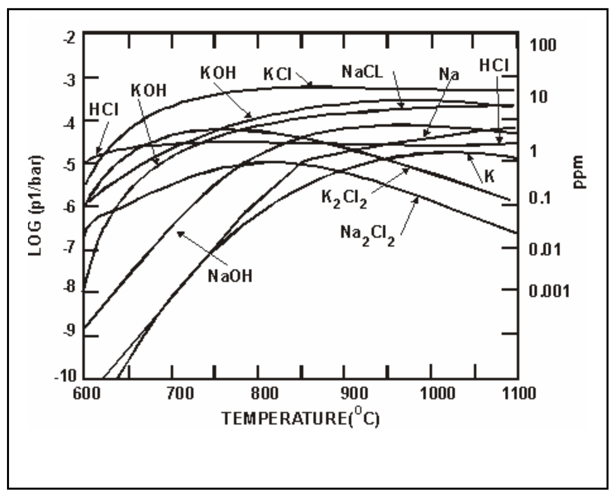


The water spray hits the outerwall of the blower and any condensed particulate matter is taken off the gas. This technique has been found excellent as the maintenance of the system can be handled very easily.



For high pressure gasifiers the cleaning system uses a candle to permit filteration of high quality, but at the expense of the high pressure drop (of the order of an atmosphere or more).





Major test programme for qualification of the gasifier under Indo-Swiss programme.

- Test schedule/test plan suggested by Swiss experts based on a European standard.
- Third party analysis qualified initially by Swiss group.
- Rigrous tests operations over 8 tests lasting 8-10 hours each.

- Gas analysis; Tar analysis - hot and cold end; Overall mass and energy balances; Particle size analysis.

Results

Detailed results available on causarina.

Paramater	Value	Comments
Gasification efficiency (Hot)	80 % to 85 %	At full load, about 5% reduction at 30 % load
Gas Cal Value	4.5 to 4.8 MJ/m^3	Cal value equilibrates after 1 to 3 hours from start.
Hydrogen Content	16 to 19 %	Hydrogen fraction behaviour same as above; better fraction in wood with 10 to 15 % moisture. Important for engine application.
Particulate (Hot) (Cold)	700 mg/m^3 50 mg/m^3	Hot tar is an indication of the load
Tar (Hot) (Cold)	120 mg/m^3 20 mg/m^3	on the cleanup system

Diesel replacement in every case tested on a variety of diesel engines exceeds 85 % at 80 % rated load.

Effluent per kg moisture free wood

Item	P+T	BOD	COD	Phenol	DOC	NH_3/NH_4
g/kg (mf-wood)	1.45	0.14	1.90	0.077	2.32	1.72

Woody residues tested

Species	Density (kg/m3)	Moisture content (%)	No. Hours	Chip Size for 100 kWe
Causarina	550 to 650	< 15	200	~75 mm; Mixture with tiny branches 50 %, 10 to 15 mm; + 10 % Sawdust
Eucalyptus + mixed species	400 to 650	< 15	6000	50 to 75 mm
Phadauk	1050 to 1100	~ 15	700	Same as above
Silver Oak	250 to 300	~ 20	150	Same as above
Pine (European)	200 to 250	< 30	30	Same as above
Mulberry stalk	300 to 350	~ 15	1000	10 to 20 mm dia, 30 to 50 mm long (20 kWe reactor)
Ipomia	200 to 250	~ 15	8	On small reactor
Jungle wood	300 to 600	~ 20	100	- same as above -

Technology Packages

Stoves & Combustors

- Single pan stoves ~ 1- 2kW - both woody & powdery biomass for domestic use
  Cost : Rs 185/-
- Three pan ASTRA OLE for domestic use
  Cost : Rs 250/-
- Small power level combustors ~ 5 - 50 kW for community kitchens, bakery, hotels, pottery kilns, silk industry
  Cost : Rs 300 - 2000/-
- Large power level combustors ~ upto 500 kW for boilers, foundry units, spices drying applications
  Cost : Rs 800 - 1000/kWth
- Possible to design & build combustors for specific applications to meet the client requirement

Small biomass based power plants (SBPP)

- Power level ~ 5, 20, 100, 500, 1000 kW electric
  ~ 20, 80, 400, 2000 kW thermal
- Diesel saving in dual fuel mode up to 85%
- Suitable for base load operation

