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By

Siyam Khalid[1], Abdullah Yasar[1], Rameesha Tanveer[1], Iqra Wasif[1], Amtul Bari Tabinda[1]

ABSTRACT

In megacities, excessive wastewater is generated regularly from municipal sources. This includes grey water and black water where almost 90% of the grey water originates from laundry. The conventional method of cleaning clothes involves abundant use of water with detergents. It leads to large amounts of grey water laden with detergent residues like ethyl alcohol, phosphates, anionic surfactant (alcohol sulfate, benzene and alcohol ethoxy sulphate), 2-aminoethanol, and non-ionic surfactants. This water is discharged into the natural streams resulting in contamination. Ozone-based laundry system uses ozonated water to wash clothes where 100% water is discharged into the streams avoiding any waste. Overall, this method uses 50% less water compared to conventional methods as no further water is used to remove detergent residue from clothes results show no damage done to clothes and the fabric remains soft without the addition of fabric softener leading to an increase in fabric life. Implementation of this method in a mega city such as Lahore whose population exceeds 11 million will be able to hundreds of tons of water. Not only the cost of water will be saved but the cost of detergent will also be avoided making this process budget-friendly and cost-effective. This process is also by Sustainable development goals especially SDG 6, Clean water and sanitation, as further contamination of streams is avoided and less water is consumed to perform daily life activities which leads to the availability of clean water to the majority of people.

1. INTRODUCTION

Over the last few years, the treatment of domestic wastewater has gathered considerable attention in developing countries. A substantial portion of domestic wastewater consists of laundry effluents. A typical laundry machine generates 50 to 200 L of effluent per wash (Iribarnegaray et al., 2017). Detergents are a major contributing factor in terms of creating water pollution from laundry effluent. Detergents are mostly comprised of surfactants such as liner sulfonates, alkylbenzene sulfonates, olein sulfonate, sulfates, buffers like sodium tripolyphosphate, and other long carbon compounds. Surfactants above 0.5 mg

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per L in water are harmful to health and make water treatment essential (Rao, 2020).

These surfactants are not completely degraded in the laundry process. They can only be degraded by certain microorganisms. Their release, through laundry wastewater, leads to the development of massive foam in streams and rivers. Phosphate is also a component of detergents. It enters the water through laundry wastewater and causes eutrophication, which is the enrichment of nutrients. The blooms reduce oxygen penetration in water, resulting in defective absorption of dissolved oxygen in water (Samadi, 2020). The most extensively studied and feasible methods for the treatment of laundry surfactants are biological treatment methods. Changes in water chemistry and laundry types have made surfactants recalcitrant and non-biodegradable which have increased activity and toxicity (Neral, 2017).

The laundry contains different types of microbes which originate from human skin, body secretion and soil. Different activities like cooking, eating and outdoor activities influence the distribution of microbes on clothes. Epidemiological studies have revealed that fabrics are involved in transmitting infectious diseases (Cardis et al., 2007). Pathogens in clothes have different routes of transmission. Pathogens associated with human illness are likely to be found on fabric. Bacteria such as Salmonella, which cause intestinal diseases and *Methicillin resistant Staphylococcus aureus* (MARS) which causes skin infection are associated with textile fabric. E. coli and faecal bacteria which are most common in the undergarment of adults and children are associated with clothes. The fungi which are present in clothes also contribute to infectious diseases. Clothing has been associated with the transmission of Microsporum canis. This group of fungi causes dermatitis (Abney et al., 2021).

In the past few decades, the treatment of surfactants has gathered considerable attention. Different treatment methods have been introduced for the treatment of ionic surfactants such as ion exchange, wet air oxidation, membrane filtration, coagulation and filtration, photocatalytic degradation, Fenton oxidation, ozonation and other advance oxidative process. The possibility of complete mineralization and zero sludge makes the Advance oxidization process an attractive approach. The advanced oxidation process involves ozone, UV, H2O2, TiO2, persulfate, photocatalysis and Fenton (Patil et al., 2020). These processes can be used individually or combined to produce strong oxidizing OH radicals. Studies on ozonation in wastewater have shown that it reduces 25 to 60 percent of laundry wastewater COD.

Wastewater from laundry contains organic and inorganic substances. The organic constituent found in laundry wastewater includes soaps, detergent, aromatic solvent, oil, fats, grease, and biological substance. The inorganic substances include heavy metal, soil, dust, sand, metal ion and particles. These substances increase the COD, BOD and Total Suspended Solid (TSS) of laundry wastewater, which seems the treatment more difficult (Riesenberger, 2001). To improve the

current laundry practices we introduced and tested an ozone-based laundry system in our local hospitals and households.

2. Ozone utilization in various fields

Air and water are considered the most important factors to support life on Earth, but unfortunately, human beings exploit these resources through several activities. Ozone (O_3) has an atomic weight of 47.998. It is triatomic oxygen, which has pungent order and gives a transparent to blue colour in high concentration. It is a strong oxidizing agent next to Fluorine, which is the chemically most active among all elements. Ozone breaks down many organic and inorganic compounds and kills a broad spectrum of bacteria, viruses, and algae 1000 times faster than chlorine. Whenever oxidation occurs, it converts to oxygen, leaving no residue and pungent order. Ozone storage is practically not possible, but its generation is easy.

