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Design of Biomass Gasifiers for Power generation, cold storage and Heating for Jammu and Kashmir state

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ABSTRACT

The complete gasification comprises all the processes, which convert the solid fuel into a gaseous and liquid product leaving only parts of the mineral constituents of the fuel as a residue. The essence of gasification is the conversion of solid carbon to combustible carbon monoxide by thermochemical reactions of fuel. Gasifies are relatively simple devices. The mechanics of their operation, such as feeding and gas cleanup, are also simple. The introduction of small scale producer-engine systems as the replacement for diesel or gasoline driven power units and generators for small scale industries in urban areas, as well as on the village level, seems to be highly attractive. The difficulties are not so much to obtain a combustible gas but to generate it in a physical and chemical state necessary for long term use in the internal combustion engine. The state of Jammu and Kashmir has one of the best potentials of bioenergy as it has largest wastelands, forest cover and horticulture production which can be useful for power generation, heating and cold storage. The present studies are based on the design of biomass gasifier and its applications in the production of electricity, heat generation and running cold storage units.

Key words: Gasifies, Heat recovery unit, Pyrolysis, Gas-Engine Generator, HVAC systems, Cold storage, Biomass.

1. INTRODUCTION

Global economic and social developments are the key factors in energy demand and energy supply. The contrary is also true - a secure energy supply in each country will guarantee sustainable development, economic growth, and quality of life. As a result of economic growth, urbanization, and social development, the world energy demand has increased continuously during the last decades. There are commonly two categories of energy sources: fossil fuels and non-fossil fuels. Because the utilization of non-fossil energy sources has faced many challenges in terms of high capital expenditure, low energy conversion efficiency, environmental impacts, and difficulty in the implementation depending on the type of non-fossil energy sources [1-3]. Bioenergy is one of best solutions in India for off grid electricity generation. Moreover, it can not only help in sustainable development but can also be used for heating applications and run cold storage units for managing post-harvest losses in Indian agriculture. The deign of such biomass gasifiers and terminology of biomass gasification process is given as :

1.1 Terminology

Gasification Process: Gasification is a thermochemical process in which biomass is subjected to a high temperature and depending on the quantity of oxygen supplied pyrolysis and gasification of biomass occur.

Gasifier: A reactor, which converts solid fuels in to gaseous fuel through thermo-chemical process.

Producer gas: It is mixture of gases produced when materials like wood, charcoal, coke, slack, lignite or crop residue are burnt in the presence of insufficient air.

Pyrolysis: It is the process in which the heat uses to breakdown biomass and yields charcoal, wood-oils, tars, and gases. It is the first step in the combustion and gasification of biomass.

Pyrolysis zone: In this zone the solid material starts breaking at 250°C producing char as well as condensable and non-condensable gases. All the pyrolysis products move to the oxidation zone.

Oxidation zone: In this zone, oxygen (air) is introduced. A very important function of oxidation zone apart from the heat generation is to convert and oxidise all the condensable organic products from the pyrolysis zone.

Reduction zone: In this zone the sensible heat of the gases and charcoal is absorbed in the endothermic reactions between water, CO_2 and carbon in the charcoal.

Equivalence ratio: The equivalence ratio is defined as the ratio of actual air used in a run to stoichiometric air requirement for the run.

Turn down ratio: Turn down ratio of a gasifier is the ratio of maximum to minimum gas generation rates at which it can be reasonably efficiently operated without drop in quality of gas.

Gasification efficiency: It is the percentage energy of biomass converted in to a cold producer gas (free from tar).

