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Short communication

Utilization of greenhouse effect for the treatment of COVID-19 contaminated disposable waste - A simple technology for developing countries

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ABSTRACT

Countries with abundant solar radiation have the potential to invest in simple technologies for deactivation of many bacteria and viruses in medical solid waste. In addition to the traditional Infection and Prevention Control (IPC) measures, these simple technologies contribute to better protection of health care workers in countries with compromised solid management schemes. Monitoring of temperature, relative humidity and ultraviolet inside containers soundly designed to collect disposal infectious waste illustrated to deactivate several viruses and bacteria. Casanova et al., 2010, used some surrogate viruses to overcome the challenges of working with SARS-CoV, concluded that by temperature above 40 °C most of viruses become below levels of detection after 90 min. Here we are proposing a model of a simple transparent container almost 200 L in volume that allow solar energy to be accumulated inside. In summer conditions in the testing site, temperature inside the container reached above 50 °C when the ambient air temperature was around 30 °C. The container was built using epoxy glass to guarantee maximum heat penetration. Actual temperature measurement inside the container was measured in real time against ambient air temperature. We present a mathematical model for predication of maximum temperature at different positions inside the container and their relation to different ambient air temperature scenarios. The mathematical formulas used are based on the conservation laws and a good agreement of a full month of field measurements were obtained. Even in winter conditions in many of developing countries air temperature can maintain levels above 20 °C, which will produce temperature around 30 °C and viruses can reach levels below detection limit in maximum 3 h.

1. Introduction

Infectious solid waste management usually uses expensive techniques such as incineration, chemical treatment or autoclaving to insure minimizing or eliminating of the hazardous substances in these wastes. Personal Protective Equipment (PPE) for personnel managing patients suffering from infectious diseases can be either reusable or disposable. The reusable equipment needs to go through sterilization process to guarantee the elimination of any biological contamination. The disposable materials need to go through some processes before it is end of life disposal in a safe manner to guarantee low or no risk of infection to personnel responsible for its full life cycle from usage to final disposal. In many health care facilities in poor countries, financial capacities are limited to invest in modern techniques and protocols for how to deal with infectious waste is often lacking. There is not enough analysis on infection among health care waste handlers in low income countries or countries with no adequate medical solid waste management scheme. However, in such context it is important to explore all possible measures to protect workers under this category from getting infected as a result of exposure to biologically contaminated medical waste. In lack of enough Personal Protection Equipment (PPEs) and an integrated medical solid waste management schemes in health care facilities, it is important to investigate innovative ways to take advantage of environmental conditions to control the virus survivals on surfaces of medical waste. Little

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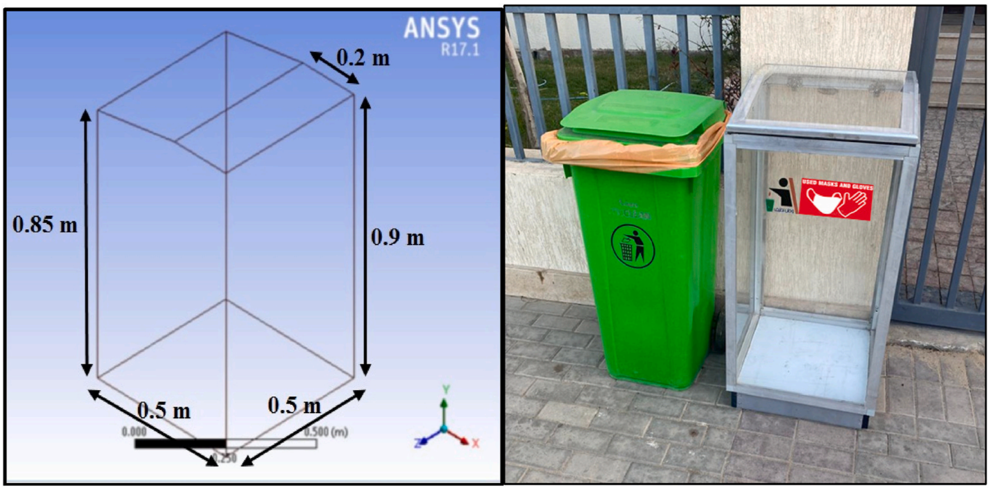

