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Recovery of coagulants from water works sludge: A review

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ABSTRACT

The management of the ever increasing residual sludge from our waterworks in an economical and environmentally friendly manner remains a very important issue. This has led to genuine efforts aimed at its beneficial re-use. The recovery of coagulants from water works sludge have been studied for several years, because of the toxic nature of free and complexed aluminum species to aquatic life, cost benefit of the recovery and the stringent environmental regulations on disposal of these sludge on land or into water bodies. This paper presents a review of the available reports of the researches on the various methods of recovery of coagulant from water works sludge.

Key words: Coagulants, Recovery methods, Water works, Sludge.

INTRODUCTION

There is a growing competition for water world wide because water is essential for all living things [1,2,3] and water quality provide the basis for judging the suitability of water for its designated uses [4]. Large quantity of aluminium- laden sludge is produced from various water works worldwide. Researches have shown that water works sludge contains 39% aluminum by weight after coagulation [5,6]. Studies have shown that free and complexed aluminum species are toxic to aquatic life, including benthic organisms [7,8]. Research result has also revealed aluminium's contributory influence to occurrence of alzhemer's disease [9]. Consequently, the water treatment sludge must be handled in accordance with environmental regulations in force particularly in this era when emphasis is on green technology. According to environmental protection regulations, it is required to minimize the quantity of wastes produced or where possible, the wastes should be re-used or processed as secondary raw materials and where this is not possible; the solid should be put back in the environment where the space occupied should be as little as possible and at a minimum cost [10]. There are thousands of drinking water treatment plants world wide which use coagulants for efficient removal of particulate solids and colloids thereby producing several tons of sludge per year [11,12], thus justifying the need for concern over their disposal and associated costs. The sludge produced in some selected countries is shown on the figure 1 below.

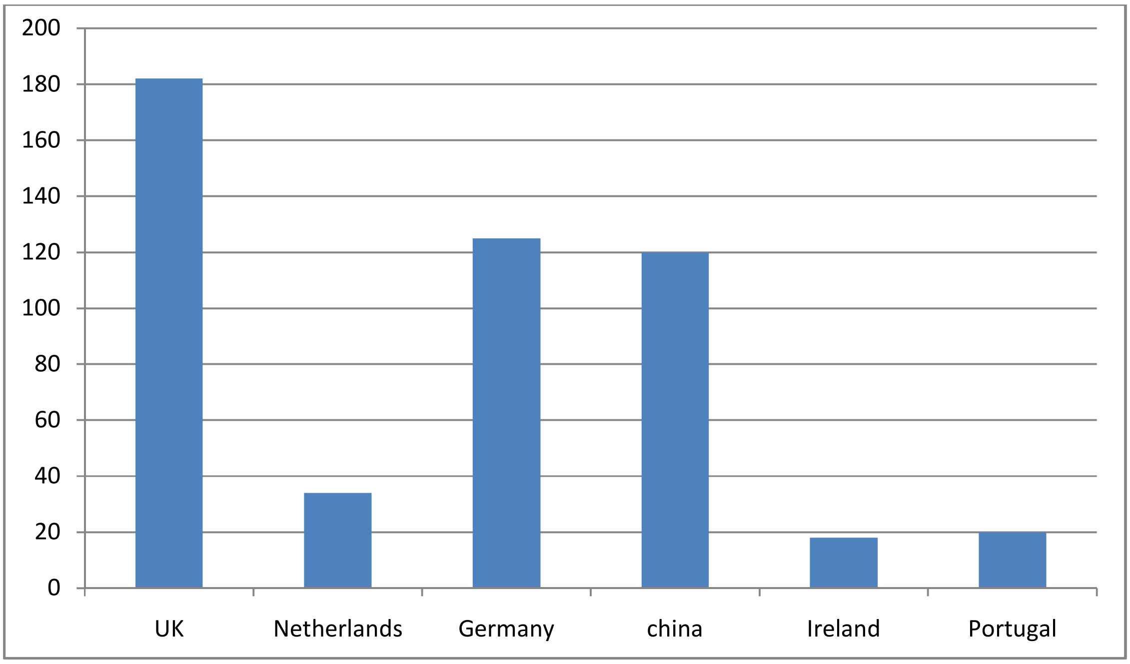

Fig. 1 Quantity of Waterworks sludge (x 10^3 t/Ds) produced in selected countries, from [11]