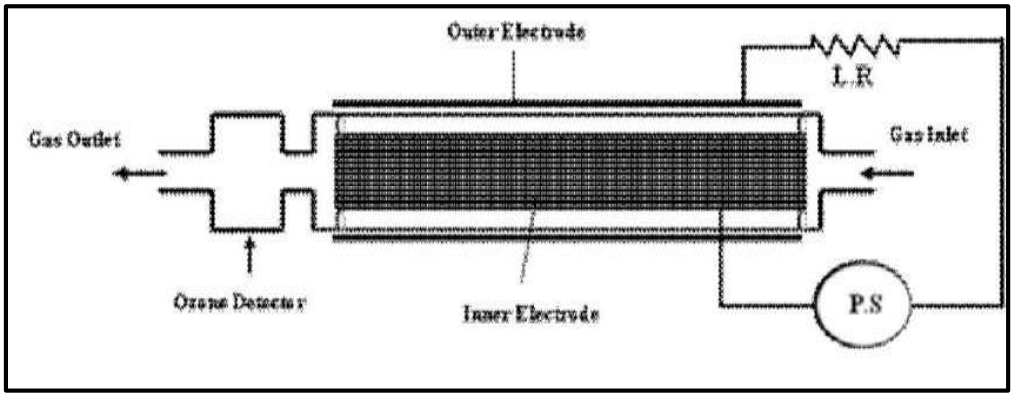


Figure 1: The systematic diagram of the ozone generator (Ghaffar et al., 2016)

Ozone stability is relatively low. It remains for several hours in the air and almost half an hour in water at room temperature. Above 90°C it decomposes rapidly. (Agosto, 2013). In the United States, the use of ozone was first introduced in the 1970s in commercial laundry systems to overcome all the issues related to water and air. The early use of ozone gave inappropriate results, and their performance was also not good because of a lack of understanding and in-depth study about ozone equipment. After this, a lot of practice and testing were performed and as a result, all the problems associated with the ozone laundry technique vanished. Then in the 1990s, ozone was again introduced in a commercial laundry system which promotes the use of ozone by giving recommended results and the best performance (Rice, 2009).

Ozone (O3) is a colorless gas at room temperature that is poisonous and has a distinct odor that can be detected at concentrations as low as 0.02 to 0.05 ppm, which is far below health-related levels. Ozone is generated by UV lamps, high-voltage electric arcs, and gamma radiation plants in the stratosphere, troposphere (photochemical smog), and UV lamps, high-voltage electric arcs, and gamma

radiation plants (Neral, 2017). Ozone is a potent oxidizing agent (2, 07 mV) and has been used to disinfect drinking water for many years.

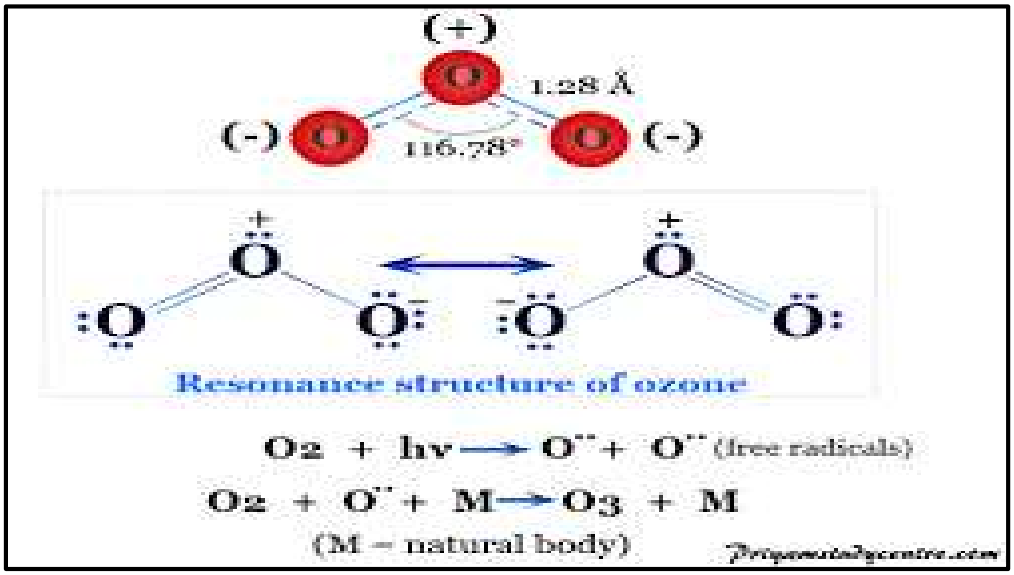


Figure 2: Structural Representation of ozone (Gardoni et al., 2012)

2.1 Ozone as a substitute for conventional detergent

When the detergent is used in the laundry, then the pH of the water is increasing due to the presence of different chemicals in the detergent. The main object of using ozone in laundry systems is to reduce the amount of these chemicals present in water bodies (Cardis, 2007). In the hospital, different types of microorganisms are present in the laundry (clothes and bed sheets). The presence of these microorganisms gives odor therefore, the ozone is used to remove the smell and disinfect the hospital laundry by killing the entire microorganism present in it (Hook, 2007). The use of ozone in the laundry is also helpful because the consumption of water and electricity is less than compared to traditional laundry. The ozone water can be used in 4 to 5 washes while in traditional laundry the water is wasted in every 2 washes (Sophar, 2009).

