OPTIMIZATION OF TIME AND ROTATIONAL SPEED OF DISC FOR TINNED MILK USING NUMERICAL SIMULATIONS FOR UNIFORM HEAT DISTRIBUTION

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A B S T R A C T

CFD is a technique which incorporates the numerical methods and algorithms to solve and analyze problems. The present study involves using CFD technique modeling of microwave heating of half and one liter tinned milk. The project revolves around performing the uniform temperature distribution inside the microwave and to predict the optimum time required for heating the tinned milk with half liter and one liter for different power inputs (P_1, P_2, P_3 and P_4) and at different rotational speed of microwave table (8 rpm, 10 rpm and 12 rpm). The microwave oven model is created with the suitable dimensions using CATIA V5 R17 software. The geometrical model of microwave oven and its components are converted from physical domain into computational domain using discretizing the whole microwave oven model using HYPERMESH 10 software. The elements of each component are segregated to create a different cell zones to apply boundary condition. Suitable materials and materials properties are selected for numerical analysis of tinned milk, which resemble the actual microwave oven heating. Selected suitable boundary conditions for each zone in a microwave oven is applied in FLUENT for analyzing the problem depending on working condition to enhance the accuracy and efficiency. The optimized values for heating half liter tinned milk to reach 65ºC and to attain uniform heat distribution will occur at power input P_4 (1.4 kW) and rotational speed of disc 10 rpm with time 417 sec. The optimized values for heating one liter tinned milk to reach 65ºC and to attain uniform heat distribution will occur at power input P_1 (1.1 kW) and rotational speed of disc 12 rpm with time 1121 sec.

Keywords: CFD, Microwave, RTE (ready to eat) and Tinned Milk

I. INTRODUCTION

The microwave oven is one of the great inventions of the 20th century. The most common application of microwave heating is the domestic microwave oven is shown in figure1. Microwave heating is preferred for pasteurization and sterilization over the conventional heating for the basic reason that the process is fast and requires minimum come-up time (CUT) to the desired process temperature. To process liquid foods, high-temperature short-time (HTST) processes have been accepted by the food processing industry to reduce the adverse thermal degradation in food quality while ensuring food safety. However, the HTST process is not suitable for solid foods processed by conventional methods due to slow heat conduction, which often causes overheating at the solid surface during the time needed for the heat to be transferred to the slowest heating point of the food.

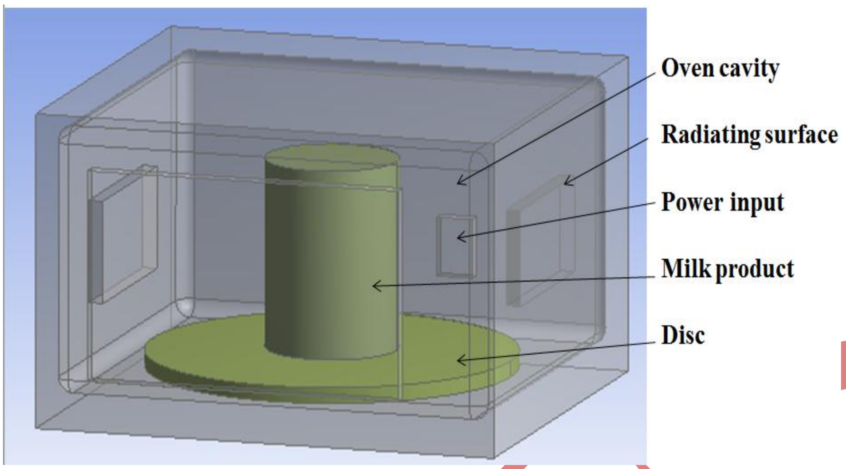


Fig 1: Geometrical model of microwave oven

The microwaves pass through food most molecules have a positive charge at one end, a negative one at the other. The negative part of the molecule rotates to align itself to the positive charge of the wave, and then as the microwave changes to negative, the molecule rotates again, the positively charged end this time being attracted to the negative charge. This effect causes the molecules in the food to rotate, which causes them to have kinetic energy, which they get rid of as heat. In an alternating current electric field, the polarity of the field is varied at the rate of microwave frequency and molecules attempt to align themselves with the changing field. Heat is generated rapidly as a result of internal molecular friction.

