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Review Article

A Comprehensive Review on Sewage Collection and Treatment: Historical Perspective

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Abstract

A comprehensive review is presented on sewage collection, treatment and sludge formation, keeping in mind the current interest of the scientific community working on various aspect of clean environment, waste management and disposal in an environmentally friendly way. The emphasis of the review is on sewage and sewage sludge which is an endless commodity: the management of which is one of the biggest challenges for United Arab Emirates, the Gulf Cooperation Council and other developing countries relying particularly on agriculture. With the rapidly population growth the sewage waste is likely to be increased and thus procedures are to be well understood to manage this waste to a resource. The review presents historical perspective from many countries where such practice was initiated. The areas such as separation and disposal of sewage sludge, sewage treatment procedures, primary, secondary and tertiary treatments are presented as well as removal of phosphorous, nitrogen, pathogens and metals have been included.

Keywords: Sewage Sludge; Waste; Pathogens; Metals; Nitrification; Biological Oxygen Demand

Introduction

In the next one or two decades, the largest rates of urbanization will occur in the smaller urban centers [1]. This will greatly impact wastewater production and the potential for both decentralized treatment and use. About two third of the world's population have access to improved sanitation. By 2030, global demand for energy and water is expected to grow by 40% and 50%, respectively [1]. Most of this growth will be in cities, which will require new approaches to wastewater management. On average, high-income countries treat about 70% of the wastewater they generate, while that ratio drops to 38% in upper middle-income countries and to 28% in lower middle-income countries. In low-income countries, only 8% of industrial and municipal wastewater undergoes treatment of any kind [2]. The above estimates support the often-cited approximation that, globally, it is likely that over 80% of wastewater is released to the environment without adequate treatment.

The urbanization of cities, building more permanent sites, industrial revolution, excessive use of water in the households, and rapidly increasing population density led not only to increased human waste per unit area but also raised the concerns of how to handle and dispose of the sewage effluents in a human and environment friendly manner. This situation is bound to worsen in the years and decades to come as urbanization and human development index increases on a global level. The urban areas with access to plenty of water, quantity of sewage effluents is over 200 liters per person per day and may reach to over 500 liters per person per day in more developed societies. Of this volume, the share of human excreta (faeces + urine) averages about 1.5 liters. Thus, already the human excreta is diluted by about 130 times or even more at source thereby creating a big burden on the disposal system.

Wastewater treatment (WWT) includes physical, chemical, and biological processes to eliminate pollutants. Once treated, water can be released back into nature. Sewage is waste matter from domestic and industrial establishments that is carried away in sewers and/or drains for dumping and subsequent conversion into non-toxic form. Sludge is a by-product of water and wastewater treatment operations. A by-product of sewage treatment is usually a semi-solid waste or slurry called sewage sludge that must undergo further treatment before being suitable for disposal or land application. The primary sludge contains precipitated solids that occur during the primary treatment in the primary clarifiers. The secondary sludge separated in the secondary cleaners contains the sewage sludge purified from the secondary treatment bioreactors.

Historically, the main concerns have been the pathogens, while that of heavy metals and organic pollutants are of relatively recent origin and became increasingly more important with reference to industrial revolution. Until recently, wastewater sanitation focused on minimizing health risks, primarily the infectious diseases [3].

The problem is not of disposing sewage effluents, but the risks of human health hazards and environmental pollution attached to them. This has been taken care of through revolutionary developments over the past few decades with the major objective of handling and disposing of sewage effluents in environment-friendly manner.

Collection and disposal of sewage effluents over the centuries and decades

The collection and disposal of domestic wastewater effluents goes back to 3500 - 2500 BC where in the Mesopotamian Empire, people used to connect some houses to a storm water drain system to carry away wastes. The system kept advancing in the coming centuries in accordance with increase in population and their awareness as reported by various authors [3,4]. Reports available for the duration of 300 BC to 500 AD indicated that Ancient Greeks used to have public latrines which drained into sewers that conveyed the sewage and storm water to a collection basin outside the city. From there brick-lined conduits took the wastewater to agricultural fields where it was used for irrigation. The early Greeks understood the relationship between water quality and general public health. This concern was passed onto the Romans who were skillful and technologically advanced. By the 3rd century, the sewers in Rome were vaulted underground networks [3] and in 4th century, Rome had over 1300 public fountains and 856 private/public baths [4].

