Stand alone small power level systems

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Abstract

Stand alone small power level systems as a route to low investment decentralised systems with low gestation period are discussed. Current costs of investments and energy of alternate systems are used to argue for bio-residue based power generation system. Recent developments in these technologies, third party validation efforts based on rigorous tests are brought out. Potentialities for constructing a replicable power generation system which enhances the number of wage days in villages, their agricultural productivity and also the quality of life in villages are explained. Current experiences in this direction at ASTRA, IISc are brought out.

Background

Much has been written on the possibility of decentralised power generation systems. The groups that are euphoric about the concept of small decentralised power generation system argue about the over dependence on fossil fuels which are used at rates to exhaustion and lead to warming problem due to net carbon-dioxide transfer into the atmosphere. They also argue that the hidden subsidies in centralised power supply have led to the inability of alternate renewable sources to compete.

Authorities involved with large scale power generation in the country does not bother about these arguments. They would argue thus: Today, we have in place a certain MW's of power (~ 85,000) supply in the country. We are deficient by a non-insignificant fraction (~ 10,000) of these MW's. Hence we should consider those approaches to fulfill these needs. To imagine a hundred thousand 100 kWe plants to generate 10,000 MWe or a twenty thousand, 500 kWe plants would take a long time to fructify. Therefore we must consider plants of large size ~ a few hundred MW's each. This has led to the consideration of large scale power plants based on imported coal or natural gas if need be, if indigenous sources are inadequate. These also imply need of large amounts of finances at 3-4 crores/MWe typically 600 - 2000 crores depending on the power level.. Since we are short of funds, we better get it from outside, if necessary. Many of the power purchase agreements (PPA) made with the above thoughts have run into rough weather. Partly, the over-enthusiasm by the suppliers, some foreign, to exploit the difficult local circumstances has led to non-transparent negotiations and consequent unfavorable PPA's and lot of controversy. Of course, it is important to distinguish between bad PPAand intrinsic merit.

A minuscule group in the country has put together another scenario in which conventional approaches and renewables need not operate in an exclusive manner but a cooperative one. The arguments are that centralised supply should be tempered with approaches on reducing T & D losses, energy conservation at utilities, looking for the least power level for economic operation and renewable. By and large these approaches are respected at seminars, but not taken note of elsewhere.

In recent times, the presence of renewable is felt in wind power generation. About 500 MWe have been installed; another 300~MWe is in the process of installation. Again there have been problems. The over-enthusiasm of private entrepreneurs and somewhat unguided action on the part of state electricity authorities has led to installation beyond the capacity of evacuation. As such the energy generated is much less than can be expected from installed capacity. The presence of wind mills is felt because it is in terms of MW's. Otherwise, it would have been laid wayside in the minds of people.

Amongst the renewables, wind power as contemplated now cannot qualify for stand alone power generation. For, at the power level contemplated, grid synchronisation is the practice. Also one of the defects of wind power generation shared by solar photo voltaic (SPV's) is its inability to provide power on demand unless excessive backup hardware - up to 75 % of the rated capacity is provided for. For wind or sunshine allows for 20-30 % energy capture at rated capacity due to low winds or limited day light hours.

This leads to two other major renewables, namely micro-hydel and bio-resource. Micro-hydels can be used only where there are water discharges at acceptable heads. These, many times are in remote locations and it is not obvious that there are communities available to use the electricity generated. However, wherever such energy exists it is indeed a very vital alternative.

Bio-resource, which is essentially stored solar energy, does not suffer the above disadvantages. It is some times argued that bio-resource is a weak solar energy converter - photosynthetic-efficiencies ~ 1.5-2 % and what can we expect from it. It is not to be forgotten that the possible higher efficiency of conversion of SPV's ~ 9 % or the futuristic 20 % cannot produce food and even if the photosynthetic efficiency considerations show weakness, the fact that societies have to survive by this process for their food implies that this technology will be deployed by societies for all time to come. Bio-residue productivities need only to be matched to local demands in the new concept of stand alone systems. As will be shown later, this is entirely possible and hence bio-residue option has to be given serious thought to. Typical ranges of power level costs of installation over which technologies are available.

Table 1 Economic comparisons amongst renewables and conventional system

Mode	Range of power Lavel available	Cost per Million, Rs	Cosst of energy. Rs/ kwh	Gestation period for functioning	Energy Million units/hr
SPV	0.5 – 100	3-350	8-12	0.5	2-3
Solar Thermal	10-30 MW	100-150	4-2	3-4	2-3
Wind	200-500	35-45	2-3	0.5	2-3
Microhydel	20-1`00	35-45	1.5-2.5	1	5-7
Bioresource	2-500	15-20	1.5-2.5	0.5	5-7
Thermal Coal	2-300 MW	30-40	1.5-2.5	3-6	5-7

Ode	Range of power level available, kW	Cost per MW Millions, Rs.	Cost of energy Rs./kWh	Gestation peiod for functioning, Yr.	Energy Million units/Yr.
SPV	0.5 - 100	300 - 350	8 - 12	0.5	2 - 3
Solar thermal	10 - 30 MW	100 - 150	4 - 6	3 - 4	2 - 3
Wind	200 - 500	35 - 45	2 - 3	0.5	2 - 3
Microhydel	20 - 100	35 - 45	1.5 - 2.5	1.0	5 - 7
Bioresource	2 - 500	15 - 20	1.5 - 2.5	0.5	5 - 7
Thermal-coal	3 - 200 MW	30 - 40	1.5 - 2.5	3 - 6	5 - 7

As can be seen from the table the lowest cost system is bio-residue based power generation system. This is in part because it is based on the conventional power pack namely reciprocating diesel/gas engine. As long as the bio-residue is

based on agro residue its availability is ensured over large parts of the country. The gestation period for realising the electricity generation from the point of cash flow is typically half an year or less for small power level systems and between 3-6 years for large power level conventional systems.

