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Design of a microwave based mobile thermo-chemical unit for biomedical waste treatment

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ABSTRACT

Biomedical waste (BMW) contains pathogenic microorganisms that may severely harm the community and environment. Due to the Covid pandemic-2019, isolated wards at health care units and even due to the home treated patients; vast quantities of BMW are generated. Covid-19 converts even ordinary waste such as gloves, testing kits, and personal protective equipment into high-risk BMW. The appropriate disposal of such waste involves safety, affordability, and efficacy; hence can be considered a complex issue. A solution proposed in this article is an OSBMWTU (on-site biomedical waste treatment unit) by using microwave radiation. The possibility of enhancing the thermal effect of microwave radiation by using chemical additives was tested. The proposed machine reduces waste volume, inactivates microorganisms, and disposes BMW on-site. Findings suggest that adding butter spray to microwave radiation enhances thermal effectiveness by 43%, increasing treatment temperature while minimizing time, power, and running costs. The proposed machine will work automatically after filling the BMW, thus, minimizing the human involvement. It prevents bio-hazardous waste accumulation and decreases its volume by up to 80%. The designed machine is characterized by safety, low cost, and small dimensions. A machine that can handle 72 kg BMW/day can be set up on-site in an area of 1.5 m2. The suggestion of the proposed machine as a BMW management and treatment system will reduce environmental pollution due to BMW during COVID-19 and even after the pandemic.

Keywords: Biomedical waste, Covid-19, Microwave, On-site treatment, Thermo-chemical

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1. Introduction

Different types of wastes accumulate every year over the world [1, 2]. Treatment of these wastes or recycling them can decrease their harmful effects and support the sustainability [3-5]. The emergence of modern diagnostic and treatment medicinal procedures has produced a by-product that presents a significant challenge to the world, a threat to the environment. Therefore, it is an issue of global concern. Nevertheless, the inaccurate waste management practices adopted in medical centers worldwide threaten people in and outside hospitals and also the ecosystem [6]. More than 5 million people worldwide lose their lives, and most are children, due to improper BMW management [7]. Although many efforts have been made to overcome the deficiencies in BMW management, there are many challenges in the implementation of improvements by government and NGO sectors, such as color-coding proposed by WHO. The worker awareness and costs are the greatest barriers [8]. Due to the COVID-19 pandemic, the BMW generated from hospitals and quarantine centers required particular concern [9]. In the COVID-19 epidemic, a new type of BMW and apparent

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changes in the composition of these wastes has emerged [10]. COVID-19 virus transmission routes include human-to-human contact, direct contact with contaminated things, and BMW from infected individuals. The virus was alive up to 3 days after application to surfaces, such as those in hospitals, medical centers, or private quarantine [11]. Accordingly, BMW streams may be a channel for viral propagation, posing a considerable risk to health workers, operators, and the community. With limited resources and capability, many governments have committed to sterilizing BMW by autoclaving or spraying 0.5 percent chlorine solution and storing it into double bags before incineration or permitted dumping [12]. Overall, BMW ended with collection from hospitals and sent to temporary transit places under the above mentioned method. Consequently, the materials are treated and the treated waste is transferred to waste disposal centers; at this point, the amount of the generated BMW is uncertain and indeterminable, as the number of infections and its severity cannot be predictable. Furthermore, it increases the risk of ordinary waste by infecting them with high-risk BMW [13]. Mixing of shredded items may also contaminate the entire pile of BMW rapidly, even if the microbes are contained only in one small component (Figure 1). This mode of handling BMW may also cause many other problems as the collected waste by bags may overfill, tear open, or be deflated, releasing the infectious materials. As a result, the management style of temporary BMW storage and transit stages is inadequate or at least at an undesirable level. Thus, whatever the followed style of managing and disposing of BMW, it is challenging to control spreading the virus among patients and the surrounding community who knowingly and unknowingly encounter this waste. On the other hand, it may contaminate natural resources when the land-filling is dome with fillings that contain traces of hazardous BMW [14]. Therefore, an effective and practical solution is required, to reduce the adverse effects of BMW. Different methods have been proposed to decontaminate the BMW; one of these techniques is electromagnetic waves (microwave). Specific conditions have to be taken into accounts, such as keeping the sites (operating theaters, ICU wards, and medical laboratories) clean and free of smoke; hence, microwave radiation treatment technology meets these requirements. Microwave technique has two factors on microorganism disinfection. The first is that the radiation itself can reduce the effectiveness of microbes sometimes even down to 0%. The second is the thermal effect [15]. Corona-viruses survive for a short time at higher temperatures, and according to literature, the recommended temperature for thermally destroying corona-virus is greater than 75℃ for three min. of exposure time or greater than 60℃ for 20 min. exposure time [16].

