Design of Grey Water Treatment Units

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Abstract*: One way to conserve water is to find a safe way to use it more than once. Grey water recycling is now accepted as sustainable solution to the general increase of the fresh water demand. Grey water refers to water that has already been used in some way but which can be reused or recycled in order to conserve fresh water. It is considered relatively simple to treat grey water to make it safe for public use because of lower levels of contaminants.*

In this paper we have taken into consideration the possibilities of treating the grey water from our college canteen and ladies hostel of the college. The process of implementation included collection of waste water, excluding black water, from college canteen and ladies hostel of the college. Various treatment units like storage tank, screen chamber, skimming tank, sedimentation tank, trickling filter, secondary clarifier and chlorination tank were designed.

This study highlights the conservation of fresh water in the campus, taking into consideration the increase in demand for fresh water. A partial break down of wastage of fresh water is expected to be accomplished through this paper

Key words: Grey water, fresh water and black water

1. INTRODUCTION

Water pollution in many developing regions causes serious problems. The increase in population and the improvement of people's daily life in these areas result not only in an increase in volume of waste water, but also in a change of waste water composition. Water conservation and reuse are becoming increasingly important as we now face serious problem including reduced ground water and surface water levels, droughts and changing climatic pattern. Over 50% of the water demand from domestic and industrial applications could be met by water of lower quality than fully treated water including applications such as process water, toilet flushing etc. Substituting the quality water for non potable purposes to preserve high quality water resources is highly efficient and practical, especially in arid region and developing countries. In most of cities since the housing area is concentrated in a region such as flats, apartments or residential colonies, it is easy to collect the domestic waste water and to treat this for re-use. Meeting different needs with appropriate water quality may prove to be economically more beneficial and at the same time reduce the needs for new supplies at a high margin (Halalsheh, 2008). As per new building rules also, it is strict that each apartment should have a waste water treatment so that the water expelled to municipal waste after treatment system can be reduced. So it will be reliable as well as sustainable technique to treat the domestic wastewater and to reuse it for non potable purposes. In this chapter sources, characteristics and various treatment methods of grey water are discussed.

1.1 GREY WATER COMPOSITION

Grey water is the waste water generated in the bath room, laundry and kitchen. Grey water is therefore the component of domestic waste water, which has not originated from the toilet or urinal.

- Grey water from bathrooms

Water used in hand washing and bathing generates around 50-60% of total grey water and is considered to be the least contaminated type of grey water. Common chemical contaminants include soap, shampoo, hair dye, toothpaste and cleaning products. It also has some faecal contamination (and the associated bacteria and viruses) through body washing.

- Grey water from cloth washing

Water used in cloth washing generates around 25-35% of total grey water. Waste water from cloth washing varies in quality from wash water to rinse water to second rinse water. Grey water generated due to cloth washing can have faecal contamination with the associated pathogens and parasites such as bacteria.

- Grey water from kitchen

Kitchen grey water contributes about 10% of the total grey water in volume. It is contaminated with food particles, oils, fats and other wastes. It readily promotes and supports the growth of micro-organisms. Kitchen grey water also contains chemical pollutants such as detergents and cleaning agents which are alkaline in nature and contains various chemicals. Therefore kitchen waste water may not be well suited for reuse in all types of grey water systems. Grey water makes up to about 60-70% of domestic waste water volume. In terms of basic water quality parameters, it is considered to be comparable to low or medium grade waste water. As compared to domestic waste water, grey water tends to contain fewer solids and is less turbid than all domestic waste water. The concentration of organics is somewhat similar to domestic waste water. Their chemical nature is quite different. Soaps and detergents are often alkaline, so the pH of grey water is normally within the range of 6-8. Unlike waste waters that contain higher concentrations of N, P and K, only minor qualities of nutrients have been detected in grey water samples. Grey water composition varies widely from house hold, depending on personal habits of the residents and the products used in home.

