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CHARACTERIZATION OF BIOMASS SOLID WASTE FOR LIQUID FUEL PRODUCTION

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Abstract-- In most of the south Asian countries agricultural by-products and waste of wood industries are the major biomass solid wastes. Utilizing these wastes for improved energy recovery a tremendous energy saving could be realized. Pyrolysis, a thermochemical conversion process has been projected as one of the most competitive ways of producing liquid fuel from organic solid waste. For this purpose studies on the characteristics of solid wastes are essential in selecting suitable feedstocks as well as in the design and construction of a suitable thermal conversion system. In this study investigations have been conducted on the characterization of locally available agricultural by-products: rice-straw, jute-stick and bagasse. This primary characterization included the physical properties, proximate analysis, elemental analysis, calorific value and thermogravimetric analysis (TGA). The physical characteristic of these wastes such as particle size distribution and bulk density have been considered. The elemental composition by ultimate analysis, in terms of carbon, hydrogen, nitrogen, oxygen and sulfur (CHNOS) content of the selected biomass was determined. The thermal characteristics of the selected solid wastes were obtained by thermogravimetric analysis (TGA). From these studies it is found that rice-straw, jute-stick and bagasse are good feedstocks for conversion to get liquid fuel. It is also found that the operating temperature range of the conversion system to be designed for the selected biomass is 300^0 to 600^0C. Thus, further pyrolysis studies may be proceeded using these feed materials.

Keywords: Biomass, Pyrolysis, Solid waste, TGA.

INTRODUCTION

Recently there has been a resurgence of global interest in renewable energy resources from organic solid waste. The heightened awareness is driven by environmental concern and shortage of non-renewable energy resources. Bangladesh, India, Nepal, Pakistan and Bhutan are agriculture-based country. The major agricultural by-products of these countries are rice-straw, jute-stick and bagasse. In 1998-99, the production of these by-products in Bangladesh were 25.88, 1.2 and 1 million metric tons respectively (Statistical Yearbook, 1999). The traditional use of these by-products are as fuel for cooking, cattle-feed and raw materials for paper and pulp industries. However, a large amount of this is wasted and create disposal problem. These carboneous solid wastes are renewable energy sources and therefore, the potential of converting them into useful energy such as liquid fuel, should be seriously considered. In this way, the wastes would be more readily usable and environmentally more acceptable. Pyrolysis as a multi-product process has shown the potential of recovering hydrocarbon liquid from carboneous solid waste, besides the char and the gas products. The pyrolytic liquid (pyro-curde oil), which is less bulky and more convenient to handle than the original solid waste, may be used as raw fuel or upgraded to higher quality fuel and chemicals and hence, have potential to conserve depleting petroleum oil reserves [Bridgwater and Bridge, 1991]. Studies on the characteristics of solid wastes in terms of their physical and chemical properties and thermochemical characteristics are essential in developing a suitable thermal conversion system. The main criteria of feedstock suitability for thermal processing are low moisture and ash content. High volatile matter content is desirable for production of pyro-crude oil by pyrolysis conversion [Bridgwater and Bridge, 1991]. These information can be obtained by proximate analysis. The TGA gives information about the temperature at which pyrolysis is initiated, when the rate is maximum and the temperature at which the process is completed.

CHARACTERISATION STUDIES

For this characterization studies the samples of rice-straw and jute-stick were collected locally in Rajshahi and the bagasse was collected from Rajshahi Sugar Mills Limited, Horian, Rajshahi, Bangladesh. The air-dried samples were ground of sizes 0 to 1180 μm. In these studies the analyses that have been considered are: physical properties, proximate and ultimate

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analysis, heating value and thermal gravimetric analysis.

Physical Properties

The particle size of the biomass has an important bearing on the ability to be heated quickly in a given heat flux environment. Biomass particles are rarely spherical or even cubic, but tend to have a length that is several times longer than the thickness or the width i.e. a pin chip [Diebold and Bridgwater, 1997]. Particle size distribution and bulk density are most important physical properties of biomass solid waste for their thermochemical conversion [Rossi, 1984]. The sample preparation methods, like drying, grinding and milling etc. influence the values of these parameters. The design of a feeding system, feed rate and mixing behavior of feed materials with bed particles depend on the particle size and bulk density of the feedstock. The bulk density mostly depends on the moisture content, shape and size of the solid feed particles. This property of rice-straw, jute-stick and bagasse particles prepared by commonly used hammer milling techniques have been presented in Table-1.