Power generation from bio-residues can be performed by two ways. The more conventional one is combustion route in which the heat is used to generate high pressure steam and power there from. This is satisfactory at large power levels, typically at more than 5 MWe. The other route is via gasification at the end of which a clean combustible gas can be used to run an internal combustion reciprocating or rotary (gas turbine) engine.

Gasification is the process of converting solid fuels to gaseous fuel. It is not simply pyrolysis; pyrolysis is only one of the steps in the conversion process. The other steps are combustion with air and reduction of the product of combustion (water vapor and carbon dioxide) into combustible gases, (carbon monoxide, hydrogen, methane, some higher hydrocarbons) and inerts, (carbon dioxide and nitrogen). The process leads to a gas with some fine dust and condensable compounds termed tar, both of which must be restricted to low values if the gas is to be used in internal combustion engines.

The energy conversion process via reciprocating engines leads to efficiencies of 15 to 20 % at 20 kWe power level, 25 to 30 % at 100 to 150 kWe level, 30 to 35 % at 200 kWe and above particularly in turbocharged mode. The energy conversion via gas turbines leads to efficiencies about 5 % lower than reciprocating engines. The maintenance cost of the gas turbine engines is generally lower than in reciprocating engines because the reciprocating motion is more taxing structurally than rotary motion.

One has a further facility of being able to use the exhaust gas in either case (reciprocating or gas turbine engines) in cogeneration mode either for electricity through steam turbines or more practically, for raising process steam.

Bio-residues considered and their properties

Biomass is classified into woody and powdery base on its availability in natural form. The former is taken to connote biomass whose average density is larger than about 200 kg/m^3 and ash content limited to about 2 %. Typical examples are fire wood, cotton stalk, mulberry stalk, corn cobs, coconut frown and shells and weeds like eupatorium, lantana camera and other similar materials. The point to note here is that woody biomass is not limited to firewood, but several agricultural wastes also qualify for this title. All other biomass which are in loose form and lower densities are identified here are powdery. This includes several or most agricultural residues like sawdust, rice husk, rice straw, bagasse, sugarcane trash, ground nut shells, coir pith, prunes from tea/coffee plantations and so on. The reason for the choice of the word powdery is that many such agricultural wastes are close to a form in which pulverisation with a low power device (~ 0.04-0.07 kWh/kg) can bring it into the form of powder. This also increases the bulk densities of the raw material helping in conveying at lower costs. Once biomass is pulverised the conversion device may be designed to accept a variety of biomass. The densities of such biomass is in the range 50-150 kg/m^3 and ash content up to 20 %.

It is known that all biomass have roughly the same CHNO composition on an ash.

free basis. This also implies that the calorific value of biomass is about same for all biomasses excepting due to the effect of non-combustible mineral content.

At sun dried condition, implying moisture content of 8-10 %, the calorific value of all biomasses is in the range of 12-16 MJ/kg. The lower end belongs to rice husk and straw and the higher end belongs to wood/bagasse and such materials. If we note that the calorific value of coal found in India and a few other parts of the world having high ash content like 30-40 % is about 15-20 MJ/kg, we come to a conclusion that biomass is comparable in the heating value to such coals. While coals have to be mined and transported over large distances for use, causing economic problems on the one hand and global warming effects on the other, biomass can be grown in most places except where the climate is most inhospitable.

Woody biomass gasifier

Reactor

The development of the gasifier over a range of power levels of 3.7 to 100 kWe and field experience are described in a series of earlier publications from this laboratory (Dasappa et al, 1989, Mukunda et al, 1993, Mukunda et al, 1994, Mukunda et al, 1994a, Ravindranath et al, 1990, Srinivas et al, 1992). Also described are the differences between the open top system and the classical closed top system. These are not addressed in any detail here. However, a brief description is provided here.

The principal element of woody biomass gasifier is the reactor as in Figure 1. This reactor design with air drawn from top as well side air nozzles reduces the unreliable operation of the closed top design particularly when the feed stock has high moisture content (around 25 % or more) and also provide a good turn down ratio with little tar content (Mukunda et al, 1994). The reasons for the good performance of this system vis-a-vis the closed top design (see Mukunda et al, 1993) are that the improvement in performance is related to the more homogeneous flow of air through the bed which is near one-dimensional, and to the fact that the approach to final fuel rich condition is from an initial lean state through stoichiometry. The second point leads to lower generation of tar and whatever is generated is cracked to smaller sized molecules as the gas traverses through a long uniformly arranged bed of hot charcoal without any low temperature zones. The possibility of using biomass with a higher moisture content than in a classical reactor is related to the geometry in which the hot gases from the bottom of the reactor pass through an annular region transferring back part of the heat into the wood chips in the upper zones. This permits better drying before the wood chips enter the combustion zone.

