Journal of Business and Environmental Management (JBEM)

Volume 2, Number 2, 2023, Pages 24 – 44

Journal Home Page

https://journals.airsd.org/index.php/jbem

Greywater Characteristics and Treatment Processes: A Review

Shahzeb[1], Zahid Mehmood khan[2], Hafiz Umar Farid[3] & Arshad Ameen[4]

[1-4]*Department of Agricultural Engineering, Bahauddin Zakariya University Multan, Pakistan*
Email:shahzebh54@gmail.com

ARTICLE INFO

Article History:

Received:	July	20, 2023
Revised:	August	25,2023
Accepted:	September	25,2023
Available Online:	November	20,2023

Keywords:

Aluminium Sulphate, Ferric Chloride, Chemical Coagulation, Greywater, Pollutants removal

ABSTRACT

Treatment of greywater has become justifiable to fulfil the increasing demand of fresh water and environment protection. The availability of water has reduced from 1299 m3 per capita in 1996-97 to 1100 m3 per capita in 2006 and it is expected to less than 700 m3 per capita in 2025. The worldwide population is projected to surpass nine billion by 2050 and total water consumption of urban will surge by 62% from 1995. Water used in clothes washing produce approximately 25-35%, kitchen 11 %, bath tubes 48 % and hand wash 7 % of greywater. Therefore, there is a dire need of treatment of greywater. The different technologies which are used in the treatment of greywater may be classified as physical separation techniques, biological treatments and chemical or advance oxidation processes (AOPs). In chemical treatments there are different processes such as chemical and electrocoagulation. The percentage removal efficiency of chemical coagulation for BOD, COD, Turbidity is 88.78 %, 63.72 % and 90.88 % respectively. Chemical coagulation can also remove bacteria, microbial pollutants and total organic carbon.

Corresponding Author's Email: shahzebh54@gmail.com

INTRODUCTION

Water is life. It is universally provided via precipitation at comparatively continuous rate of 47000 km^3 yr^{-1} from which withdrawn only 6800 km^3 for use. Nevertheless, as population of world is increasing approximately 85 million yr^{-1}, the fresh water accessibility per persons going to be decreasing (Zadeh & Sara et al., 2013). At this amount, the quantity of human beings which are living in water are facing in scarcity of water or water stressed countries is projected to upsurge half of billion to three billion in 2025 (Oteng-Peprah & Michael 2018). To focus such huge issue, moreover hard or soft channel solutions exist. Water having possible sources of contaminants for treatments and recycling are greywater, sewage and rainwater. wastewater is treated and reused for crop and garden irrigation in different countries including Australia, Europe, USA, India, the Mediterranean region, Africa and china rainwater harvesting are invigorated in many countries such as Brazil, Central Africa, Australia, UK and USA (Matos & Cristina et al., 2012).

Greywater may be defined as waste that includes water from kitchen, laundry, washing machine, sink, showers and it excludes the toilet waste. The quantity of greywater generated within a home differs throughout the days with the large amount being generated after and before in hours of working. Greywater also differs in amount as well as configuration depending on the different kind of chemicals which are used for the washing of clothes and dishes (soaps, detergents, toothpastes, etc.), gender, member of household, age, country and water availability, etc. The different technologies which are used in the treatment of greywater may be classified as physical separation techniques, biological treatments and chemical or advance oxidation processes (AOPs). In chemical treatments there are different processes such as chemical and electrocoagulation (Zadeh & Sara et al., 2013). In my research I am going to perform or analyze the chemical coagulation. The percentage removal efficiency of chemical coagulation for BOD, COD, Turbidity is 88.78 %, 63.72 % and 90.88 % respectively.

Greywater Generation

Greywater is described as any effluent produced from commercial properties or public and private deprived of any contribution from bidets, urinals or toilets seriously contaminated industrial development of water (Eriksson et al., 2002). According to this definition, wastewater which produced from laundry, washing machine, showers, kitchen sinks and dishwashers classified as greywater. Greywater can be classified in two types less strength greywater (light greywater) and high strength (greywater dark greywater). Light greywater can be defined as waste water from bathroom (contains shampoos, soaps, body care products, hair and body fats) and washbasin (comprises of toothpaste, shaving waste, hairs and soaps). Dark greywater can be defined as waste water from kitchen sinks (contains food residues, dish washing detergents and high amount of oil and fats) and laundry (contains soaps, paints, bleaches, non-biodegradable solvents and oils). (Ghaitidak and Yadav, 2013)

Because of daily actions tangled in its creation, the quality and quantity of greywater differs significantly even inside a property, and subsequent greywater characteristics have been discussed by Jefferson et al., (2000):

1) Large difference in quality and therefore a vigorous treatment system required
2) Large sequential unpredictability in quantity can produce the requirement of storage, and
3) minimum levels of biodegradable organic complexes and nutrients as compared to the municipal wastewater.

Numerous constraints have been exploited to characterize the quality of greywater. Friedler (2004) calculated different constraints according to the Standard Approaches for the analysis of Wastewater. These parameters included total suspended solids, pH, total nitrogen, total dissolved solids, total phosphorous, chemical oxygen demand (COD) and biochemical oxygen demand (BOD_5). Consumption of water depends on accessibility of resources and the quality of life standards. The greywater quantity depends on the living standard, consumption of water, resident habits, structures of population (i.e., age, gender) and installations of water for a given population (Ghaitidak & Yadav et al., 2013). Therefore, greywater differs from 50- 80 % of wastewater volume generate from households (Santos & Pinto et al., 2012). The distinctive greywater volume differs from 91-120 l/p/d, though the greywater volume in less income countries are practices prolonged water shortage may be low as 20 to 30 l/p/d (Albalawneh & Abeer et al., 2015). The greywater quantity differs between in rural and urban areas.

The literature which are published shows that about 47% creates from wash basin, 27% of generates from dishwasher and kitchen sink, shower and bathroom and 26% generates from washing machine and laundry (Albalawneh & Abeer et al., 2015). Rendering to NSW (2006) contribution of greywater is 68% of the total effluent produced from homes mostly comprises of laundry 34 %, hand wash 7 %, kitchen 10 % and bath 49 %.

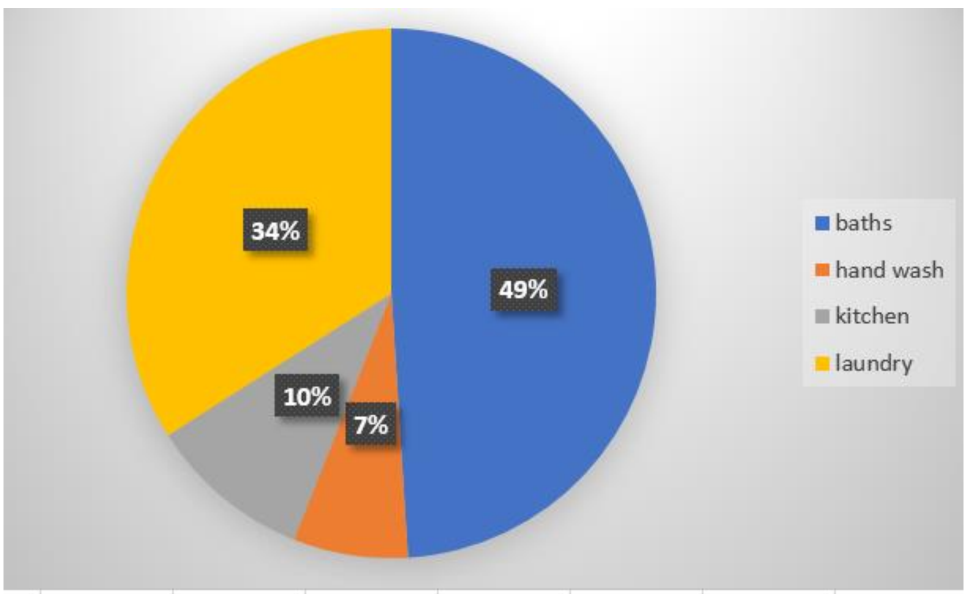

Figure 1.1: *Greywater distribution generated in a household (New South Wales Population Health Survey 2006 (HOIST))*