In the United State Kingdom, a six-month study on testing of bacteria by using an OTEX laundry technique was conducted in the hospital by Queen Elizabeth II. The two types of microorganisms such as MARS*, Clostridium difficile* are merely present. In this study, firstly the traditional method was used to remove the microorganisms which contaminate the cloths and mops of the hospital. For this purpose, the temperature was set at 71℃ for 60 minutes and the detergent was also added to it (Denvir, 2002). This method showed that the total viable count of microorganisms was the same, and the cloths/mops were still contaminated with bacteria. This will ultimately cause infection in patients and doctors. The results proved that the conventional method was not enough to remove the bacteria's presence in the hospital laundry. After this, the 6-month trial-based study of OTEX

laundry technique was used in this hospital which was started on 17th May 2005. The ozone was generated and then used for washing laundry by the hospital. The results of this study showed that no type of bacteria was present in the hospital laundry and thus the hospital stuff was disinfected. The smell present in the clothes of the hospital also vanished. Hence, on 6th December 2005, the OTEX laundering technique was installed in QE- II hospital (Deburm, 2011).

2.2 Ozone as a preservative for fruits and vegetable

All over the world, the food administration department works a lot for the preservation, protection and quality improvement of fruits and vegetables. Different technologies such as freezing, dehydration, sterilization, chlorination, fermentation, etc. were adopted, but unfortunately, these will not give 100 percent efficient results. These methods are not good because the shelf life and the quality of food are decreasing. The chlorination method is widely used to disinfect foods, but trihalomethane is formed as a byproduct (Karaca, 2007). The formation of this product gives an adverse effect on both the environment and human health. In the present years, most people choose organic fruits, because they thought that they are free from any type of contamination and ensure better taste. Many different food industries use ozone-based techniques to preserve their vegetables and foods. The ozone is produced when the oxygen molecule is a breakdown, into a single oxygen atom and thus this atom reacts with oxygen molecules and as a result, ozone is formed. This ozone base layer is formed when these products are passed from the ozone. The decomposition of ozone only produces oxygen; therefore, the quality of foods is not reduced (Kim, 2003).

In 2002s, an ozone-based study was conducted in the Tennessee Valley to decrease the level of microbes which was present in the products of cut fruits and salads. This study was named as Strickland Project. Strickland, (2010) before this study, a large amount of chlorine was added to food to provide protection against insects and increase the shelf life. Unfortunately, the excess amount of chlorine gives order and changed the taste of food. The Food and Drug Administration modified the use of ozone as an antimicrobial agent for food is very helpful because this will increase the storage capacity of foods. The Food Science Technology department in Tennessee used the samples which were refrigerated in Strickland operation. For this purpose, the FTNON machine of two stages was used. In this machine, chlorine had been already present, which was used as an antimicrobial agent for food, but the presences of ozone lower the use of chlorine. Then all the products are transferred to the laboratory and further testing was performed. After 25 days, the result showed that the addition of ozone increases the storage capacity of food, improved the quality of food, and also removes all the insects and dirt. The counts of bacteria also decreased (Garcia, 2001).

In Turkey, a study was conducted to increase the shelf life of strawberries. The storage capacity of strawberries is short because of the high rate of respiration and loss of water. The tissues present in strawberries are very sensitive; therefore, they are easily affected when fungal microorganisms attack them. In this experiment,

the aqueous phase ozone of different concentrations was used for the preservation of strawberries. The concentration of ozone such as 0.15 ppm, 0.075 ppm and 0.25 ppm were used, and the strawberries were exposed to these concentrations for 2 to 5 minutes. The freshly harvested strawberries were put into a plastic container with ice and then transferred to the laboratory for different testing. The colour and the softness of strawberries are affected when they are under-ripe and overripe, respectively (Aday, 2014). In the laboratory, Fourier transforms near-infrared are used to check the efficiency of strawberries in different concentrations. The pH, colour, electrical conductivity, and texture of strawberries do not change when they are exposed to an ozone concentration of 0.15 ppm and 0.075 ppm. While the 0.25 ppm concentration of ozone showed that the colour, pH, and quality of strawberries were changed. The aqueous ozone was used because the gaseous phase ozone is helpful only for the removal of mould on fruits. The softness and the quality of food are reduced when the gas ozone is used. The growth of bacteria is also not affected by using gaseous ozone (Resende, 2008; Nadas, 2003).

The fruits such as blackberries, apples, strawberries, grapes, peaches, lemons, cherries, oranges, etc. do not have a long shelf life because of the presence of a high concentration of chlorine and other chemicals. The quality of fruits is also spoiling because of the presence of E. coli, P. italium, B. cinerea and other harmful bacteria in these fruits. The study in the US showed that many harmful bacteria are present in foods due to improper storage, a smaller number of equipment, contaminated water, etc. These microbes in food cause serious health issues in humans and almost 9045 deaths were recorded in the US per year. Therefore, ozone is used for the inactivation of microbes present in foods. The use of ozone in the aqueous phase reduces the growth of microorganisms which causes spoilage and reduces the rate of activations of pathogen bacteria. In fresh fruits, the use of ozone produces oxidative stress, which is helpful in the formation of antioxidants. The layer of ozone in fruits also increases the shelf life and the chances of a microbial attack are reduced. The count of bacteria in different vegetables is also reduced when ozone is used for their preservation (Pandiselvam, 2019).

