Design and Development of a Far Infrared Rice Flour Gelatinizer

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Abstract- A far infrared continuous type rice flour gelatinizer was developed and tested. At presentrice flour is roasted in batch process using electricity or firewood in industry. The existing batch type conduction heating roasters are labor intensive and energy inefficient. Radiation heating is more effective compared to conduction and convection in food processing.At present, there are no far infrared heating continuous type rice flour roasters for industrial use. An auger was used to mix and move flour in the machine. At the top and the bottom of the auger, far infrared heaters were established to supply radiation heat. The industrial requirement was to get gelatinized rice flour at the rate of 300kg/h. To achieve required rpm, heater height and temperature and retention time were considered.Driving mechanism was developed to rotatethe auger at 28 rpm. Control system was developed using 16F684 microprocessor to control the heaters' temperature and auger by modulating pulse width to achieve the maximum gelatinization of rice flour while maintaining the required output. One thermocouple and three LM35 sensors were used to automate the system. Styrofoam and wood boards were used to insulate the machine.Rice flour was added from the rice mill at a rate of 300kg/h to the gelatinizer.Maximum input flour temperature from the mill was 75°C and output temperature from the gelatinizer was 90°C. Machine's inner surface temperature was maintained at 100°C. Outer surface temperature was 66°C. Moisture content at the output was 11.30% wet basis and viscosity was 350Mpa/s.Machine power consumption was 4.8kW/h. Moisture was removed at a rate of 0.24 L/h.

Index Terms- Far infrared radiation, Gelatinization, 16F684 Microprocessor, Pulse width modulation

I. Introduction

Rice is the staple food in Sri Lanka and usually consumed as whole grain. Rice flour based foods are also common in local diet, and has gained a remarkable market interest in recent past. The raw rice flour has relatively short shelf life and poor in desirable qualities for further processing.Roasting is one of the methods to increase the quality and the shelf life of rice flour for decades. Roasted rice flour has good keeping quality and pasting properties compared to the non-roasted rice flour. Dry roasting is a process by which heat is applied to dry foodstuffs without the use of oil or water as a carrier and usually the product is stirred while roasting to ensure even heating.Roasting usually causes caramelization or Maillard browning of the surface, which is sometime considered as flavor enhancement.

Gelatinization of flour is the main objective of roasting. Starch gelatinization is a process that breaks down the intermolecular bonds of starch molecules in the presence of water and heat. The process begins with the native starch granules absorbing water and swelling (Richard*et al*., 1998). Gelatinization improves the availability of starch for amylase hydrolysis. Schirmer*et al*. (2015) has studied the common gelatinization pattern of rice flour. Gelatinization of rice flour starts at 60°C and maximum gelatinization occurs at 90 to 110 °C in rice flour. The optimum gelatinization percentage is reached at 110 °C and the retention time required is 12 seconds(Abiram*et al*., 2012.).Viscosity change is one of the indicators used to identify the level of gelatinization and rice flour shows maximum viscosity at 110 °C. The flour should be retained in this temperature at least for 12 seconds to achieve the required percentage of gelatinization. The quality of roasted rice flour depends on the percentage of gelatinization. When gelatinization does not occur properly, the texture, taste and color of the flour varies and subsequently the expected quality of the final product cannot be obtained. Therefore it is necessary to get the correct gelatinization to preserve the quality of roasted rice flour.

Infrared radiation is the part of the electromagnetic spectrum lying between ultraviolet and microwave energy. It is normally classified into three regions near, mid and far infrared corresponding to the spectral ranges of 0.78 to 1.4, 1.4 to 3, and 3 to 1000 µm respectively. Infrared radiation drying is fundamentally different from convective drying since the material is dried directly by absorption of infrared energy rather than transferring heat from the air (Das andBal, 2009). The danger of product overheating is low in this method because of rapid heating, which requires exact condition control (Shakai and Hanzawa, 1994). Some of the other benefits are uniformity of drying, reduced quality losses due to absence of solute migration in food material, versatile, simple, compact equipment, environmentally clean operation, ease of automation, efficient heat transfer which reduces the processing time and energy costs. Air in the equipment is not heated by infrared; consequently, the air temperature may be kept at normal levels. Because of these features, infrared heating has been accepted as an important means of cooking, drying, roasting, baking, blanching, and pasteurization of food and agricultural products (Lloyd *et al*.,2003; Rajan*et al*., 2002; Sharma *et al, 2005*;