The current design of the reactor consists of a vertical tubular reactor with an open top and a water seal at the bottom. The high temperature portion of the reactor, i. e. where the reactor bed temperature exceeds 600 °C, is lined with a ceramic material of low thermal conductivity. This zone is from about 0.75 m above the air nozzle to the reactor bottom. The hot gas drawn below the grate is passed through the annulus of a stainless steel concentric shell placed above the ceramic lined shells. The entire reactor surface along with the re-circulating duct which connects the bottom of the reactor to the annular region at the top is insulated with alumino silicate blankets. The hot gas which enters the annulus around 500 °C, transfers some heat to the wood chips inside, improving the thermal efficiency of the system, in addition to drying the wood chips in this zone. The inner wall temperature reaches more than 350 °C after a few hours of operation at full power and this condition is favourable for the preparation of wood chips before their entry into the combustion zone. Consequent upon these features, it has been possible to successfully gasify pine wood (low density - 180 kg/m^3) at moisture content as high as 30 % (recent tests on IISc gasifier at Chatel-St-Denis, Switzerland).

For engine application, gas must be cooled to room temperature and must be much cleaner compared to thermal applications. The acceptable upper limit of particulate content appears to be around 50 mg/m^3 irrespective of particle size, which is generally less than 10 m. However, if the particle sizes are smaller than about one micron, this limit is unimportant as the particulate matter flows along with the gas without deposition at bends, corners and passages.

In order to increase the density of the gas, the gas is cooled to ambient temperature by indirect and/or direct means and is filtered adequately to reduce the particulate content. Cooling in high power systems is best handled by direct injection of cooling water unless there is specific plan of utilisation of the low grade heat. A sand bed filter is deployed to remove the particulates collected by the cooling water in the spray tower. Periodic washing of this sand bed is adequate to keep the operation smooth. Experiments have shown that some part of the tar also gets deposited in the filter circuit, particularly when the moisture carryover from the cooler causes slight wetting of the sand bed. Typical schematic of the system for engine applications is shown in Figure 2.

Gasifier Performance

The performance of the gasifier can be described in terms of the composition of the cold gas, its calorific value, the particulate and tar levels at various loads. The ratio of the cold gas flow rate to the wood consumption rate is about 2.6 0.1. Measurements on a specially built system with instrumentation and test schedule lasting for 10 hours each as per a procedure adopted from European standards and monitored by Swiss scientists (Mukunda et al, 1994) have led to gas composition and calorific value as follows: The gas composition is H_2 = 20 2 %, CO = 19 1%, CH_4 = 1.5 0.5 %, CO_2 = 12 1%, and the rest N_2. The calorific value keeps rising for about a few hours and towards the steady state it approaches about 4.75 MJ/kg. The particulate and tar (P&T) data for both hot and cold ends were measured in these tests. The reason for this is as follows. The amount of P&T generated at the hot end has to be brought down to acceptable levels by the cleaning system. Should the amount at the hot end be very large, then the load on the cleaning system also will be significant. This implies the need for a more elaborate clean-up system and/or more frequent maintenance. It is not often that P&T data at the hot end is obtained since very little is reported in literature. The present results indicate that the hot end tar is 100 mg/m^3 and comes down to 20 10 mg/m^3 at the end of the fine filter (cold end). Part of this tar is washed by the cooling water, part is deposited in the sand bed filter. The particulate level also comes down to 50 mg/m^3 at the cold end from about 700 mg/m^3 at the hot end. Experiments have shown that the gas can be compatible with gas turbine operations as well since even the fine particulate matter will be oxidized inside the combustor and relatively light fine ash will simply be carried through the passages between rotors and stators.

Operation with Engines

The commercially available diesel engine needs to be modified only at the air intake region. The air intake is fitted with a manifold into which the air and gas lines are connected. The air line is open to atmosphere through a control valve. The engine sucks both air and gas simultaneously and the gas air ratio can be controlled by operating the air control valve. The mixture also passes through the final oil filter so that any possible residual particulate matter is held back preventing possible deposition at the valve seatings. The dual-fuel operation is aimed at reducing the diesel consumption at any fixed load. This is performed by the governor fitted on the engines. In an actual dual-fuel operation, the desired diesel replacement is achieved by reducing the air flow into the engine by operating the air control valve. The engine draws in a specific flow rate through the air manifold. Hence, the sum of air and gas flow rate is constant and when air flow is decreased the gas flow through the system increases. This increases the contribution of the energy from the gas. Hence, the engine governor comes into operation and cuts down the diesel to maintain the speed. Reducing the air flow rate will reduce the diesel flow only as long as the gas air mixture remains lean. If the mixture becomes richer, the engine stalls. One therefore, has to be slightly away from such a condition. The diesel replacement under conditions close to stall can be between 90 to 93%. Providing for a safety margin of about 5 to 6 %, 85 to 87% diesel replacement can be obtained. This can be done either manually or automatically. The details concerning the automated control system are available in Crasta et al (1993) This system was tested in a field installation at Port Blair and found to perform excellently.