The objective of this study is to introduce practical solutions to solve BMW management and treatment deficiency under any circumstances in general or specifically during the pandemic to avoid human and environmental infection. With consideration to the thermal effect of microwave radiation in microorganism disinfection, current research employs this effect in designing an On-site BMW Treatment Unit (OSBMWTU), which can be considered to be an improved technique to disinfect the BMW from viruses and hazardous microorganisms. Furthermore, the influence of several chemical additions was investigated to make the BMW treatment process more efficient and cost-effective by increasing treatment temperatures and decreasing the amount of electrical energy used and the treatment time. The proposed designs are smoke-free, highly effective, fast, and easy to operation

2. Materials and methods

This study can broadly be divided into two parts. In the first part several fluids were applied to a prepared sample that represent BMW and subjected to several doses of microwave radiation. The objective was to find the effects of these fluids in increasing the thermal dissipation. The fluids were selected on the knowledge acquired from previously done experiments [17] and trial & error applications (Table 1). In the other part of the work, an OSBMWTU machine was design with estimated optimum parameters, dimensions, and settings. The outcome of the first part has been employed to enhance the heating effect of the designed machine.

3. Experimental work

The artificial BMW samples were prepared by shredding unused scalp veins, syringes, blood bags, disposable infusion sets etc. following the practices described in literature [18]. Figure 2 depicts the components used for samples and Figure 3 shows author preparing the samples in the laboratory. A sample of shredded materials was shown in Figure 1. Once the components were shredded and mixed they were sampled into 0.5 kg portions. Each sample contained approximately 30% hard plastic, 28% plastic film, 37% fabric and paper and 5% metal and rubber by weight. Four types of fluids and semi-fluids have been prepared with following composition:

Distilled water (DW)

Ethanol 70% (ET)
Common detergent mixed with equal volume of water (DT)
Melted cow butter (MB)

Figure 1. Shredded BMW: mixing of small pieces of shredded components rapidly contaminate the entire pile of waste

Table 1. Reasons for selecting the fluids for spraying

Fluid	Reason behind choosing
[1]DW	Increase the treatment temperature generated by microwave radiation in a safe and cost-effective manner
ET	Synergistic effect of alcohols for the inactivation protocol of the COVID-19 virus and many other microorganisms.
DT	Economical and available low-cost material that control the proliferation of viruses and bacteria [17]
MB	The fatty materials attain high temperatures rapidly under the application of microwaves

[1]DW: Distilled water, ET: ethanol 70%, Detergent in water, MB: melted butter

Figure 2. Components used to prepare samples of BMW

Figure 3. Preparation of the samples in the laboratory

Each fluid was sprayed on a separate BMW sample, with a commonly found spray gun. Volumetric measurements show that for every fluid, a single spray shot emits 0.52 ml on average. Each sample of 0.5 kg mass was sprayed with 20 shots of fluid. Thus, each sample received approximately 10.4 ml of fluid. The Sample was placed in the middle of a 21 l microwave oven with variable power settings that range from 100 W to 1000W. As per the availability of instrument settings, samples were applied with microwaves of power at 100 W, 300 W, 550 W, 700 W and 1000 W. Samples were exposed to microwaves for 3 min, 5 min and 10 min. In each case, the experiment was repeated three times and the average values obtained have been presented under results. Immediately after applying microwaves, the temperature of the sample was measured with a universal infrared laser surface thermometer (Bosch) with range -30 °C to +500 °C and precision of 0.1 °C. Depending on the outcomes of experimental work, sketches and drawings of the OSBMWTU machine were prepared separately and integrated them to develop a complete set of detailed drawings, engineering drawings, sub-assemblies, and assembly drawings were prepared using AutoCAD software. Previously published work has been adopted as guidelines [18].

