UNIVERSITI PUTRA MALAYSIA

DESIGN, CONSTRUCTION AND PERFORMANCE OF AN OHMIC FRUIT JUICE EVAPORATOR

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By

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A	The effective cross-sectional area of the conducting space between the metal conductors (electrodes), cm^2
C_p	Specific heat capacity, kJ/kg°C.
F	Feed mass flow rate kg/h.
h	Enthalpy, kJ/kg °C.
h_f	Enthalpy of the feed steam, kJ/kg°C.
h_p	Enthalpy of the product steam, kJ/kg°C.
I	Electric current, amperes.
I_1	Apparent current passing through set 1 of electrodes, amperes.
I_2	Apparent current passing through set 2 of electrodes, amperes.
I_3	Apparent current passing through set 3 of electrodes, amperes.
I_{av}	Average apparent current, amperes.
K	Temperature compensation constant.
K_1	Constant.
K_2	Constant
L	The distance between the inert metal electrodes at the end of the gab (the shortest distance between electrodes), cm.
l	The level inside the FJOE, cm.
l_{in}	Initial level of the fluid inside the FJOE, cm.
l_{in}	Final level of the fluid inside the FJOE, cm
m	Temperature coefficient (constant).
M_s	Mass flow rate of the equivalent steam, kg/h
P	Electric power consumption kJ/s..
P	Product mass flow rate, kg/h.
Q	Heat rate input to the FJOE, kJ/kg
Q_s	Equivalent steam energy, kJ/kg
R	Electric resistance, ohms.
T	Temperature, °C.
T_f	Feed stream temperature, °C.
T_p	Product stream temperature, °C.
T_{ref}	Reference temperature, °C.
u	Energy generation per unit volume.
v	Voltage, volts.
V	Evaporation rate, kg/h.
X_f	Mass fraction of the pineapple juice in the feed stream.
X_p	Mass fraction of the pineapple juice in the product stream.
∇v	Voltage gradient.
σ	Electrical conductivity (mS/cm).
σ_T	Electrical conductivity at any temperature T (mS/cm).
σ_{ref}	Electrical conductivity at reference temperature (mS/cm).
λ	Latent heat of vaporization, kJ/kg°C.
λ_s	Latent heat of vaporization of steam at boiling point, kJ/kg°C.
ρ	Electric resistivity of the metal electrode, $\mu\Omega$.cm

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Chairman: Ir Hishamuddin Bin Jamaludin

Faculty: Engineering

A fruit juice ohmic evaporator (FJOE) was designed and constructed. The design was done in accordance with the basic principle of ohmic heating to provide heat for evaporation instead of steam or conventional direct heating, to overcome problems arising through these methods of heating.

The FJOE was constructed mainly from stainless-steel. A cylinderical heating vessel of internal diameter 20.5 cm and length of 31 cm was constructed to enclose electrodes supplying the heat for evaporation. The heating vessel was coated internally with epoxy resin to isolate the wall of the vessel from electric current passing through the fluid. Three sets of electrodes connected to the three-phase alternating current supply were used. Each set of electrodes composed of a three parallel stainless-steel plates. A vacuum pump was used to lower the boiling point of the juice below 65 °C and as low as 45 °C to prevent the nutrient material from damage.

Salt-water solution and pineapple juice were used to study the performance of the FJOE. Three types of tests were done. Preliminary tests were conducted to ensure

that the FJOE operates within the design limits and to check for fluid and electric leakage. Performance of the FJOE was computed by testing the system in both batch and continuous operation using salt-water solution and pineapple juice.

Electric conductivity of the dilute pineapple juice was first measured to find the maximum allowable level of the juice inside the FJOE to prevent current overload or high temperatures during evaporations.

Four tests using salt-water solution, two of them in batch mode and two in a continuous mode were conducted. Another four test using pineapple juice of initial concentration of 10% were conducted to achieve a final concentration of 40%, two of them were batch tests and the others in continuous mode operation.

Results of all tests were tabulated and illustrated in graphs. Electric current and the total area of electrodes used was found to be the controlling factors during evaporation using the FJOE. Increasing the total contact area between electrodes and the fluid was found to increase the average apparent current and hence the power consumption.

Energy cost using the FJOE was found to be relatively cheap and of low cost and the evaporation economy was found to be 0.7. The FJOE was found to be a suitable evaporation equipment for concentrating fruit juices and other food materials in a small scale industries without any need of steam boilers and of low energy cost.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia
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REKABENTUK, PEMBINAAN DAN PRESTASI SEBUAH ALAT PENYEJAT JUS BUAH-BUAHAN OHMIC

Oleh

MOHAMED HASSAN MOHAMED GAILY

Julai 1999

Pengerusi: Ir. Hishamuddin Bin Jamaludin

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Penyejat Jus Buah-buahan Ohmic (PJBO) telah direkabentuk dan di bina. Rekabentuknya adalah mengikut prinsip asas pemanasan ohmic bagi penyejatan dengan tidak menggunakan stim atau pemanasan secara langsung untuk mengatasi masalah yang terdapat dengan kaedah tersebut.