Proximate Analysis

Proximate analysis gives information about feedstock suitability in terms of moisture content, ash content, volatile matter content and fixed carbon. The test was conducted according to the ASTM test procedures in the laboratory of Fuel Research and Development Institute, Bangladesh Council of Science and Industrial Research (BCSIR), Dhaka, Bangladesh. The test results of the proximate analysis for the selected biomass samples are presented in Table-2.

Table 1: Bulk density in kg/m^3 with wt% of respective particles of their total weight

Solid wastes	0 to 300μm	300 to 600μm	600 to 1180μm	300 to 1180μm
Rice-straw	230.07 6.30%	232.48 46.70%	214.28 47.00%	223.47 93.70%
Jute-stick	168.22 5.54%	176.60 45.44%	181.03 49.02%	178.84 94.46%
Bagasse	145.91 6.20%	177.65 45.70%	176.53 48.10%	177.08 93.80%

Table 2: Proximate analysis of the solid wastes

Solid wastes	Moisture content %wt	Ash content %wt	Volatile matter %wt	Fixed carbon %wt
Rice-straw	9.47	13.41	64.45	12.67
Jute-stick	9.02	0.78	78.40	11.80
Bagasse	9.51	1.94	74.98	13.57

Elemental Analysis

Table-3: Elemental analysis of the selected biomass (Ash free, by difference)

Samples	C wt%	H wt%	N wt%	O wt%	S wt%
Rice-straw	36.48	3.60	-	46.51	-
Jute-stick	44.94	4.38	-	49.90	-
Bagasse	43.77	6.83	-	47.46	-

The elemental composition by ultimate analysis, in terms of carbon, hydrogen, nitrogen, oxygen and sulfur (CHNOS) content of the selected biomass is essential for their pyrolysis conversion upon which the pyrolysis product quality depends. The test was carried out by an Elemental Analyzer EA 1108 model in the laboratory of Analytical Research Division, BCSIR, Dhaka, Bangladesh. The technique used for the determination of CHNS is based on the quantitative "dynamic flash combustion" method. Less than 15mg of each of the samples of sizes 300 to 1180μm is held in a tin container, placed inside the auto sampler drum where they are purged with a continuos flow of helium and then dropped at preset intervals into a vertical quartz tube maintained at 1020°C (combustion reactor). When the samples are dropped inside the furnace, the helium stream is temporarily enriched with pure oxygen and the sample and its container melt and the tin promotes a violent reaction (flash combustion) in a temporary enriched atmosphere of oxygen. Under these favorable conditions even thermally resistant substances are completely oxidized. The quantitative combustion is then achieved by passing the mixture of gases over a catalyst layer. The mixture plug of combustion gases is then passed over copper to remove the excess of oxygen and to reduce the nitrogen oxides to elemental nitrogen. The resulting mixture is directed to the chromatographic column (porapak PQS) where the individual components are separated and eluted as nitrogen (N_2), carbon dioxide (CO_2), water and sulfur dioxide (SO_2) with the help of a thermal conductivity detector whose signal feeds a potentiometric recorder of an integrator or the automatic workstation known as EAGER 200. The instrument is calibrated with the analysis of standard compounds using the K factors calculation. The oxygen content was determined by difference, knowing the ash content. The elemental analysis of the biomass is presented in Table-3.

Gross Calorific Value

The higher heating values of the prepared samples were determined using Plain Oxygen Bomb Calorimeter of model PARR 1341. The test was carried out in the Heat Engine Laboratory of Bangladesh Institute of Technology (BIT) Rajshahi, Bangladesh. The gross calorific value of the selected biomass solid wastes of particle size of 300 to 1180μm are given in Table – 4.

