# CHAPTER II

## THE CHEMISTRY AND TECHNOLOGY OF AIR GASIFICATION OF BIOMASS

The principal objective of biomass gasification is to turn biomass into a gas which contains CO and $H_2$ using a thermochemical process. The reaction scheme usually involves the coupling of exothermic reactions ($O_2$ combustion reactions ) with a number of endothermic gasification reactions in an oxidation zone and in an adjacent reduction zone. During the operation of a gasifier the biomass and the volatiles emanating will oxidize in the oxidation zone ( also known as combustion or flaming pyrolysis zone ) at temperatures from as low as 500 C to about 1200 C depending on the gasifier and biomass used. Radiant heat from the oxidation zone where exothermic reactions take place will be used in the adjacent reduction zone where the endothermic reduction reactions take place at temperatures several hundred degrees lower. The gasification process can be described in a simplified manner by the following chemical reactions between the carbon and the oxygen carrier.

The exothermic reaction of carbon in the oxidation zone ( 4, 5, 6, 7, 8 ,9,10).

The combustion reaction

$$C + O_2 \rightleftharpoons CO_2 \qquad \Delta H=-97,000 \text{ cal/gmole} \qquad (1)$$

which releases heat that radiates to the drying zone and the reduction zone. We do not mention here the volatiles comprising C,H,O which partly oxidize in the oxidation zone.

The endothermic set of reactions which occur in the reduction zone comprise three major reactions (4,5,6,7,8,9,10).

( neglection the cracking of leftover volatiles coming from the pyrolysis zone )

The Boudouard reaction(4,5,6,7,8,9,10)

$CO_2 + C \rightleftharpoons 2CO \quad \Delta H=+38,000$ cal/gmole (2)

The water gas reaction(4,5,6,7,8,9,10)

$H_2O + C \rightleftharpoons H_2 + CO \, \Delta H=+28,000$ cal/gmole (3)

equations (2) and (3) can be written as a single reversible reaction.

The water gas shift reaction(4,5,6,7,8,9,10)

$CO + H_2 \rightleftharpoons CO + H_2O \, \Delta H=+10,000$ kcal/kmol (4)

Thus the reduction reactions may be described by either equations (2) and (3) or equations (2) and (4). These endothermic reactions control the upper limit of temperatures in the reduction zone.

A third independent reaction, or the fourth reaction, that can take place in the reduction zone is the exothermic hydrogasification of carbon which takes place due to the presence of hydrogen produced by reactions (3) or (4)

Hydrogasification reaction (4,5,6,7,8,9,10 )

$C + 2H_2 \rightleftharpoons CH_4 \quad \Delta H = -21,000$ cal/gmole (5)

It is possible theoretically to use the heats of formations of the various constituents to determine the various equilibrium constants of each of the four reactions.

It is known that a given gasifier will operate at an equivalence ratio dictated by mechanical design and fuel properties. Thus by increasing air flow rate through a gasifier there is an automatic increase in biomass being reacted, much like the action of a carburator in a car upon a sudden demand in load. If there was a way to stop the biomass flow to the gasifier then less biomass would react witn air and the equivalence ratio would increase. At an equivalence ratio of one one has a stoichiometric amount of oxygen for complete combustion, thus for 1 mole of wood represented by the generally accepted formula (5) $CH_{1.4}O_{0.6}$ an equivalence ratio of (or 1.46 g.oxygen/g.wood or 6.95 gair/gwood) one would mean that 1.05 moles of $O_2$ must be added. Normally gasifiers that have been built in the past are known to have equivalence ratios of 0.20-0.40.