PJBO dibina menggunakan “stainless-steel” sebagai komponen utama. Takungan silinder pemanas mempunyai ukuran jejari dalam 20.5 cm dan panjangnya ialah 31cm dimana diletakkan elektrod di dalamnya untuk membekalkan haba penyejatan. Takungan pemanasan disalut dibahagian dalamnya dengan “epoxy resin" sebagai penebat dinding takungan daripada arus elektrik yang melalui cecair. Tiga sel elektrod disambungkan kepada bekalan arus tiga fasa. Setiap sel elektrod mempunyai tiga plat “stainless-steel” selari. Pam hampagas telah digunakan untuk menurunkan titik didih jus kepada 65 °C dan tidak melebihi 45 °C untuk mengelakkan zat-zat makanan dimusnahkan.

Larutan garam dan jus nanas telah digunakan di dalam menentukan keupayaan PJBO. Tiga jenis ujian telah dijalankan. Ujian permulaan dilakukan untuk memastikan PJBO beroperasi didalam had rekabentuk dan untuk memastikan tiada kebocoran cecair dan arus. Keupayaan PJBO dikira secara ujian berkelompok dan berterusan dengan menggunakan larutan garam dan jus nanas.

Konduktiviti elektrik bagi jus nanas cair diukur untuk mendapatkan paras maksimum jus dalam PJBO bagi mengatasi arus berlebihan atau suhu yang tinggi ketika penyejatan.

Empat ujian menggunakan larutan air-garam, dimana dua daripadanya secara berkelompok dan selebihnya secara berterusan. Empat ujian menggunakan jus nanas dengan kepekatan 10% hinga mencapai 40% kepekatan telah juga dilakukan.

Keputusan dari ujian ini dijadualkan serta dipersembahkan dalam bentuk graf. Arus elektrik dan luas elektrod yang di gunakan ditentukan sebagai faktor yang mempengaruhi penyejatan oleh PJBO. Peningkatan luas permukaan antara elektrod dan bendalir di dapati meningkatkan kadar arus elektrik purata dan pengunaan kuasa.

Kos tenaga menggunakan PJBO didapati murah dan ekonomi stim ialah 0.7. PJBO didapati sebagai alat yang sesuai untuk memekatkan jus buah-buahan dan bahan makanan lain dalam industri kecil tanpa memerlukan dandang dengan kos tenaga yang rendah.

CHAPTER I

INTRODUCTION

Recently, there has been a widespread growth of interest and research activity in the heat processing, aseptic packing and processing of food products. Interest in rapid methods of heating and non-thermal microbial inactivation in the food industry has resulted in revived attention towards new technologies. One of these new technologies is ohmic heating.

Ohmic heating is an operation in which heat is internally generated within foods due to the passage of alternating electrical current.

Ohmic heating works because most foods contain ionic species such as salts and acids, which acts as electrolytes, thus an electric current can be made to pass through the food. The food is internally heated due to its electrical resistance, without involving any heating medium or heat transfer surface.

Concentration of Liquid Foods

Industrially concentration is achieved by evaporation of water to a certain level using particular type of evaporator depending on specification of the material under evaporation and its characteristics.

Any evaporator utilised for liquid food products will contain the following units:

a. A container.

b. A heat source

c. A condenser.

d. And a method of maintaining vacuum.

In most evaporators, the heating medium will be steam or some other condensing vapour. When using steam as a heating medium, the resistance to heat transfer is normally created by a condensate film on the heating-medium side of the heat transfer surface, so problems occurs with this type of heating. Fouling of heat transfer surfaces is one of these problems, which can be a major cause of declining efficiency in evaporation system. Another problem arises with proteinaceaus food that when exposed to hot heat transfer surface will result in some destruction of flavours and nutrients.

These heat-transfer problems can now be overcome by ohmic heating, which operates by the direct passage of electrical current through the continuous flow of food product.

The specialised designs of evaporator that have been developed since the open evaporating pan, have been based primarily upon the target of decreasing overall heat treatment i.e. the time-temperature combination, to which the product is exposed during the evaporation (Clark, 1971). The use of vacuum operation was an early step in this direction of reducing the level of heat treatment otherwise occurring.

Several methods of heating were applied to provide heat for evaporation such as direct heating, utilising waste or low-pressure steam and mechanical vapour compression.