II. PROBLEM DEFINITION AND PROBLEM SPECIFICATION

The company is 150 years old and has many outlets spread in and around USA. Borden diary has "READY TO SERVE" (RTS) outlets around various places in US and entire region of North America.

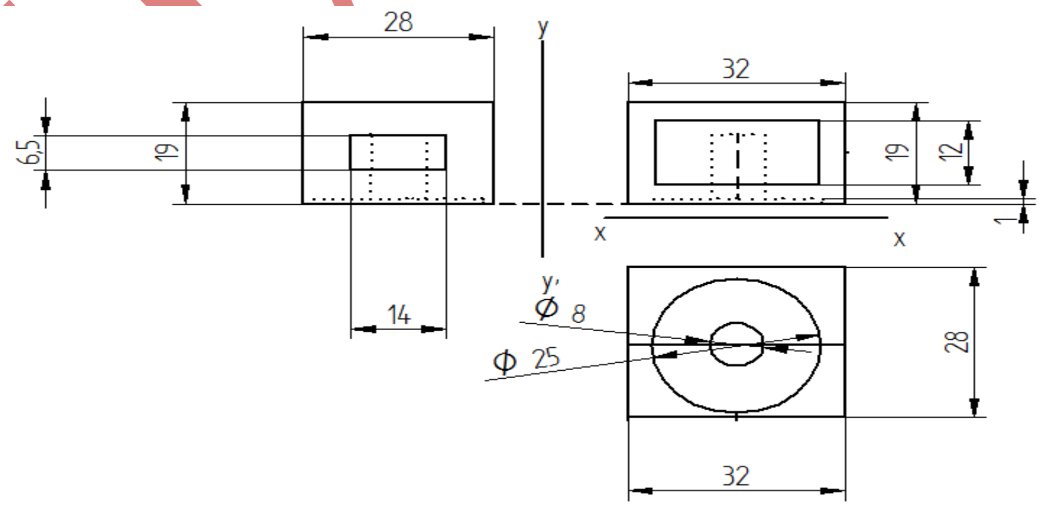


Fig 2: line diagram shows the different views of microwave oven

In these RTS they serve both Cold as well as hot milk drinks i.e., (Flavored and Unflavored milk packages). In the recent survey it has been seen that the customer is not satisfied with the hot drinks that is supplied to them during the winter season.On behalf of this survey they have to see how the existing microwaves in outlets can be efficiently used to serve the customers. In the milk heating the each microwave ovens are operated four different power inputs (1.1kW, 1.2kW, 1.3kW and 1.4kW) and three different rpm (8rpm, 10rpm an 12 rpm).

The problem is for particular power input for a microwave oven there is no particular specified rpm (speed of rotation of turn table or disc) for minimizing heating time and to get uniform heat distribution in the tinned milk. So optimization of Speed and heating time is needed for a particular power input.

III. METHODOLOGY

CATIA V5R17 modeling software helps to create geometrical model of microwave oven. Figure 2 shows the front, side and top views of microwave oven and also it shows the suitable dimensions and suitable position of each component in the microwave oven assembly. The solid geometrical model of microwave oven and its components are converted from physical domain into computational domain using discretizing the whole microwave oven model into finite number of elements. The finite numbers of elements are created using the software HYPERMESH 10.

