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PRODUCTION OF PYROLYTIC LIQUID USING GRASS AS FEED MATERIAL

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ABSTRACT
A fixed bed pyrolysis system was designed and fabricated in the current study. Pyrolysis is one of the most important thermochemical energy conversion methods for wastes and biomasses. Due to higher conversion capability of biomass in to liquid, fixed bed pyrolysis system is more favorable among different other thermochemical conversion processes. The major components of the current pyrolysis system are fixed bed reactor, condenser and liquid collector. Kans grass (*Saccharum spontaneum)* was chosen as feed material as it is available in Bangladesh. There are many reasons for choosing grass as feed material, such as, it is cheap, easy to grow, and does not interfere with agriculture production for human and animal consumption. For a fixed bed pyrolysis of grass as feed material, a maximum of 32 wt% liquid yield was obtained at reaction temperature of 450 °C and running time of 90 minutes.

Keywords: Pyrolysis, Grass, Pyrolytic Liquid.

1. INTRODUCTION
Sources of energy can be categorized as renewable and non renewable. It is generally accepted that renewable sources of energy can be reproduced, while non renewable sources of energy cannot be reproduced. The use of renewable energy is increasing tremendously as the nonrenewable energy is being depleted day by day at an alarming rate. In this context, researchers are devoted to explore alternative source of energy. Biomass is one of the excellent choices of alternative source of energy. Biomass derived oil in the form of biofuel and/or biodiesel is the important choice for the fuel researchers. Biofuel or biodiesel offers several advantages like; they are biodegradable, non toxic, offer less emission when used as engine fuel and are renewable in nature. Biofuel or biodiesel can be produced by well known transesterification process.

Unlike combustion process, pyrolysis is a thermal degradation process that produced pyrolytic liquid from wastes and biomasses. In addition to pyrolytic liquid, gas and char were also derived [1]. The pyrolytic liquid is one of the important targets for the fuel researchers, because it has fuel like properties and can be used in internal combustion (IC) engines. But, before using in IC engine, pyrolytic liquids need upgrading.

Islam et al. [2] conducted experiment with palm oil shell as feed material in a fluidized bed pyrolysis reactor using nitrogen as fluidizing gas and silica sand as bed material. A 58 wt% pyrolytic liquid yield was reported at an optimum temperature of 500 ºC with an apparent vapor residence time of 1.48 second.

Another work was performed by Islam et al. [3] using sugarcane bagasse as fixed bed feed material for liquid fuel production Authors reported that at a reactor bed temperature of 450 ºC for a feed particle size of 300-600µm and at a gas flow rate of 4 lpm (liter per minute), an oil yield of 49 wt% of dry feed was obtained.

Previous work elucidated that a maximum of 54 wt% liquid oil at a reaction temperature of 450 ºC was obtained from fixed bed pyrolysis of municipal solid waste [4].

Demiral et al. [5] worked with grape bagasse for bio oil production using pyrolysis system. Authors investigated maximum bio oil yield with the process variables of temperature in the range of 350-600 ºC, heating rate of 10-50 ºC/min and nitrogen gas flow rate of 50-200 cc/min. A maximum of 27.60% oil yield was obtained at the final pyrolysis temperature of 550 ºC , sweeping gas flow rate of 100 cm3/min and heating rate of 50 ºC /min in a fixed-bed reactor.

Khairuddin et al. [6] also investigated optimized bio oil yield from fixed bed pyrolysis of rice husk using response surface methodology. Authors reported that temperature, hating rate, particle size and holding time significantly affected the bio oil yield. The maximum bio oil yield was obtained at pyrolysis temperature of 473.37

ºC, heating rate of 100 ºC/min, particle size of 0.6mm and holding time of 1 minute.

The maximum pyrolytic liquid yield of 55% was obtained with oil palm empty fruit bunches as reported by Sulaiman et al. [7]. Authors conducted experiment in a bench scale fluidized bed system and found that the maximum liquid yield was obtained at residence time of 1.03 s and at reactor temperature of 450ºC.

A research project was conducted [8] for liquid and solid bio-fuel applications using switch grass. The switch grass was converted to fuel pellets. The results revealed that combustion of fuels exhibited the best bio fuel cycle in the context of economics, land use and energy.

