Performance Of Rice Husk Screw Feeder For Fixed Bed Combustion

Tamaria Panggabean, Tineke Mandang, Leopold Oscar Nelwan, Wawan Hermawan

Abstract : The accuracy and smoothness of the husk fuel feed in a fixed bed combustion furnace is very important in improving the performance of the husk combustion. In this study, a screw feeder was designed to feed rice husks into the combustion chamber, according to combustion requirements smoothly. The feeding mechanism used is that the husk from the hopper is fed into a screw feeder which is rotated by an electric motor. The husk feeding rate can be regulated by controlling the rotational speed of the electric motor using an inverter. For smooth feeding, a tapered outer diameter screw was used with the screw outer diameter enlarging from 48 mm at the inlet to 69 mm at the outlet. The husk feeding performance was tested in: 1) the non-combustion conditions and 2) the combustion conditions in a fixed bed furnace. The results of the performance test without combustion showed that the feed rate of the husk increased linearly with the increasing of the screw rotating speed. The husk feeding rate at 10-35 rpm screw rotating speed was 2.85-10.91 g/s. In the combustion test, the screw feeder could feed the husks to the combustion chamber smoothly. The temperature of the combustion chamber increased as the husk feed increases. There was no significant increase in temperature in the screw feeder and no burning of husks in the screw feeder.

Keywords : combustion, feeding performance, fixed bed furnace, rice husk, screw feeder

1 INTRODUCTION

Rice husk is an important byproduct in the rice production industry. There is worldwide a production of ~700 million tons/year of rice-related waste, such as straw, shells, and stalk. The fuel potential of rice husk alone is ~80 million tons/year worldwide, corresponding to an energy potential of ~1.2×10^9 GJ [1]. According to [2], biomass combustion is a complex phenomenon due to its various variations and physical structure. Biomass consists of lower carbon, higher oxygen, higher volatile content and lower heating value. According to [3] there are three main types of furnaces for direct combustion of biomass: fluidised beds, pulverized combustion (suspension) and fixed bed systems. The fixed bed furnace has a pile of fuel that rests on the grate and the grates can be fixed, moving, rotating, or vibrating. The simplest form of a fixed bed system is campfire. Fuel air is fed through natural convection. Solid biomass is usually used in small-scale factory fixed beds. Combustion in fixed bed furnaces is one of the most common thermo-chemical conversion methods. Fixed beds are preferred on a small scale, because of their simplicity, versatility and low investment costs. The ability to investigate the combustion process in these furnaces using a relatively low-cost numerical model [4]. One of the problems in fixed bed furnaces with rice husk fuel is the feeding of rice husk. The pre-existing feeding system is traditional husk feeding with human assistance and pneumatic husk feeding. Traditional feeding systems with human assistance have the disadvantage of combustion which produces very much black smoke. However, it has the advantage of not requiring costs in feeding [5]. Rice husk feeding with pneumatic system is using a blower. The pneumatic feeding system has the advantage of being able to automatically feed husks into the furnace and low manufacturing costs. However, this feeding system has the disadvantage that there are still piles of unburnt husks in the furnace and produce a low heating value [6]. With the current mechanism, feeding is not yet smooth and stable. Based on the evaluation of the design concept using the weighting method with objective tree, a screw conveyor type feeding system was chosen. Screw conveyor is a device that is mostly used to transport varieties of materials at a desired and controlled flow rate [7]. The screw conveyor basically consists of a rotating screw shaft in the trough and a drive unit for running the shaft. The screw conveyor consists of a shaft that carries helicoids flightings on its outer surface. These flightings are enclosed either in a trough for horizontal augers or in a tube for elevating augers [8]. [9] stated that the fill rate is the number of particles that can be delivered in a screw conveyor. The screw conveyor filling factor is a key point for transmission efficiency [10]. Problems with the rice husk feeding system in a fixed bed furnace are: the flow of the husk in the feeder part that is unstable and jammed, the feed of the husk that is not continuous resulting in a pile of unburned husks in the furnace combustion chamber. So, we need a new design of rice husk feeder system for fixed bed furnaces, which can stable feed the husk without traffic, no heat traveling to the hopper, does not result in a pile of unburned husks, to support complete combustion in the combustion chamber. This study aims to examine performance of the feed conveyor husk on a fixed bed combustion furnace.

