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COVID19 isolation room machine based on the 2003SARS Machine installed in Prince of Wales Hospital

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Abstract:
From statistics, the highest COVID19 fatality rate in Hong Kong is the cluster of elderly staying in nursing homes. This research and development focus on the improvement of their existing isolation rooms by replacing the window fans by the newly designed negative pressure isolation room machine. Since the highest fatality cluster is in the group of people in care homes, we design a negative pressure isolation room machine for the use in the isolation rooms which do not have negative pressure function. To reduce the spread of the new coronavirus and airborne pathogens (such as tuberculosis, measles, and chickenpox), symptomatic patients should be isolated as soon as possible. Although there are isolation rooms in nursing homes or rehabilitation homes, they have no negative pressure function and can only provide limited isolation to reduce the risk of transmission. Existing negative pressure isolation wards use air filters to isolate viruses in the air, but the air filters will hinder air circulation and require a lot of electricity to generate negative pressure, and the viruses will be left on the air filters. When staff replace the air filter, there is a risk of infection. A novel filterless method was proposed during 2003 SARS. The effectiveness and advantages of using aqueous ozone to disinfect air is reviewed. These concepts are used to construct a prototype negative pressure room device, call COVID Machine, to ensure the exhaust air is not contaminated. A preliminary test is carried out on the prototype to show that it can effectively reduce bacteria in the exhaust air.

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I. INTRODUCTION

A detailed comparison of SARS 2003 (SARS-CoV) and COVID 19 (SARS-CoV-2) from causes to preventions in Hong Kong can be found in [1].During the 2003 SARS Epidemic in Hong Kong, it was reported that the chance of infection was exceptionally high for the nurses or clinical assistants service the SARS patients inside SARS triage wards, where they perform procedures such as the insertion of flexible pipes into the throats of these patients. Aerosols expelled by the patients during these procedures are very contagious and cannot be effectively contained by the existing ventilation system in the hospital. We designed a device ("SARS Machine") to capture the aerosols as the procedure is being performed to eliminate the infection risks.

The new COVID19 isolation room machine proposed in this paper is based on the SARS machine that we installed in the Prince of Wales Hospital in Hong Kong during the SARS epidemic [2]. SARS triage wards normally housed all the new cases with high viral load and therefore they were the most dangerous sites in Hong Kong, demanding full cleaning of air respired from the patients. Spitting out saliva was the most natural response of a patient and such body fluid contains the virus. Although 100% fresh air intake and 100% exhaustion of room air is the normal ventilation design in operating theatres (OTs) in hospitals. The genuine problem is that the exhausted air from OTs is not so harmful or infectious while that from the SARS patients is really poisonous to the general public. The SARS machine was designed for immediate air extraction around the mouth and nose of the patient at 80 km/hour or 22 m/s. The real issue was to make sure that the exhaust air was virial free. Air filters, either paper and nylon filters, have been used in air-conditioning systems for decades. However, these filters are ineffective on viruses which are much smaller than average dust particles. Additionally, conventional filters impede airflow and can be hazardous to replace. We designed the SARS machine that did not use conventional filters. The SARS machine was filterless. From statistics, the highest COVID19 fatality rate in Hong Kong is the cluster of elderly staying in nursing homes. This research and development is focus on the improvement of their existing isolation rooms by replacing the window fans by the newly designed negative pressure isolation room machine. In this paper, we present a filterless negative pressure isolation room machine that does not require any replacement parts and free of maintenance for nursing homes in Hong Kong. The paper is organized in eight paragraphs.

II. SARS2003 MACHINE

The conventional ventilation and air-conditioning (VAC) systems in hospitals in Hong Kong has not been designed for the accommodating patients with highly infectious diseases. Normally, fresh air is mixed with the return air from the wards, then cooled down, dehumidified, and filtered before it is supplied back to the wards. Filtering is mainly for removing the dust which is microns in size. This kind of VAC system is totally useless in preventing the spreading of SARS virus when it is attached to tiny water droplets or particles which are conveyed by the air stream. That is the reason why a guideline of 100% supply and exhaustion is adopted for OTs in the hospitals. SARS virus is new to the world and most of its behaviour is still unknown to us. Information obtained so far reveals that SARS virus can be destroyed under high temperature, i.e. 38^{o}C or above, and SARS virus can be killed by bleaching water [3], with a ratio of 1:49. Furthermore, it had been estimated that an air extraction rate of around 10 l/s/patient may be good enough to prevent SARS virus from staying in an indoor environment even when the patient coughs or spits. Air extracted around the face of the patient was fully mixed with bleaching water with a ratio of 1:49 and the temperature will be raised to 70^{o}C or higher before exhaustion to the outdoor environment, a high safety margin again. Such extracted air should never be allowed to go back to the air-conditioning system of the hospital because there was still a small chance that the air was toxic and an air flow of 20 l/s at 70^{o}C is certainly a very heavy burden to the chillers and air handling units of the hospital. Hence, what was proposed was not a filtering system. It was a cleaning system. The extracted air stream from the patients was broken down into small air particles and they were mixed with a fountain of bleaching water using patented spirals. The spirals allowed full mixing but did not impose a high air resistance. Finally, the air stream was heated up.

