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Heating Effects of Microwave Radiation on Disposable Materials in the Presence of Various Soaking Media

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Abstract:

The ability of various soaking media in enhancing the temperature of waste materials, once they are exposed to microwaves has been investigated. Such information helps development of microwave techniques to destroy viruses, spores and other microorganisms by temperature enhancement if they may not be affected by microwave radiation itself. Oily media were observed to have higher elevation in temperature; however, they have the inherent drawback of sticking into the inner surface of the container. Such drawbacks can be minimized by using enclosed non-stick container for the microwave application.

Among aqueous fluids, commonly found detergent solution showed the best performance in raising the temperature. Such material has many other advantages such as, low cost, non-toxic nature, environment friendliness, ready availability etc.

Keywords: Microwave radiation; treatment; temperature; thermal effects; microorganism.

1.Introduction:

The term 'microwave waste treatment' is used to refer irradiation of waste treatment technology by use of microwaves. Microwave treatments is one of the most emerging physical disinfection techniques because in many cases provides distinct advantages over conventional techniques in terms of product properties, inexpensive, process time saving, environmental compatibility, lower cost, greater speed, and suitable for a wide range of materials and waste (Appleton, Colder et al. 2005, Kothari V. 2011, Salema and Ani 2011, Chandrasekaran, Ramanathan et al. 2013, Aguilar-Reynosa, Romaní et al. 2017). Microwave technique is based on the radiation ability to alter physical and chemical in addition to biological properties of waste.

Microwaves in general are very short wavelength electromagnetic waves which have a wide frequency range extending from infrared to radio waves (Diaz, Savage et al. 2005, Moliere 2005, Ha, Kim et al. 2013, Hamoud-Agha, Curet et al. 2013). Microwaves are generated in a special oscillator by converting electrical energy into radiation energy. The most dominant frequency spectrum that is used to treat waste is 2.450 GHz (Menéndez, Arenillas et al. 2010, Oliveira, Nogueira et al. 2010, Chandrasekaran, Ramanathan et al. 2013, Nasri, Daghfous et al. 2013). At this frequency, the molecules in the waste vibrate at 2450 million times per second and this leads to the generation of heat and the breaking of internal chemical bonds inside the waste. From biological side, due to the presence of water as a component of every biological system, microwave radiation can much enhance the microorganism lethal rate by resonance phenomena(Hamoud-Agha, Curet et al. 2013). In addition to the radiation effect, the thermal effect which produced from heat generated indirectly by microwave radiation can be considered as a one of the best form of energy that can disinfect and sterilize a wide range of wastes.

In microwave waste treatment, the heat generation differs from other thermal waste treatments as the heat is generated from inside the waste molecules and transferred to the outside surface, whereas other methods apply heat to the outside of the waste (Popescu, Misawa et al. 2008, (EPA) 2009, Hossain, Santhanam et al. 2011, Chandrasekaran, Ramanathan et al. 2013).

The abovementioned heat that generated from microwave radiation is dependent on the ability of a particular substance to absorb microwave energy and effectively convert the electromagnetic radiation energy into heat (Chandrasekaran, Ramanathan et al. 2013, Gonzalez-Arenzana, Santamaria et al. 2013, Hamoud-Agha, Curet et al. 2013, Jerby 2017). Moreover, the specific heat of materials that subjected to microwave radiation is an important property in the thermal behaviour of those materials. For this reason, products with a low specific heat such as oil may heat very rapidly, and even faster than water of the same weight as those stated by sources (Umesh Hebbar, Rastogi et al. 2012). The health care waste (HCW) contains various types of microorganisms as fungi, viruses and spores which are lethally affected by the thermal effect of microwave during the waste treatment (McDonnell 2007, Oliveira, Nogueira et al. 2010, Hashim, Mahrouq et al. 2011). Although extensive research has been carried out on the effect of increasing heat on microbes, no research is available which adequately covers how to increase the generated heat by microwave by using additive.

Hence, the major objective of this study is to accelerate rise the temperature generated from the microwave by adding some of soaking materials. The results can be used to develop the HCW treatment by the microwave technique by using minimum consuming power, treatment time and the operating cost as a result.