Previous work on ohmic heating is limited, and researches were focused towards heating and pasteurisation and till now there is no published work on concentration of fluid foods by ohmic evaporation.

Objective of the Study

The concentration of fruit juices by conventional evaporation systems usually causes loss of volatile flavour substances. Other problems may arise with liquid foodstuffs, such as foaming, which makes it difficult to separate the vapours from condensed liquids, and the fouling of the heat transfer surface by already suspended or developed in solubilised matter. Thus recently, other methods of heating were established to overcome the above mentioned problems. These alternative methods include dielectric heating, microwave heating and ohmic heating.

Commercial concentration processes by evaporators require steam boilers to provide the required heat. However, for small-scale industries it will be uneconomical to use steam boilers. Hence it will be beneficial to apply an economical method(s) that overcomes all the above mentioned problems.

In Sudan and Malaysia the small and medium scale food industries are wide spread. They serve socio-economic objectives, and it will be advantageous for these industries if a technique for concentrating fruit juice that overcomes the stated problems. Thus there will be no need for steam boiler to be used by small and medium scale food industries and the concentration of the fruit juice by evaporation can be achieved by the heat generated from the passage of electric current through the juice. Recent researches on ohmic heating in food industry were conducted and further work is needed in this area and till now there is no published papers or work in application of ohmic heating in evaporation.

The main objectives of this study are:

1. To design and construct an ohmic fruit juice concentrator which operates from an alternating current source of 50-60 Hz i. e. from a public mains supply system.
2. To study the performance of the ohmic fruit juice concentrator by evaluating the following parameters:

- The concentration.
- The temperature.
- Change of electrical conductivity.
- Change of electric current during the process.
- Time needed to complete the process from initial concentration to the final concentration.
- Power consumption

3. To develop a control strategy for the system.

CHAPTER II

LITERATURE REVIEWS

The literature review was done and divided into the following aspects as a good guide for design, material selection and the method used in this project:

1. Concentration by evaporation.
2. The ohmic heating.
3. The pineapple juice.

Principles of Concentration by Evaporation

Water is the predominant ingredient in most food materials and exceeds 85% in milk and in fruit and vegetable juices. This water content can frequently be advantageously reduced, to lower container, storage and shipping costs, or to achieve other desirable results in food processing. The concentration of a solution (fruit juice) by boiling off solvents (water) is usually achieved by evaporation.

For liquid foods, evaporation is the most common method for reducing the water content. There is some application of fractional crystallisation to citrus juices, but for practical reasons, single and multiple effect vacuum pans with or without recovery devices are most widely used for reducing the water content of liquid foods.

Evaporation Equipment

Basically, evaporation is used to concentrate a solution consisting of non-volatile solute and a volatile solvent, without any attempt to fractionate the solvent. The more common types of evaporators are described briefly. Mehra, (1986) in his feature report discussed most types of evaporators and their uses, advantages and disadvantages. These types are:

Solar Evaporators

These evaporators consist of a series of large ponds, in which seawater or brine is concentrated, with solar energy as a heating source. This is followed by further evaporation in large, open natural basins or crystallising areas.

Batch-pan Evaporators

These were the first devices to use steam for indirect heat transfer to accomplish evaporation. Batch pan evaporation is one of the oldest methods of concentration. The batch pan can be jacketed vessel or one with internal coils. Heat transfer can be aided by agitation, though this may not always be possible. In most cases, large temperature difference cannot be used, as these may result in product degradation and increased fouling. Thus the capacity of this type of evaporator is low compared with other types, limiting its application.

