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Comparative assessment of water treatment using polymeric and inorganic coagulants

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ABSTRACT

Portable water plays a vital role in improving human life, particularly in controlling the spread of diseases. However, problems associated with lack of potable water are still common especially in developing countries including Malawi. Until now little information exists on the effectiveness of available commercial coagulants used by national water boards in Malawi. Therefore, this study was undertaken in Southern Region Water Board (SRWB) to investigate the efficiency of polymeric coagulants (sufdfloc 3850 and algaefloc 19s) in turbidity reduction comparative with inorganic coagulant (aluminium sulphate) at Zomba, Liwonde, Mangochi, Chikwawa and Mulanje Treatment plants. The jar test method was used to determine the effectiveness of the water coagulants. The results revealed that sudfloc 3850 was most effective in reducing turbidity at Mangochi (99.4 ± 0.06%) and Liwonde (97.2 ± 0.04%) using 0.4 mg L^{-1} flocculant dose. The Zomba, Mulanje and Chikwawa plants gave 19.56 ± 0.03%, 29.23 ± 0.02% and 9.43 ± 0.02% total reductions respectively. Algaefloc 19s afforded the highest turbidity reduction at Liwonde and Mangochi plants (98.66 ± 0.06 and 97.48 ± 0.05% at a dose of 0.4 and 0.6 mg L^{-1} respectively), while Chikwawa provided the lowest (9.52 ± 0.01%). At the Zomba and Mulanje plants 20.5 ± 0.03% and 28.4 ± 0.04% reductions were obtained respectively. The inorganic flocculant, alum provided a 99.0 ± 0.05% and 98.6 ± 0.04% reduction at a dose of 4.0 mg L^{-1} and 6.0 mg L^{-1} at Zomba and Liwonde plants respectively. The lowest reductions in turbidity were achieved at Chikwawa (7.50 ± 0.01%), Mangochi (12.97 ± 0.02%) and Mulanje (25.00 ± 0.02). The best and optimum pH ranges for polymeric and inorganic coagulants were 7.20–7.80 and 7.35 to 7.57 respectively. The results further revealed that sudfloc 3850 and algaefloc 19s achieved faster formation of heavy flocs than alum. At 0.4 mg L^{-1} flocculant dosage sudfloc 3850 and algaefloc 19s required ten times lower dosages than alum. Therefore, the polymeric coagulants could be used instead of alum, the choice dependant on the type of water.

1. Introduction

1.1. Background

Water is a finite natural resource and many parts of the world are facing increasing pressures on their water resources. Water plays a vital role in improving human life, particularly in the prevention of the spread of disease causing microorganisms. Thus, the search for safe and clean water has been an area of priority concern since time immemorial (Hall and Dietrich, 2000; Tebbutt, 1998). Water is at the centre of Millennium Development Goals (MDGs) numbers 1, 3 and 7, and indirectly linked with the other MDGs (WHO, 2008; GWP, 2010). However, many people in developing world (about 1.1 billion), usually in the rural areas, do not have safe water supply and also lack adequate sanitation (WHO/UNICEF, 2008, GWP, 2010). Despite enormous progress made in improving water supply coverage especially during the International Drinking-Water Supply and Sanitation Decade, 1981–1990 (IDWSSD), the lack of access to potable water still remains a major burden of water borne diseases and constraint to socio-economic development (Helmer et al., 1998). Outbreaks of water borne diseases continue to

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present a major health problem worldwide particularly in developing countries including Malawi (GWP, 2010; MoIWD, 2010; Manda, 2009).

1.2. Drinking water treatment

Water treatment is a process of making water suitable for its application or returning its natural state. The treatment may include mechanical, physical, biological, and chemical methods. The objective of water treatment is to produce safe and potable drinking water. Water to be supplied for public use must be potable i.e., satisfactory for drinking purposes from the standpoint of its chemical, physical and biological characteristics. Drinking water should, preferably, be obtained from a source free from pollution. The raw water normally available from surface water sources is, however, not directly suitable for drinking purposes. The period prior to 500 BC to 1000 AD people used naturally occurring products in the purification of water (de Manor, 2007). In the 20th century, water treatment methods progressed significantly with the incorporation of filtration processes in the treatment system and the introduction of chemical methods for water disinfection using chlorine and ozone. Common water sources for municipal water supplies are deep wells, shallow wells, rivers, natural lakes, and reservoirs. Depending on the quality of the raw water, the extent of pollution and the regulations for safeguarding of public health, drinking water is treated by various methods before it reaches the consumer (Tebbutt, 1998; de Manor, 2007).

