International Journal of Advancements in Mechanical and Aeronautical Engineering – IJAMAE 2018
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Volume 5 : Issue 1- [ISSN : 2372-4153] - Publication Date: 25 June, 2018

Steam Consumption Analysis on The Venting Process in Direct Steam Retort

[Sasithorn Payakthong [1], Teerachart Pornpibul[2]]

Abstract— **Presently, the steam consumption usage of the retort was unable to be found, since the equipment used in sterilization were those that used steam as a medium to provide heat. When high temperature steam is needed, the pressure of the steam becomes high as well. Thus, when sterilizing, pressure must also be maintained in addition to temperature, since high pressures can result in damage to the product, and temperatures can rise above the standard. Thus, some of the steam must be released throughout the process, and in the first parts of the sterilization, air must also be vented from the machine by opening the vent pipe. Since the inside of the retort contains steam and air mixed together, some steam is also released after the vent pipe has been opened. Thus, one can't measure the true amount of steam, resulting in the production of steam of excess pressure and amount than needed to support the steam needed for sterilization. This study will study the process of sterilization of canned coconuts and coffee. The period of venting is a very important period, since any leftover air in the retort can create a cool point, and it's also important to the temperature. Thus, this period is one that uses the most steam. This thesis aims to present a thermodynamics model for sterilization with the use of a direct steam retort in order to find the true rate of steam usage for this type of retort, since the period of venting in both types of the product tends to increase temperature and have similar product volumes for each sterilization cycle. Following an analysis from the model, it was discovered that the rate of steam usage for both coconut water and coffee have similar values, where the rate of steam usage was 0.237 kg/s for coconut water and 0.238 kg/s for coffee. After a comparison between the temperature obtained from the model compared to the measured value during the air expulsion period, it was discovered that both products have similar tendencies to increase temperature compared to the temperature obtained from measurement, with percentage error values between 0.5-1.8 %.**

Keywords— ***Sterilization, Retort,Venting Process and Cool point***

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Introduction

Presently, there are studies and construction of mathematical models of vertical direct steam retorts, which helps to find the rate of steam usage by proposing ways to create a model by considering the rate of heat transfer of various pieces of equipment inside the retort for the system (for sterilization). This adds a level of difficulty and complexity as one must consider heat transfer in many areas, resulting in many factors that must be considered, and the steam inside the retort is also considered to be an ideal gas. [6]. The aforementioned methods allow for finding the rate of steam usage of vertical direct steam retorts, which physically appears different from horizontal direct steam retorts, and the considerations concern only the retort itself, and not the actual installation. Thus, this thesis aims to present a thermodynamics model of sterilization by a horizontal direct steam retort, which uses the principles of the mass balance and energy balance in an unsteady state to consider. The system includes whatever is inside the retort, which includes steam, dry air, and the product. Other equipment includes the vent pipe, which is considered to be extubated from the retort in order to release air to the environment. A comparison of temperature results between the model and those recorded from the retort will be done, as well as the net rates of steam usage from the model with the approximated steam usage of the retort, which will be considered using the subtraction of steam usage of other heating equipment with known steam usage rates and the loss of steam, with added water taken into consideration.

Sterilization

The process of sterilization can be divided into 3 parts, which are the venting, sterilizing, and cooling periods.

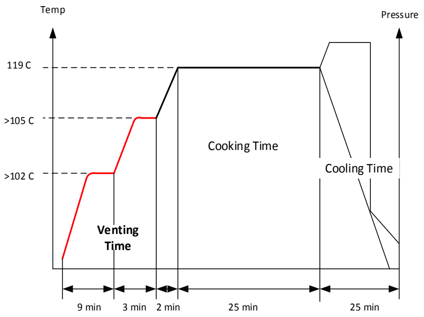

Fig. 1 Temperature and Pressure according to manufacturing standards

- The first step includes air venting from the retort, which normally will use steam pressure. It is the period where temperature will increase inside the retort until the temperature for sterilization is reached.

- The second step includes sterilization, or the period that 'cooks' the product. The temperature can range between 110-170 degrees Celsius for killing heat-resistant bacteria.

- The final step includes cooling inside the retort, to protect the container from losing shape due to differences in pressure.

