The Effect of Wave Stirring Mechanism in Improving Heating Uniformity in Microwave Chamber For Fishing Industry

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***Abstract*— Fishing industries in tropical countries needed to spend big portion of their resources to freeze their fish product to postpone its rotten condition. This study aimed to offer lower cost solution to postpone fish rotting process. The solution used electromagnetic heating process in a big metal chamber powered by a magnetron which was connected to a waveguide and a pyramidal horn antenna. Non-uniform heating problem was addressed using electromagnetic wave stirring mechanism. Computer simulation showed that various angle of wave stirring mechanism (0^0, 15^0, 30^0, 45^0, 60^0 and 75^0) provide different pattern of hot and cold spot in the chamber, thus swinging the stirring mechanism created more uniform heating process. Experimental validation showed that fish samples can be heated to 70 ^{0}C in various spots, high enough to kill the microbes that made the fish rotten.**

Keywords—Microwave heating, stirring mechanism, heating uniformity.

I. Introduction

Fishing industry currently use deep frozen process to postpone the rotting process of their fish product. Deep frozen process requires extreme temperature ranging from –30 ^{0}C to -70 ^{0}C. This extreme temperature is needed to totally hibernate the microbes that cause the rotting process in fish products. Temperature range between -30 ^{0}C to 10 ^{0}C creates slow development condition for microbes, while temperature range between 10 ^{0}C to 35 ^{0}C creates optimal temperature for microbe development. Temperature range above 45 ^{0}C starts killing the microbes, while almost all the microbes that creates rotten condition dies in 70 ^{0}C [1].

Implementation of deep-frozen process is crucial since fish catching and storing duration in fishing ship may take months. Without any treatment, fish in tropical countries get rotten in 8-12 hours after boarding the ship [2]. However, frozen process requires high and continue supply of power, usually produced by generator set which consumes expensive fossil fuel that require big space for storage. These condition leads to high initial and operation cost for fishing industries players. Some of them then turns to cheap but toxic chemical liquid such as formalin to prevent the rotting process in expense of the health of unaware consumers.

This study aimed to verify whether heating uniformity of microwave chamber can be improved so that it can be used in fishing ships in capital countries to replace the novel method of freezing the fishes.

Microwave heating methods are favorable due to its handiness and short duration heating. However, this method of heating produces non uniform temperatures on the object, creating the cold and hot spots. Stirring mechanism is one of the methods of enhancing the uniformity of heating, other than carousel and wave chopping method.

The process of increasing uniformity in microwave heating has been studied. Various methods have been recommended to improve heating uniformity in microwave heating such as varying the sample [3], using microwave dryer [4], using two rotary waveguides [5], using food carrier design [6], using continuous system [7], and using rotating structure [8].

However, those methods are intended for small chambers where the objects can be easily rotated or moved. The method in increasing temperature uniformity used in this research is suitable when the object is hard or cannot be rotated or moved. So instead of rotating or moving the object, the direction of the microwave was manipulated by swinging metallic plates in the microwave chamber. Different angle of metallic plates created different power distribution pattern within the chamber. Thus, swinging these plates created power fluctuation in every location within the chamber, creating more heating uniformity.

There has been no earlier study about 3D modelling food heating in microwave heating device using wave stirring mechanism. The objective of this study was to model the heating of the object inside a microwave chamber using wave stirring mechanism. Using the model, the effect of wave stirring mechanism in enhancing heat uniformity was determined, as well as the optimum heating duration and operation schedule.

With this model, hot and cold spots in the chamber can be simulated with different angle of wave stirring mechanism. Several different angles were used to observe the different pattern of hot and cold spots. Validation of the model had been performed using the combination of analogue thermometer and endoscope digital camera to obtain the temperature increment pattern in 5 spots with different power level.

II. Materials and Methods

This study used computer simulation and experimental validation as the research methodology.

A. Computer Simulation

1) Simulation description and objective

Computer simulation had 3 objectives, which were:

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1. To identify the maximum and mean value of electromagnetic energy level of the chamber for each of 6 different angles of stirring mechanism.
2. To obtain the hot and cold spot pattern for each of 6 different angles of stirring mechanism, and
3. To indicate the sample spots for placing the fish sample for temperature increment pattern measurement.

