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RESEARCH ARTICLE

ECO-FRIENDLY, COST EFFECTIVE, AUTO-STERILIZATION OF ISOLATION GOWN: RECENT AND FORTHCOMING ASPECT

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Abstract

This review addresses the issue of biomedical waste in the form of PPE (personal protection equipment) kit. COVID -19 pandemic has brought life into standstill. It has affected life of each and every person. This includes both direct effect in terms of health and indirect effect in terms of economic loss, business losses which have also resulted into sudden surge in unemployment. But apart from these directly visible effects there is one particular effect which is far sighted but cruel reality of present condition. It is the problem of biomedical wastage arising due to extensive use of PPE kits especially in the form of face mask and isolation gown. As layman is expected to wear face mask all the time, many countries has made it mandatory. It is very important to think about its effective, environment friendly disposal. Similarly isolation gown has also become very common in many medical and non-medical industries. If we don't dispose off used gown properly then the whole purpose of its use will get defeated as it further leads to disease transmission. While selecting method of disposal, it is very important to consider its adverse effect on environment. Incineration, shredding and deep pit burial are some of the common method of disposal of biomedical waste approved by health authorities of different countries, but these are not environment friendly. There are some other disinfection methods like ultra-violet (UV) irradiation, chemical disinfection with the help of them medical isolation gown can be reused but these methods have many disadvantages including being expensive, non-eco-friendly, some methods require expertise in handling machine, some affect the virus barrier ability of gown etc. Considering these problems, this review explored the idea of reusable isolation gown which doesn't require any expertise for its disinfection at the same time it doesn't adversely affect the environment. We proposed the idea of applying layer of photocatalyst which can inhibit the enzymatic activity of cells of microbes which will stop their replication. This can prove very useful in preventing the disease transmission. There are many reports on antimicrobial properties of various semiconductorphotocatalyst which can further be improved by doping it with metal like Cu or Ag which are already popular for their medicinal properties. Major problem with most of the semiconductor

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photocatalysts is that they show antimicrobial properties within UV range due to their wide band gap. This is not possible just by drying under sun as earth doesn't receive enough ultra violet radiation to start the photocatalysis effectively. This problem is addressed by suggesting different methods/doping to bring photocatalysis range of these photocatalysts within UV-visible range. This would bring major change in isolation gown uses, as people will be able to reuse gown just after drying it under sunlight for some time. This is expected to lower the biomedical waste in the form of gown and mask by manifolds.

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Introduction:-

PPE stands for personal protection equipment for protection of health care worker (HCW) or any wearer from infection. This includes partial coverage kit which comprises gown, gloves and face mask or full coverage kit including goggles, face mask, face shield, gown, gloves, rubber boots, head cover etc. depending upon the nature of the infection. PPE kit is an essential part of health care services especially in case of infectious diseases such as Hepatitis B, Hepatitis C, Human Immunodeficiency Virus as it protect the health workers. (Bell, 1997; Cardo and Bell, 1997; CfDC, 1998; Labor, 1991; Lovitt et al., 1992; LYNCH et al., 1987; Mahoney et al., 1997; Weber and Rutala, 1989)But in pandemic situation like EBOLA or Covid-19, its role has become even more important. According to different guidelines issued by different countries, even non health workers are ordered to wear PPE kit. These are normally non–health care industries such as saloon, construction, research laboratory etc. These also include those workplaces where government has not directed for use of PPE kit, still people are using it out of fear. This has leads to two major problems firstly, shortage of PPE kits for HCW where these are extremely important and secondly disposal of these PPE kits. There are many reports which have talked about shortage of PPE kits in even developed countries like US. This problem is even more prominent in developing and least developingcountries (Livingston et al., 2020). Sudden rise in demand and low supply has left health worker ill-equipped in war against Covid-19. Even WHO has warned that supply of PPE is rapidly depleting. This shortage can be resolved by either providing sufficient supply of these protection kits or by making reusable self-cleaning kit. Increasing the production can solve the immediate problem, but this will leads to another major problem of disposal. In some cases HCW are bound to use polythene, which are not safe. Out of all the components of PPE kit like gowns, face masks, gloves, eye protection, face shields and shoe - head coverings, most of them can easily be sanitized for reuse without damaging the protective layer except for gown and shoe-head cover. This review mainly focuses on self-cleaning gown and shoe- head cover.