Requirements

- Biomass (bulk density > 250 kg/m3)
  Availability at nominal rates (<1.5 Rs / dry kg)
- Site (15m x 6m x 5m -ht) for housing a 100 kWe system + space for storing biomass

- Water availability in case of engine application
- Minimum plant load 60%

Wood gasifier plant package consists of

Electrical

- Ceramic reactor
- Stainless steel coolers
- Sand filter
- Blower + water pump
- Engine + Alternator set
- Wood cutting machine
- Instrumentation

Power	3.75 kWe	20 kWe	100 kWe
Installation/kWe	Rs 30,000	Rs 25,000	Rs 20,000
GeneratioAn/unit	Rs 4.50	Rs 3.90	Rs 3.55

Power	20 kWth	80 kWth	400 kWth
Installation/kWth	Rs 2,500	Rs 2,000	Rs 1,000

Thermal

- Ceramic reactor
- Blower + water pump
- Burner
- Biomass cutting machine

Small biomass based power plants (SBPP)

Possibilities

- To retrofit with existing diesel engine without modifications on the engine
- Suitable for captive power generation
- Suitable for grid synchronisation
- Suitable as decentralised power system, namely for rural electrification

↓

Irrigation, Illumination, supply of drinking water & energising local industries

Small biomass based power plants (SBPP)

Benefits

- Improved quality of electricity made available - Voltage & Frequency
- Dependency on grid supply reduced
- Increased productivity - both in agriculture & Industry
- Employment for the local people as a result of industrialisation
- Improvement in quality of life

↓

Supply of hygienic drinking water, illumination, higher income from agriculture through irrigation

Field Experience -1

Hours run on various systems

Years	System capacity kW	Min-Max Hours run per system/ yr	Accumulated No. Systems	Total Hours
1987 to1990	3.7 kW (pump)	100 to 500	120-450	40,000
1988 to 1995	3.7 kWe	1400	2 (Hosahalli)	8000
1995 +	20 kWe	2800	1(Hosahalli)	2800
1990 to 1996	70 kWe	700 to 1200	1(Port Blair)	4000
1992 +	20 kWe	400	1 (Ungra)	800
1995 +	40 + 40 kWe	1800	1(Orchha)	1800
1996 +	400 kWth (tea drying)	600	1(Coonoor)	600

Field Experience - 3

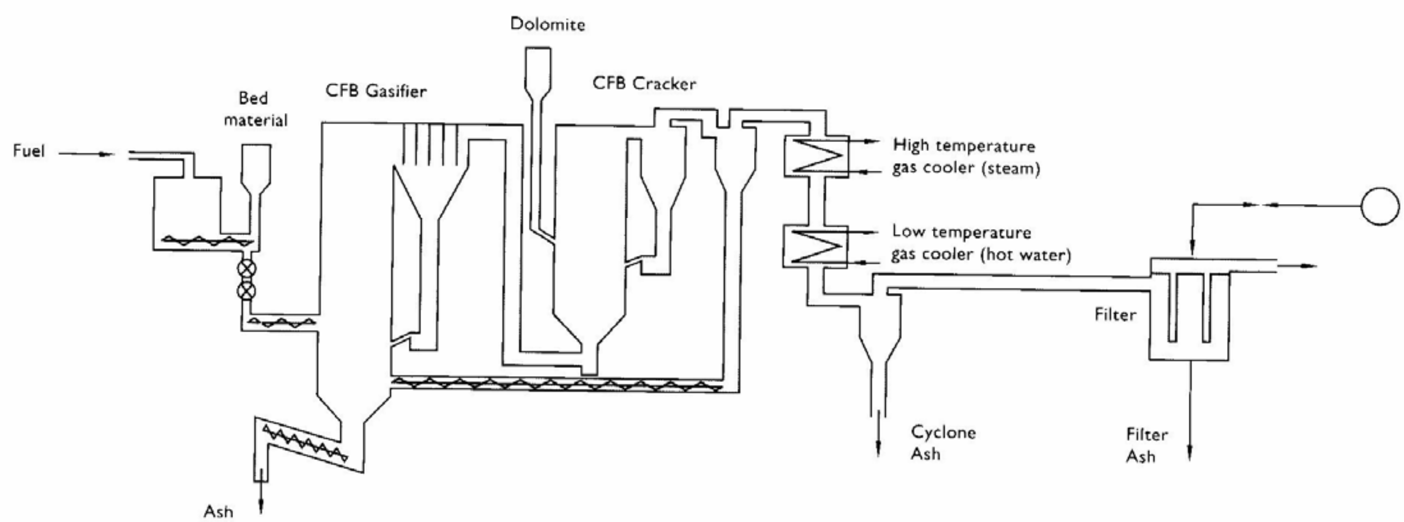
Woody Residues tested at various locations

