Review on solid-liquid separation using various conditioning methods

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Abstract. The increase in industrialization and population in the recent days the sludge production is also increased which has become difficult to handle it. Sludge used to be incinerated, compost and landfilling before disposal, but as it is not economic and environmentally friendly most of researchers are concentrating on the sludge dewatering process which are sustainable technologies so that sludge can be converted to semi solid which will be easy to handle and transport. Some sludge is used to produce to biogas, organic matter and also source of energy further processing was not done as it contains toxic compounds in it. Hence studies on sludge dewatering can be useful in terms of environmental and economic point of view. The present review work is on study of different properties of sludge, their effect on sludge dewatering, fundamentals of sludge and assessment of sludge dewaterability.

Keywords: Sludge, Dewatering, Conditioning, capillary suction time, free water.

1. Introduction

The increasing rate of urbanization and industrialization as resulted in the production of sludge. Sludge consists of various matrix of inorganic particles like contaminants, dirt and microorganisms, fibrous matters, organic particles and extracellular polymers particles which are bounded with various lipids, proteins, organic acids and polysaccharides. Improper disposal of sludge results in human health and environmental effects such as odour, pathogenic microorganisms, heavy metals leaching, groundwater contamination etc. hence it is very much necessary to dispose of the sludge in the safe, effective, and cost-efficient way. Composting, incineration, anaerobic digestion, sludge dewatering, landfilling, gasification are the various methods used for sludge processing and handling. The sludge quantity varies according to the population and sewerage expansions etc., the sludge content generation is increasing every year which leads to the increase in transportation and handling cost and also impacts on environment [1].

Various types of sludge’s are available like primary sludge, biological sludge, mixed sludge, digested sludge, mineral sludge and physical-chemical sludge. Also, there are different forms of water in the sludge, shown in the Figure 1, which are as follows,
Free water: - Water that can be easily isolated by gravitational settling. Free water is not chemically or mechanically bound to the sludge. Around 75% of the water in the sludge is free water.

Interstitial water: - The water which is surrounded to the sludge particle as a floc and which can be removed by mechanical dewatering means. About 20% water in the sludge is of interstitial water.

Vicinal water: - It is also very difficult to extract the water that is physically attached to the sludge particles.

Water of hydration: - Water that attached to the sludge particles chemically. Around 2.5% water in sludge is of Water of hydration.

The sewage sludge characteristics and the quantities are depended on its sludge type and also level of treatment. Sludge’s are classified into different forms:

- Primary sludge: - The sludge collected from the settling chamber.
- Biological sludge: - Sludge obtained during the biological treatment.
- Digested sludge: - This are the sludge produced from the biological stabilization.
- Mixed sludge: - It is the mixture of primary and biological sludge.
- Physico-chemical sludge: - It is generated by the physico-chemical treatment of wastewater.
- Mineral sludge: - it is produced from the mineral industries, quarry etc.,

2. Characteristics of the sludge

Sludge has a very high convoluted nature due to which there is a vast change in their characteristics like physical, chemical and biological. Understanding the behaviour of sludge and its characteristics is utmost difficult issues in the treatment of sludge [3]. However, it is important to study its properties and understand the concept and also its effect on the treatment system.

In the early study it was shown that as the sludge quantity increases, phosphorous content decreases. So it was stated that sludge characteristic changes with respect to the source [4]. Table 1 shows the various sludge characteristics.

| Physical Characteristics | Chemical Characteristics | Biological Characteristics |
|--------------------------|--------------------------|----------------------------|
| Odour                    | pH                       | Microbial community       |
| Colour                   | Alkalinity                | Surface polymers          |
| Drainability             | Solid concentration      | Sludge stability           |
| Specific gravity         | Surface charge            |                            |
| Settleability            | Fertilizer and nutrient value |                        |
| Particle size and shape  | Heavy metal and toxic organics |                     |
After sludge conditioning, thickening and digestion, sludge is dewatered before processing it to incineration, landfilling and composting, which leads to reduction in sludge content and sludge transportation cost [5]. In this study, it is aimed to address on sludge dewatering options. Figure 2 shows the different stages of sludge treatment processes.

