Chapter

Coronavirus Disinfection Physical Methods

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Abstract

Since 2019, the spread of the Coronavirus pandemic becomes the global health crisis. To fight the pandemic, several measures were adopted such as: Hygiene measure, massive test, social distancing, quarantine and distancing. Disinfection is an important operation in the fight against the spread of Corona virus pandemic. The disinfection methods are of chemical and physical type. In this work, we focused our interest to the physical methods. These methods are classified in three principal categories: irradiation techniques, heat treatment and mechanical techniques. All the different aspect of techniques are exposed in this chapter. The efficiency of the used techniques is also discussed.

Keywords: Covid-19, disinfection, irradiation, heat treatment, mechanical treatment

1. Introduction

The COVID-19 pandemic is the global health crisis, with 133 991 203 infected persons and 2 903 728 deaths in the world until 09/04/2021 [1]. The virus responsible for the disease is mostly transmitted through aerosols. To fight the pandemic spread, several measures have been adopted such as the disinfection. This operation consists in reducing the number of microorganisms: viruses, bacteria, fungi … Eliminating all microorganisms is called sterilization [2]. Disinfection techniques are classified in two categories: Chemicals and physical types [3–6]. Applying a chemical agents such as acids, Alcohols, Aldehydes,Alkalis, Biguanides, Halogens, Oxidizing agents and Quaternary ammonium compounds, permits to disinfect surfaces and medical devices [4, 6]. Al-Sayah [6] has shown that the used chemical agents have excellent biocidal activity within a short time, easy to use and low toxicity. However, if chemical agents' concentration is high, the medical devices can be damaged and risk toxic effects on the technician [7]. Since 1908, Chick-and Watson have proposed a model to study the kinetics disinfection of water chlorination [8]. This model was refined by taking into account the disinfection process such as dissipating/volatile disinfectant [9–13]. The physical disinfection methods are classified in three categories: **(1)** Mechanical, **(2)** thermal treatment and **(3)** radiation effect [14]. The mechanical treatments include disinfection of surfaces by ultra-sound, plasma treatment and detergent action. Using ionizing or non-ionizing radiation (UV light, X rays, gamma rays, electron beam and heavy metals) is an important technique to disinfect surface. The efficiency of treatment depends on the penetration depth of the radiation; this is due to the wave length [15, 16]. The thermal treatment consists of heating or cooling medical devices. In this context, cold plasma was considered as an emergent disinfection technology [16]. Heating infected medical devices by using steam under pressure or autoclave is a routine procedure in health care. In this chapter, we focus our interest on the disinfection physical methods used to fight Coronavirus spread. As we have mentioned previously, in a first step the different disinfection categories are discussed and so their efficiency and limitations are reported.

2. Irradiation techniques

The radiation includes non-ionizing radiation, such as UV rays, infrared rays,... etc. and ionizing radiation, such as α-β particles, neutrino, X-rays, −rays, the two last radiation are considered as indirectly ionizing radiations. The most common irradiation techniques used for killing Corona virus are UVC and -X rays.

2.1 UVC irradiation

2.1.1 The germicide lamps

UV light spectrum is ranged between 400 and 100 nanometers. It can be divided in three categories: UVA (400–315 nm), UVB (315–280 nm) and UVC (280–100 nm). The UV radiations are emitted by the sun, but UVC does not reach the earth's surface due to the ozone layer in the atmosphere. The UVC is known as a powerful radiation to inactivate microbes and virus especially for the wavelength 254 nm. This type of radiation is produced artificially by the so called Germicidal lamps and microbes as it reported by several authors [3, 16–18]. The disinfection efficiency depends on lamp placement, mixing degree of room air, room configuration, lamp age air movement patterns and relative humidity, RH. Considering respectively, N_0 and N, the number of initial micro-organisms at t = 0 s, and at a given time t. According to Kaniho and Ohgaki [17], N and N_0 can be connected by the following Equation [17]:

$$N(t) = N_0 e^{-ZI.t} \tag{1}$$

Where, Z($cm^2/\mu Ws$) and I($\mu W/cm^2$) are respectively the microorganism susceptibility factor and the UVC lamp intensity. Several authors [18, 19], have shown that the susceptibility parameters depends RH, where UVC effectiveness decreases with increasing relative humidity [19]. In practice, the dose received by microorganisms by surface unity is considered to estimate the efficiency of a lamp. In fact the dose, *D*, is calculated according Eq. **(2)**:

$$D = It \tag{2}$$

Where, I ($\mu W/cm^2$) and t(s), are respectively the UVC lamp intensity and the irradiation time. The required dose to inactivate 90% of microorganisms is denoted D90. We report in **Table 1**, required dose, D90, to inactivate bacteria in different conditions and medium (water, surface, air-low RH and air-high RH).

The SARS-CoV-2 inactivation dose corresponds to D90 = 7 J/m^2 [21, 22], its susceptibility is 3 times greater than common cold virus (Influenza). Recently, Heilingloh et al. [23] have shown that the UVC required dose for complete inactivation of a high infected sample after 9 min of irradiation corresponds to 10,48 J/m^2. The sample was at a distance 3 cm of the UVC source.