Table 4: Gross calorific values of the solid wastes

Solid waste	Calorific Value kJ/kg	Calorific value MJ/m^3
Rice-straw	16233.00	3627.58
Jute-stick	18274.20	3268.15
Bagasse	17253.60	3055.26

Thermal Gravimetric Analysis (TGA)

Thermogravimetric (TG) plot determination: The thermal characteristics of rice-straw, jute-stick and bagasse particles have been investigated by thermogravimetric analyzer (TGA) study. The instrument used for this purpose was SHIMADZU TGA-50 model and the tests were conducted at the laboratory of Fuel Research and Development Institute, BCSIR, Dhaka, Bangladesh. The samples were air-dried and of sizes 300 to 1180 μm. In each of the experiments less than 15 mg of samples was used. The analysis was done in an inert atmosphere of helium at a constant flow rate of 20 ml/min. The samples were subjected to different controlled heating rates over a temperature range of 0^o to 1000°C. The heating rates employed were 40° and 60°C/min. During the process of pyrolysis, the weight percentages of the initial weight of the sample were recorded continuously as function of temperature and time by a computer connected to the system and from these recordings, thermogravimetric (TG) plots were obtained. The TG curve indicates the fractional weight loss of the sample with temperature and time. The plots obtained at two heating rates of 40° and 60°C/min for rice-straw, jute-stick and bagasse pyrolysis are presented in Figs. 1, 2, 3, 4, 5 and 6.

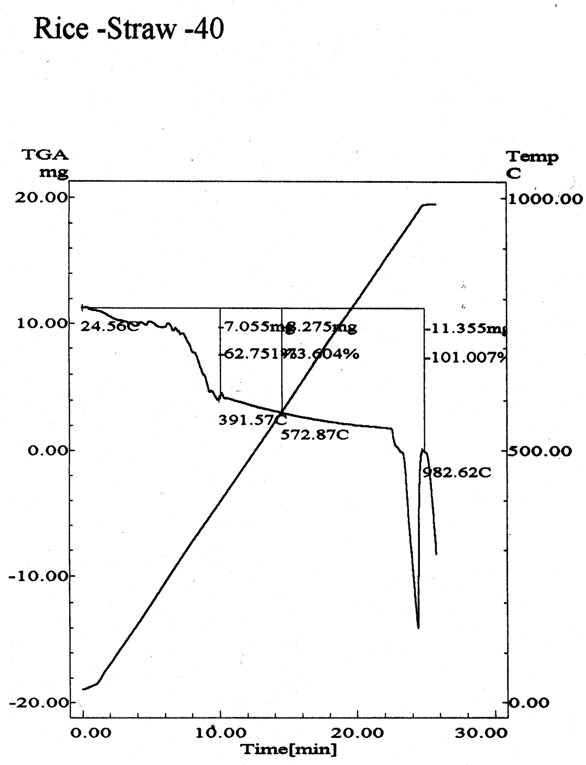

Fig. 2 TG plot for rice-straw in helium at 40^{0}C/min.

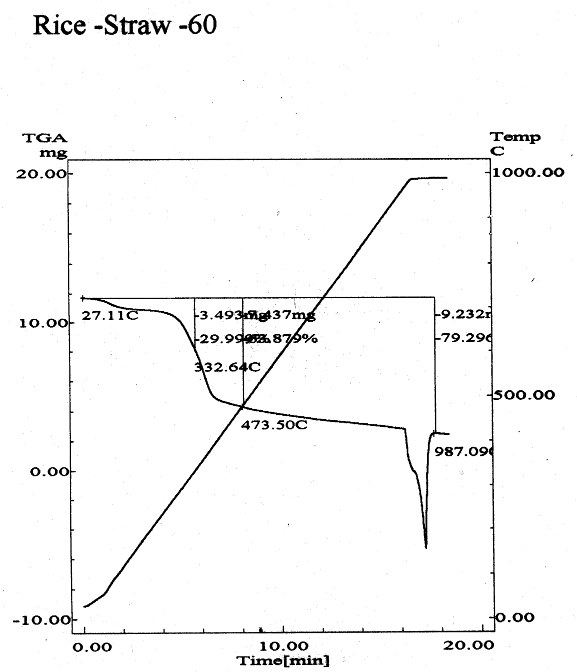

Fig. 1 TG plot for rice-straw in helium at 60^{0}C/min.

