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Design and Development of An Inclined Down-draught Gasifier

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ABSTRACT. *A down-draught inclined gasifier based on a previous up-draught prototype was improved through a step-by-step modification process. The modification was undertaken to obtain a stable pyrolysis front. It was necessary to reduce the comburant injection area by restricting the preferential paths developed on the upper parts of the reaction zone. Nevertheless, it was impossible to curtail the forward movement of the pyrolysis front without increasing the inlet temperature of the comburant. This was achieved by extending the heat exchanger.*

The ignition system was improved to eliminate the problem of tar accumulation. Most of the classical gasifiers have a throat section. A throat was incorporated in the original down draught gasifier but it proved redundant since the husk in itself may have formed a dynamic constricting throat. Among further refinements required is improvement in flexibility in order to accommodate a wider range of feed stock.

INTRODUCTION

The technique of gasification using bio-mass, a renewable energy resource, is one method of converting indirect solar energy. Kutz *et al.*, (1983) defined gasification as the partial oxidation of a solid fuel which produces a combustible gas. The producer gas thus generated has a relatively low heating value in the order of 2.7 to 7.4 MJ/m^3, and can be burned much like natural gas (Kutz *et al.*, 1983). The combustible components of the gas are mainly CO, H_2, and CH_4.

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There are three main types of gasifiers: up-draft, down-draught, and cross-draught. In the up-draught reactors, the flow of air and gas is in an upward direction, whereas in down-draught gasifiers the air and gas flow is in a downward direction. In the cross-draught type, the flow of air and gas is across the producer (reactor), though not necessarily in the same horizontal plane (Beagle, 1978). The up-draught gasifiers show the highest gas efficiency, but the producer gas is loaded with tar. The down-draught reactors show moderate gas efficiency and less loading on producer gas with tar or dust. The temperature of gas at the outlet in a down-draught gasifier is in the range of 500 - 700°C, whereas it is 300 - 600°C in an up-draught reactor (Schoeters and Buekens, 1982).

In every gasifier, phenomena of drying, heating, thermal decomposition, gasification and combustion take place. Thermal decomposition or the pyrolysis is an endothermic reaction which produces a gas containing not only CO and H_2, but also other pyrolysis products.

Up-draught reactors are often subjected to problems related to tar accumulation even though they are more efficient. Fusion of silica is one of the serious problems encountered in both up-draught as well as down-draught gasifiers, and more so in the latter type, since oxidation and oxydo-reduction reactions take place at very high temperatures. Therefore, ash in the form of oxides gets reduced to its elements which fuse at high temperatures causing serious problems for evacuation of ash. Paddy husk for example, contains 18% silica (Basnayake, 1986), and it is important to develop reactors which could be operated so as to avoid fusion of silica.

The quality of producer gas is very important for agricultural applications. The particulate emissions present a potential source of contamination when grains are dried directly with exhaust gases. The down-draught channel gasifier described by Kutz *et al.*, (1983) also discusses the particulate emissions from the reactor, where the concentration of particulate emissions increased with the increasing rate of gasification, and the particulate emission rate was approximately proportional to the second power of the gasification rate.

In the classical vertical reactors, the reaction rates were controlled by the rate of removal of ash or char. Frequent maintenance of the ash or char removal mechanisms is a must for efficient maintenance of this type of gasifiers or pyrolysers (Basnayake, 1986).

In the inclined up-draught gasifier reactor developed at the Department of Agricultural Engineering, University of Peradeniya (referred to as Basnayake Reactor here in after) the rate of reaction was controlled by regulating the rate of feeding of the bio-mass, using a simple piston mechanism. The gasifier functioned efficiently for a duration of one hour and became impossible to operate beyond that point without cleaning the accumulated tar on the piston mechanism and grill. The objective of this study was to improve the functioning of the inclined reactor.

MATERIALS AND METHODS

The Design

To overcome the problems encountered in the Basnayake reactor, a down-draught version of the same inclined reactor was designed. The inclined down-draught gasifier consisted of five main components: a hopper for feed stock, a feeding mechanism, a hollow cylindrical section for firing, an ash collector and a torch (Figure 1). Paddy husk was used as the combustible material.

