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Development of Viroreaper sanitization chamber for COVID 19

Hirak Ranjan Das\textsuperscript{a}, Dinesh Bhatia\textsuperscript{b,∗}, Kalyan Kr Das\textsuperscript{c}, Animesh Mishra\textsuperscript{d}

\textsuperscript{a} Department of Mechanical Engineering, Royal Global University, Guwahati, Assam, India
\textsuperscript{b} Department of Biomedical Engineering, North Eastern Hill University, Shillong, Meghalaya, India
\textsuperscript{c} Department of Mechanical Engineering, Assam Engineering College, Guwahati, Assam, India
\textsuperscript{d} Department of Cardiology, North Eastern Indira Gandhi Regional Institute of Health and Medical Sciences, Shillong, 793018, Meghalaya, India

\section{Abstract}

The entire world present is facing with the COVID 19 pandemic. As per studies worldwide SARS-CoV-2 by sequencing analysis is 95\% homogenous similar to the bat coronavirus and almost 70\% similar to the SARS-CoV-1. SARS CoV-2 is a respiratory problem which in its worst form of disease causes ARDS and hampers the patient's ability to breathe on his own and has to be put on Ventilator. As per WHO (World Health Organization) guidelines, sanitization is an effective way of prevention from the infection. The proper sanitization being not feasible and time consuming in certain cases, faster and effective alternatives of sanitization processes are necessary. As per recently published study by researchers in Beijing, China, it was observed that with each degree rise in temperature and percent humidity, the contagiousness of the disease caused by the Coronavirus, named COVID 19 goes down significantly. R-naught or \( R_0 \) can be referred as the average number of people that gets infected from one sick person among a population which is not immune to the virus. The closer to zero an \( R_0 \) value becomes, the better the results indicating less spread of the disease. A lower \( R_0 \) means the outbreak is slowing or declining while a higher one means its swelling or growing at faster rate. The \( R_0 \) of the coronavirus hovers between 2 and 2.5 as per World Health Organization or WHO meaning that each new person spreads the disease to about 2.2 people on an average. The chamber being developed is aimed at lowering the \( R_0 \) value so that the infection rate slows down. The chamber was developed at significantly lower costs. In this study, an attempt has been made to fabricate a chamber with a homogenous environment inside the chamber for better results, with the help of numerical simulation to decide the optimum angle for the inclination of fins and location of the momentum source.

\section{Introduction}

COVID 19 pandemic has spread all over the world and as per WHO, till date fifty five lakhs people are infected worldwide and more than three lakhs have died due to this contagious disease with numbers increasing rapidly with each passing day. In absence of proper vaccine and medication, the only way to restrict the infection rate is early diagnosis and separation of infected people from the remaining population to prevent community spread. The detection of the Corona virus infection at an early stage proves to be helpful in isolating the infected individuals by social distancing or self-quarantine at their homes for a period of fourteen days to twenty days which prevents the spread of this viral disease. The patients are screened at hospitals or airports with help of thermal or infrared scanners, which are not reliable as symptoms in asymptomatic individuals for the disease may prevail and occur after few days and not immediately when scanned with the thermal device such as thermometer which are being widely deployed at different screening facilities. By that time these asymptomatic individuals have already mixed in the society and spread the disease multifold making it a dreaded communicable disease affecting millions globally with fast rate of replication. Hence, a long-lasting and potent solution to the pandemic is the need of the hour.

\section{Methods}

The chamber is designed and fabricated in two phases. The first phase was to design the chamber and the second phase was to fabricate it. The first phase of the design was to design a chamber which is capable of disinfecting the clothes and commonly used daily wear items. The second phase was to fabricate it from the design. The chamber was developed at significantly lower costs. The chamber is designed in such a way that the disinfection is done by exposing the objects to be disinfected inside the chamber to a homogenous temperature and humidity-controlled environment to disinfect daily used material. The chamber was designed in an efficient way that the disinfection is achieved within 24 hours. Moreover, in a condition where the virus that was dried was stored at higher temperature (\( >38^\circ\text{C} \)) and high relative humidity (\( >95\% \)), there was an additional degradation in virus activity at each point in time. Taking into consideration the above research, we developed a COVID De-Incubator chamber to disinfect the clothes and commonly used daily wear items. Our results were exciting as the disinfection proved to be effective at temperatures of 75 – 80 \(^\circ\text{C}\) and humidity levels at 80 – 90\%. Moreover, the chamber was developed at significantly lower costs. In this study, an attempt has been made to fabricate a chamber with temperature and humidity-controlled environment to disinfect daily used material. Using fins and momentum source, a homogenous environment is created inside the chamber for better results, with the help of numerical simulation to decide the optimum angle for the inclination of fins and location of the momentum source.