2.Material and methods:

In this study, thermal effect of microwave radiation on gauzes was discussed in term of possibility to rise the generated temperature from the radiation. The main item used in this study was a domestic microwave oven. The microwave oven was a Panasonic model (NN-GD570 S) with a frequency of 2450 MHz (0.1225 m wavelength) and a capacity of 27 L and also Pyrex cookware Visions VSD-3.5, as shown in Fig. 1 (the cookware contents gauzes inside the microwave), in addition, an IR thermometer Fluke mini 62, Fig. 2, were used. The items mentioned below were also used for each experimental work:

1. Facial cotton (gauzes) 5*5 cm
2. Deionized water
3. Detergent (dish washer) brand Sunlight
4. Denatured ethanol 70 %
5. Reduced salt Margarine
6. Soya bean oil brand Vesoya
7. Corn oil brand Daisy
8. Palm oil brand Vesawit
9. Engine (Motor) oil brand Shell HELIX HX5 10W-30

2.1 Calibration of the Microwave Oven:

It was essential to calibrate the microwave oven used for the experiments before the disposable items (facial cotton or gauze) were exposed to microwave radiation in a range of powers. The oven device was set to operate at 10 % or 30 % of its nominal power, according to the manufacturer's instructions. At first, 1000 g of distilled water was placed in a 1500 mL glass beaker. The initial temperature of the water was measured by using an IR thermometer Fluke mini 62 as shown in Fig. **2**. Then the glass beaker was put inside the oven device in the middle point, after which the oven was set to work for 120 seconds at 100 W or 300 W. The beaker was then replaced and the temperature of the water measured again. The experiment was implemented in three times to get the real dissipated power, which was calculated by the principle of conservation of energy, using the following formula.

$$P = \frac{M_A \cdot C_{PA} \cdot \Delta T}{t} + \frac{M_V \cdot C_{PV} \cdot \Delta T}{t} \quad (1)$$

where P is the real power absorbed by the sample (W), M_A and M_V are the mass of the water sample and the glass beaker (kg) respectively, C_{PA} and C_{PV} are the specific heat of the water and the specific heat of the glass (J/kg K) respectively, t is the time (s), whereas ΔT is the temperature difference (K). The temperature of the glass was theoretically assumed to be the same as that of the water in each calibration test (Schubert and Regier 2005, Tonuci, Paschoalatto et al. 2008, Leadbeater 2010, Oliveira, Nogueira et al. 2010).

Fig. 1: Domestic microwave Panasonic model (NN-GD570 S

Fig. 2: IR Thermometer

2.2 Assessment of Applying Microwave Radiation on Soaked Materials:

An investigation was conducted to examine whether adding various solutions to the disposable items will raise the generated temperature, by significant amount. The microwave oven was set to operate at 100 W, 300 W, 550 W, 700 W, and 1000 W for 2.5, 5, and 10 minutes. Three pieces of facial cotton (gauzes) were placed at the centre of Pyrex cookware each time and then 10 ml from each liquid was added to these pieces of facial cotton. The temperature of the items at the starting point was hypothetically assumed to be the same as room temperature 28°C.

The first trial was conducted without any added liquid i.e. just three pieces of facial cotton so it is treated as the reference material, in order to make a clear comparison between absolute materials and materials soaked with liquids. Added liquids were categorized in to two main groups. The first group consisted of aqueous materials, namely, water, detergent (dish washing liquid), and denatured ethanol (70 % concentration). The second group were oily or greasy solutions, namely, reduced salt margarine, soya bean oil, corn oil, palm oil, and motor oil.

After setting the operation of the microwave power, microwave energy was applied on three pieces of facial cotton, reference material, at the above mentioned powers and time durations. Once the time period is finished and the microwave oven is stopped, the IR thermometer was used to measure the temperature of the three facial cotton pieces to obtain three values and then the average temperature. The same steps were repeated with different facial cotton pieces, the same microwave power and 10 mL of specific solution, but with different time durations.