Having presented the chemistry of gasification let us introduce the classical biomass gasifier types used. A gas producer is a device which consists of a solid fuel container equipped with air inlets also called tuyeres, a gas exit and grate through which ash is removed. The units can be made out of fire bricks, steel plates, concrete, and even empty oil barrels. The designs of gasifiers depend mainly on whether it is to be a portable or a stationary unit, and especially it will depend on the fuel to be gasified to a very large extent. Portable gasifiers mounted on trucks and tractors need to operate under a wide range of temperatures and load conditions, whereas stationary units used for heating, generation of electricity or pumping water operate under a steady load although this need not be always true. It is in any case highly desirable to generate a clean (mostly tar free and particulate free) gas leaving the gas producer at steady flow rates and at a moderate temperature and containing as little moisture as possible. These conditions which give high engine efficiencies lessen the load on the cleaning train and eliminate engine clogging are difficult achieve. A gasifier mounted on an automobile should have a good load following capability and generate a gas which needs no elaborate cleaning train and which leaves the gasifier as cool as possible. Producer gas that is to be fed in a burner can have a high temperature and a high tar content as long as no condensation of tars occur in the piping leading to the burner.

But the presence of nitrogen results in a dilute "low energy" of 120-200 Btu/SCF (6,7,8). It is to be noted that natural gas has a calorific content of 1070 Btu/SCF ( 5,6 ). Air gasifiers can be classified into 4 main types : updraft, downdraft, crossdraft, and fluidized beds. Although other designs exist such as suspended solid gasification they will not be mentionned here.

An updraft gasifier has clearly defined zones for partial combustion, reduction and distillation. The air flows countercurren-tly to the solid biomass and introduced at the bottom of the gasifier. Due to countercurrent flow of biomass and air this design allows the gas to leave the gas producer at low temperatures. Sensible heat losses are reduces because heat given up by the gas is used to dry and preheat the fuel before if reaches the reaction zones. Unfortunately products from the distillation and drying zones consisting mainly of water, tar and oil vapors and leave the gasifier uncracked, and will eventually condense at temperatures between 125 - 400 C ( 1,4,7,8,10 ). A common updraft gasifier with the gas outlet at the very top is therefore unsuitable for high volatile fuels when tar free gas is required. Because of high temperatures at the bottom where oxidation occurs ash from certain biomass may melt and produce slag on the grates( 1,10,12 ). Thus most updraft gasifiers operate with a wet air blast to increase the gas quality and keep the temperature below the melting point of the ash.

To avoid too much tar generated from updraft gasifiers, the

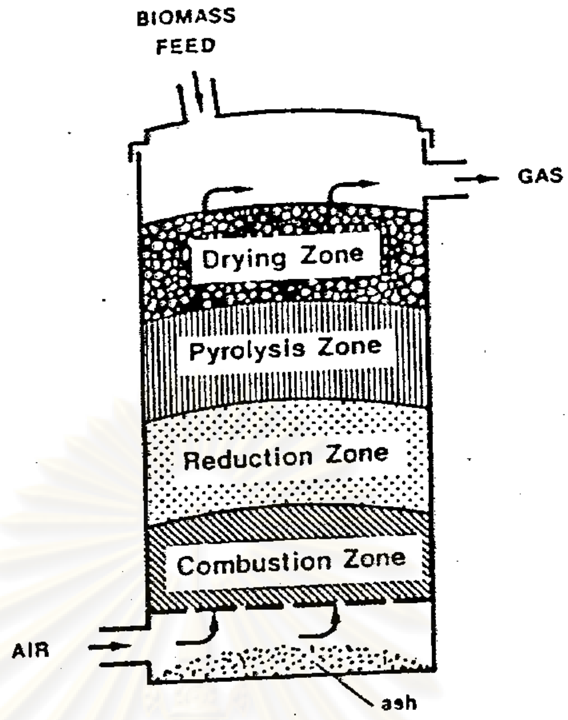


FIGURE 2.1 SCHEMATIC DIAGRAM OF UPDRAFT GASIFIER (5)