D90(J/m²)				
Bacteria	**Water**	**Surface**	**Air-Low RH**	**Air-High RH**
Bacillus subtilis spores	131	88	95	89
Eschenchia coli	26	22	5	11
Mecobacterium bovis BCG	—	22	13	33

Table 1.
The required D90 values of some bacteria in different conditions and medium [20].

2.1.2 The Corona-virus inactivation process

UV-C (254 nm) is the most effective germicidal region of the UV spectrum. In fact, the UVC light is absorbed by DNA and RNA, causing photochemical damage and fusion of pyrimidines. The pyrimidine dimmers interrupt transcription and replication of RNA and DNA and so inactivate the virus [24]. The different devices using UVC technique revolve around the disinfection unit type, where complementary devices are used to ensure maximum efficiency. Certain devices can be mobile or ordered. The device types are discussed in the next sections.

2.1.3 UVC devices

2.1.3.1 Conventional lamps and UVC-LEDs

The UVC radiation is generated by artificial sources, which we called disinfection unity. It includes lamps and UVC-Lamps. The lamps contain a gas, mercury or xenon, or a mixture of gases such as xenon-mercury (in small quantity), however UVC-LEDs are manufactured from semiconductors [25, 26]. The UVC-LEDs are an alternative to conventional lamps due to their compact size and energy saving. However, their cost is relatively high, light emitting (UVC-LEDs can be continuous or pulsed.Several authors have reported that pulsed UVC-LEDs are more effective then continuous and conventional lamps [27–29].

2.1.3.2 Reflective wall and humidifiers

To enhance the inactivation virus effectiveness, reflective wall and humidifiers are used as complementary devices. In fact, several authors [27–32], have shown that using reflective walls reduce the inactivation microorganism's time. On the other hand, Woo et al. [33], have shown that using deionized water as humidifier enhance the disinfection effectiveness.

2.1.3.3 Chemical disinfectant

Usually, disinfectant devices are combined with chemical disinfectants and were used to inactivate microorganisms in hospitals. Usual lamps and/or UVC-LEDs were used with gaseous ozone and hydrogen peroxide vapor. Several authors [34, 35], have shown that using chemical agents, such as hydrogen peroxide vapor, in addition to conventional UVC treatment permit more effective disinfection.

2.1.3.4 Mobile and automated UVC devices

Disinfecting robot is an emerging technology used to fight against the spread of Covid-19 in public transport, hospitals and any closed areas. However, it requires a mastery of mechanics, electronics and programming. In fact, the mobile UVC device, Tru-D, has been shown to be more efficient than the static device and inactivate microorganisms within a period between three and four hours [36]. It was also shown that the used robot is quicker than chemical agents such as hydrogen peroxide. In this context, Bentancor and Vidal [37], have used a programmed device to communicate with the robot using Bluetooth devices and can be operated thanks to a mobile application. Recently, Guettari et al. [38] have shown that mobile robots are the most efficient device to inactivate microorganisms and developed an i-Robot UVC, this robot is essentially composed with two lamps on the top. Several sensors are integrated to measure physical parameters such as temperature and humidity to control the mobility of the robot to detect motion and to avoid obstacles. The disinfection time is monitored by Wi-Fi.

2.1.3.5 Advantages and limitations

Using UVC (200-280 nm) radiation has been successful in inactivating various viruses. This physical technique is non-toxic, non-corrosive to medical devices and environmentally friendly, it does not have to be portable. The disinfection time is reduced when complementary devices are used. However, this type of radiation is not highly penetrating and it may be ineffective of masks. Handling this type of radiation presents a significant danger for the human health. Primary skin cancers can manifested after a long period. So, the ICNIRP have reported the limit values for exposure to this kind of radiation [39].

2.2 Gamma rays irradiation

2.2.1 Virus inactivation

When Cobalt 59, the natural state of Cobalt, is bombarded with neutrons, it produces a synthetic radioactive isotope of Cobalt-60, which decays by beta disintegration to the stable Nickel-60. The gamma emission obeys the following Equation [40]:

$$^{59}_{27}Co + n \rightarrow {}^{60}_{27}Co \rightarrow {}^{60}_{28}Ni + e^{-} + gamma.irradiation \tag{3}$$

The Gamma irradiation emitted by Cobalt 60 was performed sterilization in food science and to develop vaccine [41]. In fact, the treatment consists to irradiate products until 50 kGy and it known as bio-security of food. The required doses depend on the nature of microorganisms (bacteria, virus, pathogens and parasites).

Family virus	Virus structure	Presence of envelop	Diameter (nm)	D90	
				Minimum	Maximum
Adenoviridae	Double stranded-DNA	No	70-90	3.5	5.61
Birnaviridae	Double stranded-RNA	No	60	6.2	10
Coronovirdae	Single stranded-RNA	Yes	120-160	<2	3.6
Flaviviriadae	Single stranded-RNA	Yes	40-60	1.8	8.6

Table 2.
The required D90 (maximum and minimum) values of some virus and their properties [42].