4. Results and discussion

4.1. Experimental work

Table 2 indicates the effect of adding fluids under several periods of exposure and power ratings, in increasing the temperature of the treatment. The presence of these fluids in the disinfection procedure leads to shorter time of application, lower power and increases the microorganism reduction speed in the treatment process. As it is expected the temperature of the sample with no fluid spray or a given fluid spray increases with either the time of exposure or the power. When both factors are increased together, the temperature increment is higher. All though a linear correlation is not visible the following observations were made with respect to the temperature increment and difference (Diff.) of samples with each fluid sprayed where Diff. is defined as,

$$Diff. = \frac{T_F - T_{NF}}{T_{NF}} \times 100\ \%$$

TNF: Temperature of sample with no fluid sprayed
TF: Temperature of sample with fluid sprayed.
The negative sign of Diff. indicates that the temperature of the sample sprayed with a fluid at the end of the application of microwaves is less than that of the sample with no fluid sprayed.

- The temperature of material without any fluid added increases with microwave power and time of exposure due to the moisture in the sample. During the time of experiment, the relative humidity of the laboratory was around 60%-70%. The outcomes would have changed slightly under different RH conditions.

- Application of distilled water leads to a moderate increase in the thermal effect of microwaves. Understandably the *Diff.* gave a positive value in all cases, as the number of water molecules available for acquiring rotational and vibration energy at resonance frequency (2.45 GHz) is higher than that in the sample with no fluid sprayed. The maximum *Diff.* was observed at the power of 300 W and exposure time of 3 min. The *Diff.* has a decreasing trend with increasing power and exposure time. A possible reason may be the evaporation of water molecules thus after a certain time of exposure at a given power there may be only a slight difference between the samples of with and without fluid sprayed. This time may be reduced with increasing power.
- The highest temperatures in general have been shown by the samples sprayed with melted butter. This category also showed consistently high values of *Diff.* as well. The heat generation of the sample under microwave exposure is still the oscillation of water molecules (note that butter has about 30% water by weight). The observation of higher temperatures in samples sprayed with MT may be due to the specific heat capacity of butter fat which is approximately 1800 J $kg^{-1}K^{-1}$ [19]. In contrast, the specific heat of the water is approximately 4200 J $kg^{-1}K^{-1}$. As the specific heat capacity of the butter is lower than that of water, it requires less energy to increase the temperature than water does. Thus, although water absorbs more energy than butter, the butter will heat up faster under microwave radiation. In terms of boiling point, since water boils at a lower temperature than butter, BMW sprinkled with butter spray seems to get much hotter than the sample with only distilled water. Accordingly, using butter spray during BMW treatment processing may be an appropriate method to increase the thermal effect of the electromagnetic waves and speed up the procedure.
- The outcomes show that the ET spray has negative impact on the temperature rise in most cases, especially, at higher microwave powers and exposure times, where *Diff.* can reach values as low as -30%. A speculated reason may be the fast evaporation of ethanol with its water content at a low temperature that leads to cooling of the medium and reducing the water content for further heating. Nevertheless, it should be noted that ethanol is a highly effective against various enveloped viruses. Ethanol can disable the virus by disintegrating the protective envelope [20]. Thus, ethanol spray may be used as a pre-treatment for disinfection of pathogens, before applying water or butter spray for microwave exposure.
- Water-detergent solution is also considered in this experiment as it has pathogen disinfecting effect in addition to the enhancement of temperature increment under microwaves. It produces reasonably good results with *Diff.* values in the 20-30 range especially for moderate power ratings and exposure times. Being a low-cost and easy to make fluid with no social issues such as that in the case of ethanol, DT could be considered as a good contender to be used as a spraying medium in many healthcare environments, especially in developing countries.

4.2. Osbmwtu machine design

The design of OSBMWTU is classified into three main parts: entry point of BMW and crusher, microwave chamber for disinfection, compressing and disposing unit.

Entry point and crusher: Entrance and crusher parts of the machine consist of a feeder box of dimensions 30 cm × 30 cm × 10 cm and an automatic open/close trap-gate to feed BMW (top loading) to the crushing chamber. The gates, once opened have an opening area of 31 cm × 10 cm. There is a gap of 1 cm between the opened gates and the crusher blades. The shredding chamber has two crusher blades (figure 4 and 5), and a drive shaft connected to an electric motor. Figure 6 depicts its appearance inside the machine. The upper part occupies 70 cm of the total height of the machine (Figure 7). The shredded/crushed materials are directed to the microwave chamber through a hopper of which the upper surface dimensions are 35 cm × 10 cm with a total height of 30 cm (Figure 4 and 7). Due to the undesired noise generated in the crushing process this whole part should be covered with soundproof materials. This is of significance as the machine is designed to be used in patient wards.

