CHAPTER 1
INTRODUCTION

Energy is a vital factor for the social and economic development of any country. Man used dry leaves and wood in the primitive ages to satisfy his energy needs. He discovered and started using various energy sources to meet his demands. The present energy use is largely dependent on fossil fuels like coal and oil. A significant amount of pollutant emissions from the energy sector is related to the use of fossil fuels for power generation. There are drastic changes in the composition and behaviour of our atmosphere due to increasing pollution. Global warming due to greenhouse effect is one such problem, which threatens the sustainable development of the world.

There is a growing scientific agreement that the emissions from the combustion of fossil fuels are causing a significant warming of the global climate. Scientists have predicted a global temperature rise of 1 to 3.5°C by the year 2100, with major potential effects on sea level, precipitation patterns, weather, agriculture and biodiversity (Meyerson, 1997). Global agricultural productivity is also expected to be affected by the change of climate (Achanta, 1993).

The demand for energy is continuously increasing. Commercial energy consumption is expected to grow more rapidly than the national economies of the developing countries (OTA, 1992). Assuming a GDP growth rate of 5%, commercial energy demand for India for the year 2009-10 is projected to be
600 million tons of oil equivalent (mtoe) compared to the 1990 consumption level of 200 mtoe (TERI, 1992). It suggests that the emission of pollutants can increase unless other environmental friendly energy sources are utilised.

The rapid industrialisation has resulted in the maximum utilisation of conventional fossil fuel sources. Fossil fuels are limited in availability and the environmental constraints are also becoming severe over the years. Hence, there is not only an immediate necessity to conserve the fossil fuel sources but also to explore the utilisation of alternative and renewable energy sources like biomass, solar and wind energy. These renewable sources are non-polluting in nature and can contribute to the generation of clean energy in an environmental friendly way (Nordin, 1993). Among these energy sources that can supplement or substitute fossil fuels, biomass fuels appear as a promising option with the general world-wide potential. The comparison of biomass energy with other renewable energy options on the common basis of energy efficiencies and economics indicates its significant advantages and hence it deserves serious attention.

1.1 BIOMASS ENERGY

Biomass is organic matter produced by plants and their derivatives. It refers to a range of products derived from photosynthesis by plants. It is essentially solar energy captured by green plants during photosynthesis and stored as chemical energy in the plants. The biomass resource consists of natural vegetation, energy crops cultivated specially for their energy content, biomass residues and biomass wastes.

Biomass has the potential to supply a significant portion of the electricity consumed in industrialised nations and a major share of power mix in the developing countries. It is the world's fourth largest energy source and the first
in developing countries (Hall et al, 1992). It already accounts for about 15% of world energy use and 38% of energy use in developing countries (Hall et al, 1993). Biomass residues are plentiful, particularly in the agricultural based developing countries. The world annual potential of biomass residues is about 3433 million tons, with energy content of $62 \times 10^{12}$ MJ (Kinoshita, et al, 1996).

The carbon dioxide released during the combustion of biomass is offset by the photosynthesis of new biomass. Hence, the utilisation of biomass for power generation can result in little or no accumulation of carbon dioxide in the atmosphere. In addition, most of the biomass resources naturally have low sulphur and heavy metal contents (Nordin, 1994; Jenkins and Ebeling, 1985) and therefore subsequent pollutant emissions are low. These can significantly contribute to the sustainable development. In addition to the above benefits, a significant switchover from fossil fuels to biomass fuels would also have large economical and social benefits (Sandberg, 1982; Takeda, 1983; Joshi et al, 1993).

In most of the countries, power is produced in a central power station and distributed to rest of the country, the major part of which lies faraway from the central power plant. In fact, the cost of the distribution system is sometimes even higher than that for the power generation itself (Sandberg, 1982). In addition to that a considerable amount of energy is wasted in distribution systems. Therefore, the long-term energy concerns suggest the need for decentralised energy conversion systems.