Air filters have been used in air-conditioning systems for decades, namely paper filters and nylon filters etc. However, these filters can only filter the dirt or big dust particles in the air stream. They have no effect on the organic virus which is much smaller than a dust particle. Although SARS virus can be killed when in contact with bleaching water, it was useless to blow air into bleaching water because the virus inside the big air bubbles would have no contact with the bleaching water. Active charcoal was first used as the filtering medium when bleaching water was sprayed on the top and the extracted air stream was dragged from the bottom. But we were facing two great problems. First, the counter flow of the two kinds of fluid greatly increased the air resistance and hence a very low air extraction rate was achieved. Second, the charcoal almost blocked the whole air stream. Then, we tried sand and pebbles but the experiments failed again. Sand was as dense as the active charcoal while pebbles provided air gaps so big that air/water mixing was not far from satisfaction. Finally, we tried to use “spirals”, as shown in Figure 1 and Figure 2. The spirals had the ability to fully mixing the toxic air and the bleaching water. Furthermore, the two kinds of fluid were arranged to flow in the same direction so that air resistance was minimized. Several modifications on the initial design had been made and the final model was shown in Figure 3.

Figure 3 is self-explanatory. A hood was placed by the side of the head of the patient and air with virus was drawn into it by a high pressure blower fan. Bleaching water at a ratio of 1:49 was sprayed onto the spirals where the air stream was atomized and mixed with the bleaching water. The blower was arranged to locate at the downstream to make sure air moving through it was completely sterilized. The outcome of the development and performance of the virus cleaner for severe acute respiratory syndrome (SARS) triage wards for minimising the spread of virus inside the SARS wards was published in HKIE Transactions [2]. We had been successful in developing an effective mechanism to clean contaminated air respired by patients, particularly those in SARS triage wards. The stages of the air cleaning process of this novel machine included:

a) A movable hood draws air into a flexible pipe that is placed by the patient.
b) The contaminated air is mixed with 1:49 concentration of bleaching water from a spray installed at the top.
c) Under the spray, patented ‘spirals’ are used to increase the contact area and retention time between the air flow and the chlorine water.
d) The sterilized air is then mixed with water heated to 70°C at which the virus cannot survive, again using the patented ‘spirals’ to increase the contact area.
e) The air is then expelled through a window to the atmosphere after it has been fully sterilized.

Its efficiency had been illustrated by both computer simulations and chemical experiments in laboratories. The SRARS machine can help to protect patients, healthcare workers and visitors in the ward against the infection of respiratory diseases through contaminated air. The final design was given in Figure 4 and the final product in Figure 5 was installed in Ward 9A at Prince of Wales Hospital.

III. COVID19 ISOLATION ROOM MACHINE FOR NURSING HOMES

A detailed comparison of SARS 2003 (SRAS-CoV) and COVID 19 (SARS-CoV-2) from causes to preventions in Hong Kong can be found in [2]. Since the highest fatality cluster is in the group of people in care homes, we design a negative pressure isolation room machine for the use in the isolation rooms which do not have negative pressure function. In order to reduce the spread of the new coronavirus and airborne pathogens (such as tuberculosis, measles, and chickenpox), symptomatic patients should be isolated as soon as possible, and the negative pressure isolation ward in the hospital is monitored by the central control room. If the control room has problems, all the isolation ward will be useless. Although there are isolation wards in nursing homes or rehabilitation homes, they have no negative pressure function and can only provide limited isolation to reduce the risk of transmission. Existing negative pressure isolation wards use air filters to isolate viruses in the air, but the air filters will hinder air circulation and require a lot of electricity to generate negative pressure, and the viruses will be left on the air filters. When staff replace the air filter, there is a great risk of infection.