Different PPE Kit standard issued by WHO and textile industry

To standardize the quality parameter of Covid-19 PPE kit, it is important to understand its mode of transmission. According to WHO COVID-19 virus is primarily transmitted between people through both indirect and direct routes.(Bai et al., 2020; Burke, 2020; Chan et al., 2020; Huang et al., 2020; Liu et al., 2020; Wang et al., 2020) Indirect contact route include droplet transmission from infected person through coughing or sneezing to a healthy person when he come in 1m close proximity.(Kilinc, 2015) Touching the surface or object like thermometer used on infected person by HCW or any healthy person comes under indirect transmission. Apart from this, airborne transmission (particle size $< 5\mu m$) which is different from droplet transmission (particle size $> 5\text{-}10\mu m$) is not reported in COVID – 19 except under some specific cases like open suction, disconnecting the patient from ventilator, bronchoscopy etc. Considering its mode of transmission WHO has recommended apposite use of all PPE,not only the surgical masks. Gown is a one of the important element of any PPE kit as it cut the direct contact between patient and HCW. But not all the isolation gowns are effective in prevention of transfer of microorganism from patient to wearer.Different microorganism have different survival period ranging from few minutes to several months on PPE kits.(Borkow and Gabbay, 2008; Neely and Orloff, 2001; Sidwell et al., 1966, 1967)Cleaning method of PPE kit also depends upon the nature of the microorganism as few disseminates just by drying whereas some require thorough cleaning. But sometime extreme cleaning methods may damage the gown textile which makes it unsafe to be part of PPE kit. (Kilinc, 2015; Loh et al., 2000; Nicas and Sun, 2006; Perry et al., 2001; Wong et al., 1991)

Fabric used in isolation gowns

Gowns can be classified on the basis of its use and protection level. U. S. food and drug administration has classified gown into four different categories on the basis its protection level.

1. Minimal risk: Level 1 which include basic care, cover gown for visitors
2. Low risk: Level 2 which include during blood draw, or a pathology lab
3. Moderate risk: Level 3which include inserting an intravenous (IV) line, in the emergency room, or for trauma cases
4. High risk: Level 4 which include long, fluid intense procedures, surgery, when pathogen resistance is needed or infectious diseases are suspected (non-airborne)

On the basis of uses, gowns can be classified as disposable and reusable. Disposable gown are normally made up of nonwoven material (with basic row material of synthetic fibers like polyester, polypropylene etc.) in combination with some plastic material which decrease its liquid penetration. Methods of formation of these gowns also play an important role in deciding its effectiveness as contact barrier; there are different methods available namely mechanical, chemical, thermal methods. But considering the possible hazards of disposing huge no of isolation gown, it is recommended to use reusable gown. These are normally made up of cotton or polyester or combination of both. Their reusability depends upon their material and method of synthesis. Both single use and multiple use gowns have to undergo various quality checks like tensile strength, seam strength, tear resistance, lint generation, water vapor transmission (breathability) etc. before their marketing. Cleaning process of reusable gown should also not affect much above mentioned property of that gown. Textile barrier performance is also a very important property of an isolation gown. This is determined by:

1. Smoothness of clothing: fabric with irregular surface is proved to be more effective in controlling transmission of virus/dust particles.(Gupta, 1988; Leonas and Miller, 1990)
2. Microfiber with very fine and thin fabric also provide higher level of protection.
3. Fabric of gown should have higher absorbency like natural fibers cotton, wool etc. as in cloths with low absorbance power (polyester) liquid containing virus can wick along the fabric due to capillary action.
4. Twisted yarns also provide good barrier.
5. Coating with special material, lamination, fabric thickness, smaller pore size can further enhance the protection level of gown(Leonas and Jinkins, 1997; Rutala and Weber, 2001)
6. Outermost layer of an isolation gown should have a layer of water repellent. Normally fluorocarbon based chemicals are used for this purpose. Though these chemicals do not provide resistance against liquid with low surface tension.(Meyer and Beck, 1995; Pissiotis et al., 1997)
7. Antibacterial, antimicrobial, antivirus chemicals are also very important in reducing the disease transmission(Committee, 2012; Huang, 2000)

But application of different layers of barrier should not make gown unbreathable.