In Bangladesh Kans grass (*Saccharum spontaneum*) grow in river side. There is no project in Bangladesh for liquid production from grass that can be used as engine industrial uses power generation etc. A large number of research and work in the field of pyrolysis has been carried out in U.S.A, Canada, EC (European Community) etc. Recently Malaysia and India have given their attention towards the pyrolysis technology. The feasibility of this technology has been proved from the results of experimental research study on pyrolysis. Thus, Kans grass (*Saccharum spontaneum*) was selected as the feed material of this study.

In this current investigation, pyrolytic liquid was derived from renewable biomass Kans grass. The investigation is divided in to two parts. In the first part of this investigation, design and fabrication of the pyrolysis reactor was done and the second part of this study pyrolytic liquid was produced from Kans grass. Pyrolytic liquid characterization was also performed in the second part of the current investigation.

2. DESIGN AND FABRICATION OF THE EXPERIMENTAL SETUP

2.1 Introduction

The design and fabrication of the fixed bed pyrolyser is a major part of this work. The main parts of the system are fixed bed reactor and condenser. The pyrolysis system was designed based on the following considerations:

- Short vapor residence time usually less than 5 seconds in the reactor and a rapid condensation of the vapor product to promote high yield of pyrolytic liquid product.
- Reliable heat supply for required heating of the system.
- Adequate gas flow rate to dispose of the vapor mixture.
- Proper mass flow rate of vapor and water for proper condensation.
- Size of the system such that sufficient amount of pyrolytic liquid can be produced.

2.2 Design of a reactor

Pyrolysis may be classified as fixed bed pyrolysis and fluidized bed pyrolysis. In fixed bed pyrolysis the feed material is fixed. The product yields from fixed bed pyrolysis may be liquid, char and gas. In the current investigation, a fixed bed pyrolyser was designed and fabricated. The gas flow rate and the volume of the reactor determine the apparent vapor residence time in the reactor and this vapor residence time is an important parameter in fast pyrolysis process for maximizing liquid product. For fast pyrolysis the residence time should be between 5 sec. For the ease of fabrication, a cylindrical reactor was considered for the system using stainless steel pipe. The pipe that was used as reactor is 30 cm in length and 7.62 cm in diameter. The schematic diagram of a pyrolysis reactor is shown in Figure 1.

2.3 Design consideration of a rector

Assumption:
Apparent vapor residence time, t = 4.1 sec (<5 sec)
Dia of reactor, d = 7.62 cm (commercially available)
Therefore, reactor area, $A_R = \pi d^2/4 = 45.60\ cm^2$
Gas flow rate, $Q_g = 8$ lit/min = 133.33 cm^3/ sec
Effective volume for gas flow = Q*t = 546.67 cm^3

However, it is about 40% of the total reactor volume. As about 60% of the volume of the reactor is occupied by the feed material, the total volume of the reactor

$V = 546.67/0.4 = 1366.725\ cm^3$.
Q = AV (continuity equation) = A*L/t (as V = L/t)
$L = Q*t/A = 1366.725/45.60 = 29.97\ cm \approx 30\ cm$

Thus, the reactor length, L = 30 cm.

2.4 Design consideration of a condenser

Assumption:
Water flow rate, m_w = 4 liter/min = 0.067 kg/sec
Water inlet temperature, t_{w1} = 25°C
Water outlet temperature, t_{w2} = 35°C
Inlet temperature of vapor, t_{g1} = 500°C
Outlet temperature of vapor, t_{g2} = 30°C
Specific heat of water, C_w = 4.2 kJ/kg-K
Specific heat of vapor, C_V= 2.2 kJ/kg-K
Heat flow rate, $Q = m_v C_v (t_{g1} - t_{g2}) = m_w C_w (t_{w2} - t_{w1})$
$= m_v \times 2.2 \times (500 - 30) = 0.067 \times 4.2 \times (35 - 25)$
$= 2.814$ kW ------- (1)
or, m_v = 0.00272 kg/sec
∴ Mass flow rate of vapor, m_v = 0.00272 kg/sec.

The overall heat transfer between water and vapor can be calculated by equation (2)
$Q = U_0 A \Delta T_m$ -------- (2)

Where,
U_0 = Overall heat transfer co-efficient of stainless steel (320 W/m^2-K)
A = Minimum area of condenser tube
ΔT_m = Minimum log mean temperature difference = $(T_1 - T_2) / [\ln (T_1/T_2)]$
= (475–5) / ln 95 = 103.20 °C

Where,
T_1 is the inlet temperature difference = (500+273) – (25+273) = 475 K

T_2 is the outlet temperature difference = (35+273) – (30+273) = 5 K
Using equation (1) and (2), we have
$2.814 \times 1000 = 320 \times 103.20 \times A$
$\therefore A = 0.0852 \text{ m}^2 = \pi d_c L_c$ ----------- (3)

If the diameter of the condenser tube (inner), d_c = 5.08 cm (commercially available).