I. Methodology

A. *Heating Equipment Modelling*

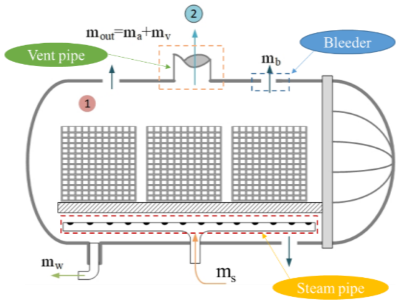

Fig. 2 Horizontal Steam-Air Retort (cross-sectional view of Horizontal Steam-Air Retort used for study)

- Modelling of the steam pipe within a horizontal steam-air retort

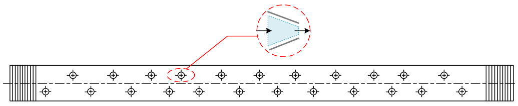

Fig. 3 Steam distribution pipe in a retort

The characteristics of the flow of steam through the steam pipe will be similar to flow through a nozzle, since there is a change in the cross section of the flow, resulting in the steam flowing through the holes around the pipe to be flowing at high speeds and be distributive due to the pressure inside the tank being different from the steam's pressure.

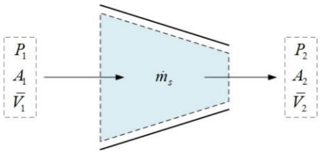

Fig. 4 Steam mass flow through Nozzle

<u>Mass balance:</u>

$$\sum \dot{m}_{in} - \sum \dot{m}_{out} = \Delta \dot{m}_{sys} \tag{1}$$

Since we have done an analysis of only the steam pipe, the rate of inward flow of the steam mass is equal to the outward flow of the steam mass, resulting in no changes to mass inside the analysed equipment.

$$\sum \dot{m}_{in} = \sum \dot{m}_{out} \tag{2}$$

<u>Energy balance:</u>

$$\dot{Q} - \dot{W} + \sum \dot{E}_{in} - \sum \dot{E}_{out} = \Delta \dot{E}_{sys} \tag{3}$$

Since there is no heat $\left(\dot{Q}\right)$ and work $\left(\dot{W}\right)$ through the control volume of the system and there being no changes in energy inside the system due to the consideration of a stable system, $\sum \dot{E}_{in} = \sum \dot{E}_{out}$, and the equation for calculating the desired amount of steam for the retort is as follows.

$$\left(\frac{1}{2}\dot{m}_{s,in}\bar{v}_{s,in}{}^{2} + \dot{m}_{s,in}gz + P_{s,in}V\right)_{in} = \left(\frac{1}{2}\dot{m}_{s,out}\bar{v}_{s,out}{}^{2} + \dot{m}_{s,out}gz + P_{inside}V\right)_{out} \tag{4}$$

Since the velocity of flow of steam inwards through the nozzle is very low when compared to that of outward flow $\left(\bar{v}_{s,in} \ll \bar{v}_{s,out}\right)$, for easier consideration the condition of $\left(\bar{v}_{s,in} \approx 0\right)$ is stipulated. Also, from the considered equipment, the potential energy has very little effect and is as such not considered. Thus, the equation can be rearranged as follows.

$$\bar{v}_{s,out} = \sqrt{2\left(\frac{P_{s,in} - P_{inside}}{\rho_S}\right)} \tag{5}$$

The Mass flow rate can be obtained from $\left(\dot{m} = \rho A \bar{v}\right)$

$$\dot{m}_s = \rho_s A_s \sqrt{2\left(\frac{P_{s,in} - P_{inside}}{\rho_S}\right)} \tag{6}$$

- Modelling of the bleeder of the horizontal direct steam retort

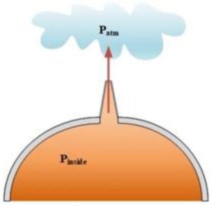

Fig. 5 Mass flow through Bleeder

The task of the bleeder is to maintain the pressure inside the tank. The venting period may not be very impactful to the rate of steam distribution, since the main potential will come from the mass that flowed out through the vent pipes. However, the importance of the bleeder will be clear in the sterilization period, which is to control pressure inside the retort and not letting it increase excessively. The mass of the steam flowing through the bleeder will be characteristically like flow through a nozzle [5]. Thus, we can use the same equations (5) and (6) for finding the rate of flow through the bleeder, resulting in the following equation.

$$\dot{m}_b = \rho_v A_b \sqrt{2\left(\frac{P_{inside} - P_{atm}}{\rho_V}\right)} \tag{7}$$

- Modelling of the vent pipe of the horizontal steam direct retort.