The purpose of the present invention is to provide an air filter used in negative pressure isolation wards. The technical problem to be solved is to filter the air, and the structure is simple and environmentally friendly. Compared with the prior art, the present invention provides an air channel, a water filter baffle in the air channel, a filter medium is laid on the water filter baffle, and aqueous ozone is sprayed into the air channel to filter the air. The device is equipped with an ozone generating device to repeatedly electrolyze the aqueous ozone to increase the ozone content. Through continuous circulation, not only the structure is simple, but also energy consumption is saved. Since there is no replacement part, it is very environment friendly and maintenance free.

We aim to provide air exchange over 10 times in an hour for a typical isolation room in the nursing room of size $10m^2$ based on the principle of the SRAS machine. The design is scalable that can be scaled up for hospitals, schools and shopping malls. Although the original design is to catch and kill virus and bacteria before discharging, the function can be reversed to provide virial free air into the premises. We use aqueous ozone instead of bleach water as ozone can be generated automatically without human intervention which is an advantage for maintenance free purpose. Ozone dissolved in water is an effective disinfectant and can be reorganized into oxygen using cold atmospheric plasma or UVC before discharging into the environment.

IV. THE PROTOTYPE OF THE COBID19 ISOLATION ROOM MACHINE

This section describes the layout of the current design. The schematics are in Figure 6.The machine has a housing consisting of four air chambers, A, B, C and D and two water chambers E and F. The chambers are separated by three partitions for the flow of the infected air inside the housing. The extractor fan on the right side of the housing creates a lower pressure than the room pressure that sucks the infected air entering into the housing from air chamber A flowing to B, C and D. Each of the air chamber has a water shower that sprays atomized ozone water mixing with the infected air through the Spirals. The ozone water is produced from the ozone generator with the associated diffuser at the bottom of the water chamber E and fed to the showers via the water pump at the bottom of the water chamber F. There is a particle barrier at the entrance on the left of the housing to filter out air particles, a protection barrier on the exit to stop external objects (e.g. rain) from coming in. The water barrier 1 stops moisture to go out and the water barrier 2 is to avoid the Spirals dropping down the water chambers. From experience, water moisture does go out from the exit on the right side and a water level sensor is necessary to feed in water from outside to maintain the water level. For air conditioning purpose, there is a thermoelectric unit (in red) that produce temperature difference by electric energy without using a compressor. The water is heat up by the unit. The heat in the water is conducted by the heatpipe to the upper part of the air chamber D and extracted to outdoor through the extractor fan. The heat transfer of the heatpipe is by phase changes of the substance inside it very efficiently. Therefore, the machine can replace the window type air-conditioner of the isolation room effectively.

When there a suction inside the air chambers, the water level at water chamber F will be higher than that at water chamber E. The difference will be dependent on the suction intensity. Therefore, the barrier between E and F should be low enough so that air will not be able to pass through the barrier. The water level sensor is placed slightly above water level at chamber F. Due to suction, the water level is higher than the sensor. Therefore, the machine should be turned off a few minutes daily, so that water is leveled in chambers E and F and the water level sensor will effectively activate the required water intake. There is an ozone sensor at the exit to check the ozone level. The UVC/plasma generator will be activated to decompose the ozone into oxygen if the level is higher than permitted. In case that UVC/plasma cannot bring back the ozone level to safety, the ozone generator will be turned off until the ozone level is acceptable. Using high-voltage ionization, part of the oxygen in the air is decomposed and polymerized into ozone. Ozone is easy to decompose and cannot be stored. It needs to be prepared and used on-site. It is very soluble in water to avoid allergic symptoms caused by gaseous ozone. The principle of ozone sterilization is that ozone acts on the cell membrane of bacteria and other microorganisms, causing cell membrane damage, metabolic disorders, and growth. Inhibition; if ozone breaks through the cell membrane and continues to penetrate, the lipoproteins and lipopolysaccharides in the membrane are destroyed, the cell permeability changes, and the body is killed. While ozone kills viruses, oxidation directly destroys its genetic material-RNA or DNA, thereby killing the virus.

V. EFFECTIVENESS OF AQUEOUS OZONE TO DISABLE VIRUS

It was announced that "Ozone can be used to destroy the new coronavirus and disinfect areas" in Thailand Medical news Feb 05 2020 and cited 17 scientific studies in [4]. It was also noted that, typically ozone generators should only be used by trained personnel as ozone is dangerous to humans and brief exposure to it in gas form can be dangerous. The safe use of aqueous ozone was reviewed in [5].However, it is very safe to clean infected air via aqueous ozone with spiral when exhausting to outdoor as the ozone gas will stay in water. The effectiveness of aqueous ozone to disable virus can be found in [6].

