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Engineering 9 (2022) 13–16

Contents lists available at ScienceDirect

Engineering

journal homepage: www.elsevier.com/locate/eng

Views & Comments

A Multi-Stage Green Barrier Strategy for the Control of Global SARS-CoV-2 Transmission via Cold Chain Goods

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1. The object-to-human transmission route of SARS-CoV-2

At the time of writing, coronavirus disease 2019 (COVID-19), which is caused by the severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2), has been a global pandemic for more than a year. As of 22 September 2021, the global cumulative incidence exceeds 229 million cases, and the number of deaths has exceeded 4.75 million [1]. The current situation of epidemic prevention and control within the countries around the world can be roughly divided into two stages: the pandemic stage that the United States, the United Kingdom, and India are still experiencing (as of 23 September 2021, newly reported cases in the last 24 h in the United States, United Kingdom, and India are 202 840, 31 095, and 26 964, respectively [1]); and the normalized epidemic prevention and control stage that countries such as China and New Zealand are currently in.

Recent studies report that positive results for COVID-19 have been detected in environmental and blood samples from March to October 2019 in Italy, the United States, France, and Spain [2]. As this finding indicates, sorting out the origin and transmission route of SARS-CoV-2 on a global scale is a very complex issue that has received a great deal of international attention. According to published research results, human-to-human transmission via respiratory droplets and close contact is the main transmission route of SARS-CoV-2 [3]. At the same time, however, it has been reported that there are cold chain practitioners who have been infected via contact with contaminated cold chain goods in China [4]. Moreover, it has been found that SARS-CoV-2 can persist on contaminated frozen products, and the presence of SARS-CoV-2 in unopened packages and containers has been found in different cities by means of nucleotide acid tests or the isolation of live virus [4,5]. The transmission of SARS-CoV-2 from contaminated cold chain foods to people has been listed as the possible introduction and transmission route of the epidemic by the joint World Health Organization (WHO)–China study, although more research is needed to identify the exact infection route (i.e., oral, touch, aerosol, etc.) [5]. Therefore, contact with objects contaminated by SARS-CoV-2 may also cause infection.

As a low-temperature environment is conducive to the long-term survival of the virus [6], the object-to-human transmission route that through direct contact with contaminated cold chain goods may play a key role in the outbreak and spread of the COVID-19 pandemic. Compared with other representative pandemic outbreaks in the past hundred years, the COVID-19 pandemic represents the first time that cold chain goods have been especially emphasized as a possible key medium for virus transmission, as well as the first time they may have caused a serious global concern.

Cold chain logistics is the process by which refrigerated or frozen products are organized and passed along a cold chain. It is a unique type of supply chain in which products (e.g., food, medicine, flowers) are always kept in an appropriate low-temperature environment to ensure their quality and reduce their loss. It consists of main four parts: cold chain processing, refrigerated warehouse storage, refrigerated transportation and distribution, and refrigerated retail. Based on statistical data for 2018, the global cold chain market size was valued at 167.99 billion USD, and the food cold chain held the dominant role, accounting for more than 75% of the entire cold chain market [7]. Taking China as an example, the total demand for cold chain logistics has increased from 92 million tonnes in 2014 to about 265 million tonnes in 2020, with an overall market size of more than 383.2 billion CNY [8,9]. Considering the continuous growth of the global population and the increasing emphasis on food safety, it can be deduced that the total demand and scale of global cold chain logistics will continue to grow rapidly, especially in developing countries.

However, when cold chain goods, with its rapidly growing demand, becomes the medium for the object-to-human transmission route of the virus, it is impractical to conduct epidemic prevention and control by interrupting the international trade of cold chain goods over the long term. Thus, the question of how to cut off the object-to-human transmission route of the virus has become a new global challenge. Under these conditions, the effective disinfection of cold chain goods is likely to be the most viable choice. However, several key problems have been recognized in practical disinfection processes, including the following:

(1) Virus detection and disinfection during the customs procedures of both importing and exporting countries play a key role in cutting off the viral transmission route. However, at present, virus detection in most customs procedures is conducted by means of spot checks, which cannot confirm the complete detection of infected goods.

https://doi.org/10.1016/j.eng.2021.08.013
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(2) The repeated spraying of conventional liquid disinfectants to disinfect refrigerated warehouses and containers is not only time-consuming, but also requires tedious manual operation.

(3) Since the temperature inside the containers in cold chain logistics is always maintained at around −20 °C, it is easy for commonly utilized disinfectants, including sodium hypochlorite, peroxyacetic acid, and H_2O_2, to freeze once they have been sprayed, resulting in a prominent decline of disinfection efficacy. At the same time, the use of ultraviolet and ionization radiation methods for packed containers results in the problem of blind corners for disinfection.

(4) Secondary pollution and disinfection byproducts are issues that result from the abundant utilization of disinfectants, which may develop into severe risks to both humans and the environment.

