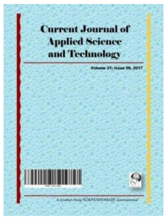

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Development of Ohmic Heating Model for Parboiling of *Oryza sativa* L.

Aaradhana Patel[1*] and Mohan Singh[1]

[1]*Department of Post Harvest Process and Food Engineering, Jawaharlal Nehru Krishi Vishwa Vidyalaya, Jabalpur, Madhya Pradesh 482004, India.*

Authors' contributions

This work was carried out in collaboration between both authors. Author AP designed the study, performed the statistical analysis, wrote the protocol and wrote the first draft of the manuscript. Author MS managed the analyses of the study and managed the literature searches. Both authors read and approved the final manuscript.

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ABSTRACT

Ohmic heating is an alternative and fast technology for processing of food products, which takes its name from Ohm's law. The basic principle of this technique is the conversion of electrical energy into heat, resulting in internal heat generation within the food products e.g. - Paddy. The aim of the study is to develop an ohmic heating model for parboiling of paddy. In this study the voltage is applied directly to the end of both electrodes from an electrical source which causes internal energy generation into the food material, like- paddy. This technology has a wide range of applications in the area of food processing. In the present study, a laboratory scale ohmic heater was developed for the parboiling of paddy.

Keywords: Ohmic heating; electrode; paddy; parboiling; electrical conductivity.

1. INTRODUCTION

Paddy (*Oryza sativa L.*) is an important food crop of India and second most important crop of the world. In India, rice processing is the oldest and the largest agro-processing industry. At present it has a turnover of more than Rs. 36,500 crores per annum. India processes about 85 million

**Corresponding author: Email: aradhana1910@gmail.com;*

tonnes of paddy per year and provides staple food grain and other valuable products required by the population. Recently, more than 50% of the overall rice production is processed by modern mills, 40% by conventional mills, and the remaining 10% by hand pounding. Cost of production is an important variable that influences the profits, which are also an indicator of management efficiency. Over years in country, many rice processing units have to be closed down. The main reason for closure is higher costs and lower net returns. The modern mills are operated by adopting new technology and the recovery percent of head rice is more compared to the conventional units. In the case of conventional milling units, the age-old technology has resulted in higher percentage of broken, which yield less return [1].

Pregelatinized rice (also called converted rice) is the rice made from milling of partially boiled paddy. Paddy parboiling process is an old practice. The three basic steps of parboiling are soaking, steaming and drying. This technique yields easy milling as well as reduced breakage during milling. The processes involve soaking the paddy in hot water usually at around 70˚C for 10 to 24 hours in order to saturate the paddy with moisture. The soaked paddy is then steam heated till they are gelatinized. They are then dried and milled [2].

Starch gelatinization is a process of breaking down the intermolecular bonds of starch molecules in the presence of water and heat, allowing the hydrogen bonding sites (the hydroxyl hydrogen and oxygen) to engage more water. This irreversibly dissolves the starch granule in water. Water acts as a plasticizer. Three main processes happen to the starch granule: granule swelling, crystal or double helical melting, and amylose leaching [3].

The gelatinization temperature of starch depends upon plant type and the amount of water present, pH, types and concentration of salt, sugar, fat and protein in the recipe, as well as starch derivatization technology are used. Some types of unmodified native starches start swelling at 55°C other types at 85°C [3].

Pregelatinized starch is starch which has been cooked and then dried in the starch factory on a drum dryer or in an extruder making the starch cold-water-soluble. Spray dryers are used to obtain dry starch sugars and low viscous pre-gelatinized starch powder [3].

The parboiling imparts hardness to the grain because gelatinization of starch-filled up the cracks and fissures. The degree of gelatinization can be estimated by determining equilibrium moisture content at saturation, sedimentation test, alkali dispersion test and water uptake ratio. Steam is used to complete the gelatinization process as it does not remove moisture from the paddy rather it adds moisture by condensation. During steaming the spread of water-soluble substances inside the paddy grain which is begun during soaking is continued and increased; the granular texture of endosperm becomes pasty due to gelatinization; any crack in caryopsis is sealed; the endosperm becomes compact and translucent; most of the biological processes are completely annihilated and the enzymes are also inactivated [4].