Staack*et al*., 2008). Combinations of infra-red heating with microwave heating and other common conductive and convective modes of heating has been evaluated by Krishnamurthy*et al.*, (2008).

At present the industry uses batch type conduction/convection roasting methods to gelatinize rice flour.The batch type machines are time consuming, high energy consuming and labor intensive.The industry requires a fast and energy efficient, continuous type rice flour roasting method.Designing a continuous rice flour gelatinizer is important which avoids the demerits of batch type roasting machines.Therefore the objective of this study was to design and develop a far-infrared (FIR) rice flour gelatinizer with a capacity of the 300 kg/h for industrial use.

II. METHODOLOGY

Continuous type far infrared rice flour gelatinizer was designed and fabricated with a capacity of 300 kg/h for industrial use. The degree of gelatinization basically depends on temperature and moisture content and, the quality of roasted rice flour depends on the percentage of gelatinization. Therefore a special attention has been given to the factors of temperature, moisture content and mixing of flour in the design.The top and frontviews of the designed rice flour gelatinizer are illustrated in the Figures 1 and 2.

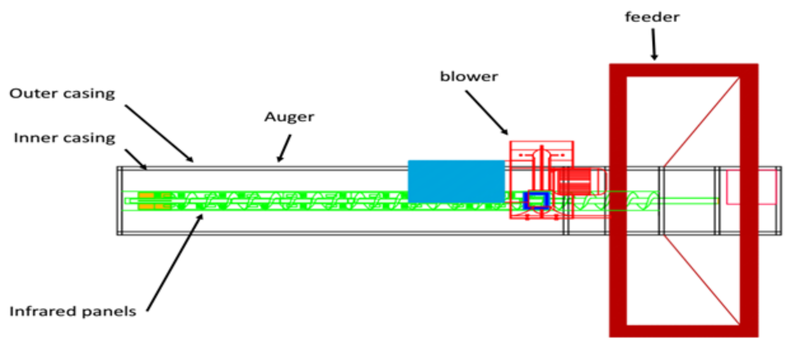


Figure 1: Top view of the gelatinizer

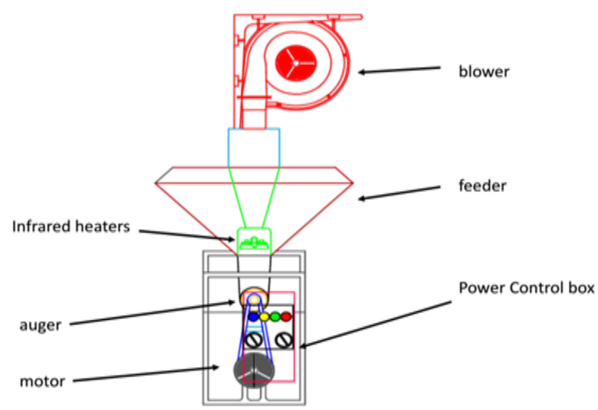


Figure 2: Front view of the gelatinizer

Design of the auger and mixing mechanism

The auger and the casing was made out of iron plates and the length of auger was 1.7m (Figure 3). Auger was mount on two roller bearings at the ends and the gap between auger and the casing was 0.01 cm. Mild steel plate connected between screws was used to mix rice flour to get uniform heating. The plates move up and down while rotating the auger to remove flour in the casing.Sprocket wheels and chain were used to drive the auger. The motor speed was reduced by six time and the auger speed was maintained at 28 rpm. A blower was used to remove air on top of the auger in counter current way.