The interest and activity for obtaining energy from biomass has expanded tremendously in the last few years in both the developed and the developing countries. In United States, the implementation of the Public Utilities Regulatory Policy Act led to the installation of biomass energy systems to the tune of 8000 MW. In Brazil, 62% of the national transport fuel was
produced by Alcohol Programme, where the fossil fuel contribution was only 25% (WEC, 1994a). A government supported programme for district-heating systems in Austria resulted in the 10% substitution of primary energy sources by biomass.

In India, the Department of Non-conventional Energy Sources (DNES) was set up in 1982 to implement new and renewable energy programmes. Subsequently, it became the Ministry of Non-conventional Energy Sources (MNES). It is now responsible for the formulation of policies and programmes in renewable energy sources including research and development and their implementation.

In 1986, a programme in biomass gasification was started in India by interlinking elements of research & development and demonstration projects to develop gasification systems with appropriate application package (Gupta, 1993). The exploitable potential of agricultural and agro-industrial residues for power generation is estimated to be about 17,000 MW (Singh, 1997). Three thousand number of biomass gasification systems, whose capacity totals to about 30 MW have been installed in India by 1996-97 (MNES, 1997).

An overview of the biomass gasification and other related activities in India are summarised by Parikh, 1985. The Ministry is also providing financial assistance for gasification systems in the form of loan and subsidy. The subsidies constitute about 25 to 30% of the gasification system (Kandelwal, 1997). A few gasification systems operating on agricultural and agro-industrial residues are available (Patil and Rao, 1993; Chauhan, 1996), but they are yet to become popular. However, as a result of indigenous technology development, wood gasification systems have become popular and commercially available for thermal and shaft power applications.
1.2 THERMOCHEMICAL BIOMASS CONVERSION METHODS

There is a wide range of processes available for converting biomass into more valuable fuels. The thermal conversion of biomass fuels includes pyrolysis, direct combustion, and gasification (Brandon et al., 1984; Bridgewater, 1991; Bridgewater and Boocock, 1997).

Pyrolysis is the thermal (pyro) decomposition (lysis) of the fuel in the absence of oxidising agent at temperatures of 200 to 600°C to yield pyrolysis vapour, oil, and char. The commercial pyrolysis process concentrates upon the production of char or oil due to demand for them in the industries. When the biomass is burnt directly with sufficient amount of air, the high temperature flue gas can be used to raise steam to produce electric power. If the combustion is performed at elevated pressure, the high pressure and high temperature flue gas may be expanded through a gas turbine to produce power.

Gasification is the process of converting biomass into a gaseous fuel by means of partial oxidation at high temperature. In this thermochemical process, combustible gas is obtained from a solid fuel by reacting the fuel with an understoichiometric amount of an oxidant, usually air (Beenackers and Van Swaaij, 1984). This product gas is composed of carbon monoxide, carbon dioxide, hydrogen, water vapour, and small amounts of hydrocarbons. This combustible product gas is usually called as 'producer gas'.

1.3 HISTORICAL EVOLUTION OF GASIFIERS

The technology of breaking down organic or carbonaceous material to generate a combustible gas dates back to the eighteenth century. In 1812, the first coal-gas company was started in London. The first US company was charted in Baltimore in 1816 (Foley and Barnard, 1983). In the late 19th and early 20th centuries, much effort was put into the design of gasifiers and
manufacture of producer gas became a major feature of the widespread industrial use of coal. By converting the solid coal fuel into a gaseous fuel, its versatility was greatly increased and it could be easily conveyed to the point of use and employed in a precise and controlled manner.

In Germany, in particular, methods were also devised for using other low-grade feedstock such as lignite, peat and vegetable wastage. Many problems including ash removal, ash clinkering, production of tar free gases and gas cleaning were successfully tackled to the extent of practical requirements. Many different types of gasifiers were also developed to meet various types of applications. In the early 1900s there were many large engines (say 5400 hp) fuelled by producer gas employed for electricity generation, pumping and other stationary uses in different parts of the world (Kaupp, 1984b). As the suction stroke was used to draw gas from the gasifier into the engine, they were frequently referred to as suction gas engines.