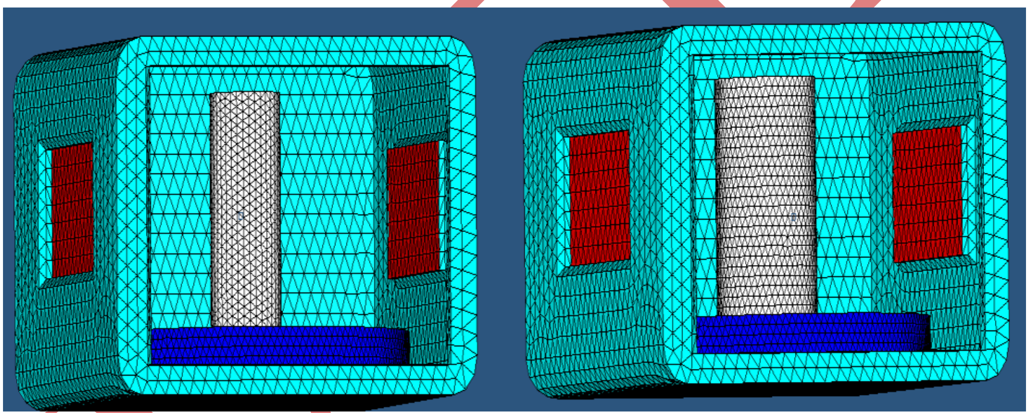


Fig 3: Meshed diagram shows the location of microwave oven components

The elements of each component are segregated to create a different cell zones to apply boundary condition. Some of Boundary conditions are listed in the table. The locations of microwave oven meshed components are shown in the figure 3. Triangular elements are used as 2-D elements and tetrahedron elements are used as 3-D elements in the microwave oven meshed model.

The materials and there properties which have been selected in the analysis of microwave oven heating of Tinned milk are listed in the table 1.

The correctness of the numerical calculation results is largely dependent on boundary conditions. If these do not correspond to the actual situation, the solution of equations does not give the expected values. Boundary conditions are the physical assumptions that implement on the boundaries of the computational domain. The relevant boundary conditions for different zones are listed in the table 2

Table 1:Materials and material properties used in the Microwave oven

Name	K W/mK	C_P J/kgK	Density kg/m^3	Emissivity	TEC $10^{-6}K^{-1}$	R.I
Borosilicate	1.3	750	2230	0.95	3.3	1.474
Polyethylene	0.42	2250	940	0.1	200	1.54
Polypropylene	0.22	1800	946	0.97	150	1.49
Polystyrene	0.033	1300	1040	0.91	70	1.6
Glass	5	840	2800	0.94	20	1.474
Steel	45	502	793	0.11	17.3	2.47

Table 2: Boundary conditions for different zones

zones	**Boundary conditions**
Wall	Adiabatic stationary wall
Disc	Rotating component with the speed of 8 rpm,10 rpm and 12 rpm with respect to and 12 rpm with respect to y axis
Heating surface	Which produces radiations as per power input supplied to the magnetron
Interface zone and fluid	interface coupled condition and fluid is initially stationary

IV. RESULTS AND DISCUSSION

In this project the optimized results are presented based on uniform heating of the tinned milk and the minimum time take to reach temperature range near to the 65^{0}C. Temperature Contours are listed for both half liter and one liter milk tins for different power inputs and for different rotational speed of disc.

Radiation's is applied in terms of constant heat fluxes, to find heat flux for different operating power range; it is calculated by using the formula shown below.

$$q_s = \frac{W}{A_s} \qquad 1$$

As per company requirement tinned milk was heated using microwave oven at four different power inputs namely 1.1 kW, 1.2 kW, 1.3 kW and 1.4 kW (P_1, P_2, P_3, and P_4) respectively. From these power input range heat flux need to be calculated for each power input. Using above mentioned eq.1 heat flux was calculated for four different power inputs (p_1, p_2, p_3, and p_4). They are 120879.12 W/m^2, 1318668.13 W/m^2, 142852 W/m^2 and 1538846.15 W/m^2 respectively.

The following factors are considered for analyzing the numerical results.

I. The electromagnetic wave penetrates into the surface of the food product and the power absorbed by the food is assumed to be decay exponentially into the sample based on the lambert's law. This is given by the equation 2.

$$P_x = P_0 e^{-2x\beta} \qquad 2$$

II. P_x is the power absorbed by the food item (W), P_0 is the incident power (W), x is the depth from its surface (m) and β is the attenuation coefficient (m^{-1}).

III. The surface to volume ratio is high for one liter tinned milk when compared to the half-liter milk which require more time to heat when compared to the half-liter milk.

IV. As the frequency is increased the penetration depth will decreased. For tinned milk with 75 % to 100% concentration the penetration depth is about 25 mm to 30 mm for the frequency 2450 MHz.

V. Surface to volume ratio for one liter tinned milk is more when compared to the half-liter hence the approaching time of the electromagnetic wave is more in case of low rotational speed of disc.