With the fall of the Roman Empire, sanitation technology entered its dark ages [4]. The ages-old practice of separating drinking water and human wastes was largely abandoned, and consequently waste water started migrating easily from waste pits into wells. The period witnessed the rivers of London and Paris as a kind of open sewer [4]. Diseases like dysentery, typhus, and typhoid wiped out many hundreds of thousands of people in the middle ages [4]. In the 12th century, the Cistercians introduced the use of city refuse and sewer water as fertilizers on their land [5]. Such and other management practices spared the Black Plague of 1349 [4]. Thus from 206 BC to 24AD, stone lavatory with running water came into being as witnessed in a royal tomb from the Western Han dynasty in the central province of Henan, China. During 19th Century, Sir Edwin Chadwick (1800 - 1890) recommended the use of water-closets, discharge of domestic wastewater direct to sewer, sewers to also take solid refuse from streets and convey sewage to an agricultural area away from town where its manure value could be utilized (now called land treatment). One major result of this recommendations was the Public Health Act of 1848 that led to setting up of local Boards of Health and gave them the power to construct sewers [6]. In 1848, the first comprehensive sewer network in Europe was established in Hamburg that became functional in 1853 [6]. Mouras, designed a cesspool in France in 1860 cited by Cooper, [7] in which the inlet and outlet pipes dipped below the water surface thus forming a water seal and creating anaerobic conditions for microbial liquefaction of the solids [8]. This was the precursor of modern septic tanks. The main purpose of these tanks was to remove solids from waste water before its discharge into the nearest stream or river. However, since the effluent was largely untreated which caused pollution of streams and rivers [4] thereby, suggesting the need for having a disposal technology. Consequently, first federal regulation of sewage, Rivers and Harbors Appropriations ("Refuse Act") appeared in 1899 which prohibited discharge of solids to navigational waters without permit from US Army Corps of Engineers. The first comprehensive sever systems in the United States was built in Chicago and Brooklyn during 1950 while the first Royal Commission on Sewage Disposal in UK was formed its in 1898.

Until the second half of the 19th century, it was common practice to discharge wastewater into the natural water bodies like rivers and oceans. It was believed, that through such a disposal, wastewater is diluted satisfactorily, and the suspended matter dissipated. However, the menace of 19th century cholera was attributed to the usage of drinking water that was contaminated with sewage water [4,3] which later established the relationship of cholera to contaminated water, its origins in India and the path it took to Europe [4,3]. This resulted in gradual development of sewer system that led the way to the separation of human sewage wastes from drinking water whether of wells or other sub-surface water bodies [4]. The industrial revolution and increasing population density of cities increased the human waste and further aggravate the disposal problems in most of the countries [9].

Chadwick [10] was the first to suggest that sewage may be driven to an agricultural area, an approach now coined as “land treatment”. Thus, land application could be considered as a pioneering step towards treatment of sewage effluents [6]. This disposal was also beset with problems of hygiene, water-logging, and ground water pollution. By 1893, it was known that effluents entering the agricultural field possesses 66% more dissolved organics compared to those leaving the field while process of nitrification gets nearly completed during this process [11]. Up to 1900, all sewage treatment wherever it existed was carried out by land treatment therefore; people in large towns and cities bought more land for their sewage ‘farms’ that were not always successful due to the water-logging problem [9]. Besides, use of lands for disposal of raw sewage effluents appeared to have concerns such as the requirements of large areas of land that was expensive, disposal does not achieve the hygiene standards required in terms of bacterial and viral pathogens, availability to both autotrophic and heterotrophic microbes of nutrient like N and P present in the effluents that increases ground water pollution and eutrophication of surface water bodies and the fear of polluting the human food chain through presence of hazardous organic and heavy metal in the effluents. To avoid risks related to these ingredients, separation of solids or the so-called sewage sludge has become a pre-requisite before disposal of water even to water bodies.

Separation and disposal of sewage sludge

Sedimentation of solids is considered the first step towards separating it from water to be disposed of. First signs appeared in 1829 when trenches or pits were dug to get the heavier solids settled/removed prior to land application of liquids [8]. When the pits were filled they were covered, and new ones dug. The next development consisted of flat-bottomed mostly clay-lined tanks operated on a fill-and-draw basis, with the removal of water by siphoning. Introduction of Imhoff tank in Germany was the next development that deployed two chambers thus allowing the separation of the settlement and sludge digestion processes. In 1895, Cameron and Cummins (cited by Cooper, [7]) patented a system that they called ‘septic tank’. In 1930’s sludge drying, and incineration were introduced in Chicago, Illinois, USA. The period after 1960 saw rapid deployment of chemical conditioners (polymers, poly-electrolytes), and dissolved air floatation for enhanced solids separation and thickening. However, first record of chemical treatment of sewage discharges comes from Paris using lime as the precipitant [12]. In the United States, the first sewage treatment plant using chemical precipitation was built in 1890 in Worcester, Massachusetts for the recovery of solids.