Disposal and sterilization process of isolation gowns

Disposal of virus infected PPE kit specially the isolation gown possess great problem as COVID-19 pandemic has resulted into sudden surge in such kind of waste. There are majorly three options for their disposal (1) incineration (2) deep burial pit (3) shredding. All these methods have their own pros and cons and different countries have directed different options based on their facilities. For example in England PPE waste materials come under infectious or offensive, which it need to burn under high temperature to avoid transmission of disease. In India also, incineration is suggested for disposal of biomedical waste but the central pollution control board (CPCB) hasalso directed disposal of used PPE kit in deep burial pits if the common biomedical waste treatment facility (CBWTF) is not available. Italy has adopted even extra safety procedure which includes storage of waste in multiple layer sealed container which is moved via special corridors. In Wuhan city of China where the waste generation become 6-7 times than normal, new biomedical waste plants were set up to deal with it.

Incineration

Incineration involves thermal decomposition of waste at high temperature to reduce its volume. Combustible waste with high organic content is the best suited for this process. (Vogel, 1983) As a primary solution for disposal of biomedical waste, incineration has many pros and cons. Its main advantage is that the huge pile of wastage can be disposed off within few minutes, leading to complete elimination of virus. (Oppelt, 1987) The energy generated during burning can be used for electricity production. Another advantage of incineration is that, it doesn’t require large land area for its plant setup. Apart from initial set up cost its maintenance is comparatively cheaper. But one of its major disadvantages is release of harmful gases during burning of waste. This leads to air pollution which is extremely harmful for human and animal health. (Allsopp et al., 2001) The residual ash is normally disposed off directly into landfill which may leach into groundwater and contaminate it. (Gautam et al., 2010) This problem has been solved upto certain extend by adopting new green technology which involve cleaning of flue gases before releasing it in the atmosphere. But as mentioned earlier, biomedical waste in terms of PPE kit has entered into layman life that doesn't have access to these fancy incineration plants. (Brunner, 1993)

Deep burial pit

Another solution to get rid of the biomedical waste especially isolation gown is burial of waste in landfill. This doesn't leads to any air pollution due to release of toxic gases. The installation and maintenance cost is also law. But the transportation of waste to such land fill is quite expensive as it involves packaging of biomedical waste in multilayered sealed package to avoid transmission of virus. Normally landfills far away from the main city are chosen for this purpose, which further add to the transportation cost. (Patil and Shekdar, 2001; Singh et al., 2007)

Shredding

In few places shredding is also adopted for waste disposal. But this practice is not very safe as it still need to be dispose off via deep burial pit or incineration. The only advantage of this practice is that it reduces the volume of the waste by manifold but adversely the shredding machine is normally quite inexpensive. (Gautam et al., 2010)

Sterilizing the isolation gown

Considering the huge waste it creates, cleaning and sterilization of isolation gown should be the alternate option of dealing with biomedical waste. There are many options available for sterilization of isolation gown namely, Ultraviolet (UV) rays, chemicals sterilization using chemicals containing chlorine, ozonolysis etc.

