POLY ALUMINIUM CHLORIDE AS AN ALTERNATIVE TO ALUM AS A COAGULANT IN WATER TREATMENT

Shyama Dharmasinghe

(Adm. No: 139206L)

Degree of Master of Engineering in Environment Engineering and Management

Department of Civil Engineering

University of Moratuwa
Sri Lanka

September 2017

POLY ALUMINIUM CHLORIDE AS AN ALTERNATIVE TO ALUM AS A COAGULANT IN WATER TREATMENT

Shyama Dharmasinghe

(Adm. No: 139206L)

Degree of Master of Engineering in Environment Engineering and Management

Department of Civil Engineering

University of Moratuwa
Sri Lanka

September 2017

DECLARATION OF THE CANDIDATE AND SUPERVISOR

I declare that this is my own work and thesis does not incorporate without acknowledgement any material previously submitted for a Degree or Diploma in any other University or institute of higher learning and to the best of my knowledge and belief it does not contain any material previously published or written by another person except where the acknowledgement is made in the text.

Also, I hereby grant to University of Moratuwa the non-exclusive right to reproduce and distribute my thesis, in whole or part in print, electronic or other medium. I retain the right to use this content in whole or part in future works (such as articles or books).

………………………… ………………………..

S.Dharmasinghe Date

The above candidate has carried out research for the Masters under my supervision.

…………………………… ……………………….

Signature of the Supervisor: Date

Prof (Mrs) N. Rathnayake
Professor
Department of Civil Engineering
University of Moratuwa

ABSTRACT

Water generally contains suspended and colloidal solids from land erosion, decaying vegetation, microorganisms, and color producing compounds. In addition, due to urbanization and industrial development, pollution of water bodies has become a serious concern. As surface water is the most common source of water supply, the need for treatment of water increases as the surface water bodies get polluted.

Coagulation and flocculation using chemicals, followed by sedimentation or clarification, filtration and disinfection is the conventional method of removal of the above contaminants from raw water. A wide variety of chemicals are used to achieve good coagulation/flocculation in the water industry.

Aluminium Sulphate (alum) is one of the most widely used coagulants in Sri Lanka. The main reasons for the usage of alum are its affordability, availability and lack of low cost alternatives. However, there are other costs and problems associated with the use of alum. Due to the high sludge handling cost, pH adjustment and slow formation of flocs, and also recent issues related to availability of alum at a reasonable cost, the need has arisen to select alternative coagulants for the coagulation process. Poly Aluminium Chloride (PACL) is used as a coagulant in a few treatment plants in Sri Lanka and neighboring countries as an alternative to alum.

In this study, it was aimed to compare the performance of the two coagulants alum and PACL in turbidity and colour removal and to assess the feasibility of substituting alum with PACL. Jar tests were carried out to obtain the optimum coagulant doses required and floc size using water from the two sources supplying the Colombo North area (Kelani Ganga at Biyagama) and Colombo South area (Kalu Ganga at Kandana) when the seasonal variation in river flows caused variations in turbidity. In addition, a questionnaire survey was carried out to investigate the opinions of engineers, chemists and operators who have used both coagulants in the treatment process.

The study revealed that the overall performance of PACL is better than alum with respect to floc size and the optimum dosage required is less for the former. From the opinion survey, it was evident that the majority of those who have used both coagulants recommended the use of PACL, even though some modifications to Plant are needed.

Key Words: Water Treatment, Coagulants, Alum, Poly Aluminium Chloride, Turbidity

ACKNOWLEDGEMENT

I would like to take this opportunity to express my sincere appreciation and indebtedness to my supervisor Professor Mrs N. Rathnayake for her valuable guidance and advice, to complete the research successfully.

Further, I am grateful to Professor Jagath Manathunga and the course coordinator to the MSc in Environmental Management and Engineering Programme, Professor Mahesh Jayaweera in University of Moratuwa for their valuable guidance, instructions and technical advices, continuously for the enhance my knowledge in the field of evironmental Engineering. Also, I like to thankful to non-academic staff of the university who support to complete the research successfully in many ways.

I am extremely appreciative of Mr. Wijeratne, Manager of the Kandana Water Treatment Plant and his staff, for providing the water plant data, raw water samples and all chemicals in my laboratory work. As well, I would like to acknowledge all staff of the Biyagama Water Treatment Plant for giving me their support to fulfill my laboratory work. Also, I like to thankful to my immediate senior officer, Mr.G.M.Mathuranesan and other section colleagues for their valuable guidance and instruction given me to complete this research successfully. This research would not have been accomplished without their support.

Moreover, I am grateful to the staff of National Water Supply & Drainage Board for their cooperation and providing required information for the study. I am extending my gratitude to the staff of Library in National Water Supply & Drainage Board to provide valuable handbooks, reports and other relevant documents to success my Thesis.

Finally, I acknowledge the support received from numerous others not mentioned above, who contributed to obtain the valuable achievements in my career.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF ABBREVIATIONS

Abbreviation	Description
ALUM	Aluminium Sulphate
Al	Aluminium
AWWA	American Water Works Association
^{0}C	Degrees Celsius
EPA	Environmental Protection Agency
FSD	Floc Size Distribution
g	Grams
HU	Hessan Units
MCL	Maximum Concentration Level
mg/l	Milligrams per liter
NOM	Natural Organic Matter
NTU	Nephelometric Turbidity Meter
NWSDB	National Water Supply & Drainage Board
PACL	Poly Aluminium Chloride
PAS	Poly Aluminium Sulphate
PASS	Poly Aluminium Silicate Sulphate
ppm	parts per million
TCU	True Colour Units
WHO	World Health Organization
WSP	Water Safety Plan
WTP	Water Treatment Plant

APPENDICES

1.0 INTRODUCTION

Water is one of the major natural resources of the world. Most of the earth's water is sea water. Although 67% of the earth's surface is covered by water, only less than 2.7% of the earth's water is freshwater. About 2.5% of the water is fresh water that does not contain significant levels of dissolved minerals or salt and two thirds of it is frozen in ice caps and glaciers. Accordingly, less than 0.01% is available for human use. Clean drinking water is a basic human need. But, more than one in six people still lack reliable access to safe drinking water especially in the developing world [1].

Water generally contains suspended and colloidal solids from land erosion, decayed vegetation, microorganisms, and colour-producing compounds [2]. Increasing population growth, improvements of living standards, and industrial and commercial development are factors that increase the community's water consumption. The quality of drinking water for humans has been badly affected by pollution. Surface water consists of colloidal impurities which produce turbidity and colour which indicate the poor quality of the water. Therefore, it is necessary to add chemicals that help to settle these colloidal impurities in a short period of time. These chemicals are named coagulants and are used for coagulation and flocculation in water treatment [3].

Water treatment is essential to provide safe drinking water for people. Common processes of water treatment include coagulation, flocculation, sedimentation, filtration and disinfection. Coagulation/flocculation is a part of the water treatment process whereby the colloidal particles are made to agglomerate and settle down at the bottom of the tanks as flocs [4]. Coagulants are necessary for optimizing coagulation which could remove turbidity and organic matter. Proper coagulation is essential for good filtration and disinfection. Optimizing coagulation is the most cost-effective way to reduce treated water turbidity and disinfection [5].

1.1 Background to Research

Surface water has different kinds of suspended materials which cause turbidity and colour. Turbidity causes a range of issues depending on the water sources. Turbidity can be reduced by dosing with chemical coagulants. There are several reagents available in the market. But, it is important to select the best quality, effective coagulant to treat water efficiently.

Commonly used coagulants in water treatment are:

1. Coagulants based on aluminum, such as aluminum sulfate (Al_2 $(SO_4)_3.18H_2O$), sodium aluminates (Na_3AlO_3), poly aluminum chloride [Al_2 $(OH)_xCl_{6-x}$]n, potash aluminum (AlK $(SO_4)_2$. $2H_2O$), and ammonia aluminum ($AlNH_4$ $(SO_4)_2$ $.12H_2O$),
2. Coagulants based on iron, such as ferric sulfate ($FeSO_4.7H_2O$), chlorinated coppers, and ferric chloride ($FeCl_3$),
3. Polyelectrolytes, which are long-chain synthetic polymers with a high molecular weight. These organic chemicals are commercially available under a wide variety of trade names [2].

Population increase and consequent increase in water demand, National Water Supply & Drainage Board (NWSDB) has to increase the supply of water and design and construct new water treatment plant systems or advanced technology processes within the treatment train to meet the increased demand for water by a growing population.

However, construction of new water treatment systems has various limitations. Future projects will be much more expensive and require capital investment; due to increasing social and environmental awareness delays will occur; project implementation takes time; land is required for new projects; distant sources have to be reached which are very expensive to development and convey to the proposed treatment plant, etc. Therefore, new technology is required for improvement of the water treatment process using existing water treatment plants themselves.

1.2 Problem Statement

In Sri Lanka, most of the Water Treatment Plants are operated by the NWSDB. The main water sources for the water treatment plants are surface water. In the treatment process, aluminium sulphate is widely used as a coagulant regent in the coagulation process.

However, there are many problems associated with the use of aluminium sulphate in the treatment process as follows:

1. Alum is highly acidic and it induces a drop in the pH value of water. This creates the need to feed additional chemicals (lime or caustic soda) to compensate for the declining pH value. Large amounts of aluminium hydroxide sludge are produced by the use of alum. Considering all the steps in the treatment process, the cost of using alum is an indirect expense in the following activities in the treatment:
   - Pre and post pH adjustment (lime or caustic soda, etc.)
   - Sludge treatment
   - Sludge disposal

2. At present alum is imported from China. The Chinese Government has suspended the manufacture of alum for safety reasons and environmental pollution. Importing alum from other countries may be costly. Therefore, another coagulation chemical has to be used instead of alum.

There are several alternatives that are used as coagulants in other parts of the world. PACL is used in a limited number of treatment plants in Sri Lanka as an alternative to alum. In order to minimize the above problems and achieve a cost- effective and efficient treatment process the use of a proper coagulant is vital in the treatment process.

1.3 Aim and Objective of the Research

The main objective of this research is to find a coagulant as an alternative to aluminium sulphate, taking into consideration the issues encountered.