5.1 Numerical results for half liter tinned milk

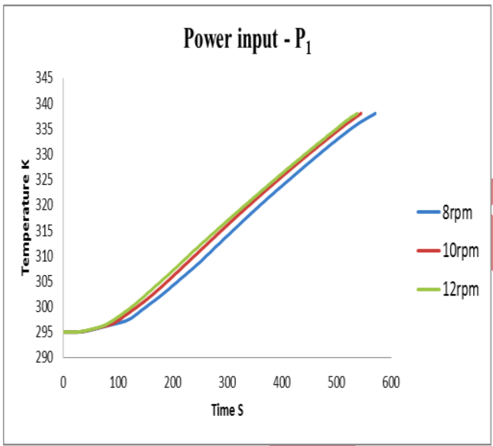


Fig 4 : Temperatue v/s time variation for P_1

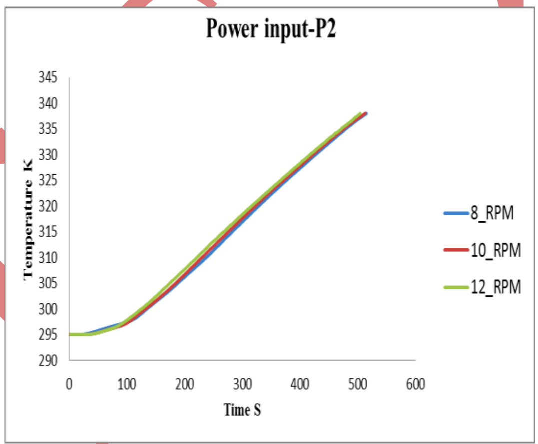


Fig 5: Temperatue v/s time variation for P_2

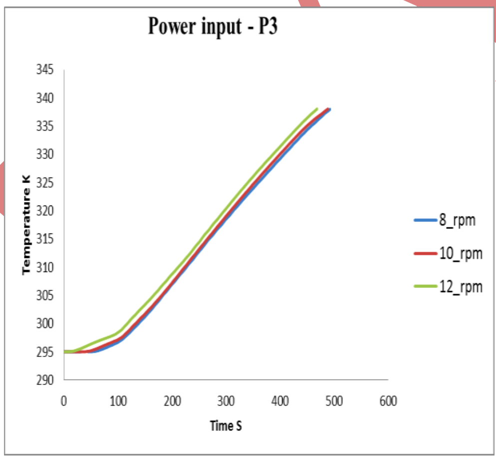


Fig 6: Temperatue v/s time variation for P_3

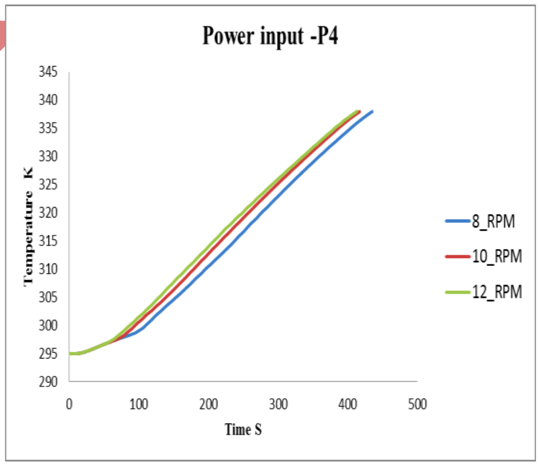


Fig 7: Temperatue v/s time variation for P_4

Figures 4 –7 show the temperature variations with respect to time for power input P_1, P_2, P_3 and P_4 for different rotational speed of disc. From the graphs it can be conclude that at 12rpm speed it consumes less heating time when compared to that of 8rpm and10rpm. Because at 12 rpm, turbulence effect is high this increases molecular motion and also heat transfer rate in the tinned milk. The time difference between 8 rpm to 10 rpm and 10 rpm to 12 rpm is 4 S and 9 S respectively. So there was no much variation in time with increase in rpm at power input P2. From comparing figure 4 and 5 it shows that with increase in power input there was decrease in heating time with increase in rpm. From the temperature plots figure 6-7 it shows that at 8 rpm and 10 rpm there was marginal variation in heating time for half liter tinned milk. But at 12 rpm heating time was reduced by 24 S and 20 S at 8 rpm and 10 rpm respectively. With increase in rotational speed of disc, turbulence intensity also increases which affects the heat transfer rate. The random motion of the milk molecules cause proper mixing of molecules as well as heat generated inside the tin when the molecules colloid each other. In one liter tinned milk has more molecules when compared to the half-liter so that the sole effect of turbulence intensity is more in case of the one liter tinned milk when compared to the half-liter tinned milk.