So, using equation (3), we have,
$L_c = 0.0852 \times 10000 / \pi \times 5.08 = 53.39$ cm = 54 cm

Thus, the condenser tube (inner) length = 54 cm.

3. EXPERIMENTAL STUDY
3.1 Feed Material Preparation
The Kans grass was collected and cut. It was then crushed into three sizes. The sizes are 300-600 μm, 1.18-1.70 mm and 2.36-3.00 mm. Again it was washed and dried with the help of oven. Thus, the feed material was prepared.

Table 1: Components of Kans grass (*Saccharum spontaneum)* (on oven-dry basis) [9]

Chemical composition	wt% (dry basis)
Cellulose	43.78±0.4
Hemi cellulose	24.22±0.5
Acid insoluble lignin	23.45±0.3
Acid soluble lignin	2.85±0.4
Ash	4.62±0.2

4. EXPERIMENTAL RESULTS
4.1 Experimental Run
The experiments were conducted under different operating conditions. This various operating conditions were resulted in various amounts of pyrolytic products. Pyrolytic liquid product obtained from the grass by fixed bed pyrolysis system was analyzed for different properties. The tested properties include higher calorific value, kinematic viscosity, density, flash and fire points. Three sizes of grasses were used in this study. The sizes are 300-600 μm, 1.18-1.70 mm and 2.36-3.00 mm. The experimental results of the run at different conditions with their effects are presented in this chapter.

4.2 Effect Of Operating Temperature
Figure 2 shows the effect of variation of fixed bed reactor temperature on the pyrolysis products derived from grass of feed size 300-600 μm. From the plotted results, it appears that the liquid yield at lower and higher temperatures was less in comparison to some intermediate temperature. However, the char yield was higher at lower temperature and this was found to be decreasing with increasing temperature. The gas yield was high at lower temperature with a trend of low and high yield with increasing temperature. The maximum liquid yield was obtained an intermediate temperature of 450°C. The reason behind this trend may be that the lower temperature was not high enough for the pyrolysis devolatilisation reaction to take place completely rendering lesser amount of liquid and gaseous products. Again the higher temperature above 450°C, may cause secondary cracking reaction of the vapors, yielding more gas. However, the intermediate temperature was sufficient enough for complete pyrolysis reaction to take place and at the same time this temperature was not high enough for secondary reaction to take place rendering maximum quantity of liquid product with less amounts of char residue and gaseous product.

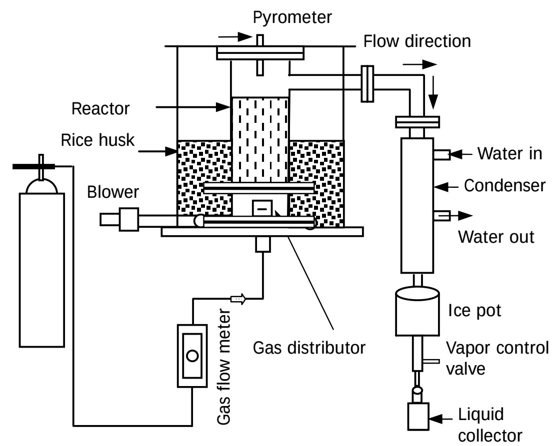

Fig 1. Schematic diagram of a pyrolysis system

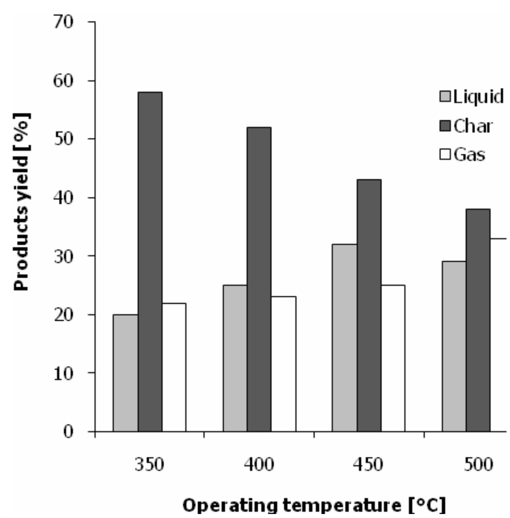

Fig 2. Effect of operating temperature on products yield (feed material size 300-600μm, running time 90 minutes).