2) Simulation process

Model for simulation used aluminum and air as the material. Aluminum was used as the material for waveguide, pyramidal cone antenna and the chamber while air was used as the surrounding material. Block diagram of the system can be seen in Fig. 1.

Simulation was conducted 7 times, the first one was to get radiation pattern from magnetron, wave guide, antenna, and metallic chamber without using wave stirring mechanism. It served as control result. Wave stirring mechanism was used in other 6 simulations. Each simulation used different angles (0^0, 15^0, 30^0, 45^0, 60^0 and 75^0). All simulation used 1000-watt excitation signal, triggered from a port in the waveguide. Configuration of metallic plates in wave stirring mechanism can be seen in Fig. 2.

The results of 6 simulations were combined to identify the highest and average value of power level. This was required to prevent overheated condition. 3D coordinates of the highest and the average value were then obtained. These coordinates were used in the process of capturing the temperature increment pattern in experimental validation process.

B. Experimental Validation

1) Device description and objective

A microwave heating device had been developed from a 2450 MHz magnetron, taken from 1000 watt microwave oven. The magnetron was connected to a 40 mm x 80 mm rectangular waveguide. The wave guide was attached to a pyramidal cone antenna (328 mm in width x 243 mm in height and 160 mm in length). The pyramidal cone antenna was attached to an aluminum chamber (1 m in width, 1 m in height and 2 m in length) to mimic the shape of fish chamber in ship. The image of physical model can be seen in Fig. 3.

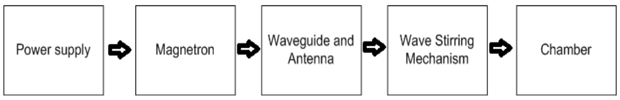

Fig. 1. Block diagram of heating device

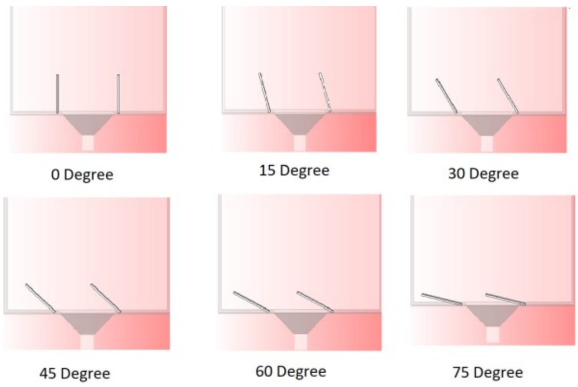

Fig. 2. Configuration of metallic plates in stirring mechanism.

Analog thermometer and endoscope digital camera covered with steel pipe were utilized to capture the temperature increment pattern of the fish sample. Analog thermometer was used because no digital thermometer can withstand the high radiation level in the chamber was available. Endoscope digital camera was used to minimize the deviation of hot and cold spot from computer simulation due to wave scattering effect. Steel pipe was needed to cover the endoscope digital camera so that it can withstand the high-power electromagnetic radiation level in the chamber.

The objective of experiment was to obtain temperature incremental pattern for a specific power level. These patterns were combined to determine the operation schedule of the device, so that samples in relatively cold spots can get near to target temperature (60 ^{0}C -70 ^{0}C) while samples in relatively hot spots were not overheated (>80 ^{0}C).

2) Experimental process

Eleven fish samples were chosen from the Northern Red Snapper (*Lutjanus Campechanus)* with similar weight (215-237 grams). 5 samples were used to get the temperature incremental pattern and 6 samples were used to get comparison of fish condition after being heated. Samples were stored in freezer before the experiment. Frozen samples were washed and soaked in clean water until it reached the standard starting temperature of 30 ^{0}C, the same as surrounding temperature. One sample was split in two from top to bottom to get the picture of fresh fish condition.

Each fish sample was placed in a specific spot with specific power level. Analog thermometer bar was inserted from fish mouth until it reached its abdomen (±125 mm from fish mouth). Endoscope digital camera was positioned to capture the video of analog thermometer during the radiation process. Video of analog thermometer was observed to obtain the temperature increment pattern of that specific power level. Each fish samples that had been heated to certain level were split in two to get the picture of their inner condition. The pictures of the finished fish samples were compared to the picture of raw fish.

