Development of Infectious Disease Control Technologies Toward Establishing Safe and Secure Society

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There is a desire to establish a safe and secure society against the spread of infectious diseases including the novel coronavirus disease through the reduction of the risk of infection. Mitsubishi Heavy Industries, Ltd. (MHI) has been developing infectious disease control technologies and products for air conditioners used in transportation systems such as railway vehicles, ferries and large spaces. This report introduces some of the technologies under development. As virus control technologies, a virus removal method using airflow control and virus inactivation methods using physical or chemical means (UV-C, agents, ozone, adsorbents) are described and as a visualization technology, a method of estimating the behavior of infectious materials and infection risk by simulation (CFD, epidemiological model, etc.) is described.

1. Introduction

To cope with the spread of infectious diseases including the recent novel coronavirus disease (COVID-19), measures for reducing the risk of infection are required. MHI has been promoting the development of infectious disease control technologies and products that are used in vehicles for transportation systems and ferries, as well as important infrastructure with large spaces such as large commercial facilities, airports and hospitals in order to suppress the spread of infection.

2. Transmission routes and infectious disease control technologies

It is known that the transmission of infectious diseases occurs through droplets, contact and airborne particles (**Figure 1**)[(1)]. According to the Ministry of Health, Labour and Welfare, the main transmission routes of COVID-19 are through droplets and contact.

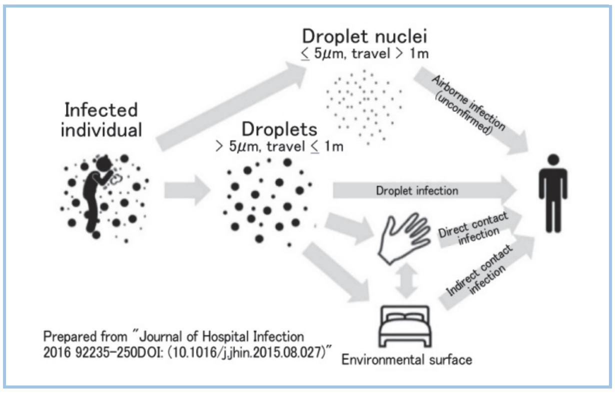

Figure 1 Main transmission routes of infectious diseases[(1)]

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MHI has been promoting the development of countermeasure technologies to deal with these transmission routes. This report introduces virus control technologies using airflow control to efficiently eliminate virus and the inactivation of viruses by ultraviolet rays, ozone and a formulation (enzyme, urea), as well as a simulation technology for estimating the behavior of infectious materials in spaces.

3. Infectious disease control technologies

For measures against infectious diseases, we conduct monitoring/measurement and the check of the efficacy, as well as the virus control and the estimation of the efficacy. Here, the virus control technologies and the visualization technology under development are described.

3.1 Virus control technologies

(1) Airflow control

With the airflow control technology, airborne viruses are taken into air conditioners and the virus are removed or inactivated in the air conditioners in order to reduce the risk of infection. There is an airflow control method using the recirculating airflow control which has been proven with our products. In the recirculating airflow control, recirculating air vortices are generated in the space between the blowout port of an air conditioner and the floor surface or wall surface and air is taken in through the suction port of the air conditioner. The recirculating air vortices formed in the space allow much air and airborne viruses to be efficiently taken in from the space at the same time (**Figures 2** and **3**). As a result, the risk of droplet infection can be reduced.