2 METHOD

The research was carried out by first designing the screw conveyor used to feed the husk in the fixed bed furnace. After the screw conveyor is made according to the design criteria, then the rate and discharge of the screw conveyor feed is tested for two treatments, namely the treatment before combustion and during combustion.

2.1 Characteristics of Rice Husks

The rice husk used in this study was rice from the Inpari 23 type of rice obtained from the "Pak Jarwo" rice mill in Dramaga sub-district, Bogor. Rice husk that is packed in plastic sacks is dried in bulk in a tub type dryer with heat energy sourced from the sun. Before the husk is used as a feed test material on a screw conveyor, the measurement of the characteristics of rice husk is carried out first.

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Measurement of the characteristics of rice husk is carried out at the Laboratory of Processing and Agricultural Product Engineering, Bogor Agricultural University. Measurements of length, width and thickness of husk were carried out using "Tricle Brand" calipers. Husk mass measurements were performed using "Fujitex" digital scales. Measurement of density is done by weighing the mass of rice husk using a digital scale that is inserted in a container with a volume of one liter using a measuring cup. Measurement of angle of repose is done by stacking rice husks on the end of a stainless steel plate then slowly lifting it with a certain slope. If the stack of husk has slid and fallen, then the angle is formed using an arc. Measurement of water content is done using the gravimetric method using an oven. Measuring the husk friction coefficient with stainless steel is done simply using loading. The characteristics of rice husk used in this study can be seen in Table 1. The graph of the distribution of length, width and thickness of the husk can be seen in Figure 1.

TABLE 1

Characteristics of rice husks

Commodity	Length (mm)	Width (mm)	Thick (mm)	Mass (g)	Density (kg/m^3)
Rice husk	8.7-12.0	2.4-3.3	0.5-1.5	0.0017	138.23

Angle of repose (degree)	friction coefficient rice husk –stainless steel	friction coefficient rice husk-rice husk	Water content (%)
47.6	0.51	0.931	10.65