Fig. 1. The dimensions of the medical waste bin (to the left and the actual prototype is to the right). The dimensions are representing the clear dimensions of the acrylic sheets directly exposed to sun and connected using aluminum. The theoretical part for prediction of the temperature inside the bin was built on a three-dimensional model of greenhouse structure. The temperature environments for simulation calculation are in hot summer with no wind. Entire medical recycle bin model is divided into 47,887 elements. Iterative calculation is conducted using two CPU 3.07 GHz quad-core workstation in simulation.

attention was paid to advantages of some environmental conditions prevailing in some countries. However, it is reported that the COVID-19 can be transmitted largely by garbage collectors (Ouhsine et al., 2020). The survival of the COVID-19 virus on surfaces was subject to some research, however these researchers were not inclusive (WHO and UNICEF 2020). In this study we are examining three environmental aspects of affecting the survival of similar viruses as a proxy indicator for the COVID 19 survival on surfaces. These atmospheric indicators, Relative Humidity (RH), Air Temperature (AT) and Ultraviolet Irradiation (UV), aim to develop some guidance and operations procedures to an intermediate storage unit at health care facilities for COVID-19 PPEs in preparation for a final safe disposal among municipal waste.

2. Background

Several studies were directed examine the relation between environmental conditions such as Air Temperature (AT) on the survival of viruses and bacteria on different surfaces, for instance Hepatitis A Virus (Mbithi et al., 1991) and avian influenza viruses (Paek et al., 2010). Another study on the Coronavirus, Casanova et al., (2010), using two potential surrogates were evaluated in this study; transmissible gastroenteritis virus (TGEV) and mouse hepatitis virus (MHV) concluded that, these viruses can survive on different surfaces from hours to days and the optimum deactivation of the virus happened at around 50% RH. The same study confirmed that the virus infectivity with increased by temperatures higher than 40 °C and at this level of temperature, RH was not significant for the deactivation of the viruses. Following the SARS outbreak in 2003 some studies were conducted to examine the survival of the virus in relation to environmental conditions. In a study by Duan et al., (2003) on the SARS CoV–P9 on its deactivation when exposed to UV (260 nM) for about 60 min resulted in the destruction of virus infectivity. The same study pointed out that the virus was totally deactivated after 90, 60, 30 min at 56 °C, 67 °C and 75 °C respectively. In countries with abundance of solar radiation and long sunny hours, it is easy to achieve these favorable conditions for virus inactivation with simple technology. The proposed technology here depends on producing simple collection system based on minimum protection procedures and low costing.

With more than 15 million confirmed cases in Africa and Latin America alone, it is obvious that the amount of medical solid waste production has increased dramatically. The IPC measures usually not being optimal in theses settings, so complementary measures needs to be in place to minimize possible infections to these vulnerable group. The fate of the solid waste produced is usually that the medical waste will be mixed with municipal waste. According to our knowledge no detailed research concerning infection among solid waste collectors in low and middle income countries has been carried out.

3. Methodology

A model for a simple acrylic waste collection bin was constructed with clear shits dimensions of 0.9 m high and a square base 0.5 m in length. The bin had an open led 0.2 m length from one side of the top, Fig. 1. The bin was exposed to direct solar radiation at a site in Cairo, Egypt (longitude 29.9°, latitude 31.39°) and temperature was measured with 1 h interval between 11:00 a.m. and 4:00 p.m. for the full month of June in 2020. The bin was closed during the whole measurement period during the day. The temperature measured using TESTO 875i thermal imager with temperatures range up to 327 °C and the accuracy is ±2% of reading.

The storage volume of the bin is approximately 200 L (0.5 × 0.5*0.85 cm) and the different in head in the front 0.85 m and in the back 0.9 m is to make a slope to insure the direct sun light to enter the bin to give maximum temperature using greenhouse effect.