2. CHARACTERISTICS OF GREY WATER

The characteristics of domestic grey water are influenced by several factors, primary influences are plumbing fixtures and appliances present as well as their frequency of use. Additionally the characteristics of residing family in terms of number of family members, age levels and mobility are important as in the overall socio economic status of the family. Grey water contain considerable amount of BOD, COD, turbidity, chlorides and suspended solids. Biological oxygen demand of grey water equals or may exceed that of black water. This is primarily because of food waste and grease from the kitchen waste. Due to kitchen sink lows, total suspended solids may equal to those found in toilet water and will far exceed toilet flows when garbage disposal is used. Grey water also contains a mixture of chemicals used in a variety of household products resulting in a complex chemical composition. The addition of household chemicals can also change the bulk chemical characteristics of the water such as pH, suspended solids, biological oxygen demand and conductivity. Grey water comprises about 60% of typical household waste water flow. The physical, chemical and microbial characteristics of grey water vary based upon the sources connected to the collection system, household composition as well as household chemical usage of the residents (Eriksson et al., 2002). According to different studies, grey water makes up on average more than half of the BOD load, up to two thirds of the total phosphorous load (where phosphate containing detergents are used) and one fourth of the total suspended solids load. This clearly reveals the importance of including grey water in sanitation programmes. Focusing only on black water will not meet the objective of providing adequate sanitation and reducing public health risks and environmental degradation.

2.1 Physical Characteristics of Grey Water

- Temperature

Grey water temperature is often higher than that of the water supply and varies within a range of 18-30ºC. These rather high temperatures are attributed to the use of warm water for personal hygiene and discharge of cooking water. These temperatures are not critical for biological treatment processes (aerobic and anaerobic digestion occurs within a range o 15-50ºC, with an optimal range of 25-35ºC). On the other hand, higher temperatures can cause increased bacterial growth and decreased $CaCO_3$ solubility, causing precipitation in storage tanks or piping systems.

- Suspended solids

Food, oil and soil particles from kitchen sinks, or hair and fibres from laundry can lead to higher solids content in grey water. These particles and colloids can cause turbidity in the water and may even result in physical clogging of pipes, pumps and filter used in treatment processes. Especially non-biodegradable fibres from clothing (polyester, nylon, and polyethylene), powdered detergents and soaps, as well as colloids are the main reasons of physical clogging. Suspended solids concentrations in grey water range from 50-300 mg/L, but can be as high as 1500mg/L. The highest concentrations of suspended solids are typically found in kitchen and laundry grey water. Suspended solids concentrations strongly depend on the amount of water used. Observations in Nepal, Malaysia, Israel, Vietnam and the united states revealed average suspended solids loads of 10-30 g/p/d, contributing to 25-30% of the total daily suspended solids loads in domestic waste water, including toilet waste water (Ledin et al., 2001).

2.2 Chemical Characteristics of Grey water

The chemical parameters of relevance are hydro chemical parameters such as pH, alkalinity, electrical conductivity, sodium adsorption ratio (SAR), biological and chemical oxygen demand (BOD, COD), nutrient content(nitrogen, phosphorus), and problematic substances such as heavy metals, disinfectants, bleach, surfactants or organic pollutants in detergents. Certain studies reported the presence of personal care products, medicines, hazardous organic pollutants etc in grey water (Erikson et al., 2002).

- pH and alkalinity

The pH indicates whether a liquid is acidic or basic. For easier treatment and to avoid negative impacts on soil and plants when reused, grey water should show a pH in the range of 6.5 - 8.4. The pH value of grey water, which strongly depends on the pH value of the water supply, usually lies within the optimal range. However, ChristovaBoal et al. (1996) observed 9.3-10 pH values in laundry grey water, partly as a result of sodium hydroxide based soaps and bleach used. Grey water with high pH values alone are not problematic when applied as irrigation water, but the combination of high pH and high alkalinity, a measure of water's ability to neutralize acidity, is of particular concern. Grey water alkalinity (indicated as $CaCO_3$ concentrations) is usually within a range of 20-340 mg/L (Ledin et al., 2001), with highest levels observed in laundry and kitchen greywater.