The required dose to inactivate 90% of microorganisms depends on environmental factors such as water content, media and temperature. The process of inactivation consists to induce damage in intercellular acids as a physicochemical damage in a single-strand break or double-strand break. Two processes can damage the DNA: **(1)** direct energy deposition;**(2)** secondary interactions with surrounding water molecules which permitting the formation of OH^- free radicals. The irradiation susceptibility of virus is lower than other microorganisms; this is due to their low dimension. The estimated dose D90 (minimum and maximum) to inactivate various virus was reported in **Table 2**. The structure, size and the presence of envelop was also indicated.

2.2.1.1 The target theory

The inactivation of viruses by irradiation is perfectly described by the target theory. In fact, the hit probability P for N targets to be hit n times by radiation is described according the following equation:

$$P = \left[1 - e^{-\nu D} \sum_{k=0}^{n-1} \frac{(\nu D)^k}{k!}\right]^N \tag{4}$$

Where D and, ν are respectively, the radiation dose and the target volume. The single-hit-single-target model corresponds to one targets, n = 1, and to be high one time by radiation, n = 1. So, the hit probability is reduced to Eq. **(5)**.

$$P = 1 - e^{-\nu D} \tag{5}$$

The quantity, νD is connected to the fluence, $F(\text{particles/cm}^2)$, and the inactivation cross section, $\sigma(cm^2)$, according the following Equation [41]:

$$\nu D = FD \tag{6}$$

2.2.1.2 Corona virus inactivation by gamma irradiation

In a recent work, Feldmann et al. [43], have studied the effect of gamma irradiation on infected tissues with Coronavirus. They have used doses ranged between 10 kGy and 40 kGy and found that the virus was completely inactivated at 10 kGy and recommend a 20 kGy dose. Several authors [44–46], have studied the disinfection of N-95 masks. These masks are designed to filter 95% of particles of size 0.3 μm. However, in this doses range (10 kGy-20 kGy), radiation can damage the masks tissues because of the cross linking and/or scissioning polymer [47]. It was shown also that the inactivation of Coronavirus depends on the infected medium, which can reduce the required D90 doses to 0.5 kGy [48].

2.2.1.3 Advantages and limitations

Gamma ray irradiation produce uniform dose and can travel through the surface due to their highly penetration depth. The technique does not induce an increasing of temperature; the disinfection time is about few minutes in maximum. However, gamma radiation requires an adequate and expansive device. This method can damage medical devices.

3. Heat treatment

3.1 Heat treatment as major method for SARS-CoV-2inactivation

Since the onset of the Covid-19 pandemic, the influence of temperature has been the subject of intensive discussion among epidemiologists about its influence on the dynamics of the spread of the virus on the one hand and its inactivation on the other hand. Such a debate seemed obvious given that heating has long been considered as the acquired effects of this thermodynamic parameter as well as on the physico-chemical properties of biological macromolecules (proteins, enzymes, etc.) and microorganisms (viruses, parasites). From this point of view, the change in temperature could induce changes of conformational nature, the destruction (and formation) of chemical bonds, changes in physical phases which result in variations of a functional nature. Moreover, virologists have raised questions about the ability of high temperatures to destroy chemical bonds within the SARS-CoV-2 virus and to cause morphological variations in order to be able to inactivate its functions or reduce its virulence. Several works has been conducted in this regard to highlight how heating can help combat the Covid-19 pandemic. In this section we present the most uplifting among them [49–53].

3.2 Heating to inactivate the virus

From the first months of the pandemic, typical studies were carried out to observe the direct impact of an increase in temperature on the stability of SARS-CoV-2. They revealed that SARS-CoV-2 keeps its stability for 24 hours at a temperature of 37° C, On the other hand, heating up to 56° C for 30 minutes succeeded in inactivating the virus. However, such process preserved the stability of viral RNA in both human sera and sputum samples.

Te Faye and his collaborators [54] published a work in which they introduced a predictive thermodynamic model, based on the rate of a first order reaction and Arrhenius law. This model makes it possible to correlate data related to contamination and disinfection using heating. Their results provided very relevant information to help on the disinfection of protective equipment such as masks. For example, they have shown that exposing N95-type masks for 3 minutes can reduce the viral load of SARS-CoV-2 by almost 99%.

Batejat et al. [49] subjected cells infected with SARS-CoV-2 to 3 different temperatures and varying the heating time from 30 seconds to 60 minutes. They observed that SARS-CoV-2 could be inactivated in less than 30 minutes, 15 minutes and 3 minutes at 56° C, 65° C and 95° C respectively.

3.3 Thermal inactivation improves RNA quality

Based on what we quoted in the previous section on the heating power to inactivate the SARS-CoV-2, it seems evident that several laboratories would uses heating to reduce the risk of catching up with the virus.