3. Results and discussion:

The fact is that not all microorganisms which are present in HCW are adversely affected by microwave radiation alone. In addition, HCW contains other pathogenic microorganisms such as fungi, viruses and spores i.e. *Bacillus atrophaeus*, *Geobacillus* and *Clostridium* which are not affected by microwave radiation (McDonnell 2007, Oliveira, Nogueira et al. 2010). In contrast, these microorganisms are only lethally affected solely by the thermal effect (Hashim, Mahrouq et al. 2011). This work objectively investigates the possibility of raising the temperature of the disposable items which are soaked with different liquids and materials. The results of this study can be considered as a preliminary study that can be used to improve the waste treatment process by using the microwave technique. This can be achieved by a rise in temperature generated indirectly by microwaves to kill the aforementioned microorganisms, which otherwise are not affected by microwave radiation but are affected by thermal treatment so as to consume less power and time

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such that the treatment will be more economical as a result. The discussion in this section of the current study is divided into three groups depending on the nature of the added materials and to facilitate understanding of the effect of added materials on the temperature of the samples and to ease comparison between them. The first group is without added materials, the second is the effect of adding aqueous solutions and finally the effect of adding oily materials on the rise of temperature of the samples. However, the materials used were selected as representative materials with following qualities: Easy to find or prepare and easy to apply, non-toxic and having less environmental impact, low cost.

Fig. 3 refers to the discussion points in this section whereby the effect of the three variables (applied microwave power, treatment time, and effect of added auxiliary materials) on the temperature of the samples discussed.

The discussion in the following sections starts with the first group which examines the influence of changing the applied power and time together with reference material on the temperatures of the gauze as a base line for comparison. The second group investigates the increase in temperature by the use of aqueous solutions. Lastly, the effect of adding different oil based materials is explored as a third group to find out which one of the materials used will cause a change in temperature of the disposable items more than the others.

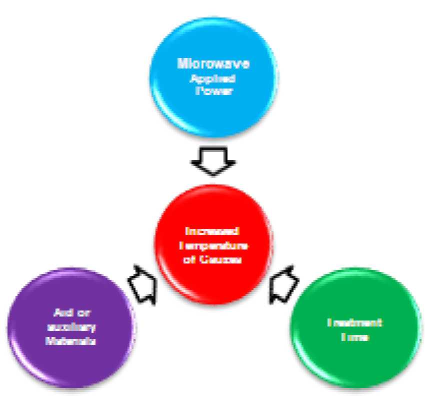

Fig. 3: Factors influencing the rise in temperature.

3.1 Temperature Increment of Materials:

The experimental data that shows the effect of the changes due to microwave radiation and time on the temperature of the tested gauzes without any added material is presented in Fig. 4. This Fig. shows that there is a notable increase in temperature with microwave radiation power. The same correlation was observed between the duration of applying radiation and the temperature. This refers back to the microwave phenomena which can be explained by the dissipated power of 1000 W which causes a stronger vibration of the particles than the other powers of 700 W, 550 W, 300 W, and 100 W respectively. As a result, this leads to a higher rise in temperature resulting from exposure to 1000 W than for instance the other power values. In addition, according to the time duration for particle vibration the period of 10 minutes is longer than for 5 and 2.5 minutes respectively, which leads to greater friction between the particles that generate more heat which is expressed by an increase in temperature of the disposable items. The results of this section are shown in Fig. 4 which can be considered as a baseline or reference for comparison with the added materials to show the effect of those added materials on the temperature rise.

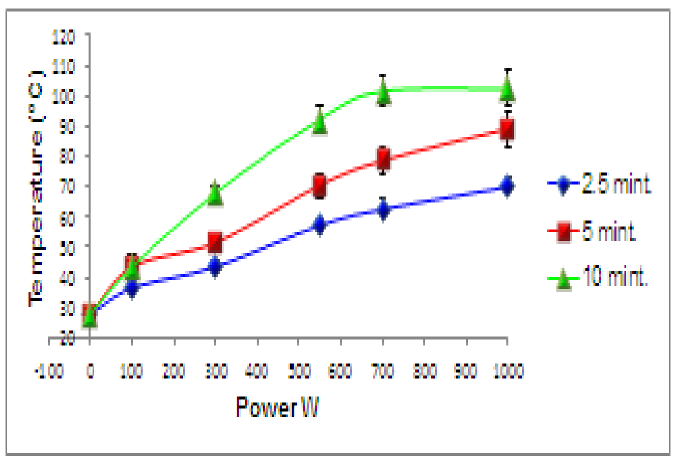

Fig.4: Temperature trends of microwave radiation power and microwave radiation duration

It is also worth noting that the temperature with less change when the disposable items were subjected to 700-1000 W after 10 minutes where the temperature slightly increased from 101- 102.3 °C. In addition, Fig. 5.a shows the original gauze, meanwhile, burn marks were observed on the facial cotton gauze after they were applied to microwave radiation, as shown in Fig. 5.b and a distinctive smell of burning clothe was sensed in the laboratory. The high temperature rise stops or decreases after several minutes which may be due to the percentage humidity at the beginning which was higher at the start than in the last few minutes of the experiment.