2.3 Ozone as an industrial stains remover

The textile rental service association conducted a broad-way study for the removal of stains (blood, wine, and cocoa) present on clothes. They used Dodecynlbenzoicsuccinic acid (DBSA) and Tide methods and then compared these with the ozone technique. The electrochemical method was used for the formation of ozone, in which the ozone is produced when the water reacts as an oxygen atom. The ozonator machine was used which produces the ozone electrochemically on site because the ozone cannot be stored. An ozone cell outside the machine was put into the water. The electrolyzer is present inside the cell which generates ozone in water (Roger, 1997). The temperature and the pH of the water were checked before the experiment. After washing the clothes with ozone, different tests, i.e., analysis of water, whiteness test and material test were

performed for checking the efficiency of ozone. The results show that Tide and DBSA methods do not remove these stains completely while the level of CO in water was increased. The whiteness and the quality of clothes were also reduced during these techniques. On the other hand, the use of ozone proved useful because the whiteness of clothes was not decreased. The level of harmful microorganisms, COD and turbidity in the water was also less (Glaze, 2008).

Cotton is the world's most-grown crop, and it is coming with a large variety. The outer layer of cotton is the primary wall which is primarily of cellulose, waxes and pectin, and its inner part comprises the secondary wall and lumen (Reid, 2007). Raw cotton is processed to remove naturally occurring color impurities before its use in the textile industry, and the method used for this is bleaching (Fei et al., 2015). Different oxidizing and reducing agents are used to remove color impurities in cotton. Peroxide is the best bleaching agent and is mostly used in the industry for cellulose products. Hydrogen peroxide is the most used bleaching agent in the industry due to its simple use and eco-friendly nature (Topalovic et al., 2007). Cellulose bleaching with alkali peroxide is a developed industrial process, but other studies ensure more ecological protection and cost efficiency. For instance, peroxide bleaching with TAED/H202, ensures fabric whiteness compared to the conventional method, but with much less batch time, without reducing fabric strength, and with less alkali use (Long et al., 2013). The other study with a focus on the use of potassium peroxide as a bleach activator in the peroxide bleaching with an eco-friendly commercial stabilizer was found more successful in saving time and energy (Wasif and Indi 2010). Abdul-Halim and Al-Deyab (2011) in their study tested practice acetic acid for low-temperature bleaching of cotton. In an aqueous solution of glucose and oxygen, hydrogen oxide enzyme produces hydrogen peroxide which is used in cotton bleaching (Tavcer, 2012).

Ozone is among the strongest oxidizing agents and reacts with almost any organic substance as well as with water. There are several intermediates of this reaction such as epoxide, peroxide, per-hydroxyl, and hydroxyl radicals. Some of these intermediates are useful in bleaching cotton. The formation of these intermediate compounds depends on the reaction condition. Different studies supported that bleaching of wet grey cotton can be successfully achieved with an acceptable whiteness. The process has minimal chemical damage to cellulose and takes less treatment time. The zone-bleached fabric has properties like conventionally bleached fabric (Prabahran and Rao, 2001). The moisture content of cotton fabric was emphasized in ozonation. Other studies have also shown the usability of ozone-bleaching cotton fabric.

The ozone is used in many industries for washing the organic stains such as ketchup, chai present on the cloths. It is not easy to store ozone; therefore, the ozone must be produced on the site where the ozone-based laundry technique is performed. The removal of stains on cloth by using ozone is working successfully. After this, different tests were performed by using cotton jeans cloths to notice the change in color and fabric of clothes. These experiments show very effective results. The fabric of the clothes is changing when detergent is used for washing

purposes. The long-term and continuous use of detergent for washing fades the color of clothes. Whereas the use of ozone for washing does not change the fabric and color of clothes (Zhou, 2020).

2.4 Ozone as an insecticide, pesticide and fungicide

The ozone plays an important role in the agriculture field by preventing crops from insects and fungus attacks. Pesticides and other toxins decrease the productivity of crops and damage plants. All around the world, almost 27% of crops are lost because of the presence of microorganisms. These infected crops cause different diseases in humans and pollute the environment. For the removal of these toxins from plants different methods are used, but these are not effective. These techniques do not reduce the growth of harmful bacteria. When the ozonation method is used to save the crops then it shows that Mancozeb, azinophos methyl and other bacteria are degraded completely (Ikehata, 2005). The concentration and the phase of ozone are varying according to the conditions. Some bacteria are degraded in the aqueous phase while some are degraded in the gaseous phase.

When the grains are stored, then the rate of attack of insects and different antimicrobials is increasing, and this will ultimately reduce the quality of grains. The ozone is used to store food grains for a long time because ozone can lower the rate of pathogens by damaging their cell wall. The use of ozone also kills maize weevil, larvae, and other insects by oxidizing their cytoplasmic membrane. The storage capacity of grains is increasing while the number of pests is decreasing (Dubois, 2006). It is very difficult to store cheese and nuts at atmospheric temperature. After 3 to 4 days, the moulds are starting to appear on these products. In cheese, different mycotoxins such as Aflatoxin, Citrinin etc. are present. Therefore, a lower concentration of ozone is used in the ripening process of cheese to control the growth of harmful microorganisms. The addition of ozone in the process of ripening increases the storage capacity of cheese for approximately 12 weeks. The functioning of mycotoxins in cheese is reduced when the ozone is used for storing cheese (Janpoor et al., 2011).