Since virologists analyze the existence of viruses by conventional PCR and RT-PCR tests, a polymerase technique based on the extraction of virus RNA. So, to get the best results from PCR test, it is essential to have the virus RNA of better quality. In this context, questions were raised about the effect of heating on the quality of results obtained. Hemati et al. [50] exposed 36 samples from COVID - 19 patients to thermal inactivation (60° C for 30 min). The results were surprising and very satisfactory. In fact, heating increased significantly the concentration of the extracted RNAs.

3.4 The use of microwave for hospital disinfection

Another problem that raises concern in relation to combating the harmful effects of Covid 19 lies in the level of waste treatment, especially hospital waste of all kinds (medicine excretion, active component of drugs and metabolite, chemicals, residues of pharmaceuticals,,). It is also known that an important part of this waste is discharged into hospital wastewater, so the problem of disinfecting this water is an important challenge. For this, Wang et al. [51] have suggested several physical disinfection technologies of hospital wastes and wastewater to mitigate the virus spread in China. Among them, they used microwaves of frequencies between (2,450 ± 50) MHz and (915 ± 25) MHz in order to reach temperature of disinfection. Indeed, the heat of disinfection is generated by molecular vibrations in the medium traversed by the microwaves.

According to Ohtsu et al. [52], Microwave disinfection technology is an energy efficient technique, in which heat loss is relatively slow, fast acting. It is also characterized by its low environmental pollution since there will be no residues and toxic products left after disinfection.

3.5 Solar heating to inactivate the SARS-CoV-2

Wang et al. [53] have proposed a simple, economic and ecological technique, which makes it possible to disinfect places with very high population density in which social distance is practically inapplicable, namely, cars, busses and other means of public transport (**Figure 1**).

The technique called "Solar heating for the deactivation of heat-sensitive pathogens", it is based on a simple direct exposure of cars to the sun heat for a few minutes during which the air temperature rises from 30°C to temperatures ranged between 50°C and 60°C. Wang and his coworkers [53] have assumed that this simple technique has already proven its effectiveness in in agronomy to kill weeds and soil pathogens. So, therefore it can be applied in the fight against covid-19 as a method of surfaces decontamination. The reported results of Wang et al. confirmed that hot air passively generated by Solar heating in enclosed spaces is an effective disinfection method with benefits without additional costs and chemicals. However, the disadvantage of this method is its dependence to hot climates. For this

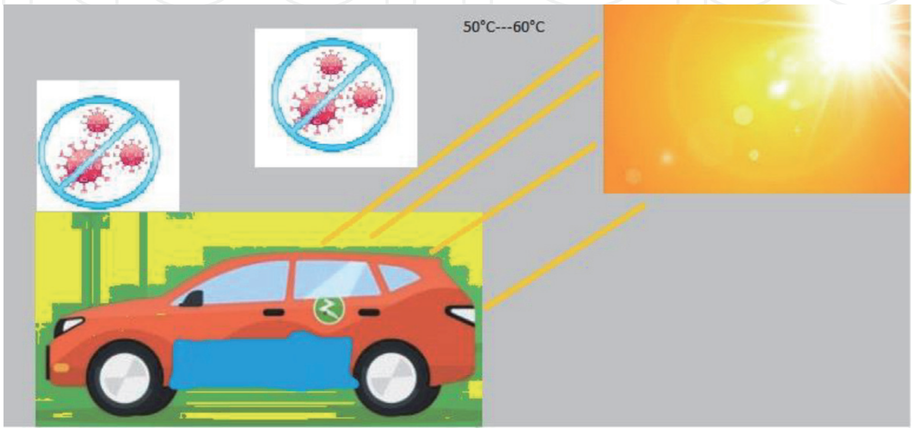

Figure 1.
Schematic representation of car exposed to solar heat.

reason, they assumed that the use of heaters in parking places could be a solution to overcome this handicap.

3.6 Dry heat for masks disinfection

Faced with the shortage of means of protection against covid-19 namely protective masks, Rubio-Romero published a paper review [55] in which he discussed the characteristics of the different types of disposable masks, considered as an alternative. To do this, he detailed the various methods of disinfection, in particular the physical methods of disinfection of deposited masks. Among these methods, he focused on dry heat disinfection. From this perspective, the main challenge was to guarantee total disinfection of the masks at temperatures over 56°C without affecting their filtering capacity. Based on this, both the Spanish Ministry of Labor and Social Economy and the International Medical Center of Beijing indicate that FFP respirators maintain their filtration efficiency after being disinfected at 70° C for 30 min.

3.7 Use of cold plasma for SARS-CoV-2 inactivation

Plasma is formed when a gas is subjected to a potential difference high enough to ionize molecules. As a result, the main properties of a plasma (electrical conductivity, etc.) depend essentially on the density of electrons but also on their volume fraction. The latter is directly influenced by temperature. Typically, the best known of plasmas is that of nuclear reactions, which is subjected to high temperatures of up to K. For this reason, plasma at ambient temperatures is called cold plasma or non-thermal plasma. At this temperature scale, cold plasma does find several industrial applications.