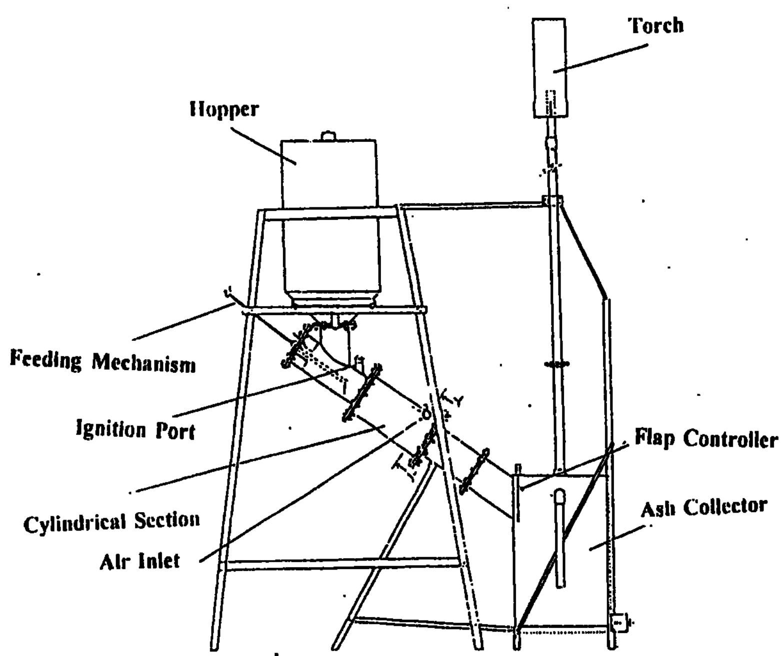

Figure 1. Inclined Downdraught Gasifier (Side Elevation)

The hopper as in the earlier model was constructed as shown in Figure 1. The sealed hopper has a cone at the bottom at an angle of 35° to the horizontal plane and mounted vertically on the inclined cylinder in such a way that the paddy husk was expected to flow freely downward through the cylinder without any application of an external force.

The inclined hollow cylindrical section was initially designed to have a throat (Figure 2) by reducing the cross sectional area by 25%. It restricted the flow to maintain a column of paddy-husk completely filling the cylinder in the reaction zone. This zone was lined using fire clay to prevent "melt-down" of the reactor at high temperatures. The throat was made of fire clay as shown in Figure 1 protruding at the top, while the bottom part remained without obstructions. A heat exchanger enveloping the reaction zone was constructed to obtain a stream of hot air entering the reaction zone along its opening at the periphery. This hot air pyrolysed the husk on contact.

A flap was built at the bottom of the cylindrical section not only to guide the movement of producer gas tangentially actuating a semi-cyclone behaviour at the entrance of the ash collector, but also to maintain a column of ash and char. The char column held in the path of the active reaction zone would then be able to reduce the combusted pyrolysis products, CO_2, H_2O and heavy tar to produce CO, H_2, CH_4 and low molecular hydrocarbons.

The semi-cyclone effect assists the separation of particulate matter and gas removed from the center of the container. The pressure inside the ash collector was maintained at 75 mm of water for safety reasons by using a water seal. A simple air suction type torch was designed to combust the emitting producer gas.

The feeding mechanism was originally designed to give the action of a rake, consisting of a rod and plate arrangement. A chamber was built at the topmost corner of the cylindrical tube prior to the entry point of paddy husk and the rod was mounted using two bushes on the two plates fitted across the cylindrical tube. Air at ambient temperature was introduced into this chamber prior to firing the gasifier, and this was continued until the firing was over to prevent any pyrolysis products of CO moving in an upward direction and leaking through the feeding mechanism.