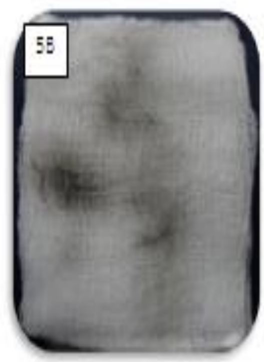

Fig. 5A: Gauzes before applying microwave	Fig.5B. After applying microwave and changing to a dark colour microwave radiation

3.2 Temperature Increment in the Presence of Aqueous Solutions:

An experiment was designed and several tests were conducted to determine the effects of adding a small amount (10 mL) of aqueous solution on the temperature rise of the disposable gauze tested. The soaked gauzes were subjected to the same range of applied microwave power as in the previous experiment (from 100 W to 1000 W) and again the experiments were repeated with three time durations (2.5, 5, and 10 minutes). The aqueous solutions tested were tap water, denatured ethanol 70 % and detergent solution. As presented in Fig. 6, Fig. 7, and Fig. 8 the temperature of the disposable gauzes with reference material from Section .3.1. can be considered as a baseline for comparison with these three groups to show the effect of adding the aforementioned aqueous solutions on the increase of temperature.

In general, it is confirmed from Fig. 6, Fig. 7 and Fig. 8 which show the three sets of power Vs temperature graphs where the temperature increase occurs in direct proportion to the power of the microwave radiation and time for all trends. Starting with the first set of results for 2.5 minute duration as presented in Fig. 6, the temperature rise of gauze is almost twofold for all trends for the tested gauzes as compared to the control temperature (28°C). For the gauzes soaked with detergent solution, the temperature reached 85.3°C, which is the highest temperature as compared to the gauzes soaked with tap water and Ethanol 70 % solution and the trend for the gauzes with reference material. At the end of this set 2.5 minute duration, the temperatures of the gauze soaked in Ethanol 70 % solution and reference material were very close with only a slight difference whereby the Ethanol trend rose to 72 °C and the latter rose to 70 °C.

Contrary to expectations with regard to the gauzes soaked with Ethanol, the second and third sets presented in Fig. 7 and Fig. 8 show interesting results. The temperature trend of Ethanol in the abovementioned figures show that even with a power increase of more than 300 W, the trend presents a marked levelling off. In addition, the temperature for reference material after 300 W becomes more than that for Ethanol which gave no corresponding temperature rise after 300 W still the end of the experiments for both the second and third sets. The most likely cause has been presented recently by Geng and others as they attributed this type of result to the low evaporation point of Ethanol (Geng, Xin et al. 2012). In addition, Ethanol tends to combine with water molecules in the surrounding area for the sample tested and evaporates at a relatively low temperature which makes the environment around the area of the samples drier than that for the gauzes with reference material, and thus will not be

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allowed to heat up further (Geng, Xin et al. 2012, Jia, Qiao et al. 2013). These results were not encouraging for the use of ethanol as a soaking material to increase the temperature in the waste treatment process.

Turning to the comparison between the temperatures of the gauzes soaked with water and those soaked with a detergent solution, in the third set for the 10 minute duration, it is shown in Fig. 8 that the temperature of the gauzes soaked with tap water under 1000 W lies between that of the gauzes soaked with detergent solution and reference material (110.3 °C). In addition, it was more than the temperature achieved by the gauze soaked with Ethanol. This combination of findings provides some support for the conceptual premise as reported by Leadbeater in his book in which he stated that water is more efficient than Ethanol in converting incident microwave power into heat energy (Leadbeater 2010). Consequently, the temperature of the water soaked gauzes is higher than those for ethanol. In addition, the evaporation point of Ethanol is less than that for water as discussed before. This causes the area surrounding the Ethanol gauzes to become dry earlier than the water soaked gauzes which thus prevents an increase in temperature. The highest temperature of all sets of aqueous solutions was (128 C). This temperature was achieved by adding detergent at 10 minute duration under 1000 W as presented in Fig. 8. This result provides further support for the fact as concluded by Oliveira and his team who found in their study that the detergent material absorbs microwave radiation more efficiently than other aqueous solutions (Oliveira, Nogueira et al. 2010). Consequently, this leads to gauzes soaked with detergent to achieve the highest temperature increase from among the other aqueous solutions used. An interesting observation for the detergent solution was that the tested gauzes swelled or expanded like dough after applying microwave radiation as shown in Fig. 9A for untreated gauze and Fig.9B for soaked with detergent and treated gauze. This phenomenon may be due to the radiation which caused vibration in the molecules of the detergent solution that generated foam as shown in Fig. 9. This observed result leads to form a homogenous thermal distribution among the treated material particles which enhances the treatment process. These findings have important implications for developing HCW treatment by adding detergent solution to the HCW that is to be treated by microwave radiation rather than using the other tested aqueous solutions to increase the temperature.