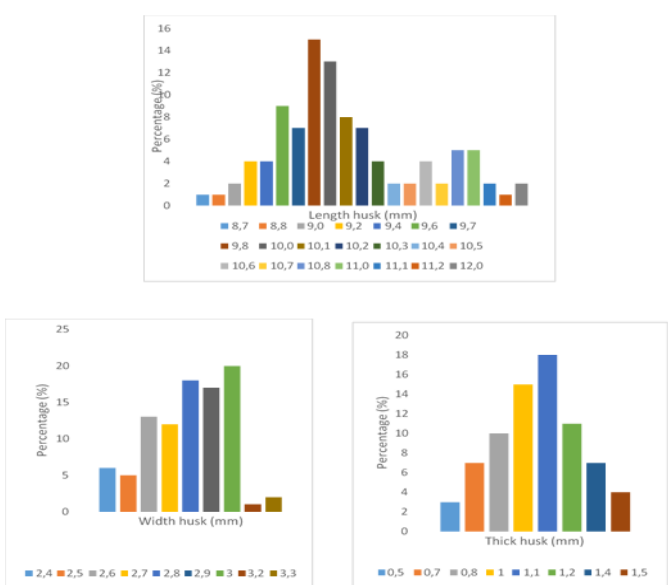

Fig 1. *The graph of the distribution of length, width and thickness*

2.2 Screw Conveyor Design

Screw conveyors are designed with a feeding capacity of 11-15 kg/h, with a frequency of 34 Hz inverters and a screw speed of 20 rpm.The structure of the screw conveyor feeder system that is designed is composed of: (a) a hopper to accommodate the husk, (b) a screw conveyor, (c) a husk feeder channel to the combustion chamber, (d) a screw motor electric drive (e) a power transmission system consisting of a reduction gearbox, and pulley transmission system and V belt, (f) frame seat for all components and (g) inverters to regulate the frequency of electric current to the electric motor. Hopper made of stainless steel thickness of 1 mm. The dimensions of the screw conveyor hopper consist of a pyramid hopper of length, width and height were 500, 300 and 150 mm, respectively. Hopper beams with length, width and height were 500, 300 and 100 mm, respectively. The inlet of the husk from the hopper is 145 mm long and 100 mm wide and given a divider that can be opened and closed. The inlet of the husk from the screw is 80 mm long and 50 mm wide. The screw is made of stainless steel with a thickness of 0.1 mm. The shaft is made of solid cylinder steel. The entrance hole of the husk into the furnace chamber is 150 mm long and 80 mm wide. The dimensions of the screw consist of a shaft diameter of 19 mm, a screw length of 450 mm, a small screw diameter of 48 mm and a large screw diameter of 69 mm. The screw conveyor components used in this study can be seen in Figure 2. The screw conveyor with dimension each component can be seen in Figure 3.