The developments mentioned above were all directed at effectively separating the solids from the liquid phase so that the latter could be safely and more conveniently disposed in water bodies or elsewhere. The current driving issues include i) further control of pathogens and ii) the minimizing release of excessive nutrients, elements, and chemicals to the environment.

Evolution of sewage treatment process

Excreta management generally comprises four stages i.e. i) collection, ii) transportation to a suitable location, iii) storage and/or treatment, and iv) reusing and/or returning to the environment. There are three basic systems to handle/manage human excreta that are, i) latrines and pits containing the waste to be transported to disposal sites as a semi-solid material, ii) domestic level localized collection and disposal of excreta into septic tanks with or without its transport to the centralized treatment facility, and iii) centralized sewerage system (using excessive amounts of water in a closet) that culminates at treatment facilities.

Latrines and pit toilets

In principle, the pit latrines receive waste cumulatively and thus they act as a batch-fed system with a slow accumulation of solids in the pit. Chaggu [13] proposed that pits share many common characteristics with anaerobic reactors or digesters that have generally four key biological and chemical stages of anaerobic digestion i.e. i) hydrolysis, ii) acidogenesis, iii) acetogenesis, and iv) methanogenesis. In the first stage complex long-chain macromolecules are hydrolyzed to short-chain compounds. This hydrolysis is catalyzed by enzymes (cellulase, protease and lipase) from hydrolytic bacteria. In acidogenesis, the soluble substrates produced in step-1 are used by the microbes to form organic acids. The third stage of anaerobic digestion is characterized by the production of acetic acid, CO_2, and hydrogen. In methanogenesis, methanogens use the intermediate products of the preceding stages and produce methane, carbon dioxide and water. The remaining, non-digestible material which forms greater part of the sludge needs special measures to be handled and disposed because pit latrines are generally inefficient in digesting organic matter as both aerobic and anaerobic cannot work effectively for longer time and result in slow/incomplete breakdown.

Septic tank

It is an underground tank where all the water-borne waste from a house is deposited and decomposed by bacteria. Solids and dead bacteria settle to the bottom as sludge while the liquid portion flows into the ground through a 'soak away' comprising either a network of underground pipes or a stone filled pit that allows the effluent to percolate into the soil. The sludge needs to be removed periodically for the tank to function properly.

Connected to the septic tank is the water closet system generally with a piped water supply. The latrine is usually a pedestal. The feces and urine are initially deposed in an S-trap at the base of the pedestal until the user activates a lever to release water stored in a tank (cistern) situated at the rear of the pedestal. Both paper and water wash cleaning are possible. The momentum created by the water flushes the feces and urine into a drain and eventually carries it to the septic tank or treatment site. Smell and flies are prevented by the S-trap which creates seal to the drain.

Centralized sewerage system culminating at treatment plant

As mentioned above, land application was found to be an effective treatment process to address the adverse effects on human health and environmental safety, measures especially of ever increasing metal pollutants and all kind of other city waste including glass, plastics, and metals had to be adopted in the re-use of wastewater and sludge in agriculture and for irrigation purposes, respectively. Thus, the development of sewerage system and the treatment of wastewater became a requirement to make the whole system human and environment friendly and hence the technology of centralized collection and an organized disposal of wastewater need to be developed. The sewage treatment system as we see it today has been through immense advancements but consists mainly of 3 steps i.e. primary, secondary and tertiary treatment.

Primary treatment

This refers to the physical treatment of wastewater by the gravity-driven settling of solids and floatation of scum (froth). This step is a simple and cost-effective method of separating material potentially harmful to the sewage treatment system components and infrastructure. Pre-treatment consists of physical and mechanical operations, such as screening, sieving, blast cleaning, oil separation and fat extraction. It allows the removal of voluminous items, sands and grease. The residues from pretreatments are not considered to be sludge. They are disposed of in landfills. In floatation, air is introduced into the wastewater in the form of fine bubbles, which attach themselves to the particles to be removed. The particles then rise to the surface and are removed by skimming. In the mechanical stage, 50 to 70% of the suspended solids are separated with a concomitant reduction of 25 - 40% in biological oxygen demand (BOD). Besides, physical treatment, suspended solids may be coagulated using chemicals. Coagulation (flocculation) is the addition and rapid mixing of a coagulant to neutralize charges and collapse the colloidal particles, so they can agglomerate and settle. Flocculation generally precedes sedimentation and filtration processes. The slow mixing allows the particles to agglomerate into heavier, more settleable/filterable solids.