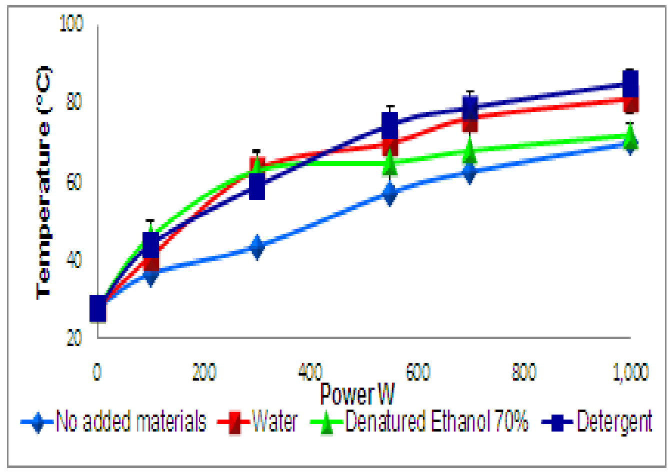

Fig. 6: Temperature/power on gauzes with aqueous solutions subjected to microwave radiation for 2.5 minutes

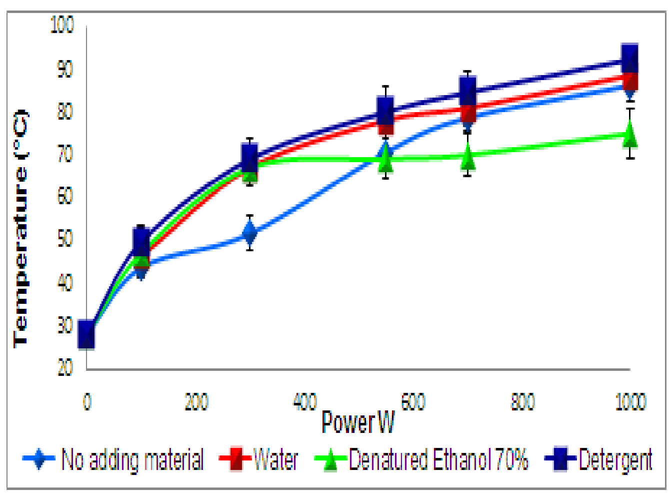

Fig. 7: Temperature/power on gauzes with aqueous solutions subjected to microwave radiation for 5 minutes

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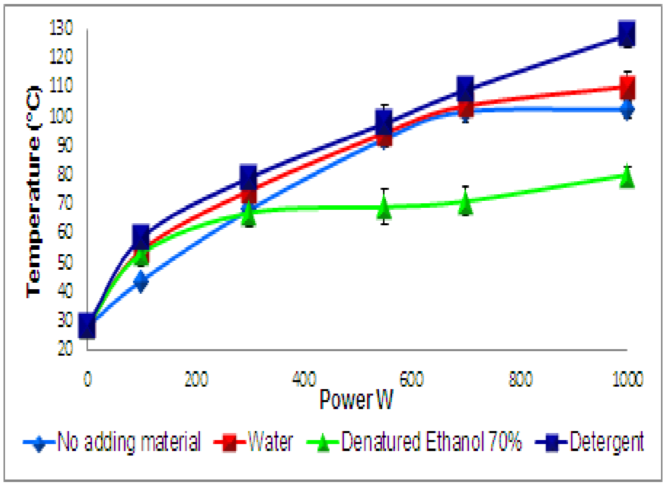