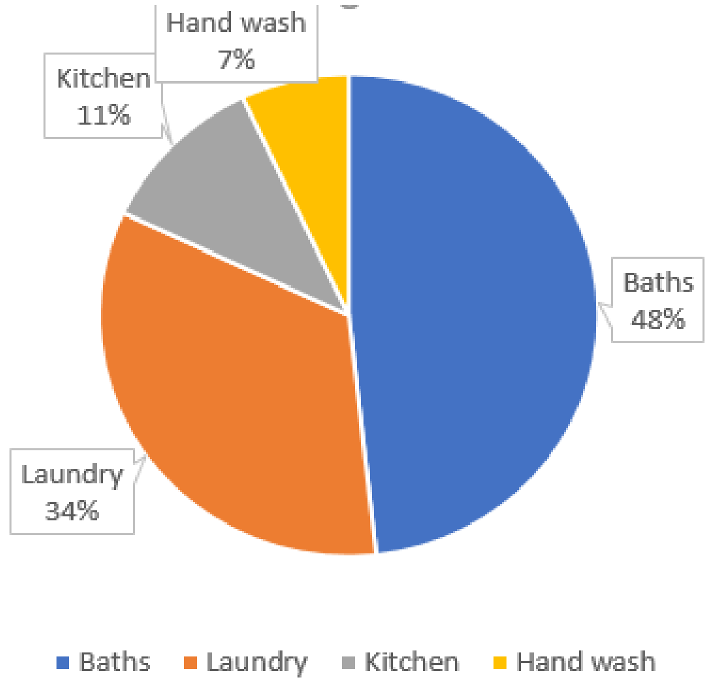

Figure 1.2: *Greywater distribution of house in L/day (New South Wales Population Health Survey 2006 (HOIST))*

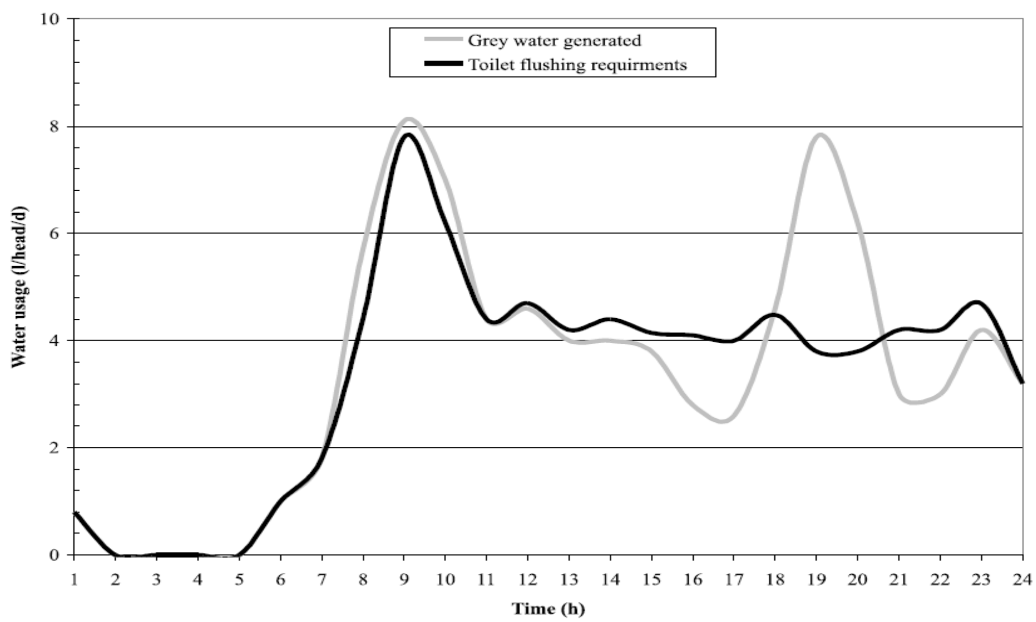

Figure 1.3 *Typical greywater generation and toilets flushing requirement in college (Surrendran & Wheatley 1998)*

Greywater Characteristics

Greywater without treatment contains large number of bacteria, microbial pollutants, high difference in organic amount, it is warm and rich in nutrients that make it a perfect medium for microbial activity and bacterial growth (Zadeh & Sara et al., 2013). On the previous research the concentration of organics in greywater is like as settled household wastewater but concentration of suspended solids is much lesser as wastewater from toilets which are not included (Jefferson et al, 2004).

Greywater is produced for the outcomes of the standards of living of the concerned people. Consequently, characteristics of greywater are highly flexible and affected by lifestyle, cultural and social conduct of the inhabitants, the consumption and water availability. Untreated greywater contains huge number of bacteria, microbiological contamination, high inconsistency in concentration of organics, greywater is rich in nutrients and warm that make it perfect medium for microbiological development and movement of microbial (Zadeh & Sara et al., 2013).

Table 1.1: *Greywater characteristics (Fangyue Li et al., 2008)*

Parameters	**Bathroom**	**Laundry**	**Kitchen**	**Mixed**
pH	6.4-8.1	7.1-10	5.9-7.4	6.3-8.1
TSS (mg/L)	7-505	68-465	134-1300	25-183
Turbidity(NTU)	44-375	50-444	298	29-375
COD (mg/L)	100-633	231-2950	26-2050	100-700
BOD (mg/L)	50-300	48-472	536-1460	47-466
TN (mg/L)	3.6-19.4	1.1-40.3	11.4-74	1.7-343
TP (mg/L)	0.11->48.8	>171	2.9->74	0.11-22.8

Composition of Greywater

The greywater composition differs and is heavily an image of lifestyle standard and choice of chemicals which are used for washing of clothes, cleaning and bathing. The greywater characteristics also influenced by the kind of distribution system and the quality supply of water (Albalawneh & Abeer 2015). The greywater composition can also be affected by biological and chemical degradation of some compounds within the storage system and transportations. Siegrist (1997) explain that greywater ingredients have the following percentage load of household wastewater.

- 70 % of phosphorous
- 63 % of the BOD_5

- 65 % of the flow
- 39 % of total suspended solids
- 18 % of the total nitrogen

Physical, chemical and biological characteristics of greywater varies from home to home and mainly depends on the family members and them performs (Oteng & Michael et al.,2018). There are mainly three greywater streams, obtained from the bathroom, kitchen and laundry.

Bathroom

Waste produced from the baths contribute roughly 55 % volume of greywater generated by a distinctive home in western Australia (Albalawneh & Abeer et al., 2015). Cleaning products, lint, hair dyes, hair, oils and body fats often polluted wastewater of bathroom. Also present few bacteria, viruses and fecal contamination.