Secondary treatment (Activated sludge process)

Secondary treatment refers to the treatment of wastewater to remove dissolved solids from the wastewater, also called activated sludge process. This step is mediated by microorganisms especially bacteria that break down organic materials in wastewater after primary treatment. Techniques such as lagooning, bacterial beds, filtration or bio-filtration form part of the secondary treatment process in which micro-organisms consume the wastes in aerated tanks, followed by settling of the micro-organisms and associated solids in a clarifier (a quiet settling tank) or pond.

In 1982, Warington wrote that, sewage contains the organisms for its own destruction, and these can be cultivated to do the job of sewage reduction. He pioneered the idea of a filter bed which would have a greater oxidizing power than would be possessed by an ordinary soil [9] and suggested the use of a filter containing more porous medium than natural soil [8]. Robert Koch discovered the cholera inducing bacteria from surface waters [14] which were often used as sources of drinking water without any processing.

The idea that there might be better ways to treat wastewater effluents using organisms gradually started emerging in the second part of 19th century. In 1860's, Sir Edward Frankland in London, UK, established the fundamental principles of filtration through soil on which much of future developments depended. He developed trickling sand filter technology that involved passing of wastewater contained in inter-connected cylinders filled with different media such as sand, soil and gravel. At present, trickling filtration is an aerobic fixed-film biological treatment process that consists of a structure packed with inert medium such as rock, wood, or plastic. The wastewater is distributed over the upper surface of the medium by either a fixed spray nozzle system or a rotating distribution system. The inert medium develops a biological slime that absorbs and biodegrades organic pollutants. Air flows through the filter by convection, thereby providing the oxygen needed to maintain aerobic conditions.

Purifying sewage will be first to separate the sludge, inoculated under aerated conditions with some organisms specially cultivated for the purpose and then to discharge it into the stream in a purified condition [7]. This is probably the first of its kind of suggestion that microbial inoculation hastens the cleansing of effluents. The idea that there might be a way of biologically treating sewage was revolutionary at the time, but the sewage farm did demonstrate that if sewage was passed through a sandy, gravelly soil it became less polluting. From this came the idea of 'artificial ground' which led on to the 'contact bed' concept. After the suggestions by Warington. Baldwin Latham installed 'artificial filters' at Merton, south of London, that contained alternating layers of burnt clay and soil [8].

The modern biological filters [9] involve primary and secondary treatment. The dramatic breakthrough in biological filter design for more reliable performance was made in the US at the Lawrence Experimental Station. This was the first of its kind of wastewater processing facility where experiments clearly demonstrated nearly complete removal of organics and oxidation of NH_4. Experiments with intermittent soil filtration were carried out in the last decade of 19th century.

Since about 1882, experiments had been carried out on the aeration of settled sewage, but proper activated sludge process was introduced in 1913 based on the observations that concentration of aerobic bacteria can be increased by intermittent settling and aeration of sewage for several hours. In USA, the first activated sludge process was established in Houston, Texas, in 1916 followed by its wide adoption. By 1927, several large-scale tests were carried out and facilities established at San Marcos in Texas (500m^3 per day), Houston, Texas (40,000m^3 per day), Des Plaines, Illinois (20,000m^3 per day), Milwaukee (170,000m m^3 per day), Indianapolis (190,000m^3 per day), and Chicago (660,000m^3 per day). In Indianapolis, compressed air was pushed through perforations that produced a spiral flow of air bubbles. Subsequent developments were the surface aeration using a vertical shaft that enabled sufficient oxygen transfer and mixing of the water and sludge [16]. In Denmark, activated sludge process was introduced and applied for the first time in 1922 [17] while first experimental plant based on activated sludge was built by Imhoff in 1924 at Essen [18] and a full-scale system at Essen-Rellinghausen in 1926. In Germany, the full scale activated sludge plant was built in 1926 at Rellinghausen with emphasis on different sedimentation tank designs [19]. In 1927, Kessener (cited by Cooper, [7]) treated an abattoir effluent at Apeldoorn, in the Netherlands (Institute of Water Pollution Control) using an activated sludge process equipped with a brush aerator. In 1927, the first book was written on the activated sludge process by Martin. By 1938, the activated sludge process was in operation in hundreds of full-scale sewage treatment works [19].