**Figure 2** shows the main stages of sludge treatment processes

Sludge dewaterability is also sometimes referred as sludge filterability. Final solid content achievable by reducing the sludge volume is the main goals of dewatering. There are different ways to improve dewaterability of bio sludge. [6] reported that the filterability of sludge is used to check initially
the output of dewatering. Also, he has analysed and concluded that sludge treatment, transportation of sludge and disposal of sludge requires 50 to 60% cost of wastewater treatment in the treatment plant.

3. Sludge conditioning

Solid liquid separation is necessary and can be achieved by mechanical thickening and sludge dewatering by conditioning. Physical processes, biological and chemical processes are the methods used for the sludge conditioning and these methods changes the characteristics of the sludge by gaining the dewatering performance by enhancing the settleability, filterability and also by releasing the trapped water.

3.1 Chemical conditioning

When certain chemicals are applied to either a raw or digested sludge or with other mixture, they develop a relatively insoluble flock that agglomerates suspended and colloidal particles, conditioning is carried out using organic or inorganic additives. Chemical conditioning is done in small scale researchers when compare to large scale treatment. The main intension of sludge conditioning is to create a rigid lattice structure so that the liquid content easily flows between the sludge particles without resistance [7].

The efficiency of Chemical conditioning is affected by various factors like properties of the sludge, type of sludge, type of conditioners used, pH, mixing rate, dewatering method etc., The conditioners for the sludge conditioning are selected based on the sludge type to be dewatered. The two main mechanisms which takes place in chemical conditioning are neutralization and particle bridging for the formation of floc structure. Usually, the wastewater sludge possesses an anion charge hence for the neutralization process a cation charge additive are used so that individual particles are flocculated. Following are the various chemical conditioning methods.

- Organic additives: Organic additives in terms of polyelectrolyte are used since many years so as to enhance efficiency of mechanical dewaterability during the conditioning of sludge. Two different mechanisms may clarify sludge conditioning by polyelectrolytes: charging neutralization and interparticle bridging [8].
- inorganic additives: inorganic additives are also considered quite expense that the organic counterparts, and can be widely used in various treatment practices, such as sludge dewatering, wastewater beverage industry. Since the coagulant is mainly based on aluminium or iron, it is highly useful in reducing turbidity and dewatering of the sludge [9].

3.2 Physical conditioning

From an economic and environmental point of view, physical conditioning techniques are usually more beneficial among the methods used to increase the dewater capacity of bio sludges [10].

A broad variety of systems achieve through the physical conditioning. Physical conditioners, including minerals and carbonaceous materials, which helps in developing voids so that a firm lattice structure is obtained. physical conditioners are are called as skeleton builders.

| Table 2. Various physical conditioners |
|---------------------------------------|
| **Form of filter aid** | **Skeleton materials** |
| Inorganic | Alum sludge |
| Fly ash |
| Gypsum |
| Lime |
| Cement Kiln dust |
Non-chemical additives are also called physical conditioners. Various physical conditioners are listed in Table 2. Physical conditioners are the highly porous inert materials that minimize high compressibility, enhance solid permeability and enhance sludge mechanical power. Carbonaceous materials have a high advantage in the process of dewatering sludge when compared to mineral materials, since it contains high heating value, high porosity and low ash content[11]. Following are the various physical conditioning methods.

- **Non-Chemical Additives**: Non-Chemical Additives are the conditioners used in sludge dewatering which may be organic or carbonaceous. Non-Chemical Additives helps in mechanical dewatering as the load is applied to the sludge these additives helps in providing porous structure with more voids so that the liquid can be easily penetrated as well as the compressibility of the sludge is reduced. Hence these additives are also called as skeleton materials or filter aid[12].

- **Cavitation pre-treatment**: Cavitation is a mechanism through which the local pressure in the liquid phase is decreases below the equilibrium vapor pressure and some microcavities or microbubbles are created after reaching an unstable diameter, gradually rising and violently collapsing. This method generates a shock wave that locally causes high temperature[13].

- **Thermal pre-treatment**: Heat allows water to escape from the sludge when the organic sludge is heated. Thermal treatment systems release water that is bound within the sludge's cell structure, thus enhancing the sludge's dewatering and thickening functionality. In thermal pre-treatment the sludge is treated at 70-190°C this range, thermal pre-treatment will split the cell wall and the biologically degrading proteins release [14].

