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Tankesh Kumar
Department of Processing and Food Engineering, College of Agricultural Engineering, Acharya N. G. Ranga Agricultural University, Andhra Pradesh, India

Corresponding Author:
Tankesh Kumar
Department of Processing and Food Engineering, College of Agricultural Engineering, Acharya N. G. Ranga Agricultural University, Andhra Pradesh, India

Development of a laboratory scale ohmic heating system for pasteurization of grape juice

Tankesh Kumar

Abstract
The aims of this study were to develop a laboratory scale ohmic heating system for pasteurization of grape juice and to evaluate the effects of ohmic heating on the microbiological quality of the juice. The system was mainly composed of a cylindrical heating chamber (borosil glass), two electrodes (SS 304), and a variable auto transformer. It was equipped with an analog voltmeter and ammeter for measurement of voltage and current, respectively. A mercury thermometer was used to measure the temperature of the juice. The capacity of the system was 150 mL. The juice was pasteurized at different combinations of voltage gradient (10-40 V cm-1), temperature (55-85 °C) and holding time (1-5 min). Total plate count, yeast and mould count and system performance for grape juice were determined. The microbial counts of grape juice significantly decreased ($p < 0.05$) when the voltage gradient, temperature and holding time were increased. The higher electric field strength results in a greater reduction of pathogens. The microbial counts of the juice treated with the combination of 30 V cm-1:85 °C:5 min were below the recommended limit till 21 days of storage. As the voltage gradient increased, the system performance decreased. The system performance coefficients for grape juice samples were in the range of 0.57-0.99. Bubbling was observed above 75 °C especially at high voltage gradients. These results suggest that ohmic heating might be effectively and efficiently used to pasteurize fruit juices.

Keywords: Ohmic heating, grape juice, pasteurization, total plate count, yeast and mould count, system performance coefficient

Introduction
Nowadays, processed fruit juices are widely included in breakfast and snack by health-conscious people and foodies which have boosted the growth of fruit juice industry. The demand of processed fruit juices is rising day by day as these are healthier alternative, time saving and distinct in sensory characteristics. Grape juice is one of the top fruit juice in the consumer’s preference due to its exceptional juiciness, vibrant flavour and colour. It is blessed with a bundle of nutritional and medicinal properties. Grape juice is packed with lots of vitamins and minerals like vitamin B1, vitamin B2, vitamin K, potassium, copper and dietary fibres (Rolle *et al*., 2011) [10]. Grape juice exhibits anti-inflammatory, anti-microbial and anti-aging effects and protects against diabetes, heart disease and cancer (Chuang and McIntosh, 2011; Dohadwala and Vita, 2009) [3, 4]. Some other positive health benefits of the consumption of grape juice, such as protection of low-density lipoprotein (LDL) against oxidation, decrease of native plasma protein oxidation, and reduction of platelet aggregation, have also been reported by researchers (Yadav *et al.*, 2009) [12]. The microbiological safety is a major concern of the fruit juice industry for protection of consumer’s health and life as well as for preservation and shelf life extension of the product. Although conventional pasteurization ensures the safety and prolonged shelf life of juice, it often leads to detrimental changes in the sensory qualities of the product. Conventional pasteurization of juices can trigger a series of undesirable reactions such as the destruction of vitamins, the reaction between sugars and amino acids (Maillard reaction), the destruction of pigments (carotenoids) and the formation of toxic products (Braddock, 1999) [2]. The conventional heating techniques for liquids rely on heat transfer from a hot surface. This can cause fouling of the surfaces for certain products.

Ohmic heating is a process of heating the food by passing electric current through food which resists the flow of electricity. Ohmic heating takes its name from Ohm’s law. When an alternating current passes through the food placed between two electrodes, the food is heated by internal heat generation. Most foods contain high levels of water and dissolved salts and these solutions can conduct electricity through electrolytic conduction. When electrolytes are placed in an electric field, the ions present within the electrolyte move towards the electrodes with opposite charges. The movement of ions in the electrolyte generates heat. Also the moving ions within it collide to each other, which in turn increase their kinetic energy, thereby heating the product. Heat is dissipated directly into the fluid itself by Joule heating. The amount of heat is directly related to the current flow caused by the voltage gradients in the food and the electrical conductivity of the food material (Sastry and Li, 1996) [11]. This technology provides a rapid and uniform heating and lesser thermal abuse to the product in comparison with conventional heating (Leizerson and Shimoni 2005) [9]. By considering the above facts, the study was thus conducted with the objectives to develop a laboratory scale ohmic heating system for pasteurization of grape juice and to evaluate the effect of ohmic heating on microbiological quality of the juice.