Laundry

Waste produced from the washing machine or laundry contribute almost 34 % volume of greywater generated by a distinctive home in western Australia (Albalawneh & Abeer et al.,2015). Quality of laundry wastewater depends on material which are used for the washing of clothes. The laundry greywater typically contains chemicals, nutrients, cleaning agents, greases, lint and oils. Some viruses, bacteria and faecal pollutants may also present.

Kitchen

Waste that is produced from kitchen contribute roughly 11 % volume of greywater generated by a representative home in western Australia (Albalawneh & Abeer et al., 2015). Kitchen greywater is severely polluted cooking oils, food particles and grease place heavier load on the greywater treatment systems and have the possible for the blockages of the systems.

Constituents of Greywater from Laundry and bath tubes

Laundry contents from greywater substances such as human tissue, dirt, pathogens and chemicals from which detergents used. Detergents of laundry comprises different types of ingredients which everyone have multiple purposes (Albalawneh & Abeer et al., 2015). Formulas of Detergents and surfactants are composite and reflecting varied demands of market consumer. Detergents from washing machine or laundry contains surfactants, builders, bleach, enzymes and many more agents. The greywater content is strongly affected the cleaning water by temperature.

Foam Builders

Builders are the softeners of water, which remove magnesium's, calcium and contains different cations of metal in hard water, in resulting additional soft water. that soft water is good coordinated with the combination of soap and consequently increase plumbing lifetime (Zadeh & Sara et al., 2013). Builders can contribute 58 % to the chemical composition in laundry greywater. Surfactants ions of hard water contact with soaps of actions, as a result they produce off-white hard chalky deposit which can be say that lime scale, by the production of this fouling can take place in the plumbing that create galvanic corrosion. sodium tri-polyphosphate and sodium carbonate are the most important. Good performing stimulate is phosphate for algae, fauna and bacteria in rivers; oceans and lakes, at very high rates makes them coloration. By which a comprehensive oxygen supply decay both in bottom layers and at the surface of the water bodies and in the result killing of fish (Ahmad & Hesham, et al. 2016). In assessment between liquids and powder cleaners shows that powder have high content of phosphorus as compared of liquids (Albalawneh & Abeer et al., 2015). In detergents of laundry sodium is one of the most important salts and has the solemn effect upon being dangerous as well as minimizing the permeability soil (Zadeh & Sara et al., 2013).

Surfactants

Surfactants in laundry wastewater are mostly organic compounds that minimize surface tension amongst a solid and a liquid and among two solids and two liquids. The mechanisms which include the adsorption at the laundry interface and oil-solution of surfactants. Surfactants contains both hydrophilic group and hydrophobic groups. Hydrophilic group can be categories into different groups which are nonionic, zwitterions, anionic and cationic (Zadeh & Sara et al., 2013). Surfactants can contribute 36% to the detergent chemical composition in the laundry and bath tubes laundry wastewater. Detergents of laundry can also consist of many types of surfactants mixtures to increase the cleaning efficiency. At high concentrations of surfactants micelles process take place, when surfactants present in aggregate forms, that processes more frequently where surfactants concentration is high in hand washing processes. Micelles can take place in the solution which gives the surfactants of these solubility properties and cleaning ability (Albalawneh & Abeer 2015). All surfactants cannot decompose, many surfactants forms complexes, that are hard to decompose. Other surfactants are toxic for the life of aquatic, although others have effect hormone-like (Zhu & Rothermel et al., 2014). Anionic surfactants just like LAS; Linear alkyl benzene sulfates, that are used in high volume due to their low manufacture cost and their ease.

Bleach

Bleach contains different types of chemicals which can be added to remove the color. Bleaching agent can remove the stains from clothes which cannot remove from the laundering processes. Hydrogen peroxide and sodium hypochlorite mostly used as a bleaching agent (Albalawneh & Abeer et al., 2015). Bleach can contribute 2.5 % to the detergent's chemical composition in laundry greywater. Sodium hypochlorite is injurious for human health because of etching effect the damage of skin and are very poisonous to aquatic life. Though, the bleaching compound is extremely active, and it can be reacted organic materials present in the greywater in the drain before wastewater reaches at the wastewater treatment plants (Eco-Forum, 2007).

Enzymes

Problematic stains similarly can be removed by using the enzymes. Which act as catalyst between enzymes and stains to increase the speed of chemical reaction so that materials can be cleaned away with the help of surfactants. Enzymes can contribute 2.5 % to the detergent's chemical composition in laundry greywater. Proteins are the enzymes so that they are totally biodegradable, it cannot be toxic for animals and plants in the atmosphere. Though enzymes are the source of allergy if enzymes are breathed in large concentration for the large period (Sara et al., 2014).

Nitrogen and Phosphorous

Two main elements, phosphorous and nitrogen, are important for the biodegradation. Nitrogen is important constituent of enzymes and biomass (that are accountable for biodegradation). Phosphorous is used in laundry detergents as a builder and deflocculating agent. The amount of phosphorous in laundry wastewater varies depending on types of detergents used. Phosphorus is present in wastewater almost solely as orthophosphate, condensed phosphate such as pyro^{-}, meta^{-} and other polyphosphate and organic bound phosphate. In respect of elimination of organic constituents, the ideal ratio of COD:N:P places in between 100:10:1 and 100:20:1. Although additional amount of phosphorous and nitrogen reduced in the treatment plant of wastewater.

Greywater Associated Risks and Hazards

In the past greywater without treatment caused aesthetic and hygienic problems. Untreated greywater banned because of associated health risks with add up of number of indicator organisms, not only for domestic used, but also because presence of malodors and formation of slime (biofilm) in storage and greywater pipes. In greywater bad odors and formation of biofilm caused the organic compounds degradation processes. These processes of degradation deplete the oxygen in the waste water, producing anaerobic condition and malodor as a result.

Greywater characteristics in the contrast of two different households, (Albalawneh & Abeer et al., 2015) noticed the presence of faecal streptococci coliform, faecal coliforms, pseudomonas aeruginosa and originate that general chemical, physical microbial quality of unprocessed wastewater between secondary effluent and fresh wastewater. In both cases the levels of total coliforms have the same, the household which have child occupants more that have higher level of fecal coliforms. (Eriksson et al., 2002) revised reviews on the existence of pathogens from greywater which are shigella dysenteries, salmonella typhosa, bacteria, pathogenic enteric, polioviruses, legionella pneumophila, adenoviruses and echoviruses.

Eriksson et al. (2002) revised studies the existence of pathogens in the greywater which are Shigella dysenteries Salmonella typhosa, pathogenic enteric bacteria, Legionella pneumophila, echoviruses, adenoviruses poliovirus. Commonly, value of organisms which are fecal coliforms that are used to show the intensity of bacteriological pollution and consequently it concludes the possible for viral infection. Though, believed that hazards can be over-estimated due to the thermo-tolerant (faecal) coliforms can be live on organic degradable material and produce in the arrangement. So, they projected a “microbial quantitative risk assessment” depend on faecal enterococci.

In many cases, storage of greywater is essential for the reuse of greywater, nevertheless storage for long time of unprocessed greywater leads to violent odors due to the anaerobic organic degradation of pollutants and the development of sulphate (Albalawneh & Abeer 2015). Nevertheless, it have been revealed that greywater storage for the period of 24 hours (but not above the 48 hours) progresses its quality because of reduction in COD and settling down of suspended matter and minimization in COD, but level of total coliforms was enlarged representing an environment that maintained growth of microbial during time of storage. Using computer related simulation model, (Dixon et al. 2000) presented that ideal greywater storage capacity for a home of four inhabitants was 250 L, and approximately 1000 liter for a multioccupancy house and it was strongly does not depend upon on the level of occupancy.