Microwave chamber: After the shredding process, BMW move to the microwave chamber through the hopper (Figure 5). The microwave chamber has two center opening doors, one as an inlet and the second as an outlet to dispose BMW to the compressing unit. The magnetron and electronics will be placed outside the chamber and enclosed with a suitable electromagnetic shielding material to minimize outward penetration of stray radiation.

Microwave chamber: After the shredding process, BMW move to the microwave chamber through the hopper (Figure 4). The microwave chamber has two center opening doors, one as an inlet and the second as an outlet to dispose BMW to the compressing unit. The magnetron and electronics will be placed outside the chamber and enclosed with a suitable electromagnetic shielding material to minimize outward penetration of stray radiation.

Table 2. Temperature attend at the end of exposure of samples to microwaves and the percentage difference between the temperature attend by the sample sprayed with fluid and that without fluid

Time (Min.)	Power (W)	No fluid	After BT Added		After DW added		After ET added		After DT added	
		Temp **(°C)**	Temp (°C)	*Diff.* (%)	Temp. (°C)	*Diff.* (%)	Temp. (°C)	*Diff.* (%)	Temp. (°C)	*Diff.* (%)
3	0	31	31	-	31	-	31	-	31	-
	100	40	36	-10	43	+8	48	+20	47	+18
	300	47	60	+28	66	+40	65	+38	62	+32
	550	60	91	+52	73	+22	67	+12	76	+27
	700	66	96	+46	78	+18	70	+24	81	+23
	1000	73	103	+41	84	+15	75	+3	87	+19
5	0	31	31	-	31	-	31	-	31	-
	100	43	41	-5	49	+14	50	+16	52	+21
	300	54	88	+63	70	+30	70	+30	71	+32
	550	74	108	+46	80	+8	72	+3	83	+12
	700	82	113	+38	83	+1	73	-11	88	+7
	1000	92	116	+26	93	+1	78	-15	96	+4
10	0	31	31	-	31	-	31	-	31	-
	100	47	57	+21	57	+21	55	+17	60	+28
	300	71	100	+41	78	+10	70	-1	82	+16
	550	95	116	+22	97	+2	72	-24	107	+13
	700	105	136	+30	107	+2	74	-30	112	+7
	1000	105	151	+44	113	+8	83	-21	130	+24

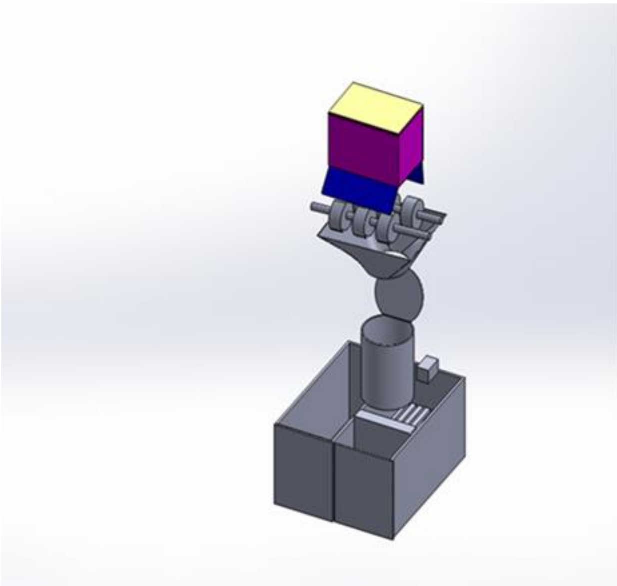

Figure 4. Components of the OSBMWTU

In addition, to ensure a good distribution of microwave radiation through particles of BMW, a movable base is provided to rotate around the vertical axis to ensure all particles are exposed to radiation. We also propose a mechanism where an auto spraying fluid container fixed to the outer body of the OSBMWTU machine, from which a tube is directed into the upper part of the microwave chamber, ending with a nozzle, to facilitate the selected fluid being sprayed to the shredded material. A vertical shaft with few blades can be fitted to the rotating base to mix up the sprayed fluid uniformly in the BMW load. All components inside the chamber should be made with materials that can withstand microwave heating. This proposed mechanism for spraying the fluid has not been included in the diagram as that is optional. If such design is not cost effective the fluid can manually be added to the BMW before inserting them into the entry box. The microwave chamber part is also designed to have 30 cm to optimize the size and function of the device. Compressing and disposing unit: The lower part of the unit contains a compressor or baler partition (Figure 5) with four wheels at the bottom of the machine (Figure 6 and 7), which has a total height of 30cm. This part also has two gates to facilitate the flow of materials from the microwave chamber (after treatment) to the compressing unit. The upper gate is used to insert materials and has a standard door with a microwave chamber. The second gate is used to push out the materials after compressing. This part consists of an electric motor connected with the part that ejects the treated waste that has been processed and compressed. The treated BMW output can be collected into either sealable disposal bags or reusable cans with appropriate covers and lids.