2.5 Ozone is an effective agent for hospitals and its laundry

In the hospital, different types of viruses and microorganisms such as MRSA, *Escherichia coli,* C. difficile*, Streptococcus faecaelis* etc. are present. The use of detergent for washing cloths and other stuff in hospital is not good because the detergent does not kill the microorganism. After washing, some stains of microorganisms remain active on cloths and then give odor. They also cause serious health effects on humans by causing different diseases. The ozone does not work properly in hot water and may decompose while on the other hand, ozone works more efficiently in cold water. The spores of C. difficile and MRSA are removed from the hospital laundry when the ozone is added to cold water. Different studies on ozone show that when the ozone is used at 10℃ temperature for 10 minutes, then no spores of bacteria and viruses are present in hospital cloths. The ozone first damages the external layer of harmful microbes then enters their body

and destroys the functioning of microorganisms completely. The smell which is present in hospital clothes is also removed. Therefore, the use of ozone in hospital washing is very effective (Wren, 2008).

The use of ozone in hospital and hotel laundry has risen dramatically over the last three decades. In certain cases, ozone has been empirically shown to help in the conservation of natural resources, the reduction of energy use, and the extension of textile life. Recently, comprehensive research into the proper use of ozone in industrial laundries, as well as the effects of ozone on textile quality and hygiene, began (Tapp, 2013). The purpose of doing laundry is to remove impurities, unpleasant order, and microorganisms, but by doing that the fabric structure and surface remain undamaged. The laundry process is complex. It is a combination of physical and chemical factors in an aqueous solution which affects fabric cleaning. There are certain factors which affect the laundry process such as chemical action, mechanical action, time, and temperature. There is also another quality parameter water, which is crucial in the laundry. Water is important in the cleaning process. It acts as an agent in solution to transport detergent and heat in the laundry. With the help of detergent, it absorbs organic and inorganic impurities. It released soil away from the fabric and dilutes the detergent solution in the rinsing process (Scheid et al., 2016).

Laundry is the most common household occupation to ensure hygiene, reduce infection risk and protect the health of a household member. There have been significant developments in the last decade in the laundry process which has increased its efficiency and energy consumption, but statistic shows wasteful consumption of water and energy in the household sector among which the largest energy consumer is washing machine.

Due to rising environmental problems, environmental legislation demands the development of new technology for household laundry machines. The introduction of ozone in the laundry has significantly increased in the last decade. There has been supporting research which highlights the various benefits in the form of energy, water, chemical, detergent reduction and health (Branko, 2018). Ozone is a powerful biocide that integrates with commercial laundry to give an effective disinfection system. The OTEX which is a commercially available ozone laundry system has proved more efficient in decontaminating microbial infection. During this process, ozone is injected directly into water through a sparger system which provides a continual flow of ozonated water in the laundry process. This process ensures that the wash load is continually treated with ozone to provide disinfection (Humphrey's et al., 2012).

When we do laundry, we usually think of using detergents, hot water, and fabric softeners, but there are huge advancements in the methods we use to do laundry, through which we can achieve high-quality standards without using hot water and harmful chemicals. The ingredients from detergents can contain harmful materials such as volatile organic compounds. Understanding the VOCs used in detergent is important to help us go green (US EPA, 2021). The ingredients used in some

popular brands of detergents contain ethyl alcohol, anionic surfactant (alcohol sulfate, benzene and alcohol ethoxy sulphate), 2-aminoethanol, and non-ionic surfactants (alcohol ethoxylate) which can be released into the air through laundry process. The VOCs in the air are serious hazards. The product labelled fragrance free is mostly scented with a synthetic compound which masks the smell of the compound they contain. The manufacturer won't label them on a product because they consider it as a trade secret and are not required to list them on the product description. According to US EPA the air inside the house is two to five times more polluted than the air outside, and in some extreme cases, it is 100 times more polluted. The compound containing VOCs should be used in a well-ventilated, which means bringing fresh outside and mixing it with indoor air. The laundry rooms are not well-ventilated, so the presence of VOCs causes serious respiratory problems in such rooms.