- Salinity and sodium adsorption ratio (SAR)

Grey water contains also salts, indicated as electrical conductivity (EC). EC measures salinity of all the ions dissolved in grey water, including negatively charged ions (e.g: Cl^-, NO_3^-) and positively charged ions (e.g:Ca^{2+}, Na^+). The most common salt is sodium chloride. Other important sources of salts are sodium-based soaps, nitrates and phosphates present in detergents and washing powders. The electrical conductivity of grey water is typically in the range of 300-1500 μS/cm, but can be as high as 2700 μS/cm (Burnat and Mahmoud, 2005). Salinity of grey water is normally not problematic, but can become a hazard when grey water is reused for irrigation. High EC of irrigation water can considerably reduce yield potential. This problem can be overcome by choosing more salt-tolerant plants.

The sodium hazard is indicated as sodium adsorption ratio (SAR), which quantifies the proportion of sodium (Na^+) to calcium (Ca^{2+}) and magnesium (Mg^{2+}). SAR values of grey water are within a typical range of 2-10, depending mainly on the laundry powder used by the household (Bino, 2004). Sodium salts are utilized as filler in laundry detergents. In laundry waste water, sodium concentrations can be as high as 530mg/L (Friedler, 2004). Sodium is of special concern when applied to loamy soils poor calcite or calcium/magnesium. High SAR may result in the degradation of well structured soils (dispersion of soil clay minerals), thus limiting aeration and water permeability. The sodium hazard can best be avoided by using low sodium products, such as liquid laundry detergents.

- Biological and chemical oxygen demand (BOD, COD)

The biological and chemical oxygen demand (BOD<COD) are parameters to measure the organic pollution in water. COD describes the amount of oxygen required to oxidize all organic matter found in grey water. BOD describes biological oxidation to bacteria within a certain time span (normally 5 days (BOD_5)). The main groups of organic substances found in waste water comprise proteins (mainly from food), carbohydrates (such as sugar or cellulose), fats and oils as well as different synthetic organic molecules surfactants that are not easily biodegradable. Discharging grey water with high BOD and Cod concentration into surface water results in oxygen deletion, which is then no longer available for aquatic life. The BOD loads observed in grey water in different countries amount to 20-50 g/p/d (Friedler, 2004).A BOD and COD concentration on grey water strongly depends on the amount of water and products used in household (especially detergents, soaps, oils and fats). Where water consumption is relatively low, BOD and COD concentrations are high. The COD/BOD ratio is a good indicator of grey water biodegradability. A COD/BOD ratio below 2-2.5 indicates easily degradable waste water. Grey water is generally considered easily biodegradable with BOD accounting for up to 90% of the ultimate oxygen demand (DelPorto and Steinfeld, 2000). Different studies indicate low grey water biodegradability with COD/BOD ratios of 2.9 - 3.6. This is attributed to the fact that biodegradability of grey water depends primarily on the type of synthetic surfactants used in detergents and on the amount of oil and fat present

- Nutrients (Nitrogen, Phosphorous)