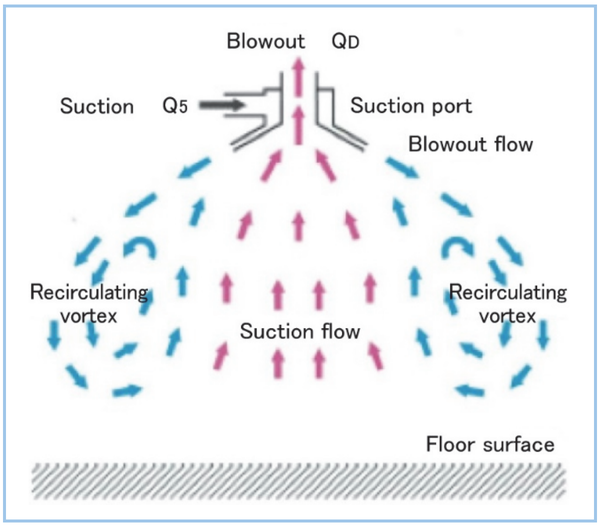

Figure 2 Concept of recirculating airflow control

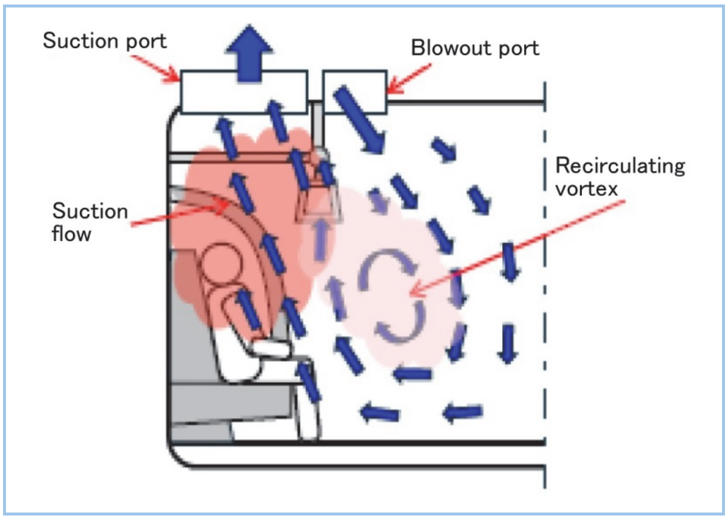

Figure 3 Proposed application of recirculating airflow control to vehicle interior space

We used CFD (Computational Fluid Dynamics) to verify the effects of the airflow control applied to the interior space of a vehicle for transportation systems and conducted a verification test using a real-scale mockup to examine the recirculating airflow generation state. We could quantitatively estimate that the modification of the air outlet of an airflow device could improve the rate of collection of particles floating in a space.

(2) Ultraviolet rays

The inactivation of viruses by ultraviolet rays reduces the risk of infection. The Ultraviolet-C light-emitting diodes (UV-C LED) are used to irradiate the ultraviolet rays. There are two application methods: one is a method where air containing viruses is taken in and the air is irradiated with UV-C to inactivate the airborne viruses and the other is a method where UV-C are irradiated to the entire space to inactivate any viruses existing on surfaces of parts that are touched by people, such as wall surfaces and handrails. The former method can reduce the risk of droplet infection and the latter method can reduce the risk of contact infection.

To verify the virus inactivation effect of UV-C, MHI conducted a verification test in a joint research effort with Professor Katayama from the Omura Satoshi Memorial Institute of Kitasato University(2). In the test, a liquid containing tens of thousands of SARS-CoV-2 particles was applied and spread on a resin plate and from a distance of 3 cm, deep-ultraviolet rays were irradiated by UV-C LED. Viruses on the irradiated surface were collected and the efficacy of the inactivation method was measured. The result revealed that 10 minutes of irradiation could almost entirely inactivate the viruses.

(3) Agent

The inactivation of viruses by an agent (enzyme-urea) reduces the risk of infection. This enzyme-urea agent has been on the market for about 20 years as a material (bio-clear filter) for air conditioners (BEAVER air conditioners, Mitsubishi Heavy Industries Thermal Systems, Ltd.) (**Figure 4**). Since 2020, masks using the bio-clear filters (Beaver Mask, Mitsubishi Heavy Industries Thermal Systems, Ltd.) have been sold.