Specific gasification rate: Specific gasification rate is the quantity of biomass consumed per unit time and cross-sectional area of gasifier. SGR may be calculated by following relation.

$$SGR = \left[\frac{Weight\ of\ dry\ biomass\ used\ per\ unit\ time\left(kg\,h^{-1}\right)}{Cross-\sec tional\ area\ of\ the\ reactor\left(m^2\right)} \right]$$

2. TYPES OF GASIFIER

The gasifiers are generally classified based on the flow of materials and gases inside the reactor. Following four types of gasifiers are commonly used:

(i) Up draft gasifier,

(ii) Down draft gasifier

(iii) Cross draft gasifier

(iv) Fluidized bed gasifier

2.1 Factors influencing the performance of gasifier:

- Moisture content
- Volatile matters
- Ash content
- Energy content
- Equivalence ratio

The presence of moisture is essential for gasification reaction but when it is present in excess it has detrimental effects on the gasifier. The presence of high moisture content requires large quantity heat for evaporation of this moisture. The moisture content of 8 to 15 per cent is considered desirable. The high moisture content lowers the combustion efficiency and creates problem in flow of material. The density of material is also an important factor while considering energy content of feeds on a volumetric basis, and in transporting, handling and sizing of the reactor vessels. The basic feed characteristics is more easily judged from the dugout angle of repose. Good feed hopper design calls for a cone angle that is double the dugout angle of repose. With an angle of repose over 45°, the feed may not flow even in a straight cylinder and will require some agitator.

Average size of feed stalk should be between 15 to 75 mm. The average heating value of material should be more than 10 MJ/kg. The ash fusion temperature should be more than 1150°C. The fuels with high ash content require much greater attention to grate design, gas disengagement and positive char ash removal.

The fuel size influences the pressure drop across the gasification. Bridging of large fuel size has the problem in small stationary gasifier, which is the main cause of the slag formation because the fuel stops flowing at an uncharged air input rate. The size of fuel recommended for different gasifier is given in table 7. The air fuel ratio may increase at some locations, which may cause the slag formation.

3. DESIGN OF GASIFIER

The first step in the design of gasifier is to identify the application and size/ capacity of the gasifier in terms of the gas requirement and the type and quantity of fuel to be gasified.

Components of the gasifier

The main components of the gasifier are:

(i) Grate (ii) Throat

(iii) Air nozzle/air distribution system (iv) Ash removal system, ash removal port

(v) Gas outlet (vi) Ignition port

(vii) Biomass feeding port (viii) Hopper

3.1 DESIGN OF DOWN DRAFT GASIFIER (WITHOUT THROAT)

There are following steps for calculating different parameters of throat less gasifier.

(I) Fuel consumption (q) $q = \dfrac{3600 \times P}{\eta_{tot} \times H_w}$

Where:

q = fuel consumption, *kg/h*

P = engine output, *kW*

η_o = overall efficiency, i.e. (Gasification efficiency X Engine combustion efficiency)

H_w = lower heating value of biomass, *kJ/kg*

(II) Quantity of gas produced, Q = $\dfrac{\eta_c \times q \times H_w}{H_g}$

where:

η_c = gasification efficiency

q = fuel consumption, *kg/h*

H_w & H_g = lower calorific values of biomass and producer gas in *kJ/kg* and kJ/Nm^3

(III) Volume of reactor, $V = \dfrac{t \times q}{S_p}$

where:

t = time of operation

S_p = piled density of biomass, kg/m^3

(IV) Area required, A = (fuel consumption / specific gasification rate)

Diameter of the reactor, $D = \sqrt{\dfrac{A}{\pi / 4}}$

(V) Height of the reactor, h = $\frac{V \times 4}{\pi D^2}$

3.2 DESIGN OF UPDRAFT GASIFIER

The design of a gasifier depends mainly on the fuel to be gasified. High efficiency, tar free gas and excellent hearth load are desirable properties of gasifier that contradict each other thermodynamically and cannot be simultaneously optimized. Important points in the design of an updraft gasifier are;

(i) Size and type of the grate.

(ii) Location and diameter of gas outlet

(iii) Method of air distribution system

(iv) Ash removal system

(v) Hopper size and shape

Ignition port, fuel feeding, ash removal port/duct are common to all types of gasifier.

3.3 GRATE

The grate design is also very important for the efficient functioning of the gasifier because it performs the several functions. The grate separates the ash bin from the partial combustion zone and supports the entire fuel column. The grate design must allow for the ash to move freely through it into the ash bin and at the same time prevent carbonized fuel falling through it. Another important point in the design and operation is the protection layer of ash that should be maintained above the grate. Too thick ash layer seriously interfere with the operation due to increase in pressure drop from the gasifier and hence lower gasification rate. The average gasification rates of biomass considered for design of grate are given in table 8.