Grey water normally contains low levels of nutrients compared to toilet waste water. Especially the high phosphorous contents sometimes observed in grey water can lead to problems such as algae growth in receiving water. Levels of nitrogen in grey water are relatively low (urine being the main nitrogen contributor to domestic wastewater). Kitchen wastewater is the main source of nitrogen in domestic grey water, the lowest nitrogen levels are generally observed in bathroom and laundry grey water. Nitrogen in grey water originates from ammonia and ammonia-containing cleansing products as well as from proteins in meats, vegetables, protein containing shampoos, and other household products (DelPorto and Steinfeld, 2000). In some special cases, even the water supply can be an important source of ammonium nitrogen. Typical values of nitrogen in mixed household grey water are found within a range of 5-50 mg/L. in countries where phosphorus-containing detergents have not been banned, dishwashing and laundry detergents are the main sources of phosphorous in grey water. Average phosphorous concentrations are typically found within a range of 4-14 mg/L in regions where non-phosphorous detergents are used (Eriksson et al., 2002). Low nitrogen limits microbial processes, thus hindering degradation of organic matter in biological treatment processes. When untreated grey water is applied to soils (e.g. in filtration trenches or for irrigation purposes), undigested organic matter, such as fats, oils, soaps, detergents etc., may accumulate and clog the soil or infiltration beds (Del Porto and Steinfeld, 2000). This risk must be taken into account when implementing natural grey water treatment and disposal/reuse systems. Frequent monitoring and adjustments (e.g. addition of nitrogen from alternative sources such as urine) are a precondition for a satisfactory long term performance of such systems.

- Oil and grease (O and G)

Grey water may contain significant amounts of fat such as oil and grease (O&G) originating mainly from kitchen sinks and dishwashers (e.g. cooking grease, vegetable oil, food grease etc.). Important O&G concentrations can also be observed in bathroom and laundry grey water, with O&G concentrations ranging between 37 and 7 mg/L and 8-35 mg/L, respectively (ChristovaBoal et al., 1996). The O&G content of kitchen grey water strongly depends on the cooking and disposal habits of the household. As soon as grey water cools down, grease and fat congeal and can cause mats on the surface of settling tanks, on the interior of pipes and other surfaces. This may cause a shutdown of treatment and disposal units such as infiltration trenches or irrigation fields. It is therefore important that O&G concentrations are maintained at acceptable levels (<30 mg/L) to avoid problems with downstream treatment and disposal systems.

- Surfactants and other household chemicals

Surfactants are the main component of household cleaning products. Surfactants, also called surface- active agents, are organic chemicals altering the properties of water. They consist of a hydrophilic head and hydrophobic tail. By lowering the surface tension of water, they allow the cleaning solution to wet a surface (e.g. clothes, dishes etc) more rapidly. They also emulsify oily stains and keep them dispersed and suspended so that they do not settle back on the surface.

The most common surfactants used in household cleansing chemicals are LAS (Linear Alkyl Benzene Sulphonate), AES (Alcohol Ether Sulphate) and AE (Alcohol Ethoxylate). Laundry and automatic dishwashing detergents are the main sources of surfactants in grey water; other sources include personal cleansing products and household cleaners. The amount of surfactants present in grey water is strongly dependent on type and amount of detergent used. Various studies revealed that surfactant concentrations in grey water ranging between 1 and 60 mg/L, and averaging 17-40 mg/L. The highest concentrations where observed in laundry, shower and kitchens sink grey water. Most studies indicate full biodegradation of common surfactants in aerobic environments, such as in aerobic treatment systems and unsaturated soil. During grey water irrigation, toxicity problems may occur if boron ions (similar to sodium ions) are taken up by plants and accumulate to concentrations high enough to cause crop damage or reduced yield. Detergents are the main sources of boron in grey water. Although boron is an essential micronutrient for plants, excessive amounts are toxic. Gross et al. (2005) observed boron concentrations reaching 3 mg/L in laundry grey water. The recommended maximum value for irrigated water amounts to 1.0 mg/L for sensitive crops such as lemon, onion or bean (FAO, 1985). Bleach, disinfectants and solvents are further substances of concern in grey water. Inhibition of the biological process by bleach begins at concentrations as low as 1.4 mL/L, with quite a substantial inhibition occurring at 3 mL/L. By using the environmental friendly household chemicals and refraining from pouring hazardous substances(paint, solvents etc.) into the sink, the levels of toxic substances in grey water can be maintained low (Ridderstolpe, 2004). Since many environmental friendly detergents are available on the market, the problems with grey water treatment reuse and disposal systems can be minimized.