Cold plasma can be generated by applications of voltages ranging from 100 V up to a few kilovolts in direct current, and for radio frequencies in alternating current. In addition, this can only occur under very specific pressure conditions (a pressure between 1 Pa and 10^5 Pa).

3.7.1 Cold plasma as a disinfection technology

For years, cold plasma has been used to decontaminate and disinfect surfaces of steel, plastics, textiles … It is also used to decontaminate some liquids and also air.

The disinfection technique is often known as «One Atmosphere Uniform Glow Discharge Plasma (OAUGDP)". The advantage of this technique is that it provides both uniform and low power density, which protects against any kind of damage to contaminated surfaces. This property gives it a strong implication in the medical field [56].

Several factors are involved in influencing the effectiveness of cold plasma disinfection. In this regard, mention may be made of the nature of the reactive species provided; it has been observed [57] that the use of oxygen species can support oxidation. The pressure conditions, the geometry of the electrodes … It has also been observed that the speed of reactive species improves the inactivation of microbes. Increasing the applied electrical difference can play an important role in increasing the density of electrons, or even reactive species (**Figure 2**).

3.7.2 Mode of inactivation of microorganisms by OAUGDP

The mechanism of action of plasma on microorganisms is based on two simultaneous effects. The first effect is a thermal effect, which causes volatilization of cell

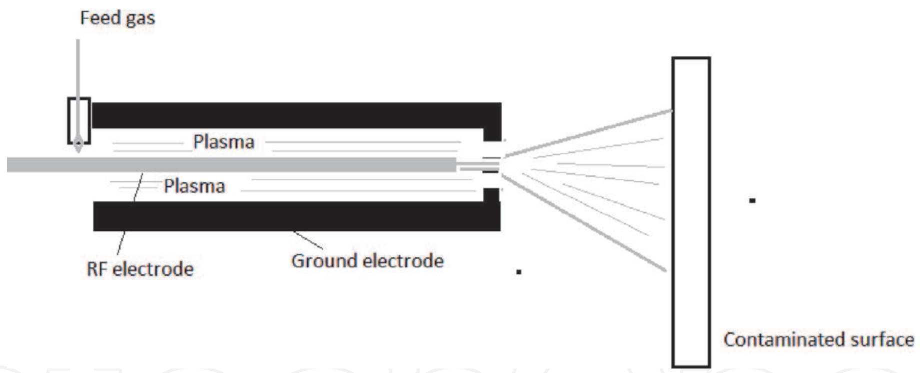

Figure 2.
The atmospheric pressure plasma jet (APPJ) as designed by Hermann et al. [57].

membranes due to its exposure to plasma gas. This facilitates the exchange of proteins between the intracellular and extracellular media. The second effect is the result of the decomposition of organic and inorganic compounds by reactive species from plasma such as ozone, hydroxyl groups, nitric oxides … [56].

3.7.3 Application of cold plasma in the fight against Covid-19 pandemic

First, many researchers have considered using cold plasma to enhance surface decontamination procedures. All of them have been based on their power of microbial decontamination of materials, surfaces proven for a very long time. As example,Bekeschus et al. published a paper [58] recommending the use of cold plasma in the disinfection of contaminated surfaces, liquids… They do, however, advise caution when using it on human tissues in order to minimize its negative effects on the body. Indeed, it is known that the viral load of SARS-CoV-2 is channeled initially from the mouth then the throat before reaching the lungs. Given that the plasma generates the formation of ozone (O3) and nitrogen oxide (NOx). These two gases are essential for the inactivation of pathogens, but they are toxic to the lungs if they accumulate in high quantities. Therefore, it was necessary to be careful about the triggering of toxicological reactions produced by the gas in the plasma.

Otherwise, since SARS-CoV-2 has shown its ability to stabilize for hours on different types of surfaces such as metals, plastics and cardboard. This paralyzes the efforts to destroy transmission chains. For this purpose, Chen and his coworkers [59] at the University of California have reported excellent results on their work conducted on the inactivation of coronavirus Sars-Cov-2 using cold atmospheric plasma by targeting surfaces of leather, plastics and some metals.. They used an atmospheric plasma gas fed with argon. The characteristics of the atmospheric pressure plasma Jet (APPJ) (**Figure 2**) device used are as follows:

- An input power of approximately 12 W.
- The flow rates for the argon (Ar) and helium (He) plasmas were 6.4 l / min and 16.5 l / min, respectively.
- The discharge voltages for (Ar) and (He) feed gases were 16.8 kV and 16.6 kV.

Thus, they exposed surfaces contaminated by SARS-CoV-2 to cold argon and helium gases. Then compared to surfaces not exposed to gases [59]. The findings were so promising: they observed that the treatment with argon gas inactivated all the viruses for the different surfaces within a period of less than 180 seconds.