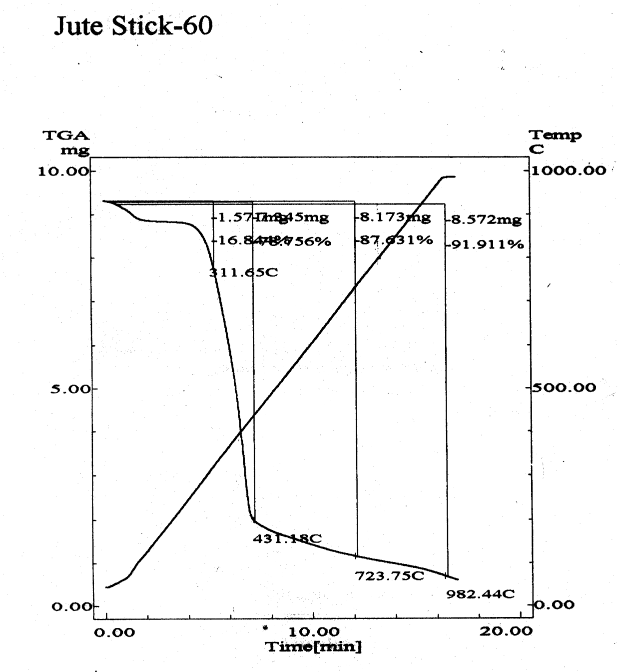

Fig. 3 TG plot for jute-stick in helium at 60^{0}C/min.

Jute Stick--40

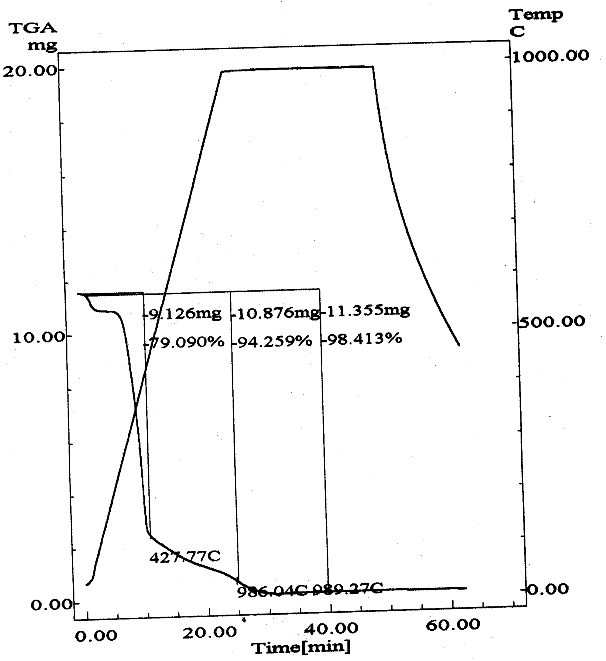

Fig. 4 TG plot for jute-stick in helium at 40^{0}C/min.

BAGASSE-40

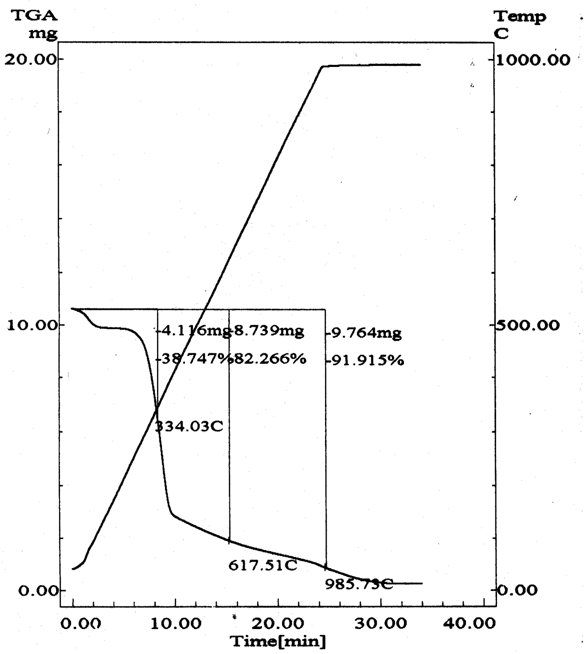

Fig. 6 TG plot for bagasse in helium at 40^{0}C/min.