In the first half of this century, about 100 updraft husk gasifier systems were built by Italian and British firms to fuel internal combustion engines in Southern Europe and several developing countries. A gasifier unit for engines upto 120 HP was advertised in 1910. They generated producer gas with a high heating value of about 6.7 MJ/m³ and a high volume of tar. The tar was recovered as a valuable by-product and used to pave floors or repair roads. Although the gas might have had a higher tar content even after cleaning, the then engines seem to have had a higher tolerance for tar than the present day engines.

After the First World War large scale coal gasification entered a new phase of development. The first industrial process, based on a gas-solid fluidized bed (Winkler fluidized bed gasifier) was introduced in 1926 and a
number of such units were built and operated in various parts of the world for the production of low and medium energy gas. The Lurgi pressurised gasifier was invented in the 1930s.

In Italy there was research into the use of rice husk as a gasifier fuel during the 1920s. Because of their high ash content and its variable chemical composition, rice husk is particularly difficult to use in gasifiers (Foley and Barnard, 1983). In 1930s, Italian research bore fruit and resulted in commercial rice husk gasifiers which were used with internal combustion engines for driving machinery in the rice mills (Beagle, 1982). This was an achievement that had been restricted only to Italy. This technology seems to have been lost after the Second World War.

The gasifier-engine system was used extensively for vehicle operation during the Second World War period, particularly in Europe. Considerable amount of research conducted on fluidized bed gasification systems led to the development of several commercial scale processes (Van den Aarsen et al., 1986). But all these came to an end when cheap petroleum fuels become available in the late 1960s.

In the late 1970s, a renewed interest in gasifier systems was triggered by rapid rise in oil prices. The downdraft types of gasifiers were used widely, in this period. A number of countries started using them for power generation, mainly for stationary applications. International development aid agencies supported many pilot plants and programmes in many developing countries. While technically advanced developing countries like India, Indonesia, Thailand, Philippines and Brazil designed and manufactured their own systems, other technically week countries were supplied with equipments from Europe and USA.
In 1980s, the sustained efforts of the researchers also led to the development of other types of gasifiers like stratified downdraft gasifier in USA, but none of the designs proved entirely satisfactory. Meanwhile, the information on Chinese throatless gasifier, developed a decade earlier, attracted the attention because of its successful operation. The validity of the throatless design for a husk gasifier was demonstrated in 1984. This led to the installation and operation of throatless and topless gasifier with some modifications in many parts of the world, particularly in the Asian countries (Cruz, 1983).

The contemporary interest in the development of gasifiers is to meet the increasing energy demand, to replace the present polluting fossil fuel sources and to decentralise the power generation through gasification of biomass and agro-wastes.

1.4 WHY GASIFICATION?

There are number of advantages in favour of biomass gasification. A country will be less vulnerable to high energy prices or energy shortages if it has biomass combustion or gasification at its disposal. There are many cases in which gasification of biomass has advantages over direct combustion of biomass fuels. For instance, small-scale generation of electricity can be realised by combustion of gas in internal combustion engines, without the necessity of steam cycles. Diesel engines can be operated on producer gas with minimum modifications in dual fuel mode. It is also easy to restore the full diesel operation in the diesel engine, in case of any failure of gasifier. Ash related problems associated with direct combustion also indicates that the gasification is a convenient method for converting biomass fuels, particularly those with high ash contents and/or low ash melting points (Hiler, 1982).
Gasification is a very simple process to convert solid fuels into gaseous fuels. It can be used to gasify even low-grade agricultural solid residues to combustible gases to meet the energy requirements in a decentralised manner. Gasification of solid fuels also extends the range of its applications. The gaseous fuel could easily be transported to the point of application in an industrial plant. The utilisation of gaseous fuels could be easily and precisely controlled. It is a convenient form of fuel used for a wide range of direct-heating applications, requiring an easily controlled clean flame. It is an attractive fuel for boilers, kilns or furnaces. Another advantage over direct combustion is that the producer gas can be cleaned in relatively compact units prior to combustion. Since gasification results in less pollutant emissions, it is also an environmentally clean way of utilising fuels.