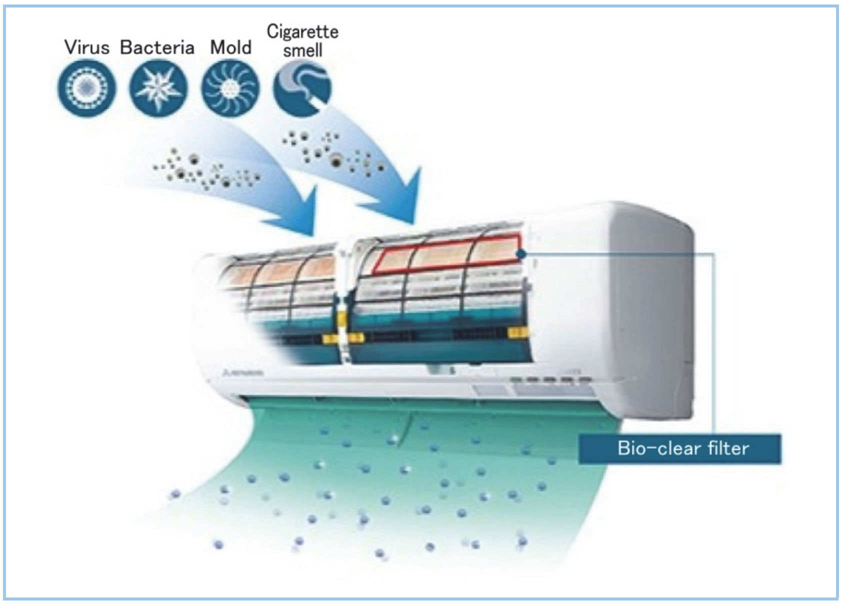

Figure 4 Image of air conditioner using bio-clear filter

To verify the virus inactivation effect of the (enzyme-urea) agent, we conducted a verification test in a joint research effort with Professor Katayama from the Omura Satoshi Memorial Institute of Kitasato University(2). The test results confirmed that tens of thousands of SARS-CoV-2 particles were inactivated almost entirely by the virus inactivation agent (urea and enzyme) contained in the dust collecting air filter with a reaction time of 60 minutes.

The combination of the (enzyme-urea) agent with air conditioners can reduce the risk of droplet infection.

(4) Ozone

Ozone has a high oxidative power and has been used for the reduction of the activities of bacteria and viruses. Concerning the efficacy of ozone in the inactivation of the novel coronavirus, a research group from Nara Medical University announced in May 2020 that the novel coronavirus was inactivated by exposure to ozone gas[3]. They consider that a CT value of 330 (ozone concentration of 6 ppm, 55-minute exposure) can inactivate the novel coronavirus to 1/1,000 through 1/10,000 and a CT value of 60 (ozone concentration of 1 ppm, 60-minute exposure) can inactivate the novel coronavirus to 1/10 to 1/100. (CT value: Performance index indicating the ozone treatment condition. It is expressed as a product of ozone concentration C (ppm) and exposure time T (min).)

In the commercialization of ozone treatment, Mitsubishi Power Environmental Solutions, Ltd. (currently, Mitsubishi Heavy Industries Power Environmental Solutions, Ltd.) released an air cleaning device using an ozone generator for use in large spaces in September 2021[4]. The air cleaning device enables purification with a large volume of air (3,000 m^3/h) and it has been proposed that it be introduced widely in large, enclosed spaces such as the domes of arenas, as well as in airports, shopping malls, large theme parks, hospitals, etc. Ozone spraying can suppress the activity of viruses that exist in a space and on floor or wall surfaces, while purifying large spaces. Accordingly, the risk of droplet infection and contact infection can be reduced.

MHI has also been developing a small-size, light-weight, large-air flow (about 1,500 m^3/h) and low-cost ozone spraying device for smaller spaces (**Figure 5**). The intended users are transport service operators of trains, buses, etc. and we propose that ozone spraying should be introduced instead of the current wiping work (**Figure 6**). To examine the characteristics of ozone spraying in railway vehicles, we conducted an ozone spraying test and simulation (CFD), using actual vehicles at MHI's MIHARA Test Center (Hiroshima prefecture). Based on the test result, we have been conducting the optimization of the ozone spraying method (spraying position, spraying time, etc.).

Power	Weight	Outside dimensions (mm)
AC 100V	up to 10kg	W400xL500xH250

Figure 5　Appearance of small-size ozone generator

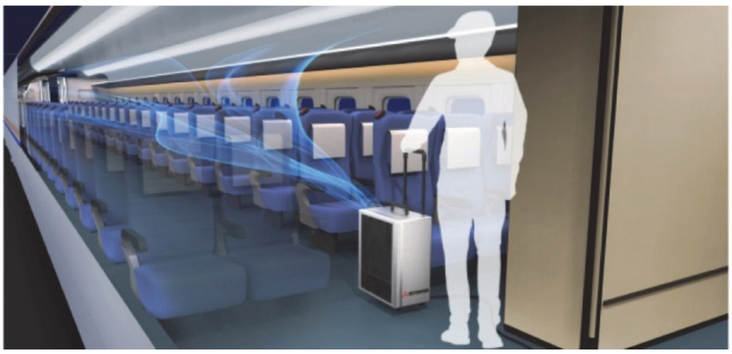

Figure 6　Image of ozone generation/spraying

(5)　Adsorbent

The University of Hong Kong reported that the stability of the novel coronavirus differed by the surfaces to which it attached and no virus could be detected from printing paper and tissue paper after 3 hours[5].