2. Materials and Methods
2.1 Development of Ohmic Heating System
The laboratory scale ohmic heating system was developed at College of Food Science and Technology, Bapatla as per the schematic diagram shown in Figure 1. The main components of ohmic heating sytem are - heating chamber, electrodes, power supply and data acquisition system.

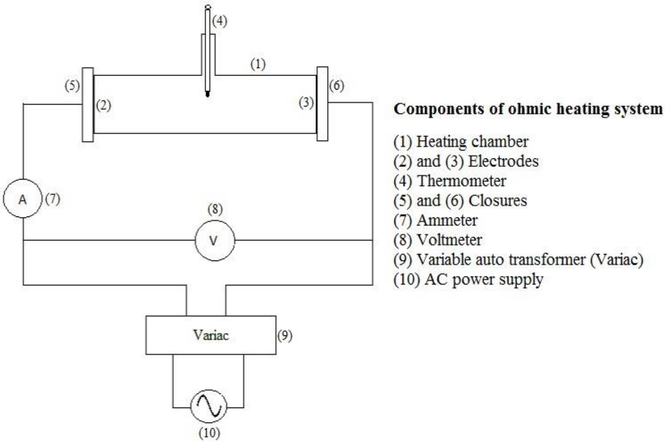

Fig 1: Schematic diagram of ohmic heating system

2.1.1 Ohmic heating chamber
In this study, the cylindrical borosil glass of dimension 0.045 m × 0.15 m (internal diameter × length) was procured from M/s Delta Scientific Company, Vijayawada. The effective length the chamber was 0.1 m. One vertical tubular passage of 0.01 m × 0.03 m was provided at the center of the chamber to facilitate the removal of water vapour and to hold a thermometer. The capacity of the heating chamber was calculated as follows:

$$\text{Capacity of heating chamber } (m^3) = \frac{\pi \times Dc^2 \times l}{4}$$

where
Dc^2 = Internal diameter of heating chamber, m
l = Length of heating chamber filled with sample, m

2.1.2 Electrodes
Two small discs made of food grade stainless steel (SS 304) were used as electrode. Diameter and thickness of the electrodes were 0.044 m and 0.002 m, respectively. Electrodes were fixed to the closures of the chamber using screws and nuts at a distance of 0.1 m.

2.1.3 Power Supply and variable auto transformer
The single phase alternating current from the domestic supply (220 V, 50 Hz) was used as the source of power. A variable auto transformer (Sun Electrical Industries, Thane) of capacity (input-220 V, output-400 V) was connected to the ohmic heating system for obtaining desired voltage gradient between the electrodes.

2.1.4 Data acquisition system
The changes in temperature of the juice during the process were measured by mercury thermometer. An analog ammeter (Meco Instruments, India) ranging 0-15 amp and analog voltmeter (KEC, India) ranging 0-500 V were used to measure the current and voltage, respectively.

2.1.5 Holder
To hold the heating chamber safely and to make it easier to move during the operation, a holder was made from seasoned wood in the workshop (College of Agricultural Engineering, Bapatla). The holder was provided with a base (0.2 × 0.1 × 0.05 m3) and two legs (0.1 × 0.07 × 0.02 m3 each). The legs were cut in semi-circular shape of diameter
0.47 at the top-center.

2.2 Sample preparation
Grapes (*Vitis vinifera* L.) were purchased from a local market in Bapatla, Andhra Pradesh (India) and stored at refrigeration conditions (4 °C) prior to experiments. Berries were manually removed from bunches, washed in tap water and drained. The juice was extracted from grape berries using Sujata Powermatic juicer (Mittal Electronics, Delhi) and filtered with four-fold of clean muslin cloth.

2.3 Pasteurization process
Grape juice was treated using different combinations of voltage gradient (10, 20, 30 and 40 V cm-1), temperature (55, 65, 75 and 85 °C) and holding time (1, 3 and 5 min). 150 mL samples of filtered juice were taken in the heating chamber and heated by alternating current using described combinations (Figure 2). Then the juices were transferred into the sterilized glass bottles and cooled immediately at 10 °C temperature. All the pasteurized juice samples were stored at refrigerated temperature (4 ºC) for 21 days and their microbiological properties were evaluated at an interval of 7 days.