Fig. 8: Temperature/power on gauzes with aqueous solutions subjected to microwave radiation for 10 minutes

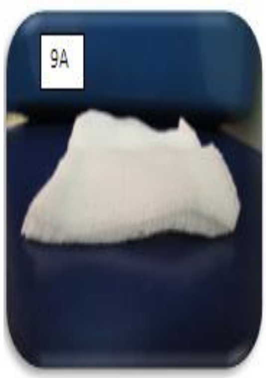

Fig. 9: (A) New facial gauze

Fig.9B:Gauze after soaking with detergent solution and applying microwave radiation

3.3Temperature Increment of Disposables using Oily Materials:

The third set of data gave an insight into the temperature ranges generated by applying microwave radiation to gauzes soaked with various oil based materials. The oils tested were corn oil, soya bean oil, palm oil, as organic oils and engine oil as synthetic oil. The experiments were also extended to test the effect of soaking the gauzes with margarine. From the data summarized in Fig. 10, Fig. 11, and Fig. 12, the increased temperatures of gauze were similar to those with the previous two groups, namely with reference substances and aqueous solutions. This implies that that the gauze temperatures were raised with increasing microwave power and applied time. Generally, the margarine reached the highest value of temperatures followed by the corn oil, soya bean oil, palm oil, and then the engine oil for the three time intervals. As shown in Fig. 10, the largest difference in the final temperature of the gauzes after 2.5 minutes was 43°C between the margarine at 100°C and engine oil at 57°C. The lowest rise in temperature for the engine oil was due to the fact that it is originally designed to decrease the heat generated in a vehicle engine (Neal and Neal 2013, Wang, Lv et al. 2013). In contrast, the temperature of the gauzes of the three other oils and the gauze with reference material fluctuated from 69.6°C for palm oil, 70°C for the reference material, 71.6 °C for soya bean oil, and 78.3 °C for corn oil. When microwave power was applied for 5 minutes as in Fig. 11, the same increasing trend was noted, but at a slower rate of increase. This result reflects the ability of oily materials to absorb and turn incident microwave radiation into kinetic energy to appear as a heat over time (Leadbeater 2010, Encinar, Gonzalez et al. 2012). Finally, with regard to the experiment of applying microwave radiation for 10 minutes, the results are shown in Fig. 12. The highest temperature for gauzes soaked in oily materials was achieved by the margarine oil at 148.3°C. The gauzes soaked in corn oil reached 145.6 °C, followed by gauzes with soya bean 143 °C, 141.6 °C for Palm oil, and 136 °C for gauzes soaked in engine oil. To sum up, the observed differences were obvious between the gauzes with oily materials and without additional materials. This situation clarifies that the efficiency to absorb microwave radiation rises sharply in the presence of oil based materials which was the contributing factor that influenced the increase in temperature of the disposable items. Hence, oily materials can be considered as an accelerating factor for heating process of HCW (Farag, Sobhy et al. 2012). Oily material may be an appropriate method to increase the temperature of the HCW. The gauze soaked in margarine turned to a dark colour at the end of microwaves application as shown in Fig. 13.

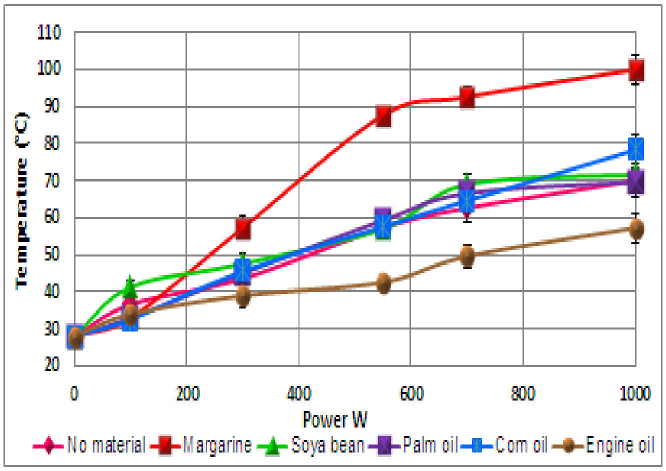

Fig. 10: Temperature/power for gauzes with oily materials subjected to microwave radiation for 2.5 minutes

stuck on the internal walls of the Pyrex cookware in such a way that it was difficult to clean for reuse in further experiments. This evidence indicates a disadvantage of using oily materials to be added to the HCW in microwave treatment of HCW.