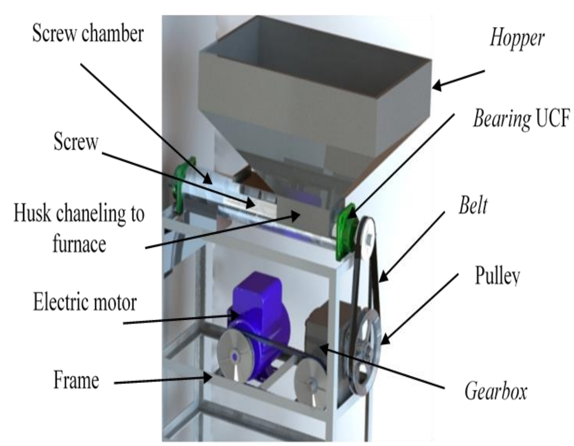

Fig 2. *Screw conveyor components*

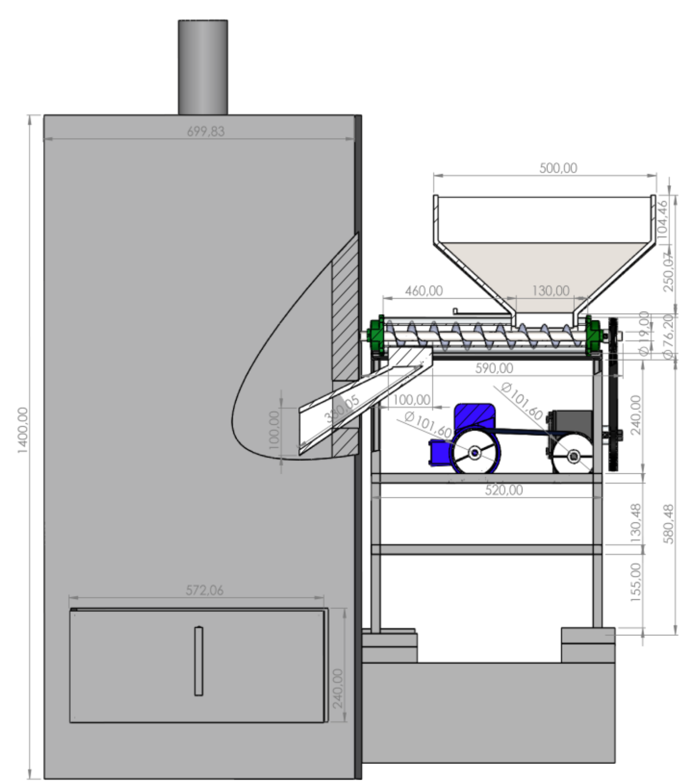

Fig 3. *The screw conveyor with dimension each component*

2.3 Testing of the Rate and Discharge Feed Screw Conveyors

Testing the rate and discharge of screw conveyor feeds is carried out with two treatments, namely testing before combustion and during combustion. Tests before combustion are carried out in the following stages: (1) husk fuel is weighed using a scale of 1 kg and put on the hopper (2) the electric motor is operated and connected to the inverter (3) the inverter is set at frequencies 19, 26, 34, 43, 51 and 60 Hz so that it is obtained actual rotational speed of the screw 10, 15, 20, 25, 30 and 35 rpm respectively (4) The screw conveyor is operated then measured how much time to feed at each screw speed using a stopwatch. The treatment of each screw rotational speed is repeated 3 times. Tests during combustion take place with the following stages: (1) husk fuel is weighed using a scale of 1 kg and put on the hopper (2) the electric motor is operated and connected to the inverter (3) the inverter is set at frequencies 19, 26, 34, 43, 51 and 60 Hz so that it is obtained actual rotational speed of the screw 10, 15, 20, 25, 30, and 35 rpm respectively (4) the furnace and screw conveyor are operated (5) the husk is fed to the furnace and burned (6) after the combustion has been stable, the husk feeding time measurement is performed using a stopwatch at each screw rotational speed. The treatment of each screw rotational speed is repeated 3 times. From the mass of the husk being fed and the feeding time will be obtained the rate of the husk feeding. From the husk volume that is fed and the feeding time will be obtained husk feed discharge. The feed rate and the husk feed discharge are obtained from equations 1 and 2.

$$v = m/t \quad (1)$$

Where

v : husk feed rate (g/s)
m : the husk mass fed (g)
t : husk feeding time (s)

$$Q = v/t \quad (2)$$

Where

Q : husk feed discharge (cm^3/s)
v : the volume of the husk fed (cm^3)
t : husk feeding time (s)

2.4 Temperature Measurement Method During Combustion

Temperature measurements during combustion are carried out using type K thermocouples. Temperature measurements at each measurement point are carried out every 1 minute and the results of temperature measurements are stored in Graphtec midi LOGGER GL 240. During the combustion process air flow velocity measurements are also taken at the measurement point, namely the primary channel, secondary channel, fuel inlet channel, ambient channel and outlet channel using anemometer KANOMAX. Measurement of air flow velocity is carried out every 5 minutes. Temperature measurements at each point can be seen in fixed bed combustion operating system in Figure 4.