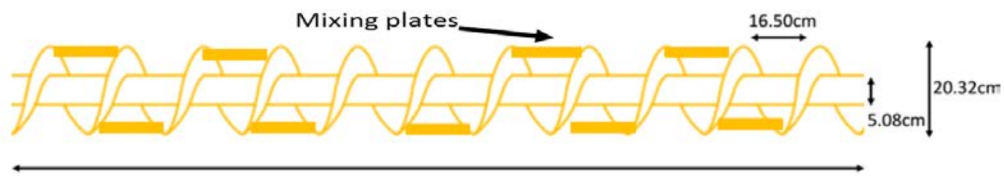


Figure 3: Auger after attaching the plates

Design of FIR heating mechanism

A total of 14 far infrared panels(black,ceramic, 240×60mm, 1000W) were used for the design. Nine panels were mounted on an iron plate and fixed at the top of the auger (Figure 4). The gap between auger and infrared panels were 0.1 m. A top cover was used to cover the IR panels. Five IR panels were established to heat auger from the bottom and an iron cover was used to cover the heaters.All wires used to connect the heaters and motor with the control box were insulated using heat resistant casings and flexible aluminum tubes. Machine required three phase power supply since it contains 14 far infrared heaters of 1000W.Styrofoam and wood boards were used for insulation. In between two wood boards 0.05 m thick Styrofoam sheet was placed. The outer surface was covered with mild steel sheets.

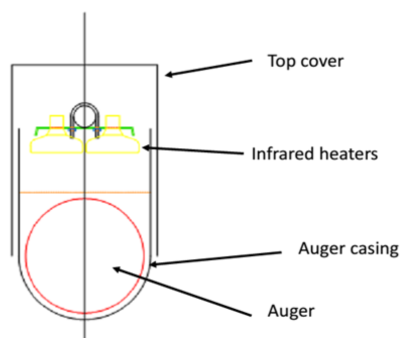


Figure 4: Arrangement of the FIR heaters

Development of the control system

System was automated using a microcontroller (16F684) based control system with semiconductor type temperature sensors (LM35, Texas instruments, USA). Heater power was controlled by a pulse width modulated power supply with a duty cycle of 50% to avoid rising the surface temperature of the heaters above 350 ^{o}C.Surface temperature of the heaters were controlled to minimize the risk of fire during operation. Three phase power meter was used to measure the power consumption of the machine. The surface temperature of the augur housing was controlled at 100 ^{o}C using the same 16F684 microcontrollerby switching ON/OFF heaters by sensing the surface temperature using semiconductor temperature sensors (LM35). Heaters were switched on and off using Solid State Relays (SSR).

Provision was given for selecting the operation modes “Manual” and “Auto” using a toggle switch. In the auto mode the set temperature of 100 ^{o}C was achieved automatically. In the Manual mode there was a provision to change the duty cycle by changing on time and off time using variable resistors. A programming port was fixed to the microcontroller to change the program at any time as required. A gap of 0.01 m was maintained between the heaters and auger to avoid the risk of fire.

Measurement of temperature and moisture content

The rice flour is directly fed to the gelatinizer after milling. The flour input and output temperatures were measured using thermocouples (K type) and an infrared thermometer (Fluke 572-2) at 5 minutes intervals. The machine’ outer surface temperature was measured at three places at 5 minutes intervals.(T1: closer to the inlet of the machine, T2: middle of the machine, T3:closer to the outlet of the machine. The moisture content of raw rice, input and output flour to the gelatinizer, and the flour after sieving was measured using moisture meter (Ohaus, MB45).

Viscosity of rice flour

During the gelatinization, rice flour starch granules starts to swell. As a result the diameter of the starch granules will increase and the shape of the granule changes, hence viscosity changes. Viscosity of the flour paste was measured to study the effectiveness of the developed FIR gelatinizer. For measurement of viscosity a slurry of starch was made by adding 100 ml of water to 55 g rice flour. Then the slurry was transferred to a 500 ml beaker and placed in a water bath at 30 °C to maintain the constant temperature throughout the measurement. Temperature was recorded after reaching the equilibrium. Viscometer (Tokimac, BL) with Spindle (No 2) was used to measure the viscosity in triplicates.