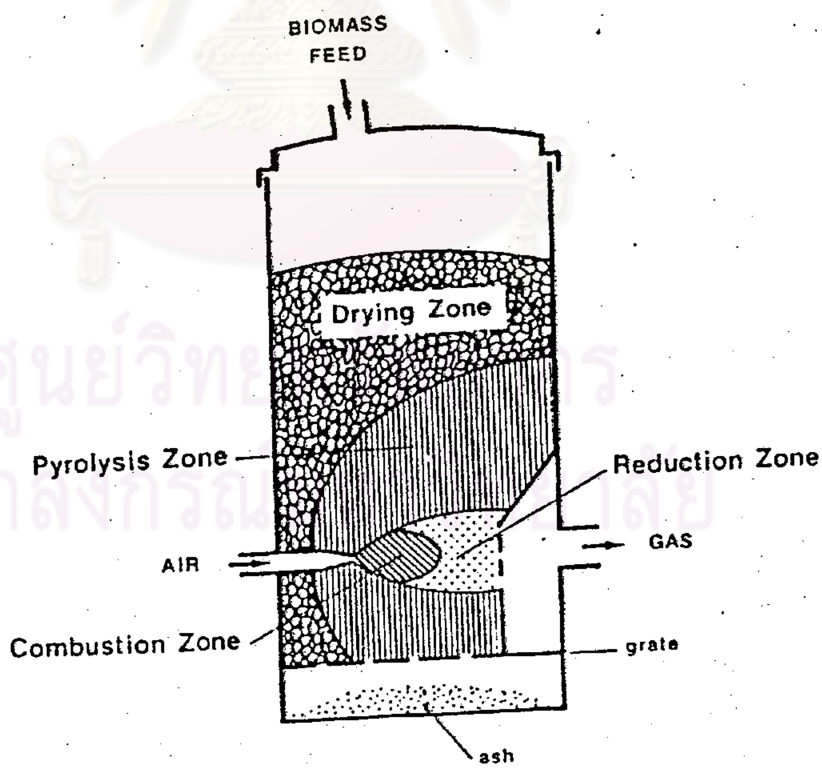


FIGURE 2.2 SCHEMATIC DIAGRAM OF DOWNDRAFT GASIFIER (5)

producer gas may be drawn off just above the reduction zone. The fuel used must also have low volatiles content. Drawing off the gas just above the reduction zone has the beneficial effect of theoretically obtaining a more tar free gas but resulting in high exit temperatures and decreased overall efficiency ( 1,6,9,10 ).

Updraft gasifiers designed to operate at temperatures below the ash melting point must have a grate to separate the ash from the partial combustion zone and also support the entire fuel column. The grate design must also allow for the ash to move freely through it into the ash bin and prevent carbon loss. In most updraft coke or charcoal gasifiers steam is injected or evaporated into the hot partial combustion zone causing beneficial effects on gas quality and prevent the lower part of the gasifier from overheating. The gas output of an updraft gasifier is limited by the amount of fuel that can be gasified. The specific gasification rate depends on the fuel, the design and the mode of operation. Rotating and fixed grate gasifiers are usually operated from 100-200 kg/m2-h (10) but a prolonged operation under such high loads results in excessive wear of the fire lining and the tuyeres. An updraft gasifier is shown in figure 2.1

The downdraft (cocurrentflow) gasifier shown in figure 2.2 is designed specifically to significantly reduce tars and oils from the gas. The general idea behind this design is that the tarry oils and vapours given off in the distillation zone are highly unstable at high temperatures. Air is introduced to the gasifier through a set of nozzles (or tuyeres) and the products of combustion are reduced as they pass through a bed of hot charcoal extending some distance down to the grate. In continuous operation the descending biomass is pyrolysed into charcoal and volatiles. The volatiles and part of the charcoal are burned in the oxidation zone. In the reduction zones the products of oxidation and gases that have passed unreacted will react in the reduction zone as explained previously. The throat of downdraft gasifiers is normaly situated at the level of the oxidation zone and is used to crack as much unoxidized volatiles as possible in order to reduce tar content.