The specific objectives were to:

- Study the available alternatives and their advantages and disadvantages through a review of literature, and select one or two suitable chemicals for further study
- Assess the acceptability of the selected alternative/s compared to alum using a questionnaire survey among the treatment plant operating staff and other officers.
- Compare turbidity removal efficiency and floc settling properties at different turbidity levels for the selected alternative/s and aluminium sulphate (alum) using laboratory data
- Investigate the financial aspects of using the selected alternative/s and alum

1.4 Selection of Coagulants

The quality of raw water and the contaminant classification, have a significant impact on the type of chemicals used for liquid-solid separation. The liquid-solid separation processes of coagulation/flocculation and subsequent filtration, when optimized, can remove all organic, inorganic and suspended matter to a level below water quality standards in most cases [6]. There are several factors to consider;

1. The amount of alkalinity present in the water may remove some coagulants from consideration.
2. The amount of turbidity present may only determine the amount of coagulant that may be required [7].

The most significant factor is the selection of the proper type and amount of coagulant chemical to add to the water for the treatment.

The jar test has been and is still the most widely used method of laboratory testing to evaluate the coagulation process of untreated water. This test provides information on the effects of the monitoring process performance, evaluating water quality conditions (raw and treated water), checking and adjusting process controls and equipment, and visually inspecting the facilities. The jar test is often used for the design of treatment facilities and in the routine operation of treatment plants [5].

The effect of raw water turbidity, pH and colour on the effectiveness of a traditional coagulant viz. aluminium sulphate ($Al_2 (SO_4)_3.18H_2O$) as well as a newer coagulant viz. poly aluminium chloride $[Al_2(OH)_xCl_{6-x}]n$ is studied in order to evaluate the capability of these two coagulants to improve the quality of surface water treatment applications.

Data from tests done in the current study as well as past testing records are included in the analysis. They are used to illustrate the importance of selecting the best coagulant for the individual raw waters.

1.5 Study Location and Scope of Work

This study was carried out for the drinking water sources of Kalu Ganga and Kelani Ganga in Sri Lanka. A number of jar tests was carried out at the Kandana Water Treatment Plant and Biyagama Water Treatment Plant which are situated in Kalutara, and Gampaha Districts respectively.

Sri Lanka being a tropical country, this area is characterized by hot, humid climatic conditions with sunshine throughout the day. These sources were carefully selected in view of their largest water production in Sri Lanka. The study area indicating the two selected sources and water treatment plants is shown in Figure 1.1 and Figure 1.2.

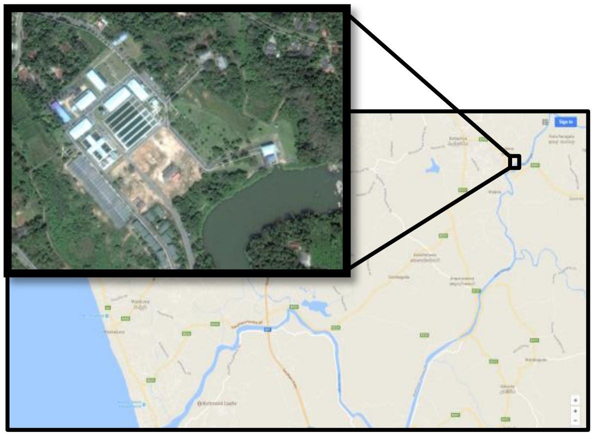


Figure 1.1: Site Map of the Study Area in Kandana Treatment Plant (Google Map)

Figure 1.2: Site Map of the Study Area in Biyagama Treatment Plant (Google Map)

1.6 Scope of the Research

At present NWSDB supplies water in all districts in Sri Lanka and serve a population of 8 million through 325 Water Supply Schemes with 176 intakes. These intakes are operated by extracting water from several rivers. Of them, Kalu Ganga and Kelani Ganga were selected. These two river intakes supply 48 % of the total water production by NWSDB.

In addition, to simplify study, only turbidity, colour and pH have been considered as water parameters as they are the main independent parameters known to directly affect the coagulation process.

2.0 LITERATURE REVIEW

2.1 Introduction

2.1.1 Background to the Literature Review

This chapter presents a brief review of the literature on the use of coagulants applied in the coagulation and flocculation process. Proper coagulation is essential for good filtration performance and for disinfection byproduct control. As such, optimizing coagulation is the most cost-effective way to decrease treated water turbidity and increase health benefits.

2.1.2 Waterborne Disease and Health Condition

Access to safe drinking water is essential to health, a basic human right and a component of an effective policy for health protection and development at national, regional and local levels.

The WHO Drinking Water Quality Guidelines describe a quality of water that is suitable for lifelong consumption. Therefore, a continuous effort should be made to maintain drinking water quality at the highest possible level. An important concept in improving drinking water safety is improvement in long-term health.

Diseases of various kinds continue to occur all over the world in which inadequate water treatment almost always plays a major role. In some countries where the infrastructure for water and sewage is poor, waterborne diseases (e.g., cholera and typhoid) still result in overwhelming epidemics. Even in developed countries these diseases are widespread owing to infrastructure failures. Therefore, preventing waterborne diseases must remain a top priority in water treatment [8].

2.2 Treatment of Drinking Water

Water treatment is the processing of water to achieve a water quality that meets specified goals or standards up to the end user or a community. Goals and standards can include the requirements of regulatory agencies, and requirements associated with specific industrial processes and the community.

The quality of surface water depends on the character and area of the watershed, its geology, topography, the amount and nature of development, and weather conditions. The impurities in the water can be classified as suspended solids, dissolved solids, dissolved gases, colour, taste and odour, and micro-organisms.

The principal objective of a water treatment plant is to produce water that fulfills a set of drinking water quality standards. Basic considerations of the water treatment process train depend upon the characteristics and seasonal variations in the raw water quality, regulatory constraints, site conditions, plant economics, and many other factors.

Coagulation, flocculation, sedimentation and filtration remove particles, including microorganisms (bacteria, viruses, protozoa). Chemical coagulation is the most important step in determining the removal efficiency of colloidal particles by coagulation, flocculation and clarification processes in water treatment. It directly affects the removal efficiency of granular media filtration units and has indirect impacts on the efficiency of the disinfection process [4].

2.3 Coagulation and Coagulants

2.3.1 Coagulation

Definition of Coagulation

The term 'coagulation' describes the effect produced when certain chemicals are added to raw water containing slowly settling or non-settleable particles. The chemicals hydrolyze and neutralize the electrical charges of the colloidal particles, which begin to form agglomerations termed 'floc', which will be removed by clarification and filtration [5].

Coagulants Used to Treat Drinking Water

The different experiments conducted using coagulation- flocculation processes allowed identifying potential products that may be used as coagulants for water treatment. Aluminum and iron-based coagulants are widely available in the market and are used as coagulants in water treatment process. According to the literature, the performance of each coagulant fluctuates according to the type of water being treated. In this section the characteristics of two primary inorganic coagulants – alum and PACL – are reviewed.

2.3.2 Factors Affecting Coagulation

Several water quality parameters such as the amount of particulate material, the amount and nature of the natural organic matter (NOM) are present in raw water. Factors that affect coagulation: the dissolved Al species present upon coagulant addition; the presence of precipitated aluminium hydroxide solids; the concentrations of particles and NOM; the chemical properties of these contaminants and their reactivity with dissolved Al species and the pH of coagulation[9] [10]. Some easily measurable physical-chemical parameters that define water quality are turbidity, colour pH /alkalinity.

(a) Turbidity of Water

The turbidity of water is caused by suspended particles or colloidal matter that obstructs light transmission through the water. The treated water turbidity should be less than 5NTU, and if at all possible, below 1 NTU. Turbidity affects the efficiency of disinfection by providing protection for organisms [8].

(b) The Colour of Water

Colour is a common characteristic of surface water. Colour in natural water results from organic and inorganic compounds of both natural and synthetic origin including suspended solids or dissolved materials. The colour of drinking water is usually due to the presence of coloured organic matter and is influenced by the presence of iron and other metals. According to WHO Guidelines, levels of color below 15TCU are acceptable to consumers [8].

(c) pH of Water

pH is the most important operational water quality parameter but it has no direct impact on the consumer. pH correction is necessary at all stages of water treatment to ensure acceptable clarification and disinfection. For effective disinfection with chlorine, pH should preferably be less than eight and not less than seven due to corrosion [8].

(d) Alkalinity of Water

Alkalinity is a characteristic of natural water that provides buffering capacity and maintains the pH of water within the range from 6.0 to 8.5, is caused by bicarbonate and carbonate ions (HCO_3^- and CO_3^{2-}) and small portions of silicate, phosphate organic acids and hydroxides. For a healthy fresh water, the desirable bicarbonate alkalinity range is 30 to 130 mg/l as $CaCO_3$; the pH is well maintained within the range of 6.5 to 8.2 [11].

2.3.3 Electrical Properties of Particles

The electrical property of fine particulate matter suspended in water is surface charged, and it contributes to relative stability, causing particles to remain in suspension without aggregating for long periods of time. The particulate suspensions are thermodynamically unstable and, given sufficient time, colloids and fine particles will settle after flocculating. However, this process is not economically feasible because it is very slow. The particulate stability will provide the techniques that can be used to destabilize particulates [12].

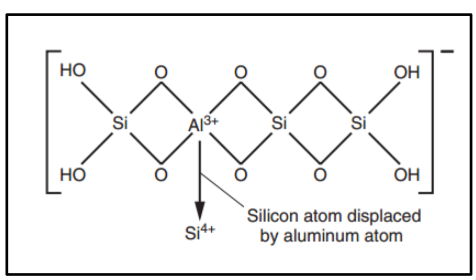


Figure 2.1: Charge acquisition through isomorphous substitution of Al for Si

Source : Crittenden et al.,MWH's Water Treatment Principles and Design, (2012)

2.3.4 Mechanisms of Coagulation

The objective of coagulation and flocculation is to condition impurities, especially non-settleable solids and colour, for removal from the water being treated. Coagulating chemicals cause non-settleable particles to bunch together to form floc. In the coagulation process, chemicals are added which will primarily cause the colloidal particles to become destabilized and bunched together. When small pieces of floc bunch together, they may form larger, heavier flocs, which settle out and are removed as sludge. Surface water requires treatment to remove particulate impurities and colour before their distribution to the consumer in order to comply with quality standards.

Selection of the type and dosage of coagulant depends on the characteristics of the coagulant, the concentration and type of particulates, concentration and characteristics of natural organic matter, water temperature, and quality of the raw water. The interdependence of these characteristics is understood qualitatively simultaneously [9][13].

