A THERMODYNAMIC ANALYSIS OF JUICE PASTEURIZATION PROCESS

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Abstract: *A superior fruit or vegetable juice should be healthy and nutritious, in this purpose being heated and treated. Exergy analysis is a tool able to indicate whether or not and how it is possible to design more efficient energy systems by diminishing the inefficiencies existing in the analyzed systems. This analysis is considering the quantity and quality of the energy. Exergy efficiency evaluates the efficiency of a process by considering the second law of thermodynamics. Being seen that the production process of juices involves a lot of stages, is concluded that a significant amount of energy is consumed. For the improvement of this process are calculated exergy efficiencies for a pasteurization unit comprised in the juice production flow chart, when inlet hot water temperature is increased from 87 to 100^{o}C, by keeping the other parameters constant. Are obtained reduced values for the exergy efficiency together with the increment of the hot water temperature at the entrance of the pasteurization unit. Better values for the exergy efficiency are seen in the same operating conditions, but for a reduced mass rate of the hot water. For a decrease of about 82% of this mass rate the afferent average exergy efficiency is higher with about 80%.*

Keywords: *exergy efficiency, hot water, temperature.*

Introduction

Fruit and vegetable juices are important business mostly in developed countries since they are not alcoholic drinks which supply vitamin C to the consumer. The most common fruits and vegetables used for extraction are: citric, apples, pears, apricots, strawberries, pineapples, mangoes, tomatoes, carrots and others [1]. The flow chart of production process is given bellow (see Figure 1).

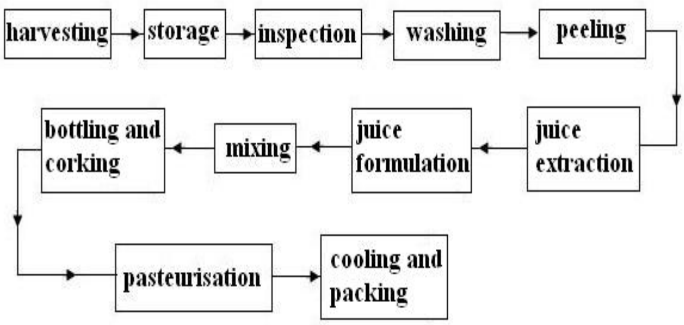

Fig. 1 Raw material processing for juice.

Harvesting – raw materials should be picked at correct sugar concentration.
Storage – should avoid the bruising of raw materials from the bottom.
Inspection – should remove the raw materials damaged.
Washing – is done under water sprays and brush rollers.
Peeling – is done manually.
Juice extraction **–** is done by an extractor.
Juice formulation – consists in enriching by ingredients such as sugar, preservatives and water in order to get the right formulation.
Mixing – the juice is mixed in a reservoir by the help of a mixer to get a homogeneous blending of the formulated juice.
Bottling – the mixed juice is bottled or corked in a manual or automatic manner.
Pasteurization – bottled juice is heated to a specific temperature for a determined period, enough to destroy certain bacteria.
Some forms of pasteurization are given below[2].
Flash pasteurization – consists of a plate pasteurizer with heat recovery and final product cooling. Temperatures ranging between (85-95^o C) for a period of time between (15-60) sec are used.
In–pack pasteurization – is a saving procedure when the bottled product, being tightly closed, is immersed into a tank filled with hot water (the used temperature is about 70^{o}C), for about 20 min. For thermal security, it is recommended a pre–immersion into a tank using a temperature of about 40^{o}C.
High–pressure pasteurization – is often met in the pasteurization of fruit juice in containers. Since the process occurs as a batch operation, this pasteurization type appears to be expensive enough.
Cooling and Packaging – the pasteurized juice is cooled and put into special cartoons to be transported to retailer.
From the above described steps, it is seen that juice industry involves a considerable use of energy and materials [3]. In order to improve the efficiency of juice production process, it is important to know the losses taking place in the process and their causes. For better energy use, it is important to be aware of the quantity and quality of energy. This can be achieved by applying the laws of Thermodynamics. The quality of energy is expressed through the thermodynamic function called exergy. The importance of the calculation of exergy efficiency consists in the fact that it includes the quality level of the converted energy [4].
This paper develops an exergy analysis, in steady state, for the step called "pasteurization" in the juice production process.

Experimental

The first law of thermodynamics states that energy cannot be created nor destroyed and its quantity remains constant in all processes. The second law of thermodynamics states that energy is degraded in all processes and its quality decreases.
The quality of energy is defined by specialists as the potential to transform energy into work. The potential to produce work is called exergy [5].
Thus, according to the first law of thermodynamics:

Energy in = Energy out

and according to the second law of thermodynamics:

Energy in > Energy out

Energy is defined by:

Energy = Exergy + Anergy

The energy of high convertibility potential has high share of exergy. The anergy represents the part of the energy that can not be transformed into work.
The exergy of an amount of matter is given by the amount of work resulting from a system able to bring the matter to equilibrium with the environment through

a reversible process. This system is defined by the following aspects:

- in the system occur only reversible processes
- the system is open, has a constant volume and a steady flow is entering and leaving the system
- the kinetic and potential energy of the matter are neglected
- heat can be exchanged with environment at the temperature T_0
- for the conversion of matter into environmental components only matter from the environment, under environmental conditions, should be used
- at the exit of the system, matter is in equilibrium with the environment.