Table 1 summarized the ability of ozone disinfection when comparing with other methods found from US EPA, CDC and WHO in terms of the CT (concentration times time in minutes) value.

Table 1. Benchmarking table for comparison of various disinfection agents and their efficiencies using CT-value (mg.min/L)*.

Type	Log inactivation	Ozone	Hypochlorite	Chlorine dioxide	Free chlorine	Peracetic acid (PAA)
E. coli	2	<0.02	25-30	<1	<0.05	25-30
Viruses	4	<0.1	<0.1	25-30	6	Scarce studies
Protozoa	3	1-2	10-20	15-25	>100	Scarce studies

Every technique has its specific advantages and its own application area. In the table below some of the advantages and disadvantages are shown.

It is difficult to make a general comparison to represent all applications and water qualities. However, as can be seen in the table above, when comparing typical water disinfection attributes ozonation stands out as an environmentally friendly, robust, combatible, and effective water disinfection treatment. A typical CT-value (mg.min/L) to disable virus is 0.1 or 20 sec for 0.3 mg /L ozone. Because the spirals have the ability to eliminate smoke particles in our clean incense burners, the virus will be trapped in the ozone water for much longer than 20 sec. Additional ozone disinfection references can be found in [7] to [9].For commercialization, we shall make it in the form of window air-conditioners for wider application. In fact, we can make it more attractive as a new type of air-conditioner using Peltier to heat up the water and release cold air to the room. This will be designed and manufactured during the trial run period and make it commercial after that.

VI. IMPROVEMENT BY AQUEOUS OZONE

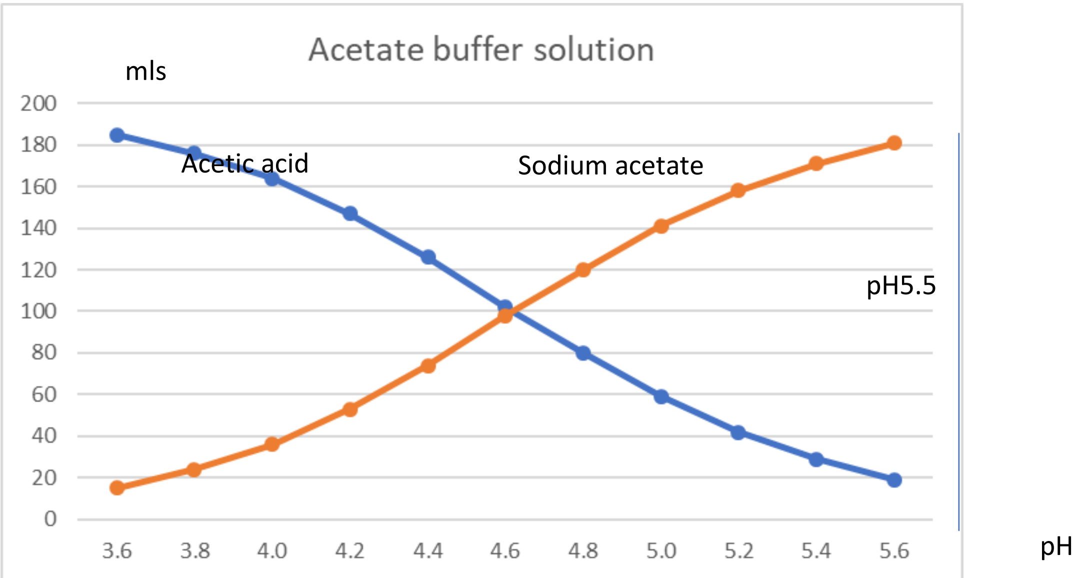
Antimicrobial effects of aqueous ozone were studied in combination with acetate, propionate, or butyrate short chain fatty acids (SCFA) as well as citrate or oxalate buffer formulations against *Staphylococcus aureus* on glass coupons in [10]. Aqueous ozone combined with an acetate buffer was also evaluated against *Salmonella enterica* and *Klebsiella pneumoniae*. They found that the acetate, propionate, and butyrate buffered aqueous ozone combinations at pH5.5had a significant 3–4 log reduction of S. aureus ($P<0.05$) colony forming unit (CFU) and concluded that all buffer systems tested had a significantly greater reduction in CFUs following treatment with the combination of buffer and ozone, compared to treatment with buffer or ozone individually and these formulations have potential to sanitize without residues, using an environmentally conscious formulation.