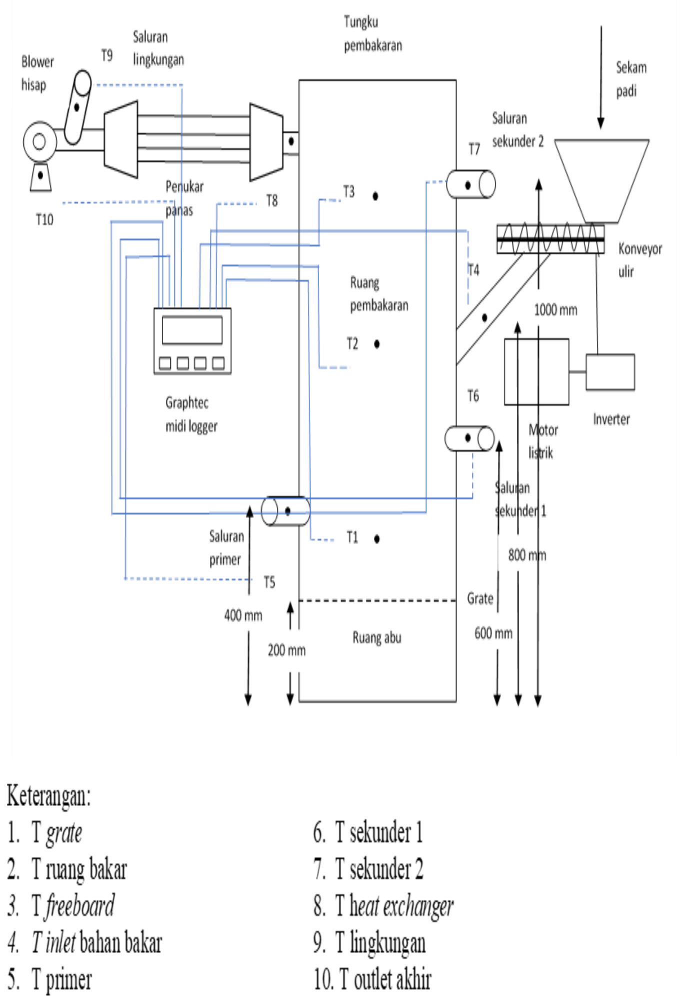

Figure 4. *Fixed bed combustion operating system*

3 Results and Discussion

3.1 Screw Conveyor Performance

The screw conveyors that are designed can work as planned. This can be seen from the tests carried out before combustion, the husk fed from the screw channel to the furnace can run smoothly and there is no pile of unburned husks for the screw rotational speed of 10-35 rpm. The same thing can be seen in the treatment during the combustion takes place, the husk that is fed from the screw channel to the furnace can run smoothly and there is no pile of unburnt husks for the screw rotational speed of 10-35 rpm. Because of there is no file of unburn husks, so there is no smoke in the furnace outlet. The designed screw conveyor husk feeder prototype has been able to feed the husk before combustion by 11.34-44.93 kg/h and during the combustion by 10.26-39.28 kg/h.

3.2 Rate and Discharge of Feeding Conveyor Screw Before Combustion

Retrieval of the output data is carried out to determine the rate and discharge of the feed conveyor screw before combustion. The test results show each component used works well as planned. Data collection on the time of the husk feeding was carried out at the rotating speed of the screw 10, 15, 20, 25, 30 and 35 rpm. Different rotational speed of the screw producing different husk feed rates and discharge. Feed rates for rotational speeds of 10, 15, 20, 25, 30 and 35 rpm were 3.15, 5.16, 6.97, 7.29, 9.71 and 12.48 g/s, respectively. The resulting husk feed discharge for the rotating speed of screw 10, 15, 20, 25, 30 and 35 rpm were 22.79, 37.30, 50.42, 52.72, 70.29 and 90.32 cm^3/s, respectively. The relationship between the screw rotational speed and the feed rate and the husk feed discharge before combustion can be seen in Figures 5 and 6.

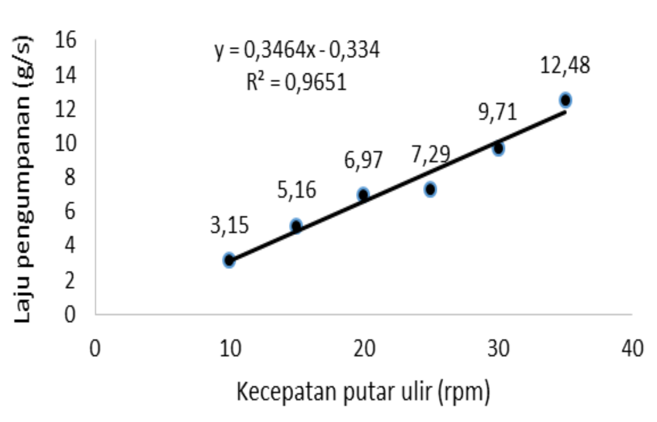

Fig 5. *Relationship of screw rotational speed to feed rate before combustion*

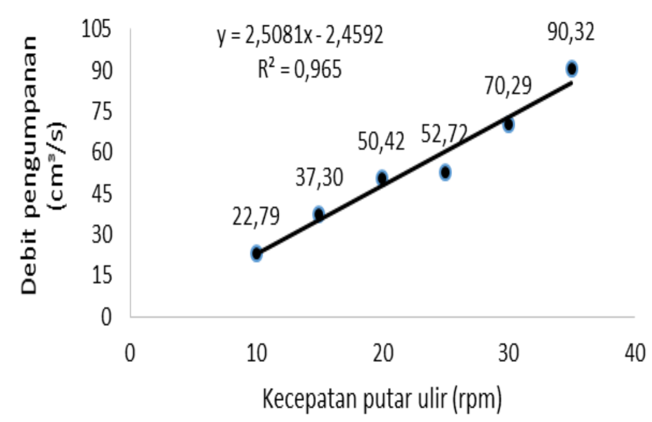

Fig 6. *Relationship of screw rotational speed to feed discharge before combustion*

Figures 5 and 6 show the treatment of the feed rate and discharge before combustion, the screw rotational speed is directly proportional to the feed rate and the husk feed discharge. The more the screw rotational speed increases, the higher the rate of feed and discharge of the husk is produced, and vice versa. Figures 5 and 6 show the values of R^2 = 0.9651 and R^2 = 0.965. This means that the feed rate and feed discharge depend on the screw rotational speed. An increase in screw rotational speed will result in an increase in the mass and volume of the husk which will be fed to the furnace combustion chamber and result in a short time of feeding husk to the furnace combustion chamber.