In Netherlands, the sludge disposal cost stands at a staggering sum of £30-£40 million as reported by [13], while in Ireland, it has been predicted that the cost will double by the end of next decade from a current estimate of 15,000 to 18,000 t/pa of the dried solids [14]. The aggregation of small colloidal particles into a larger mass or flocs referred to as coagulation is usually facilitated with the aid of chemical agents called coagulants [15,16]. Wide ranges of high performance organic and inorganic coagulants have been developed. They include aluminum sulphate, aluminum hydroxide chloride, sodium aluminate, ferric aluminum sulphate, poly aluminum chloride, polyDADMAC, EPIDMA cationic coagulants etc [17]. Coagulation generates the bulk of the residual materials during water treatment process and the type of and amount of coagulant used have significant effect on the amount of residue produced [18]. Sludge contains suspension of inorganic and organic substances typically, hydrated aluminum oxide and iron oxide [10]. In the treatment process, alum is finally converted into insoluble aluminum hydroxide ($Al(OH)_3$), which contains about 25% to 50% of the solids in the water treatment sludge [19,6]. It is still an issue to choose a disposal method for the water treatment sludge that would be reasonable in terms of technology and economy. There are Laboratory and full scale attempts at using waterworks sludge as a component in the manufacture of several materials such as concrete, cement mortars, clay materials, fired ceramic products (e.g. bricks, pipes and tiles) [20]; as geotechnical works materials [21; as a potential for use in agriculture and silviculture [22,23,24]; as a primary source of aluminium and iron based coagulants through several recovery process [12,18,25]; and for phosphorus reduction during wastewater treatment [26,27,28,29,30,31]. Direct application of alum sludge as a coagulant or coagulation aid shows that alum sludge was able to remove turbidity, TCOD and anionic surfactant [32]. The recovery of coagulant has high economic advantage and recommended as a suitable treatment option for the disposal of water works sludge [18,32]. This paper is aimed at reviewing the current status of researches on the various methods of recovering coagulant from water works sludge.

Nature of waterworks sludge

The nature of waterworks sludge depends on the type of coagulants and other treatment chemical used for the water treatment. Sludge is in particulate or gelatinous form consisting of microorganisms, organic and suspended matter, coagulants and other chemical elements. Typical composition of sludge can be seen on table 1 below.

Table 1. Typical composition of water treatment works derived sludge (mean values ± SD)

parameter	unit	Alum sludge	Ferric sludge	Lime sludge
Aluminum	% dry weight	29.7±13.3	10.0±4.8	0.5±0.8
Iron	,,	10.2±12	26.0±15.5	3.3±5.8
Calcium	,,	2.9±1.7	8.32±9.5	33.1±21.1
Magnesium	,,	0.89±0.8	1.6	2.2±1.04
SiO_2	,,	33.4±26.2	nd	54.57
pH		7.0±1.4	8.0±1.6	8.9±1.8
BOD	Mg/l	45(2-104)	nd	nd
P	% dry weight	0.35	0.36	0.02
Zinc	Mg/kg	33.9±28	18.7±16	2.5±0.7
± Lead	,,	44.1±38.2	19.3±25.3	1.87±1.13
Ca± dmium	,,	0.5	0.48±0.26	0.44±0.02
Ni± ckel	,,	44.3±38.4	42.9±39.2	0.98±0.52
Copper	,,	33.72±32.5	18.7±25.8	3.6±3.1
Chromium	,,	25.0±20.1	25.7±21.6	1.3±0.2
Cobalt	,,	1.06	1.61±1.1	0.67+0.05
Total solids	Mg/l	2500-52345	2132-5074	nd

Data from [11]

The composition of sludge depends on the characteristics of the raw water, type of coagulant used and the dosage applied and plant operating conditions.