Five specific spots were chosen based on their average power level from 6 wave stirring angle. Spot A had the lowest power level while spot E had the highest. Temperature incremental pattern from each spot was analyzed to determine the optimum heating duration of the device, so that most of the microbes in the coldest spot are killed, without making the fish in the hottest spot overly heated.

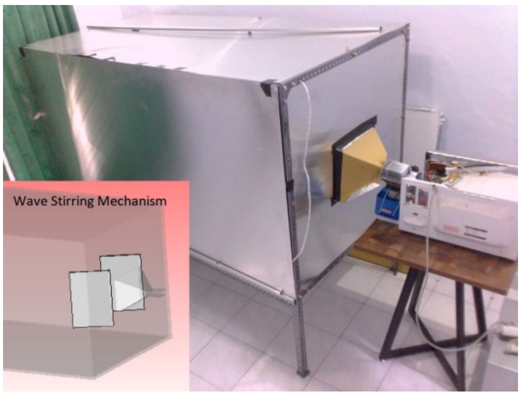

Fig. 3. Physical model of heating device

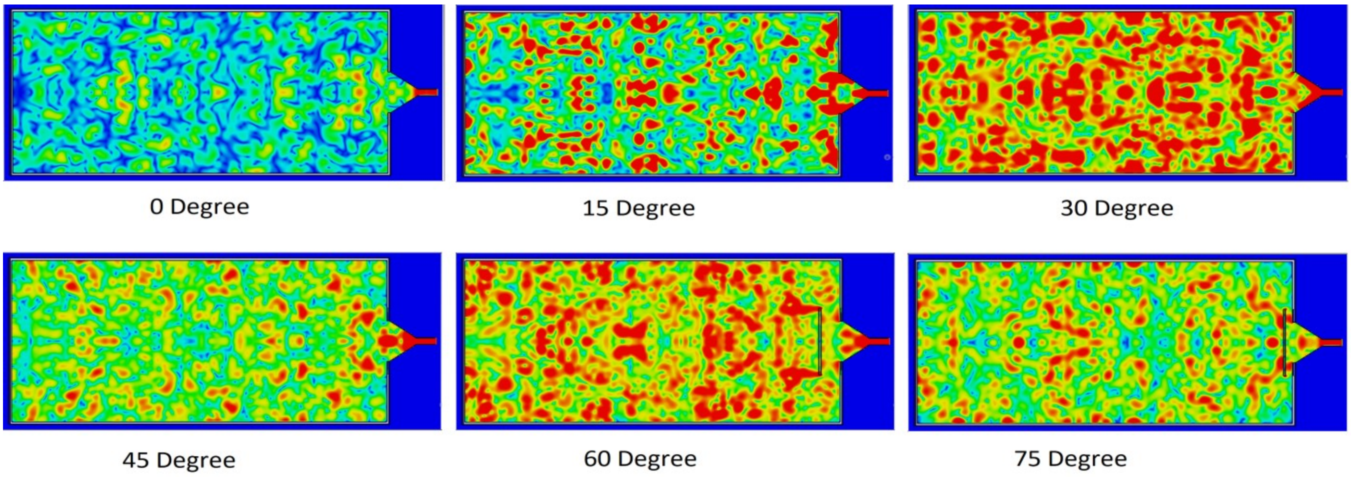

Fig. 4. Power level distribution result of 6 differemt angle

III. Results and Discussion

A. Computer Simulation Result

Power level distribution profiles for 6 different angles of wave stirring mechanism within microwave chamber were shown in three dimensions. Every location within the chamber had specific power level for specific angle configuation in wave stirring mechanism. Thus, swinging the angle of wave stirring mechanism created fluctuating power level in every location within the chamber. Simulation results can be seen in Fig. 4.

Power level of majority of the coordinates within the chamber fluctuated from slightly low to slightly high, creating medium spots. These medium spots enabled better condition for heat uniformity. Even though not dominant, there were some coordinates which only fluctuated from low to medium (cold spots) and some other fluctuated only from medium to high (hot spots).

Five spots with different power level were determined for experimental validation. The ratio between the lowest and the highest power level was 400%. Coordinates and power level of those sample spots can be seen in Table 1.