3.3 Rate and Discharge of Feeding of the Conveyor Screw During Combustion Process

The data collection of the feed output is carried out to determine the feed rate and discharge of the screw conveyor feed during combustion. The test results show each component used works well as planned. Data collection time of husk feeding was carried out at screw rotational speeds of 10, 15, 20, 25, 30 and 35 rpm. Different screw rotational speeds resulting in different feed rates and husk feed discharges. The resulting husk feed rates for screw rotational speeds of 10, 15, 20, 25, 30 and 35 rpm were 2.85, 3.83, 4.87, 6.66, 8.85 and 10.91 g/s, respectively. The resulting husk feed discharge for the rotating speed of screw of 10, 15, 20, 25, 30 and 35 rpm were 20.60, 27.70, 35.22, 48.17, 64.03 and 78.94 cm^3/s, respectively. The relationship between the screw rotational speed and the feed rate and feed husk discharge during the combustion can be seen in Figures 7 and 8.

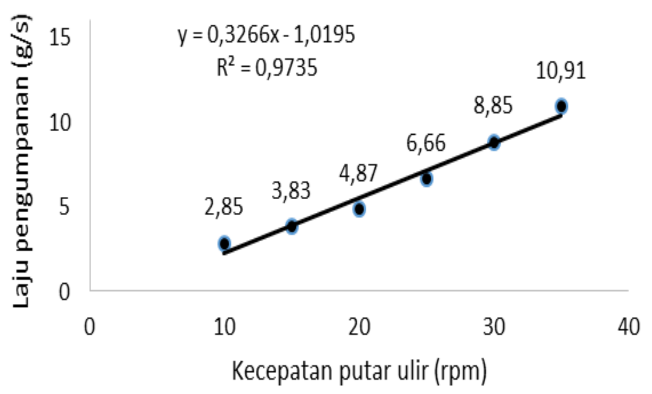

***Fig 7.** Relationship of screw rotational speed to feed rate during combustion*

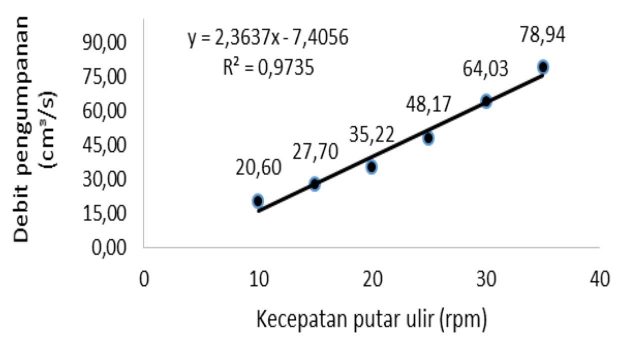

***Fig 8.** Relationship of screw rotational speed to feed discharge during combustion*

Figures 7 and 8 show that during combustion, the rotational speed of the screw is directly proportional to the feed rate and the husk feed discharge. The more the screw rotational speed increases, the higher the feed rate and the resulting feed discharge, and vice versa. This is in accordance with [11] which states that particle transportation increases with increasing rotating speed of screw conveyors. Figures 7 and 8 show the values of R^2 = 0.9735 and R^2 = 0.9735. This means that the feed rate and feed discharge depend on the screw rotational speed. An increase in screw rotational speed will result in an increase in the mass and volume of the husk which will be fed to the furnace combustion chamber and result in a short time of feeding husk to the furnace combustion chamberWhen viewed from the two treatments before combustion and during combustion takes place the rate of feed and discharge of husk feed is different in value even with relatively the same trendline. This is because the treatment during combustion takes place using additional primary air duct components, secondary air duct 1, secondary air duct 2 and suction blower while the pre-combustion treatment is not. The use of primary air ducts, secondary ducts 1 and secondary ducts 2 and the use of suction blowers in the treatment during combustion affects the husk feeding time for each different screw rotational speed, thereby automatically affecting the feed rate and feed husk discharge. The treatment during combustion takes place resulting in the rate and discharge of the husk feed lower than the treatment before combustion. The primary air channel functions to create a solid combustion reaction, the secondary air channel 1 and the secondary air channel 2 function to react to volatile combustion released from the husk. All three channels provide resistance which results in the flow of husk from the screw conveyor channel to the furnace combustion chamber to slow down a bit so that the time of husk feeding during combustion takes longer than before combustion. During the combustion there are three air ducts used to assist the combustion process, namely the primary air duct, secondary air duct 1 and secondary air duct 2. The velocity of air flow in each channel can be seen in Table 2.