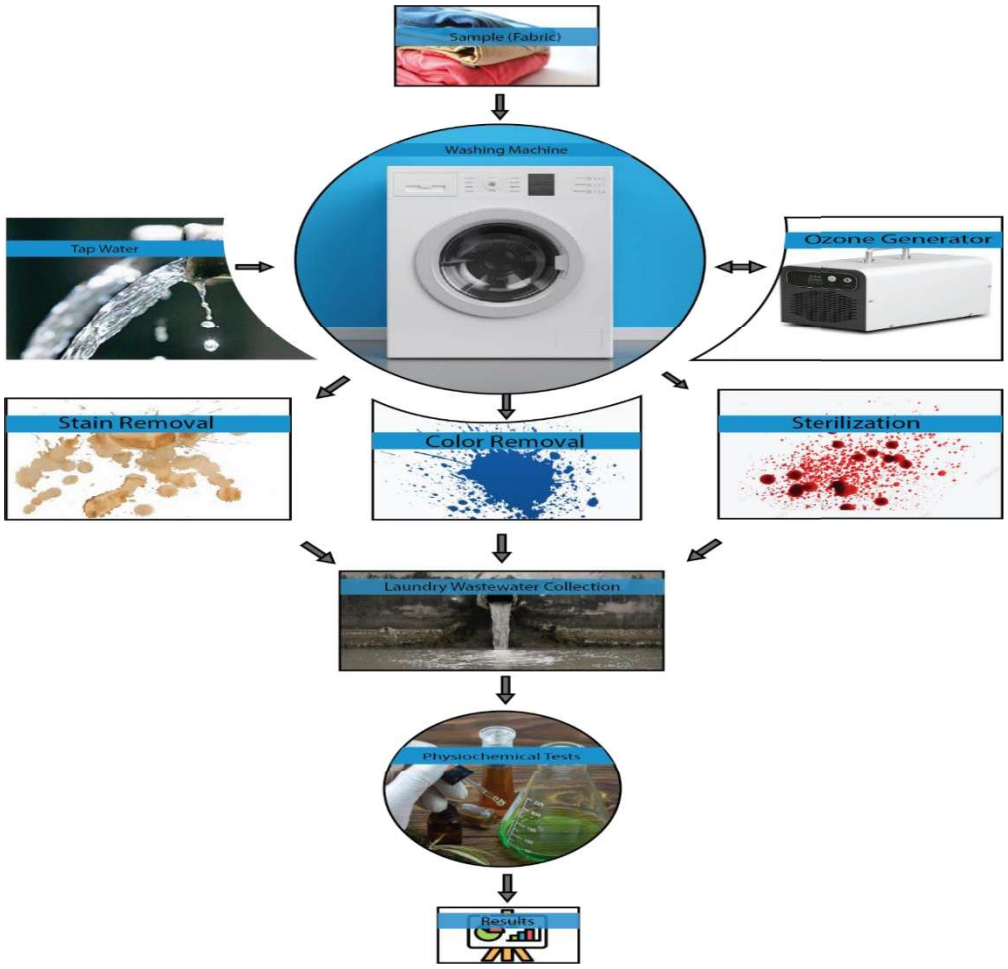


Figure 3: Pictorial illustration of ozone used for the removal of organic and inorganic stains

While washing fabric detergent is not 100% removed. The detergent that remains on the fabric causes serious skin issues. There are two types of skin problems which arise from detergents or soap remains. Irritation, in which red, itchy rashes appear as soon as you put clothes on. The irritation goes as the irritant is removed. Dermatitis also appears as red, itchy rashes, but not with immediate effect. If you have a true allergic condition, then this may last for weeks. The immune system takes time to recognize the allergens; meanwhile, you can be exposed to allergens multiple times without body response (Tamburro, 2021).

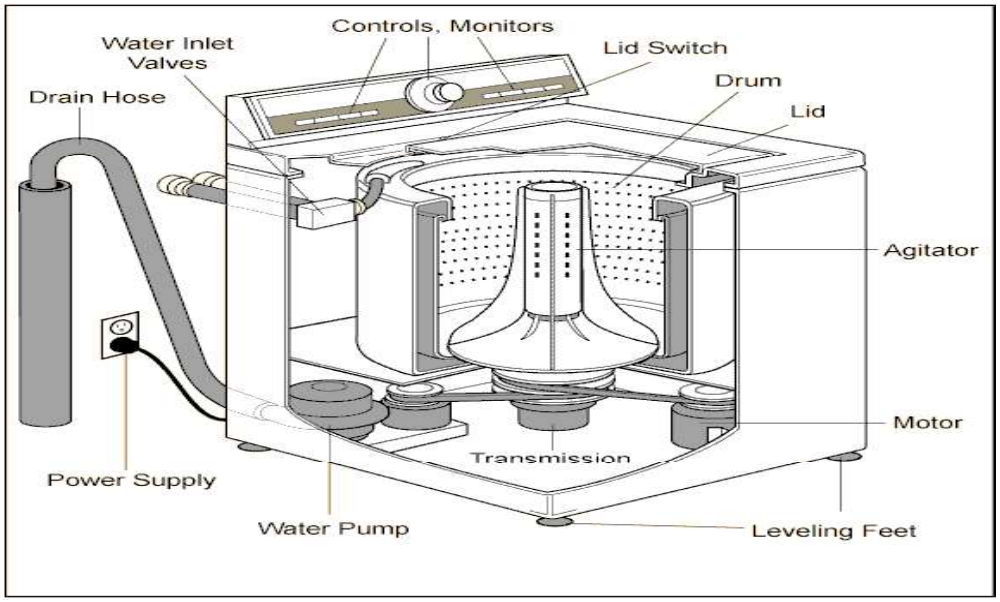


Figure 4: Systematic diagram of conventional washing machine (Bhatawadekar et al., 2015)

The laundering process, which includes water washing and dual-phase washing, uses a lot of water. The cleanliness obtained by laundering is the result of synergistic action between mechanical energy, chemical energy, thermal energy, and time. These factors separate soil from textile fibres (Warmoeskerken et al., 2002). The most common ingredient used in the laundry is bleach, surfactant, and water softener. The amount of chemicals added depends on the type of cleaning item. The surfactants used in detergents can remove both soluble and insoluble soil molecules. The lipophilic end of the surfactant penetrates oily soil, while the other hydrophilic end solubilizes the oil. These actions disperse soil in water, which pollutes water (Šostar-Turk et al., 2005).