The method of air injection and the geometry of the combustion zone and particularly the throat area are parameters which determine tar cracking. There are now four traditional classifications of downdraft gasifier designs

1. Wall tuyeres and conventional throat
2. Central tuyere pointed downward, and conventional throat
3. Middle tuyere pointed upward, and conventional throat
4. Wall tuyeres and choke plate.

and there are of course many variations of these designs. Downdraft gasifiers are generally not suitable for high ash content fuel which tend to slag at low temperatures, and also are not suitable for high moisture content fuels. Any slags formed in the oxidation zone may flow downward, cool and solidify in the reduction zone and finally obstruct the gas and fuel flow. A well designed rotating grate system and operation below the ash melting point are therefore essential if fuels with high ash contents are used in gasifiers. For downdraft gasifiers, the combined moisture in the fuel and the humidity of the air may often be sufficient for the generation of some hydrogen. The throat is one of the most vulnerable spots in a downdraft gasifier due to the heat produced there.

Figure 2.3 shows a crossdraft gasifier. Crossdraft gasifiers are compact, are faster to start , and have good load following capabilities. However crossdraft gasifiers generally use charcoal and have high gas exit temperatures.

Crossdraft gasifiers are sensitive to design parameters such as fire length, residence time of gas, and amount of water injected. Crossdraft gasifier were used in the past mostly for vehicular applications.

Fluidized beds provide uniform temperatures and efficient contact between gases and solids. A typical fluidized bed is shown in Fig. 2.4. Because of its higher throughput, it is more compact, but the higher velocities carry the ash and char out with the gas from which they must be separated in cyclones or bag filters. The beds usually contain either inert material (such as sand) or reactive materials ( such as catalysts ). These aid in heat transfer and provide catalytic or gas cleaning action. In a true fluidized bed, the solids mix very rapidly and provide high heat transfer between all parts of the bed. It is to be noted that fluidized beds provide a gas which contains particulates and tars to a greater extent than downdraft gasifiers and thus are not generally connected to an internal combustion engine. Their interest lies in the gasification of a wide spectrum of non-wood biomass which are difficult to gasify in fixed bed gasifiers such as rice straw for example.

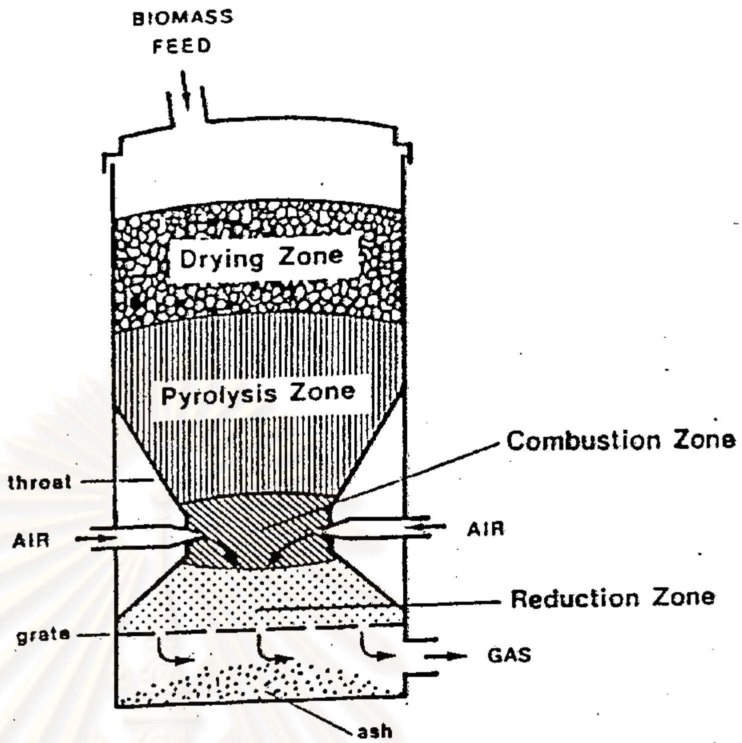


FIGURE 2.3 SCHEMATIC DIAGRAM OF CROSSDRAFT GASIFIER (5)