Parameters, which influences the grate design, are:

(i) Rate of ash removal

(ii) Superficial gas velocity and flow field

(iii) Size distribution of the char

(iv) Bulk density of the char

(v) Construction and cost maintenance

The area of grate may be calculated by following formula:

$$A = \frac{q}{SGR}$$

Where,

A	=	grate area, m^2
q	=	biomass consumption, kg/h
SGR	=	specific gasification rate of biomass, $kg/h\text{-}m^2$

The diameter of grate: $D = \sqrt{\frac{4A}{\pi}}$

3.4 LOCATION OF GAS OUTLET

The updraft gasifier draws off the gases just above the reduction zone. The drawing off the gas above the reduction zone has the beneficial effect of obtaining a more tar free gas but results in high exit temperature and decreased overall efficiency. The other point, which is to be considered for the location of gas outlet, is the space between the top of the fuel column and gas exit. The large capacity gasifier provides a free space of fuel below the gas exit that allows the gas to expand, cool down and decreased its velocity before it reaches the outlet pipe. The low velocity results into the coarse fuel particles entrained in the gas current are allowed to settle down and do not reach the gas exit.

Assumptions that allow an exact representation of terminal velocity of a particle are:

- The particle is spherical and rigid and no slip exists between the particle and the gas.

- The gas is homogeneous within the length scale of the particles.
- The settling velocity is so low that all inertia effects are negligible.
- The flow field is laminar.

3.5 ASH REMOVAL SYSTEMS

The following ash removal options are available:

a) Fixed grate allowing for periodic removal of the ash.

b) Mechanical, rotating grate allowing for periodic removal of the ash.

c) Mechanical, rotating grate allowing for continuous ash removal.

The agro residues in general have 20 to 30 percent residues (Ash) after gasification. The space occupies by the ash is in the range of 10 to 25 per cent of volume of the fuel. The density of ash had 50 to 100 kg/m^3.

4. WORKING OF 50 KW BIOMASS GASIFIER AT NATIONAL INSTITUTE OF SOLAR ENERGY, GURGAON.

Presently a 50 kw wood based downdraft gasifier is being used for the project. The downdraft or co-current gasifier is prominently used since, tar entrainment problem in the gas stream is minimized in co-current or downdraft gasifiers, in which primary gasification air is introduced at or above the gasifier oxidation zone and the producer gas leaves from the bottom of the gasifier (so, the air and fuel flow move in the same direction – co-current). Tarry distillation products from the fuel in this gasifier types have to pass through the burning bed of charcoal and by means of this they are converted into gas. The tar decomposition degree depends on the gasifier hot zone temperature and on the residence time of tarry vapors there. Wood based chips are used and fed from the top of gasifier. The moisture content of feed is about 18 %. The different type of wood chips is used in the gasifier, depending on the availability. The biomass fuel is fed at top of the gasifier and air is supplied at regular intervals. The hot combustion gases are passed through the fuel bed and this leads to generation of combustible gas.

5. GAS-ENGINE GENERATOR

Both type of IC engines. i.e. Spark ignition engines and compression ignition engines can be used with biomass derived fuels, although the technologies are somewhat different. The spark ignition engines operating on gasoline and kerosene are often preferred for applications where low weight is an advantage and where the shorter lifetime (typically less than 5000 hours) and lower efficiency (typically about 25 % at full power) can be accepted from an economic point of view. This situation often applies when the annual number of operating hours is low, say less than 500.

Compression ignition engines operating on diesel fuel, are heavier, are generally designed for lifetime of more than 20,000 hours, and show a higher efficiency (typically about 35 % at full power). They are preferred for applications where weight is less important and where the gains on lifetime and fuel economy compensate for the higher price of engine.