Since the installation of retorts differ by manufacturing companies, including different pipe placements in reality, there will be difficulties and complexities that necessitate removing them and finding a loss coefficient to compensate for the removal of some variables.

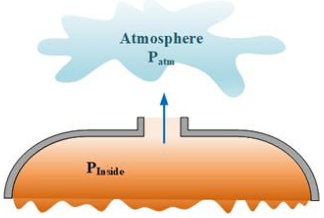

Fig. 6 Mass flow through Vent pipe

From Bernoulli's equation in the case where friction flow is discounted, it can be said that

$$\left(\frac{\bar{v}_{v,in}{}^{2}}{2g}+\frac{P_{inside}}{\rho g}+z_1\right)_{in}=\left(\frac{\bar{v}_{v,out}{}^{2}}{2g}+\frac{P_{atm}}{\rho g}+z_2\right)_{out} \tag{8}$$

The inward velocity is very low compared to the outward velocity. $\left(\bar{v}_{v,in} \ll \bar{v}_{v,out}\right)$ Thus for the simplicity of consideration, it was decided that $\left(\bar{v}_{v,in}\approx 0\right)$ and since the impacts of pipe length, joints and bends were removed, there must be a coefficient as well, after which the equation can be rearranged as follows.

$$\bar{v}_{v,out}=C\sqrt{2\left(\frac{P_{inside}-P_{atm}}{\rho_v}\right)} \tag{9}$$

The velocity obtained from the analysis is the speed of steam expelled from the vent pipe, but since steam and air are mixed together in there, the speed of air expelled from the vent pipe will also be equal $\left(\bar{v}_{v,out}=\bar{v}_{a,out}\right)$

$$\dot{m}_{v,out}=\rho_v A_V\sqrt{2\left(\frac{P_{inside}-P_{atm}}{\rho_V}\right)} \tag{10}$$

$$\dot{m}_{a,out}=\rho_a A_V\sqrt{2\left(\frac{P_{inside}-P_{atm}}{\rho_a}\right)} \tag{11}$$

B. *Heating System Modelling*

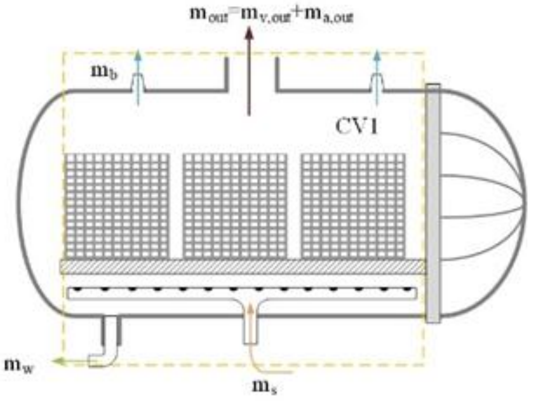

Fig. 7 control Volume 1 for Energy balance

Mass Balance:

$$\sum\dot{m}_{in}-\sum\dot{m}_{out}=\Delta\dot{m}_{sys}$$

$$\dot{m}_2=\dot{m}_s-\dot{m}_b-\dot{m}_{v,out}-\dot{m}_{cond}+\dot{m}_1 \tag{12}$$

Energy Balance:

$$\Delta E_{sys}=\cancel{Q}+\cancel{W}+E_{steam}-E_{vent}-E_{bleeder}-E_{condensate} \tag{13}$$

$$\Delta U_{sys}=m_s\left(\frac{1}{2}\bar{v}_s{}^{2}+h_s\right)_{steam}-m_{v,vent}\left(\frac{1}{2}\bar{v}_{v,vent}{}^{2}+h_v\right)_{vent}-m_{a,vent}\left(\frac{1}{2}\bar{v}_{a,vent}{}^{2}+h_a\right)_{vent}-m_b\left(\frac{1}{2}\bar{v}_b{}^{2}+h_b\right)_{bleed}-\left(m_c h_f\right)_{cond} \tag{14}$$

- No work has entered or exited the system. $\left(W=0\right)$
- The system is considered to receive heat from steam only, where heat loss to the environment is minimal $\left(Q\approx 0\right)$
- Changes of potential and kinetic energy in the system were not considered.