Coagulation involves reactions between coagulant chemicals, natural organic matter molecules, and the surfaces of particles.

The following mechanisms can be used to achieve particulate destabilization:

(1) Compression of the electrical double layer

Electrostatic potential surrounding a charged particle in solution, consisting of a layer of counterions adsorbed directly to the surface and a diffuse layer of ions forming a cloud of charge around the particle

(2) Adsorption and charge neutralization

The coagulant- colloidal systems indicates that interactions other than electrostatics are responsible for destabilization.

(3) Adsorption and interparticle bridging

The polymer chains adsorb on particle surfaces at one or more sites along the polymer chain. The rest of the polymer may remain extended into the solution and adsorb on available surface sites of other particles, thus creating a ‘‘bridge’’ between particle surfaces. If the extended polymer cannot find vacant sites on the surface of other particulates, no bridging will occur.

(4) Enmeshment in a precipitate, or ‘‘sweep floc.’’

Entrapment or capture of particles by amorphous precipitates that form when a coagulant is added to water.

These mechanisms become apparent in water treatment. This is the reason that destabilization strategies exploit several mechanisms simultaneously [4].

Sweep Flocculation

Although particles may be effectively destabilized by charge neutralization, there are two disadvantages in water treatment:

- Relatively exact control of coagulant dosage is needed for optimum destabilization
- The particle collision rate and the coagulation rate depend on the particle concentration and can be very low for dilute suspensions

Both of these problems can be overcome if higher coagulants dosages are used since considerable quantities of amorphous hydroxide precipitate are then formed. In the case of aluminium coagulants, optimum pH settings are close to the point of minimum solubility. The precise mechanisms show that impurity particles are enmeshed in the increasing precipitate[14].

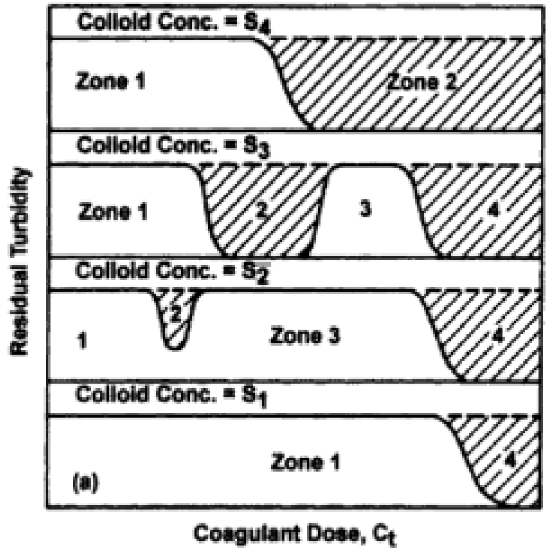


Figure 2.2: Schematic representation of coagulation observed in jar tests using Al or Fe

Source : Faust and Aly, Chemistry of Water Treatment, 2nd Edition,(1998)

Sweep flocculation generally shows more improved particle removal than when particles are destabilized just by charge neutralization. The different mechanisms define four zones of coagulant dosing as follows:

Zone 1 Very low coagulant dosage; particles still negative and hence stable. No destabilization occurs.

Zone 2 Dosage sufficient to give charge neutralization and destabilization. Aggregation occurs and residual turbidity is low or nil.

Zone 3 Higher dosages give charge neutralization and destabilization

Zone 4 Still higher dosages give hydroxide precipitate and sweep flocculation where the colloids are swept from solution by the coagulants [14] [15].

2.3.5 Types of Chemicals Used for Coagulation

Generally, metal coagulants such as salts of aluminium and iron have been used commonly as coagulants and flocculants in the water treatment process. These coagulants are sensitive to pH and alkalinity of the raw water and may cause reversal of turbidity at high doses. Commonly used coagulants in the purification process in water treatment are as follows:

Table 2.1: Coagulants Used in Water Treatment

S.No	Chemical	Common Name	Formula
1	Aluminium Sulphate	Alum, Filter Alum,	$Al_2(SO_4)_3.18H_2O$
2	Poly Aluminium Chloride	PACL	$Al_2(OH)_3Cl_3$
3	Chlorinated Ferrous	Chlorinated Copperas	$Fe_2(SO_4)_3.FeCl_2$
4	Ferric Chloride	Chloride of Iron	$FeCl_3.6\ H_2O$
5	Ferric Sulphate	Iron Sulphate, Ferrifloc	$Fe_2(SO_4)_3.H_2O$
6	Ferrous Sulphate	Copperas, Sugar	$FeSO_4.7H_2O$
7	Potassium Aluminium	Potash Alum	$K_2SO_4.Al_2(SO_4)_3.24\ H_2O$
8	Sodium Aluminate	Soda Alum	$Na_2Al_2O_3$

Source : https://www.google.lk/search?q=chapter+2+literature +review coagulation +in+water+treatment&oq,2017/08/04

Generally, several types of coagulants and aids are available for the plant process schemes and the dosages of these chemicals can be regulated to meet changes in raw water quality. Because of this complexity, no systematic criteria can be applied across all drinking water treatment facilities. Therefore, coagulant selection must be addressed for each facility according to its own circumstances [2].

Evaluation of Coagulants

Coagulants are evaluated for two reasons, namely, to choose the best coagulant in terms of performance and cost and to ensure consistent quality of the product. When choosing a suitable primary coagulant the jar test remains the most effective tool for this application

Application and it is a very versatile test that can be used for the following:

1. Coagulant selection
2. Dosage selection
3. Coagulant aid type and dosage selection
4. Determination of optimum
5. Determination of best settlement and /or filtration methods [16].

Many chemicals are used in the coagulation and flocculation process and designers should consider the following factors in selecting the chemicals:

- Effectiveness
- Cost
- Reliability of supply
- Sludge considerations
- Compatibility with other treatment processes
- Environmental effects
- Labour and equipment requirements for storage, feeding and handling [17].

The aluminum forms of coagulant such as PAS, PASS, PACL, etc. usually cost twice as much as alum because they are derived from these salts[18] [19]. In order to reduce cost and to constantly produce good quality drinking water, producers often use alum in cases when raw water is easily treatable and complex forms, like PASS are used when raw water is difficult to treat[20][21].PASS (which contains a silicate, a mineral agent of polymerization) is preferred to alum in cold conditions because it rapidly forms hydroxide aluminum flocs that adsorb impurities on their surfaces[22].

The optimum use of PASS, PACL and other complex forms normally yield lower soluble alumina residuals in the clarified water than alum dosages [23]. The other complex forms, PAS, poly-aluminum chloride and pre-hydrolyzed alum are also more effective than alum in cold water conditions and their selection is dependent on raw water characteristics such as pH, alkalinity, organic content, inorganic impurities and the clarification process being used. Bench-scale and pilot tests are required to select the best coagulant to use in any condition of raw water [18].

2.3.6 Past Results of Experiments

The results of the study [24] on the performance of five coagulants of the poly ferric sulfate, ferric chloride, alum, poly aluminum chloride and poly aluminum ferrous chloride in turbidity removal from raw water are as follows.

Figures 2.3 to 2.6 compare the removal efficiency of tested coagulant in optimum dosage and pH. As the Figures show, in the input turbidity NTU300 (Figure 2.3) removal efficiency of five coagulants are close together and in all cases turbidity removal efficiency is above 90%, but the best turbidity removal efficiency is for poly aluminum ferrous chloride with an efficiency of 98.25 %.

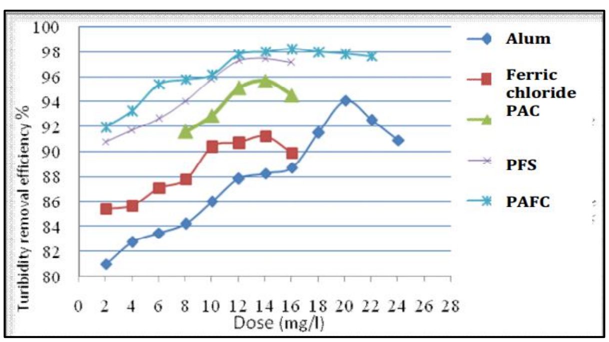


Figure 2.3: Turbidity Removal Efficiency of Coagulants in Input Turbidity of 300NTU

Source : Fazeli et.al. Bulletin of Environment, Pharmacology and Life Sciences, 3(6) 78-88, (2014) At an input turbidity of NTU150 (Figure 2.4), the highest turbidity removal efficiency of tested coagulants is obtained as poly ferric sulfate (98.66%), poly aluminum ferrous sulfate (96.24%), ferric chloride (95.11%), poly aluminum chloride (94.63%) and alum (93.62%) respectively.

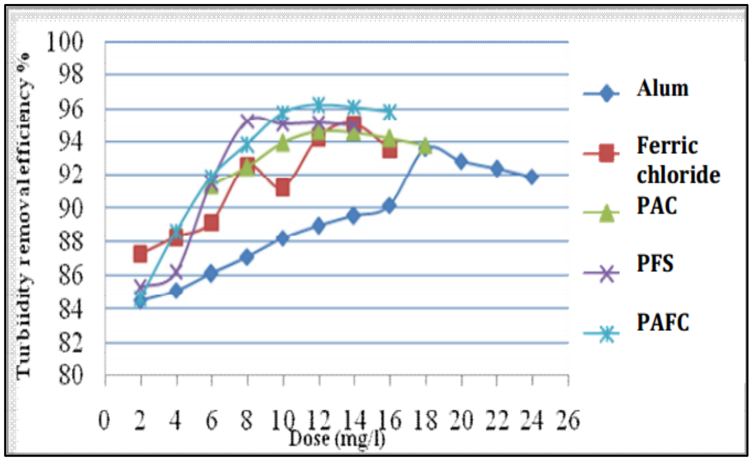


Figure 2.4: Turbidity Removal Efficiency of Coagulant in Turbidity of 150NTU

Source : Fazeli et.al, Bulletin of Environment, Pharmacology and Life Sciences, 3(6) 78-88, (2014)

At an input turbidity of 100 NTU (Figure 2.5) the highest turbidity removal efficiency is for poly ferric sulfate with 98.87%.