Khadi & Village Industries Commission, project profile for raw & parboiled rice mill gives the information about investment on plant and machinery for raw rice in the milling section 57 lakhs and excuse duty & other taxes is 9 lakhs; total investment on raw rice project is 66 lakhs, and for parboiled rice project total investment is Rs.120 lakhs which include 54 lakhs in milling section, 33 lakhs in steam plant, 17 lakhs in steam boiler and 16 lakhs in excuse duty & other taxes [5].

In the traditional parboiling plant, heating of soaked paddy is carried out in parboiling tank by direct injection of steam generated in the steam boiler which is fitted outside the rice mill in utility section. Boiler unit consists of boiler, fuel tank, water tank, water supply, insulated piping from boiler up to parboiling tank [5]. The entire boiler unit needs separate care and for this purpose, a certified boiler operator with helper needs to be maintained and paid throughout the year, which adds to the processing cost of parboiling rice. If this heating system may be changed from traditional steam heating with the ohmic heating system, then it will be possible to simply attach two electrodes on the two opposite faces of parboiling tank which will help in resistance/ohmic heating of entire mass of paddy soaked in water housed inside the parboiling tank. The desired temperature can be generated in desired time by applying the recommended voltage for the given distance between two electrodes [6].

In 1827, Georg Ohm, was the first to outline which is known as Ohm's law but recognition of the thermal effects of electricity within a conductor was the first elucidated by James Prescott Joule in 1840. The technology was once again revived in the 1980 and some industrial applications have resulted, including pasteurization of liquid eggs and processing of fruit products, among others. The ohmic heating concept was used in the early 20th century where electric pasteurization of milk and other food materials were achieved by pumping the fluid between plates with a voltage difference between them [7].

Ohmic heating is a resistance heating technique for liquids and pumpable particles [8]. It consists of equipment for passing alternative current through the fluid between electrodes. Ohmic heating is used in a wide range of applications such as pasteurization, sterilization, preheating, blanching [9].

This is one of the excellent alternative methods of heating, this technique shows much promise especially in food industry over the last few decades because there is an increasing shift from batch thermal operation towards continuous high temperature and short time processing of foods [10].

This technique involves several advantages like heating of food material by internal heat generation without the limitation of conventional heat transfer and some of the non-uniformity commonly associated with microwave heating due to limited dielectric penetration. Heating takes place volumetrically and the product does not experience a large temperature gradient within itself as it heats. Higher temperature in particulates than liquid can be achieved which is impossible for conventional heating, reducing risks of fouling on heat transfer surface and burning of food product, resulting in minimal mechanical damage and better nutrient and vitamin retention [11]. It has high energy efficiency because 90% of electrical energy is converted into heat.

The method optimizes capital investment and product safety as a result of high solids loading capacity. Its process control is fairly easy due to instant switch-on and shut down. Since it does not contain moving parts, the maintenance cost is low. The system can be stored and distributed in ambient temperature when confined with an aseptic filling system. It does not create any noise and is environment friendly [12]. Similarly, ohmic heating was found to be more efficient for the required microbial and pectin esterase inactivation due to a shorter residence time while released flavour compounds were not degraded as quickly as during conventional pasteurization [13].

1.1 Principle

An ohmic heater is an electrical heating device that uses a liquid's own electrical resistance to generate the heat. Ohmic heating works on the principle of Ohm's law of electricity. The passage of electric current through an electricity conductive food material obeys Ohm's law and heat is generated due to electrical resistance of food [14].

$$V \propto I$$
$$V = IR \tag{1}$$

Where,

V = Voltage (volt),
I = Current (ampere),
R = Resistance (Ohm).