Coagulant recovery methods

Generally, the methods of recovery of coagulants from water works sludge are acidification, alkalization, ion exchange and membrane separation [33]. However, a combination of these methods may be used to achieve a higher recovery.

Acid Digestion: The basic concept of coagulant recovery is acid digestion process where sulphuric acid react with insoluble aluminum hydroxide to form dilute liquid alum.

$$2Al(OH)_3.3H_2O + 3H_2SO_4 + 2H_2O \rightarrow Al_2(SO)_4.14H_2O$$

This has been tried on a laboratory scale, in pilot scale studies, and in full-scale at one of the treatment plants of Durham, N.C. [10,34,6]. Acidification is a high efficiency and low cost method among the above methods. According to [35], the aluminum recovery by acid extraction (pH 1.0 – 3.0) can reach 70-90%. However, this process is non-selective as it recovers along with alum all other substances that are soluble under high acidic conditions such as manganese, zinc, and lead. This will result in the built up of impurity in water if it is recycled for use as coagulant and if this recovered alum is reused there will trihalomethane formation during chlorination stage of the water treatment. Trihalomethanes are suspected carcinogens, regulated by the USEPA [33,36]. However, the recycled coagulant can be used in waste water treatment. Coagulant recovery from sludge generated in the clarification of pulp mill wastewater using acid digestion which was the re-used in the same process have been reported [37]. [38] reported that recovered coagulant has higher ability to reduce chemical oxygen demand (COD), total nitrogen (N-T) and total phosphorus (T-P) in the clarification of sewage and waste water from coastal land fill site in comparison with that of commercial $Al_2(SO_4)_3$ and poly Aluminum chloride (PACl). [39] also investigated the use of recycled alum for lead removal. Other research works on use acid digestion (acidification) have also been reported [33,40,41,42]. To improve the quality of alum recovered, acid treatment can be followed by ultra filtration. However, this suffers from various shortcomings such as fouling, decreased membrane life due to pressure differential, a decrease in flux with continued deposition, and the relative high cost of pumping [19]. An investigation on the feasibility of ferric ion recovery from chemical sludge and its recycle in chemically enhanced primary treatment (CEPT) through acidification show that the recovered coagulants can be used in CEPT with pollutant removal efficiency similar to that of fresh coagulant [42].

Alkalization: As an alternative to acidification, the amphoteric nature of aluminum oxide also permits alum recovery from water sludge under alkaline conditions. A report of feasibility of coagulant recycling by alkaline reaction of aluminum hydroxide sludge by [43] using sodium hydroxide (NaOH) and lime $Ca(OH)_2$ at pH ranges of 11.4-11.8 and 11.2-11.6 respectively gives yield of aluminates at 80% with NaOH and 30% with $Ca(OH)_2$. [44] also reported 79 -90% recovery of alum using alkaline method at a pH of 12.0. Similarly, [35] reported that highest removal efficiencies were found at the pH ranges of 11.4 – 11.8 and 11.2 – 11.6 using NaOH and $Ca(OH)_2$ respectively. However, the alkaline digestion process has the same limitations as the acid digestion process because high amount of natural organic matter are present in the recovered solution [19,33].