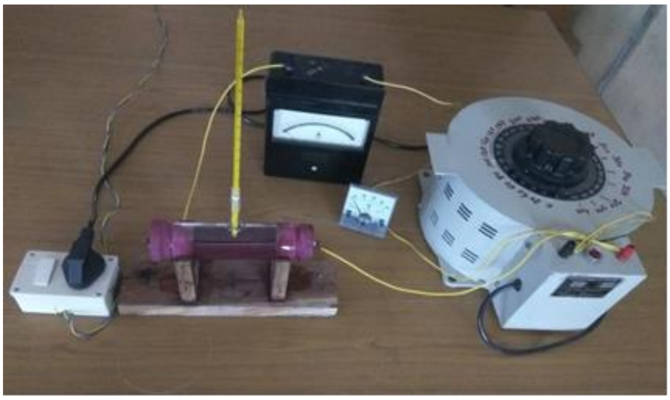

Fig 2: Pasteurization of grape juice by ohmic heating

2.4 Determination of Microbiological Properties
The enumeration of total plate count and yeast-mould count in grape juice were carried out by spread plate method and serial dilution technique (AOAC, 2005) [1]. For determination of total plate count, the media was prepared with plate count agar and the bacterial plates were incubated for 2 days at 37 °C. Yeast and mould count was determined using potato

dextrose agar. The yeast and mould plates were incubated for 5 days at 25 °C. The number of colonies was counted with digital colony counter and the surviving population was determined in terms of cfu mL-1 using following formula,

2.5 Statistical Analysis
The effect of voltage gradient, temperature and holding time on microbial counts were statistically analyzed by analysis of variance (ANOVA) using Statistical Package for Social Sciences (SPSS) version SPSS 16.0 software. The confidence level used to determine statistical significance was 95%.

2.6 System Performance Coefficient
System performance coefficient (SPC) of ohmic heating system was defined as the ratio of net energy utilized to heat the sample to total input energy. SPC was calculated as follows (Icier and Ilicali, 2005b) [7],

$$SPC = \frac{Q_t}{E_g}$$

$Q_t = m \times Cp\ (Tf - Ti)$

$C_p = 1.675 + 2.5Xw$

$E_g = V \times I \times t$

Where

Qt = Net energy used for heating by the ohmic heating system (J)

Eg = Total energy given to the ohmic heating system (J)

m = Weight of the juice (kg)

Cp = Specific heat of grape juice (kJ/kg-K)

Tf = Final temperature of sample (°C) *Ti* = Initial temperature of sample (°C) *Xw* = Moisture content of juice (%)

V = Applied voltage between electrodes (V)

I = Current flowing through the material (amp)

t = Time for which electrical power supplied to the system (s)

3. Results and Discussion
3.1 Effect of Ohmic Heating on Microbiological Quality of Grape Juice
Total plate count and Yeast and mould count in fresh grape juice were observed to be 3.1×103 cfu mL-1 and 0.83×103 cfu mL-1. It was noted that the microbial counts of grape juice significantly ($p< 0.05$) decreased when voltage gradient, temperature and holding time were increased (Figure 3-4). The higher electric field strength results in a greater reduction of pathogens. The electric breakdown or electroporation mechanism of cell membranes by electric current is the predominant non-thermal effect of ohmic heating (Kulshrestha and Sastry, 2003) [8]. The electroporation increases with increase in electric field leads to increase permeability of the cell wall (Yoon *et al*., 2002) [13]. The bubble formation was observed at 40 V cm-1 beyond 75 °C which might have resulted in a lower microbial destruction. It was found that microbial load in grape juice for all treatmen*1.1* significantly increased during storage period. The increase in total plate count could be possible due to presence of air at around headspace inside the bottle or contamination from the packaging material. On 21st day, total plate count and yeast and mould count of grape juice treated by 30 V cm-1:85 °C:5 min were much below the recommended levels i.e., <50 cfu mL-1 and <2 cfu mL-1, respectively (FSSAI, 2011) [5].