4. Ultrasound technology: a promising alternative for decontamination

Since its appearance, SARS-CoV-2 has gained a consensus among virologists on its very specific properties in relation to its high capacity for mutation and its speed of propagation. As a result, scientists have always sought to improve the efficiency of methods of disinfecting surfaces in order to decontaminate them from suspensions carrying the virus. From this perspective, ultrasound can represent an effective physical method. Indeed, the mechanical action of ultrasound on the suspensions of contaminated surfaces will be able to clean them while avoiding the side effects and dangers associated with the use of disinfection chemicals.

4.1 Principle of ultrasonic disinfection

Widely used in the medical field, Ultrasounds are mechanical sound waves, which translate the propagation of acoustic energy in the form of pressure waves. Their frequency range exceeds that of the frequencies of audible sound waves (above 16 kHz). The acoustic intensity I represents the flow of the acoustic power Ps through a surface A. Considering that the pressure amplitude is denoted by "p", the different parameters characterizing the propagation of an ultrasonic one are linked by the equation:

$$I = \frac{P_s}{A} = \frac{p^2}{\rho c} = \frac{p^2}{Z} \tag{7}$$

Where ρ is the density of the medium, ε is the amplitude of the ultrasound, ω is the angular speed (ω = 2πf where f is the frequency), is the speed of sound. The equation can be reduced to the following form:

$$I = \varepsilon^2 \omega^2 Z \tag{8}$$

With Z is the acoustic impedance defined by the product ρ × c. During their propagation through different interfaces (air / water for example), ultrasound can undergo either reflections, attenuations or even diffusions. An attenuation coefficient is thus introduced to describe the effect of this passage on the characteristics of the wave transmitted by an interface. For example, for ultrasounds of frequency 20 kHz, the coefficient of their attenuation through a distance of 24 cm is equal to 2. 10^7 cm^{-1}. since the difference in impedance is very slight between water and biological cells (approximately 5%), the transmission of ultrasound through biological cells is fluid. This perfectly explains their great use in diagnostic and therapeutic ultrasound [60].

4.2 Uses of ultrasound in wastewater disinfection

First, ultrasound was used to disinfect wastewater. The process of ultrasonic disinfection mainly relies on cavitation. Indeed, cavitation is a kind of concentration of energy in well-localized areas in a fluid. This cavitation leads to the creation of very extreme physical conditions (temperatures between 1726.85°C and 4726.85°C, pressures between 1800 atm and 3000 atm) [60]. These conditions cause the appearance of effects directly related to disinfection.

The first is a sonochemical effect which results in the destruction of chemical bonds in water. Thus, several types of free radicals are formed. The second effect is the sonoluminescence effect, which characterizes the emission of photons by excitation of gases.

When the collapse of the water bubbles is produced in the vicinity of a solid surface, a jet of particles will be emitted with a high velocity (up to 300 m / S), thus causing very strong mechanical effects such as the wave acoustic shock, sound emission … damage to this surface by these different physical effects contributes to disinfection [61]. According to Gibson et al. [60], the contribution of sonoluminescence and sonochemical effects to disinfection is very negligible in comparison with the mechanical and thermal effects.

4.3 Factors influencing droplet cavitation

Knowing that wastewater contains many types of particles, their interactions with ultrasound do not occur in the same way. Which can alter the cavitation process. For this, several factors must be taken into consideration. The most important of these is the nucleation of the droplets. This nucleation can be affected by the surface tension of liquid S. In fact, in a vapor pressure liquid, the critical pressure necessary to increase the bubble radius of radius R is expressed by the following equation:

$$P_{cr} = P_v - 2\frac{S}{R} \tag{9}$$

Moreover, for a droplet deposited on a liquid surface, the surface tension also depends on the contact angle of this droplet with the surface, which generally varies between 0 (hydrophobic substances) and 180° (hydrophilic substances):

$$P_{cr} = P_v - 2\frac{S\sin\theta}{R} \tag{10}$$

From an energetic point of view, the cavitation process can be altered by failure in one of the energy conversion steps. According to Löning et al. [62], the energy conversion process follows the following Scheme:

$$E_{EL} \rightarrow E_{HF} \rightarrow E_{TH} \rightarrow E_{CAV} \rightarrow E_{DOS} \rightarrow E_{EFF}$$

Where E_{EL} is the input of electrical energy, E_{HF} is the energy of ultrasound, E_{TH} is the power of input into the fluid, E_{CAV} is the energy of droplet cavitation, E_{DOS} is the energy determined by dosimetry, and E_{EFF} is the energy expended on a specific effect.

4.4 Mechanical effects of ultrasound

Gibson et al. [60] have summarized the main conclusions in relation to the mechanical effects of ultrasound in the form of a few points:

- Droplet disturbance is more noticeable at low ultrasound frequencies.
- Ultrasound has the ability to degrade polymer chains (lipids, proteins, etc.), especially for high molecular masses.
- The mechanical action of ultrasound can lead to cell lysis.