Greywater Treatment Systems

The different treatment methods which have been useful in the treatment of greywater can be summarized as physical separation processes techniques, biological treatments and advance or chemical processes. In different illustrations, for improving the efficiency in the removal of contaminants sequences of processes which have been proposed or to minimize the size apparatus a used of coagulants. In the review of treatment of greywater (Pidou et al., 2007) reviewed the direction in shift from coarse filtration or membrane filtration together with disinfection in 1970s to biological processes of greywater in 1980s and 1990s, tracked reed beds and inexpensive replacements such as ponds and membrane bioreactors in end of 1990s. They also pointed that for the treatments of greywater only three kinds of chemical have been useful in the literature, and these are photocatalysis, chemical coagulation and electro-coagulation. In greywater treatment the purpose of AOPs is certainly limited and emphasis looks as a photocatalysis (Oteng & Michael et al., 2018). Consequently, samples from wastewater and drinking water treatments have been comprised in this unit. Following review emphases for the removal of contaminants as find out parameters such as COD, BOD and total or dissolved organic carbon.

Physical Separation Techniques for Greywater treatment

Physical separation processes comprise sand filtration, membrane filtration and sedimentation/coagulation. These processes basically transfer impurities from one mode to another, and these commonly produce the requirement to dispose of the concentrated or separated impurities (Oteng & Michael et al., 2018). Prathapar et al. designed “Wudhu Water Works” for ablution water treatment, which is formed from the mosques. These systems were fundamentally activated carbon/sand filtration attached with a disinfection component by using chlorine medicines. Low-cost and simple unit was capable for the treatment of ablution water collected from the mosques to the compulsory standards in Oman at that moment initial COD level was less (COD = 51 mg /L), while as greywater comprises an advanced level of pollutants, working of sand filtration system is less (Bratby et al., 2006). There are two physical separation techniques, which are membrane filtration technology and sand filter techniques.

Membrane Filtration Technique

Membrane filtration is a method used to separate the particles which is present in the wastewater. The partial-permeable membrane performs as a barrier which retain heavier particles, which permits the smaller particles pass through the membrane. (Bratby et al., 2006). commented that nanofiltration, reverse osmosis and ultrafiltration are energy exhaustive; few energy demanding are microfiltration processes do not eliminate BOD, therefore permeate has the capability for regrowth of microbial in the system of distribution and the discharge of offensive odor. These conclusions were also grasped by Ramon et al. (2004) for the treatment of low strength greywater (COD = 170 mg /L) with the direct membrane filtration.

Sand filters Technique

Sand filters have been revised and used for the treatment of greywater, they have low cost and easy in operation and maintenance and effectively eliminate the total suspended solids. Sand filters can also remove the COD effectively. However, removal efficiency differs and depend on different parameters size of particle, hydraulic rate of loading and sand layer height. Chaillou et al revised that increasing the removal of COD because of formation of biofilm on the sand filter. In water shortages regions, sand filters are being used for the treatment of greywater by attaining economic efficiency. Treatment of greywater using sand filters are required more consideration, because there is deficiency of research on clogging of time and potential for the biofilm formation. There are two types of sand filters which are slow sand filters and bio-sand filters.

Biological Treatment of Greywater

Biological treatments of greywater are basically reliable and cheap and some of recommended biological treatment methods for the treatment of greywater contain plant covered vertical or horizontal soil flow filters, fluidized bed reactors, rotating biological contractors (RBCs) and trickling filters (Bratby et al., 2006). In review of different types of biologically based treatments, Pidou et al. (2007) establish that hydraulic retention time lies between 0.79 hours to 2.8 days, liable on the greywater strength he hired a recycled vertical flow for the treatment of greywater constructed wetland (COD = 840 mg/L). Almost 80% lessening in COD was found after 8 hours greywater treatment and the water which is treated was assumed by researchers to be appropriate for irrigation of garden and landscape, though consequent disinfection of greywater effluent was recommended.

Biological treating system of greywater which formed from dish-washing and hand-washing basin in a student hostel (BOD_7 = 47 mg /L) was examined by Günther (2000). Based on the concept of a "wetpark", pathogenic bacteria, nutrients and BOD were removed when the raw greywater flowed through three succeeding ponds. The "wetpark" was claimed to removal of BOD is 98%, bacteria and nutrient efficiently with extra paybacks which are low costs (compared with a conventional wastewater treatment system), it is providing addictation for animals, enhance local bio-diversity, and having leisure, psychological and aesthetic values. However, it also been recognized that the system is essential a lengthy turnover time and a massive area for construction (chin et al., 2009).

Sequencing Batch Reactor (SBR) Treatment systems

Jefferson et al. (2000) revised a sequencing batch reactor (SBR) for the treatment of greywater (COD = 79 mg/L). Through operating step-feed mode and cyclic, important development was constructed for denitrification and nitrification when associated with normal operation. A consequent microfiltration component was suggested to diminish the hazard of pathogens and suspended solids being approved over in the treated waste. The treated waste had a COD of 20 mg/L. Researchers such as Jefferson et al. (2000) have suggest that the combination of membrane filtration technology with biological treatment. Such integration comprises of biologically aerated filters (BAF) and membrane bioreactors (MBR). The former services fixed film biological reactors depth of filtration although the latter combines side-stream microfiltration membrane or submerged with an activated sludge reactor. Between these, hydraulically operated submerged-type Membrane bio rectors have been verified to create the constantly of high value permeate (COD fall from 120 ± 74.4 mg /L to 9.6 ± 7.4 mg /L), while huge cost of capital was recognized (Jefferson et al., 2000). Rafat et al. (2012) Related a sand filter, a combination of sand filter and RBC, and ultrafiltration module with MBR to treat less potency of greywater (COD = 211 mg /L).

Trickling Filter Technology

Present-days trickling filters can made up to 40 feet Hight and consist high performance structured-sheet plastic media, in order with ventilation systems and modern supply. These filters treatment capacity has been radically improved in evaluation with filters of earlier mid-century. The function of trickling filter has been prolonged elsewhere before biochemical oxygen demand (BOD) roughing filters comprise of secondary oxidation of carbon and tertiary filters nitrification. Trickling filter is reliable and simple. With less moving parts as compared to the activated sludge systems or other treatment system, trickling filter need significantly less operational oversight and maintenance. Trickling filter have good resistance to shock loading because of nature of attached growth. Trickling filter need less energy than other treatment option because it is green technology (Zhu & Rothermel et al., 2014). Typically, need only power for pumping, energy required for trickling filter is less as compared to the power aeration hungry blowers which is used in activated sludge treatment system and, in some cases fans. When installed and properly operated, trickling filters are described to use 30-50 % less energy as compared to the others treatment options.