In principle, there are four different types of exergy: kinetic, potential, physical and chemical:

$$Ex = Ex_k + Ex_p + Ex_{ph} + Ex_{ch} \quad (1)$$

Kinetic and potential exergy have the same significance like the corresponding energy terms. These components are usually neglected when analyzing industrial processes. Physical exergy is the work obtainable by taking a substance through reversible physical processes from its initial state, defined by the temperature *T* and the pressure *p*, to the state given by the temperature and pressure of the environment (T_0 and p_0). Physical exergy plays a significant role when optimizing thermal and mechanical processes. Chemical exergy represents the maximum work produced when the substance is brought from the environmental state to the dead state, by a process implying heat transfer and exchange of the substances only with the environment.

For the exergy calculation, it is compulsory to define temperature, pressure and chemical composition for the environment where the analyzed systems work.

The exergy of an amount of matter is estimated by:

$$Ex = \left(H - H_0\right) - T_0\left(S - S_0\right) \quad (2)$$

In this equation "*H*" is the enthalpy and "*S*" is the entropy.

One of the main equations of the exergy analysis, the exergy balance, is given below:

$$Ex_{in} = Ex_{out} + Ex_{loss} + Ex_{dest} \quad (3)$$

Exergy losses are given by exergy flowing to the surroundings, while exergy destruction indicates the loss of exergy inside the process boundaries due to irreversibility (see Figure 2).

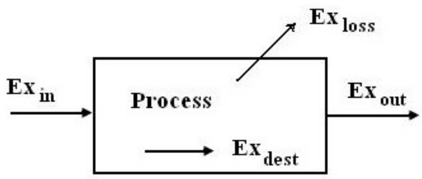

Fig. 2 Representation of exergies

The exergy efficiency is a general performance criterium; it denotes the part of the available work which is actually used [6].

$$\varepsilon = \frac{Ex_{out}}{Ex_{in}} \quad (4)$$

As shown, pasteurization is a thermal treatment aiming at the destruction of pathogenic agents. Pasteurized juice is a safe drink due to the fact that it has been heated long enough time to kill bacteria. Also, the shelf life of the product is extended, but with minimal impact on flavour. Exergy analysis is a strong tool often used to identify inefficiencies during the steps involved in the juice production process [7].

In this paper, the exergy efficiencies during pasteurization for two operation situations: hot water inlet temperature rises, for two values of the mass flow rate are calculated.

In our case, hot water evacuates heat to the fruit juice, thus the temperature of hot water will decrease with $\Delta t_{hw} = 37^o C$, while the temperature of juice fruit will increase with $\Delta t_{fj} = 48^o C$; weight rates are: $\dot{m}_{hw} = 3{,}4\, kg/s$ and $\dot{m}_{fj} = 2{,}2\, kg/s$.

Results and discussion

Inlet temperature of hot water varies in the range $(87\div100)^o$ C, the other working parameters being kept at the same level. In the first case, the mass rate of the hot water is 3, 4 kg/s and in the second case decreased to 2. 8 kg/s. Exergy efficiencies in both cases (see Table 1) are noted.

The values obtained show that there is an increase of hot water temperature at the entrance of the unit, resulting a decrease in the values of exergy efficiency. This observation is available also when the hot water mass rate is diminished.

Table 1.
Results for exergy efficiency

$\dot{m}_{hw} = 3{,}4\, kg/s$	
hot water inlet temperature, ^{o}C	exergy efficiency
87	53.82
90	48.74
93	46.35
95	44
97	42.28
100	38.86
$\dot{m} = 2{,}8\, kg/s$	
hot water inlet temperature, ^{o}C	exergy efficiency
87	65.31
90	61.14
93	56.73
95	53.21
97	51.32
100	47.08

For lower hot water mass rate, better exergy efficiencies are noted.

Conclusions

Fruit and vegetable can be kept fresher and longer by the help of pasteurization. It deals with heating the product to high temperature for a short period of time. As a result, bacteria, molds and undesirable microorganisms are eliminated. This procedure makes the juice more cost efficient. The exergy analysis method was developed in order to determine the exergy losses and potential of reducing these losses in engineering systems. The way chosen to assess the performance of the pasteurization unit analyzed in this study, to transform resources, is the exergy efficiency. When hot water temperature at the entrance of the pasteurization unit increases in the range (87-100^o C), while other parameters are kept constant, a decrease for the values of exergy efficiency is obtained. An improvement of exergy efficiency values is seen when the hot water mass rate is reduced. For an increase of 82.35% in this mass rate, an average of 81.6% in the exergy efficiency is gained.

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