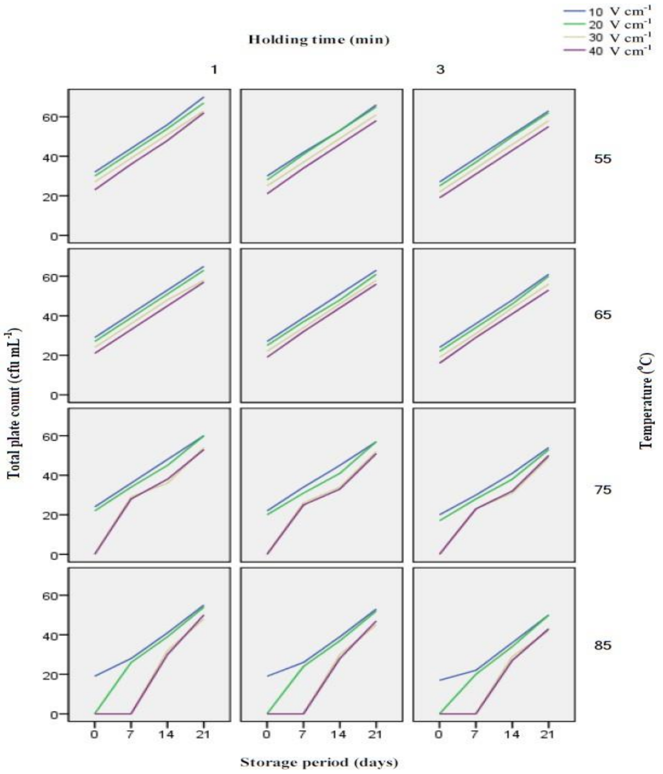

Fig 3: Effect of ohmic heating on total plate count of grape juice

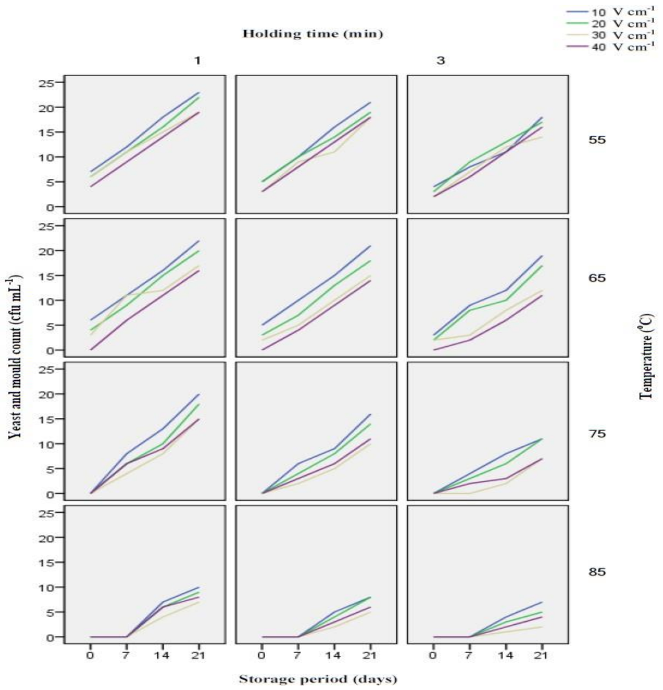

Fig 4: Effect of ohmic heating on yeast and mould count of grape juice

3.2 System Performance Coefficient (SPC)
The system performance coefficient (SPC) of developed ohmic heating system was obtained in the range of 0.57-0.99. The highest SPC was observed to be 0.99 at 10 V cm-1. At 30 V cm-1 with 85 ºC, SPC of the system was 0.73. The value of SPC was comparable with the reported values 0.54-0.92 for lemon juice (Darvish *et al*., 2011). It was observed that SPC decreased with increasing both voltage gradient and heating

temperature (Figure 5). A similar decrease in SPC was reported by Icier and Ilicali (2005a) [6] for orange juice. It may be attributed to higher energy loss at higher voltage gradient and higher temperature. Since the heating chamber was not sealed and adiabatic hence vapor evaporation and heat transfer to the outside environment resulted in a large amount of heat dissipation during the heating process. At voltage gradient of 40 V cm-1, formation of bubbles were observed, especially when the temperature of samples reached above 75 °C. It may be due to violent evaporation of water in the samples caused by the higher values of current passing through the system when voltage gradient was increased.

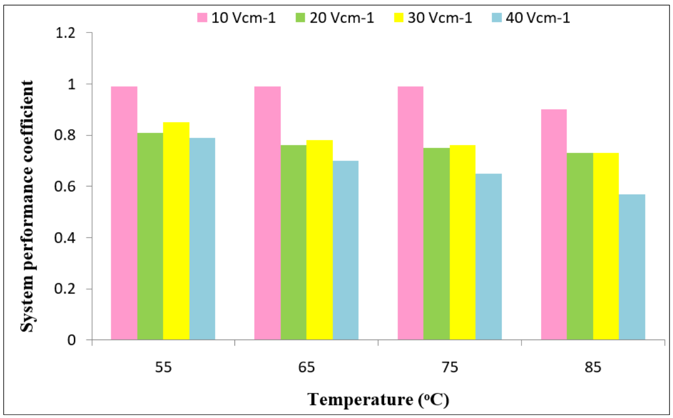

Fig 5: Changes in System performance coefficient of developed ohmic heating system with temperature at different voltage gradients

4. Conclusions

Voltage gradient of 30 V cm-1, tempearature 85 °C and the holding time of 5 min were optimized for the pasteurization of grape juice. Microbiological quality of the juice for this combination was better than the others after a storage period of 21 days. The system performance coefficients (SPC) for grape juice samples were in the range of 0.57-0.99. For effective pasteurization of grape juice, the most acceptable value of SPC was 0.73 which indicates that the system was well energy efficient too. In conclusion, it may be stated that ohmic heating could be considered as an effective alternative for the pasteurization of grape juice.

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