(5) The excessive utilization of disinfectants will result in their release into the environment through wastewater discharge, which may facilitate the bacterial acquisition of antimicrobial resistance (AMR). It has been proposed that the global spread of AMR holds potential to be the biggest global health challenge next to the COVID-19 pandemic [10].

2. A multi-stage disinfection system for cold chain goods

To solve the above mentioned problems and cut off the object-to-human transmission route that depends on cold chain goods as its medium, we propose a system of multi-stage barriers in this study. As shown in Fig. 1, the system is set up by establishing targeted virus prevention and disinfection strategies for five key steps throughout the whole life cycle of cold chain goods, based on the specific characteristics of every step. The details are as follows.

2.1. Cold chain processing and disinfection in customs

Recently, there have been frequent occurrences of COVID-19 infection clusters within meat processing plants in many countries, such as Germany and England [11], indicating the importance and urgency of virus prevention, control, and disinfection for cold chain processing. Workers at such plants may be at a higher risk of acquiring infection with SARS-CoV-2 via the object-to-human transmission route, due to their frequent close contact with products in cold chain processing. Moreover, the cold and enclosed environment of the processing workshop also facilitates the human-to-human transmission of the virus. Therefore, effective methods for preventing cluster infection at this step include the intensive and effective disinfection of upstream raw materials, limiting the number of people in the workplace, and strengthening personal protection by having the workers wear protective equipment. For the international cold chain logistics, special attention should be paid on the effective disinfection in customs of both importing and exporting countries. It is recommended to utilize the highly automatic disinfection technologies, such as ozone, for the preventive disinfection of all cold chain goods.

2.2. Refrigerated warehouse storage

Studies have shown that the infectivity of SARS-CoV-2 can remain almost constant for viruses on the surface of chicken, salmon, and pork at both 4 °C (the standard temperature for refrigerated storage) and −20 °C (the standard temperature for frozen storage) for 20 days [12]. In a recently reported case, a worker at a refrigerated warehouse in Tianjin, China, was infected by SARS-CoV-2. Furthermore, positive results have been obtained from samples taken from the outer packaging of frozen food, as well as from the door handles of refrigerated warehouses in many cities. These findings indicate the risk of object-to-human transmission in refrigerated warehouses. Effective cleaning and disinfection of walls, floors, and goods is the main way to cut off the virus transmission routes in refrigerated warehouses. However, as mentioned earlier, conventional liquid disinfectants freeze easily, resulting in a decline in disinfection efficacy and introducing a special challenge for disinfection in refrigerated warehouses, which are characterized by low temperatures and thermal insulation. Moreover, product overstocking exacerbates the previously mentioned problem of blind corners from disinfection when using ultraviolet radiation and ionization for disinfection. Therefore, updating the disinfection technology used in refrigerated warehouses is essential for breaking the virus transmission route, and thus is an urgent issue that currently needs to be solved.

2.3. Refrigerated transportation and distribution

Refrigerated transportation and distribution involves transporting goods by water in refrigerated vessels and containers, usually over long distances and across borders; transporting it by land in refrigerated trains and trucks; and transporting it by air using high-cost air transportation. Similar to refrigerated warehouses, the containers and freezers used in refrigerated transportation and distribution must be disinfected under the conditions of low temperature and an enclosed environment. It should be noted that the containers and freezers used in this step have the advantages of mobility and small volume in comparison with refrigerated warehouses. Based on these features, mobile and modular disinfection equipment can be developed for this step in order to accelerate

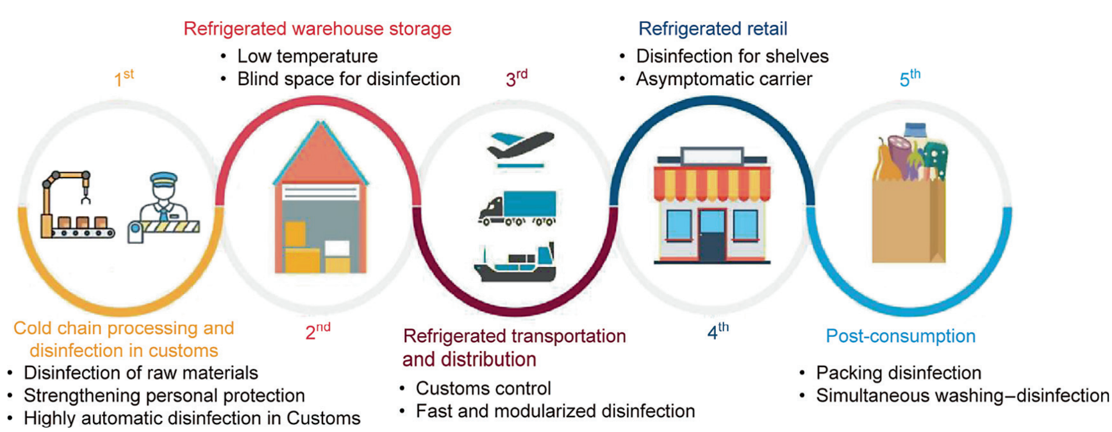

Fig. 1. Schematic of the multi-stage disinfection system for cold chain goods.

the disinfection process by the simultaneous disinfection of multiple units.