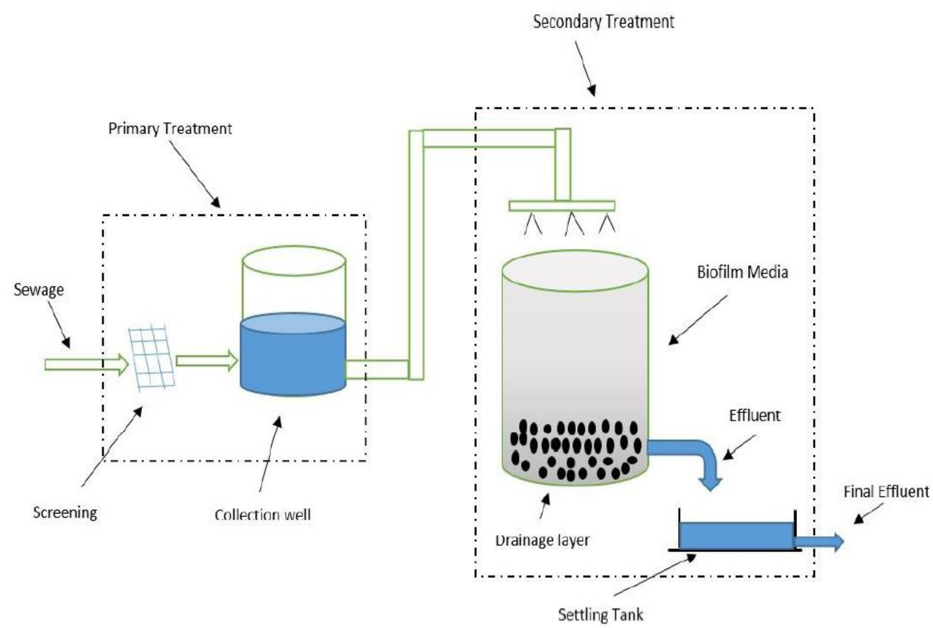

Figure 2.1 *Trickling filter technology (Imran Ali et al., 2016)*

Fluidized Bed Reactors (FBR) Treatment System

Different types of chemical reactions can be carried out by using FBR. In this reactor a catalyst is used to speed up the reaction such that the solid remains suspended and particle behavior is changed to fluid. Due to some beneficial properties of this reactor like temperature maintenance, homogenous mixing and to operate continuously helps it to contribute to Industry at a large scale. A Distributor is used in order to provide a support to the Solid Substrate which is made up of a porous plate. In this reactor the liquid substance is passed through the catalytic substance while the solid substance is screened out by keeping the velocity low. Such reactor is called packed reactor. When the fluid velocity is increased then the solid substrate is balanced (Sahoo et al.,2012). When the velocity is increased beyond limit the particles inside the reactor begins to rotate as the centrifugal action applied on it, now this is the stage when the reactor derives its name as an FBR. Moreover, this reactor can be used in order to study various properties of fluid.

Rotating Biological Contactor Treatment System

A rotating biological contactor (RBCs) are used for the treatment of wastewater as a primary treatment. Sand and grit removal and coarse material in the primary treatment processes can be take place. Rotating biological contactor contains stacks of rotating disks which is mounted on horizontal shaft. The rotating disks are partially submerged and waste water is rotated through these disks. The rotating biological contactors permitting the effluent to come in connection with biological medium for the removal of contaminants which is present in the wastewater before disposal of greywater in the environment usually receiving body (lake, river or ocean).

Chemical Processes for Greywater

Chemical processes for the treatment of greywater contain dissolved air flotation, chemical oxidation, advance oxidation processes, electro-coagulation and chemical coagulation.

Chemical Oxidation

Chemical oxidation method uses chemical oxidants which are hydrogen peroxide (H_2O_2), ozone (O_3), chlorine and potassium permanganate to oxidize the pollutants which are present in wastewater (Rafat et al., 2012). Chemical oxidation using chlorine as an oxidant followed by membrane filtration. Using strong chemical oxidant (e.g hypochlorite) is shown to cause high membrane fouling and adversely affect the performance of treatment. Chemical oxidation converts the large organics molecules into the small organic molecules, which increase the membrane fouling and increase the passage more and small readily organics of degradable concluded the membrane (Jefferson et al .,2000)

Coagulation

Coagulation is one of the most significant physio-chemical processes which is used in the treatment of wastewater. Colloids (organic and inorganic) and ions (heavy metals) are typically detained in solution by charge of electric (Bratby et al., 2006). The adding of ions in the solution with different charges destabilized the colloids, permitting them to coagulate. Coagulation can be attained by electrical charge method and chemical coagulants. Aluminum sulphate or alum ($Al_2(SO_4)_3.18H_2O$) and ferric chloride are the chemical substances which are normally used for the treatment of wastewater. There are two types of coagulation which are chemical coagulation and electro-coagulation.

Electro-Coagulation

Electro-coagulation is a treatment processes in which electrical current are applying to treat and flocculate without having additional coagulation. Shammas et., al revised that coagulation take place with the applied current, capable of eliminating small particles since applying direct current. Electro-coagulation also diminish residue for production of waste. Electro-coagulation comprises of pairs of metals sheets which is called electrodes, that are placed in pairs of two cathodes and anodes. According to the principles of electrochemistry, at cathode oxidation (losses electron) take place, while reduction (gains of electron) take place on the water, thus production of wastewater improved treated (Ahmad & Hesham et al., 2016). When electrode and cathode make interaction with the wastewater, metal is released in the apparatus. When that occurs, particulates are deactivated by the development complexes of hydroxide for objective of establishing agglomerates. That agglomerates can settle in the bottom of the jar/tank and can be separate from filtration. Though, when one thinks an electrocoagulation apparatus particulate instead float on the tank by means produced hydrogen bubbles which are formed from the anode.

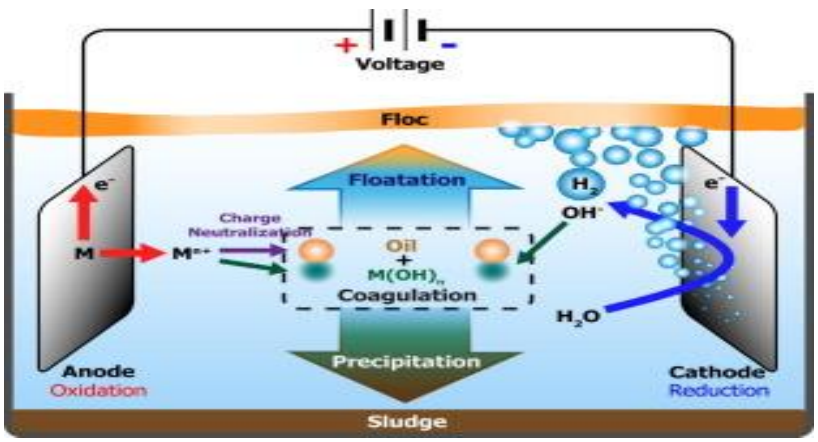

Figure 2.2 *Electro-coagulation (Tian and Weihua He 2016)*

Chemical Coagulation

The process of chemical coagulation which involves flocculation phenomena is used to boost the abolition finely separated solids by establishing more voluntarily settleable flocs, before filtration or sedimentation. In wastewater treatment, coagulation is the method through which colloidal, dissolved and suspended matter are undermined by the accumulation of a chemical coagulant. Conventional coagulants like ferric sulfate, ferric chloride and alum hydrolyze quickly when spread in water forming unsolvable precipitates and condensing the electrical double coating of the suspended particles. The particles adsorb the precipitants in the water nullifying the charge on it, and later allow for interparticle connecting. The composition of NOM and its concentration greatly disturb the interaction of the coagulation phenomena. The process of flocculation through which the damaged particles pelletize and form particles of flocculant, or “floc.” Velocity slope and particles enduring random charring motion affect particles to collide and connect to another particles, increasing the removal efficiency of dissolved material turbidity (Bratby et al., 2006).