Ion Exchange and Membrane processes: Researches have been carried out on the industrial use of ion exchange membranes for separation processes such as in recycling and in water and wastewater treatment processes [45,46,47]. In order to improve the quality of the recovered coagulants using acidification process, the acidic leachate may be treated by ion exchange. The first process conceptualization was based on the use of liquid ion exchanger (LIE) [48] which uses organic solvents to recover highly pure concentrated alum from sludge and the second developed much later relied on the use of a composite ion exchanger [49]. However, the technical feasibility of the two proposed solutions was limited by physical thermodynamic and kinetic problems [12]. A laboratory scale comparative experiments between weak (carboxylate) and strong (sulphonic) cation resins performance with respect to a typical water clarifier sludge leachate (pH 3.5) of multicomponent polyvalent Al/Fe/Na ionic system was carried by [12] and carboxylate resin was found to be more suitable. [50] investigated the separation and recovery of Al(III) and Fe(III) species from clarifier sludge using ion exchange resin based on weak electrolyte carboxylate resin (purolite C106) where aluminum and ferric species were recovered during the regeneration stage. During the last two decades pressure driven membrane processes namely reverse osmosis (RO), nanofiltration (NF) and Ultrafiltration (UF) have found increased applications in water utilities and chemical industries [51,52,53]. These processes have the advantages of ability to remove particles and colloid almost completely, controlling microorganisms and pathogen and low cost. In this process, aluminum ions are selectively sorbed from an aqueous phase onto a composite membrane and there after desorbed, with the release of aluminum ions as the composite membrane is generated in a sulphuric acid solution. However, they are susceptible to fouling because particulate matter or large molecules concentrate on the membrane surface. Membrane fouling causes a decrease in membrane performance due to reduction of permeate flux through the membrane as a result of increased flow resistance due to pore blocking, concentration polarisation and cake formation [54]. Also, composite ion exchange materials are not available in sizes appropriate for large applications and the process is not capable of concentrating alum to high levels and there is always a solvent carryover that requires further treatment [18,51].

Donnan membrane process: Prakash and SenGupta in their United States patent 6495047 in 2002 invented a process for the selective recovery of a trivalent metal coagulant compound from clarifier solution based on the Donnan co-ion exclusion phenomenon to overcome the short comings of the earlier methods. The Donnan membrane principle states that non diffusible fixed charges in one phase in contact with water can be utilized to modulate the distribution of ions in both phases leading to efficient separation, product recovery, synthesis of smart materials and other innovate applications [55]. The Donnan membrane process or Donnan dialysis which is driven by electrochemical potential gradient across an ion exchange membrane is uniquely capable of recovering alum from water sludge in a single step process using sulphuric acid and a cation exchange membrane and can concentrate alum in the recovered solution; achieve near complete rejection of natural organic matter (NOM) or dissolved organic carbon (DOC); reduce carryover of heavy metals such as copper, zinc etc into the recovered alum; provide the use of recovered alum as coagulant in the same plant without the possibility of trichloromethane formation upon chlorination; and reduce the volume of sludge and the cost of its disposal [19].

Economic Assessment of Coagulant Recovery

Research results will remain a mere academic exercise if the whole process is not economically viable. The economic feasibility of the coagulant recovery from waterworks sludge has been largely overlooked over the years. However, a recent work by [56] used empirical data taken from bench-scale tests of coagulant recovery using Donnan dialysis (DD) with bulk chemical prices to determine the operational expenditure (OPEX) for full-scale recovery. Calculated values were compared with existing coagulant dosing procedures, with those based on electrodialysis (ED) and ultrafiltration (UF), to determine the cost benefit. It was determined that under current commodity and technology prices, coagulant recovery by DD offers no cost benefit in comparison to conventional practice. Process improvements, such as incorporating acid recovery, identifying alternative waste disposal routes and improving membrane performance, can significantly increase economic viability. UF was shown to provide OPEX reductions of around 40% when compared to conventional practice, and ED was found to be cost neutral. None of the assessed technologies are currently able to offer cost benefit for ferric coagulant.

CONCLUSION

Coagulant recovery from waterworks sludge for re-use, though not a new concept remains a key option towards the reduction of chemical usage in the water industry. The whole concept has undergone modifications and improvements over the years through research efforts. In this paper various treatment methods such as acidification, alkalization and ion exchange and membrane processes were reviewed. Ion selective membranes have recently been shown to satisfactorily address the problem of product quality. There is however need for further researches on the economic feasibility which has been largely overlooked.

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