Table 1. Location and power level of sample spots

Spot Code	Power Level (10^4 V.A / m^2)	3D Coordinates		
		X	Y	Z
A	6	25,5	-47,7	119,4
B	9	0,4	-47,7	35,1
C	12	8,7	-47,7	176,1
D	18	15,2	-47,7	96,6
E	24	6,9	-47,7	127,4

B. Experimental Validation Result

To obtain the temperature increment pattern, five different patterns for temperature increment were obtained from 5 sample spots. It was observed that spot A, with the lowest power level which was 6. 104 V.A /m2, required 24:03 minutes to reach 70 ^{0}C. While for the similar duration, spot E with the highest power level of 24.104 V. A/m2, had almost reached 80 ^{0}C.

It was observed that the duration to increase 1 ^{0}C was getting longer as the temperature of the sample increased. It was also observed that four-fold power level difference only created 10 ^{0}C difference in temperature when the objects were heated for 24 minutes. Details can be seen in Fig 5.

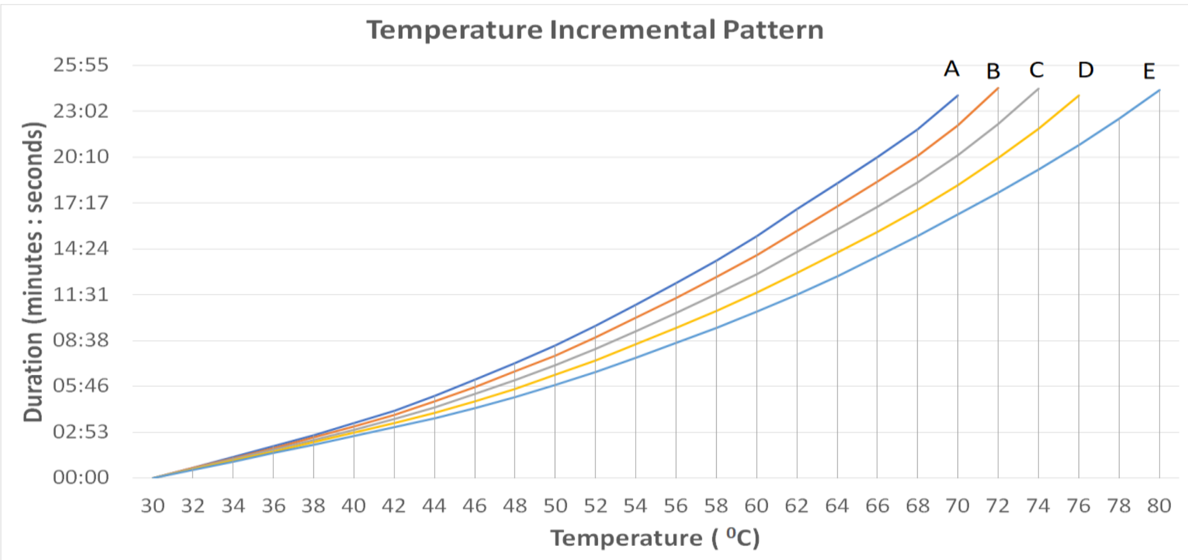

Fig. 5. Temperature incremental pattern in 5 sample spots

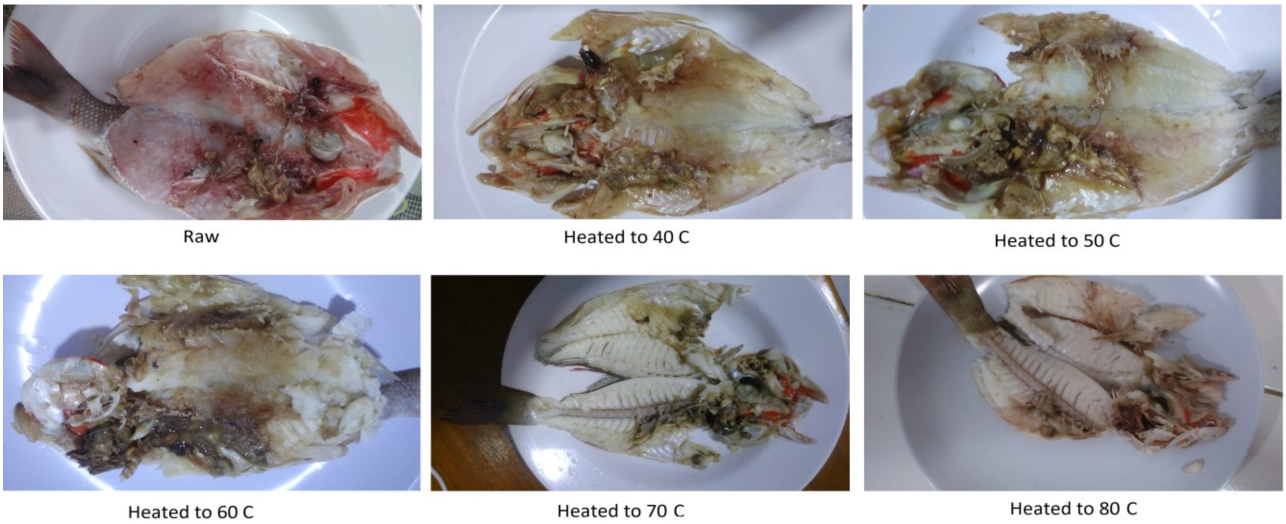

Fig. 6. Comparison of fish samples (they are split in two after being heated to see the inner condition of the samples)

C. Discussion

1) Stirring mechanism control

The swinging range and speed of wave stirring mechanism can be controlled by implementing a small electric motor with speed and angle controller. This swinging process works like windshield wiper in the car.

2) Optimum operation

Fish gets rotten when the number of microbes reach $5x10^5$ CFU/g [9]. It is usually happened around 8-12 hours in tropical countries. So, it is safe to schedule the operation of this microwave heating device to run for 25 minutes every 4-6 hours. This opeation schedule eliminates the microbes when their population is still small.

Further optimization will need artificial intelligence approach to bring optimum result. The object of optimization are the heating duration and range of angle of wave stirring mechanism while the dimension of the chamber, the amount and power of magnetron are presumably fixed.

3) Safety implementation

Safety concern needs to be fully satisfied to implement this solution in fishing industries. The inside wall of fish storage room must be covered with metal plate, preferably aluminum due to its low cost, lightweight and anti-corrosion feature. The storage room must also be sealed properly and auto shut off mechanism must be in place just like safety mechanism in regular microwave oven.

4) Economic impact

The heating duration to kill the microbes is around 25 minutes. This heating process should only be repeated for every 4-6 hours to keep the number of microbes low, totalling only around 2 hours of daily operation. The total energy cost needed for this solution is much less than current novel method, deep freezing, that requires high power and nonstop operation.