Another possibility is the conversion of the biomass to a combustible gas (producer gas), which can be used as fuel in the engine. Spark ignition engines can use producer gas without major modification. Compression ignition engines will not operate on this gas only, but can be run on a mixture of gas and suitable liquid fuel. The present engine used in the project runs on combustible gas (producer gas) produced from the wood biomass, when it is burned with less air than is needed to achieve complete combustion. The producer gas consists of combustible components carbon monoxide, hydrogen and some methane mixed with carbon dioxide, water vapour and nitrogen. Before its introduction into the engine the gas must be cleaned to remove dust and tars. Various types of cleaners have been used for this purpose, e.g., cyclones, wet scrubbers, large volumes filled with sawdust, wood wool, pieces of cork or coir fiber. However, in this system it’s necessary to clean the inlet manifold of the engine more often. The gas outlet of gasifier is connected with the various downstream systems viz cyclones, Flare with valve, Engine gas control valve, cyclones and Engine shut-off valve. Gas produced in Gasifier is scrubbed and cooled. Cool, Clean Gas and Air is then sucked into the Engine through a mixer butterfly consisting of piping and valves arrangement. The gas is cooled in order to avoid condensation in the inlet manifold when the gas (which contains some water vapor) is mixed with ambient air. Cooling of gas will also lead to an improved engine power output, as it will increase the volumetric energy content of the gas-air mixture supplied to engine. The Gasifier is started with a Battery (12V) and AC Scrubber Pump. The producer gas then starts engine on gas mode. Governor linked control butterfly is provided to vary the gas quantity as per electrical load on the generator, keeping frequency within limits. The shaft of the gas engine is coupled with the generator which produces the electricity. Some portion of the electricity is used in the pump of the cold storage system and rest of the electricity is given to the Smart Grid. From the smart grid, the electricity can be used for other ends use application.

Figure1. Plate No. 1 Gas-Engine Generator

5.1 WASTE HEAT RECOVERY UNIT

Shell in tube heat recovery system is used for recovery of heat from exhaust of engine. The system has also a provision to fire producer gas as an auxiliary arrangement in case sufficient exhaust and solar heat is not available to meet the requirement of vapor absorption machine. In the system pressurized water is used for the heat observer/heat carrier. System is also receiving the heat from solar system through the flow of hot water. The temperature of engine exhaust was found to be near 400 ^{0}C .After the heat recovery flue gas was going and temperature flue gas/exhaust was observed at the outlet of heat recovery system. As such 55% of the heat of the exhaust was recovered by the heat recovery system. The burner temperature of auxiliary firing system was nearly 600 ^{0}C whereas the outlet temperature was 200 ^{0}C. As such 66 % heat was recovered by the Heat recovery system in case of auxiliary firing. The provision of three inlets (engine exhaust, auxiliary firing and solar thermal fluid) makes it one of the efficient systems and helps in energy conservation and waste heat utilization. During the non-solar hours, engine exhaust and auxiliary firing of producer gas are used as hot and cold fluids in the heat recovery unit. Auxiliary firing quantity was inversely proportional to exhaust output/electrical load consumption.

Figure 2. Plate No. 2   Waste Heat Recovery Unit

6. APPLICATION OF BIOMASS GASIFICATION TECHNOLOGY FOR POWER GENERATION, HEATING AND COLD STORAGE IN JAMMU AND KASHMIR:

Jammu and Kashmir has enormous potential of bioenergy and the same must be utilized for electricity generation and heating process. The biomass gasification can be an effective process so that electricity is generated and the waste heat is recovered through Waste heat recovery units.

The waste heat recovery unit as above can be used for HVAC systems or through forced circulation, can be used for heating purposes. Since, Kashmir is facing enormous problems of electricity in winter and colder temperature adds to agony of locals. The same technology can be used to produce electricity and direct biomass firing shall ensure that proper heating is provided to homes, offices and factories in winter. The heat recovery method can prove to be an efficient model of cogeneration of electricity and heating. As per biomass resource potential atlas, Jammu and Kashmir has a potential of more than 2000 MWe. The best available biomass in Kashmir division is forest biomass, horticulture waste (pruning of trees) and agricultural waste. Waste to energy plants can also be started which will actually work through biomass gasification process if proper segregation of municipal waste is done. Moreover, dried waste can prove an efficient source of bioenergy which shall generate electricity and the waste heat of generator through waste heat recovery unit can be used for heating. The same waste heat can be recycled and used in Vapour absorption machine and thus cold storage units can be run on small scale through available biomass. The same biomass can be customized for a variety of applications like Thermal application to meet the process heat requirement and Power application for rural electrification and captive use. There can be Substantial reduction in diesel/kerosene/furnace oil cost (since 3-4 kg of biomass can replace 1 litre of petroleum fuel). In winter season, use of castable insulation material in the fire box capable of withstanding high temperatures (up to 1860°C).Since biomass is a carbon neutral fuel, the net emission of CO_2 would amount to zero.