The wastewater from laundry discharges into water bodies. The increased surfactant concentration in water streams causes problems for both aquatic and terrestrial life. Due to rising environmental regulatory concerns related to reducing surfactant in water streams have increased. The wastewater from the laundry where dirty items are being washed contains heavy metals, mineral oil, and dangerous substance with a COD value of 1200-20,000 mg O_2/L. On the other

hand, hospital wastewater contains fats, urine, and the remains of blood (Ciabattia et al., 2011).

The health benefits of using ozone in laundry applications are quite significant. Different studies have proved that an ozone-oxygen mixture can be used to kill a variety of microorganisms in all fabrics. The advancement in technology allows us to use ozone as a detergent-less laundry solution. The effectiveness of ozone in killing microorganisms is 3,000 times higher than bleach. Ozone can be very effective at killing superbugs such as bacteria, fungi, and viruses. Oxidative stress is an essential factor in the pathogenesis of the gastrointestinal disease. The reactive oxygen species (ROS) which are the natural byproduct of cellular oxidative metabolism, play an important role in cell survival, cell death, and cell signalling. Ozone is a potent ROS that causes oxidative damage to biological molecules (Ohmine, 2005).

In laundry applications, ozone performs a tow extraordinary characteristics. One is that it leaves no residue, and the amount of detergent used in ozone laundry is much low as compared to conventional laundry systems. Ozone-washed clothes require far less rinsing so, it saves much water. The second major benefit is that ozone washing requires cold water for sanitization and cleaning, which saves a considerable amount of energy used to warm water in the conventional method of laundry. Ozone improves the efficiency of chemical actions in the water, reducing the need to wash at high temperatures. Clear Water Tech estimate that energy savings opportunities based on commercially operated ozone-washing devices are 90% for washing and 20% for drying (Rice et al., 2009).

In ozone, laundry fabric endure less wear and tear because of shorter cycle cycles and cooler temperature water. Reduced chemical exposure can also extend the life of fabrics. An analysis of ozone laundering of nurses' uniforms in the United Kingdom showed that ozone laundering eliminated significantly more moisture from laundry than a typical wash cycle (both cycles have the same final spin speed and time). As a result, ozone laundry saves time and extends the life of your linens (Hook, 2007). Some of the actions of chlorine bleach are performed with ozone in a water solution. Since ozone increases the separation of soils in the wash water, it decreases the need for bleaching by preventing the redeposition of soil onto the linen (one of the leading causes of cloth greying). Controlling ozone production, concentrations, dilutions, and other factors help ozone to remove dirt without necessarily bleaching the laundry (Rice et al., 2009).

Ozone aid in water softening. It helps to remove hardness cations (calcium and magnesium ions) from the water. This is accomplished by a complex process in which ozone adds oxygen moiety to some of the partly oxidized organic materials used in laundry soils. The oxygenated organic laundry soils will then form insoluble complexes of polyvalent cations (Ca, Mg, Fe, Al,). Softer water has a great feel in washed fabrics because it has a better sudsing and rinsing action. Instead of using a single ozone level for all washes, some new ozone laundering systems provide regulated and even variable ozone levels. Sensors are often used in several

applications to detect and, in some situations, regulate atmospheric ozone levels. These newer solutions are erasing the flaws that some of the industry's earlier systems left behind. Not only have ozone laundering programs and help been upgraded but so has the industry. The widespread need for cost-cutting, disinfection, and ‘‘green" solutions has prompted decision-makers to look at ozone technology.

According to Rodell (2021), who is an award-winning and certified architect by the National Council of Architectural Registration Boards (NCARB), commercial laundries at homes, hospitals, hotels, and universities take almost 12 steps in their workflow. The process uses a lot of water, energy, chemicals, and time to clean clothes. This creates unnecessary waste. For commercial laundry, only the cost to maintain water temperature is causing the laundry industry to move to new technology. On the contrary, ozone laundry will reduce water, chemical, energy, time, and labour required to produce a better-finished product within a shorter wash cycle. It also reduces operating costs such as utility and chemicals and extends fabric life.

The chemicals which are used in different processes such as preservation of the products, removal of stains on cloths and the inactivation of bacteria present in hospital laundry are added into the water. When these chemicals are mixed with water, then the pH of the water is increasing. This increase in water pH affects aquatic life and causes serious health issues in humans when this water is used for drinking purposes. The use of ozone for different purposes does not increase the pH of water because ozone only produces oxygen when it decomposes. The ozone-mixed wastewater is free from any chemicals therefore when this water is added to the aquatic bodies, then it will not change the aquatic conditions. This water also does not give an adverse effect on human health. The ozone is also used for the treatment of wastewater and thus makes it able to be drunk (Baur, 2004).