The advantages of electrocoagulation upon traditional coagulation relative to retention time, removal efficiency of particles, dosage of coagulant, production of sludge, cost, and ease in action and maintenance. The projected unit for the treatment of domestic greywater comprised of a collection tank, an electrocoagulation reactor, a commencement unit and a sterilization/storage tank. Aluminum salts was used so the sacrificial anode in place of iron salts in the electrolysis cell to avoid the pigmentation of the treated wastewater from the ferrous ion's oxidation. Hydrogen gas progressed at the side of cathode was used in the consequent flotation unit to distinct scum which could be scanned from the surface of water, and the treated water was then disinfected with NaOCl and stored (Yonge & David et al., 2012).

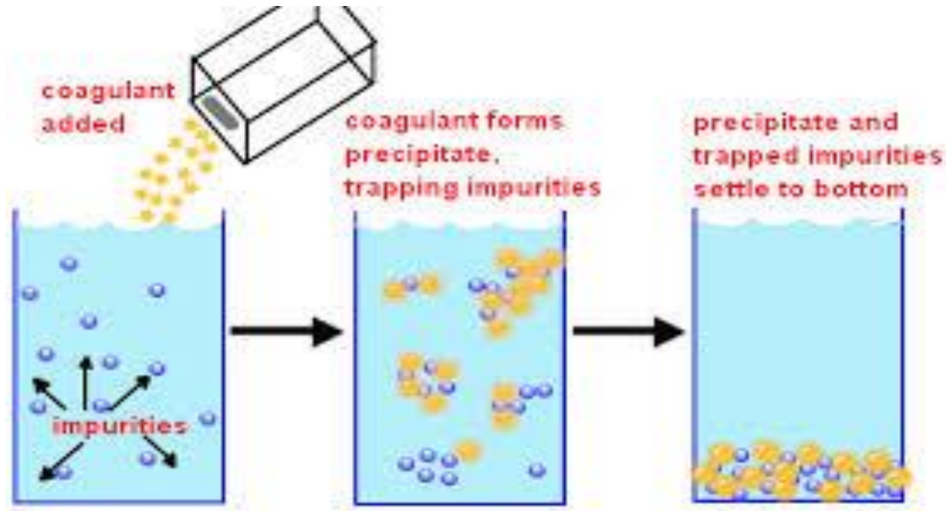

Figure 2.3 *Chemical coagulation (Yonge & David et al., 2012)*

Electrical Double Layer Theory

The electrical double layer theory describes the interaction between surfaces of colloidal particles and ions that are present in the fluid in which the colloidal particles are dispersed. The double layer model is used to visualize the ionic environment in the vicinity of a charged surface. It is easier to understand this model as a sequence of steps that would take place near the surface if its neutralizing ions were suddenly stripped away. The potentials which describes the double layer are zeta potential, stern potential and Nernst potential.

1.10.1 Zeta Potential

Zeta potential is the potential difference between the dispersion medium and the stationary layer of fluid attached to the dispersed particle. The zeta potential is caused by the net electrical charge contained within the region bounded by the slipping plane, and also depends on the location of that plane. Thus, it is widely used for quantification of the magnitude of the charge. However, zeta potential is not equal to the stern potential in the double layer. The zeta potential is a key indicator of the stability of colloidal dispersions. The magnitude of the zeta potential indicates the degree of electrostatic repulsion between adjacent, similarly charged particles in a dispersion. A colloidal suspension is stable if the particles remain in suspension and do not coagulate. The colloidal stability depends on the relative magnitude of the forces of attraction and the forces of repulsion. The magnitude of these forces is measured by the zeta potential, which is:

$$Z = \frac{4\mathrm{qd}}{\mathrm{D}}$$

Where, Z is the zeta potential,

q is the charge per unit area,

d is the thickness of the effective charge layer, and

D is the dielectric constant of the liquid.

Nernst Potential

Nernst equation is an equation that relates the reduction potential of an electrochemical reaction (half-cell or full-cell reaction) to the standard electrode potential, temperature and activities (often approximately by concentrations) of the chemical species and undergoing reduction and oxidation. The Nernst equation has a physiological application when used to calculate the potential of an ion of charge *z* across a membrane. This potential is determined using the concentration of the ion both inside and outside the cell:

$$E = \frac{\mathrm{RT}}{\mathrm{ZF}} ln \frac{(\text{Ion out side cell})}{(\text{Ion out side cell})}$$

Where, E_m is the membrane potential (in volts, equivalent to joules per coulomb),

P_{ion} is the permeability for that ion (in meters per second),
$[ion]_{out}$ is the extracellular concentration of that ion (in moles per cubic meter, to match the other SI units,
$[ion]_{in}$ is the intracellular concentration of that ion (in moles per cubic meter),
R is the ideal gas constant (joules per kelvin per mole),
T is the temperature in kelvins,
F is Faraday's constant (coulombs per mole).

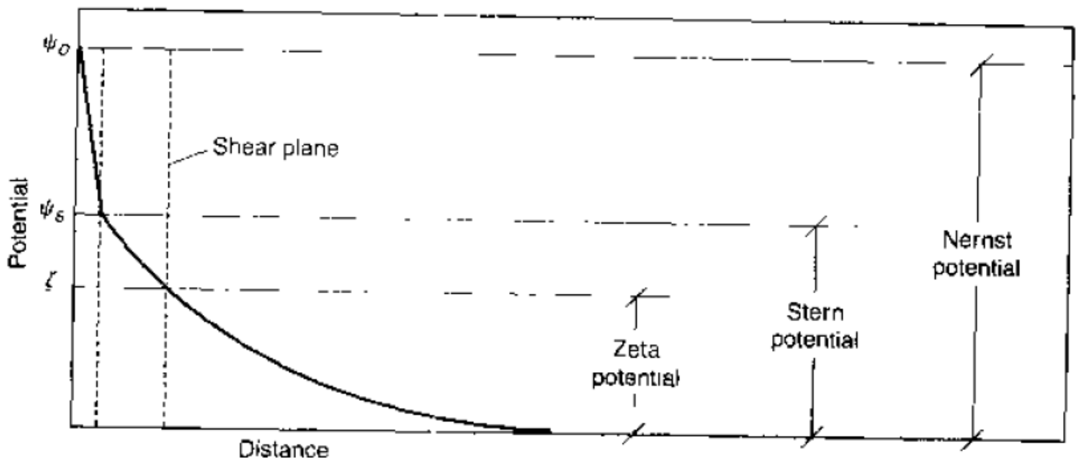

Figure 2.4 : *Stern Model of Electrical Double Layer (Shaw et al., 1966)*

Advantages of Chemical Treatment Processes Over Biological Treatment Processes

There are few advantages of Chemical Treatment Processes Over Biological Treatment Processes. In chemical treatment case results can be seen rapidly and can be adjusted reagent concentration to lessen the cost of reagent. Chemical treatment plants take fewer space as compared to the biological treatment plants. In chemical treatment automatic regulator simply applied as compared to the biological treatment and they implemented rapidly with variation in quantity. Abrupt distinction of temperature or dissolved solids amount may not affect the dosing stage of chemicals but are prospective influence working of settling tank in biological treatment (Ahmad & Hesham et al. 2016)

Chemical Coagulants

Abundant materials have been used as flocculants and coagulants aids including ferric chloride ($FeCl_3$ $.6H_2O$), alum ($Al_2(SO_4)_3.18H_2O$), ferrous sulphate ($FeSO_4$ $.7H_2O$), ferric sulphate ($Fe_2(SO_4)_3$), and lime ($Ca\ (OH)_2$). (Yonge & David et al., 2012). Many types of associated with the chemical precipitation that are increased in volume of sludge, and the resulting sludge might have poor dewatering and settling characteristics. In addition, salts of metal used as coagulant agent use alkalinity and can reduce the pH of the sewage water. the following characteristics should be occupied attention in selecting the most suitable coagulant/flocculants aids:

1) Effectiveness in eliminating the phosphorous.
2) Environmental effects.
3) Cost and consistency of supply.
4) Equipment and labor requirement for feeding, handling and storage.
5) Compatibility with other downstream or upstream processes.