- **Freeze/Thaw treatment**: Freeze / thaw treatment is one more physically effectual way to alter the arrangement of the floc and to decrease the content of bound water in the sludge. Meanwhile in the sludge is first frozen, about 15 C, and kept at this state for some time, and then thawed at room temperature. Water and solid particles separate during the formation of ice crystals [15].

### 3.3 Biological conditioning

By disrupting the gel structure of flocks by hydrolysis of EPS contained in the sludge, the biological or enzyme pre-treatment of sludge increases the dewaterability of sludge. As all enzymes are proteins and are often assumed to be environment conscious, these techniques could be very attractive, specifically when it substitutes neurotoxic acrylamide based synthetic polymers [16].

The influence, individually or in combination, of industrial microbial cellulase, protease and lipase enzymes on the decrease in solid disposal amount of anaerobically digested wastewater sludge. It has been found that a combination of these enzymes reduces total suspended solids by thirty to fifty percent by weight in equal proportion and increases solid settlement. To extract EPS from sewage sludge, enzymes and enzymes combined with sodium tripolyphosphate (STPP) were introduced. They reported that enzymes in conjunction with STTP released greater quantities of total EPS compared to enzymes on their own [17].
4. Sludge dewatering

Dewatering will be taken up before the incineration or thermal drying because it reduces the fuel consumption and also reduction in the leachate as the sludge disposal to landfill is less. Sludge dewatering helps to remove as much water from the sludge as possible, leading into the reduction of biosolids concentration and, subsequently, the transport costs. Dewatering methods widely used include mechanical methods and thermal processes. Sludge often needs a conditioning procedure before mechanical dewatering to improve the efficiency of water content removal [18].

Based on the volume as well as characteristics of the sludge, different processes are identified. Mechanical dewatering processes are compared to thermal ones when considering economy. There are two key criteria used as dewatering output representatives which are the concentration of solid cake and the consistency of centrate. After all, the vital role of the dewatering process is to maximize the solid sludge amount so as to decrease the volume of sludge, dry solid content has to be specified as a indicator that represents the process's efficacy. Although supernatant quality represents the efficiency of solid capture during the process of conditioning and dewatering, in particular, when the centrifuge is used as a dewatering process. During conditioning and dewatering, it is important to remove as many solids as achievable for the efficient operation of sewage treatment [19]. It minimizes solids disposal to the plant inlet when the liquid fraction is returned to the head – of – works. Meanwhile all the wastewater treatment plants, the aim of dewatering sludge is to establish a clean center while obtaining a cake high in solids.

5. Assessment of sludge dewaterability

Several tests used to measure the efficiency of various conditioners often provide useful information that can be used to determine sludge dewaterability. Assessment of dewaterability is an important factor in all treatment facilities and also the goal of the treatment facilities is to optimize dewatering process. Nonetheless, due to the volatile and mysterious nature of the sludge forms along with differences in dewatering methods, this work is fairly challenging. Various measurements for the dewatering process are already studied and tested out over years in combination with the dewatering technology before the dewatering assessments were created.

However, despite these developments, there is no formal dewatering index yet that can completely reflect the capacity to dewater sludge. An accurate dewatering index is believed to not only approximate the actual water separation whereas to estimate the overall achievable solid concentration of the sludge cake. One or both of these tend to lack traditional dewatering indices, and therefore they hardly properly convey the efficiency of dewatering. Following are the various indices for the assessment of sludge dewaterability.

- **Specific resistance to filtration (SRF):** Specific resistance is a general used to test dewaterability of sludge. The frequency at which water drains off from the sludge through an imposed vacuum is assessed and described in form of dewatering resistance of the sludge. Increase in specific resistance value indicates that it is less easy to dewater the sludge. SRF method has many significant benefits, as independent of the concentration of solids. It can be used particularly to estimate the concentration of the final cake after dewatering. Most of the techniques developed to determine the dewatering efficiency of filtration devices. These tests are time-consuming and the procedures are very complicated and involve a high degree of skill. Such
examinations are time-consuming and the techniques are very complex and require a high degree of expertise [20].