4.5 Surfactants (detergents) as main actors for disinfection

From a structural standpoint, the SARS-CoV-2 virus is made up of a viral wall layer that is composed of a lipoprotein envelope that wraps RNA in its interior (**Figure 3**).

To kill the virus, material is required to damage the inside of the envelope. It cannot be destroyed only by water, and therefore needs another ingredient: alcohol or surfactant as proposed by WHO [63].

Surfactants are amphiphilic molecules, composed of a polar part (hydrophilic) and another non polar part (hydrophobic) (**Figure 4**).

The hydrophilic–lipophilic balance (HLB) was introduced to measure the predominance of each of these two characters. According to Davies et al. [65, 66], its value can be determined from the following relation:

$$HLB = \sum \text{hydrophilic groups} - \sum \text{hydrophobic groups} + 7 \qquad (11)$$

This chemical structure gives surfactants a double affinity, sometimes to polar compounds and sometimes to nonpolar compounds (**Figure 5**). From a physical point of view, surfactants act as agents to attenuate the surface tension between two immiscible phases, promoting the dispersion of one into the other.

Generally, surfactant molecules are classified according to the properties of their polar part, two main families are distinguished:

- Ionic surfactants: anionic and cationic.
- Nonionic surfactants: amphoteric and dipolar.

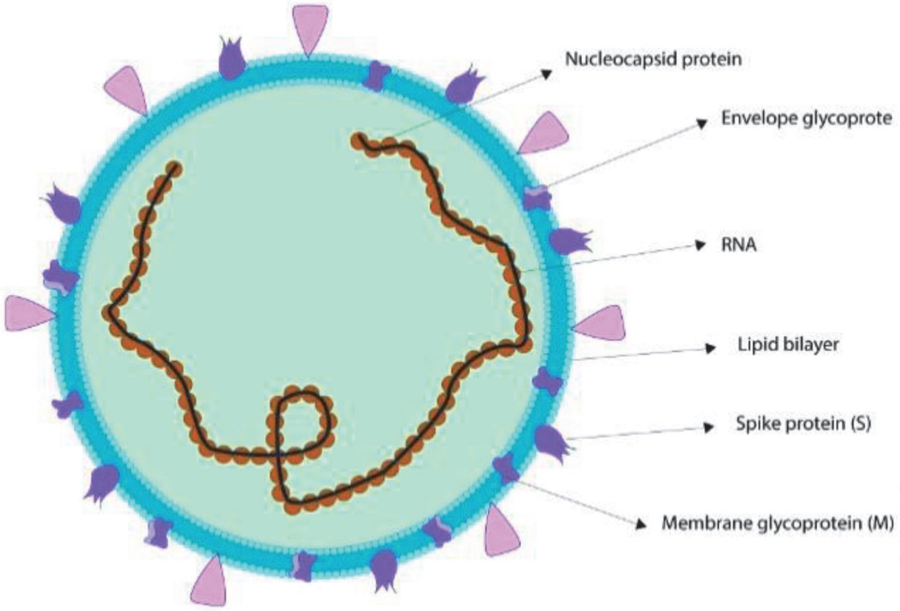

Figure 3.
Structure of the coronavirus (Sars-CoV2) [63].

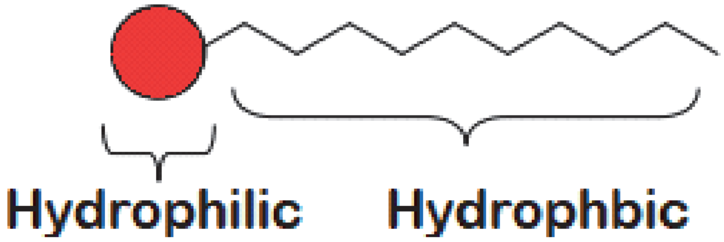

Figure 4.
Chemical structure of surfactant molecules.

A surfactant's detergency strength measures its ability to work on the soil to remove it. Every type of soil, whether fatty, solid, etc., can actually build physical connections with surfactant molecules. These interactions can be either hydrophilic (or else hydrophobic) interactions, or attractive electrostatic interactions. As a result, the detergency mechanism operates according to the different types of loads of dirt on one side and surfactant on the other side. Positive surfactants attract negatively charged soils, which they will partially neutralize. The positive part of the surfactant therefore binds to the negative part of the soil. A positively charged surfactant is interested in negatively charged soils. However, an agent (+) will not have any influence on a soiling (+) since both repel each other [67].

For long time, the soap is known for its very powerful detergent power. For this, since the Covid-19 emergence, the world health organization (WHO) recommended firstly to use it as first weapon against the virus by washing hands several times along the day. Other detergents, such as laundry detergents, are made in synthetics but they are all molecular in the same kind.

Soap is composed of fats, oils, and fatty acids. A hydrophilic polar head and a hydrophobic carbon chain, which have an affinity to organic compounds and consequently to fatty substances, constitute the molecular structure of soap.