BAGASSE-60

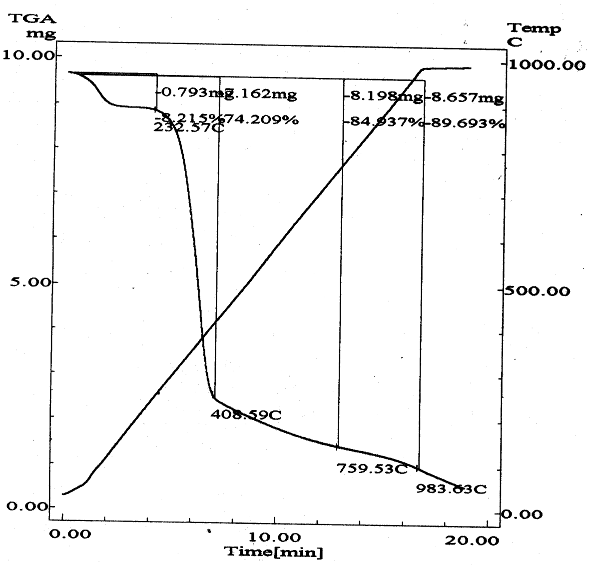

Fig. 5 TG plot for bagasse in helium at 60^{0}C/min.

Determination of degree of conversion: By using the values obtained from TG plots, the degree of conversion of the selected biomass, X in pyrolysis reaction can be derived as defined by Equation (1) [Liou and Chang, 1997]

$X = (W_o - W)/(W_o - W_\alpha)$ .... (1)

Where, W_o = initial mass of the samples, W = instantaneous mass of the samples and W_α = final mass of the sample.

Figs. 7, 8 and 9 present the plots of degree of conversion against temperature of rice-straw, jute-stick and bagasse at heating rates of 40 and 60°C/min respectively.