One of the most important developments in the recent years relates to the use of membranes. Tertiary or quaternary treatment using membranes for removing bacteria is already carried out in Europe, Australia and the US. The potential for using membranes in reverse osmosis (RO), micro-filtration (MF) and ultra-filtration (UF) has been known since the 1960s and till 1992, total operating cost dropped by four-fold, that is, by 75 per cent. It may thus be a system that has great potential for a small decentralized sewerage system and for some reuse of treated effluent. The most exciting application in membrane biological reactors is the Kubota system from Japan where membrane panels are inserted directly into the activated sludge aeration tank.

Tertiary treatment (chemical treatment for removal of metal pollutants and nutrients)

The inorganic portion of the sewage sludge is mainly the compounds of iron (Fe), phosphorus (P), calcium (Ca), aluminum (Al), and sulfur (S), including traces of heavy metals such as zinc (Zn), chromium (Cr), mercury (Hg), lead (Pb), nickel (Ni), cadmium (Cd) and copper (Cu) [20,21]. The Zinc (Zn), copper (Cu), and lead (Pb) are present in high quantities, but other heavy metals are found in traces levels [22]. Both phosphorus (P) and potassium metals are (K) in the sewage sludge have a high fertilizer value. The discharge of untreated wastewater into seas and oceans partially explains why deoxygenated dead zones are rapidly growing: an estimated

245,000 km^2 of marine ecosystems are affected, and this affects fisheries, livelihoods, and food chains [23].

Alongside the developments in biological treatment of effluents, chemical treatment had also been on the move with the major objective to clean the waste water of metals and nutrients like N and P. This so-called tertiary treatment refers to additional wastewater treatment processes that are undertaken with the goal of creating clean water suitable for a purpose.

Reduction/removal of nutrients

Sewage effluents contain substantial quantities of readily as well as potentially available nitrogen (N) and phosphorus (P) that are used by both autotrophic and heterotrophic microbes. Human excreta have C/N (1.07) and C/P (25.5) ratios that are highly conducive to the net mineralization and availability of these nutrients for the fauna that causes eutrophication of surface water bodies. This is particularly more important as NH_4 accumulates in the sewage waters because of negligible to no nitrification and NH_4 is known to be the preferred source of N for most microflora. Besides, NO_3 and NO_2 pollution of surface and sub-surface waters has its own hazards. It is important, therefore, to treat the sewage effluents to remove nutrients (N and P) that are potentially available to micro and macrofauna and flora. However, these considerations are relatively recent while use of chemicals for cleaning sewage water has been an old tradition. Below is a review of the developments in removing P and N from sewage effluents.

Removal of Phosphorus

The P recovery from wastewater is becoming an increasingly viable alternative. An estimated 22% of global P demand could be satisfied by recycling human urine and faeces worldwide [24]. The removal of phosphorus may be performed using chemical processes or biological treatments. Chemical processes consist of chemical precipitation using additives followed by sedimentation. Biological treatments employ specific micro-organisms, which can store phosphorus. It accumulates within the bacteria enabling its removal with the rest of the sludge.

The limits to which phosphorus can be reduced by chemical polishing range from 0.04 to 0.06 mg L^{-1} and depend on the interactions of stoichiometric precipitation, co-precipitation with metal hydroxide, and adsorption at low ortho-phosphorus concentrations. For biological P removal, a continuous dose of alum (5 to 8 mg L^{-1}) is reported to ensure reduction of ortho-phosphorus concentration to 0.1 mg L^{-1}. To achieve values substantially lower than 0.1 mg L^{-1}, post chemical treatment by standard water treatment coagulation, flocculation and filtration is required. However, in South Africa, technology of stream fermentation was developed that led to excellent removal of phosphorus [25]. Tremblay., *et al*. [26] experimented it at full-scale and found that a solid retention time of 2 days in the fermenter was optimal.