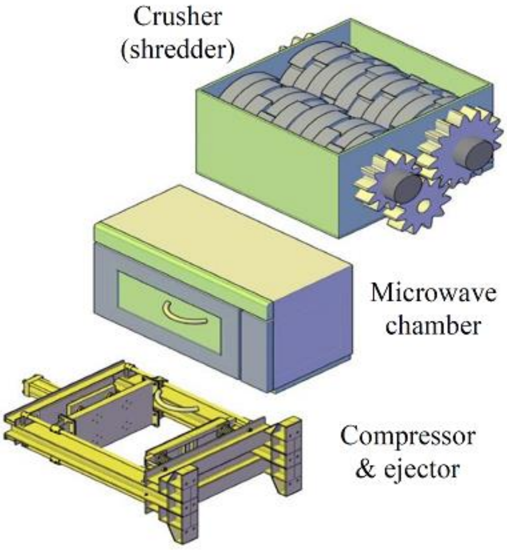

Figure 5. The crusher, microwave chamber and compressor/ejector in a detailed view.

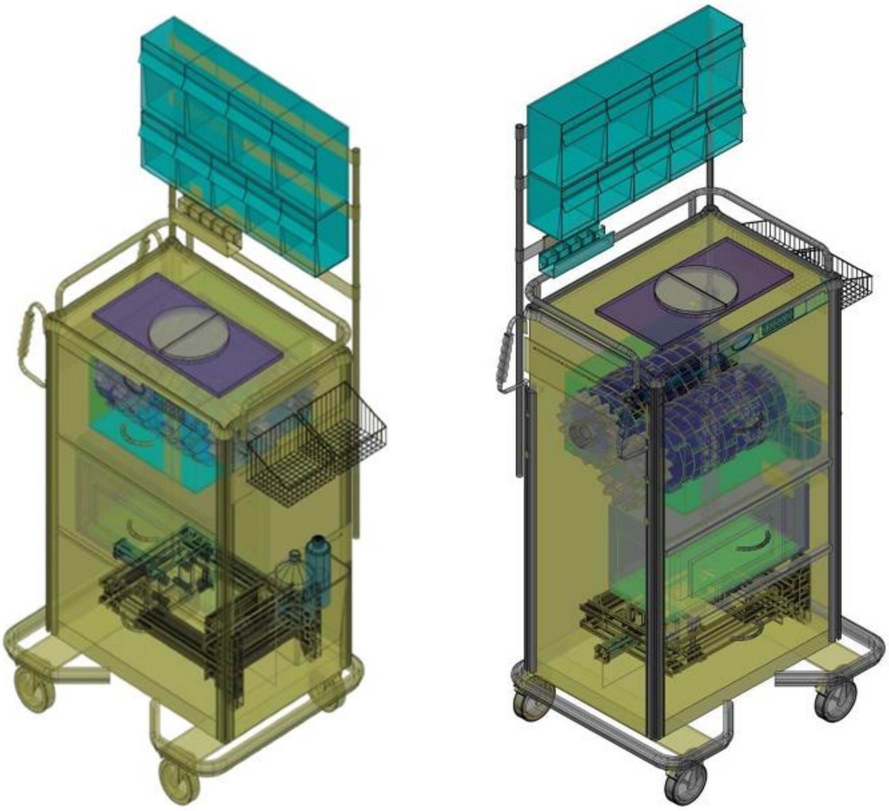

Figure 6. The 3-D view of the complete OSBMWTU in two planes of view, with internal parts semi-visible

Inactivation temperature of pathogen has been investigated in several previous studies [15]. Comparing the outcomes of these research works and the results of the experimental part of this study we propose the

following specifications for developing a microwave chamber that can fulfill the requirements of a patient ward with 100 beds
Dimensions without opening the control board ($H \times W \times D$): 130 × 60 × 50
Height of the control board: 30 cm
Maximum working floor area: 1.5 m^2
Operating voltage: 220 V – 230 V
Preferable microwave exposure: 700 W-1000 W for 5 minutes.
Operation cycle: 0.5 kg per 10 minutes.
Treatment capacity: 3 kg of BMW per hour.