Figure 8 shows the temperature contours for different power input and for different rotatonal speed of disc. From the figure 8 it shows that uniform heat distribution will not occur for all the power inputs and at the different speed. Because the frequency of electromagnetic wave generated from heat source will not match with the tinned milk, because the absorption of electromagnetic wave occurs only at certain speed depending on power input provided for heat source. It can be known that as the power is increases the heating time will be reduced. Proper mixing of milk inside the tin will occurs only at high molecular motion. But uniform heat distribution will takes place only when molecules motion due to density difference match with turbulence motion for applied speed to the tinned milk. From the temperature contours it can be concluded that for power input P_4 at 10 rpm speed uniform heat distribution has been occurred when compared to the other power input and also uniform temperature distribution takes place at minimum heating time when compared to other rotational speed of disc and different power inputs. The optimized results for half liter tinned milk are listed in the table 3.

Table 3: Heating Time and temperature difference for tinned milk for different power inputs

	Power input P_1			**Power input P_2**			**Power input P_3**			**Power input P_4**		
Rotational speed of disc (rpm)	8	10	12	8	10	12	8	10	12	8	10	12
Heating time (S)	571	550	538	515	511	504	492	488	468	435	417	413
Temperature difference (∇T) in K	7	3	2	5	3	3	5	1	4	6	0.5-1	5
Optimized value	Not suitable			Not suitable			Not suitable			10 rpm		