Location	Bioresidues tested	Density/Moisture kg/m^3/ %
Hosahalli	A range of woody residues from a mixed forest	400 - 600/ <15 %
Ungra	Mulberry stalk (agro-residue)	500 - 600/ <15 %
Orchha	Ipomia, a weed	350 - 370/ <20 %
Coonoor	Coconut shells (agro-residue)	1100 - 1200/ <15 %
Port Blair	Various residues; Phadauk	600 - 1100/ <10 %
Coffee Plantation; Coorg	Silver Oak tree branches	300 - 400/ <15 %

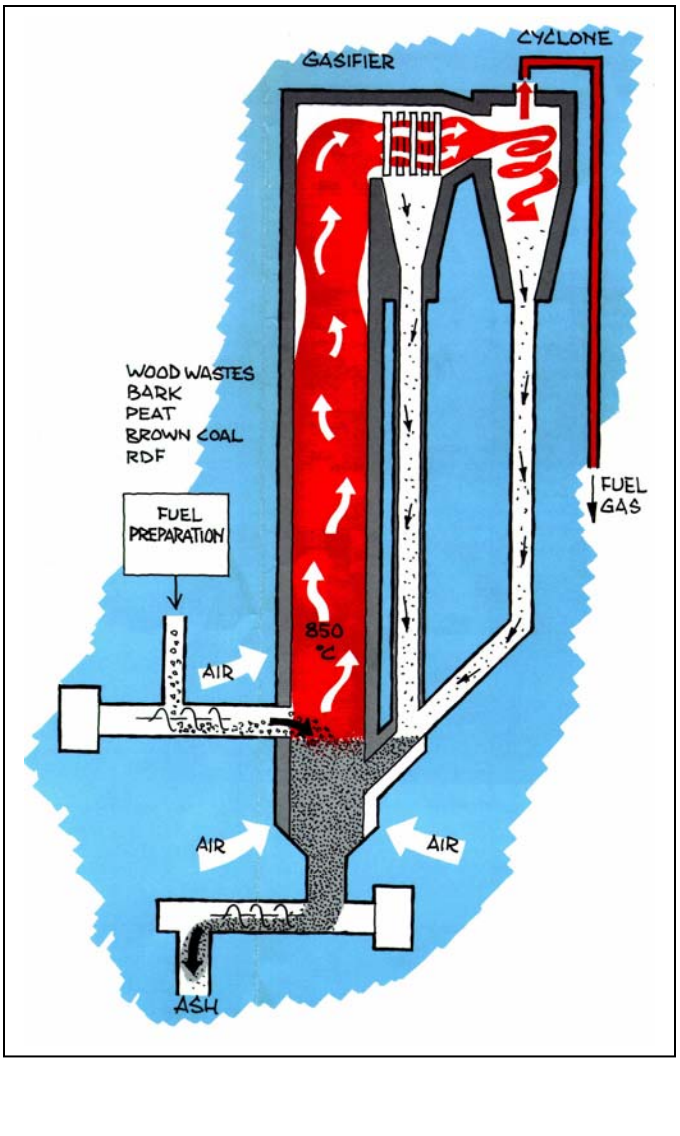
Technologies from other countries

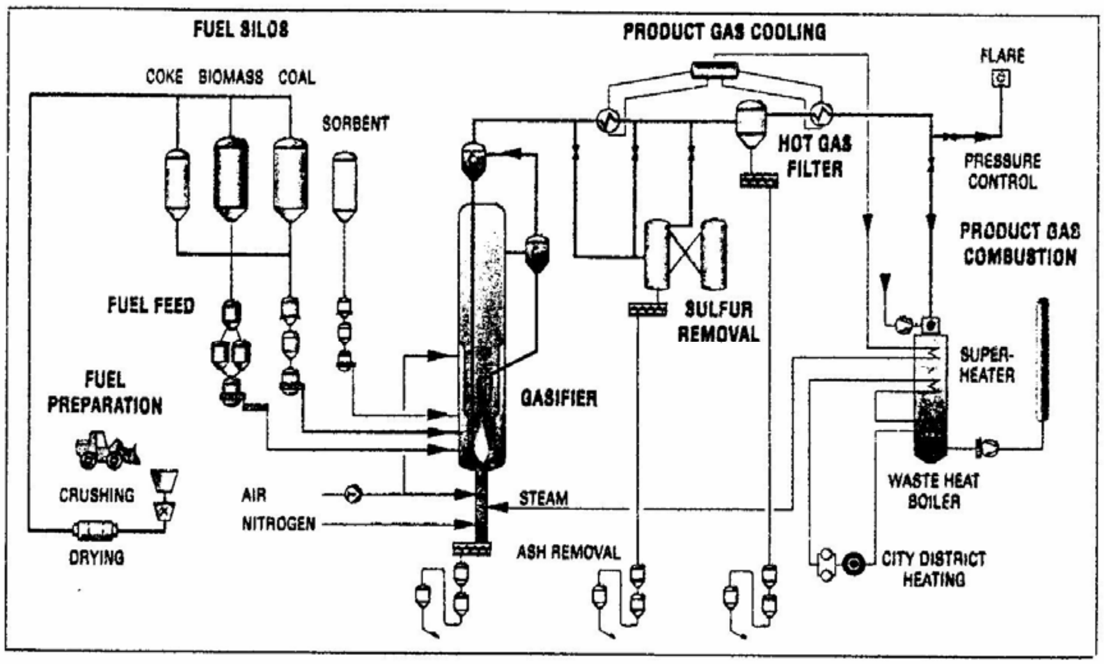
- All for large power level
- Use gas turbines/ steam turbines

Fig. 1. Pilot plant with CFB gasifier and gas cleaning in Studsvik.