Ferric Chloride

The main hydrolyzing ionic coagulants aids used in wastewater and water treatment comprise of iron and aluminum salts (Edzwald, 2011). Aluminum sulfate, ferric sulfate and ferric chloride are commercially available both solids and liquid forms. Normally ferric chloride dosages range 6 to 150 mg/L contingent on the quality of raw water. Preceding researchers have found range of optimum pH for salts of iron coagulants in between 5 and 8.5 which is slightly heavier than that salts of aluminum (Yonge & David et al., 2012).

The range of optimum pH and concentration of coagulants eventually differs on the characteristics of raw water and varies from every water source. Moreover, use coagulants of iron-based preceding to membrane filtration is coming onto the question as more of these combined processes are employed (Yonge & David et al., 2012). The chemistry accompanying with the reactions of iron and aluminum salts in water is composite and can procedure different species have influenced by pH and temperature. The alkalinity demand of ferric chloride can be determined using the stoichiometric reactions in the equation 2-2.

$$Fe^{3+} + 3H_2O \rightarrow Fe\,(OH)_3 + 3H^+ \qquad (2\text{-}1)$$

$$FeCl_3\,.\,6H_2O + 3(HCO_3^-) \rightarrow Fe\,(OH)_3 + 3Cl^- + 6H_2O + 3CO_2 \qquad (2\text{-}2)$$

Aluminum sulfate

"Alum" or Aluminum sulfate is the most normal water and wastewater treatment in the United states. When Aluminum sulphate is added to the water the reaction of hydrolysis take place, it can produce number of different dissolved aluminum hydroxide precipitates and monomeric aluminum species. The alkalinity demand of aluminum sulfate can be determined using the stoichiometric reactions in the equation 2-4 (Yonge & David et al., 2012).

$$Al^{3+} + 3H_2O \rightarrow Al\,(OH)_3 + 3H^+ \qquad (2\text{-}3)$$

$$Al_2\,(SO_4)_3 + 14H_2O + 6(HCO_3^-) \rightarrow Al\,(OH)_3 + 3SO_4^{2-} + 6CO_2 + 14H_2O \qquad (2\text{-}4)$$

Ferric sulphate

Coagulants of irons work correspondingly to the aluminum coagulants but cost of coagulants types may differ on the local supply of source. Ferric sulphate is most generally used coagulant, but furious sulphate is naturally used in applications where excess soluble ions or reducing agent required.

$$Fe^{3+} + 3H_2O \rightarrow Fe\,(OH)_3 + 3H^+ \qquad (2\text{-}5)$$

$$Fe_2(SO4)_3 + 3Ca\,(HCO_3)_2 \rightarrow 2Fe\,(OH)_3 + 6CO_2 + CaSO_4 \qquad (2\text{-}6)$$

Aluminum Chloride

Generally aluminum chloride works equally as aluminum sulphate. But aluminum chloride is more expensive, dangerous and more corrosive. Because it is normally a reserved second choice to alum. Aluminum chloride is commonly available in the form of liquid.

$$Al^{3+} + 3H_2O \rightarrow Al\,(OH)_3 + 3H^+ \qquad (2\text{-}7)$$

Table 2.2 *Coagulants which are used for the treatment of wastewater*

Coagulant	Chemical formula	Parameters	Efficiency (%)	Dose (mg/l)	Reference
Poly-aluminum chloride	$Al_2Cl(OH)_5$	Turbidity COD TSS	98.24 94 75	30	Seyed Morteza Moosavirad et al.,(2016)
Alum	$(Al_2(SO_4)_3.18H_2O)$	Turbidity COD TSS	98.70 95 90	10	Mbaeze MC et al.,2017
Ferrous sulphate	$(FeSO_4 .7H_2O)$	Turbidity COD TSS	95 94 89	10	Mbaeze MC et al.,2017
Ferric chloride	$(FeCl_3 .6H_2O)$	Turbidity COD TSS	80 70 94	30	Amuda and Alade (2016)
Aluminium poly-chloride	$Al_2Cl(OH)_5$	COD	82	20	Martin et al (2011)
Lime	$(Ca (OH)_2)$	Turbidity Color	80 82	20	Tatsi et al.,2003
Sodium diethyldithiocarbamate (DDTC)	$(C_2H_5)_2NCS_2Na$	Copper	79		Li et al., 2003

LITERATURE REVIEW SUMMARY

Greywater, wastewater that exclude input from toilets and water from industrial processes, differs suggestively in its quality and quantity because of activities which is involved in greywater production. Three key categories have been recognized: laundry greywater, bathroom greywater and kitchen greywater. Mainly, the reuse of greywater which is originated from kitchen is inappropriate because of high level of pollutants and comparatively less volume produced. Few projected applications for reuse of greywater comprise of garden irrigation and flushing of toilets and can be related such as risk to public health, blockage of distribution structures, formation of offensive odor, and soil pollution, groundwater and surface water have been raised up. Technologies for reuse of greywater basic screening devices or simple diversion system to complex arrangements such as physical separation techniques, biological treatments and advance oxidation and chemical processes. Biological techniques are commonly reliable and cheap but that prosses required long time for treatment, generate sludges. Physical separation processes move contaminates from one medium to another medium. Based on the results obtained through the examination of the qualitative and quantitative features of greywaters, it is evident that from among the treatment methods, mechanical treatments alone are not able to achieve the required purity, in this way these methods are recommended to be supplemented by chemical treatment of greywater.

REFERENCES:

Li, Fangyue, Knut Wichmann, and Ralf Otterpohl. "Review of the technological approaches for grey water treatment and reuses." Science of the total environment 407.11 (2009): 3439-3449.

Albalawneh, Abeer, and Tsun-Kuo Chang. "Review of the greywater and proposed greywater recycling scheme for agricultural irrigation reuses." International Journal of Research–Granthaalayah 3.12 (2015): 16-35.

Chin, W. "Greywater treatment by Fenton, Photo-Fenton and UVC/H2O2 processes." (2009).

Moslemi Zadeh, Sara "Sustainability evaluation of shared greywater recycling in urban mixed-use regeneration areas" Diss. University of Birmingham, 2013.

NG, MAYLE. "Household greywater reuse for garden irrigation in perth." Environmental Engineering Project 640

Sanly, Lim M., K. Chiang and Amal R. "Advanced oxidation processes for the removal of humic substances', in 1st Young Water Professionals Conference, UNSW Sydney, (2006).

Rivero, M. J., et al. "Membrane chemical reactor (MCR) combining photocatalysis and microfiltration for grey water treatment." Water Science and Technology 53.3 (2006): 173-180.