We follow [11] to prepare one liter of acetate buffer solution that will be scaled up to eight liters for the prototype. A table for acetate buffer solutions from pH3.6 to 5.6 can be found in [12] and is reproduced in Table 2 and plotted in graph 1 for the preparation of buffer water at pH5.5 by interpolation.

Table 2 pH buffer with acetic acid and sodium acetate

pH	vol of 0.1M acetic acid mls	vol of 0.1M sodium acetate mls
3.6	185	15
3.8	176	24
4.0	164	36
4.2	147	53
4.4	126	74
4.6	102	98
4.8	80	120
5.0	59	141
5.2	42	158
5.4	29	171
5.6	19	181

Graph 1 Acetate buffer solution



From the graph, we can get the required combination of acetate acid and sodium acetate for pH5.5. To prepare 0.1M acetate buffer pH5.5 under experimental condition, the required components are calculated in Table 3.

Table 3. Preparation of pH5.5 buffered water

	For 1 L solution	For 8 L solution
Sodium Acetate, trihydrate MW = 136g	11.63g (0.055M)	93.04g
Glacial acetic acid 60.05g	0.86g	6.88g
Water to	1 L	8L

The procedure for preparing 1L buffer water is given below.
1. Prepare 800 mL of distilled water in a suitable container.
2. Add 11.63 g of Sodium Acetate to the solution.
3. Add 0.86 g of Acetic Acid to the solution.
4. Adjust solution to desired pH using sodium acetate/acetate acid.
5. Add distilled water until volume is 1 L.

Since our prototype requires eight liters of buffer water, we scale it up to eight liters.The buffer solution is used to fill the water chambers E and F in Figure 6.

VII. TESTING

To find out the efficacy of disinfection of our machine, we used E.coli as the testing microbes. We prepared 25 clean LB (Lysogenic Broth) agar plates and 50ml E.coli culture of strain DH5 alpha with $1x10^6$ CFU/ml. The equipment used included a nebulizer and an aerosol impactor. The air inlet of the prototype was covered by a paper box that house the nebulizer which emitted atomized E.coli. The experiment procedures were:

1. Wiped the inside of Mark 1 Filter tank with 75% ethanol.
2. Filled the tank with 8L 0.1 M Acetate Buffer at pH 5.66
3. Started the water pump and let the water jets drizzle into the respective compartments
4. Checked whether there was any leakage from the water pump.
5. Closed the lid of the tank and turned on the extractor fan.
6. Cleaned the nebulizer with still water and filled in E.coli broth.
7. Turned on the Air filter and let water pump and extractor fan to run until a stable condition, for 10 minutes.
8. Turned on the nebulizer (air speed 0.1m/s) and placed it at the inlet of the air filter until a steady stream of aerosol was obtained.
9. At t = 0s to 2s With the pump (with clean LB plate inside, air speed 1m/s) and extractor fan running steadily
10. At t = 2 s to 12 s, Turned on impactor and collected air sample for 10 s., simultaneously, opened the lid of a clean agar plate at the air inlet facing the nebulizer for 10 s exposure.
11. At t = 12 s, Switched off the impactor and the nebulizer.
12. The whole cycles were repeated 6 times.
13. At the end of cycle 5, the plug of the impactor went busted, so the experiment was repeated once more to check whether the impactor was in working condition.

All LB agar plates were incubated at 37^oC for 12 hours and CFU were counted.

RESULTS: The negative control plates did not have bacteria growth which means that the LB agar plates were properly sterilized. Plates at the air inlet entrance had 303 to 450 CFU with an average of 380 CFU. Plates collected by the impactor at the exit had 0 to 11 CFU with an average of 2.5 CFU. It was concluded that the disinfection rate was 99.34%.