The bin is constructed in a practical way that it will not be well marked and easy to operate by the solid waste operators within the health care facility. The container should be placed outdoor in places directly exposed to the sun with clear marks showing that it is for the disposal of gloves and masks.

4. Results and discussions

4.1. Field measurements

The greenhouse effect is identified by the difference between the effective radiating temperature of the earth surface and its surface temperature. The difference between the energy emitted by the surface and can therefore be defined as the long wave energy trapped in the atmosphere (Berger and Tricot 1992). The origin of the term greenhouse was associated with providing a Controlled Environment Agriculture (CEA) through framed or inflated structure, covered by transparent or translucent material that permits optimum light and hence energy transmission. This closed structure will accumulate thermal energy if kept exposed to solar energy with little or no air movement (Jensen and Malter 1995). These conditions will generate a difference in temperature between inside the space and ambient air temperature. Egypt enjoys around 2900–3200 h of sunshine annually with annual direct normal energy density of 1970–3200 kWh/m^2 (Comsan 2010). The maximum day temperature, away from heat waves, usually reached during the month of August. The COVID -19 pandemic reached Egypt by mid-March and cases have been reported until September 2020. The experiment here was carried out during the month of June in the middle

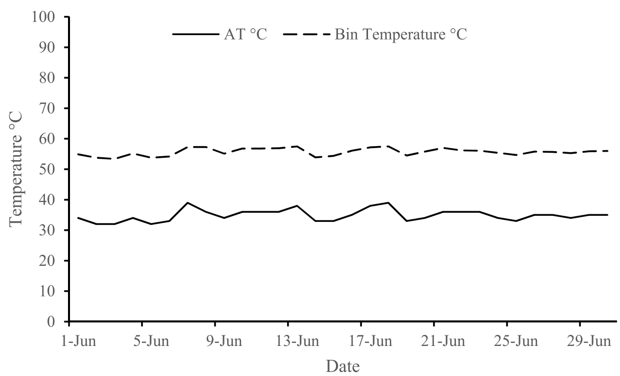

Fig. 2. Maximum recorded temperature outside and inside the bin during the month of June. During the whole the difference between the measured temperature exceeded 10 °C.

Table 1
Registered temperature on June 18, 2020, temperature was measured on 1 h interval and a difference in temperature was recorded already at the first measurement.

Time	AT (°C)	Bin Temp. (°C)
11:00	36	47.9
12:00	37	48.5
13:00	38	48.7
14:00	39	53.2
15:00	38	55.6
16:00	38	57.5

of the COVID-19 pandemic. Continuous measurements AT as well as the temperature inside the solid waste bin were carried throughout the month. Registered peaks of AT, corresponding temperature inside the bin, and times of these peaks are presented in Fig. 2.

The average peak air temperature during this month was above 30 °C and the maximum registered temperature difference between inside and outside temperature was more than 10 °C during the whole month. Table 1 shows the maximum registered daily air temperature of 39 °C around 2 p.m. on 18th of June.

4.2. Model iterations and validation

The governing equations of fluid flow and heat transfer can be considered as mathematical formulations of the conservation laws that govern all associated phenomena. These conservation laws describe the rate of change of a desired fluid property as a function of external forces in accordance with the continuity equation: the mass flows entering a fluid element must balance exactly with those leaving.

$$\frac{\partial \rho}{\partial t} + \nabla \cdot \left[\rho \vec{V}\right] = S_m \tag{1}$$

where, ρ is the air density, t is the time, $\vec{v}$ is the velocity vector and S_m is the source term.

Conservation of momentum (Newton's second law): the sum of the external forces acting on the fluid particle is equal to its rate of change of linear momentum.

$$\frac{\partial}{\partial t}(\rho \vec{v}) + \nabla \cdot \left(\rho \vec{V} \vec{V}\right) = -\nabla p + \rho \vec{g} + \vec{F} \tag{2}$$

where, p is the static pressure and $\vec{g}$ and $\vec{F}$ are the gravitational body force and external body forces respectively.