Masschelein W., 'Chapter 4: Use of Ultraviolet in Photochemical Synergistic Oxidation Processes in Water Sanitation', in Rice G. (ed.), Ultraviolet Light in Water and Wastewater Sanitation, CRC Press, Boca Raton (2002).

Yonge, David. "A comparison of aluminum and iron-based coagulants for treatment of surface water in Sarasota County, Florida." (2012).

Oteng-Peprah, Michael, Mike Agbesi Acheampong, and Nanne K. deVries. "Greywater characteristics, treatment systems, reuse strategies and user perception—a review." Water, Air, & Soil Pollution 229.8 (2018): 255.

Matos, Cristina, Ana Sampaio, and Isabel Bentes. "Greywater use in irrigation: characteristics, advantages and concerns." Irrigation-Water Management, Pollution and Alternative Strategies. IntechOpen, (2012).

Centre for Epidemiology and Research. Report on Adult Health from the New South Wales Population Health Survey. Sydney: NSW Department of Health, (2007).

Sara Adman "A sustainable Laundry Solution-with focus on water optimization in cohabamba, Boliva" Department of Civil and Environmental Engineering Division of Water Environment Technology Chalmers University of Technology (2014) page no 1-61.

Li, Fangyue, Knut Wichmann, and Ralf Otterpohl. "Review of the technological approaches for grey water treatment and reuses." Science of the total environment 407.11 (2009): 3439-3449.

Ghaitidak, Dilip M., and Kunwar D. Yadav. "Characteristics and treatment of greywater a review." Environmental Science and Pollution Research 20.5 (2013): 2795-2809.

Butler, E., Hung, Y. T., Yeh, R. Y. L., & Suleiman Al Ahmad, M. (2011). "Electrocoagulation in wastewater treatment & Water" 3(2), 495-525.

Prof. (Dr.) Abanti sahoo. “Fluidized Bed Reactor: Design and application for Abatement of fluoride”. (2012) Page no 1-38.

Zhu, Jia, and Bryan Rothermel. "Everything you need to know about trickling filters." Clear Waters Summer (2014): 16-19.

Spychała and Marcin "Removal of Volatile Solids from Greywater Using Sand Filters." Applied Sciences 9.4 (2019): 770.

Rafat Khalaphallah "Greywater treatment for reuse by slow sand filtration: study of pathogenic micro-organisms and phage survival" chemical and processing engineering (2012).

Abdel-Shafy, H. I., M. A. El-Khateeb, and M. Shehata. "Greywater treatment using different designs of sand filters." Desalination and Water Treatment 52.28-30 (2014): 5237-5242.

Pidou, M., Memon, F. A., Stephenson, T., Jefferson, B., & Jeffrey, P. "Greywater recycling: a review of treatment options and applications" Desalination and Water Treatment (2007).

Wu, Bing. "Membrane-based technology in greywater reclamation: A review." Science of the total environment 656 (2019): 184-200.

Li and Fangyue. "Treatment of household grey water with a UF membrane filtration system." Desalination and Water Treatment 5.1-3 (2009): 275-282.

Jefferson and B. "Technologies for domestic wastewater recycling." Urban water 1.4 (2000): 285-292.

C.Santos, F.Taveira-Pinto and C.Y.Cheng "Development of an experimental system for Greywater reuse" Desalination and water treatment 285 (2012) 301-305.

Vijaya V. Shegokar, Dilip S. Ramteke and Pravin U. Meshram "Design and Treatability Studies of Low-Cost Grey Water Treatment with Respect to Recycle and Reuse in Rural Areas" International Journal Current Microbiology Applied Sciences (2015) 4(8): 113-124

Jefferson and B. "Grey water characterisation and its impact on the selection and operation of technologies for urban reuse." Water science and technology 50.2 (2004): 157-164.

Bratby J. "Coagulation and Flocculation in Water and Wastewater Treatment" IWA Publishing. (2006)

Eriksson and Eva. "Characteristics of grey wastewater." *Urban water* 4.1 (2002): 85-104.

Sachin Madhavrao Kanawade. "Grey water treatment by using membrane filtration" International Journal of Multidisplinary Research and Development (2015), 2(3): 875-880.

Lamine, Mona, L. Bousselmi, and A. Ghrabi. "Biological treatment of grey water using sequencing batch reactor." Desalination 215.1-3 (2007): 127-132.

Jamrah and A. "Biological treatment of greywater using sequencing batch reactor technology." International Journal of Environmental Studies 65.1 (2008): 71-85.

Parsons, S. A., C. Bedel, and B. Jefferson. "Chemical vs. biological treatment of grey water." Chemical water and wastewater treatment VI. Springer, Berlin, Heidelberg, (2000) 383-392.

Almeida, J. S. M., N. R. A. F. Rocha, and MR Franco Junior. "Treating domestic greywater and expectations to be reused." American Journal of Environmental Engineering 3.5 (2013).

Nghiem, Long D., Nadine Oschmann, and Andrea I. Schäfer. "Fouling in greywater recycling by direct ultrafiltration." Desalination 187.1-3 (2006): 283-290.

Vuppaladadiyam and Arun K. "A review on greywater reuse: quality, risks, barriers and global scenarios." Reviews in Environmental Science and Bio/Technology 18.1 (2019): 77-99.

Pinto, Uthpala, Basant L. Maheshwari, and H. S. Grewal. "Effects of greywater irrigation on plant growth, water use and soil properties." Resources, Conservation and Recycling 54.7 (2010): 429-435.

Thomas-White and Krystal. "The bladder is not sterile: history and current discoveries on the urinary microbiome." Current bladder dysfunction reports 11.1 (2016): 18-24.

Ramona and Guy "Low strength graywater characterization and treatment by direct membrane filtration." Desalination 170.3 (2004): 241-250.

Ramprasad, C., and Ligy Philip. "Surfactants and personal care products removal in pilot scale horizontal and vertical flow constructed wetlands while treating greywater." Chemical Engineering Journal 284 (2016): 458-468.

Pangarkar BL, Parjane SB, Sane M "Design and economical performance of gray water treatment plant in rural region" World Acad Sci Eng Technol (2010) 4:782–786.

Ahmad and Hesham. "Comparison of coagulation, electrocoagulation and biological techniques for the municipal wastewater treatment." International Journal of Applied Engineering Research 11.22 (2016): 11014-11024.

Hutcherson and John Ryan. "A comparison of electrocoagulation and chemical coagulation treatment effectiveness on frac flowback and produced water." Diss. Colorado State University, (2015).

Surendran, S., and A. D. Wheatley. "Grey-water reclamation for non-potable re-use." Water and Environment Journal 12.6 (1998): 406-413.

Mbaeze, Malachy Chima, V. E. Agbazue, and N. M. Orjioke. "Comparative assessment of performance of aluminium sulphate (alum) and ferrous sulphate as coagulants in water treatment." Mod Chem. Appl 5 (2017): 1-14.

Amuda, O. Sarafadeen, et al. "1 Toxicity, Sources, and Control of Copper (Cu), Zinc (Zn), Molybdenum (Mo), Silver (Ag), and Rare Earth Elements in the Environment." Remediation of Heavy Metals in the Environment (2016).

Martin, Marcel. "Cutadapt removes adapter sequences from high-throughput sequencing reads." EMBnet. journal 17.1 (2011): 10-12.

Tatsi and A.A. "Coagulation–flocculation pretreatment of sanitary landfill leachates." Chemosphere 53.7 (2003): 737-744.