Returning to performance in dual-fuel mode, the diesel replacement is around 85% or above over most of the load range. The wood consumption is 0.95 to 1.4 kg/kWhr depending on the power level and moisture content of wood. The overall efficiency of operation, measured as the ratio of the final electrical energy output to the total input energy of diesel and wood, is another performance parameter. Diesel engines show full load efficiency of 24% in 3.7 kWe engines and 35 % in 100 kWe engines. In dual-fuel mode, efficiency is 21% in 3.7 kWe engines and 27% in 100 kWe engines, at 85 % diesel replacement.

Producer gas can be burnt in gas engines in spark ignition mode. Normally, engines for spark ignition have compression ratios of 8 to 12. A study was conducted by Ramachandra (1993) to examine if the diesel engine at compression ratio of 17 could be modified to run on spark ignition mode. This experiment showed that the engine could run on producer gas from the gasifier of IISc design at 17% efficiency with a 25% loss in power. This finding is of considerable importance in farming applications because the demand of power for surface water pumping is not as high as the power delivered by the engine (5 hp). It is also possible to convert high power diesel engines into gas engines by replacing diesel injection system with spark plug and high voltage generating device.

Gasification system for pulverised fuels

In the present approach, the system used for the gasification of pulverisable fuels is a cyclone system. Perhaps it is useful to first discuss why a woody biomass gasifier cannot be used for pulverisable fuels. One of the standard fuels on which the open top system has been used is rice husk, particularly the chinese design (Anon, 1985). In this system, a bottom rotating grate removes the char continuously. The reactor virtually acts as a pyroliser since the char conversion times are an order of magnitude larger than flaming times, so that the residence time in the reactor is inadequate to cause even a few percent conversion of the rice husk char. The primary reason for this is that in a rice char, carbon is located in points which are interlaced with silica so that access to carbon is difficult, certainly far more difficult than in wood char. In order to obviate this problem, rice husk should be pulverised. If rice husk is pulverised, then loading into a cylindrical geometry as in the reactor of wood gasifier causes large pressure drop for the flow through the bed or tunnelling of the flow will occur. Both of these are undesirable. Chinese gasifier designs are known to produce lot of tar and cleaning system has to be elaborate. In their cleaning system, the amount of water required is so large that one plant in Burma was closed down after operating for some time because of this problem. Similar arguments are valid in the case of sawdust and other pulverised fuels. For these reasons a separate design is needed for pulverised fuels. In the current design, the simple cyclone separator has been used as a cyclone reactor. Its description is provided below.

Figure 3 shows the details of the reactor. It has tangential ports, one for heating the reactor as a part of the startup system, another for introducing the pulverised fuel in a pneumatic conveying system such that the air to fuel ratio is very much fuel rich. For small power levels like 100 kWe one tangential fuel feed port is considered satisfactory. At larger power levels it may be necessary to provide more ports to homogenise the flow. The reactor has an outer mild steel shell, typically 3 to 6 mm thick on the inside of which is 75 to 100 mm thick ceramic lining. This lining is built up of refractory bricks. Typical qualification temperatures of these bricks are about 1000 C. Additional protection to the thermal environment is provided at the fuel entry location since the fuel-air mixture flows into the reactor along the tangential direction at fairly high speeds - 10 to 20 m/s.

Normally the bottom of the reactor is open to the ambient atmosphere through a small exit duct as in a cyclone. In cases where better tar control is needed a separate circulating fluid bed reactor is provided so that the contact between the gas and the red hot char is enhanced - thus increasing the reduction reactions and reducing the amount of tar or change its quality that it will not deposit even at ambient conditions anywhere in the passages.

In some instances, the partly converted char or ash has to be assisted in exiting the reactor at the bottom through a separate screw system.

The choice of the material for the central exit duct at the top is a critical element in the design. The choice is between ceramic coated creep resistant high temperature metal or high temperature light ceramic shell. Typical exit gas velocities are restricted to about 1 to 2 m/s.

For a 100 kWe system the diameter of the reactor is about 0.5 m, height being 1.8 m including the conical region. For a 2.7 MWth (625 kWe) system, diameter is about 2.0 m and height including the conical region about 3.5 m.

The System Elements

The system elements as shown in Figure 4 are the reactor, the feed system, the startup system, the cooling system, the cleaning system, an engine - compression or spark ignition kind, if the gas is to be used for running an engine, and a control system.

The feed system involves the combination of a screw feed and blower to convey it to the tangential entry of the cyclone. The only speciality of the system is that it must be capable of handling fuels of widely differing density - from 70 kg/m^3 for sugar cane trash to 350 kg/m^3 for rice husk or sawdust. For the startup system, a special design allows for the use of a low power low rate fuel oil burner is to be used. Typically, it is of 40 kWth capacity for a 100 kWe system and about 200 kWth for 2.7 MWth gasifier system. Typical startup times are less than an hour even for large power level systems.