TABLE 2

Air flow velocity in each channel

Screw rotational speed (rpm)	Air flow velocity (m/s)		
	Primary air	Secondary air 1	Secondary air 2
10	0.64	0.16	0.52
15	0.62	0.18	0.56
20	0.66	0.17	0.57
25	0.64	0.19	0.59
30	0.64	0.18	0.55
35	0.66	0.18	0.59

Table 4 shows the screw rotational speeds of 10, 15, 20, 25, 30 and 35 rpm producing air flow velocity in the primary air, secondary air 1, and secondary air 2 with a range of 0.62-0.66, 0.16-0.19 and 0.52-0.59 m/s, respectively. According Table 2 shows the screw rotational speed not related to the air flow velocity in each channel. This is primary, secondary 1 and secondary 2 air flow velocity at each screw speed is relatively different. This means that the rotating speed of the screw does not affect the speed of the air flow in each channel because the air flow is sourced from natural air which cannot be regulated air flow velocity.

3.4 Effect of Screw Rotational Speed on Temperature during Combustion

The temperature at each measurement point during combustion takes place at a screw rotational speed of 10, 15, 20, 25, 30 and 35 rpm can be seen in Table 3.

TABLE 3

Temperature at each measurement point during combustion

Screw rotational speed (rpm)	Feed discharge (cm³/s)	T grate (°C)	T combustion chamber (°C)	T freeboard (°C)	T inlet (°C)
10	20.60	344.20	66.84	73.59	31.64
15	27.70	284.70	105.83	140.37	30.70
20	35.22	502.72	155.14	184.31	31.36
25	48.17	528.91	163.18	222.63	31.50
30	64.03	556.25	228.48	270.35	32.48
35	78.94	622.44	265.54	302.33	32.98

T primary	T secondary	T outlet	T heat	T outlet

(°C)	(°C)	cb (°C)	exchanger (°C)	(°C)
31.69	31.99	55.09	59.07	45.15
51.14	31.38	165.42	106.48	66.00
113.53	34.35	204.83	129.57	70.41
73.71	36.86	237.32	150.09	79.39
109.93	38.74	289.72	174.11	88.03
60.53	41.45	296.64	194.33	94.26

Fuel inlet temperature during combustion takes place with a screw rotational speed of 10-35 rpm ranging from 30.70 to 32.98 ^{o}C. Fuel inlet temperature is relatively low. The low fuel inlet temperature causes no expansion in the screw conveyor channel so that the husk fed from the screw conveyor channel can take place smoothly. Different rotational speed produces a different temperature at each measurement point. The more the screw speed increases, the more the temperature produced at each measurement point. This is because the rotating speed of the screw will affect the discharge of the husk feed to the furnace combustion chamber. The more the screw rotational speed increases, the more the husk feeds into the furnace combustion chamber. The more the discharge of the husk feeds into the furnace combustion chamber, the higher the temperature at each measurement point during combustion.

4 CONCLUSION

The prototype of the screw conveyor husk feeder in the fixed bed furnace was successfully designed and fabricated. The feed system itself meets the design criteria and each component has worked well. The designed screw conveyor husk feeder prototype has been able to feed the husk before combustion at 11.34-44.93 kg/h and during combustion takes place at 10.26-39.28 kg/h. Test results after calibration before combustion showed the husk feeding rate increased linearly along with an increase in screw rotational speed of 10-35 rpm, it could produce a feed rate of 2.8-10.91 g/s. Husk feeder system to the fixed bed furnace combustion chamber can run smoothly. Each increase in the screw rotational speed will result in an increase in the feed rate and the husk feed discharge which will also result in an increase in temperature at each measurement point during combustion.

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