\section{Results and Discussion}

1. \section{Conclusions}

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\section{Declaration of Competing Interest}

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.
As per recently published study by researchers in Beijing, China it was observed that with each degree rise in temperature and each percent humidity increase, the contagiousness of the disease caused by the Coronavirus, named COVID-19 goes down significantly. R-naught or \( R_0 \) can be referred as the average number of people that gets infected from one sick person among a population which is not immune to the virus. The closer to zero an \( R_0 \) value the better the results indicating less spread of the disease. A lower \( R_0 \) means the outbreak is slowing or declining while a higher one means its swelling or growing at faster rate. The \( R_0 \) of the coronavirus hovers between 2 and 2.5 as per WHO meaning that each new person spreads the disease to about 2.2 people on an average. \( R_0 \) is not a fixed value, it changes depending on various factors such as proximity among people, the environmental surroundings and climatic conditions. The findings of the study stated that for every \( 1.8 \)° Fahrenheit \((1{\textdegree}C)\) increment in temperature and relative humidity increment of 1%, the Coronavirus \( R_0 \) value is observed to drop by 0.04 and 0.02. So, considering the \( R_0 \) value of the virus to be 2, an increase in 18° Fahrenheit will result in decrement of the \( R_0 \) value to 1.6 which is 20% decrease. The coronavirus \( R_0 \) value currently is 2.5 in the Northern Hemisphere and it is more than twice the value of \( R_0 \) in several regions in the Southern Hemisphere, where it's currently summer. Their research revealed that the number of new daily cases in average during the time

| Material                  | Ignition Temperature (°C) | Ease of Ignition          |
|---------------------------|---------------------------|---------------------------|
| Polyvinyl chloride (PVC)  | 575                       | Flame resistant           |
| Wool                      | 590                       | Will not ignite readily   |
| Polyester                 | 485                       | Combustible               |
| Acrylic                   | 390                       | Combustible               |
| Polypropylene             | 350                       | Burns easily              |
| Cotton                    | 390                       | Burns easily              |
| Newspaper                 | 233                       | Burns easily              |

Table 1

Material and their ignition temperature [3].

![Fig. 1](image1)

**Fig. 1.** Virus infectivity rate at high relative humidity and lower temperature, **Fig. 1.2** Virus infectivity rate at lower relative humidity and higher temperature, **Fig. 1.3** Virus infectivity rate at lower relative humidity and higher temperature for first 24 h, **Fig. 1.4** Virus infectivity rate at lower relative humidity and higher temperature for second 24 h, **Fig. 1.5** Virus infectivity rate at lower relative humidity and higher temperature for third 24 h.
period in a place like Italy, where the temperature hovered around 48°F (9°C) was four times the number of new cases in place like Thailand, where temperatures were closer to 95°F (35°C). It was found that at elevated relative humidity (>95%) with comparatively low temperatures (28°C and 33°C) failed to affect the infectivity of the virus significantly. However, higher temperatures (38°C) at 80–90% relative humidity led to some decrease in virus activity within 24 h. Moreover in a condition where the virus that was dried was stored at higher temperatures (>38°C) and high relative humidity (>95%), there was observed an additional degradation in virus activity at each point in time [3].

Taking into consideration the above research, a collaborative team comprising of faculty, scientists, doctors and industrialist developed a COVID Viroreaper sanitizer chamber to disinfect the clothes and commonly used daily wear items. After more than two months of research, discussions, trials and testing, the machine has been made compact and cost effective. The prototype-testing has been completed and field trials results were found to be satisfactory. The working of the machine can be explained by the concept of elevated temperature heating and exposure to humidity and it is assumed to be effective in controlling the virus. The temperature is maintained between 75°C to 80°C with humidity levels maintained at 80%–90% for required time period to decay the corona virus and reduce its half-life substantially. The machine finds utilisation in sanitizing several daily used items such as Polyester, Polyvinyl chloride (PVC), Wool, Polypropylene, Cotton, Newspaper, Acrylic, Metal, Leather products etc. The features of the machine include easy deployment which results in easy installation at homes and public places such as hospitals, shops, offices, bus stations, railway stations, banks, airports etc. The other feature of the machine is auto-sterilization and post usage disinfection. The machine results in less use of chemicals and reagents for the purpose of sanitization. It can also be utilised in cleaning the infected clothes with detergent [9,10].