The cooling and cleaning systems are similar to that of woody biomass gasifier.

The control system is designed to take care of the total (fuel + air) feed rate as well as the air-to-fuel ratio. It must be brought out that it is different from the control system needs of a wood gasifier where it is sufficient to control the gas flow rate. This is because the fuel feed is self-controlled in case of wood gasifier. The dual control in the case of pulverised fuel gasifier is managed by controlling the overall gas flow rate out of the reactor by a control valve on the pipe line and the pulverised fuel feed rate by controlling the speed of the screw conveyor.

Safety and Environment Hazards

The safety from exposure to the poisonous contents of the gas, namely carbon monoxide is an issue to be addressed. Since the entire operation is such that the pressure in the system is below ambient, air can leak into the system and not the gas to the outside. The air leakage at points where temperatures are high may lead to burn-off of some components and in some instances of transient operation, flame propagation at large rates. These could cause explosion. In the early developmental trials with closed top design, these were experienced. In the

current design, however, no problem of this nature has been experienced. Even if a flash-back of the flame were to occur, the pressure is released at one of the water seals-near the filter/cooler or the reactor with no untoward effect other than

splashing of water.

With regard to the effluents taken in by the wash water, it is necessary to treat them before discharge into streams or agricultural fields. Measurements show the following data on the effluent quality.

The knowledge of the nature of effluents will help design chemical treatment of the effluent.

Table 2 Effluent per kg moisture free wood

tem	P + T	BOD	COD	Phenol	DOC	NH3/NH4
g/kg mf wood	1.45	0,14	1.9	0.077	2.32	1.72

Field Experiments and Experiences

Two major field experiments tried out are the village electrification scheme at an un-electrified village called Hosahalli and irrigation water supply system at another village Ungra both near Bangalore. The experiment at Hosahalli is more than four years old and that at Ungra about an year old. In both cases, the objective was to try out an independent biomass based electricity generation system and examine if the techno-economics will be favourable. At Hosahalli, services of lighting, drinking water supply from a deep borewell, and flour milling are being given. These show that the user community will begin to demand better and greater quantum of services once they have begun to use; it has turned out that 3.7 kWe system is not adequate and the system is being upgraded to 20 kWe system. And with this magnitude of the power, it is possible to run an irrigation water supply system as well. If this is done, the possibility of self-sustained operation appears realisable. This optimism arises out of another gasifier based power generation for pumping deep borewell water for irrigational purposes. Current experience at Ungra, about ten kilometers from Hosahalli, suggests that farmers are willing to pay for the water at a rate at which the operational expenses can be covered completely. The reason for this kind of payment on irrigation water is due to the productivity from the land being three to four times what would be realised with uncertain rain water in this semi-arid region. The clear availability of water-on-demand means better planning and use of more remunerative crops like mulberry plantation used for the production of silk. The experience at Hosahalli, technical and techno-economic, have been summarised by Ravindranath et~al. (1990) and Srinivas et al. (1992).

A major experiment currently contemplated in which the use of land and water - the property of any villager - are tied together to generate electricity for enhancing the quality of life through providing the services of lighting, drinking water, minor industrial activities, and pumping water into underground aquifier for storage as well as from it into agricultural fields. The importance of the overall plan called SuTRA, an acronym for Sustainable Transformation of Rural Areas is that it is possible to generate revenue as a part of the enhanced agricultural productivity which is caused because of supply of life saving assured water for a fixed acerage of land. The revenue will pay for the investment which includes infrastructure in about five years. The financial benefit of the villagers will be enhanced two to three fold compared to the productivity without assured water supply.

Three major technological elements are the power from biomass gasifiers, leafy biomass biogas digesters and underground aquifier recharge from run-off rain water. Each of these have been tried separately but not in a meaningful combination yet. This experiment is currently begun. It is hoped that success of this will herald economic rejuvenation of semi-arid land based villages.

Availability of Residues

Studies on bio-residue generation show that in semi-arid regions, one can expect 6 tonnes/ hectare/ year in a multi-species forest on a continuous basis. Right choice of species, use of nutrients and water supply can lead to productivity up to 25 tonnes/ hectare/ year. Some agro-residues like sugarcane lead to residue generation upto 30 tonnes/ hectare/ year. At 0.5 kWe per family, a typical hamlet holding 40 families needs 20 kWe supply. This accounts for 5 kWe each for illumination, drinking water supply, and grinding mill. For irrigation, the load can be as much as 20 kWe by itself. By suitable load management, it is possible to run at 15 kWe average load for 3000 hours an year. The 45000 units of electrical energy will need about 50 tonnes bio-residue per year. At an average bio-residue productivity of 10 tonnes/hectare/year, the land required is 5 hectares. The agricultural operations of such a hamlet will cover about 20 hectares at an average land holding of half a hectare per family, typical of the population in the semi-arid region. By creating a synergy between electricity generation and agro-based bio-residue availability the sustainability of the concept is ensured.