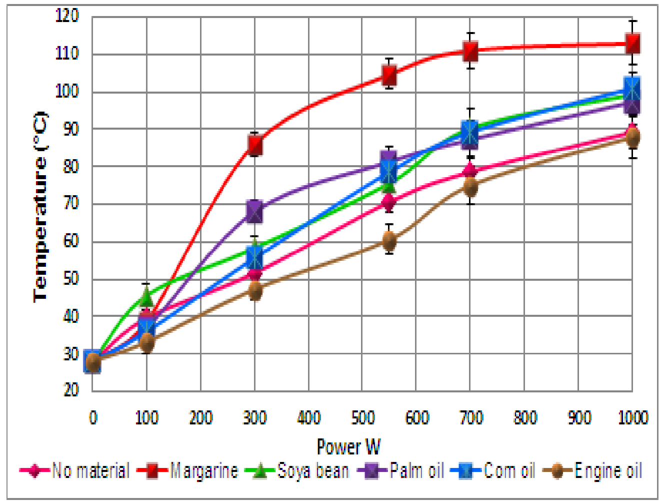

Fig. 11: Temperature/power for gauzes with oily materials subjected to microwave radiation for 5 minutes

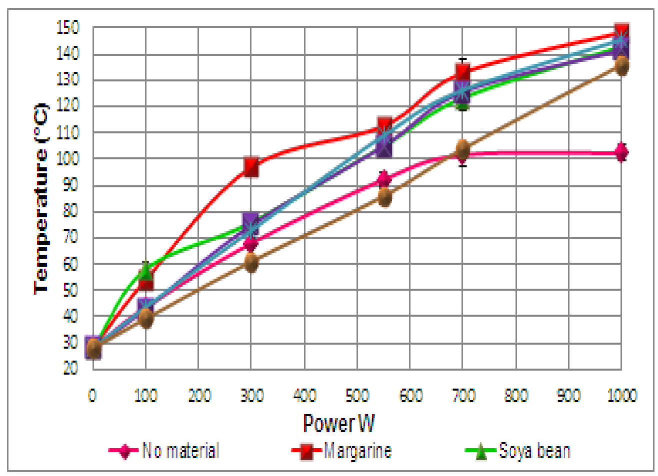

Fig. 12: Temperature/power for gauzes with oily materials subjected to microwave radiation for 10 minutes

Fig. 13: Burn margarine oil after applying microwave radiation.

4.Conclusion:

This study shows the improvements of waste treatment by electromagnetic waves (microwave) in the presence of additive materials to elevate the generated temperature. For the viruses, spores and all microorganisms which may not be affected by microwave radiation, the temperature can be considered as the most important factor that should be taken into account in the disinfection and treatment processes. In the current study, the obtained results show which one of the additive materials tested has the greatest effect in elevating the temperature of the samples.

For all cases considered, it is clear that the temperature increases with the increase of applied microwave power and processing duration. It has been determined that applying microwaves to samples in the presence of an oily medium can elevate the temperature more than that for the other additives. However there are several disadvantages of such media as well. One of the most significant limitations in using oil based materials lies in the fact that when the temperature rises, oily materials burn, which leads to environmental pollution in the surrounding area in addition to the stickiness of the treated materials which causes difficulty in cleaning the equipment used. Such drawbacks can be minimized by using enclosed non-stick container for the microwave application.

Turning to the aqueous fluids, the detergent solution is suggested as the best for the purpose of raising the temperature compared to the other solutions. The properties of aqueous solutions may be due to their ability to absorb the incident microwave energy and increase the temperature of a sample. In addition to its ease of availability, it is inexpensive and leads to uniform or homogenous thermal distribution. Homogenous thermal distribution is crucial as it is necessary to ensure that all surfaces are exposed to the disinfection temperature within the required treatment time. The most noteworthy finding to emerge from this study is that although the accompanying rise in temperature with added detergent is less than that associated with the addition of oily materials, the detergent is considered a better additive for the HCW to be treated by microwave radiation. This result is due to the aforementioned drawbacks of the use of oil based materials in this process. In this experiment, the detergent used is what is available in the market for cleaning/ washing purposes. With further experiment a much advanced detergent solution could be developed specifically for this purpose.

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