Using another approach that combines chemical and biological processes, Levin [27] patented a process in which raw activated sludge (RAS) was fermented in a "stripper" where it released phosphorus. The phosphorus-rich supernatant was treated with lime and the precipitates were removed. High levels of phosphorus removal using this process have been reported in many studies [28]. More recently, effluent phosphorus concentration of 0.05 mg L^{-1} are reported to have been achieved with a combination of biological removal and post chemical treatment [29]. Cauly Creek plant in Georgia was designed [30] with an anaerobic zone which can reduce phosphorus concentrations to less than 0.5 mg L^{-1} without any chemical addition, and that with the addition of either alum or ferric chloride ($FeCl_3$) to the membrane compartment, average effluent phosphorus of 0.1 mg L^{-1} was achieved.

Removal of Nitrogen

Nitrogen removal from sewage effluents is important to avoid subsequent problems arising from pressure of NH_4 in the treated waters to be disposed of. Efforts are therefore made to reduce NH_4 content through nitrification/de-nitrification. Nitrification in the sewage effluents was first observed in the 19th century [31] and was considered a nuisance. However, in 1930's, nitrification-de-nitrification sequence was introduced for the removal of NH_4-N. During the 1950's, de-nitrification gained attention as a process for the removal of up to 90% nitrogen from wastewater [32]. The identification of compounds that inhibited the nitrifying organisms advanced the application of the activated sludge process for nitrogen removal.

Ludzack and Ettinger [33] introduced the "Semi-aerobic Activated Sludge Process". Settled activated sludge was returned to the aerated section and primary effluent introduced in the semi-aerobic section. Aerated mixed liquor containing nitrates was recycled to this semi-aerobic section through the action of the aeration system "to supply dissolved nitrite and nitrate to compensate for reduced aeration in the influent zone." Organic carbon was removed in the first stage, nitrification was enhanced in the second stage and methanol was added in the third stage for de-nitrification. Johnson [34] described state-of-the-art biological nitrogen removal systems.

Balakrishnan and Eckenfelder [35] proposed a contact-stabilization process to store as much carbon as possible in the activated sludge which could then be used as the electron donor for de-nitrification. By the end of 1971, nitrogen removal ranging from 20 to 80% was observed in extended aeration channel systems. From 1973 to 2004, advancement in process resulted in the modern concept of step-feed nitrogen removal [36]. This required intensification of the biological processes such as adding alkalinity to optimize growth rate of nitrifiers, precise control of the oxygen supply, additional carbon for de-nitrification in the limited anoxic zones, and the need for extensive instrumentation. With these and other measures it was possible to reduce the effluent N concentration significantly. One of the most interesting developments of processes utilizing anaerobic ammonia oxidation such as ANAMMOX was described by Van Loosdrecht., *et al*. [37]. These are fully autotrophic processes with no need for organic carbon. The specialized bacteria convert ammonia directly into N_2 gas under anaerobic conditions, with nitrite as electron acceptor.

Integrated fixed media activated sludge (IFMAS) has been another approach used very successfully to reduce the basic requirements for nitrification. The floating media are added to the aeration zone to supply surface area for nitrifying organisms to cling to and kept in place by screens. The mixed liquor passes through the screens and is recycled to the anoxic zone for de-nitrification [38].

Not only NH_4, but total N and recalcitrant dissolved organic nitrogen (rDON) values of effluents may also be quite high which needs to be removed as this is the greatest obstacle to reducing nitrogen below the present limits of technology. With membrane reactors, there is no need for filtration and the option of using a de-nitrification filter for removing residual nitrates has been eliminated. Barnard [32] proposed to include an attached growth section ahead of the membrane basins where methanol-degrading organisms can grow on the media and not be washed out, ensuring less than 1 mg L^{-1} of nitrates in the effluent. McQuarrie., *et al*. [39] found that when adding media to a post-anoxic zone, the rate of de-nitrification with methanol is doubled. It should be experimentally determined if a down flow fixed media or floating media would be the best choice for post anoxic de-nitrification.

Removal of Metals

Problem of pollutant metals in sewage effluents is a relatively new concern that emerged with rapid industrialization and dumping of effluents into the municipal sewerage systems. Domestic septage contains 0.15 to 290 ppm of pollutant metals; zinc (Zn) being the highest and mercury (Hg) in lowest concentration. After treatment of sewage, however, these concentrations may reach 4 - 1200 ppm in the sewage sludge.

Chemical precipitation has been the most common method to remove metal compounds from wastewater. Most metals are relatively insoluble as hydroxides, sulfides, or carbonates and can easily be precipitated and removed. Chemical precipitation is usually performed in conjunction with coagulation/flocculation processes which facilitate the agglomeration of suspended and colloidal material. The precipitated metals are subsequently removed from the wastewater stream by liquid filtration or clarification (or some other form of gravity-assisted separation). Chemical precipitation is a two-step process and typically performed in batch operations. In the first step, precipitants are mixed with the wastewater (typically by mechanical means) allowing the formation of the insoluble metal precipitants. In the second step, the precipitated metals are removed from the wastewater, typically through filtration or clarification. If clarification is used, a flocculent is sometimes added to aid the settling process.