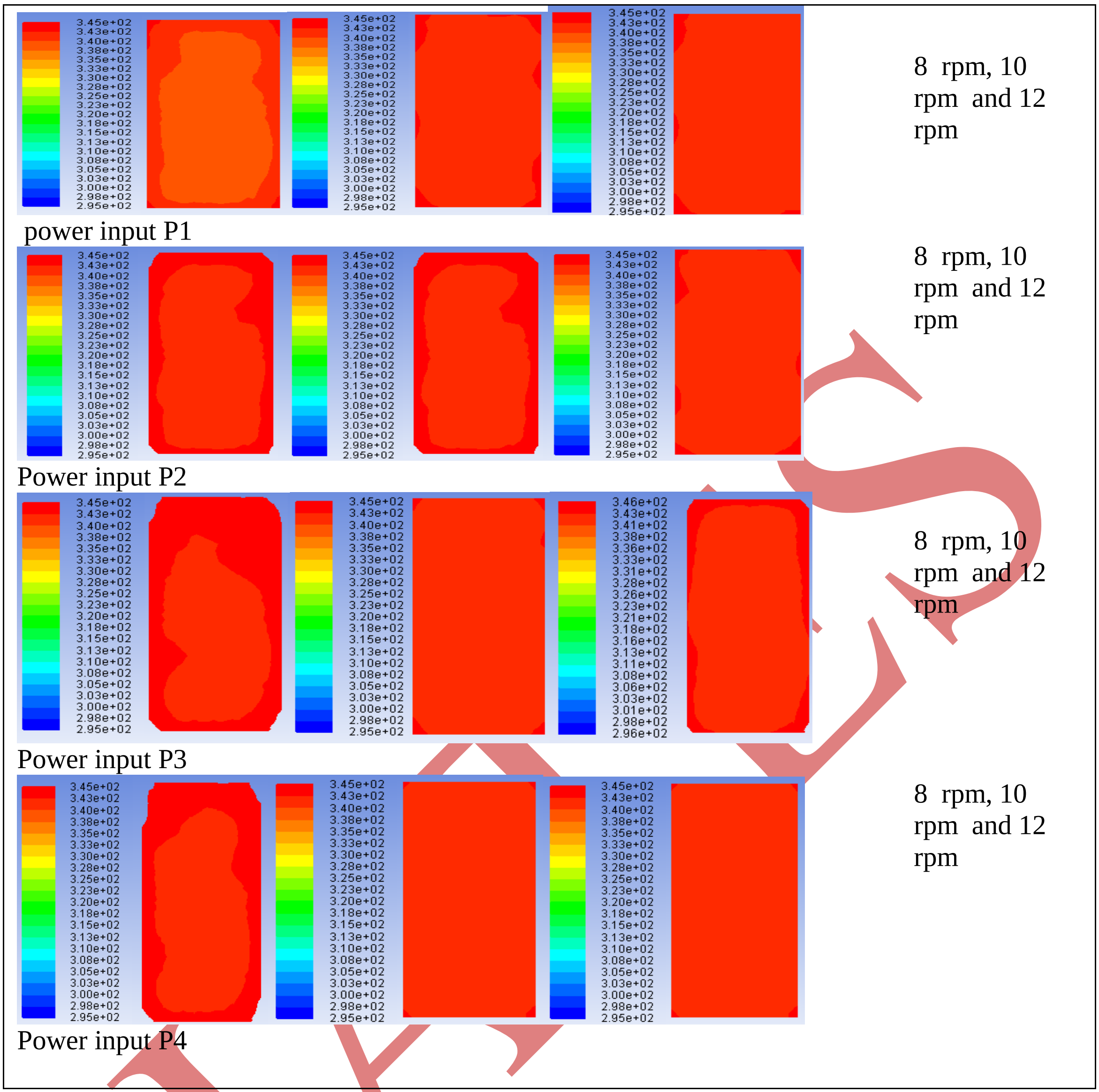


Fig 8 : Temperature contours for half liter tinned milk for different power inputs and for different rotational speed of disc.

5.2 Numerical results for one liter tinned milk

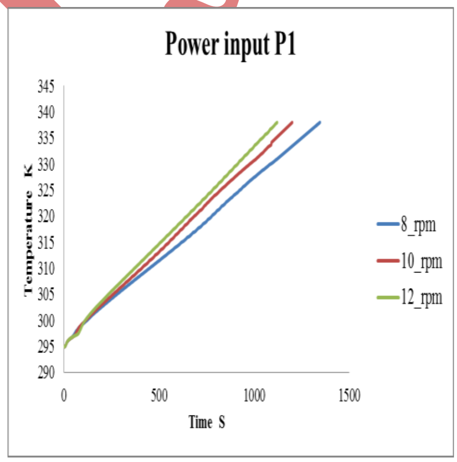


Fig 9: Temperature v/s Time variation forP_1

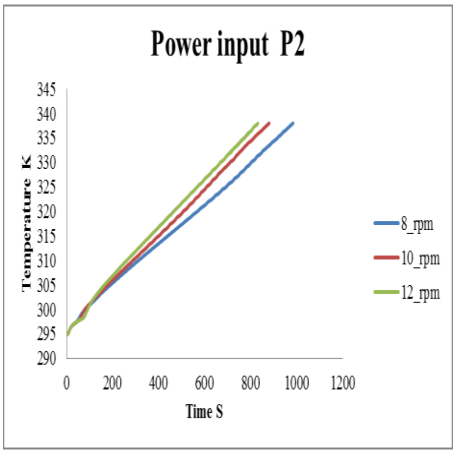
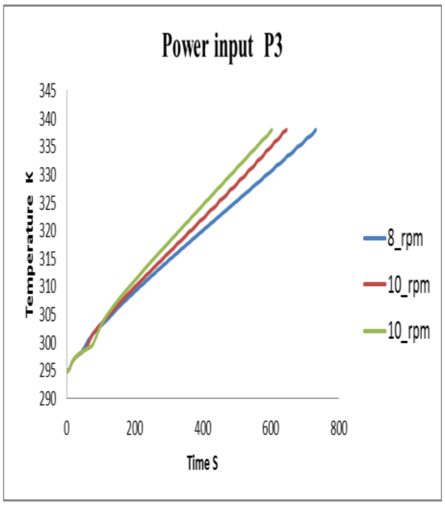