Ultraviolet (UV) radiation

UV radiations come under 100 – 400 nm wavelength range of electromagnetic radiations. It is highly effective in sterilizing the isolation gown as it severely damage the DNA and RNA of the microorganisms. This renders them to replicate and duplicate due to which they can't spread disease though they still remain alive. This process is highly popular as it does not leave any residue of disinfection which can degrade the quality of water/surface as in case of chemical disinfection. Easy operation is another benefit of this method. But this sterilization process has few disadvantages as well. Its first disadvantage is that not readily available naturally. Natural sunlight has three types of UV radiations: UVA (315-400 nm), UVB (280-315 nm) and UVC (100-280 nm). Out of these, ozone blanket absorb most of the UVC. Therefore Earth receive majorly UVA and small amount of UVB which is not enough to sterilize or kill the virus (though kill is not exactly the right word as microbe still remain alive, it just stop duplicating).(Haigh, 2007) UV can be produced artificially using mercury vapor lamp, high intensity discharge lamps etc. Many industries are using it for disinfection in the form of disinfectant chamber. It is popular disinfectant in water purification industries also. But the problem with these UV radiations is that it leads to genetic mutation in human being which may cause cancer. Moreover not all types of UV radiation can be used for disinfection. Appropriate exposure of low wavelength, high frequency (high energy) UVC is required for this purpose. Artificial UV lamps are both expensive and dangerous to be used by any nonmedical person. Knowledge of appropriate doses of UV exposure required for disinfection is also extremely important. (Bolton and Cotton, 2011; Mori et al., 2007; Rubbo and Gardner, 1965; Wolfe, 1990)

Chemical disinfection using chlorine derivatives

This is one of the old and popular practice used for sterilization/ disinfection of water and clothing material. It stared in 1920s with introduction of chlorine disinfection and within no time this became extremely popular due to law cost as compared to other disinfection methods. Now a day sodium hypochlorite (bleaching powder) is commonly used for this purpose. The commercially available bleaching powder used in home and health care unit contains 1 to 15% sodium hypochlorite. When sodium hypo chlorite comes in contact with water, hypochlorous acid(HOCl) and hypochlorite ion (OCl^-) are formed. These two chemicals play an important role for both oxidation as well as disinfection.

$$NaOCl + H_2O \rightarrow HOCl + NaOH$$

It releases nascent oxygen and chlorine hence it act as very good oxidizing agent. Its microbial activity involves inhibition of major enzymatic reaction and protein denaturation. It attacks on the cell protein of microbes, which leads to aggregation of protein and bursting of cell member. Sobsey et al (Sobsey et al., 1988) have reported mechanism of hepatitis A virus inactivation by free chlorine. Bond et al used it for inactivation of hepatitis B virus.

(Bond et al., 1983) Similarly Croughanet al studied herpes simplex virus types 1 and 2 disinfection using different disinfectants like lysol, listerine, bleach, rubbing alcohol, alcide disinfectant and UV light exposures. (Croughan and Behbehani, 1988)J. F. Maet al showed complete disinfection of Poliovirus 1 within 3 minutes. Free chlorine inactivation of norwalk virus, human rotavirus, poliovirus type 1 and simian rotavirus was studied by Keswick et al (Keswick et al., 1985) Many researchers have studied protozoa (Cursons et al., 1980; Jarroll et al., 1981; Korich et al., 1990)fungi (Whitmore and Denny, 1992)and bacteria (Bloomfield et al., 1991; Rutala et al., 1991; Skaliy et al., 1980; Sykes, 1970) inactivation by chlorine disinfection as well. It has numerous benefits. It is a cheaper option for disinfection. Although it is also harmful for human health as its acute exposure to human skin may result into irritation, its higher exposure may also prove fatal. But still it is a safer option as compared to UV radiation. Its storage and transportation is comparatively easy. It is stored under cool and dry environment as it disintegrate when it come under contact with water and air. Chlorine, chlorine dioxide and ozone in appropriate doses are also used for this purpose. But some safety measures have to be taken to protect workers and the environment, as some chlorine species may reach stratosphere and damage ozone layer. Apart from this 70% alcohol (especially isopropyl alcohol) is also recommended by WHO for disinfection. But dipping isolation PPE kit gown in any kind of disinfectant may affect its microorganism barrier capability. This also doesn't guarantee complete disinfection as expert supervision may be required for careful exposure of chemical disinfectant to the isolation gown. (Rutala and Weber, 1997)