A common process employed to remove heavy metals from relatively low–concentration waste streams, such as electroplating wastewater, is ion exchange [40]. A key advantage of the ion exchange process is that the metal contaminants can be recovered and reused. Another advantage is that ion exchange may be designed to remove certain metals only, providing effective removal of these metals from highly contaminated wastewater. A disadvantage is that the resins may be fouled by some organic substances.

Ultra-filtration (UF) is another useful process for the treatment of metal-finishing wastewater and oily wastes [41]. It can remove substances with molecular weights greater than 500, including suspended solids, oil and grease, large organic molecules, and complex heavy metals. In UF, a semi-permeable micro porous membrane performs the separation.

Removal of Pathogens

Municipal raw sewage contains high concentrations of pathogens that include bacteria, viruses, fungi (including yeasts), parasitic worms, and protozoa. The estimated concentration of these pathogens could be as high as a million of organisms per liter. Some of these organisms may prove harmful to lethal for animals including humans. Hence, greater attention is paid to eliminate or drastically reduce (to permissible levels) the pathogen content in the sewage effluents as well as treated wastewater and sludge. The sewage treatment processes must be effective in removing or destroying these pathogens before the resulting effluents and residuals are returned to the environment and cause human and animal diseases. Conventional primary and secondary treatment processes are likely to reduce the concentrations of enteric pathogens by 90 - 99%. However, additional measures need to be taken for 100% disinfection especially for the more resistant pathogens like *Cryptosporidium parvum*. For such organisms improved methods and indicators are needed. Spores of the anaerobic bacterium *Clostridium perfringens* have recently been used as indicator of the success of sewage treatment [42]. These indicators are easy to measure and were found to be more resistant to primary and secondary wastewater treatment and chlorine disinfection (chlorination) than were indicator bacteria such as fecal coliforms and enterococci.

Chlorination of sewage effluents has several important limitations like, i) formation of chlorinated compounds as by-products that are toxic to aquatic life and potentially carcinogenic to humans, ii) de-chlorination prior to discharge to the environment, iii) relatively less effect on reducing enteric viruses, bacterial spores and protozoan cysts and oocysts in sewage [43]. Viruses are quite resistant to chloramines and protozoans such as *Cryptosporidium parvum* oocysts are very resistant to both free chlorine and monochloramine as compared to indicator bacteria and typical bacterial pathogens (*Salmonella, Shigella, E coli*, etc.). These are also more resistant to other wastewater and water disinfectants including ozone, chlorine dioxide and UV radiation [43]. Ozone and chlorine dioxide are also more effective than free or combined chlorine for disinfection of *Cryptosporidium parvum* oocysts. UV radiation has received increased attention and use as a wastewater effluent disinfectant because there is no addition of chemicals to leave toxic residuals or form toxic by-products. However, doses of UV to achieve appreciable virus inactivation are high and thus the process is high in costs.

Recently, mixed oxidants are shown to efficiently inactivate *C. parvum* oocysts and *C. perfringens* spores in buffered water [44]. Free chlorine is a major ingredient, but other oxidants must be present to account for its ability to inactivate the infectivity of *C. parvum* oocysts. However, despite its promise as a disinfectant, mixed oxidant technology has not been carefully evaluated for disinfection of treated waste water.

Due to difference in health conditions of people living in industrialized and developing countries, the pathogen content is notably different [45] and therefore the appropriate treatment options are also different. For example, Helminth ova vary from 1-8 in USA to an extent of 3000 L^{-1} in some developing countries [46]. Likewise, faecal coliforms vary between 10^2 and 10^7 mL^{-1}, Salmonella species from 101 to 107 mL^{-1}, and protozoan cysts from 28 to 1800 L^{-1} [46]. To meet the regulatory disposal requirements, a reduction of 95 - 99.99% will be required through sewage treatment.