VIII. CONCLUSION AND FUTURE WORK

The current arrangement is able to deactivate the number of E. coli growing at the outlet of the COVID Machine. The installation of the machine in one of the nursing homes is shown in Figure 11. We are trying out additional improvement on the COVID19 isolation machine. Other maintenance free disinfection strategies being studied includes using UVC (ultra-violet) and bipolar ions (cold atmospheric plasma). We shall explore and perhaps incorporate those alternative technologies as a part of our next designs, for example, adding sensors to monitor the buffer solution level, ozone concentration, and other parameters, to allow control during the operation of the COVID Machine to give warning to users when the buffer solution level is low, or reduce ozone production when ozone concentration is too high. The integration with a cooling unit is under development. When there is a body of water (buffer solution) to act as a heatsink, one can incorporate a Peltier heat pump unit into the COVID Machine so that it can serve as an air-conditioner for the indoor space. A Chinese patent was filed and announced in the China National Intellectual Property Administration www.cnipa.gov.cn volume 4302 Issue 36 on 23 October 2020.

REFERENCES:

[1]. Siukan Law, Albert Wingnang Leung, Chuanshan Xu, Severe acute respiratory syndrome (SARS) and coronavirus disease-2019 (COVID-19): From causes to preventions in Hong Kong, International Journal of Infectious Diseases, 94 (2020) 156–163

[2]. Albert T P So , Andrew Y T Leung , David S C Hui, Rudolf S S Wu & Jane W Z Lu , Development of an Air Cleaner for Severe Acute Respiratory Syndrome, HKIE Transactions, Published online: 09 Apr 2013. https://doi.org/10.1080/1023697X.2005.10667991

[3]. Department of Health, Hong Kong, https://www.info.gov.hk/info/sars/en/useofbleach.htm

[4]. https://www.thailandmedical.news/news/ozone-can-be-used-to-destroy-the-new-coronavirus-and-disinfect-areas

[5]. M Hussain; MS Mahtab; IH Farooqi, The applications of ozone-based advanced oxidation processes for wastewater treatment: A review, ADVANCES IN ENVIRONMENTAL RESEARCH-AN INTERNATIONAL JOURNAL, Volume: 9 Issue: 3 Pages: 191-214

[6]. https://www.ozonetech.com/water-treatment/ozone-disinfection-drinking-water

[7]. D Roy, P K Wong, R S Engelbrecht, and E S Chian;Mechanism of enteroviral inactivation by ozone.;Appl Environ Microbiol. 1981 Mar; 41(3): 718–723.

[8]. S Young,J Torrey,V Bachmann et al; Relationship Between Inactivation and Genome Damage of Human Enteroviruses Upon Treatment by UV254, Free Chlorine, and Ozone; FOOD AND ENVIRONMENTAL VIROLOGY; Volume 12 Issue 1 Page 20-27; 2020

[9]. J Torrey, U von Gunten, T Kohn; Differences in Viral Disinfection Mechanisms as Revealed by Quantitative Transfection of Echovirus 11 Genomes; APPLIED AND ENVIRONMENTAL MICROBIOLOGY; Volume: 85 Issue: 14; Article Number: UNSP e00961-19; 2019
[10]. Holly C. Britton, Michael Draper, James E. Talmadge, Antimicrobial efficacy of aqueous ozone in combination with short chain fatty acid buffers, Infection Prevention in Practice, Volume 2, Issue 1, March 2020, 100032
[11]. https://www.aatbio.com/resources/buffer-preparations-and-recipes/acetate-buffer-ph-5
[12]. http://delloyd.50megs.com/moreinfo/buffers2.html

[13].

Figure 1 the “spiral”