The applied technologies in brick manufacture in Kashmir such as clamps, downdraught kilns require huge proportions of highly polluting coal (with an ash content as high as 40%), firewood, and biomass as fuel. In fact, the coal consumed by this industry was an astronomical 24 million tonnes countrywide.

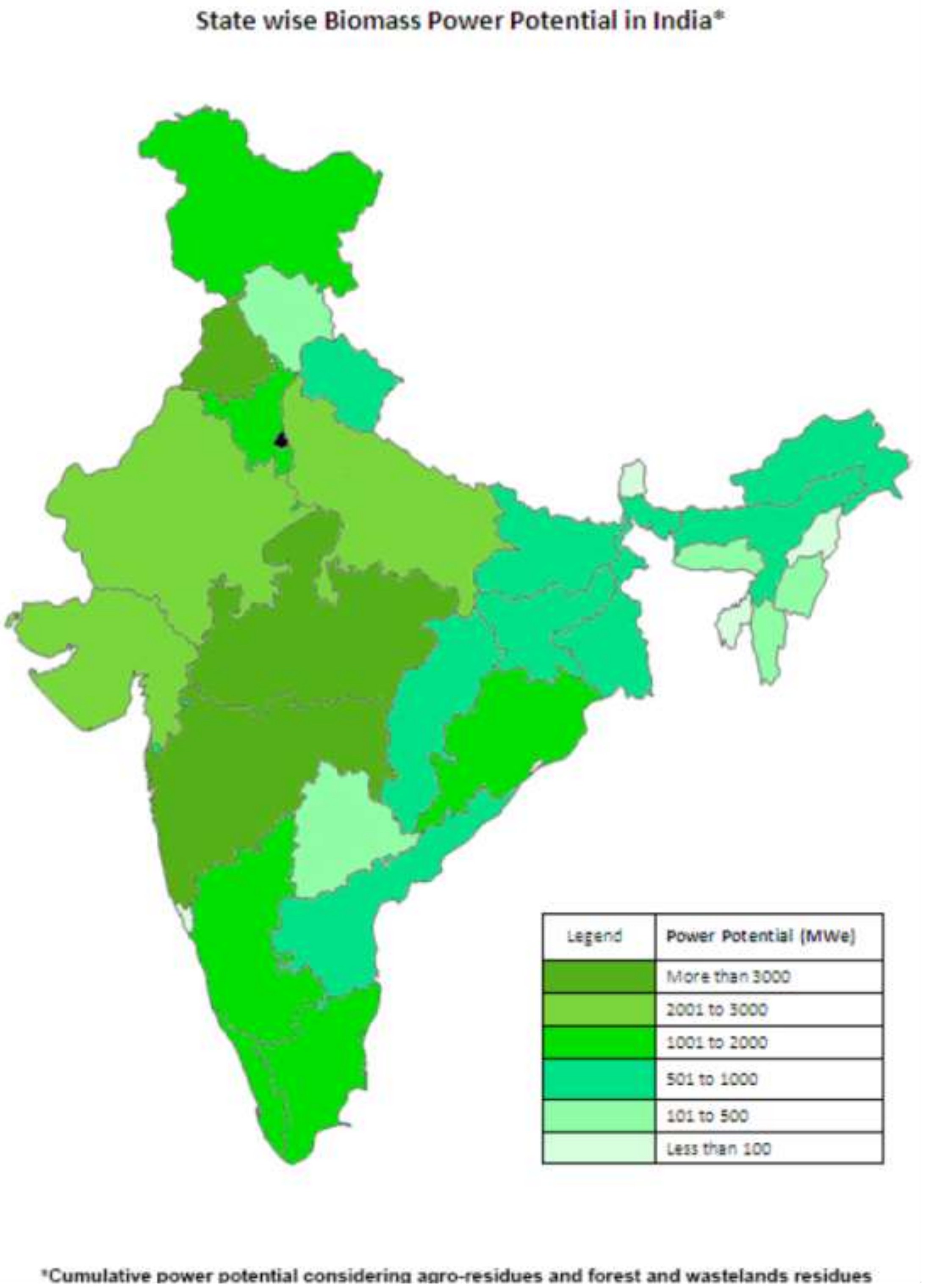

Figure 3. Cumulative power potential state wise based on agro residues, forest and wastelands.

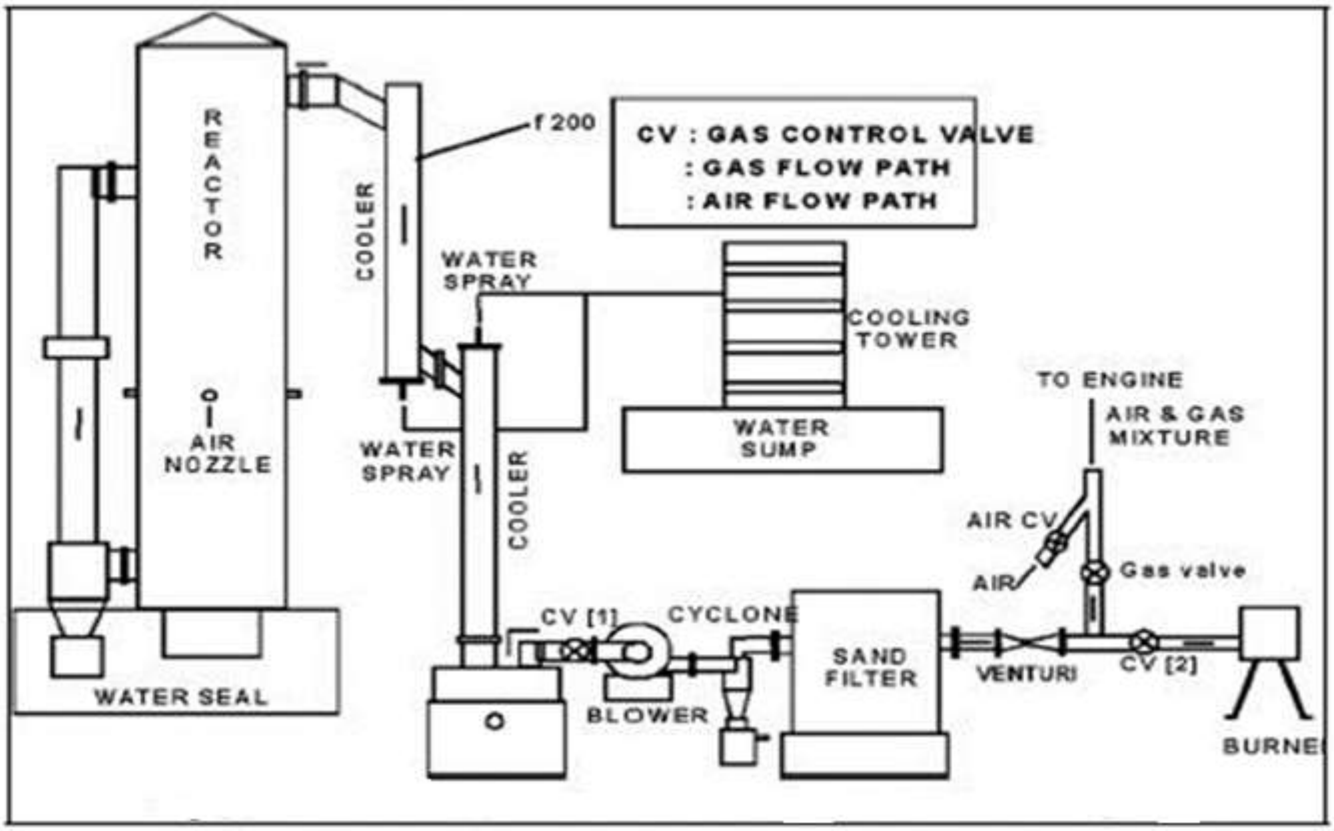

Figure 4: Schematic of a wood gasifies for power generated application.