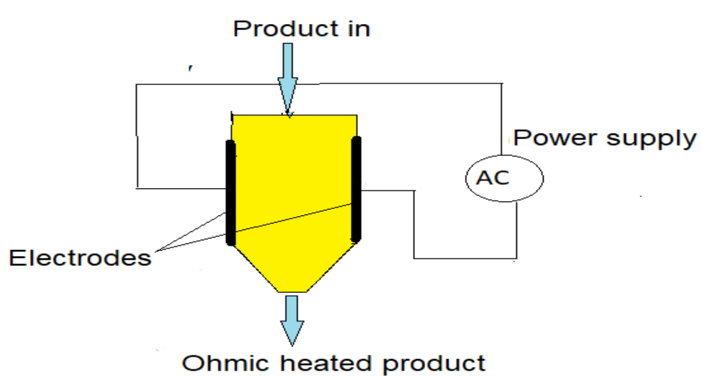

Fig. 1. The principle of ohmic heating

2. MATERIALS AND METHODS

2.1 Development of Ohmic Heating Model and Location of Work

To development of an ohmic heating model for parboiling of paddy with the help of ohmic heating setup. The following factors which are used to develop an ohmic heating model for parboiling of paddy. The experiment is carried out in post harvest process and food engineering laboratory of department of post harvest process and food engineering, college of agricultural engineering, JNKVV, Jabalpur (M.P.). The following parameters for designing of the model are given as below:

2.1.1 Chamber of ohmic heater

The selection of suitable material for an ohmic heating chamber is most important for efficient heating and also for purpose of safety during the operation of ohmic heater. The constructive material of ohmic heating chamber should be fully insulated, it should able to withstand higher temperature, it should be chemically inert and it should not affect the quality of the material, it should be light in weight and easily available in the market at reasonable cost [15]. On the basis of these factors ohmic heating chamber can be constructed by perspex sheet, CPVC pipe, PVC end cap, electrodes and plywood etc. Considering all the important factors CPVC pipe of 18.2 cm length, 4.35 cm diameter and 10.5 mm thickness has been selected for construction of the ohmic heating chamber. The cylindrical ohmic heating chamber has advantage of minimum heat loss than square and rectangular chamber and it also avoid the leakage of water from the cylinder in the absence of any joints or fitting in the chamber. The size of ohmic heating chamber will be decided on the basis of volume and density of the paddy and water. The sample of paddy and water were mixing of 100 gm paddy with the sufficient amount of water (1:1.6 as per recommendation of experimental design) and used for investigate the capacity of an ohmic heating chamber.

2.1.2 Temperature controller and sensor

LOS made digital temperature controller with copper probe was used to monitor the temperature inside the heating chamber. The copper coted (PT-100) I type temperature sensor can sense the temperature of 0-800°C is placed at the center of the heating chamber to control the temperature during ohmic heating [16].

Fig. 2. Ohmic heating chamber for paddy

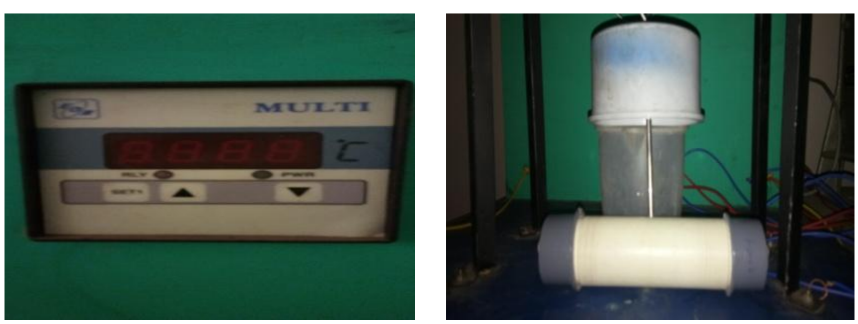

Fig. 3. Temperature controller and sensor for ohmic heating system

2.1.3 Electrode

The selection of electrode is most important factor for designing of an ohmic heating system for processing of food products. There are many types of conductive materials are available in the market such as titanium, stainless steel, aluminium and graphite, the selection of the conductive material on the basis of price and accuracy. The availability and correction resistance which may affect the efficiency of an ohmic heater [17]. The electrode should be good grade, non-corosive, chemically inert and should provide smooth finish [18]. Considering these factors stainless steel (SS), rod with 14mm diameter and 75mm length was selected as electrode material because of its accuracy and suitability are good for food products. The distance between two electrodes has been kept as 9cm to pass maximum voltage gradient of 25.23 V/cm from Indian domestic supply of 227V.