2.3 Microbial Characteristics of Grey water

Grey water may pose a health risk due to its contamination with pathogens. However, pathogens, such as viruses, bacteria, protozoa and intestinal parasites, are assumed to be present in partly high concentrations. These pathogens originate from excreta of infected persons. They can end up in grey water through hand washing after toilet use, washing of babies and children after defecation, diaper changes or diaper washing. Some pathogens may also enter the grey water system through washing of vegetables and raw meat; however, pathogens of faecal origin pose the main health risks (Ledin et al., 2001). Faecal contamination of grey water traditionally expressed by faecal indicators such as faecal coli forms strongly depends on the age distribution of the household members. High contamination must be expected where babies and young children are present. Average concentrations are reported to be around 10^3-10 CFU/100mL. Since grey water may contain high loads of easily degradable organic compounds, re-growth of enteric bacteria, such as the faecal indicators, are favoured in grey water systems. Hence, bacterial indicator numbers may lead to an overestimation of faecal loads thus risk.

3. GREYWATER TREATMENT OPTIONS

Grey water is not malodorous immediately after discharge. However, if it is collected in a tank, it will consume the oxygen very quickly and become anaerobic. Storing grey water for 48 hours at normal temperature deteriorates its quality. Biological degradation takes place and produces malodorous compounds, creating aesthetic problems. Once it reaches the septic state, grey water forms sludge that either sinks or floats depending on its gas content and density. Septic grey water can be as foul smelling as any sewage and will also contain anaerobic bacteria, some of which could include human pathogens. Consequently the key to successful grey water treatment lies in its immediate processing and reuse before reaching the anaerobic state. Grey water characteristics like COD fractions, biodegradability and biodegradation rate under aerobic and anaerobic conditions are key factors in selection, design and operation of treatment systems. Grey water treatment is necessary before reuse

- to remove substances which may be harmful to plants, health and aquatic life
- to remove substances which may be harmful to wider environment
- to remove substances that may clog the grey water system
- to reduce oxygen demand
- to reduce eutrophication effect
- to face the growing scarcity of fresh water

There is a possibility of odour generation in grey water treatment system due to the following:

- A slime layer will develop on the submerged walls of filters, collection sump and possibly in sedimentation tank and as velocity of the grey water through the system sometime is too low to scour the sides.
- If aeration is not sufficient dissolved oxygen will reduce substantially and only anaerobic bacteria will attach to the slime layer

The anaerobic condition will lead to release of odorous compounds from the system and build up of hydrogen sulphide may result in a situation hazardous to human health.

Grey water reuse methods can range from low cost methods such as the manual bucketing of grey water from the outlet of bath room, to primary treatment methods that coarsely screen oils, grease and solids from the grey water before irrigation via small trench systems, to more expensive secondary treatment systems that treat and disinfect the grey water to a high standard before using for irrigation. Some systems are quite advanced and use membrane filtration followed by UV disinfection post treatment. The choice of system will depend on a number of factors including whether a new system is being installed or a disused wastewater system is being converted because the household has been connected to sewer. A grey water treatment system consists of different treatment steps that might be considered, depending on the required quality of the effluent. Several treatment technologies can be used in each step. Technologies examined for treating greywater are classified based on three treatment principle: physical, biological, chemical or a combination of these.

3.1 Physical Treatment Systems

Filtration is most common physical treatment system employed for the treatment of grey water. Coarse filtration (sand filters) followed by sedimentation and/or disinfection is reported for the treatment. But the sand filters achieve limited removal of different fractions present in grey water and coupled with disinfection, only microorganism removal is enhanced. Alternately membrane filters achieve excellent removal rates for dissolved and suspended solids but the removal of organic matter is limited (Ramon et al., 2004). Membrane pore size is an important factor in this case and lower pore sizes give better removal of organic matter. But there is only limited removal of microorganisms in membrane filters. Another problem constraining the use of membranes is fouling of the membrane by pollutants. To eliminate the fouling problem pre-treatment like screening or sand filters will be needed (Jefferson et al, 1999).