6. RESULTS AND DISCUSSION

Auxiliary firing quantity was inversely proportional to exhaust output/electrical load consumption. The relationship between auxiliary firing required to run the VAM and power generation, corresponding to engine exhaust is given. In case of peak output, ie. if the energy output of generator is 50 kw, no biomass firing is required as the engine exhaust is sufficient to run the VAM. However, in case our electric output is zero. i.e., generator is not producing any electricity/output, in that case at least 18.66 kg of biomass is required to run the VAM, as the engine exhaust will be zero. Similarly, if the electric output is 47.093 (i.e. less than desired Output), nearly 1.085 kg of biomass is required for auxiliary firing. This shows for the running of VAM, auxiliary firing is dependent on engine exhaust, which is in turn dependent on the power generation.

Figure 5 shows the Relationship between Mass of Wood for Auxiliary firing to run VAM corresponding to Power Generation.

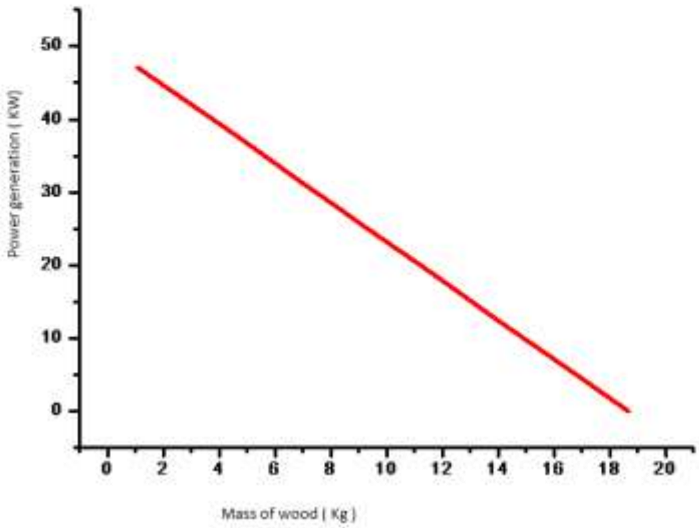

Figure 5. Mass of Wood used In auxiliary firing v/s Power generation.

The relationship of mass of wood,electricity produced and required biomass firing for heating and cooling is given in table 1 **and** shows that 18.66 Kg of biomass is required to a 20 tonne cold storage unit and aheating system (HVAC) can run on same amouint of biomass when electricity is not required.i.e direct biomass firing can be done through auxiliary firing. If the electricity genersted through Gas Engine generstor is nearly 47.09 KW, about 1 kg of biomass is reuired for auxiliary firing so that the system runs on hybridized mode.i.e electricty is produced through gas engine generator,cold storage is run through vapour absorption machine and the heat is utilized through waste heat recovery unit.This system can prove effective in colder regions like Kashmir and Leh as heating is required in winter months,electricity generation through gasification will ensure more sustanibility and effieciency of system.The cooling through VAM can efficetively run cold storage units which can be used to store horticulture produce,dairy products and other agriculture produce.

Table 1. Relationship between mass of wood used in auxiliary firing vs electricity produced for heating and cooling through VAM.

Mass of Wood	Power Gen.(KW)
18.66319444	0
16.31944444	6.279069767
15.14756944	9.418604651
13.97569444	12.55813953
12.80381944	15.69767442
11.63194444	18.8372093
10.46006944	21.97674419
9.288194444	25.11627907
8.116319444	28.25581395
6.944444444	31.39534884
5.772569444	34.53488372
4.600694444	37.6744186
3.428819444	40.81395349
2.256944444	43.95348837
1.085069444	47.09302326

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