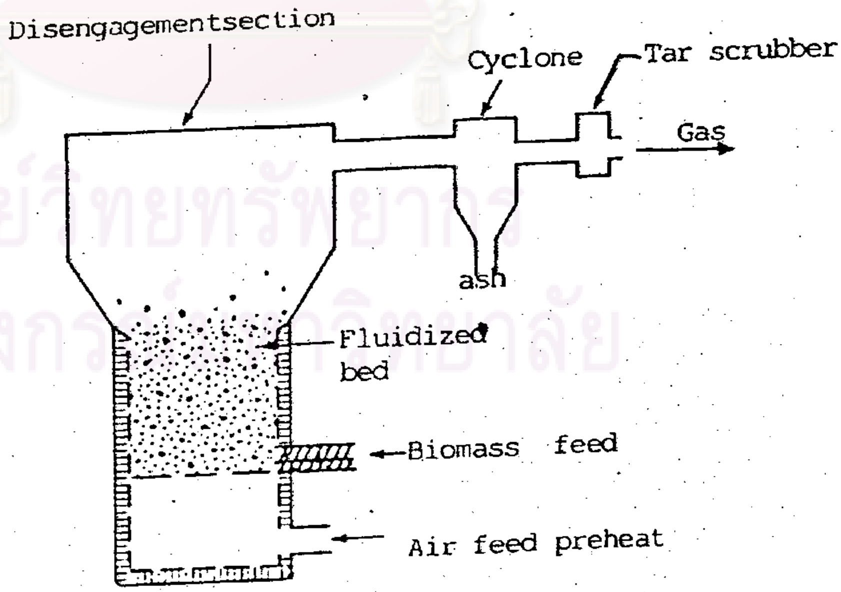


FIGURE 2.4 SCHEMATIC DIAGRAM OF FLUIDIZED BED GASIFIER (8)