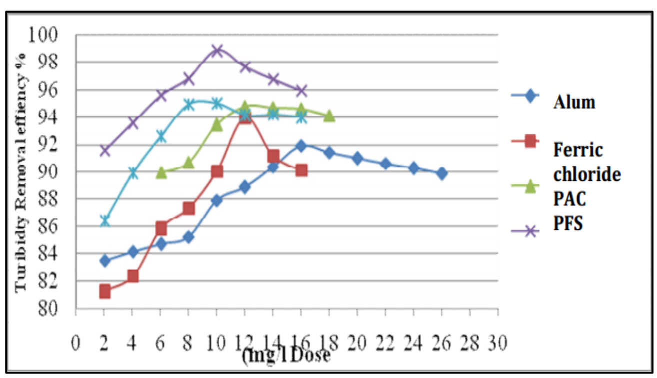


Figure 2.5: Turbidity Removal Efficiency of Coagulant in Turbidity of 100NTU

Source : Fazeli et.al, Bulletin of Environment, Pharmacology and Life Sciences, 3(6) 78-88, (2014) At an input turbidity of NTU 10 (Figure 2.6) as polymeric coagulant had expected better removal efficiency than alum and ferric chloride while the consumable dose was lower and poly ferric sulfate of 95.27% had the highest removal percent.

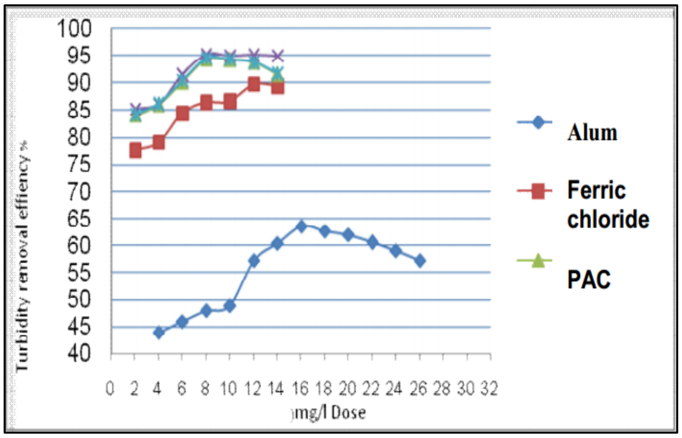


Figure 2.6: Turbidity Removal Efficiency of Coagulant in Turbidity of 10NTU

Source : Fazeli et.al.,Bulletin of Environment, Pharmacology and Life Sciences, 3(6) 78-88, (2014)

2.3.7 Aluminium

Aluminium is the most abundant metallic element and constitutes about 8% of the Earth's crust. Aluminium salts are commonly used in water treatment and coagulants to decrease organic matter, colour, turbidity and micro organism levels. The use of the element may lead to increased concentrations of aluminium in finished water. If the residual concentrations of aluminium elements are high, undesirable colour and turbidity may follow [8].

2.3.7.1 Hydrolysis of Aluminium Salts

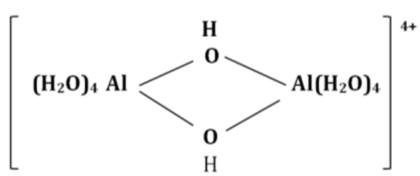
When an aluminium salt is added to the water, a series of reactions occurs in the water. This process is broadly described as hydrolysis. According to the literature [9], supported by theoretical and experimental indicators, is that aluminium ions, almost directly after addition to water, enter into a series of hydrolytic reactions with water to form a sequence of multivalent charged hydrous oxide species. Depending on pH these compounds may range from positive at the lower pH values to negative at the more basic pH values. These reactions can be represented as follows:

$$[Al(H_2O)_6]^{3+} + H_2O \longleftrightarrow [Al(H_2O)_5\,OH]^{2+} + H_3O^+$$

$$[Al(H_2O)_5\,OH]^{2+} + H_3O^+ \longleftrightarrow [Al(H_2O)_4\,(OH)_2]^{+} + H_3O^+$$

This reaction can proceed until the neutral species $Al(H_2O)_2(OH)_3$ or a negatively charged species $[Al(H_2O)_2(OH)_4]^-$ is formed.

Recent evidence proposes that the monomeric species, i.e., those compounds containing only one aluminium ion are at best brief. The second type of reactions called " olation" is the more important in coagulation. In the process of alienation, a series of polymerization reactions occurs, resulting in complexes containing several aluminium ions bridged by two hydroxyl groups. A model of a simple complex containing two aluminium ions can be illustrated as follows:



It has been suggested that the complex most significant in coagulation at low concentrations of aluminium is a polynuclear complex comprising eight aluminium ions carrying a tetrapositive charge of the form.

$$[Al_8\,(OH)_{20}]^{4+}$$

One of the important points that appeared from the study of these reactions is that both hydroxide and hydrogen ions are involved; thus pH plays an important role in coagulation. The pH of the water is of primary importance in creating the average charge of the hydrolysis products. Consequently it is significant in determining the rate of coagulation. In addition to pH, the chemical composition of water also affects the species of complex produced since negative ions other than hydroxide, particularly the di- and trivalent ions, may enter the complex and considerably adjust its properties. Thus, in the presence of sulphate, one or more sulphate ions may replace hydroxide ions in the method shown below:

$$[Al\ (H_2O)_6]^{3+} + SO_4^{2-} \longleftrightarrow [Al\ (H_2O)\ 4SO_4] + +2H_2O$$

2.3.7.2 Impacts of Substituting Aluminum-Based Coagulants in Drinking Water Treatment

According to [18], orally consumed aluminum is highly toxic to humans despite the widespread presence of this element in foods, drinking water and many antacid arrangements [25]. It has been assumed that aluminum exposure is a risk factor in the onset of Alzheimer's disease in humans. The amount of aluminum absorption depends on a number of parameters such as the aluminum salt administered, pH, bio availability and dietary factors [25]. Water treated with aluminum salts comprise forms of soluble aluminum, which is a prevalent bioavailable source consumed by humans [26]. In order to reduce its presence in drinking water, the use of alternative coagulants or alternative treatment processes must be considered, although the replacement of one coagulant or treatment process for another should be undertaken only after the safety and effectiveness of the alternative is ensured.

The use of aluminum-based coagulants is not limited by the availability of their prime mechanisms. Natural bauxite resources are plentiful and the production of sulphuric acid is common. Aluminum salts are produced from the dissolution of purified (or non-purified) aluminum tri-hydrate with sulphuric acid followed by a filtration. The cost of these coagulants usually differs according to the volume produced and the distance between the production site and the water treatment plant. A health-based guideline for the presence of aluminum in drinking water has not been established [27]. However, water treatment plants using aluminum-based coagulants should optimize their processes to decrease residual aluminum levels in treated water as a safety measure. Operational guidelines of less than 100 µg/L of total aluminum for conventional treatment plants and less than 200 µg/L of total aluminum for other types of treatment systems are recommended [18].

2.4 Aluminium-based Coagulants

Salts of aluminium or iron are the most commonly used coagulant chemicals in water treatment because they are effective, of relatively low cost, availability, and easy to handle, store, and apply. Aluminium sulfate, commonly called alum or sulfate of alumina, is still very widely used although concern about the possible adverse effects of dissolved aluminium has recently been expressed in some quarters. Other aluminium salts used are poly aluminium chloride, which may have some advantages over aluminium sulfate in the coagulation of difficult waters [18].

Optimization of coagulant dose and coagulation pH in this procedure is based on colour and turbidity removal. The use of results obtained in this way for control of water treatment may sometimes present difficulties.

2.4.1 Aluminium Sulphate (Alum)

Literature shown in BSEN 878:2004 that aluminium sulphate is used for treatment of water intended for human consumption. It describes the characteristics of aluminium sulphate and specifies the requirements for aluminium sulphate and refers to the analytical methods.

Description

Chemical Name	-Aluminium Sulphate
Empherical formula	- $Al_2 (So_4)_3$
Chemical formula	-$Al_2 (So_4)_3 nH_2o$

In relation to data gathered (Technical Specification, NWSDB) it appears all materials conform to Sri Lanka Standard (SLS, 701:1985), Specifications for aluminium sulphate are shown in Table 2.2[28].

Table 2.2: Specification for Aluminium Sulphate for Human Consumption

Characteristics	Requirements
Iron as Fe_2O_3 percent by mass, maximum allowable	0.7
Water soluble Aluminium Sulphate as Al_2O_3 percent by mass, min	16.0
Water insoluble matter, percent by mass, max	0.5
pH at 27 $\pm$ 2^0 , min	2.8
Arsenic as AS_2O_3 percent by mass, max	0.01
Heavy metals as Pb, percent by mass, max	0.02
Ammoniacal Nitrogen percent by mass, max	0.03
Lump Size:- Lumps passing through a 40.0 mm sieve, percent by mass, min	100
Age of Aluminium Sulphate from the date of manufacture when shipping	Not more than 02 months

Source : NWSDB Specification Aluminium Sulphate

Aluminium Sulphate Technology and Process

There is a batch process as well as continuous process for the manufacture of alum. Bauxite ore containing preferably less than 3% Iron is transported to the plant site and crushed to a size of 50 to 75 mm. The crushed ore is further powdered by using a pulveriser. It is realized that the finer the size of bauxite, the quicker would be the reaction rate. Usually ground bauxite of size 100 to 140 mesh is used in the process. It is essential that the ferric oxide content shall be less than 3% in the ore to obtain an acceptable product containing less than 0.1% iron.

Figure 2.7: Manufacturing Process of Aluminium Sulphate
Source : http://enfg.eu/22113/aluminium-sulphate-grinding/2017/08/14

Figure 2.8: Picture Shows the Aluminium Sulphate Sample

Prepared elements are subjected to reaction with sulfuric acid at a temperature of around 105 deg. of the desired strength of sulfuric acid in an open lead lined disasters is 52 degree. The total response time is around 12 to 16 hrs. The reacted solution is taken to a settling tank. After settling, the sludge is removed and discarded. The clear solution is concentrated in open pan evaporators [29].

2.4.1.1 Aluminium Sulphate Chemical Reaction with Water

According to the literature [30], the basic requirement for a coagulant chemical, whether a metallic salt or an organic polymer is to discharge the generally negative charges on the colloids present in the water and give rise to a precipitate. When metallic salts such as aluminium sulphate {$Al_2 (SO_4)_3 .18H_2O$} is added to the water, a series of reactions occur with the water and with other ions in the water. Sufficient quantities of the chemicals must be added to the water to exceed the solubility limit of the metal, as granulated or kibbled alum and also in liquid form. The chemical formula of pure aluminium sulphate is $Al_2 (SO_4)_3.18 H_2O$.