In consideration, the system includes the contents inside the retort, which are vapor, the product, and some dry air. Thus, ΔU_{sys} is equal to

$$\Delta U_{sys}=\Delta U_{product}+\Delta U_{dryAir}+\Delta U_{vapor} \tag{15}$$

where dry air inside the retort is considered as an ideal gas. Thus, ΔU_{dryAir} can be calculated from

$$\Delta U_{dryAir}=m_a C_{p,a}\Delta T \tag{16}$$

The following concerns $\Delta U_{product}$ in the sterilization process of canned coconut water and canned coffee. The coconut water consists of 95.6% coconut water and 4.4% nitrogen in a can with a volume of 240 ml, whereas the coffee consist of 94.4% coffee and 5.5% nitrogen in a can with a volume of 180 ml. Nitrogen must be added in place of the air inside the can, since any leftover air can result in the growth of microbes that can spoil the food.

$\Delta U_{product}$ can be calculated from the following equation.

$$\Delta U_{product}=\left(m_{product}C_{p,product}\left(\Delta T\right)\right)+\left(m_N C_{p,N}\left(\Delta T\right)\right) \tag{17}$$

Substitution of $\Delta U_{product}$ and ΔU_{dryAir} in equation (15) will result in ΔU_{vapor} , which is the part for vapor/steam when

$$\Delta U_{vapor}=U_2-U_1 \tag{18}$$

Thus, when one is aware of the energy inside the steam in the 2nd state, they will be able to find the temperature of the 2nd state as well from determining that the system consists of steam/vapor, the product and some dry air. Thus, the temperature of the vapor will be equal to the temperature of dry air and the product.

II. System simulation

Since the system of equations obtained from the modelling requires one to know the temperature and density of the steam inside the retort in the 2nd state in order to find the rate of steam usage during each considered time period, a simulation must also be used to help solve this problem regarding the system of equations. However, since there are many methods of thermal simulation, the most suitable method for the problem must be chosen. Here the most suitable method that can solve the equations' problems in this modelling is the method of successive simulation, which involves randomizing the values for the desired variables into the equations to obtain resulting values, which are repeated until there are no changes in the obtained values. [2] The reason for choosing this method was that the equations did not have an sequence for value substitution. Thus, sequential simulation cannot be used.

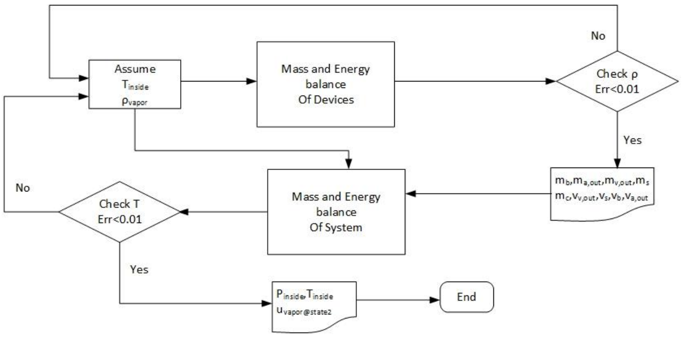

Fig. 8 Successive simulation Method Flow chart

III. Result And Discussion

After obtaining the thermodynamics model, the program MATLAB was then used to calculate the rates of steam usage and temperatures inside the retort for comparison with values obtained from measurement, where the initial condition will be set according to the standard of actual production from the studied factory.

TABLE I
INITIAL CONDITION OF MODELLING

Initial Condition		Coconut water	Coffee	Unit
Initial Temperature		60		°C
Pressure of steam		200		kPa
Surrounding Temperature		30		°C
Volume of Retort		4.27	4.27	m^3
Mass Products	liquid	230	170	ml/can
	Nitroden gas	10	10	ml/can
Quantity of Product		16,000	22,000	cans/1 batch
Dimeter of Steam Nozzle		3/16		in
Dimeter of Bleeder		1/8		in
Dimeter of Manifold Vent pipe		3		in
Temperature of Sterilization		119	121	°C

Here after system stimulation and graph plotting, the temperature of air venting of both products compared to the measured temperatures are displayed as graphs in figures 9and 10.