3.2 Chemical Treatment System

Coagulation with aluminium followed by sand filtration and electro coagulation are chemical methods employed for the treatment of grey water. Both systems achieved substantial removal efficiency with rather short contact times. Similarly photo catalytic oxidation with titanium dioxide and UV disinfection also achieve good organic and coli forms removal.

3.3 Biological Treatment System

Biological treatment is required to remove biodegradable materials from waste water. In the biological method organic matter is biologically stabilized so that no further oxygen demand is exerted by it. In the case of domestic waste water the biological treatment aims to reduce the organic content and nutrients like nitrogen and phosphorous. Biological methods may be attached growth or suspended growth process, aerobic or anaerobic process etc. if the treatment process is in the presence of oxygen aided by aerobic microorganisms it is an aerobic treatment method. If it takes place in the absence of oxygen it is anaerobic process and the treatment here is brought about by anaerobic microorganisms. The microbial mass can be kept in suspended state in liquid medium or can be attached to mediums like plastic materials, stones, silica etc. the former process is called suspended growth process and the latter, attached growth process.

The consistency in treated grey water quality can also be achieved through greater storage volumes which assist in the biological treatment processes. However, the consistency of biological treatment systems could vary greatly according to type of chemicals used at grey water sources. Some substances or products used such as laundry washing products, soap or shampoos with high amounts aluminium or zeolite could poison or hinder the biological process.

- Anaerobic treatment method

During anaerobic treatment the organic matter present in waste water is converted into carbon dioxide and methane in absence of oxygen. Anaerobic pre-treatment of grey water is recommended, particularly when grey water concentrations are high. The reasons are (1) 74% of grey water pollutants are anaerobically biodegradable. (2) Anaerobic treatment could produce less and stable sludge that is easily dewatered. (3) No energy is required for aeration. (4)Methane is produced that can be used as energy source. Up flow anaerobic sludge blanket (UASB) treating grey water produced a stable effluent quality and sludge compared with a primary settling tank. Studies show that an UASB and sequential batch reactor (SBR), when operated under the same conditions, produced the same amount of sludge and the UASB excess sludge was not well stabilized. Pre-treating grey water in anaerobic unit reduces maintenance and operation cost of the overall treatment system. The removal efficiency of the anaerobic processes could be improved by incorporating filtration, or physical treatment processes. But anaerobic systems require large start-up period and alkalinity addition. Also they are more sensitive to lower temperatures and produces odorous gases. Anaerobic treatment requires post treatment in order to meet discharge standards.

- Aerobic treatment method

Aerobic treatment is a biological process, the principle of which is the use of free or dissolved oxygen by microorganisms (aerobes) in the degradation of organic wastes. Since oxygen is available to working aerobes as an electronic acceptor, the biodegradation process can be significantly accelerated, leading to increased throughput capacity of a treatment system. The aerobic treatment system (ATS) produces a high quality secondary effluent, which can be disinfected and used for surface irrigation.

Since the ATS contains a living ecosystem of microbes to digest the waste products in the water, excessive amounts of items such as bleach or antibiotics can damage the ATS environment and reduce treatment effectiveness. Non-digestible items should also be avoided, as they build up in the system and require more frequent sludge removal. Aerobic heterotrophic bacteria found in this system are able to produce extracellular biopolymers that results in the formation of biological flocs that can be separated from the treated liquid by gravity settling with relatively low concentration of free bacteria and suspended solids (Metcalf and Eddy, 2003).