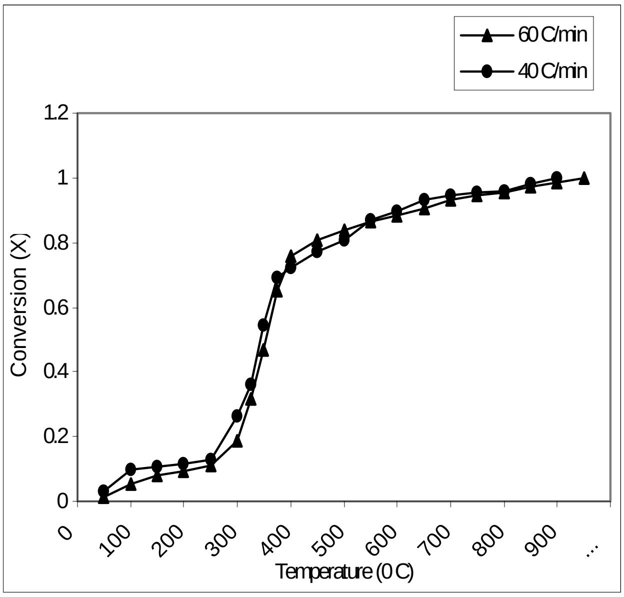

Fig. 7 Effect of heating rates on the pyrolysis conversion of rice-straw

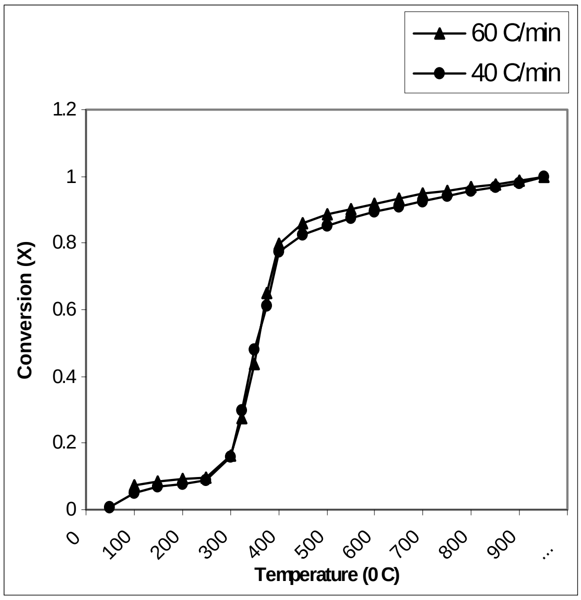

Fig. 9 Effect of heating rates on the pyrolysis conversion of bagasse

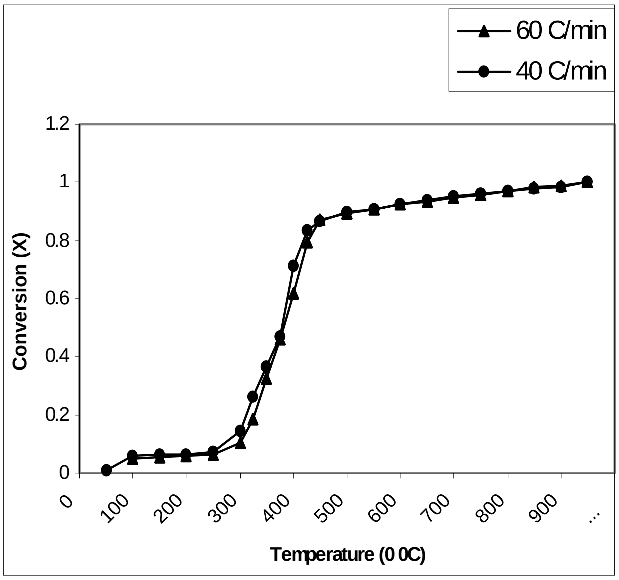

Fig. 8 Effect of heating rates on the pyrolysis conversion of jute-stick

DISCUSSION

From Table-1 it is found that more than 90% weight of the particles of each of prepared samples were in the size range of 300 to 1180μm and the bulk density of the particles within this range were higher than that of particle size range of 0 to 300μm. The preparation of larger particles is easier and less energy consuming. The higher density particles takes less volume in the reactor of the pyrolysis conversion system. This criteria of the feed materials make the system less energy consuming for their pyrolitic conversion.

Form the point of view of feedstock suitability, it is found from Table-2 that jute-stick and bagasse contain very little amount of ash and small amount of moisture. Their volatile matter contents are comparatively higher. The less moisture and ash content and higher volatile matter content of these two biomass feedstocks ensure them to be potential candidate for liquid production by pyrolytic conversion system. Rice-straw contain comparatively higher percentage of ash and slightly lower percentage of volatile matter than that of jute-stick and bagasse. However, it has also good potential for pyrolitic liquid production.

Table-3 shows that the oxygen content in rice-straw, jute-stick and bagasse are 46.51, 49.90 and 47.46 wt% respectively. The overall range for the oxygen content of woody and herbaceous biomass is 40 to 45wt% on moisture and ash free basis. One result of the high oxygen content is the relatively low lower heating value (LHV) of 19 to 20 MJ/kg of dry biomass [Grabosky and Bain, 1979], compared to the hyrdocarbon fuels having a LHV of between 40 to 44 MJ/kg. Table 4 shows that heating valuves of rice-straw, jute-stick and bagasse are 16.23, 18.27 and 17.25 MJ/kg respectively.

In the conversion plots, shown in Figs. 7, 8 and 9 there are clearly three principal stages of reaction distinguished by three significant and distinct variation of conversion for each of two heating rates for all of the samples. For a given temperature of the sample pyrolysis, the corresponding conversion at a lower rate of heating was slightly more than that at a higher rate of heating. The degree of conversion of each of three biomass solid wastes were found to increase by less than 10% when temperatures were varied up to 200°C for both heating rates. This may be related partly to the devolatilization of the hemicelluloses with a rapid increase of degree of conversion in the second stage which is due to the evolution of volatile matter of the cellulose and hemicelluloses of the biomass wastes. The second stage with a degree of conversion of up to 80% where the temperature was varied from 250^o to 500°C is mainly attributed to the decomposition of the organic constituents into volatiles and char [Islam and Nasir,1999]. The third stage indicating conversion after 80% involve the gradual breakdown of the lignin into char and gases when the temperature was varied from 500^o to 600°C. When the temperature exceeded 600°C, the organic materials were almost completely decomposed to carbon and other inorganic compounds and the higher pyrolysis temperature did not affect the loss of mass.

CONCLUSIONS

The biomass solid wastes are characterized and found to have potential to be converted into liquid fuel by pyrolysis. The size of the feedstock is selected to be in the range of 300 to 1180µm. The reactor should be designed for pyrolysis temperature range of 300^0 to 600°C. The heating system is to be designed to heat the feed material at a rate of 60°C/min. For this higher heating rate a fluidized bed system may be a good option.

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