The low energy requirement enables the use of smaller and cheaper generator set and smaller fuel tank, thus provide more space for fish storage that generates more revenue and low operational cost.

The implementation cost of this solution is also incredibly low since magnetron as the main component can be found in every microwave oven and had been produced massively since 1950. Aluminum plate as the main material for the system is also quite common and available in low price. All these factor leads to smaller owning and operating cost while enabling larger revenue for fishing industry.

5) Fish condition

Even though 6 different fishes from the same species and similar size are used as samples in heating condition, there is not much difference of fish inner condition after being heated above 40 ^{0}C. Comparison of fish condition after being heated to different temperature can be seen in Fig. 6.

The fish condition after the heating process might be the main obstacle for implementing this solution for fishing industry. The fish condition is not raw anymore, it is half cooked. This obstacle can be eliminated by educating the market about the advantage of half cooked fish while offering them lower price due to lower production cost. Most of the consumer cook their fish anyway. This condition had already settled in milk industry in the past. Currently almost no consumer drinks raw milk without pasteurization process anymore.

IV. Conclusion

Microwaves heat objects directly and faster than conventional heating. However, microwave heating provides uneven temperature distributions. An electromagnetic wave stirring mechanism was proposed to overcome this problem. 6 different angle of wave stirring mechanism were tested in computer simulation. Simulation results showed that the use of wave stirring mechanism created fluctuation in power level in every location within the chamber. Thus, providing better temperature uniformity.

Experimental validation was carried out in 5 location with specific power level to get their specific temperature incremental pattern. The result showed that to achieve lethal temperature for microbes while avoiding object overheating, heating duration should be set on 25 minutes. The heating process should be repeated regularly every 4-6 hours to avoid rotting process.

Microwave heating can be used as the new alternative for fish preservation method for fishing industry. Further research on the optimum dimension, swinging speed and range of swinging degree of metallic plates as well as heating duration and operation schedule are needed to further increase its technical and economic performance.

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