The formation of an aluminium hydroxide floc is the effect of the reaction between the acidic coagulant and the natural alkalinity of the water, which usually consists of calcium bicarbonate, as expressed in the equation below, with the insoluble products (precipitates).

$$\mathbf{Al_2(SO_4)_3 + 3Ca\ (HCO_3)_2 \longleftrightarrow 2Al\ (OH)\ 3 + 3CaSO_4 + 6CO_2}$$

If the water has insufficient alkalinity or `buffering' capacity, additional alkali such as hydrated lime, sodium hydroxide (caustic soda) or sodium carbonate (soda ash) must be provided for the reaction as expressed in the equation:

$$\mathbf{Al_2(SO_4)_3 + 3Ca\ (HCO_3)_2 \longleftrightarrow 2Al\ (OH)_3 + 3CaSO_4 + 6CO_2}$$

With soda ash added:

$$\mathbf{Al_2(SO_4)_3 + 3NaCO_3 + 3H_2O \longleftrightarrow 2Al\ (OH)_3 + 3NaSO_4 + 3CO_2}$$

The chemistry of Alum Coagulation

When alum is added to water it undergoes the reaction below. The alum reacts with bicarbonate to form aluminium hydroxide, a precipitate.

$$\mathbf{Al_2\ (SO_4)_3\ .18H_2O + 3Ca\ (HCO_3)_2 \longleftrightarrow 2Al\ (OH)_3 + 3CaSO_4 + 6CO_2 + 18\ H_2O}$$

“Alum” Alkalinity as $CaCO_3$ Precipitate Salt Gas

A dose of 1 mg/l of aluminium sulphate reacts with 5.3 mg/l of alkalinity expressed as $CaCO_3$. Thus, if no alkali is added the alkalinity will be reduced by this amount with a resultant reduction in pH. The aluminium hydroxide floc is insoluble over relatively narrow bands of pH, which may vary with the source of the raw water. Therefore, pH control is essential in coagulation, not only in the removal of turbidity and colour, but also to maintain satisfactory minimum levels of dissolved residual aluminium in the clarified water. The optimum pH for the coagulation of lowland surface waters is usually within the range 6.5 to 7.5, whereas for more highly coloured upland waters a lower pH range, typically 5.5 to 6.5, is necessary.

Aluminium sulphate is widely used as a principal coagulant to clarify water for drinking in Sri Lankan water treatment plants. The main reason why alum is so widely used is that it is available and low-cost alternatives are not available. However, there are other costs and problems associated with the use of alum. Generally, large sludge volume produce, requires frequent sludge removal operation causing increased wastage of water[31][32]. In addition to that, there is possibility of aluminium carry over in water treated with alum.

Alum has a number of disadvantages:

- Limited coagulation pH range: 5.5 to 6.5,
- Additional addition of alkalinity to the raw water is often required to achieve optimum coagulation pH, particularly for soft, coloured surface waters that are common in Sri Lanka
- Residual aluminium levels in the treated water can frequently exceed satisfactory limits, and the alum floc produced is particularly fragile. This is especially important if a coagulant is required to maximize colour removal in a micro-filtration-based water treatment process.
- Alum reacts with water to produce aluminium hydroxide and as a by-product sulfuric acid is also formed. The metal hydroxide precipitates out of solution and

entraps neutralized charged dirt particles (turbidity), as well as coagulating soluble colour and organics by adsorption.[31].

Poly aluminium chloride has been developed as an alternative coagulant for alum.

2.4.2 Poly Aluminium Chloride (PACL)

According to the literature [4] metal salts such as alum and iron hydrolyze, hydrogen ions are released, which will react with the alkalinity of the water. In the formulation of PACL coagulants, some of the acid that would have been released is neutralized with base (OH^-) when the coagulant is manufactured. The degree to which the hydrogen ions that would be released by hydrolysis are pre-neutralized is known as the basicity of the product and is given by the following relationship for pre-hydrolyzed metal salts that do not contain oxygen:

$$\textbf{Basicity (\%)} = \mathbf{B} = \mathbf{100 \times [OH] / [M] Z_M}$$

[OH]/[M]= molar ratio of hydroxide bound to metal ion

Z_M= charge on metal species

Basicity affects the ratio of polynuclear to mononuclear species present in the solution and provides an indication of the alkalinity consumption of the coagulant. PACL has a higher optimum pH value with regard to solubility than alum. It allows for the formation of precipitates at higher pH values. Moreover, unlike traditional hydrolyzing metal salts, mixing time and intensity of pre-hydrolyzed coagulants such as PACL are less harmful to complete effective coagulation [12].

Poly aluminium chloride is used in water treatment engineering for the coagulation of organic and mineral colloids prior to sedimentation and/or filtration. The aluminium destabilizes fine colloidal suspensions and supports the forming together of large conglomerations of this material in a chemical precipitate (called floc). It can be removed from the water by sedimentation, flotation and/or filtration. In addition, poly aluminium chloride is preferred over aluminium sulfate if a larger, faster forming floc is desired.

PACL is an inorganic coagulant that enables removal of turbidity, colour and taste in various WTPs, without significantly lowering pH. It can deal with high turbidity/low alkalinity conditions with little likelihood of post flocculation [33].

In relation to the data gathered and the current literature collected [22], it appears that the compound has the general formula $(Al_n(OH)_mCl_{(3n-m)})_x$ and has a polymeric structure, totally soluble in water. The length of the polymerized chain, molecular weight and number of ionic charges is determined by the degree of polymerization. On hydrolysis, various mono- and polymeric species are formed, with $Al_{13}O_4(OH)_{24}^{7+}$ being a particularly important action.

Description

Chemical Name - Poly Aluminium Sulphate Chloride Hydroxide

General formula - $(Al_n(OH)_{mCl(3n-m)})_x$

** The highly polymerized coagulant for poly aluminium chloride is denoted as n=2 and m=3 in the general formula. $(Al_2(OH)_3Cl_3)_x$

In relation to the data gathered [34], it appears all materials supplied shall be manufactured in compliance with ISO 9001:2008/2015 quality management system. The specification for poly aluminium chloride is as shown in Table 2.3.

Table 2.3: Specification for Poly Aluminium Chloride for Human Consumption

Characteristics	Requirements
Water soluble Poly Aluminium Chloride, as Al_2O_3 percent by	28
Water insoluble matter, percent by mass max	1.5
Ammoniacal Nitrogen percent by mass, max	0.01
pH of 5% solution w/v	2.5 – 4.5
Chloride as (Cl^-) percent by mass, max	33.0
Sulphate as (So_4^{2-}) percent by mass max	10.0
Basicity percent by mass, min	35.0
Arsenic as (As) ppm, max	15.0
Cadmium (as Cd) ppm, max	18.0
Cromium (as Cr) ppm, max	45.0
Mercury (as Hg) ppm, max	0.6
Nickel (as Ni) ppm, max	700
Lead (as Pb) ppm, max	90
Antimony (as Sb) ppm, max	40
Selenium (as Se) ppm, max	40
Iron (as Fe)and Manganese (as Mn) ppm, max	300
Particle size –passing through 4mm (ASTM No 5) sieve	100%

Source : NWSDB Specification for Poly Aluminium Chloride

Poly Aluminium Chloride Technology and Process

Poly aluminium salts can be produced in several ways. One way of producing poly aluminium chloride is to dissolve aluminium metal in acidic aluminium salts, e.g., aluminium chloride or medium basicity poly aluminum chlorides. When doing this hydrogen gas is produced.

Figure 2.9: Manufacturing Process of Poly Aluminium Chloride

Source : http://www.tridentpublicschool.org/Group/6843/manufacturing-process-of-poly-aluminium-chloride.html#nogo/2017/08/14

Figure 2.10: Picture Shows the Poly Aluminium Chloride Sample

Another common way of producing poly aluminium chloride is to add calcium chloride and calcium carbonate or calcium hydroxide to an aqueous solution of aluminium sulphate or sulfuric acid. According to this process calcium sulphate is achieved as a by-product, which is an excess product that may be too costly to discard.

Poly aluminium chloride may be produced by digesting aluminium hydroxide in a mixture of sulphuric acid and hydrochloric acid at a temperature of about 100 to 120 ^{0}C. To the formed liquid a carbonate is added and carbon dioxide is formed. When calcium carbonate is used solid calcium sulphate is formed which has to be divided; this involves costs.

Another common way of manufacturing poly aluminium chloride is to treat a mixture with an aluminium comprising material such as aluminium hydroxide, with aqueous hydrochloric acid or aluminium chloride at about 130-170°C under pressure. The reaction time needed for this process is in the order of 2 to 4 hours [35].

2.4.2.1 Poly Aluminium Chloride Chemical Reaction with Water

Poly aluminium chloride solution includes a sequence of products of a range in the degree of their acid neutralization, polymerization and Al_2O_3 concentration. As the acid is neutralized in the manufacturing process, the aluminium portion of the product becomes more polymerized, causing a higher cationic charge and improved performance ability. The degree of acid neutralization is measured by basicity. Basicity can range from 0% (aluminium chloride solution) to 83% (aluminium chlorohydrate solution).

Typically available poly aluminium chloride solution products have basicity ranging from 10-70% [36].

PACL hydrolyses easily related to alum, emitting polyhydroxides with long molecular chains and greater electrical charge in the solution, and contributing to maximize the physical action of the flocculation. Better coagulation is found with PACL as compared to alum at medium and high turbidity waters with quite rapid floc formation [37].

In the formulation of PACL coagulants, some of the acid that would have been released is neutralized with a base (OH^-) when the coagulant is produced. The degree to which the hydrogen ions that would be released by hydrolysis are pre-neutralized is known as the basicity.

PACL is more soluble and has a higher pH of minimum solubility that increases with increasing basicity. In solubility data for a high basicity PACL (basicity 70%) and aluminium chlorohydrate (basicity 85%) it is important to note that the pH of minimum solubility for these two PACLs is significantly higher than that for alum. These PACLs can be used as higher pH values without resulting in elevated dissolved Al levels, and the highly charged Al_{13}^{7+} species is present over a higher pH range. Due to the occurrence of Al13 the surface charge on PACL floc has a larger positive charge density than alum floc [5].