When the soap molecules are added to the water, the hydrophobic tails orient towards the air to avoid contact with the water molecules. To bring them into

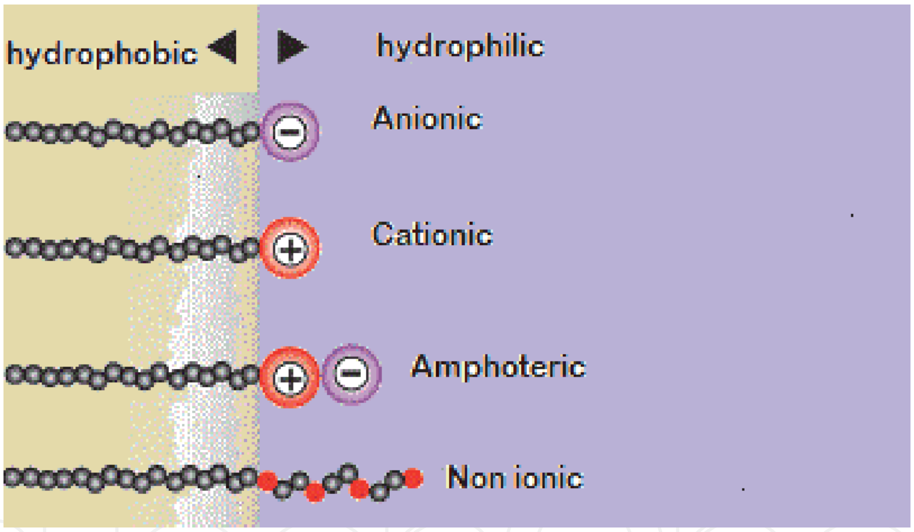

Figure 5.
Classes of surfactant molecules.

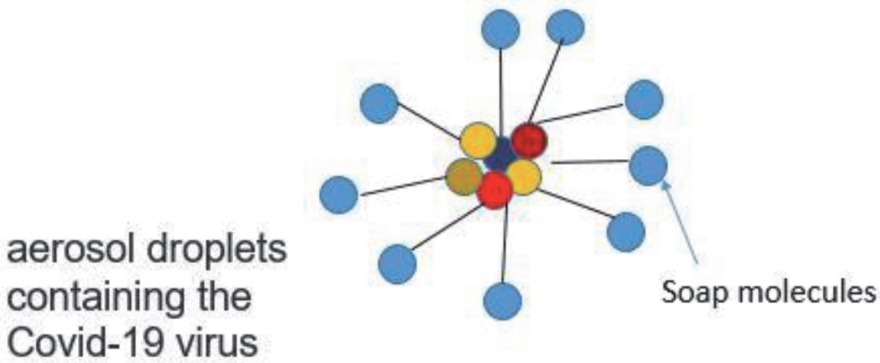

Figure 6.
Soap action on aerosol droplets containing SARS-CoV-2.

contact with the fatty compounds, mechanical action is necessary, in particular rubbing. Once in contact with the fats, the soap molecules surround it on all sides, thus forming spherical micelles (**Figure 6**). In order to decontaminate surfaces containing aerosols carrying SARS-CoV-2. A large concentration of soap molecules must be spread by rubbing the entire surface.

5. Conclusion

In the fight against a new virological epidemic, the most traditional approach is immune system development, which gives the immune system the ability to identify and attack the virus once it has entered the body. This can only be accomplished by manufacturing vaccines. However, waiting for the vaccine to be produced may cost us the lives of millions of people in a pandemic characterized by a very large spread rate such as covid-19. The use of disinfection methods (along with barrier precautions) remains the most promising way to combat this pandemic.

In this context, we have presented in this chapter the main physical methods used to disinfect contaminated surfaces. Initially, special emphasis was placed on methods based on electromagnetic irradiations, specifically ultraviolet UV radiation and gamma radiation. The required doses, capable of inactivating the virus and used in the production of disinfection devices such as UVC lamps, were presented. The parameters influencing the efficiency of these techniques have been also discussed. Second, we concentrated on the use of conventional disinfection techniques that have already proven effective in the fight against other epidemics, such as disinfection by heating, which relies on the ability of high temperatures to destroy the lipid bonds that comprise the virulent layer of SARS-CoV-2. Particular attention has been paid to the use of ultrasound in the disinfection of contaminated surfaces, this technique which is based on the mechanical action of ultrasonic waves manifested by cavitation and thus producing sonolumiscent and sonochemical effects and also a thermal effect. The principle of disinfection by gas jets of cold plasma was then described. In this regard, we presented bibliographic data demonstrating its efficacy in the decontamination of surfaces contaminated with SARS-CoV-2 in a short period (less than 2 minutes). Finally, it appears critical to discuss the basic chemical compounds used in disinfection chemicals, namely detergents. We have dedicated a section to describing the physical and structural properties of the major detergents.

We believe that, in the absence of an effective medical treatment, the bibliographical review study on various disinfection procedures represents, at this time, the best kits for both medical personnel and policymakers in the fight against this new pandemic.

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Conflict of 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.

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