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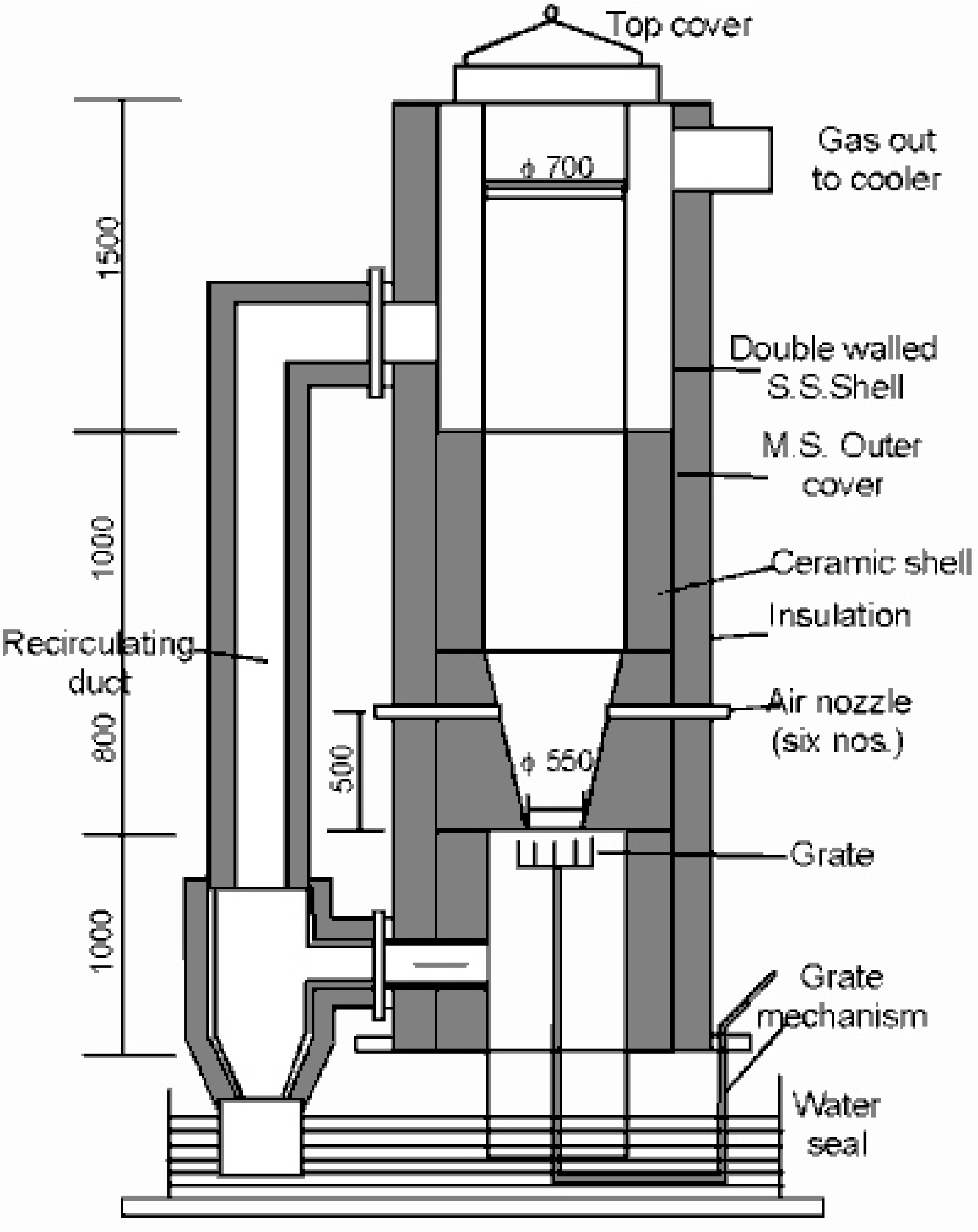