Alternative solution: photocatalyst layer over PPE kit

Photocatalysis

Over the last decades photocatalysis have emerged as one of the best possible solution for treating various type bacteria/virus (microorganism) in our surrounding environment. Photocatalysis can be explained in three major steps;

(1) **Light absorption-**In this first step photocatalyst absorbs the light and promotes electrons from valence band to the conduction band, which leave behind the electronic vacancies (i.e. holes) in the valence band. Photoexcited electrons and holes are also called photoexcitons. Energy of the photoexcitons depends on the energy band gap of the photocatalyst material. Photocatalyst have well defined energy band gap, requirement of this gap is generally different for various uses of photocatalyst. Compared to large band gap material a narrow band gap insures the absorption of a large fraction of the sunlight. Nature of the bandgap (direct/indirect) also plays a significant role in the absorption of light; meanwhile it can modify the absorption coefficient of the photocatalyst. Indirect bandgap gives a low absorption coefficient and direct bandgap gives rise high absorption coefficient.

(2) Photoexcitons dissociation- photoexcited electrons and holes have to be dissociated far apart to perform photocatalytic redox reactions. This process is called the photoexcitons dissociation, and need energy to dissociate. This dissociation energy depends on the binding energy (Eb) of photoexcitons. It has to be as low as possible to enable the efficient dissociation. If we are working at room temperature (i.e.$\approx$ 25°C) and we assume that the photoexcitons will be dissociated by the thermal energy, then Eb should be lower than kBT which is around 25 meV at room temperature.

(3) Diffusion of free charge carriers- In this step, photoexcitons have to diffuse to the surface catalytic sites where they will be used before their recombination. Diffusion coefficient 'D' of a material represents the efficiency of diffusion of charge carriers in a material. Diffusion coefficient depends on the mobility 'μ' of the charge carriers, which further linked with effective mass and on collision time (τ) of the charge carriers. Mobility and diffusion coefficient are increased if the effective mass is low, that leads to high delocalization of the charge carriers. Collision time of charge carriers depends on the defects in materials.

The actual photocatalysis starts when surface reached photoexcitons perform oxidation and reduction. These excitons interact with surroundings i.e. oxygen, water and produce different active radical oxygen species (ROS). These highly active ROS do several reactions, specifically for bacteria and viruses they rupture the cell wall or cell by which it is killed. There are various photoactive materials available, but in particularly semiconductor materials have gained a considerable attention in recent scientific community, due to their various advantageous properties like photo-stability, well defined band gap, and high surface area to volume ratio to work efficiently. Although semiconductors have various desired properties to work as efficient photocatalyst for sterilization, but an unwanted drawback is associated with most of the semiconductor photocatalysts, i.e. they have a large band gap which restricts their use to work under UV light photons only. In our surrounding environment, sun is the primary source of light photons on earth, in which approximately 44% is visible light accounts and UV light accounts only 4-5%.

Even the extensively studied semiconductor photocatalyst like TiO_2, ZnO, WO_3, and $NaTaO_3$ also suffer with this problem. This problem of wide band gap can be engineered to make them workable under visible light active by various methods like,

(i)Doping (ii) Fabrication of heterojunction

Doping

It is one of the effective methods to extend the light absorption of photocatalyst from UV to visible light region. Doping can be done with non-metal, rare earth metal(Kumaresan et al., 2010; Liang et al., 2008) and metal.(Choi et al., 2010; Kim et al., 2005)

Photocatalyst doping with non-metal

Semiconductor photocatalysts have been extensively studied with the non-metal (N, Bi, S, C, F, B, P, I,) doping.(Liu et al., 2005; Ohno et al., 2003; Yu et al., 2003) There are three different opinions regarding modification photocatalytic mechanism of non-metals doped semiconductor; **a)** band gap narrowing **b)**impurity energy levels **c)** oxygen vacancies.

a)Band gap narrowing:

It is found in various studies that when semiconductor is doped with non-metal like 'N' then non-metal's 2p state hybrids with oxygen 2p states in anatase TiO_2 because their energies are very close. Then the band gap of N-TiO_2 is narrowed and able to work under visible light.(Asahi et al., 2001; Chen et al., 2007; Cong et al., 2007; Wang et al., 2016; Wu et al., 2007)

b) Impurity energy level:

In different studies it is found that when TiO_2 oxygen sites substituted by nitrogen and other non-metal elements, form isolated impurity energy levels overhead the valence band. And when it is irradiated with UV light, electrons get excite from TiO_2 valance band and from impurity energy levels, but the irradiation with visible light excites electrons from the impurity energy level only. (Irie et al., 2003)

c)Oxygen vacancies:

Ihara, et. al. (Ihara et al., 2003)found that oxygen-deficient sites are formed in the grain boundaries. These deficient sites are important to emerge visible light photo-activity and nitrogen doped in part of oxygen-deficient sites are also important as a blocker for re-oxidation.

Photocatalyst doping with transition metal

Visible light driven photoactivity of metal-doped semiconductors can be explained by a new energy level produced in the band gap of parental semiconductor by the dispersion of metal nanoparticles in the semiconductor matrix. Electrons can be excited from the new energy level (i.e. defect state) to the conduction of semiconductor. Supplementary benefit of doping with transition metal is that it improves the trapping of electrons to inhibit electron-hole recombination during irradiation. Decrease of recombination directly enhances the photoactivity. Several approaches have been made to dope semiconductor photocatalyst with metals like, Au, Ag, Pt, Cu, Co, Ni, Cr, Mn, Mo, Nb, V, Fe, Ru, to modify the photocatalytic mechanism of semiconductor photocatalyst.(Anpo, 2000; Chen et al., 2007; Choi et al., 2010; Fuerte et al., 2001; Ihara et al., 2001; Takeuchi et al., 2000; Yamashita et al., 2001)

Doping with rare earth metal

Semiconductor doping with rare earth metals can significantly modify several physical and chemical properties of semiconductor photocatalyst. Rare earth metal doping is one of the extensively studied fields in visible light driven photocatalyst. Xu et al. fabricated several rare earth metal ions, La^{3+}, Ce^{3+}, Er^{3+}, Pr^{3+}, Gd^{3+}, Nd^{3+}, Sm^{3+} doped TiO_2 nano-photocatalyst, and witnessed the red shift toward visible region wavelength and this doping also reduced the electron-hole pair recombination rate. Among various dopants, Gd^{3+}doping was found most effective and was consistent.(Xu et al., 2002) On the other hand La^{3+}doping, being a p-type dopant, the La^{3+}ions act as electron trapper and prevent the recombination rate which results in enhanced photocatalytic activity.(Hwang et al., 2003; Zhang and Reller, 2001; Zhang et al., 2003)

Fabrication of heterojunction

Fabrication of heterojunction is one of the advanced methods to engineer the semiconductor photocatalyst materials with desired band gap to work in visible light region. In this method two or more different band gap materials chemically joined together by various synthesis methods for example CeO_2/TiO_2, SnO_2/TiO_2,$CdS/NaTaO_3$, $NaNbO_3/Ag_2S$ etc.(Karunakaran and Gomathisankar, 2013; Kumar et al., 2016; Rajkumar et al., 2015; Singh et al., 2019) Fabrication of heterojunction facilitates the interfacial charge transfer between different phases. Various types of heterojunctions have been fabricated like,

(a) Semiconductor/semiconductor
(b) Semiconductor/metal
(c) Semiconductor/electrolyte
(d) Semiconductor/molecules (Dye)
These heterojunctions facilitate interfacial charge transfer and leads to efficient various photocatalytic applications.

Effectiveness of photocatalyst layer as self-sterilizing material

To overcome shortcomings of disposal/ sterilization techniques of isolation gown, it is important to focus on self-cleaning isolation gown.