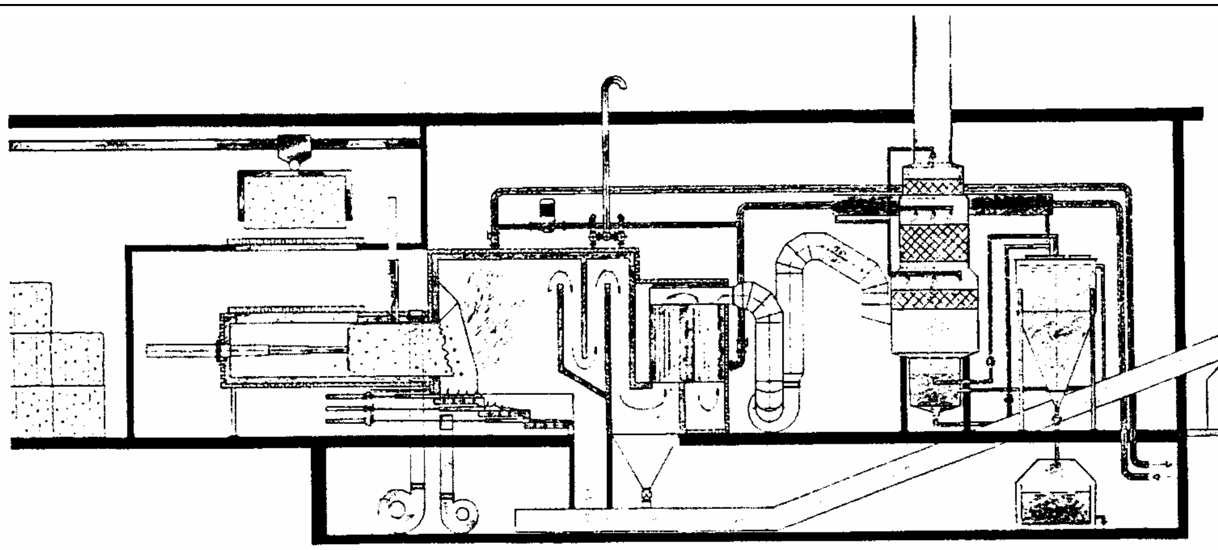


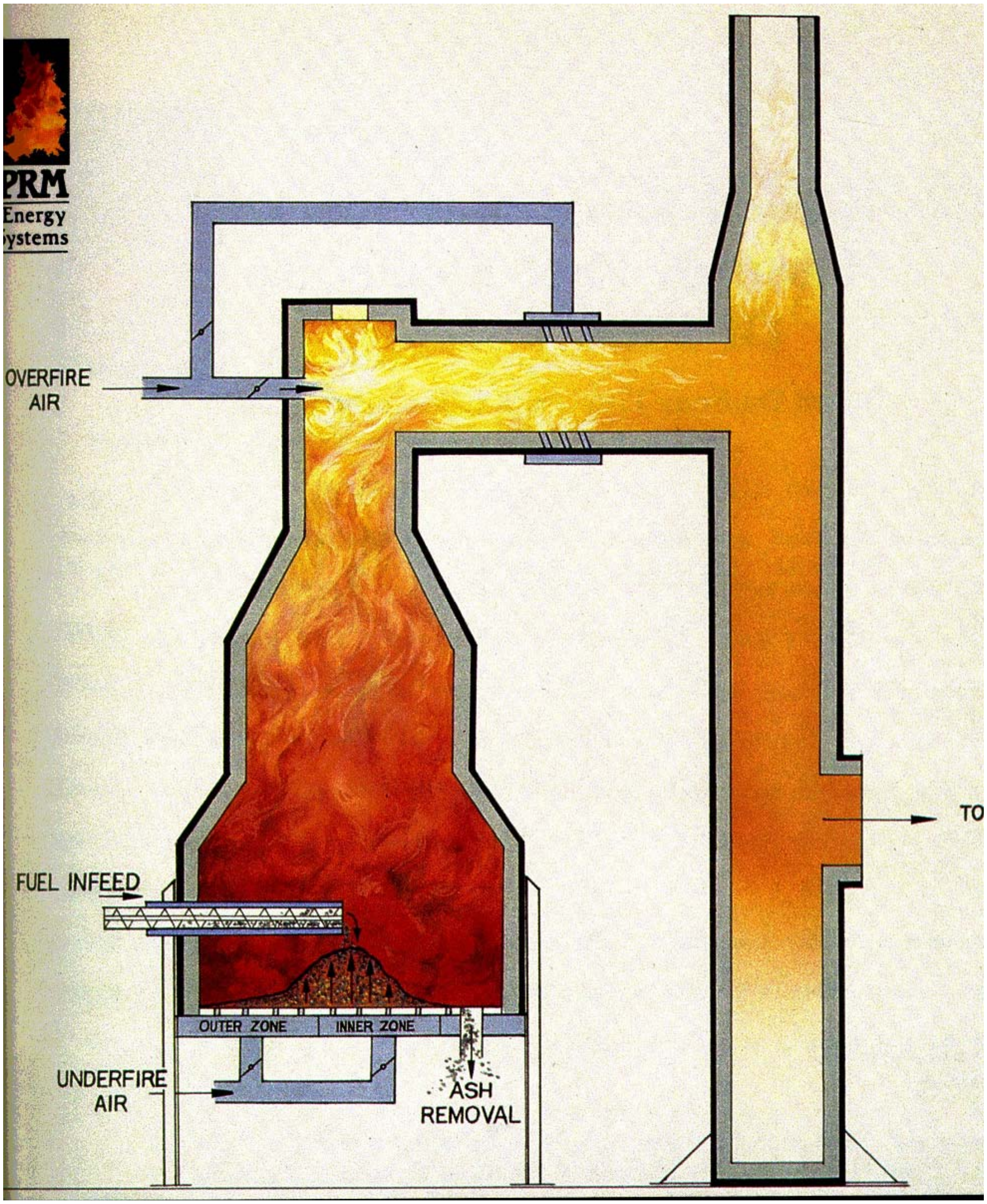
	Gasification		Combustion	
	Boiler	Combined cycle	Grate-firing	CFB-Boiler
Fuel input. MW	87.0	87.6	87.0	87.0
Heat output, MW	52.2	43.4	58.3	59.6
Electric power output, MW	24.2	31.1	19.6	20.2
Overall efficiency, %	88	85	90	92
Investment cost (cost level, 2nd quarter, 1991) MSEK	750	820	930	860





Schematic diagram of the pilot plant




PRM
Energy
Systems
OVERFIRE
AIR
FUEL INFEED
OUTER ZONE
INNER ZONE
UNDERFIRE
AIR
ASH
REMOVAL
TO