4.3 Effect Of Feed Particle Size
Figure 3 represents the percentage of weight of liquid, solid char and gaseous products for different particle size of feed material at a bed temperature of 450°C and an operating time of 90 minutes. It is observed that at 450°C the percentage of liquid collection is maximum (32%) for particle size of 300-600 μm. A small amount of liquid

yield is obtained from the larger particle size feed. This may be due to the fact that the larger size particles are not sufficiently heated up so rapidly causing incomplete pyrolysis that reduced liquid product yield.

4.4 Effect Of Running Time

Figure 4 shows the effect of variation of running time on the pyrolysis products derived from grass having the size of 300-600 µm at a temperature of 450°C. The maximum liquid yield is 32 wt% of biomass feed while the solid char product is 43 wt% at 90 minutes. It can be observed from Figure 4 that the maximum liquid yield is found at 90 minutes. Higher or lower than 90 minutes, the liquid yield was reduced due to insufficient pyrolysis reaction and higher gas discharge rate.

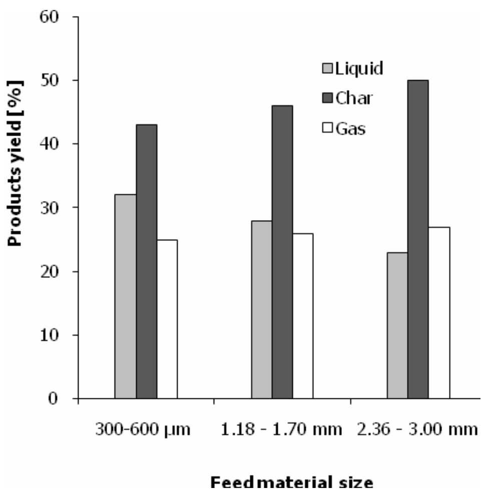

Fig 3. Effect of feed material particle size on products yield (operating temperature=450°C, running time=90 minutes).

5. STUDY OF CHARACTERIZATION OF PYROLYTIC LIQUID

The pyrolytic liquid obtained from Kans grass was characterized for its physical properties. The determined properties were: higher calorific value, kinematic viscosity density, flash point and fire point. A comparative analysis for some selected properties of pyrolytic liquid and conventional diesel fuel is shown in Table 2. The gross calorific value was determined by a bomb calorimeter (ASTM D4529). The gross calorific value of pyrolytic liquid was found to be lower than that of conventional diesel fuel. This was due to the oxygen content in the pyrolytic oil (2). The kinematic viscosity is one of the important fuel properties for compression ignition (CI) engine fuel. The kinematic viscosity was determined according to EN 3104 method. It can be observed from Table 2 that the kinematic viscosity is higher than that of diesel fuel. Thus, before using pyrolytic liquid as CI engine fuel, it needs upgrading so that viscosity should be lower. Like viscosity, the density is higher for pyrolytic oil. The density was measured according to EN 3675 method. The flash point and fire point are higher for pyrolytic oil compared to diesel fuel. The higher flash and fire points ensures safe transportation of pyrolytic oil. The flash and fire points were determined according to the EN 3679.

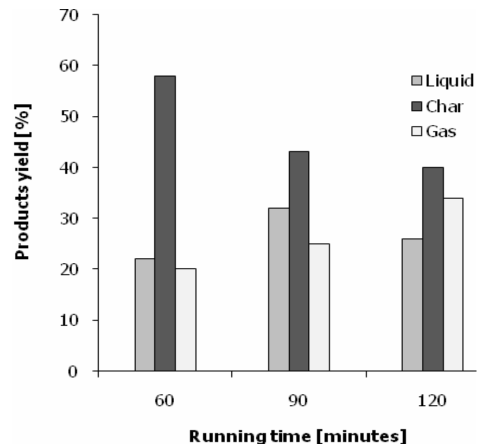

Fig 4. Effect of running time on products yield (operating temperature=450°C, feed material size 300-600µm).