Figure 2 Spirals with sprinkler

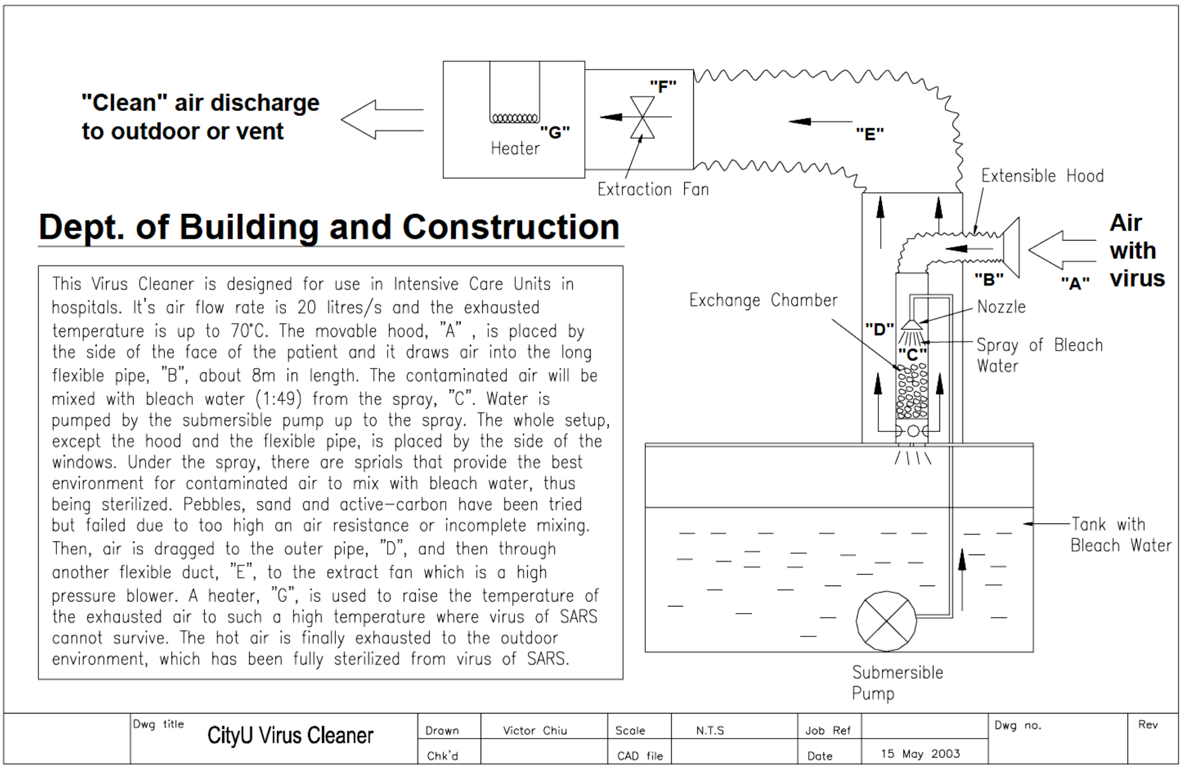


Figure 3 The conceptual design of the 2003 SARS machine

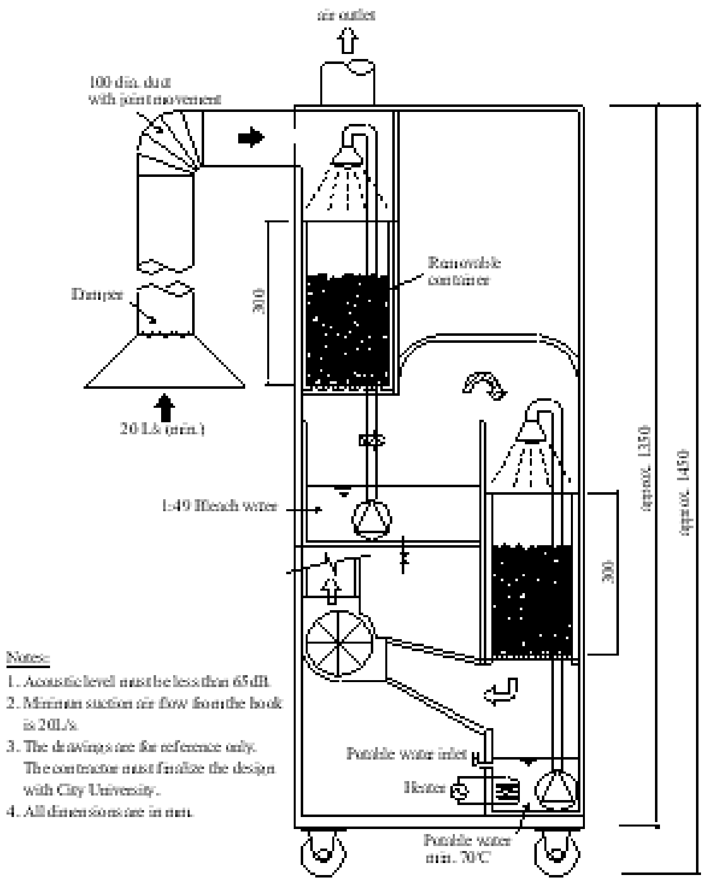


Figure 4

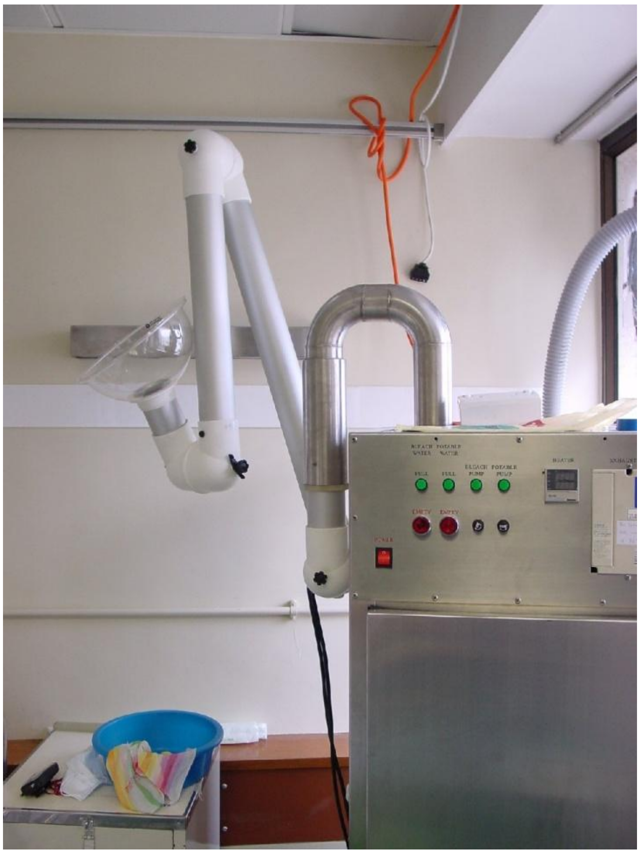


Figure 5