Fig. 4. Electrode using in ohmic heating model for parboiling of paddy

2.1.4 Multi-function meter

The multi-function meter was used in ohmic heating system for monitoring the input voltage, ampere and frequency (Hz.) of the current and it is directly connected to the main source of the current and display all readings time to time during the processing of material. It is placed on the right side of the ohmic heating system.

2.1.5 Power supply

The single phase power supply from alternating current (AC) mains (230 V, 50 Hz) was used in the experimental set-up. A constant voltage stabilizer is used before the autotransformer to control voltage functions. The electrical variables were recorded using digital multi-function meter (ampere, voltage and frequency). Important parameters in the designing of the power supply system were personal safety and equipment safety to avoid accidents during ohmic heating.

Fig. 5. Multi-function meter for ohmic heating system

2.1.6 Wooden platform, box and stand

The wooden platform of ohmic heating system having 61 cm width and 61 cm length for supporting the whole ohmic heating system or also for supporting of metal stand having 26 cm height including with 10 cm clamp for holding the heating chamber of ohmic heating system, and the hollow wooden box was used in ohmic heating system for holding the multi-function meter or temperature controller. The geometrically information of the wooden box, it's have 61 cm width, 61 cm height and 14 cm thickness of this box.

2.2 Determination of Heating Characteristics

There are some important heating characteristics like heating power, heating rate, electrical conductivity and energy efficiency that must be continuously monitored and determined during the ohmic heating process for parboiling of paddy, that are given as below.

2.2.1 Heating power (P)

The energy (P) given to the ohmic heater at a given temperature can be calculated by using the current (I) and voltage (V) values during heating time (Δt). It can be calculated by equation given below [19].

$$P = \Sigma VI\Delta t \quad (2)$$

Where,
P is the heating power (Energy)
V is Voltage

I is Current
Δt is Heating time.

2.2.2 Heating rate (Q)

Electrical current passed through the material to be heated can cause generation of sensible heat in to the material, due to which the temperature of the material can rise from initial temperature (Ti) to final temperature (Tf). Therefore, the amount of heat given to the system can be calculated from the following equation [20].

$$Q = m\ Cp\ (Tf - Ti) \quad (3)$$

Where,

Q is Heating rate
Ti is initial temperature
Tf is final temperature.

2.2.3 Electrical conductivity

It is quantity of electrical energy transferred through a unit area, per unit potential gradient and per unit time. The electrical conductivities of samples were calculated from the voltage and current data using the following equation,

$$\sigma = L / A \times I / V \quad (4)$$

Where,

σ is the electrical conductivity (S/cm)
L is the distance between electrodes (cm)
A is the area (cm^2)
I is an alternating current passing through the sample (Amp)
V is the voltage across the sample (V)

Electrical conductivity is an important parameter for ohmic treatment of food products. Rate of ohmic heating depends on the electrical conductivity of the food products during process [21].

2.2.4 Energy efficiency (∈)

Energy efficiency is used to evaluate the performance of an ohmic heating system. It is defined as the ratio of total energy utilized to heat the sample to total input energy and it can be calculated by following equation [22].

$$\text{Energy efficiency} = \frac{\text{Energy utilized to heat the sample}}{Total\ input\ energy}$$

$$\in = m\ Co\ (Tf-Ti) / \Sigma VI\Delta t \quad (5)$$

3. RESULTS AND DISCUSSION

Ohmic heating technology is the most important technology for the research purpose, professionalism and widely used for food processing industries because of its advantages over conventional heating technology. Researchers and food processing industries found superior quality product with minimal nutritional or quality degradation after using the ohmic heating technology. Its allow uniform and fast heating, simple process and designing of ohmic heater is also relatively a simple task. For the development of an ohmic heating device was done by using conductive material like electrode which was made by stainless steel and the electrodes are directly contact with the food material, e.g. Paddy, and CPVC pipe for the ohmic heating chamber are shown in Fig. 6. The volume of the ohmic heating chamber was decided on the basis of volume of paddy and water fed to the heating chamber.