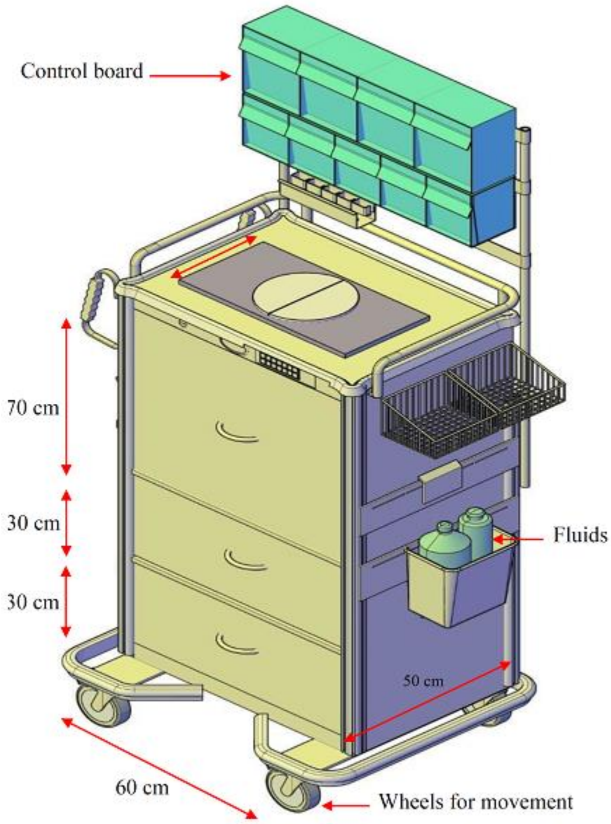

Figure 7. Complete product

If the machine is operated continuously, it can treat 72 kg BMW/day. As most healthcare systems operate without a break due to its nature, such continuous operation of the waste disinfection system may be a requirement.
The proposed machine design (on-site technique) ensures safe waste management and treatment practices as a part of emergency response services to the crisis brought upon by the COVID-19 pandemic or any similar emergency conditions. In addition, the designed machine is aimed to solve the passive management of BMW that exposes medical workers, waste handlers, patients and their families, the community, and the environment to prevent infections and injuries at any time, not only in the pandemic. As a result, the designed on-site unit can minimize unexpected fluctuations in waste composition and quantity from the side and increase infection control to prevent the danger of contamination spread which exposes medical staff, workers from another side. Microwave radiation is suggested to sterilize bio-hazardous waste, which is then turned into inert municipal garbage, reducing its volume by more than 80%. Unlike the autoclave technology, which is usually used for this purpose, the treatment by the proposed unit is characterized by the fact that it does not require any water supply or steam generator throughout the treatment procedure. Moreover, it has easy operation, safety, minimum dimensions, manufacturability, accuracy; no experts are needed. Accordingly, there is no risk from liquid effluent or excess pressure, and it has an ultra-compact size as compared with other techniques. Once the pathogen inactivation process is successfully completed, issues and threats due to BMW on wastewater management [21] and various water-related industrial systems such as energy extraction from aqua-algae [22] will be diminished.

5. Conclusions

The effect of adding chemicals to a shredded BMW during microwave treatment has been investigated. The results suggest that the thermal effect of the radiation has significantly been enhanced with sprayed melted butter. Hence, butter spray can be considered as a desired accelerating factor for the microwave treatment process of BMW. Distilled water and water-detergent can also increase the end temperature for a given microwave exposure. Ethanol (70%), which is considered in this study due to its virus disinfection capacity proved to be ineffective or rather reducing the end temperature when sprayed into the BMW. The proposed OSBMWTU has highly desired advantageous in treating BMW in a healthcare environment. At a time COVID-19 ravages all corners of the world the proposed mechanism will provide a worker and patient safe BMW disposal even at patient wards. The capacity of the machine may vary depending on the requirement. This first concept paper does not detail the electronics and control systems, electromagnetic shielding and also does not quantify the cost of construction. With a few modifications the machine can be made fully automated.

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