Fig. 1: Sectional view of the reactor

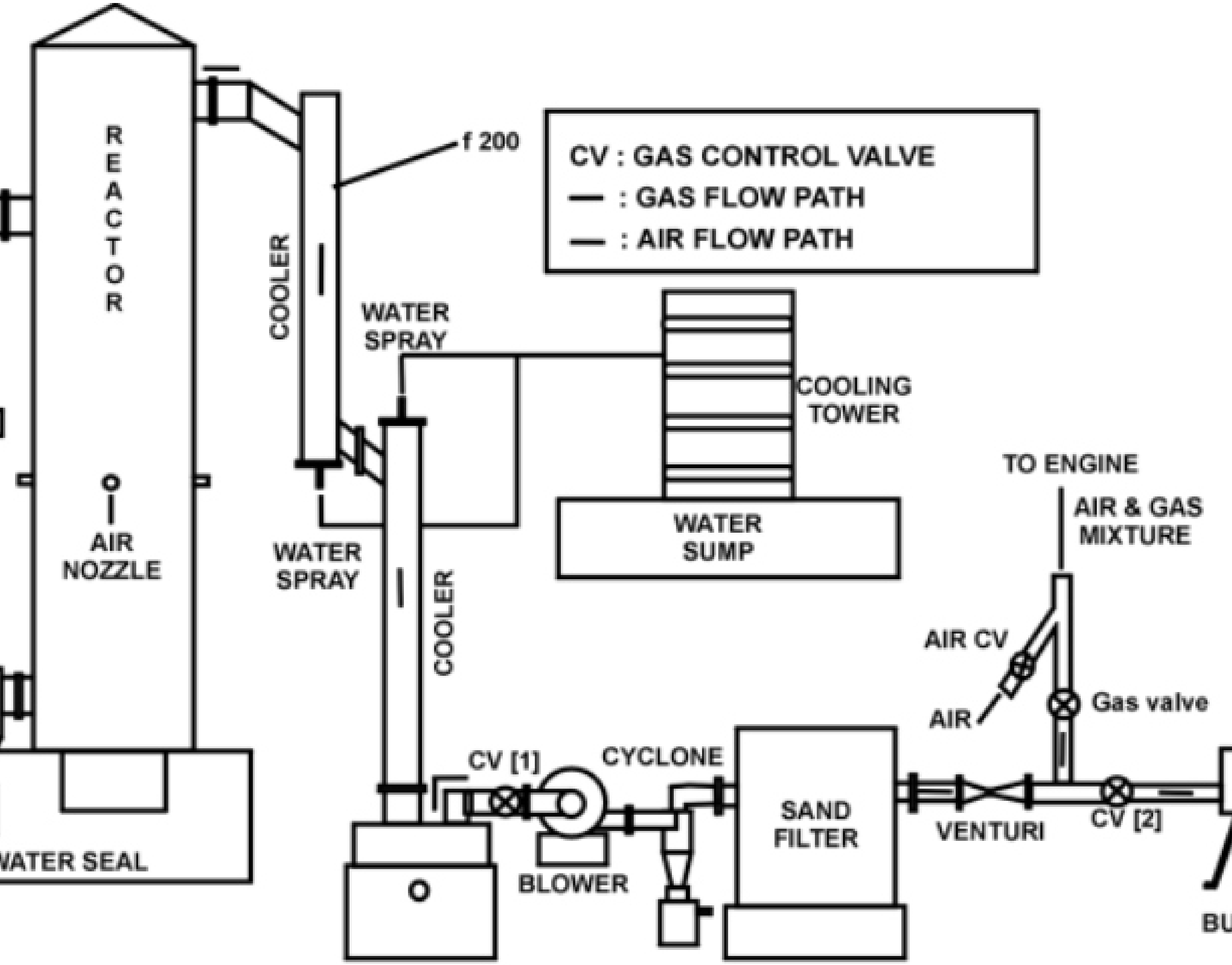
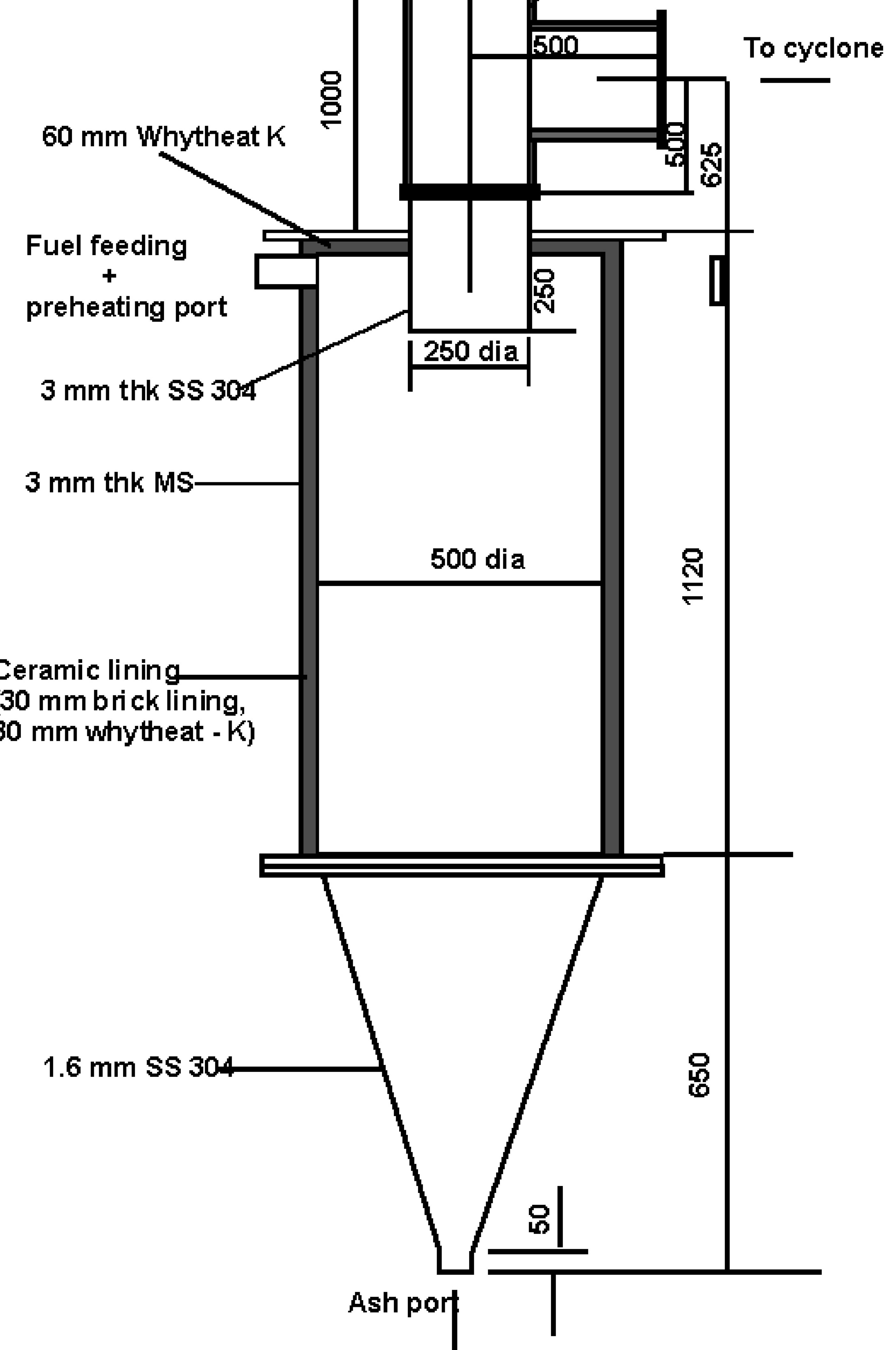