Fig 10: Temperature v/s Time variation for P_2



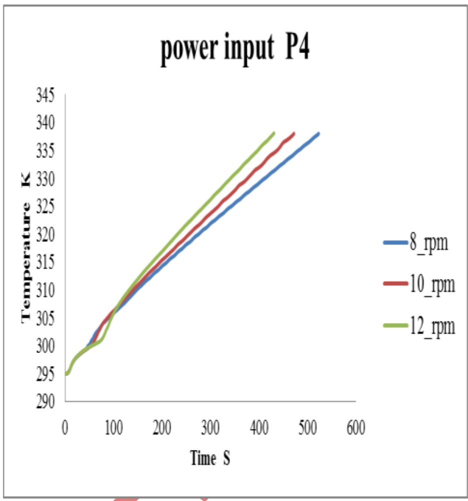


Fig 11: Temperature v/s Time variation for P_3 **Fig 12: Temperature v/s Time variation for P_4**

Figure 9-12 shows that temperature variation with respect to time graphs for different power inputs and for different rotational speed of disc. From the graphs it can be conclude that at 12rpm speed it consumes less heating time when compared to that of 8rpm and10rpm. Because at 12 rpm, turbulence effect is high this increases molecular motion and also heat transfer rate in the tinned milk.

Figure 5.13 shows that the temperature contours for different power inputs and for different rotational speed of disc. For one liter tinned milk the surface to volume ratio is more when compared to the half-liter tinned milk. One liter milk tin having the same height and the diameter is nearly doubled when compared to half liter milk tin. As per lamberts law the electromagnetic energy will decay as it moves from the outer surface to the center of the tinned milk.

Table 4:heating time and temperature difference for different power inputs for one liter tinned milk

	Power input P_1			Power input P_2			Power input P_3			Power input P_4		
Rotational speed of disc (rpm)	8	10	12	8	10	12	8	10	12	8	10	12
Heating time (S)	1346	1200	1121	1002	973	940	540	472	468	750	646	603
Temperature difference (∇T) in K	4	8	2	6	8	4	8	7	6	11	8	6
Optimized value	12 rpm			Not suitable			Not suitable			Not suitable		

The temperature contours in the first row was shown for power input P_1. At 8 rpm setup the temperature contours shows nearly uniform at is center but it is not reached 65ºC and at 12 rpm gives the uniform temperature distribution. From the second row for 8 rpm setup the temperature contours shows the uniform temperature at center of the tinned milk but at outer surface the temperature is concentrated due to low turbulence. For 10 rpm and 12 rpm setups the temperature profile will reach the uniform temperature near to 65℃.In power input P_3 and P_4 all temperature contours are over heated which cannot be taken into consideration. Because after milk reaching 70℃ there is a generation of the vapors takes place inside the tin. So as vapor pressure increases inside the tin it leads to explosion of packed tinned milk. The optimized result for one liter milk has been listed in the table 4.