Photocatalytic activity of TiO_2 is well known. It is commonly used for disinfection of water (Carey and Oliver, 1980; Dalrymple et al., 2010), solid surface and textiles. Its photocatalytic properties make it apt covering candidate for self-sterilizing devices. Numerous reports are published which have discussed about the capability of TiO_2 to kill microorganisms. During photocatalysis underultraviolet-visible radiations, TiO_2 produces reactive oxygen species (ROS) like $HO^{\bullet}$, $^{-}O_2^{\bullet}$, $HO_2^{\bullet}$, etc. This leads to complete degradation of cytoplasmic membrane/cell wall due to which cellular content leakage out and it prevents the replication of genetic material. The microbe killing and self-cleaning efficiency of TiO_2 can further be improved by combing TiO_2 with other metal like Ag or Cu which are already famous for their antimicrobial properties.

Matsunagaet.al. (Matsunaga et al., 1985) group was among the first few who studied the antimicrobial activity of TiO_2. They proved that microbial cells can be killed photo electrochemically with platinum-loaded titanium oxide semiconducting powder.The probable mechanism they explained was photoelectrochemical oxidation of cell of Coenzyme A (CoA). This leads to hindrance in respiration activity of cell which ultimately leads to death of cell. They showed complete destruction of Saccharomyces cerevisiae, Escherichia coli, Lactobacillus acidophilus and Chlorella vulgaris microorganisms within 1-2 hrs. (Matsunaga, 1985; Matsunaga et al., 1988; Matsunaga et al., 1985) TiO_2 is also reported to affect prions, a highly infectious neurodegenerativedisease.(Paspaltsis et al., 2006)Antibacterial activity of TiO_2 has been studied extensively by many researchers, it includes study on both gram positive and gram negative bacteria. TiO_2 kills gram negative bacteria more effectively as compared to gram positive due to thinner peptidoglycan layer of gram negative bacteria.(de Lima Perini et al., 2013; Kangwansupamonkon et al., 2009; Kim et al., 2003; Liu and Yang, 2003; Pal et al., 2005; Skorb et al., 2008)Although few reports have suggested opposite trend.(Kangwansupamonkon et al., 2009) Many protozoa and algae species also got affected in the presence of photocatalyst, but mostly some kind doping is required in TiO_2 for complete destruction of these microorganisms. Sökmenet al. (Sökmen et al., 2008) reported killing of Giardia intestinalis cysts in the presence of TiO_2 (anatase 99.9%) + Ag photocatalytic disinfectant. Rodriguez-Gonzalez et al. (Rodríguez-González et al., 2010) also used Ag to enhance activity of TiO_2 against Tetraselmis suecica. Many fungi can also be killed using TiO_2. Giannantonio et al. reported killing of Penicillium oxalicum, Trichoderma asperellum, Fusarium mucor, Epicoccum nigrum, Cladosporium cladospoiroides and pestalotiopsis maculans using TiO_2. (Giannantonio et al., 2009), Lu et al used 1% Ce^{3+} - TiO_2 catalyst as antifungal agent for curing crop disease due to Erysiphe cichoracearum and Peronophythora litchii. (Lu et al., 2006) This combination of photocatalyst is even more important as it absorb in visible range. Killing of virus by TiO_2 is also studied by many researchers. Most of the studies are done on virus affecting human and bacteria (especially E. coli bacteriophages).(Belháčová et al., 1999; Gerrity et al., 2008; Guimarães and Barretto, 2003; Lee et al., 1997; Sjogren and Sierka, 1994; Yu et al., 2008) Lin et al(Lin et al., 2006) studied Influenza A/H1N1 which affect the human body. They showed that TiO_2 calcined at 400°C is most effective in killing H1N1 influenza virus under 365 nm UV irradiation. Kozlovaet al. (Kozlova et al., 2010) showed that Influenza A/H3N2 can be destroyed using TiO_2. They reported 90% virus inactivation for undoped TiO_2 and 99.8% inactivation for Pt/TiO_2 in just 30 minutes. Norovirus which is responsible for gastroenteritis outbreak among humans were studied for photocatalytic inactivation by Kato et al in 2005.(Kato et al., 2005) The main source of this class of virus is consumption of sea food especially shellfish growing in polluted water. The combined treatment of ultraviolet disinfection and a photocatalyst decomposes norovirus genes great extent. Human affecting poliovirus type 1 (ATCC VFR-192) can also be destroyed photo-chemically using TiO_2 within 30 minutes. (Watts et al., 1995) SARS coronavirus i.e.serious acute respiratory syndrome coronary virus was photo-catalytically inactivated by Han et al. (Han et al., 2004) They reported that photocatalytic titanium apatite filter (PTAF) can decompose SARS CoV up to 99.99% within 6 hours under non –UV irradiation and complete inactivation of virus under UV irradiation.