2.4. Refrigerated retail

Refrigerated retail refers to the frozen storage and sales of cold chain goods in the retail step of the process. The disinfection strategy used for the refrigerated warehouses at retail terminals can be the same as that used for the aforementioned refrigerated warehouses used for storage. In particular, there is potential object-to-human transmission risk for consumers who come into direct contact with cold chain goods in the markets. Therefore, shelves of cold chain goods should be disinfected regularly throughout the day. In case asymptomatic virus carriers spread the virus to cold chain goods through droplets or contact, it is recommended to implement frequent or continuous disinfection for cold chain goods on the shelves by means of ozone ice or ultraviolet treatment.

2.5. Post-consumption

Along with the abovementioned four key steps in cold chain logistics, household disinfection in the post-consumption step is the last link of the system. It is recommended that cold chain goods should be disinfected again before eating or cooking. For the outer packaging of cold chain goods, 75% alcohol or a household ultraviolet disinfection device can be used for disinfection. For vegetables, fruits, meat, and other goods that need to be washed, the new technology of ozone microbubble water can be used to achieve efficient cleaning and disinfection simultaneously. Moreover, there is a risk of virus transmission from the goods to the water used for cleaning. Therefore, in addition to the disinfection of cold chain goods, appropriate disinfection of wastewater in households and in wastewater treatment plants is very important.

It should be noted that the disinfection performances of the five steps described here are cumulative. Assuming that the average disinfection efficiency in each step is 90%, then the overall disinfection efficiency of the system will reach 99.999%. Thus, effective disinfection can be conclusively guaranteed by establishing a system of multi-stage barriers.

3. Green disinfection methods for cold chain goods

Unlike conventional disinfection, the disinfection of cold chain goods and devices is a type of special operation at low temperatures. Thus far, conventional disinfectants—mainly chlorine-containing disinfectants—have been used to disinfect objects and goods against SARS-CoV-2. However, these disinfectants are generally only effective at room temperature. As mentioned above, disinfectant solution can easily freeze once it has been sprayed onto containers during cold chain logistics, making it difficult to achieve effective disinfection. In February 2021, the Chinese Center for Disease Control and Prevention established two formulations of chlorine-based disinfectants that can be used in low-temperature environments at −18 and −40 °C, respectively, with sodium trichloroisocyanurate ($C_3Cl_3N_3O_3$) as the main component for disinfection [13].

As mentioned earlier, the disinfection of refrigerated warehouses and containers using conventional liquid disinfectants is not only time-consuming, but also requires tedious manual operation. Typically, a team of several people can disinfect dozens of tons of goods a day by spraying liquid disinfectants. As a result, several months or more are needed to complete the disinfection process for a large refrigerated warehouse with a total capacity of thousands of tonnes. Moreover, the problem of blind corners for disinfection due to overstocking when using typical disinfection methods must also be addressed. Gaseous disinfectants, such as ozone, are alternatives with the prominent advantages of a high degree of automation, no blind corners for disinfection, and high disinfection efficacy at low temperatures. Ozone-based disinfection technology has demonstrated satisfactory performance in practical disinfection operations for cold chain logistics, such as in Dalian and Suifenhe, China.

Last but not least, given the background of normalized epidemic prevention and control, the disinfection of cold chain goods should also become normalized. To this end, special attention should be paid to possible secondary pollution caused by the disinfection process, including the risk of contaminating drinking water sources with released disinfectants, the accumulation of toxic disinfection byproducts, and persistent environmental contamination. Commonly used chlorine-containing, iodine-containing, and hyamine-based disinfectants produce disinfection byproducts that are toxic to human health, such as chlorite, chlorate, iodoacetic acid, and nitrosamine [14], so their large-scale application will cause secondary pollution problems. In addition, when packaging of cold chain goods is incinerated as solid waste, the attached disinfectant residues and disinfection byproducts produce air pollutants such as dioxins [15]. To protect against accidental pollution and safety issues, sodium trichloroisocyanurate, chlorine dioxide, and other flammable or explosive agents should be stored properly or synthesized on site. From the perspectives of safety, health, and environmental friendliness, green disinfection methods with trace amounts of—or even no—toxic byproduct generation, such as H_2O_2, peracetic acid, ultraviolet radiation, and ozone, have prominent advantages over other disinfectants. Thus, in the stage of normalized disinfection for cold chain goods, it is recommended to promote the application of green disinfection methods and investigate ways to improve their performance and economic efficiency. Furthermore, based on these efforts, relevant standards and guides must be published to facilitate the development and application of such methods.

Acknowledgments

This work is supported by the National Key Research and Development (R&D) Program of China (2019YFD1100104-03-01); the National Natural Science Foundation of China (52000048); the Cooperative Researching Project of Chunhui Program, Ministry of Education, China (HLJ2019006); and Heilongjiang Key Laboratory of Ozone Application Technology and Equipment Development (OZO202104).

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