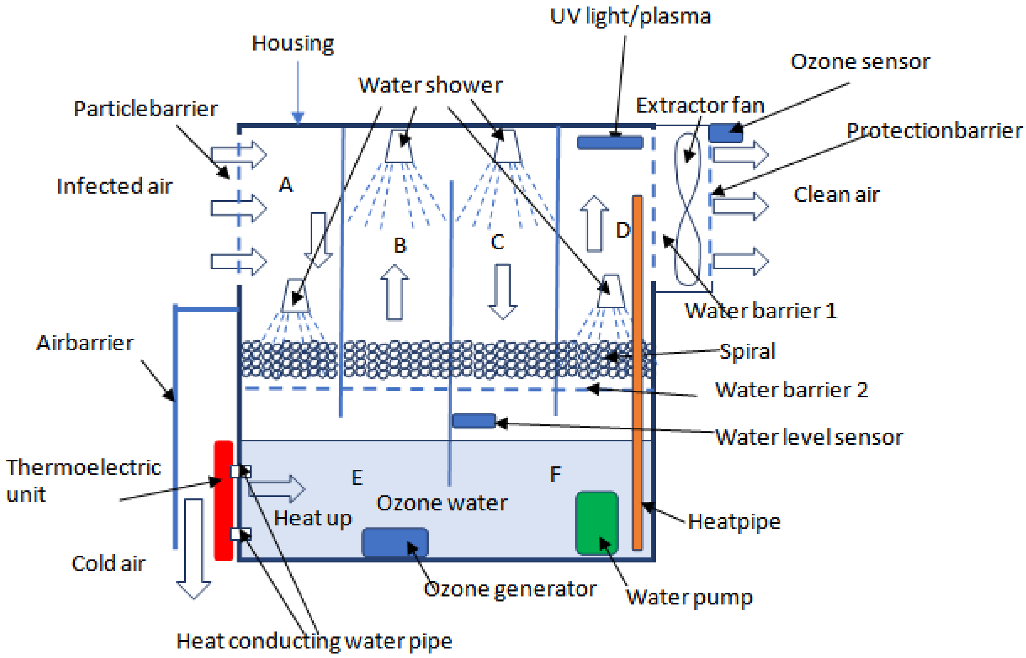


Figure 6 The conceptual design of the prototype

Figure 7 The nebulizer

Figure 8 The Impactor

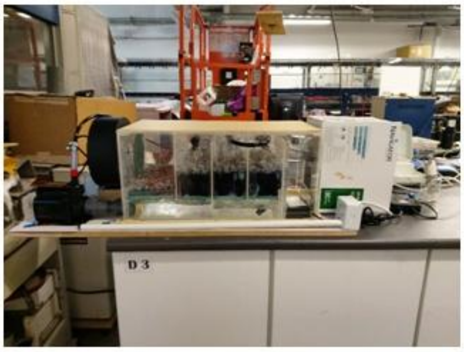


Figure 9 The prototype

Figure 10 Position of the nebulizer in the paper box

Figure 11