The present energy crisis and economic factors in the developing countries provide the strong argument for considering gasification. The economic viability of gasifiers hinges on the savings that can be made by switching over to cheap biomass fuels. These savings must be weighed against the additional capital cost of the gasifier system and the increase in operating and maintenance cost. A strong economic case can be identified for using gasifiers in many situations, particularly where the local prices of petroleum fuels are high due to high transportation cost and/or power supplies are unreliable.

Gasifiers offer a means of reducing oil consumption and hence relieving the burden on foreign exchange at the national level. If the gasification system is used to replace the grid power, it can improve the power stability independent of the quality of grid power. Biomass gasifiers can provide an economic incentive for rural people by creating the market for biomass fuels.
1.5 TYPES OF BIOMASS GASIFIERS

The most popular and widely used gasifiers are moving bed gasifiers and fluidized bed gasifiers (Reed, 1981). The moving bed gasifiers depending upon the directions of air and fuel flow can be classified into (i) Updraught (counter current) gasifiers, (ii) Downdraught (co-current) gasifiers and (iii) Crossdraught gasifiers. Another important type of gasifier is the throatless gasifier, developed by Chinese particularly for rice husk.

1.5.1 Updraught Gasifiers

In the updraught gasifiers the air enters at the bottom (Figure 1.1), while the fuel enters at the top. This is a simple type in which the downward moving biomass is first dried by the upflowing hot gas and then pyrolysed, yielding vapour and char. While the pyrolysis vapour move upward with the upflowing product gas, the char continues to move down to get gasified. The tars in the vapour either condense on the cool descending fuel or are carried out of the gasifier with the product gas, contributing to its high tar content. Channelling in the bed may occur by condensation of tar in the upper layer of biomass, which may be reduced by even distribution of gasifying agent. The remaining char from the reduction zone is burnt in the oxidation zone to produce the necessary heat to sustain the whole sequence of gasification process.

The product gas from the updraught gasifier contains high amount of tar and rich in hydrocarbons, which contributes to its high heating value. Since thorough cleaning is very difficult due to its higher tar content, its usage in internal combustion engines is restricted and mainly used for direct heating. Most of the updraught gasifiers designed during World War II for operating the vehicles overcame the problem of tar production by using charcoal as fuel. The modern use of updraught gasifiers is therefore almost limited to direct heat
Figure 1.1 Schematic Diagram of Updraught Gasifier

Figure 1.2 Schematic Diagram of Downdraught Gasifier
applications. The principle advantages of updraught gasifiers are their simple construction and high thermal efficiency.

1.5.2 Downdraught Gasifiers

In the downdraught gasifier both the air and the fuel enters at the top of the gasifier and flows down concurrently down through the throat, where most of the gasification reactions occur (Figure 1.2). The main feature of this type of gasifiers is that tars released in the pyrolysis zone is passed through the combustion zone, where they will be broken down or burnt. Thus the downdraught gasifier produces the gas with less tar content. This reduces the load on gas cleaning system and makes the producer gas from downdraft gasifier suitable fuel for internal combustion engines. Most of the mobile gasifiers used during World War II were of downdraught type, as are the majority of those currently being developed for shaft power applications.

Downdraught gasification is simple, reliable and proven for certain fuels. When fuels like wood or charcoal with low ash content is used in the downdraught units, the ash accumulation is usually not large enough to impede the flow of fuel and gas.

Rice husk is a biomass fuel with relatively high ash content of 16 to 23% (Kaupp, 1984b). Its ash contains more than 95% silica that gives rigid skeleton like structure to the ash (Xu et al, 1989). The throat of the downdraft rice husk gasifiers were found to get clogged due to high volume of ash, in addition to slagging due to localised combustion in the throat zone. The rice husk ash is mainly composed of silica and the pure silica ash melts only at 1700°C. The formation of eutectic mixture of silica in ash with small amounts of sodium and potassium, that are also present in ash, reduces the melting temperature of ash, depending upon the concentrations of later elements. The scaling up of
downdraught gasifiers to large throat diameters would be almost impossible without creating hot spots and losing the tar-cracking potential of the gasifier. The possible hot-spots in the throat region may also lead to the melting of the ash, resulting in severe slagging and further blockage of the gasifier due to the clinkers that form when the slag cools.