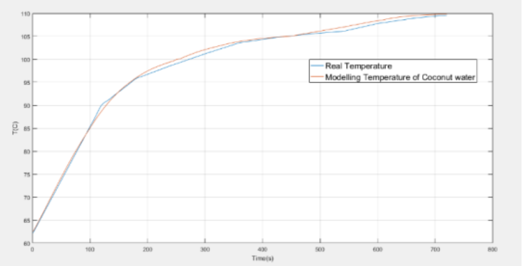

Fig. 9 Temperature inside of Coconut water(C) with Time(sec)

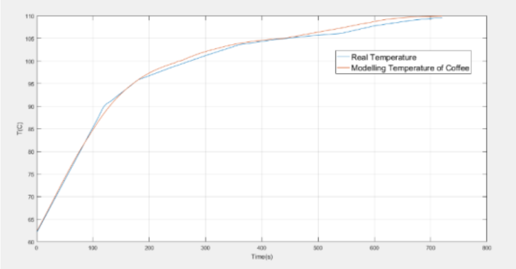

Fig. 10 Temperature inside of Coffee(C) with Time(sec)

Figures 9 and 10 display the temperature values during the venting period of the retort at various time points for both products compared with the temperatures measured using the thermometers inside the retort. The temperatures obtained from the model were like that from actual measurement, with the same tendency of increasing temperature. Since both products had different sterilization temperatures but have same temperatures during the venting period until the 12 minutes marker, the increases in temperature were different after opening the vent pipes. Furthermore, the differences between the real temperatures and that obtained from modelling were calculated as a percentage error as per figure 11.

$$\%Err = \left| \frac{(T_{real} - T_{model})}{T_{real}} \right| \times 100\% \qquad (19)$$

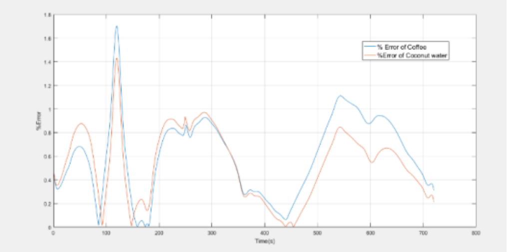

Fig. 11 %Error between Real Temperature and Temperature of Modeling with Time(sec)

Figure 11 displays the error values of temperatures obtained from the model and from measurement at various times. It can be seen that the maximum error values for are 1.42% for coconut water and 1.7% for coffee. The resulting error was very low, indicating that the tendencies for the model to be close to that of the real/measured ones and meaning that the amount of steam used in the venting period obtained from the modelling is similar to the actual amount of steam used.

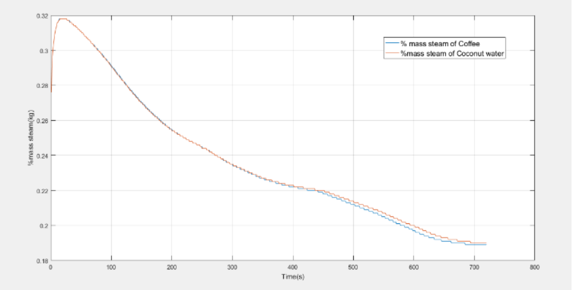

Fig. 11 mass steam(kg) with Time(sec)

IV. Conclusions

The results obtained from the modelling of the sterilization system during the venting period were that canned coconut water used 170.72 kg/12 mins while coffee used 171.13 kg/12 mins, and that the error values of temperature was the only value able to be measured. Thus, it was the only thing that can be used for comparison to ensure that the model is accurate and similar to the true value as much as possible, which was done through the analysis of errors in temperature during the venting period, which ranged between 0.5-1.8 %, which counts as very little. Thus, it can be believed that the amount obtained from the modelling was similar to that of the actual system.

V. Unit

Nomenclature	
m	mass ,(kg)
U	Internal Energy , (kJ)
Q	Heat,(kJ)
W	Work ,(kJ)
u	Internal Energy by mass,(kJ/kg)
V	Volume ,(m^3)
$\overline{v}$	Velocity , (m/s)
T	Temperature, (^oC)
t	Time , (s)
C	Loss coefficient
C_p	Specific heat, (kJ/kg ^oC)
E	Energy , (kJ)
h	Enthalpy , (kJ/kg)
Greek symbols	
ρ	Density ,(kg/m^3)
Subscripts	
in	Flow in
out	Flow out
inside	inside the Retort
v	vapor
a	dry air
s	Steam
b	Bleeder
c	Condensate
1	Initial state of the Process
2	Final state of the Process

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