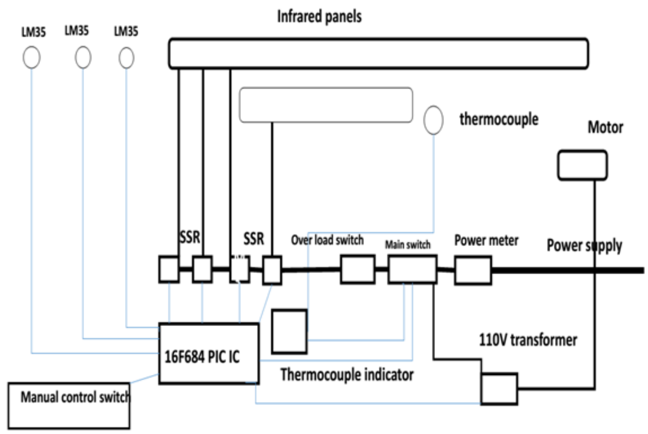


Figure 5: Diagram of the main controlling system

III. RESULTS AND DISCUSSION

The designed and fabricated rice flour gelatinizer was tested for its performance. The temperature variations of flour and the machine, the moisture content of flour and viscosity of flour were measured for evaluation of the machine. The Figure 6 shows the rice flour temperature variation at the flour input and the output.The auger does not rotate until inside surface temperature reaches 60 ^{0}C. That was the reason for having starting temperature of rice flour at 60 ^{0}C. The temperature of the flour coming out from the mill was at 50^{o}C and gradually increased to 75^{0}C. After passing through the FIR gelatinizer,the flour temperature reached 80 to 85 ^{0}C. It took 170 min to reach to this temperature and by changing the feeding rate of grains to the mill the flour output temperature increased up to 80 ^{0}C and the gelatinizer flour output temperature reached 95 ^{0}C.

The machine' inner surface temperture reached 100 ^{0}C after 150 min of operation and heaters automatically switched OFF (Figure 7 (a)). Machine's outer surface temperature variation was measured at three places on the outer surface. The Figure 7(b) shows the variation of outer surface temperature.T1 and T3 values varied in the range of 60 to 65 ^{0}C. T2 value vary around 75 ^{0}C.

The moisture content of raw rice was 14.2%wb. The input rice flour to the gelatinizer contained 12.1%wb moisture. It was 11.3%wb once flour was gelatinized and the moisture content of rice flour after sieving was 10.1%wb. According to results 0.24 L moisture removed in one hour from 300 kg of rice flour. The amount of heat loss to the environment was 0.91488 kW within one hour.

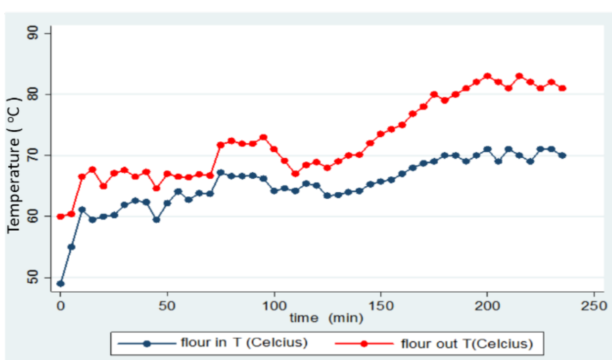
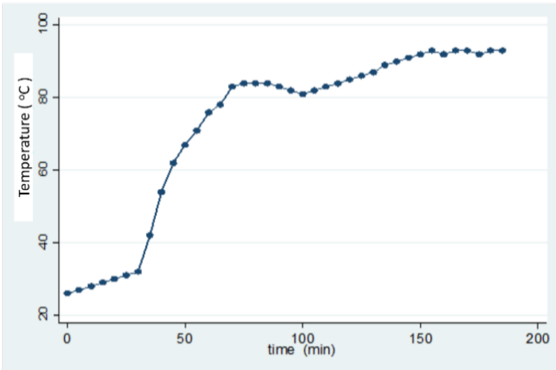