Conservation of energy (the first law of thermodynamics): the rate of

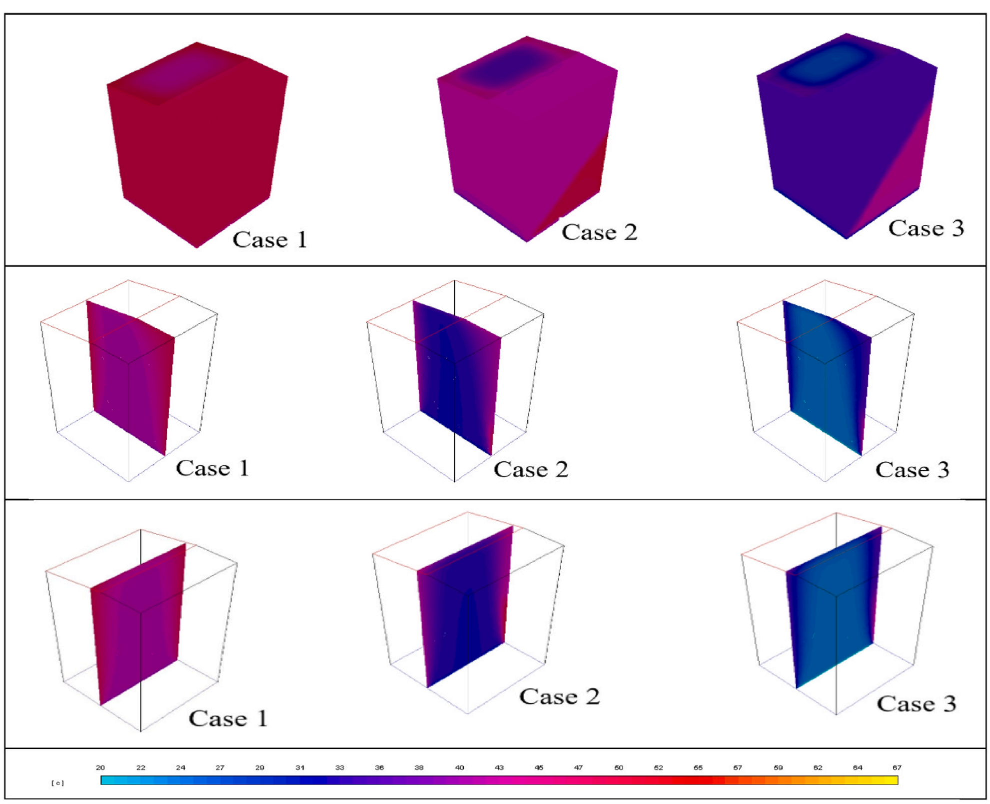

Fig. 3. Calculated temperature inside the bin with three scenarios, case 1 is using data registered at the day of maximum measured air temperature, case 2 and 3 for maximum air temperature of 20 and 30 °C respectively.

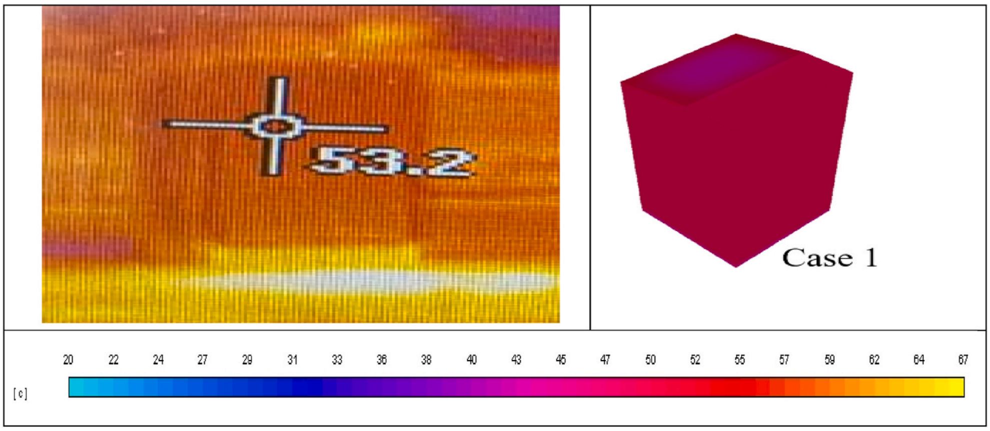

Fig. 4. Example of the maximum temperature registered and location inside the bin on June 18, 2020.