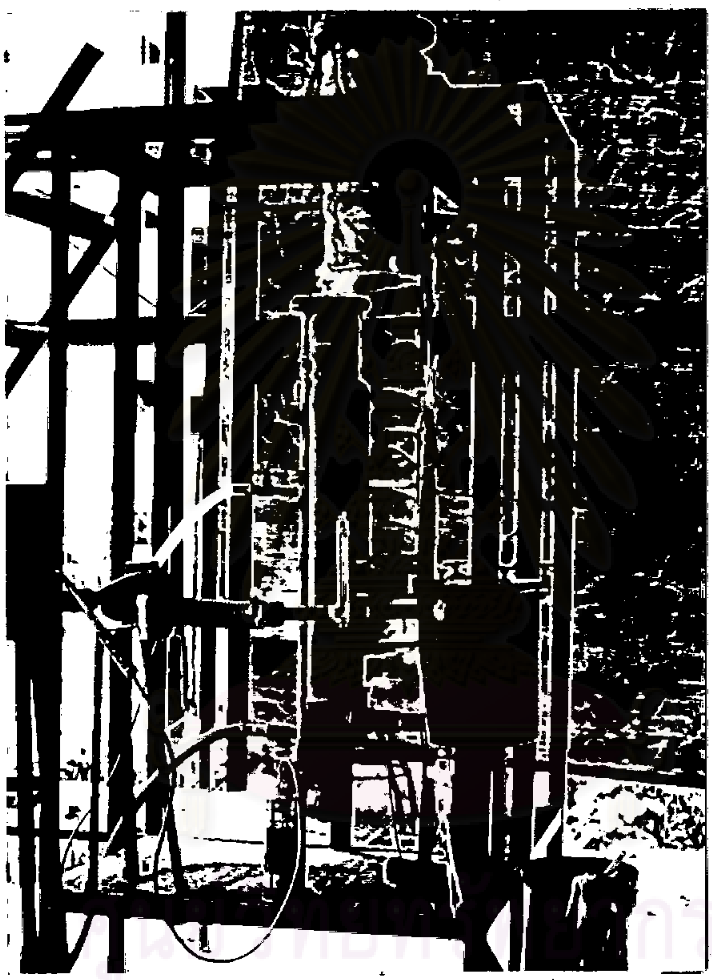



FIGURE 3.1 THE EXPERIMENTAL APPARATUS

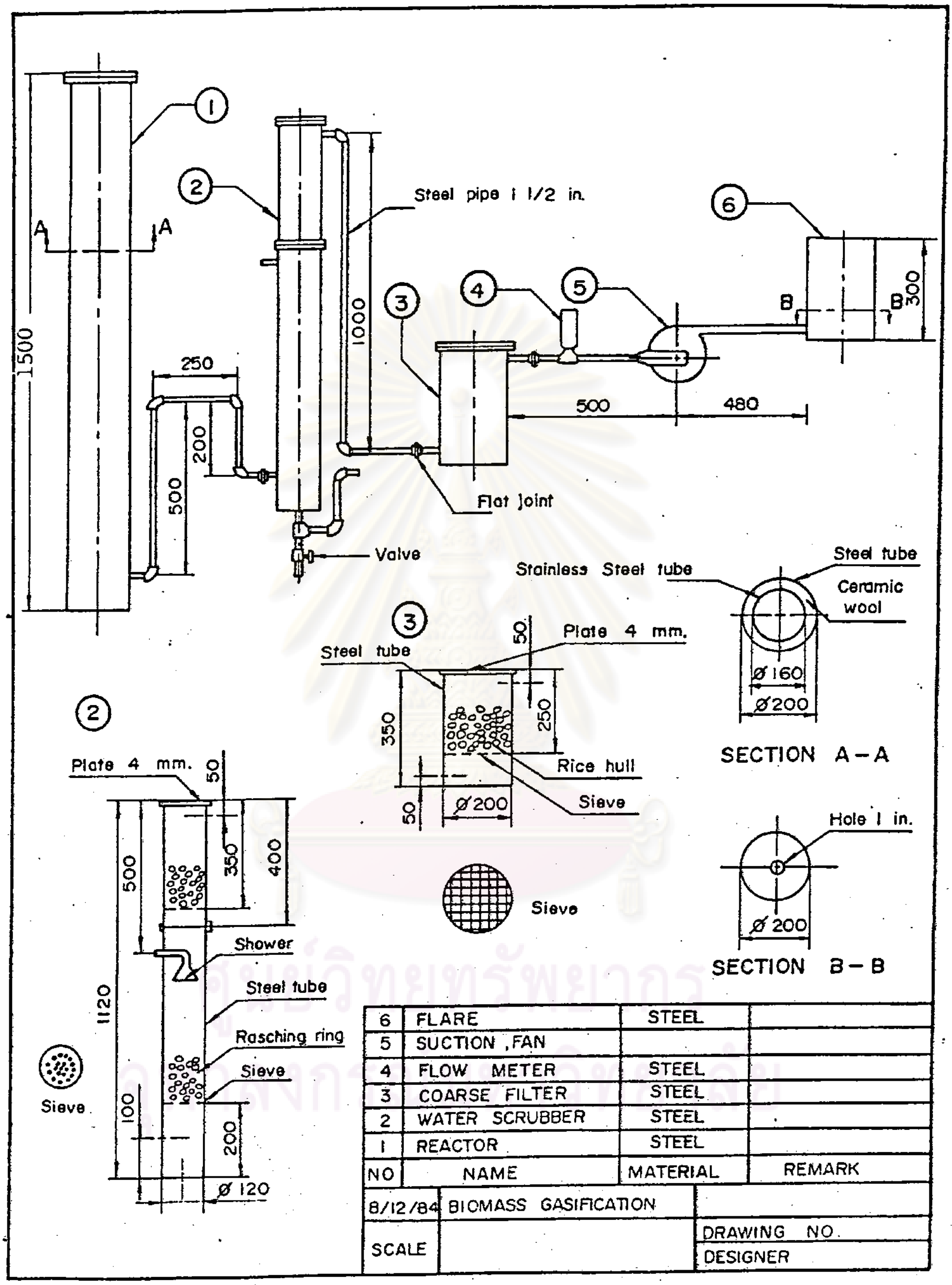


FIGURE 3.2 SCHEMATIC DIAGRAM OF EXPERIMENTAL APPARATUS