The pH of water is increasing day by day due to the presence of harmful chemicals in the water. Many industries release their wastewater into water bodies without treating it. The chemicals present in their wastewater gives adverse effects on aquatic life. Similarly, when detergent is used for washing purposes, then a lot of chemicals (present in detergent) are mixed with water. After this, the water is discharged directly into streams, rivers, lakes, etc. and thus the pH and turbidity of the water are increasing. In the aquatic environment, most of the species require appropriate conditions for their survival. The chemicals in detergent change the pH of water as a result, many species are unable to survive, and then untimely they are dying (Ural, 2012). When the ozone is used for washing purposes, then only oxygen is produced. This oxygen is not harmful to the species present in water. Therefore, the use of ozone in laundry systems is proving very useful because it will not change the conditions of the aquatic environment.

3. REACTION MECHANISM AND INJECTION METHOD OF OZONE

There are two reaction mechanisms through which ozone works. One is the direct method and the other is the indirect method. Indirect method ozone itself acts as an oxidizer and break chemical bond in stains. In the indirect method ozone first, react with water and produce $^{-}$OH radicals, which then encounter stain or soil to break the chemical bond between them. Which reaction will dominate? It depends on reaction conditions such as temperature, chemical nature of water and pH. The higher the temperature and pH, the more will be OH radicals. Hydroxyl radicals are more oxidizing in nature, but there are very short lived-in solutions. Ozone works in oxidizing mechanism to remove stains from laundry (Wren, 2008). The ozone and OH radicals (produced from the reaction of ozone and cold water) can both works as oxidant. Ozone works best at a lower temperature due to its instability. When the temperature is high, the heat will break its chemical bonds. The colder the water the longer the ozone residual time and more will be oxidation. Ozone stability will decrease, if water pH, temperature, electrical conductivity, and alkalinity increase. The half-life of ozone diminishes quickly at 85^{o}C, and at 95^{o}C ozone losses all its effectiveness and leaves the solution as gas (Weeter, 2020).

The ozone technologies are advanced and safe to use. The most common zone generator is a corona cell discharge type where two close surfaces are charged with electricity. These surfaces create a high-voltage arc of electricity. When oxygen is passed through this arc, one to ten percent of it is converted into ozone. Ozone easily dissolves in water by utilizing pressure. Mass transfer is the ability to dissolve gases in water. The mass transfer of ozone depends on the design criteria. There are two methods of injecting ozone into water (Tamburro, 2021);

3.1 Fine Infusion Bubbles

The fine bubble infusion, injection method of the washing machine is the same as used in the bottle industry to introduce ozone, where water flows from the top of the tank and exits from the bottom. The diffuser is placed at the bottom and the ozone is introduced from the bottom of the tank. The counter flow of water provides a decent mass transfer of ozone. Pressure is needed to introduce ozone in the water tank. As the column's height increases it puts more pressure on the diffuser stone. Therefore, the greater will be the mass transfer of ozone.

3.2 Venturi Injection Method

The Venturi injection method is a more reliable and most used method to transfer ozone in water. In this method applied water pressure passes through a narrow throat that constrains the water flow and creates a vacuum. This vacuum then allows ozone transfer. The disadvantage of this method is that it cost more to construct this type of system.

CONCLUSION

Ozone is a primal element for killing microbes and degrading organic and inorganic contaminants. Ozone breakdown many organic and inorganic compound and kill

a broad spectrum of bacteria, viruses, and algae 1000 times faster than chlorine. Unlike chlorine, it does not reside in water and rapidly oxidizes oxygen. It is widely used in water purification systems, but it is quite beneficial in others sectors as well such as laundry. The contaminant found in laundry includes organic waste, inorganic waste, and microorganisms. Traditional methods of laundry are not economical and cause damage to the environment. They cost more for post-treatment of laundry wastewater. The contaminant found on clothes determines the value of BOD, COD and DO in laundry wastewater. Usually, these values are very high in laundry wastewater due to the extensive use of chemicals and detergent. Instead, Ozone Laundry is very economical and environmentally friendly. Through this, both economic and environmental benefits can be achieved. The rising concerns about water pollution can be mitigated affected, and infectious diseases transmitted through clothes can be reduced.

Experiments were performed on a sample containing organic, inorganic, and microbial contamination and are compared to the traditional method of laundry. Ozone was found 9 times more efficient in cleaning different stains and killing microbes. The first phase of the trial was on organic components in which ketchup and tea strains were tested. Ozone was cleaned in a very short wash cycle, keeping all water quality parameters normal. The pH and EC, which are critical factors in determining water quality remain the same before and after the trial. The second phase was on inorganic strains of soil. Ozone showed quite significant performance in removing dirt from clothes by keeping all water quality parameters normal. This is the only phase, which has taken more than 50 minutes. In the third phase, ozone's effectiveness in sterilizing clothes was tested. Different contaminant samples of chicken blood, intestinal fluids, and faecal material were tested. Ozone killed 95 percent of all microbes in just 15 minutes of wash time. The cleanness achieved was even better as compared to detergents.

Due to its uniqueness, its applications are wide and further research and development can bring important breakthroughs. Pakistan as a developing country is facing economic and environmental problems. The methods which are used for laundry are quite old and have little effectiveness. The small-scale experiment was quite successful, and it opens opportunities in Pakistan to implement it on a large scale. Industries in Pakistan involve huge labour and commoner contaminates found on workers, laundry is skin secretion. To clean their laundry industries used a large amount of warm water and detergent which require lots of energy. Through ozone laundry, both large- and small-scale industries can achieve benefits in terms of cost reduction and environmental protection.

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