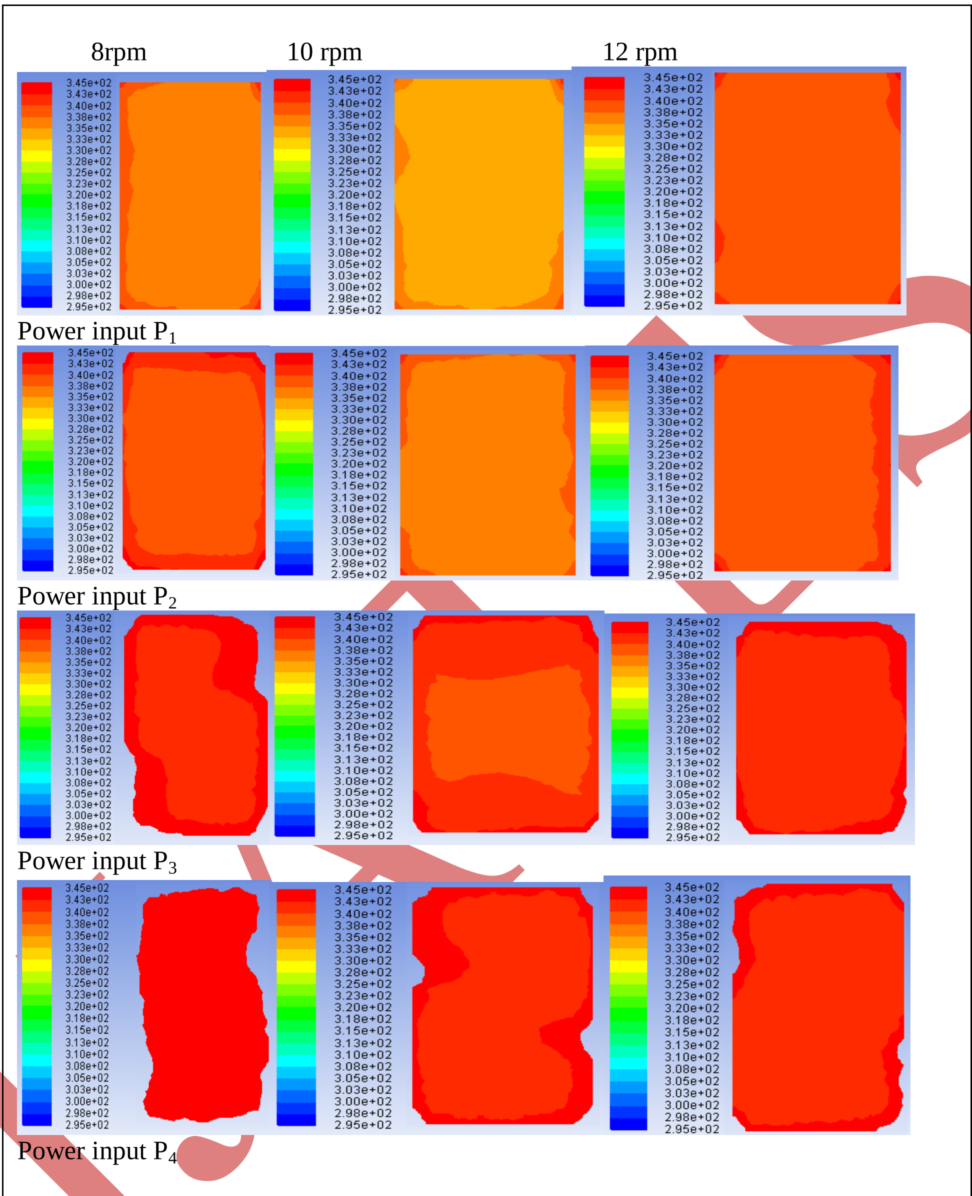


Fig 13 : Temperature contours for half liter tinned milk for different power inputs and for different rotational speed of disc.

V. CONCLUSION

- The microwave oven model is created with the suitable dimensions using CATIA V5 R17 software.
- The solid geometrical model of microwave oven and its components are converted from physical domain into computational domain using discretizing the whole microwave oven model into finite number of elements. The finite numbers of elements are created using the software HYPERMESH 10.

The elements of each component are segregated to create a different cell zones to apply boundary condition.

- Suitable materials and materials properties are selected for numerical analysis of tinned milk, which resemble the actual microwave oven heating. Selected suitable solvers, assumption and boundary conditions for analyzing the problem depending on working condition to enhance the capability, accuracy and efficiency.
- From the above mentioned factors the virtually created numerical simulation of heating of tinned milk will resemble or match with actual heating process in the microwave oven. And also this numerical heating model can be used as a good basis for understanding heat distribution when heating with other food items.
- Uniform temperature distribution can be maintained at some particular rotational speed of disc and at particular power input to the microwave oven. Minimum heating time for tinned milk is obtained at higher power input.
- The optimized values of rotational speed of disc and heating time for tinned milk is selected based on uniform temperature (minimum temperature difference) distribution and minimum heating time.
- The optimized values for heating half liter tinned milk to reach 65ºC and to attain uniform heat distribution will occur at power input P_4 (1.4 kW) and rotational speed of disc 10 rpm with time 417 sec.
- The optimized values for heating one liter tinned milk to reach 65ºC and to attain uniform heat distribution will occur at power input P_1 (1.1 kW) and rotational speed of disc 12 rpm with time 1121 sec.
- Hence it can be concluded that the obtained numerical results approximately satisfies the tested results for power input P_1 at all rotational speed of disc. These optimized results will satisfy the company requirement, so that company can satisfy the customer's needs in serving pre heated tinned milk at optimized time, speed, power and cost.

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