2. Literature review

According to experiments conducted by Hindawi, 10 μL of maintenance medium containing 10^7 TCID_{50} (Median Tissue Culture Infectious Dose) per mL of virus was placed in individual wells of a 24-well plastic plates and allowed to dry at room temperature (22–25°C) and relative humidity of 40–50% (i.e., conditions prevailing in a typical air-conditioned room). TCID_{50} is a method which is used to verify viral Dose) per mL of virus was placed in individual wells of a 24-well plastic plates and allowed to dry at room temperature (22–25°C) and relative humidity of 40–50% (i.e., conditions prevailing in a typical air-conditioned room). TCID_{50} is a method which is used to verify viral infectivity. They have noticed that if the intensity at which 50% of cells are affected when a test tube upon which cells have been cultured is injected with a dilute solution of viral fluid. One hundred microlitre of MM (Mouse-brain stock) was used to re-suspend the virus at 0 h, 3 h, 7 h, 11 h, 13 h, 24 h, and up to 4 weeks and the residual virus infectivity was titrated. Controls were included in closed screw cap eppendorf tube every time while treating in the same manner but drying was avoided. The experiment was performed at varying temperatures (28°C, 33°C, 38°C) and relative humidities (80–89%, >95%) for 3 h, 7 h, 11 h, 13 h, and every single time point extending to 24 h (0.38–3.38 log_{10}) as in comparison with elevated temperature (38°C) at a lower relative humidity 80–90% (Fig. 1.3 to 1.5) [2,4].

3. Numerical modeling

3.1. Governing equations

In CFD the main governing equations are transport equations, momentum equations and energy equations. These equations can be solved by employing methods which are numerical for the domain using the boundary conditions which can be studied from actual physics of the investigation. The main governing equations are as flows.

3.2. Turbulence

For a turbulent flow the shear stress can be expressed by Eq. 3.5.

\[
\tau = \mu \left( \frac{\partial u}{\partial y} + \frac{\partial v}{\partial x} \right)
\]  

(Eq.3.6)

In which \( \mu \) is a coefficient called the coefficient of eddy viscosity and \( \tau \) is the mean velocity in the direction of flow at a point at y distance till the solid boundary. Eddy viscosity is function of turbulence and varies with the position of the point in flow. The total shear stress in turbulent flow is summation of the shear stress given by the Newton’s law of viscosity and stress is by Boussinesq’s equation [6].

\[
\tau = \mu \frac{\partial u}{\partial y} + \mu \frac{\partial u}{\partial y} + \mu \frac{\partial v}{\partial x}
\]  

(Eq.3.7)

The above equations (Eq. 3.6 and Eq. 3.7) are solved for turbulence model by using SST model. The basis of the SST model is the “k–ω” model which comprises of the identical automatic wall treatment which is combination of a “k–ε” model (in the inner boundary layer) and “k–ε” model (in the outer region).

3.3. Continuity equation for turbulence

For Cartesian co-ordinate system turbulent incompressible fluid flow continuity equation is written as in Eq. 3.8 [5].

\[
\frac{\partial (\rho u_i)}{\partial x_i} + \frac{\partial (\rho u_j)}{\partial x_j} + \frac{\partial (\rho u_k)}{\partial x_k} = 0
\]  

(Eq.3.8)

3.4. Equation for dissipation rate energy

Equation for dissipation rate of energy is known as k–ε model. Here the term \( \varepsilon \) rate of energy loss per unit volume can be given by

\[
\varepsilon = \mu \left[ \left( \frac{\partial u_i}{\partial x_i} \right)^2 + 2 \left( \frac{\partial u_j}{\partial x_j} \right)^2 + \left( \frac{\partial u_k}{\partial x_k} \right)^2 + \frac{\partial u_i}{\partial x_j} \frac{\partial u_j}{\partial x_i} + \frac{\partial u_i}{\partial x_k} \frac{\partial u_k}{\partial x_i} + \frac{\partial u_j}{\partial x_k} \frac{\partial u_k}{\partial x_j} \right]^{3/2}
\]  

(Eq.3.12)

Thus, the generalized for the rate of change of dissipation of energy is written as in Eq.3.13

\[
\frac{\partial(\rho \varepsilon)}{\partial t} + \nabla \cdot (\rho u \varepsilon) = \nabla \cdot \left[ \mu + \frac{\mu_t}{C_{\mu K}} \right] \nabla \varepsilon + \frac{\varepsilon}{k} (C_{\mu K} \rho + P_e) - C_{\mu K} \rho L (\rho u \varepsilon)
\]  

(Eq.3.13)

Where in Eq.3.13

24 h. All the above-mentioned experiments were conducted in duplicate and the viral infection which was residual was titrated [3,4].