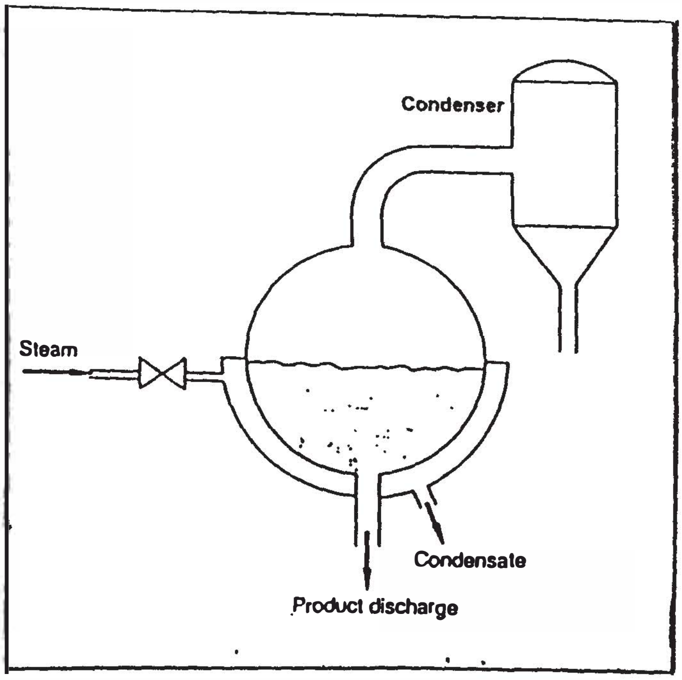

Figure 2.1: Batch-pan Evaporator

Natural- circulation Evaporators

Natural-circulation units offer a moderate range of operation and are not recommended for services where wide load fluctuations are expected. They may be operated as once-through or re-circulating units. In once-through service all evaporation is accomplished in a single pass. These units are specially useful in handling heat-sensitive materials, due to their short residence times. In re-circulating units the liquor entering the heat -transfer surfaces is at a higher concentration than the feed, its density viscosity and boiling point are high. Accordingly heat transfer coefficients tend to be low. The advantages of these evaporators are that they can be operated over a wide range of concentrations and loads and are well suited for single-effect evaporation.

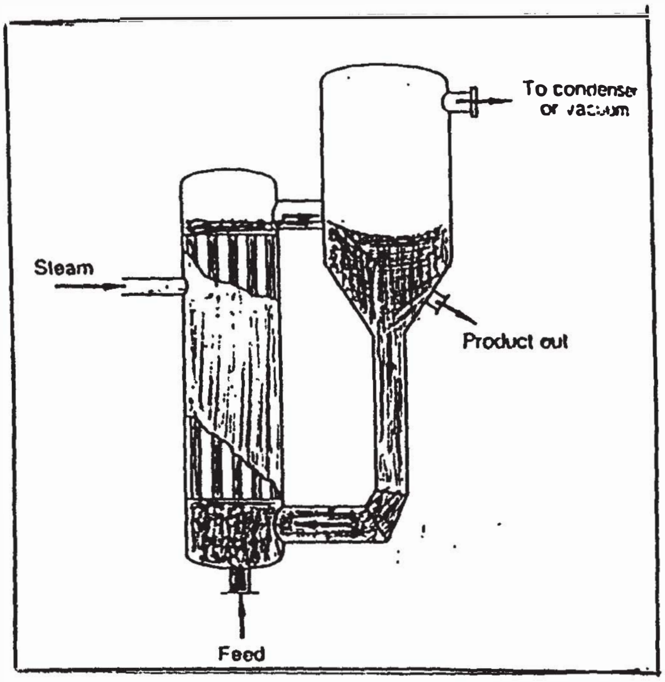

Figure 2.2: Natural-circulation Evaporator

There are several types of natural-circulation evaporators:

Short-tube Vertical Evaporators

These evaporator can be used with scaling liquids, since evaporation takes place inside the tubes, which are accessible for cleaning, but it have a disadvantage that a large area is required since the units are squat. Heat-transfer coefficients are sensitive to temperature difference and liquor viscosity, and due to large liquid hold-up, these evaporators cannot be used with heat-sensitive materials.

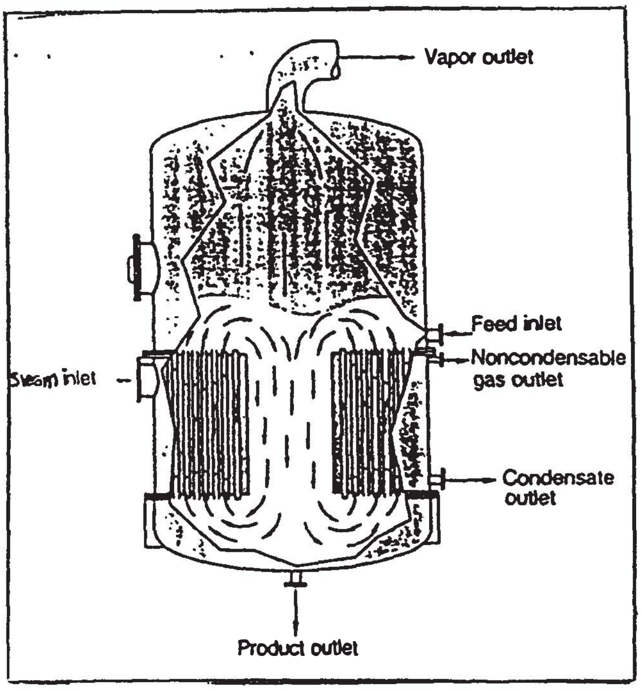

Figure 2.3: Short tube vertical Evaporator

Basket-type Evaporators

These are similar to calandria-type unit except that the tube bundle is removable, allowing easy cleaning and maintenance. Also due to construction, differential thermal expansion is not a problem.