It may be noted that the gasification of rice husk has never been successfully accomplished in small-scale downdraught gas producers. The very few updraught rice husk gas producers that existed before World War II in Italy and elsewhere are no longer in use (Kaupp, 1982).

1.5.3 Crossdraught Gasifiers

In the crossdraught gasifiers the air moves across the bed horizontally, while the fuel moves axially from the top (Figure 1.3). Air enters with high velocity to create extremely hot combustion zone. Thus the liberation of the gas is very rapid. The main advantages of the cross draught gasifiers are its rapid response to the changes in load, simplicity of construction and reduced weight. However, it is very sensitive to fuel composition and moisture content. It requires clean high quality charcoal as a fuel. It was originally designed to meet the specific needs of vehicle propulsion (Foley and Barnard, 1983).

1.5.4 Throatless Gasifiers

The throatless gasifiers are developed by Chinese for rice husk (Kaupp, 1984; Mahin, 1986). The schematic diagram of a throatless gasifier is shown in Figure 1.4. It is similar to downdraught gasifier without throat. The gasifier plant is set in a water tub, which serves as seal and ash settling pond. It is provided with a rotary grate to remove the residue ash. The product gas
contains tar and soot particles, which are to be cleaned and the gas should be cooled for shaft power applications (Patel and Rao, 1993).

1.5.5 Fluidized Bed Gasifiers

A simple fluidized bed gasifier consists of a chamber containing a bed of inert particles such as sand, supported by a distributor plate. Figure 1.5 shows the schematic arrangements of a fluidized bed gasifier. Air is blown through the distributor plate and the bed of particles at sufficient velocity to keep the bed of sand in a state of suspension and thus behaving like a fluid. Velocity at which the fluid drag on the bed particles due to the upward flowing air is sufficient to support its entire weight is called 'minimum fluidization velocity' and the bed is then said to be 'incipiently fluidized' (Howard, 1989; Geldart, 1986; Yates, 1983). When the velocity is increased above the minimum fluidization velocity, it results in a turbulent bed due to vigorously moving particles. The turbulence of the bed increases with the increasing velocity.

The fluidized bed is initially preheated by an external source to sufficiently high temperature and then the fuel is fed. The fuel particles are suspended among the inert sand particles by the air being blown up through the hot sand bed to sustain the gasification process. The bed behaves like a boiling fluid with fuel particles moving about the bed while undergoing size reduction as they are gasified. The very high surface areas available in fluidized beds due to the presence of inert particles and the constantly moving area per unit volume on which reactions can occur result in good efficiencies and higher throughput, compared with fixed beds. Uniform temperatures due to turbulent mixing and high heat capacities of sand media permit a wide range of low-grade fuels of even nonuniform size and varying moisture content to be converted to desired products (Bridgwater, 1984). Pre-processing of biomass
Figure 1.5  Schematic Diagram of Fluidized Bed Gasifier
feeds to acceptable particle size and/or moisture content usually necessary for other gasifiers can be minimised in fluidized-bed gasifiers (Miles, 1984).

The physical behaviour of reacting fluidized bed could be explained by the two phase theory of bubbling bed model (Kunii and Levenspiel, 1969). In the bubbling fluidized bed, two phases exists in the gasifier, a dense phase in the lower part of the gasifier and a dilute phase above the bed section. The dense phase consists of gas bubbling through the sand bed containing the fuel. While the large particles exhibit a overall random motion within the dense phase, the smaller particles are entrained by the bubbles and move with the gas into the dilute phase. A gradient in the particle density exists in the dilute phase with heavier particles tending to fall back into the dense phase and the lighter particles leaving the gasifier with the exiting gas. The selective entrainment and removal of smaller particles is called elutriation. This selective entrainment is effectively utilised to remove ash particles, which are below certain size.

The bed temperature could easily be controlled by adjusting the air to fuel ratio. The high thermal storage capacity inherent in the bed material acts like a thermal flywheel and can permit shutdown of the gasifier overnight and restart without external heating. The restarting of the unit without any preheating after 15 hours of shutdown is reported by Lepori et al (1980).