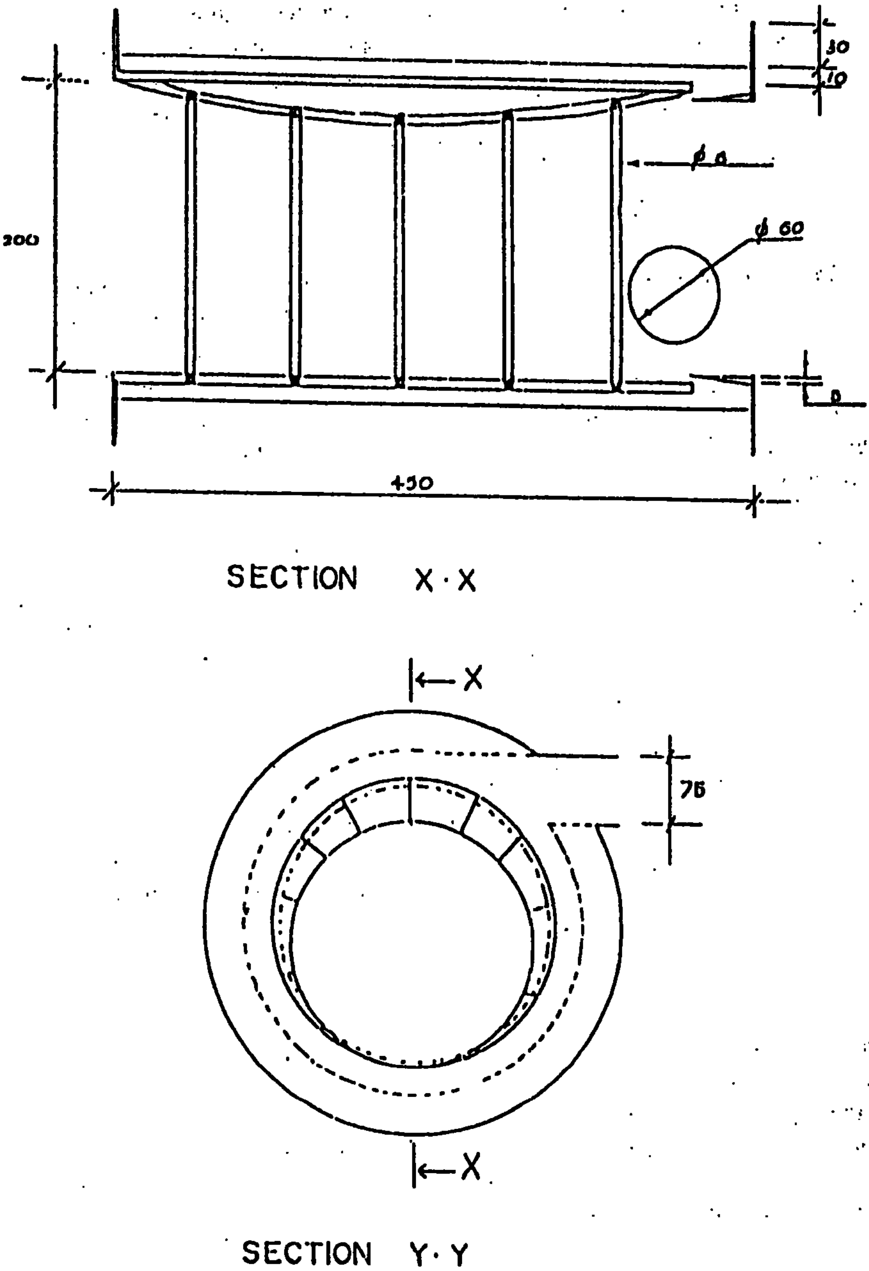

Figure 2. Throat Section in the Reaction Zone of the Inclined Downdraught Gasifier.

Operations

The sequence of operating the gasifier begins with loading the hopper. By using the feeder a completely filled column of paddy husk was obtained and charcoal was inserted through the inlet for igniting the gasifier. Once ignition takes place, air is introduced into the cylinder only through the feeding mechanism, using a centrifugal blower; replacing the cap of the ignition port and opening the air inlet valve to the heat exchanger permit activation of the reaction zone. The quantity of air was regulated by the inlet valve of the heat exchanger while keeping the feeding rate constant. (The feeding rate was kept constant assuming the existance of a free flow of paddy husk).