Higher relative humidity (>95%) at lower temperatures in comparison (28°C and 33°C) affected the infectivity of the virus significantly less (Fig. 1.1). At temperature 38°C and 80–90% relative humidity led to a 0.25–2 log_{10} loss of titre at 24 h (Fig. 1(b)). Moreover, the dried virus when stored at higher temperature (38°C) accompanied by higher relative humidity (>95%), ~1.5 additional loss of titre is observed for
computational domain as shown in Figs. 2.1 and 2.2 is considered with Hexahedral mesh of with 3,33,000 nodes on the wall with no slip boundary imposed. For better mixing and more turbulence, a fan has been used at inlet through which hot and humid air introduced as shown in Figs. 2.1 and 2.2. As the temperature and humidity changes inside chamber, so energy equation is used with 3D N-S equation to generate the values of the parameter at the nodal points [7,8]. As shown in Fig. 2.1 four numbers of fins are introduced for better turbulence of hot and humid air inside the chamber. For present study the angle inclination (α) has been changed from 15° to 90° at a step of 15° keeping all other dimensions constant. And an attempt has been made to compare the results of the chamber with inclined fins and without fins. The Grid Independence Tests was performed using the numerical simulation. The difference in errors between the coarse grid independence test and fine grid independency test was found to be 10%.

5. Results and discussion

Fig. 3.1 Air kinetic energy mid XY plan.

From Fig. 3.1 (a) and 3.1(b) it is observed that air kinetic energy contour of the flow field without fins are significantly different compared to with fins. Better turbulence in the flow field can be observed when fins are used with an inclination of 45° [5]. Same phenomenon can be observed for droplet kinetic energy contour [Refer Fig. 3.2(a) and (b)].

In the present study air velocity, droplet kinetic energy on planes for steady-state condition for the entire computational domain are presented as shown in Fig. 3.1–3.4. From these figures, it can be observed that high turbulence and large vorticities exist inside the chamber which will facilitated uniform mixing of fluid and alkaline water vapour inside the chamber. This air alkaline water mixer at the elevated temperature (or state temperature at 70 °C) and higher relative humidity is found to decrease the infectivity of the virus from the items present in the chamber. Numerical simulation is carried out using commercially available software ANSYS 19.

6. Fabricated vioreaper

The Viroreaper has a dimension of 600 mm × 400 mm × 500 mm. The initial power consumption of the machine is 500 W. The overall power consumption is 125 Wh with Auto cut off as shown in Fig. 4.1. The materials that can be sanitized are daily wearable items such as cloth, wood, plastic, cotton, plastic or polylactic acid (PLA), Acrylonitrile butadiene styrene (ABS) polymer, paper, steel, wool, leather etc. The materials which cannot be sanitized are credit and debit cards or any other magnetic strip cards. The fabricated device temperature distribution is than compared with the numerical model and a good agreement can be observed. After the fabrication of the device, pressure ratios (p/p0) at different points at the centre of the device are compared with the numerical model. The device can be used to sanitize several items made from Polyvinyl chloride (PVC), Wool, Polyester, Acrylic, Polyproulene, Cotton, Newspaper, steel, leather products etc. The device is easy to use and can be installed at homes and public utilities such as banks, shops,
hospitals, offices, bus stations, railway stations, airports etc. In this work using computational fluid dynamics flow dynamics inside the chamber is analysed for optimum air flow all around interior of the chamber for efficient virus removal. The optimum position of the fan (momentum...
source) is selected as per the numerical findings of the present numerical simulation. Also, four inclined fins are attached to the wall of the chamber for the generation of turbulence hence homogeneous environment inside the chamber. It is observed that the angle of inclination of the fins should be 450 for best homogeneous environment.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.sintel.2020.100052.

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