Proposed sterilization mechanism

Among the various studied photocatalyst materials, semiconductors are the primary choice of scientific community. The photocatalytic sterilization process based on semiconductors can be briefly descripted in simple steps: (i) when photocatalyst semiconductor is irradiated by appropriate light, photogenerated electron (e^-) and hole (h^+) are obtained. These photoelectrons and holes form reactive oxygen species (ROS), including $^{\bullet}O_2^-$, $^{\bullet}OH$. These ROS participate in the photocatalytic firefighting bacteria/virus process.(ii) ROS attack on the cell membrane by which cell membrane gets damaged, resulting in inhibition of cell membrane dependent respiration, which eventually causes cell death. Simultaneously ROS also attack on coenzyme A, by which coenzyme gets oxidized into dimer form, resulting in inhibition of coenzyme dependent respiration, which eventually also cause cell death. Various other studies have also supported the above sterilization mechanism by ROS, mentioning that ROS after rupturing cell membrane enter into cells to further oxidize macromolecular substances such as nucleic acids and proteins.(Ning et al., 2017; Wu et al., 2010) There are other studies, have suggested that the sterilization mechanism by photocatalyst is the oxidation of cell membrane/ cell wall by reactive oxygen species, which break down cell membranes and cell wall, by which cell cations (such as K^+) and intracellular macromolecules (nucleic acids and proteins) leak out and finally lead to the death of the cell.(Ganguly et al., 2018; Liang et al., 2016; Saito et al., 1992; Wang et al., 2017; Wang et al., 2012; Wu et al., 2010)There are few studies on sterilization mechanism of viruses. Most viruses coat their genetic material by protein shells so viruses have simple structure than bacteria. Therefore, the sterilization of mechanism similarly can be easily understood. When ROS rupture the surface protein, it leads to leakage and rapid destruction of RNA, which ultimately kills the virus so that its regeneration stops. (Liu et al., 2016) The above sterilization mechanism involves various factors like, different type of bacterial and virus strain and complexity in microorganism, different type of photocatalyst, so photogenerated ROS efficiency is not same for all microorganisms and it is proposed only. Therefore, it is still essential to study in detail the mechanism of photocatalytic sterilization. (Byrne et al., 2015)

Conclusions:-

In this review we have suggested methods to reduce the wastage occurring due to medical isolation gown. This include application a layer of TiO_2 or ZnO or similar type of metal oxide over isolation gown textile which can undergo photocatalysis on irradiation under ultraviolet (UV) – visible light. This will ease out the disinfection process without affecting the virus barrier capability of gown. These metal oxides are popular for their microbial properties. During photocatalysis process reactive oxygen species (ROS) species $HO^{\bullet}$, $O_2^{\bullet-}$, $HO_2^{\bullet}$, are produced which affect the duplication property of microbe due to degradation of cytoplasmic membrane and cell wall. Doping with certain metals with medicinal properties like Cu and Ag can further improve its effectiveness. Irradiation under UV light is one of the disadvantages of TiO_2 and similar metal oxide. Different methods are also discussed to bring their photo activation under visible range. Under the situation of COVID-19 pandemic this small step can lower down the biomedical waste by huge fraction without compromising with the health of the human kind.

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