Figure 6: Rice flour temperature variation at the flour input and output of the FIR gelatinizer



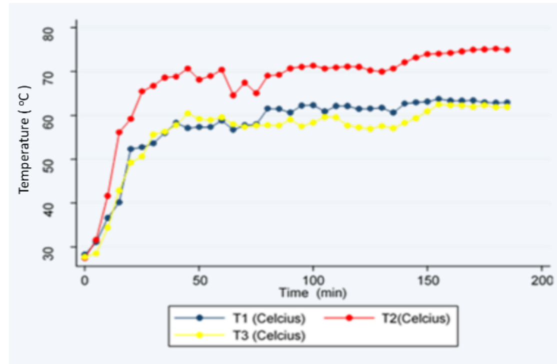


Figure 7 (a): Machine inner surface temperature variationFigure 7 (b): Machine outer surface temperature variations

IV. CONCLUSION

Based on the results, the flour temperature was maintained between 80 to 85 °C and at the same time the inner surface temperature of the FIR roaster was maintained at 100 °C. The outer surface temperature of the FIR gelatinizer was 66 °C. Flow rate of the rice flour through the roaster was 300 kg/h. Viscosity of the flour roasted in the FIR roaster was 350Mpa/s. Moisture content of the flour at the output of the machine was 11.3 % wb. Power consumption of the machine was 4.8 kW/h. Convection heat loss of the FIR roaster to the environment was 0.915 kW/h. According the results the developed FIR rice flour roaster can be introduced to the industry.

REFERENCES

[1] J. R. Richard, M. A. Asaoka and J. M. Blanshard, The physic-chemical properties of cassava starch,*Tropical Science*, 1991, 28(29): 69-90.

[2] M.Schirmer, M. Jekle and T. Becker, Starch gelatinization and its complexity for analysis. *Starch/Staerke*, 2015, 67(1-2), 30-41.

[3] G. Abhiram, K.S.P. Amaratunga, D.D.K. Galahitiyawa and K.G.W.U. Karunasinhe. Colour development and changes of the gelatinization percentage of rice flour gelatinizes by far-infrared radiation, Peradeniya University Research Sessions, Sri Lanka, 2012, 17:88

[4] I.Das and S.Bal, Drying kinetics of high moisture paddy undergoing vibrated-assisted infrared drying, *Journal of Food Engineering*, 2009, 95: 166-171.

[5] N.Shakai and T. Hanzawa, Applications and advances in far-infrared heating in Japan, *Trends in Food Science and Technology*, 1994, 5: 357-362.

[6] B. J. Lloyd, B. E. Farkas and K. M. Keener, Characterization of radiant emitters used in food processing, *Journal of Microwave Power and Electromagnetic Energy*, 2003, 38: 213.

[7] R. Ranjan, J. Irudayaraj and S. Jun, Simulation of three-dimensional infrared drying using a set of three coupled equations by the contro volume method, *Transactions of ASAE*, 2002, 45(5): 1661-1668.

[8] G.P. Sharma, R.C. Verma and P.B. Pathare. Thin-layer infrared radiation drying of onion slices. *Journal of Food Engineering*, 2005, 67:361–6.

[9] N.Staack, L. Ahrne, E. Borch and D. Knorr. Effect of infrared heating on quality and microbial decontamination in paprika powder. *Journal of Food Engineering, 2008*, 86:17.

[10] K. Krishnamurthy, H..K. Khurana, S. Jun, J. Irudayarajand A. Demirci. Infrared heating in food processing: An overview. *Comprehensive Reviews in Food Science and Food Safety, 2008, 7*: 2-13.

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