PACL also shows similar hydrolysis as represented by Equation. In this reaction, three moles of H+ are formed [36].

$$Al_2(OH)_3Cl_3 \rightarrow Al_2(OH)_3^{3+} + 3Cl^- + 3H_2O \rightarrow 2Al(OH)_3 + 3H^+ + 3Cl^-$$

Depleting Solution:

$$Al_2(OH)_{6-x}Cl_x + H_2O \longrightarrow Al_2(OH)_{6-(x-1)}Cl_{(x-1)} + HCL$$

Receiving Solution:

$$Al_2(OH)_{6-y}Cl_y + HCL \longrightarrow Al_2(OH)_{6-(y+1)}Cl_{(y+1)} + H_2O$$

The above hydrolysis reactions typically take place at a dosed water pH in the range 5.8 to 7.5, depending on the specific coagulant. Within this pH, color and colloidal matter are removed by adsorption onto/within the metal hydroxide hydrolysis products that are formed.

Advantages of poly Aluminium Chloride coagulants:

- PACL has reacts faster than aluminium sulphate since its polymeric structure which permits higher coagulation efficiency. The formed flocs are bigger which means a faster sedimentation.
- Improved turbidity, color, total organic carbon removal
- PACL consumes less alkalinity than the other coagulants. In most cases, there is no need of alkalinity addition for an effective flocculation.
- They are effective over a broader pH range compared to alum and experience shows that PACL works acceptably over a pH range of 5.0 to 8.0.
- Reduced concentration of sulphate added to the treated water. This directly affects SO_4 levels in domestic wastewater.
- Low levels of residual aluminium in the treated water can be achieved, typically 0.01-0.05 mg/L,

- PACL effort extremely well at low raw water temperatures. Flocs formed from alum at low temperatures settle very slowly, whereas flocs formed from poly aluminium coagulants tend to settle equally well at low and at normal water temperatures,
- Effective over a wider turbidity range and even at very low temperatures
- Less sludge is produced compared to alum at an equivalent dose.
- Lower doses are required to give equivalent results to alum.
- Reduced cleaning frequencies of the filters as a result longer runs in the sand filters
- Aluminium sulphate) reducing consequent health problems (Alzheimer) the increase in chloride in the treated water is much lower than the sulphate increase from alum, ensuing in lower overall increases in the TDS of the treated water.
- Lower overall treatment costs [31].

In addition, all alternative coagulants will need to be carefully studied and applied, particularly in small municipalities where staff establishment will be necessary. Treatment modifications must not affect water quality and the potential consequences caused by microbial contamination are such that its control must always be of principal significance and must never be co-operated [25].The implementation of enhanced coagulations, which maximize pathogen removals, produces low turbidities and minimizes residual aluminum [38], in Canada's water treatment plants using alum-based coagulants would be a low-cost solution in a short-term viewpoint [18].

2.5 Alkalinity and pH Adjustment

Alkalinity (mainly bicarbonate) is an extremely important variable in the coagulation process as in the removal of NOM and SOCs. Mostly, alkalinity controls the pH value, which is achieved without using supplementary addition of acid and base. For example, the stoichiometric reaction indicates that 1.0mg/L alum requires 0.45 mg/L of alkalinity as $CaCO_3$. Excessive alkalinity may increase the coagulant dosage beyond what is required for turbidity and NOM removal. Insufficient alkalinity requires the addition of a supplementary base ($NaHCO_3$, NaOH, Ca $(OH)_2$).

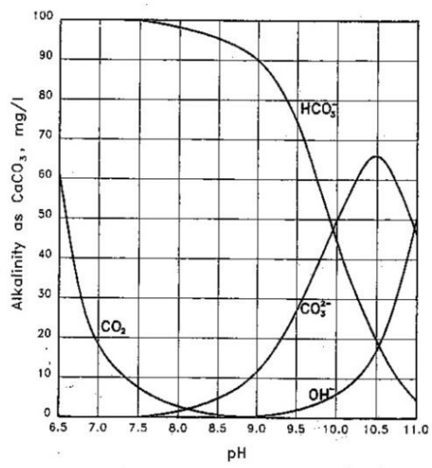


Figure 2.11: Equilibrium concentrations of CO_2 and alkalinity with respect to pH

Source : Qasim at el., Water Works Engineering, 2004

$$CO_2+Ca(OH)_2 \Longleftrightarrow CaCO_3(s)+H_2O$$
$$Ca(HCO_3)_2+Ca(OH)_2 \Longleftrightarrow 2CaCO_3(s)+2H_2O$$
$$Mg(HCO_3)_2+2Ca(OH)_2 \Longleftrightarrow 2CaCO_3(s)+ Mg(OH)_2(s)+2H_2O$$

The increase in $[H^+]$ plays an important role in corrosion. Similarly, a decrease in $[H^+]$ retards the rate of corrosion through several chemical mechanisms. An increase in the pH value increases the $[OH^-]$, which reduces the solubility of metals. If carbonate alkalinity is present, the pH value increases [12].

$$CO_2+Ca(OH)_2 \Longleftrightarrow CaCO_3(s)+H_2O$$
$$Ca(HCO_3)_2+Ca(OH)_2 \Longleftrightarrow 2CaCO_3(s)+2H_2O$$
$$Mg(HCO_3)_2+2Ca(OH)_2 \Longleftrightarrow 2CaCO_3(s)+ Mg(OH)_2(s)+2H_2O$$

The relationship between carbon dioxide (CO_2)and various forms of alkalinity represent the chemical reactions between carbon dioxide and alkalinity ions.

$$CO_2+ H_2O \Longleftrightarrow H_2CO_3 \Longleftrightarrow H^++HCO_3$$
$$Ca(HCO_3)_2+Ca(OH)_2 \Longleftrightarrow HCO_3 \Longleftrightarrow H^++CO_3$$

Table 2.4 shows the various chemicals that are employed in corrosion control treatment for pH and alkalinity adjustment. Selection of the appropriate chemical is followed by such conditions as cost, shipment and personal preference [15].

Table 2.4 : Chemicals Typically Used in pH/Alkalinity Adjustment

Chemical	Use	Alkalinity Change	Notes
Caustic Soda (NaOH)	Raise pH. Convert excess CO_2 to alkalinity species	1.55mg/l $CaCO_3$ alkalinity per mg/l as NaOH	pH control is difficult when applied to poorly buffered water.
Lime ($Ca(OH)_2$)	Raise pH. Increases alkalinity and calcium content	1.21mg/l $CaCO_3$ alkalinity per mg/l as $Ca(OH)_2$	pH control is difficult when applied to poorly buffered water.
Sodium Bicarbonate ($NaHCO_3$)	Increases alkalinity with little increase in pH	0.60mg/l $CaCO_3$ alkalinity per mg/l as $NaHCO_3$	Good alkalinity adjustment choice.
Soda Ash (Na_2CO_3)	Increases alkalinity with moderate increase in pH	0.90mg/l $CaCO_3$ alkalinity per mg/l as Na_2HCO_3	More pH increase caused as compared to $NaHCO_3$

**Source : ** Faust and Aly, Chemistry of Water Treatment, 2nd Edition, (1998)

3.0 RESEARCH METHODOLOGY

3.1 Introduction

This chapter describes the experimental plan, tests, methods, materials, and procedures used to conduct this study. A brief description of the purpose of the study is provided in the experimental plan. Water quality parameters and their measurement methods are included under the test methods and materials selection. In addition, descriptions of the sampling and testing procedures are described as well.

3.1.1 Experimental Plan

The following methodology was developed to determine the effectiveness of two coagulants, Alum and PACL of the removal of turbidity, and color. Jar testing is considered to be an acceptable and economical method for simulating full scale coagulation, flocculation, and sedimentation processes in the treatment process and was chosen to determine the effectiveness of each coagulant. The primary goal of this research is to compare the effectiveness of PACL with Alum which is the normally used coagulant in Sri Lanka. In this study, effectiveness is evaluated based on the removal efficiency of turbidity, and colour in surface water. Apart from that, the effective pH ranges and coagulant dosages are taken into account in the determination of coagulant effectiveness in water treatment.

In order to stimulate information on the aspects such as Engineers', Chemists' and Operators' views on the field application. A questionnaire survey is used to collect a considerable amount of information, issues, questions and benefits in a short period of time and in a relatively cost effective way. Also, the results of the questionnaires could be collected quickly and easily quantified to compare and contrast the both coagulants. The questionnaire is designed to obtain the approaches, attitudes and opinions of the respondent in order to get a semi quantitative result.