Household treatment methods which are in use include boiling, filtration, disinfection with chlorination or solar disinfection (Droste, 1997); while components of municipal drinking water treatment methods include storage, coarse screens, plain sedimentation basins, flocculator, clarifier, clariflocculator (for combined flocculator and clarifier system), rapid filters (gravity filters or pressure filter), disinfection, and removal of minerals and ions. Filtration process is done using several techniques including rapid granular media, slow sand and other biological filters, and Membrane filters (micro-, ultra-, nano- and reverse osmosis). Other physical-chemical removal processes consist of chemical coagulation, precipitation and complexation; adsorption (use of activated carbon, and bone char), and ion exchange (including synthetic ion exchange resins, and zeolites). The treatment processes may need pretreatment like pre-chlorination and aeration prior to conventional treatment (Letterman and Cullen, 1985; Droste, 1997) (Fig. 1).

1.2.1. Coagulation and flocculation

Coagulation is a physical and chemical reaction occurring between the alkalinity of the water and the coagulant added to the water, which results in the formation of insoluble flocs. Flocculation is the controlled motion or agitation of water which will assist in the formation of settleable floc formation (Tebbutt, 1998; Armirtharajah and O'Melia, 1990). The purpose of coagulation and flocculation is to remove particulate impurities, especially non-settleable solids (colloids) and colour from the water being treated. Non-settleable particles in water are removed by the use of coagulating chemicals (Droste, 1997). Finer particles must be chemically coagulated to produce larger floc that is removable in subsequent settling and filtration processes. Coagulation and flocculation are sensitive to factors such as type and nature of turbidity producing substances, turbidity levels, type of coagulant and its dose, the rate of change of velocity per unit distance normal to a section, and pH of water (Tebbutt, 1998). Flocculation can be achieved by various methods such as gravitational or hydraulic methods (like horizontal flow baffled flocculator, vertical flow baffled flocculator, jet flocculator), mechanical methods (like paddle flocculators), and pneumatic methods (MIWR/UNICEF, 2009).

Generally used metal coagulants in water treatment are first based on aluminium such as aluminium sulphate, sodium aluminates, potash alum, and ammonia alum, and secondly based on iron such as ferric sulphate, chlorinated ferrous sulphate, and ferric chloride (Table 1). Other new coagulants currently in use are sudfloc 3850 and algaefloc 19s (trade mark names). The most commonly used coagulant is ferric alum. However, Poly Aluminium Chloride (PAC) is also used as a coagulant with the following advantages i) it gets properly dispersed, ii) it does not have any insoluble residue, iii) it does not affect the settling tanks, iv) it is more effective than alum and v) it requires less space (may be about 50%) (Tebbutt, 1998; Droste, 1997).

PAC is disadvantageous in that it is less effective in removal of colour (Chemist and Environmental Officer, SRWB, personal communication). Synthetic polymers are used as coagulant aids to improve settling and toughness of floc. Coagulant chemicals come in two main types – primary coagulants and coagulants aids, the former neutralise the electrical charges of particles in water which cause them to clump while the later add density to slow-settling flocs and add toughness to the flocs so that they don't break up during mixing and settling processes. Primary coagulants are always used in the coagulation/flocculation process. Coagulant aids, in contrast, are not always required and are generally used to reduce flocculation time (Tebbutt, 1998; Armirtharajah and O'Melia, 1990).

1.2.2. Selection of coagulants

The most important consideration in selection of coagulants is the choosing of the proper type and amount of coagulant chemical to be added to the water to be treated. Overdosing as well as under dosing of coagulants may lead to reduced solids removal efficiency (Tebbutt, 1998). This condition may be corrected by carefully performing Jar tests and verifying process performance after making any change in the process of the coagulation process. During water treatment, the most important coagulation-flocculation process actions are to monitor process performance; evaluate water quality conditions (raw and treated water); check and adjust process controls and equipment; and visually inspect facilities (Fig. 2) (Kiely, 1996; Tebbutt, 1998; Droste, 1997).

1.2.3. Jar tests

The jar test has been and is still the most widely used method employed to evaluate the coagulation process and to aid the plant operator in optimizing the coagulation, flocculation and clarification processes. Thus, jar tests are widely used to determine optimum chemical dosages for treatment. This laboratory test attempts to simulate the full scale coagulation-flocculation process and can be conducted for a wide range of conditions. The interpretation of test results involves visual and chemical testing of the clarified water. From the turbidity values of the settled water, settling velocity distribution curves can be drawn. These curves have been found to correlate well with the plant operating data and yield useful information in evaluating pre-treatment, such as optimizing of velocity gradient and agitation and flocculation, pH, coagulation dosage and coagulant solution strength. Such curves cannot be generalized and are relevant to the plant for which the data have been collected through the jar tests. In addition, the turbidity, colour and alkalinity of the raw and treated water should be measured for evaluation of the treatment (MIWR/UNICEF, 2009; Droste, 1997; Hammer and Hammer, 2001).

1.2.4. Disinfection

This is the process of killing the microbes usually in the treated water, making the water safe to drink and preventing water-borne diseases. When water comes out of filter units, it may contain