Table 2: Fuel properties of pyrolytic liquid and diesel fuel

Properties	Pyrolytic liquid	Diesel fuel [9]
Gross calorific value (MJ/kg)	22.43	44.5
Kinematic viscosity @ 40°C (cP)	4.51	2.61
Density (kg/m^3)	1024	827.1
Flash point (°C)	107	53
Fire point (°C)	116	68

6. DISCUSSION

Different data were obtained at various operating conditions. Some products like liquid, char, gaseous product are obtained by fixed bed pyrolysis system. But among them, liquid and char were collected. The gaseous product was calculated by difference. The temperature of the reactor is considered to be a major operating parameter for liquid and char products. For dry feed materials, the maximum liquid yield was 32 wt% at 450 °C and the maximum char yield is found to be 58 wt% at 350 °C.

7. CONCLUSION

This work investigated to design and fabrication of a pyrolysis reactor for pyrolytic liquid production from Kans grass. The pyrolytic liquid characterization was also made in this investigation. The results of this work may be summarized as follows.

For a fixed bed pyrolysis of Kans grass as feed material, a maximum of 32 wt% liquid yield was obtained at a reaction temperature of 450 °C and at 90 minutes running time. The finer feed material gave the maximum liquid yield. With increasing reactor bed temperature, percentage weight of char production was decreased and the gas production was increased. The properties of the pyrolytic liquid were compared to those of diesel fuel. The fuel properties were somewhat different from those of diesel fuel and thus, needs further upgrading.

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8. REFERENCES

1. Bridgwater, A. V., and Bridge, S.A., 1991., “A Review of Biomass Pyrolysis Technologies. In: Bridgwater, A.V. and Grassi, G. (Eds). Biomass Pyrolysis liquids Upgrading and Utilisation. London: Elsevier Science; 11-92.
2. Islam, M.N., Zailani. R and Ani, F.N., 1999. “Pyrolytic Oil from Fluidized Bed Pyrolysis of Oil Palm Shell and Its Characterisation”, Renewable Energy, 17; 73-84.
3. Islam, M.R., Islam, M.N. and Islam M.N., 2003, “fixed bed pyrolysis of sugarcane bagasse for liquid Fuel production”, Proceedings of International Conference on Mechanical Engineering (ICME), Paper No. ICME03-TH-16.
4. Islam, M.N., Islam, M.N., Beg, M.R.A. and Islam, M.R., 2005, “Pyrolytic oil from fixed bed pyrolysis of municipal solid waste and its characterization”, Renewable Energy 30: 413-420.
5. Demiral, I. and Ayan, E.A., 2011, “Pyrolysis of grape bagasse: Effect of pyrolysis conditions on the product yields and characterization of the liquid product”, Bioresource Technology 102: 3946-3951.
6. Khairuddin, M.I., Suhardy, D., Nasrul, H., Khudzir, I., Saiful, A.S. and Farizul, H.K., 2011, “Thermo gravimetric analysis and the optimisation of bio-oil yield from fixed-bed pyrolysis of rice husk using response surface methodology (RSM)”, Industrial Crops and Products 33: 481-487.
7. Sulaiman, F. and Abdullah, N., 2011, “Optimum conditions for maximising pyrolysis liquids of oil palm empty fruit bunches”, Energy 36: 2352-2359.
8. Samson, R., “The Potential for Biomass Energy Crop Production in Canada”, Resource Efficient Agricultural Production. www.reap-canada.com.
9. Singh, L.K., Chaudhary, G., Majumder C.B. and Ghosh, S., 2011, “Explore the Perennial Kans grass (*Saccharum spontaneum*) Biomass for Releasing Reducing Sugars and its Optimization” Der Chemica Sinica 2(3): 154-163.

9. NOMENCLATURE

wt%	Weight percent
ºC	Degree Celsius
REAP	Resource efficient agriculture production
EC	European community
Q_g	Gas flow rate
Q	Heat flow rate
A_R	Reactor area
A	Condenser tube minimum area
d	Reactor diameter
d_c	Condenser tube diameter
V	Total volume of the reactor
L	Length of the reactor
L_c	Length of the condenser
t	Apparent vapor residence time
m_w	Water flow rate
t_{w1}	Water inlet temperature
t_{w2}	Water outlet temperature
m_v	Vapor flow rate
t_{g1}	Inlet temperature of vapor
t_{g2}	Outlet temperature of vapor,
C_w	Specific heat of water
C_v	Specific heat of vapor
kW	Kilowatt
U_0	Overall heat transfer co-efficient
ΔT_m	Minimum log mean temperature difference
kg	Kilogram
K	Kelvin
µm	Micrometer
mm	Millimeter
MJ	Megajoule
cP	Centipoise