Modifications

A series of modifications to the design were done as listed below:

a) The angle of inclination of the cylindrical section was changed to 37°.

b) The throat made of fire clay was removed and replaced with a fire clay lining of the reaction zone.

c) The length of the heat exchanger was increased.

d) The rake action of the feeding mechanism was changed to give a "push-only action" by turning the rod by 180°.

e) The comburant injection area was reduced to one sixth of its original and the opening was restricted to the bottom portion of the cylindrical section.

f) The initial ignition time was prolonged for a duration of five minutes.

g) The air flow rate was kept constant and the feeding rate was changed.

RESULTS AND DISCUSSION

The free flow of paddy-husk was achieved once the throat was removed. The rake action only disturbed the column of husk but could not overcome friction caused by the dynamic nature caused by continuously changing surface roughness of the fire clay surface. The problem was further aggravated by cracking of fire clay at high temperatures. It was also observed that a dynamic throat was created by paddy husk itself, holding the column of paddy husk intact. Therefore, by removing the throat made of fire clay and by increasing the angle of inclination to overcome the friction between fire clay and husk (which was greater than the friction between husk and metal), free flow of the paddy husk was obtained.

The feeding mechanism was successful after changing its action from "rake action" to "push only" action. The feeding mechanism was not only "trouble free" of tar accumulation as experienced in the earlier prototype, but also safer since there was no leakage of pyrolysis products.

Whenever the gasifier was fired at a point before the throat, particles beyond the active combustion front moved into the ash collector during the process of pyrolysis, resulting in complete combustion of the producer gas as well as direct combustion of some of the particles. This problem was solved by a prolonged injection of a small quantity of air through the feeding mechanism. The duration was limited to ensure ignition of particles immediately in front of the firing point, before the inlet valve of the heat exchanger was turned on, followed by feeding.

In experimentation before the modification of restricting the comburant injection area, a preferential path may have developed on the top layer of the paddy-husk, since the path could not have been developed at the bottom due to instant replenishment of the bottom layer. Thus, the frictional force at the bottom layer probably remained constant, whereas the top layer magnitude could have been reduced. Inevitably, this resulted in blowing the top husk layer into the ash collector, resulting in complete combustion. Perhaps the husk particles remaining in the bottom layers did not undergo the entire pyrolysis process in the required active zone. As suggested above, complete combustion would have taken place in the ash collector. On restricting the comburant injection area to the bottom of the reaction zone, the preferential path of hot air was curtailed.

Once these modifications were realized, trials were conducted to stabilize the gasification front. In spite of these major changes to the comburant flow pattern, the front still moved gradually towards the ash collector although there was a significant improvement. This forward movement of the front could be attributed to incomplete pyrolysis of husk at low temperatures of forced comburant (hot air). Therefore, the length of the heat exchanger was extended so as to increase the temperature of forced inlet air. This resulted in proper gasification of paddy-husk, and the producer gas burned at the torch giving a blue flame.

It was identified that the parameters affecting successful operation of this gasifier are rate of feeding, rate of air flow into the combustion area, moisture content of paddy husk, the length of the reaction zone, the angle of inclination of the cylindrical tube and the angle of the hopper cone. However, qualitative or quantitative testing and analysis were not carried out at this stage of experimentation.

FUTURE RESEARCH

Some of the modifications suggested are the automation of feeding, including a control mechanism for the hopper, and pre-heating of air before igniting the gasifier. An effective location should be determined for the ignition port so as to maintain a stable pyrolysis front. Furthermore, instead of a semi-cyclone, a complete one should be incorporated to improve the design and thereby improve the quality of gas. It is also recommended to re-design so as to improve the flexibility of changes in inclination of the gasifier to accommodate the use of a wider range of agricultural wastes as feed stock.

One of the advantages of this gasifier is that it can be operated as a pyrolyser to produce charcoal by controlling the comburant and feeding rates. The char thus produced can be used as an active ingredient in manufacturing slow-release N-fertilizers. Besides this the producer gas can be used as a substitute for fossil fuel in most internal combustion engines. This gasifier combined with direct solar energy could provide an alternative energy for various agricultural purposes. Future research should also include deriving mathematical expressions of the fronts to aid efficient functioning of the gasifier so that an industrial model could be made.

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