Removal of helminth eggs, bacteria and viruses is commonly achieved by wastewater stabilization ponds and other ‘natural’ treatment processes. However, when more ‘conventional’ or energy-intensive processes (e.g. activated sludge) are used, disinfection methods such as chlorination, ozonation and UV radiation are generally required for pathogen inactivation. These disinfection methods remove bacteria and viruses, but not helminth eggs as these are very resistant and behave quite differently from bacteria and viruses during treatment. Protozoan (oo)cysts are only slightly less resistant than helminth eggs [47]. Thus, special care must be taken when selecting a process that removes helminth eggs and protozoan (oo)cysts to the required degree. Following the same coagulation-flocculation removal principles, helminth eggs and some protozoa are removed along with the suspended solids. In advanced primary treatment that uses a high-rate lamellar settler for coagulation-flocculation substantial removal of all pathogen types can be achieved [48].

Filtration is also a useful treatment step to remove protozoan (oo)cysts and helminth eggs from effluents resulting from a primary or a secondary treatment step, whether this is physicochemical or biological, such as activated sludge. During filtration, pathogens and other particulate matter are removed as they pass through sand or other porous granular media. Efficient slow sand filtration requires optimal maturation of the surface microbiological layer (‘schmutzdecke’), cleaning and refilling without short-circuiting. Besides, simple filtration, infiltration-percolation is a low-energy consumption technology and is proven to be an efficient means of reclaiming primary or secondary effluents prior to reuse. Full-scale plant monitoring has shown significant reduction of that *E. coli,* Helminth eggs and protozoa such as *Giardia* and *Cryptosporidium* [49].

Biochemical Oxygen Demand (BOD)

One of the most commonly measured constituents of wastewater is the “biochemical oxygen demand” or BOD the value of which is often used as a robust surrogate of the degree of organic pollution of water. The function of aerobic digestion is to stabilize the waste slurry solids through prolonged ventilation, thereby reducing biological oxygen demand (BOD) and eliminating volatile solids. Biodegradable material and microorganism include prolonged oxidation of cellular material in open tanks. During this time, the biological material is reduced by about half of its original amount. Human excreta contain significant concentrations of easily decomposable components that are degraded by microorganisms requiring oxygen. Thus, BOD is an indirect measure of the quantities of decomposable materials.

The significance of BOD was felt as early as late 19th century when in 1898 Royal Commission on Sewage Disposal was formed in the UK. Sewage effluent discharged into a river should have a BOD not exceeding 4 mg L^{-1}. This can be achieved by diluting the effluent with clean water prior to discharge. Most rivers can easily assimilate effluent with a BOD of 4 mg L^{-1} without affecting fish and other aquatic life, so that effluent complying with the 30:20 standards is generally safe.

Sewage effluents high in BOD can have several implications including, i) creation of anaerobic conditions in the septic tank, (sewage treatment in the septic tank is anaerobic process because the sewage entering the tank is so high in BOD that any oxygen present in the sewage is rapidly consumed), ii) excessive growth of bacteria accompanied by anaerobiosis and death of beneficial organisms and slowing down of aerobic digestion, iii) depletion of oxygen in receiving waters that may lead to fish kill and ecosystem changes, iv) increase in anaerobic bacteria that may produce deleterious clogging substances, and v) sewage sludge (or Biosolids) produced after sewage treatment that is less effective in reducing BOD may be more attractive to vectors responsible for transporting and spreading pathogens. It is important therefore to lower the BOD of treated waters and biosolids.

BOD is easy to remove from sewage by providing oxygen during the treatment process. Most enhanced treatment units are equipped with oxygenation systems. It is important, however, to maintain reasonable levels of BOD i.e. decomposable organic matter especially in systems designed to reduce nitrogen concentrations through de-nitrification. Besides microbial approaches to reduce BOD, hydrogen peroxide (H_2O_2) has been used to reduce not only BOD but COD (chemical oxygen demand) of industrial wastewaters as well. While the cost of removing BOD and COD through chemical oxidation with hydrogen peroxide (H_2O_2) is typically greater than that through physical or biological means, there are nonetheless specific situations which justify the use of hydrogen peroxide.

Conclusions

From the comprehensive review it is concluded that sewage collection from residential areas and treatment has been started over a century in the developed countries. Overtime the technologies have been developed and now sewage water is treated at the tertiary level, a move from primary and secondary levels. In the past when sewage was treated at primary level disease like cholera was common. Current practices remove pathogens, heavy metals, nitrogen and phosphorus, thus releasing load on the tertiary treated water. The produced sludge has great value in soil health improvement in agricultural farms as well as transformation to biochar, a pre-requisite for sandy soils structure development. The sandy soils 'entisols' [50] are dominant in UAE and GCC countries.

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