- Capillary suction time (CST): CST is simple to run, it provided a fast sign of filterability, and the findings found strong reproducibility. In CST test a small test tube open at both the ends where the one end is kept at the filter paper and the other samples are dropped. Paper's capillary suction extracts centrate from the sludge, dampen up surface. Filtrate time needed to flow 1 cm is reported as capillary suction time or CST. CST measuring is simpler and uncomplicated to test, and requires less expertise than Measuring, making it more common recently. CST was originally designed to calculate the dewatering rate as a replacement for Freshwater. Given that, in reality, CST is still not considered to be fundamental methods of measuring the dewaterability of sludge. Unlike SRF, CST is influenced by solid concentration and can't figure out the final cake solids that can be achieved by dewatering devices [21].

- Time to filter (TTF): The TTF test is an experiment where in vacuum application in a Buchner funnel filled and attached with filter paper, and measuring the time needed for the collection of samples in the graduated cylinder of a fixed volume of supernatant (usually 50 percent of the sample volume). The amount of time it takes to obtain the specified filtrate volume is the TTF. The minimum TTF value is set to imply optimum sludge conditioning. The Time-to-Filter (TTF) test is an attempt to simplify the complicated procedures involved in the more basic SRF testing. The TTF test involves measuring the time needed for filtration of a sludge or a conditioned sludge sample, rather than the actual resistances, using the same laboratory technique as the SRF test.

- Zeta potential: Zeta potential (ZP) is the electric al potential that occurs over a solid particle at the shear plane. The shear plane is a interface that behave like a obstacle bed of water that stays further from the particle that travels in alliance to the particle, with the solid and water. Due to its quantification of the electrical potential that induces interparticle repulsion, ZP measurements have been used to test particle stability and successful flocculation. A near zero ZP indicates minimal electrical repulsion, allowing attractive van der Waals forces to effect agglomeration of particles [22].

- Centrifugation: During centrifugation, the liquid and solid fractions are separated under the action of centrifugal force. The factors which have to be set during centrifuge are time, temperature and speed. Factors which are influenced in centrifuge is type of sludge, temperature and concentration of solids. Centrifuges are equipped with continuous and space-saving dewatering systems combined with high performance to isolate solids from sludge mixtures. A major use is the sludge dewatering in wastewater treatment plants. The spinning parts of the centrifuge, the drum and the scroll, are powered by two inverter-controlled electric motors and controlled by software running on a PLC [23].

- Rheology: Rheological characteristics are representative of floc intensity. In the management of sewage sludge, rheological parameters are very important, not only as the design of parameters in transport, landfilling ect., but also as the control of parameters in several treatments. While early research on the rheological behavior of sewage sludge has been carried out since the 1930s. Until recently, more studies have attempted to analyze the rheology of sludge dewaterability. The purpose of the conditioning and sludge dewatering is to anticipate, track and optimize [24].

Current dewatering indices are likely to lack and also dewatering efficiency was intended rarely. SRF is an unmanageable in connection with instrument and it is consuming the time, however after filtration, it only estimates the sludge content. Whereas the usage of CST is very much and it has become popular as it is very much easy in measuring the sludge dewaterability but only limitation is that concentration of solid cannot be predicted. CST and SRF are associated with free water, nearly 20 percent of total the water content will be taken part.
6. Conclusion

The characteristics of sludge cake should be thoroughly analysed with respect to water content, solid components, and floc characteristics in terms of understanding sludge. In order to achieve the optimum dewatering efficiency, a suitable porous and incompressible sludge cake structure can thus be developed and managed. Enhance the porosity and permeability of solid cake formation by using skeleton materials or filter aids such as slag or agricultural wastes. Carbon based physical additives are usually more effective in sludge dewatering than inorganic materials due to their increase porosity. Due to its low price and eco-friendliness of used materials, once it could give expected dewatering efficiency, this technique is encouraged. For sludge with strong compressibility, chemical conditioning itself will not always attain a sufficient improvement in dewatering quality. Physical conditioners that serve as skeleton constructors have been utilized to improve sludge dewaterability by providing more stable and incompressible structures to the sludge solids. For every sludge treatment system where enhancing the dewatering process is the goal, assessment of the dewaterability of sludge significantly necessary. As always, due to the erratic and elusive behaviour of all types of sludge, particularly bio-sludge, and also inconsistencies in solid-liquid separation methods, this study is relatively difficult. Although similar metrics for the very first dewatering indices are different for the method of dewatering has been studied and implemented over the years with the science of dewatering in tandem. There seems to be a lack of one or both of these traditional dewatering indices and, therefore, they mostly convey the performance of dewatering properly.

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