Flow Diagram Methodology

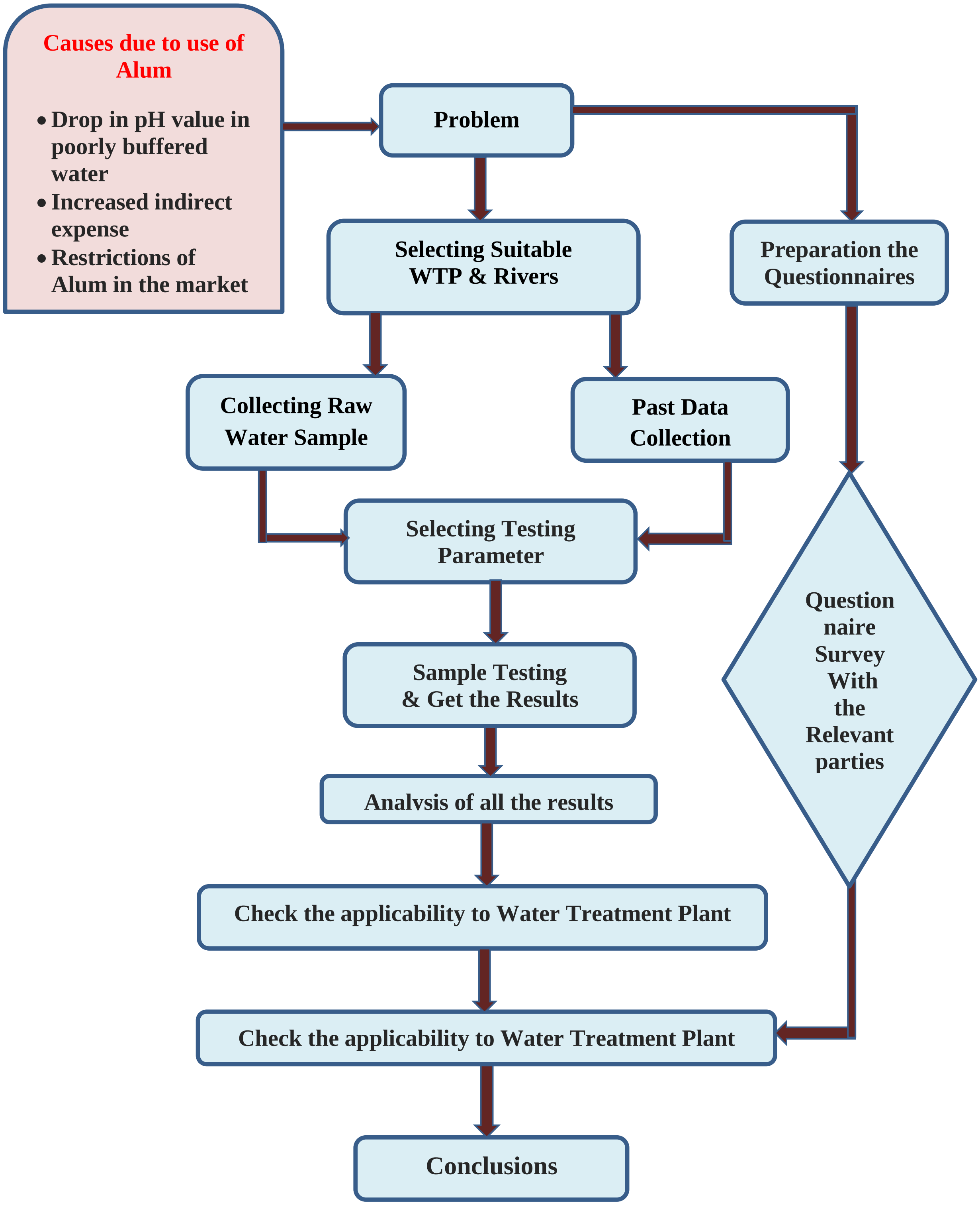


Figure 3.1: Flow Diagram Methodology

3.2 Location and Topography

The National Water Supply & Drainage Board is presently operating 325 Water Treatment Plants in the entire country covering townships and villages. The Kandana and Biyagama Water Treatment Plants are abstracting water from Kalu Ganga and Kelani Ganga respectively and these two water sources are selected for the study.

Both Kandana and Biyagama Water Treatment Plants are purifying water using conventional method and coagulation in combination with flocculation and sedimentation is a process that is usually used in water treatment to remove undesirable contaminants. Coagulation is the first important step of the water treatment process, involves the addition of a coagulant to destabilize suspended and colloidal particles, adsorb natural organic matter (NOM) to particles, and to create flocs of particles that enmesh other particles. Flocculation is the process by which larger particles are produced through flow aggregation to an appropriate size for removal from the raw water. Sedimentation is the process that is used to remove the flocs of appropriate size. All of these processes work together with the goal of maximizing removal under given water conditions through water treatment. The parameters that affect the removal efficiency include the type of coagulant used, mixing intensity used to separate the coagulant, and flocculation mixing intensity.

3.2.1 Kandana Treatment Plant

The Kandana Water Treatment Plant intake is located 12 km away from the sea mouth of the Kalu Ganga, which extracts 120,000 m^3/day of water to purify the water from Kandana Water Treatment Plant.

The Kalu Ganga is the second largest Ganga in Sri Lanka flows through in Kalutara and Ratnapura districts and it originates from Adams Peak. The length of the river is about 124km with a catchment area of 2719km^2 and flows through Ratnapura. Weganga, Kuruganga, Galatu Ela, Dumbara Oya, Yatipawwa Ela, Mawak Oya and Thebuwana tributaries are the main water sources connect to Kalu Ganga and discharges to the Indian Ocean at Kalurata town. The northern and southern areas near the basin boundary are covered by forests, paddy fields, rubber and tea plantations.

Water pollution in Kalu Ganga is many ways. Pollution enters the river directly and indirectly from houses and factories located along the river banks and waterways and canals which flow into the river. Gem and sand mining pollute the river in many ways, including color, turbidity and suspended colloid matter. In addition to that, salinity intrusion depends on low fresh water flow in the dry season and progressive degradation of river banks also cause deterioration of the quality of water in Kalu Ganga.

3.2.2 Biyagama Treatment Plant (Kelani Right Bank)

The Biyagama Water Treatment Plant's intake is located in 15 km away (upstream) from the sea mouth of the Kelani Ganga, which extracts 180,000 m^3/day of water to purify the water from Biyagama Water Treatment Plant.

The Kelani Ganga is a 145km long in Sri Lanka, stretches from the Sri Pada Mountain Range and it travels through or bordering the Sri Lankan districts of Nuwara Eliya, Ratnapura, Kegalle, Gampaha and Colombo. The Kelani Ganga flows through the capital of Sri Lanka Colombo and provides 80% of its drinking water in Western Province.

The Kelani River has become the main source of livelihood for many people living close to the river. It is used for transportation, hydro power generation, fisheries, irrigation, sand mining, and sewage disposal. This activity has many adverse effects and the results are already in the expose to water pollution.

3.3 Selection of coagulant

Figure 3.2 shows basic schematic steps in the coagulation process that follow during jar tests and include rapid mixing, slow mixing, and quiescent settling. In the rapid mix stage, the destabilizing agent is added and distributed in the whole of the jar. After a short, rapid mix period, the mixing is slowed to promote particle interaction and floc formation during the slow mix stage. Finally, the process concludes with a period of no mixing to allow for settling of flocs.

3.3.1 Factors for selection of Coagulant

Several factors have to be considered to identify the effective coagulant. The following factors are considered for the selection of coagulant.

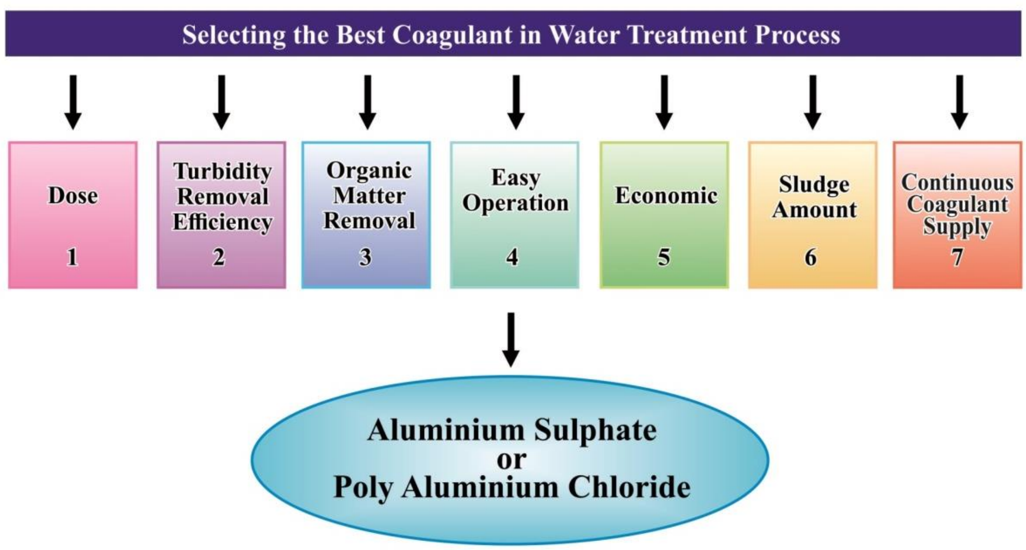


Figure 3.2: Factors for Selection Method of Coagulant for the Study

3.3.2 Experimental Design

Because of the several competing reactions and mechanisms that are operative in the coagulation process, the selection of coagulants and dosage is usually determined empirically using a bench-scale and pilot-scale studies.

This experiment was designed to understand the role of flocculation, coagulation and settling in water treatment process using Alum and PACL as the coagulants applied in the treatment process. The optimal coagulant dose would produce water with excellent settling characteristics, nearly zero color or pathogens in the effluent water and as minimum sludge was possible. Quantify best the above characteristics; the samples were analyzed for turbidity.

Selection of the type and dosage of coagulant depends on the characteristics of the coagulant, the concentration and type of particulates, concentration and characteristics of NOM, and raw water quality.

This study is designed to conduct full factorial experiment with two fixed factors, including water conditions, 6 different alum and poly aluminium chloride doses. Several numbers of jar tests were conducted using 6 sets of gang-mixer jar tests by using both Kalu Ganga and Kelani Ganga water.

3.3.3 Experimental Materials and Methods

3.3.3.1 Experimental Materials

Industrial grade Aluminium Sulphate (16%) and Poly Aluminium Chloride (28%) are selected as chemical coagulants in water treatment in NWSDB in Sri Lanka.

Preparation of coagulant chemicals

Stock coagulant solutions should be made to strength such that 1ml added to a liter of raw water will give a dose equaling 5 or 10mg/L [39]. In this study, stock solutions of Aluminium Sulphate and PACL were made at an equal 1% strength (weight/volume), since the raw water is mostly low turbidity throughout the year. Most plants use 10% strength solutions, however, for this work more dilute solutions (1%) were employed.

Coagulant solution was freshly prepared by dissolving 10g of coagulant in 1 liter of distilled water for making 1% solution of coagulant and dilutes it with distilled water on a daily basis in the treatment plants. Both Aluminium Sulphate and Poly Aluminium Chloride solutions were prepared for the jar tests.

3.3.3.2 Experimental Method

Raw water collection and characterization

Twelve litres of each raw water samples were collected on different days from a distribution chamber which is receiving water from the Kalu Ganga in Kandana and Kelani Ganga in Biyagama.

Turbidity Test

The turbidity meter HACH 2100Q used for this purpose. Before testing, samples of untreated raw water collected from the Kalu Ganga and the Kelani Ganga and after jar test prepared samples of different turbidity were measured for the purpose.

pH Test

Testing of the both river water’s pH was undertaken before and after jar test treatment with both types of coagulants by using a pH meter.

Colour Test

Colour was measured by visual comparison of the water sample with known concentrations of coloured solution, by visual comparison with special colour disks in the plant laboratories for raw water and after jar test settled water.

Reason for use of the Jar Test

Jar testing is a method of simulating a full scale water treatment process, providing system operators a reasonable idea of the way a treatment chemical. It will behave and operate with a particular type of raw water. Hence, this study, jar tests were used to mimic full scale operation to determine which treatment chemical will work best with the system's raw water.