Based on the above information, we made the hypothesis that the inactivation of the novel coronavirus by paper materials was due to the loss of infectivity caused by the adsorption of droplets containing the virus to cellulose fibers and the drying/dewatering of the droplets, followed by the denaturation of protein. We selected cotton (the main component is cellulose) that can be used especially for interior materials such as wallpaper as a cellulosic industrial material and examined the efficacy in the inactivation of the novel coronavirus through experiments. The result showed that 95% of the novel coronavirus were inactivated immediately after coming into contact with the cotton and over 99% were inactivated 6 hours after contact (**Figure 7**). We also observed by electron micrographs that there were particles of 100 nm in diameter, which were supposed to be the novel coronavirus, trapped on the surface of the cellulose fibers (**Figure 8**).

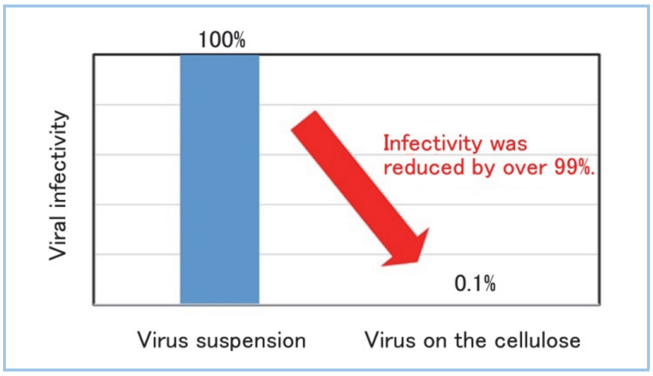

Figure 7 Efficacy of adsorbent in inactivation of novel coronavirus

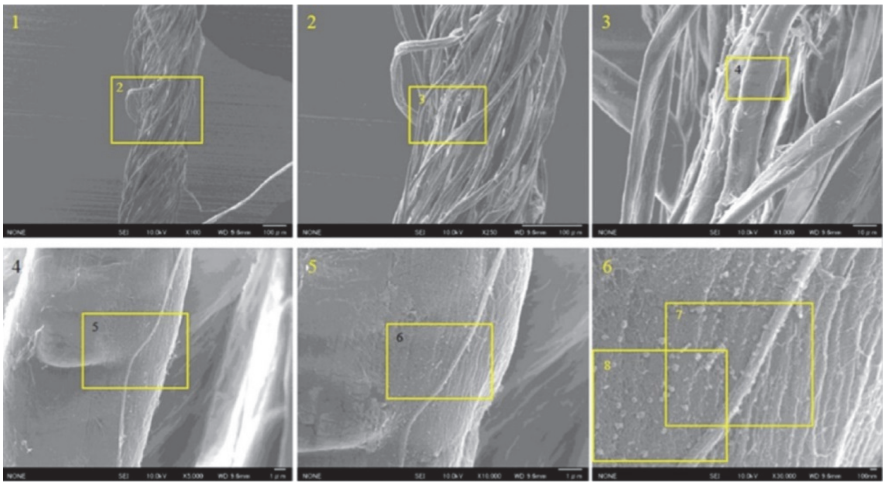

Figure 8 Electron micrographs of cotton surfaces washed after contact with novel coronavirus

3.2 Visualization technology

The virus control technologies were described in section 3.1 above, but due to the small size of the virus particles, which are about 100 nm in diameter, virus particles are hard to detect and at the present stage, it is difficult to measure the concentration of viruses in a space. Therefore, the difficulty in confirming the efficacy of virus control technologies has been an issue. To cope with this issue, MHI developed a coupled analysis method by incorporate a mathematical epidemiological model into CFD analysis software. The SIR model and Wells-Riley model were used for the mathematical epidemiological models(6) and concerning the infectivity of the novel coronavirus, the research results by Hui et al. were adopted(7). The visualization function of the CFD was used to estimate, quantify and visualize the infection transmission and local infection risk associated with advection diffusion of infectious substances. In addition, the functions and characteristics of virus control technologies were mathematically modeled, so that the efficacy of the virus control equipment in the reduction of the risk of infection could be evaluated (**Figure 9**). As a result, effective spatial arrangements of the virus control equipment can be proposed.