4. METHODOLOGY

In order to conduct the above study, and to achieve the objectives, first of all we calculated the approximate population of hostel and canteen which is selected as the place for conducting this study. Then we found out the amount of waste water generated in the college canteen and hostel. Then we took samples of waste water from hostel and canteen and tested for its characteristics. Tests like BOD, COD, Sulphate, nitrate, calcium, magnesium, total suspended solids, total dissolved solids, and organic matter were conducted. Out of these except BOD, other tests were done at Regional Analytical Centre; Kakkanad.BOD tests were conducted in College Environment Laboratory. After obtaining the characteristics, we planned layout of the units to be designed and then each unit was designed with the help of references. After design the units were drawn with help of CAD software.

4.1 CAPACITY CALCULATIONS

The capacity of the tank needed is determined assuming the percapita demand of the persons residing in the hostel and those visiting the canteen daily. The pecapita demand was assumed as 200 1/capita/day.

4.2 STUDY OF CHARACTERISTICS

To study the characteristics we collected grey water samples from canteen and hostel in intervals. Sample of 3 litres was collected and sent to regional analytical centre for analysis. We continued our study by conducting simultaneous tests in college hostel.

Table1: Characteristics of water obtained after conducting tests in regional analytical centre

BOD	64mg/l
COD	2078.4ppm
Sulphate	100ppm
Nitrate	nil
Calcium	47.36ppm
Magnesium	93.17ppm
Total suspended solids	648ppm
Total dissolvedsolids	720ppm
Organic matter	563ppm

4.3 LAYOUT OF UNITS

After studying the characteristics the dimensions of the following units were designed.

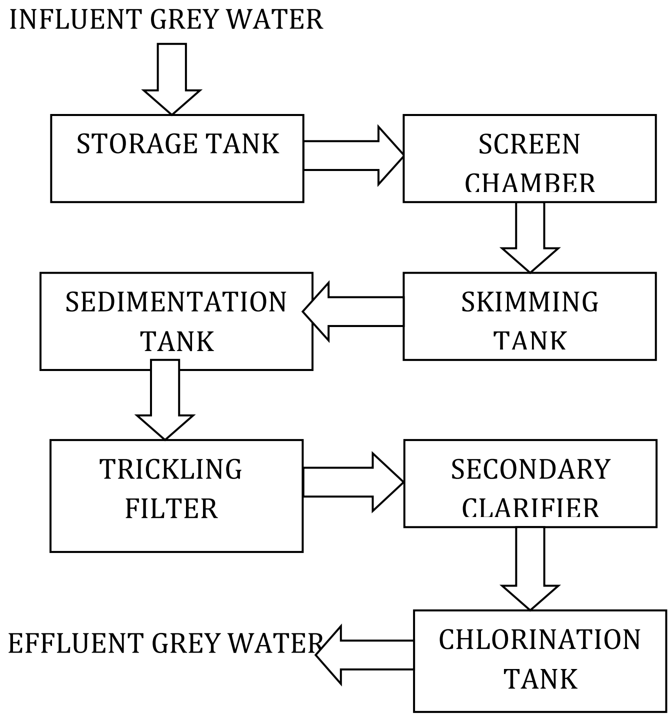

Fig 1: Flow chart showing connection between various units

5. CONCLUSION

1) Treating wastewater will surely reduce the effects of its harm and thus increasing its usability. Once undergone through the procedure of proper treatment, you will no longer receive any bad odours. The water, thus obtained, is clean and safe for use.
2) Grey water can replace drinking water for irrigating gardens or lawns especially during drought periods.
3) From Chemical analysis of waste water, we designed 6 units with following dimensions.

   a) Storage tank : 3.196 x 2.13 x 5 m^3

   b) Screen chamber : 2 x 0.239 x 0.16 m^3

   c) Skimming tank : 2.38 x 1.06 x 1.23 m^3

   d) Sedimentation tank : 14 x 3 x 4.5 m^3

   e) Trickling filte :1unitof 25m diameter (circular)

   f) Secondary clarifier : 7.5 x 5.8 x 1.45 m^3

   g) Chlorination tank : 4.7 x 2.34 x 2 m^3

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