Fuels with high ash content require much greater attention to grate design, gas disengagement and positive char-ash removal. Since the ash is removed mainly by gravity and partly assisted by gas flow, the removal of ash is a difficult problem in the conventional moving bed gasifiers. The choking is another problem because reduction in the volume of rice husk after gasification is small and the ash retains the hull shape due to the rigid silicon structure. In
the fluidized bed gasifier, however, the ash can be easily elutriated out by the exit gas. The ash can then be separated in the gas conditioning system.

Fuels with low melting point are also difficult to be gasified in moving bed gasifiers, which have different stratified zones. The temperature in the combustion zone is usually in the range of 1000 to 1300°C (Kaupp, 1984; Foley and Barnard, 1983). The temperature can also be higher than these normal values due to local hotspots. If the ash is subjected to the temperature higher than its ash deformation temperature, it can lead to ash sintering. The bed temperature in the fluidized bed can be kept below the ash deformation temperature by properly controlling its air to fuel ratio. The turbulence of the bed particles ensures good mixing and isothermal condition in the bed without any local hotspots, unlike in any other moving bed gasifiers.

During gasification volatile matter is released in the form of gases and tars. The generation of tars is considered to be a nuisance because of its condensation in less accessible places, clogging of filters etc. The thermal cracking of tars allows the formation of hydrocarbons, which significantly contribute to the heating value of the gas. This method of putting the volatile to good use can more easily be implemented in fluidized bed gasifiers than in the moving bed gasifiers (Maniatis and Beukens, 1982).

In the moving bed gasifiers, the carbon conversion efficiency of rice husk is less because the rigid ash skeleton traps a part of carbon. The turbulence in the fluidized bed can break the rigid ash skeleton to make the trapped carbon available for conversion. Rice husk ash can easily be removed from the fluidized bed by entrainment in the gas stream, from which it can be separated by particle separating system. Hence, the fluidized bed gasifiers are the promising choice for biomass fuels with high ash contents, particularly melting
at relatively low temperatures. Fluidized bed gasifiers can also readily be scaled up with considerable confidence.

There are, however, a few limitations with fluidized bed gasifiers. They require longer period of preheating and are relatively slow to bring into operation. They are suitable for constant load applications and their load following capacity is not very good, as there is no buffer stock of unburned fuel inside the gasifier. The changes in load, however, could be met by suitably adjusting the fuel feed rate. The gas from a fluidized bed gasifier may contain rather high volume tar due to low operating temperatures. The gas also entrains the fuel ash with unburned carbon particles. Hence it demands for a good gas cleaning system, particularly for shaft power applications.

In spite of the above limitations and some of the practical problems, there is a bright future for fluidized bed gasifiers. It is mainly because they could utilise fuels like rice husk and saw dust, which are widely available but are difficult to be utilised in the conventional systems.

1.6 SCOPE OF THE PRESENT WORK

In the present work, the fluidization behaviour of rice husk is studied in a transparent fluidized bed column of 150 mm diameter. The mixing behaviour of rice husk and its ash with sand are also studied in the transparent column. The initial agglomeration temperature of rice husk in both combustion and gasification atmosphere is determined using controlled fluidized bed agglomeration test. Other biomass fuels, namely, bagasse, cane trash and olive flesh are also tested to evaluate their suitability as supplement or alternative fuel. The initial agglomeration temperatures of the fuels are compared with ASTM ash fusion test results and the suitability of ASTM ash fusion test for
predicting the agglomeration behaviour of the selected biomass fuels is evaluated.

A lab scale fluidized bed gasifier of 150 mm reactor diameter is designed and fabricated. The gasification of rice husk in the fluidized bed gasifier is studied. The tar emissions from the gasifier also measured at various temperatures by using solid phase extraction method. A gas conditioning system is designed and constructed to clean and cool the gas. The cleaned producer gas from the gasifier is used in a 7.5 kW diesel generator in dual fuel mode. The performance and major emissions of the diesel engine are measured. A pilot plant gasifier of 450 mm reactor diameter is designed and constructed to study the scale-up effect. The economic analysis of the fluidized bed gasification system for power generation in rice mills is also presented.