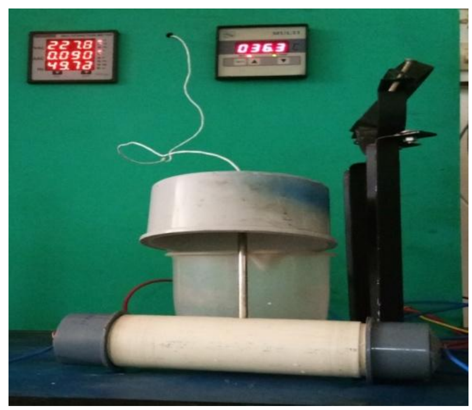

Fig. 6. Ohmic heating setup for parboiling of paddy

3.1 Volume of Cylinder

The cylinder was used in ohmic heating system in the form of an ohmic heating chamber for parboiling of paddy by ohmic heating. The volume of the cylinder can be measured by the given formula.

$$\text{Volume of Cylinder} = \pi r^2 h \quad (6)$$

Where,

r = Radius of the cylinder
h = Height of the cylinder.
π = 22/7 (3.14).

Table 1. Relationship between time, voltage, temperature and frequency

Sr. no.	Time (Min)	Voltage (V)	Temperature (°C)	Frequency (Hz)
1.	0	227	32.3	49.97
2.	5	226	42.2	49.97
3.	10	226	49	49.97
4.	15	226	57	49.97
5.	20	227	67	49.97
6.	25	229	77	50
7.	30	229	87	49.97
8.	35	228	93	49.97
9.	40	226	96.7	49.97

For measuring of the volume of an ohmic heating chamber, some geometric data are available for calculating the volume, height of the pipe is 18.2cm and the diameter of the pipe is 4.35 cm.

Volume of the cylinder (V) = $\pi r^2 h$

V= $3.14x(2.175)^2x18.2$
V = 270.35cm^3

3.2 Capacity of the Heating Chamber

Capacity of an ohmic heating system refers to the weight of sample (paddy and water) fed into the chamber per unit time. The heating chamber with cylindrical geometry was finalized to construct in order to avoid leakage of paddy and water from the system. Following parameter were recorded and used to construct the ohmic heating chamber;

Weight of the paddy taken = 100 g
Paddy and water ratio = 1:1.6
Volume of chamber = 270.35 cm^3
Weight of total sample = 260 g
Time taken = 18 min

$$Capacity = \frac{\text{weight of the sample}}{Time\ taken} kg/hr \quad (7)$$

$$= \frac{(260x60)}{(18x1000)} = 0.86 \text{ kg/hr}$$

The capacity of ohmic heating chamber as tested for parboiling of paddy as found to be 0.86 kg/hr.

Experimental data are showing in the Table 1. First taking 100 g paddy and soaked in the water for three hours and then soaked paddy is filled in ohmic heating chamber for gelatinization process, bubbling is done at 81°C to 85°C and ohmic heating treatment is given for 40 min to soaked paddy and after this drain out the water from the ohmic heating system and parboiled paddy is kept for drying process till 14% m.c. (wet basis).

4. CONCLUSION

The designed laboratory model of ohmic heating showed excellent performance during parboiling of paddy. In this system the paddy was heated from 32.3°C to 96.7°C in 40 min a voltage gradient of 25.23 V/cm. bubbling is shown at 81°C to 85°C. The heating was uniform for all purposes. Boiling and soaking of paddy during ohmic heating should be given serious attention. The ohmic heating is a fast growing technology in the food process industries. It allows for the best quality production in the food industries.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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