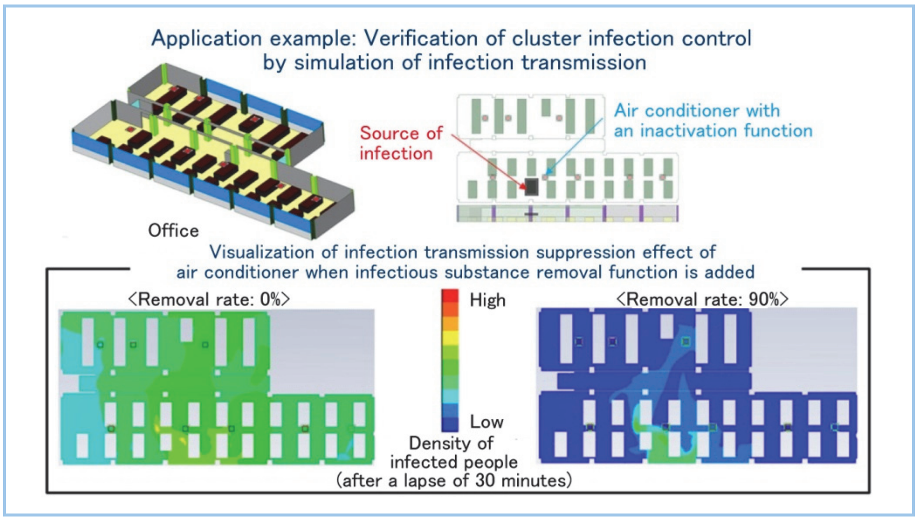

Figure 9 Estimation of spatial distribution of infectious substances

4. Conclusion

We described the study cases of the virus control technologies and visualization technology we have been developing by adding functions to our products toward making our society resilient to infectious diseases such as the novel coronavirus. It is expected that the application of these technologies can reduce the risk of infection in transportation systems, ships, airplanes and through air conditioners for large spaces. Going forward, we will continue research and development toward the implementation of these technologies into society.

References

(1) J.A.Otter et al., Transmission of SARS and MERS coronaviruses and influenza virus in healthcare settings: the possible role of dry surface contamination, Journal of Hospital Infection, 2016 Mar; 92(3): 235–250.,
https://www.ncbi.nlm.nih.gov/pmc/articles/PMC7114921/

(2) Mitsubishi Heavy Industries, Ltd, Press Release, MHI Thermal Systems Demonstrates the Potential to Remove and Inactivate the Novel Coronavirus (SARS-CoV-2) through Proprietary Air Purification technology, -Research Conducted in Partnership with Satoshi Omura Memorial Institute of Kitasato University-, (2021),
https://www.mhi.com/jp/news/210210.html

(3) Confirms Inactivation of SARS-CoV-2 by Ozone Gas, Public University Corporation Nara Medical University, (2020),
https://www.naramed-u.ac.jp/university/kenkyu-sangakukan/oshirase/r2nendo/documents/press_2.pdf

(4) Mitsubishi Heavy Industries, Ltd, Press Release, Mitsubishi Heavy Industries Power Environmental Solutions, Ltd. Developed Air Purification Systems for Large-scale Spaces Suppressing of Virus Activity by Ozone, (2021),
https://power.mhi.com/jp/news/20210929.html

(5) Alex W H Chin et al., Stability of SARS-CoV-2 in different environmental conditions, Microbe, April 02, 2020, DOI: https://doi.org/10.1016/S2666-5247(20)30003-3,
https://www.thelancet.com/journals/lanmic/article/PIIS2666-5247(20)30003-3/fulltext

(6) Hiroaki Asanuma et. al, Transmission Analysis by Coupled Simulation of Unsteady Concentration Distribution and Epidemiological Model in Hospital Space, Journal of Environmental Engineering, Architectural Institute of Japan, Vol. 78, No. 688, 481-487, Jun. 2013
https://www.jstage.jst.go.jp/article/aije/78/688/78_481/_pdf

(7) Hui Dai et al., Association of the infection probability of COVID-19 with ventilation rates in confined spaces, Build Simul. 2020 Aug 4 : 1–7,
https://www.ncbi.nlm.nih.gov/pmc/articles/PMC7398856/pdf/12273_2020_Article_703.pdf