change of energy of a fluid particle is equal to the heat addition and the work done on the particle.

$$U_j\frac{\partial T}{\partial x_j}=\frac{\partial}{\partial x_j}\left(\alpha\frac{\partial T}{\partial x_j}-\overline{u_j t}\right) \tag{3}$$

The optimization of any structure to reach maximum utilization of solar thermal energy to be attained within a structure is highly dependent on the structure geometry. Here we used ANSYS © 17.1 DESIGN MODULER pre-processor software to create the simulated grid to the prototype. A good quality mesh can assist verifying model calculation and produces fast and accurate solution. Therefore, more than one mesh type is tested and compared with each other to attain a good computational fluid dynamics solution. The different meshes used are multizone and automatic, tetrahedral patch conforming. Mesh quality is depending on many parameters, but most important ones are meshed elements, mesh skewness ratio and orthogonal ratio.

These parameters are used to ensure that, mesh density should be high enough to capture all relevant flow features and the mesh adjacent to the wall should resolve the boundary layer flow.

The best method for the medical recycle bin geometry is tetrahedral patch conforming to 47,887 elements with average skewness 0.216 and the average orthogonal is 0.864, which falls into the "excellent" range according to the software standard. The acrylic walls in the model are 3 mm thickness and added in ANSYS the material properties, it is properties is 1180 kg/m^3 density, 1470 J/kg-k specific heat and 0.19 w/m-k thermal conductivity. Three cases were calculated in the mathematical model, case one is the experimental case which implemented in the practical experiment day rush hour at 2:00 p.m. (June 18, 2020), with AT of 40 °C. The second case calculated at the outside temperature was 30 °C and the third case at 20 °C. In addition, the longitude and latitude entered in the energy calculation to calculate the solar energy effect by solar calculator. Fig. 3 shows the calculated temperature distribution in outside walls at the top of the figure and the vertical and horizontal central contours in the rest of the figure.

In case 1 the temperature inside the medical recycle bin reaches more than 50 °C and the average temperature. Case 2 with AT of 30 °C resulted in temperature of 38 °C inside the bin. These calculated temperatures are expected to increase due to the greenhouse effect as it happened in the experimental study.

The obtained temperature from the actual measurement on 18th of June as in Fig. 4 shows 53.2° at an AT of 39 °C, which is in a good agreement with the model results for case 1 as mentioned earlier.

5. Conclusions

Inverse effects of elevated temperature on viruses and bacteria have been reported by several researchers. Most of the researcher reports 40 °C as the limits where most of viruses can be under detection limits. The utilization of the greenhouse effect in the area of treatment for biological contamination of disposal PPEs before the final disposal was rarely investigated. Our data showed that with a simple technology that guarantees enough penetration of solar radiation, air temperature of around 30 °C is enough to generate a temperature of 40 °C or higher inside an acrylic solid waste bin. The unit cost of the proposed bin can be 30 $ (current production cost in Egyptian market), which is fat cheaper than alternative high technologies in this area and can be afforded by health authorities in treatment facilities for patients with communicable diseases. The proposed technology is easy to handle and with some simple instruction regarding segregation of disposable waste and standard precautions while transporting it to the bin. Waste by the end of the day can be collected and dealt with as non-infectious waste and can be treated with municipal waste. There is still some limitation on using this method at air temperature lower than 20 °C. However, investing in these technologies can guarantee quick production and effective removal for viruses during the current pandemic and for other infectious diseases as well.

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