Fig 2 SCHEMATIC OF WOOD GASIFIER FOR POWER GENERATION APPLICATION



To cyclone
500
1000
60 mm Whytheat K
500
625
Fuel feeding
+
preheating port
250
250 dia
3 mm thk SS 304
3 mm thk MS
500 dia
1120
Ceramic lining
30 mm brick lining,
30 mm whytheat - K)
1.6 mm SS 304
650
50
Ash port

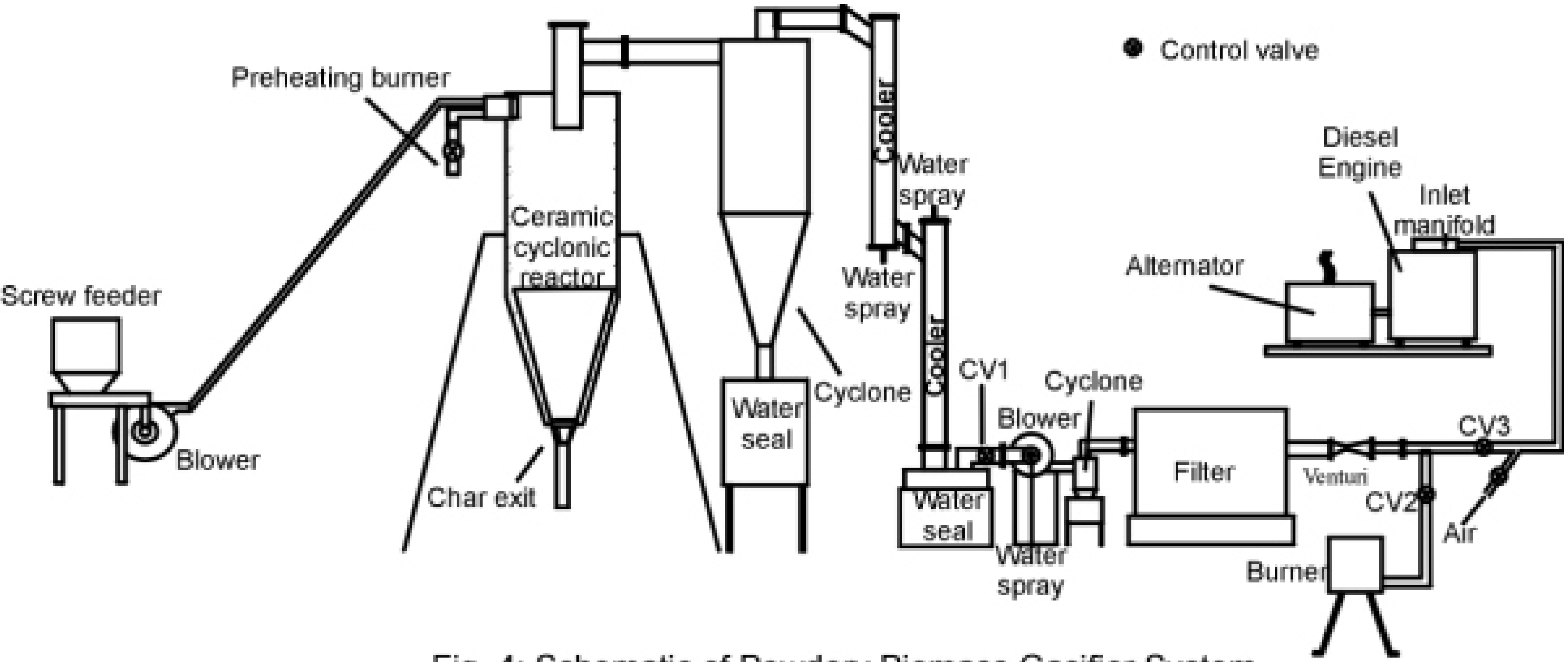


Fig. 4: Schematic of Powdery Biomass Gasifier System