In addition, jar tests are involved adjusting the amount of treatment chemicals and the sequence in which operators can be added to samples of raw water held in jars. The samples are then stirred so that the formation, development and settlement of flocs can be watched in the jars just as it would be in the full scale treatment plant.

Another important reason to perform a jar test is to save money within the treatment process. One of the common problems in water treatment is overfeeding or overdosing, especially with coagulants. This may not hurt the quality of water, but it can cost a lot of money and spend more time during the process.

Coagulation Jar Tests

All coagulation studies were conducted in Jar test apparatus (Phips and Bird, USA), by using raw water, under the ambient temperature. Jar test apparatus having 6 flat blade stirrers (each 7.6 × 2.5 cm 2) driven by 0.05 HP motor with an induced speed range of 10 to 400 rpm was used to assess Alum and PAC in coagulation of colloids and dissolved particles. BorosilR glass beakers of 1 lts capacity were used for all the experiments. The field conditions were simulated in the laboratory in Jar test apparatus with 2 minutes for rapid mixing of coagulants with raw water, 10 minutes for coagulation and flocculation, and 10 minutes for sedimentation of flocs.

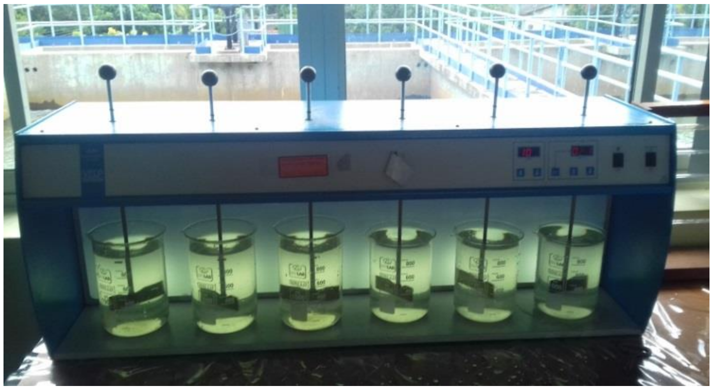


Figure3.3: Photograph Showing the Removal of Turbidity at Different Doses of Coagulants Using Jar Test Apparatus.

The jar test procedure for optimizing the dosage of coagulant includes the following steps:

1. While rapidly mixing the raw water, six different dosages of coagulants were added to each jar containing the water from the same source.
2. The coagulants were rapidly mixed at high velocity for 2 minutes with 180rpm at the maximum possible mixing intensity.
3. The stirring speed is reduced while slowly mixing the suspensions at 180rpm to 120 rpm for 4 minutes.
4. The stirring speed is further reduced while more slowly mixing the suspensions at 120 rpm to 40 rpm for 6 minutes.
5. The stirring apparatus is stopped to allow the floc to settle for 10 minutes.
6. Visual inspection was done in the check of the floc size.
7. The turbidity and color of the water samples were measured.

Figure3.4: Photograph Showing the Flocs formation at Different Dose of Coagulants Using Jar Test Apparatus

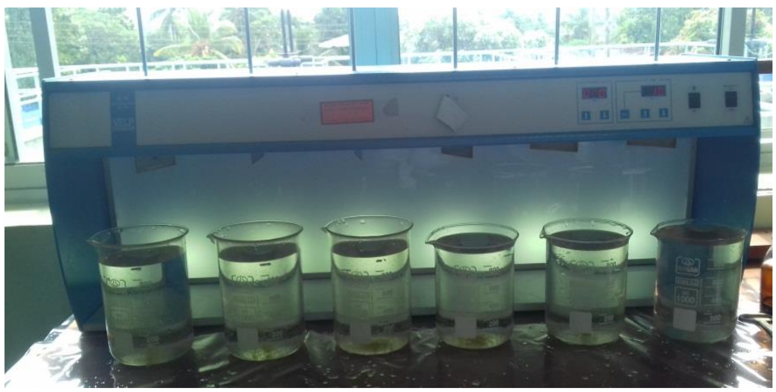


Figure3.5: Photograph Showing the Flocs Settlement at Different Dose of Coagulants Using Jar Test Apparatus

In addition to residual turbidity in jar tests, other parameters such as colour, particle size analysis, pH used as performance indicators for coagulation control in this study. Analysis of residual turbidity and floc size was conducted to evaluate coagulation performance in the treatment plant.

Based on the results of the jar tests on the treatment plants, alum and PACL were tested for removal at the selected dosages at different turbidity levels.

Flocs Analysis

There was growing interest in the coagulation flocs study in water treatment. This is because the performance of coagulation, sedimentation, filtration and disinfection processes in water treatment system is powerfully influenced by the coagulation flocs. In order to understand the factors affecting the size of coagulation flocs, microscopic particle analysis were presented.

With the increase of the floc size, coagulation process is efficient in Water Treatment Plant normally. The floc size during jar tests were observed visually and recorded in NWSDB Water Treatment Plants as per the following classification:

Table 3.1: Floc Size Index

Floc Size Index (FSI)	Indication
A	Pin Point Floc
B	Very Small Floc
C	Small Floc
D	Medium Floc
E	Large Floc
F	Lump Floc
G	Large Lump Floc

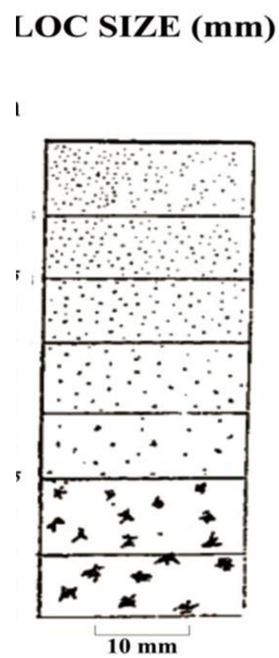


Figure 3.6: Flocs Size at Different Dose of Coagulants Using Jar Test Apparatus (NWSDB)

3.4 Optimal Coagulant Dosage Selection

Optimal Alum Dose Selection

The coagulation and flocculation treatment were selected for both of the raw water sources in Kandana and Biyagama Water Treatment Plants. A typical dose of alum in full-scale systems ranges between 05 and 150 mg/L, and depends on the raw water quality and characteristics in the sources [7]. Although the highest dosages of alum may be the best for maximum removal of turbidity and colour, the cost of removing the additional sludge produced with this dose may make it very difficult for plant operation and economically unaffordable on a cost basis.

After 10 minutes of settling, the optimal alum dose was apparent for water samples. Supernatant samples were taken from 20 mm below the water surface for turbidity measurements. Maximum turbidity removal was the parameter used to select the optimal dose; but, in some cases the second largest turbidity removal was selected as the ideal dose. The optimal alum dosage to reach sufficient turbidity removal of water sources were selected due to the optimal colour ranges. The pH did not influence the selected dose for any of the water sources.

3.5 Questionnaire Survey

3.5.1 Description of Questionnaire

Questionnaires were distributed by paper based and electronic media. It consisted of a series of questions used for gathering information that is used for the research.

The survey included three parts:

1) The first part asked screening questions to determine if the remainder of the survey should be answered

2) The second part requested information on coagulants used in WTPs in NWSDB.

3) The third part requested plant utilities, financial data and market availability about the coagulants

The first part of the survey requested information such as awareness the coagulant, age of the plant, treatment plant experience, and daily production. The second part of the survey requested general treatment plant chemicals used coagulants types and quantities, benefits of the used coagulant, reduction of the turbidity removal, water quality. The last part of the survey requested financial data and market data regarding both coagulants. Survey questions included plant utilities and overheads of the plant, man power of the plant, required finances for the coagulants, market opportunities of the coagulants, any lack of the supply in the history for the coagulants, future supply of the chemicals and overall plant revenue.

The questionnaire survey was used among the treatment plant's professionals, who were knowledgeable about the treatment plant procedures, both chemicals, water quality parameters, market situation of the world.

4.0 ANALYSIS, RESULTS AND DISCUSSION

4.1 Introduction

This Chapter presents the results of testing the performance of two types of coagulants on the clarity of the Kalu Ganga and the Kelani Ganga water samples at different levels of turbidity. The analysis, results and discussion of collected data in order to achieve the research objectives mentioned in Chapter One. Data collected from past and present jar test results in the Kadana and Biyagama Water Treatment Plants and Questionnaire Survey. These collected data was used for the analysis.

4.2 Factors affecting to the effectiveness and efficiency of usage of Coagulants

To select the optimum coagulant for water treatment, at first the effective factors in selection were recognized and compared with the tested coagulant features, before the best coagulant was selected. It is worth to mentioning that it is not possible to select and introduce the best coagulant for coagulation and flocculation in water treatment. In other words, a coagulant cannot be prescribed for all water (with different features) as the best. The coagulant was selected based on the quality conditions of entrant raw water to the water treatment plant.

There were three important components for each selection as: Goal, Criteria and Alternatives. These three principles are about the selection of the best coagulant in water treatment. Thus, the goal is to select the best coagulant in coagulation and flocculation operation in water treatment, the criteria are the effective factors in selecting the best coagulant for water treatment.

During the period of the laboratory tests, the water samples had various quality characteristics such as turbidity, colour, pH, alkalinity, odor,etc; These experimental jar tests were done every day at Kadana and Biyagama Water Treatment Plants in Sri Lanka.

Based on the results of this research, for the selection of poly aluminum coagulants were developed. In the discussion, the coagulants that were most effective for the treatment of both of the water sources examined during this research. Raw water characteristics of a both water treatment plants, raw water turbidity and the concentration and nature of raw water parameters affect the required coagulant dose, but generally do not influence the type of coagulant that is most effective.

Raw water alkalinity and water temperature are the most important raw water quality variables in terms of selecting a particular coagulant. Turbidity for raw waters in which turbidity controls coagulation, sufficient coagulant must be added to destabilize suspended colloids and/or to create a good settling floc for effective treatment to occur. However, for the waters examined in this research, raw water pH is less important for determining the appropriate coagulant dosage in both Kalu Ganga and Kelani Ganga.

Experimental Materials and Methods

Jar tests were used to evaluate the effectiveness of Aluminium Sulphate and Poly Aluminium Chloride under a variety of operating conditions for water treatment. This procedure was allowed individually on such a criteria floc formation, settling characteristics, and clarity. Generally, the best performing products provide fast floc formation, rapid settling rate, and clear supernatant. A jar test is widely used to determine optimum chemical dosages for water treatment. This laboratory test attempts to stimulate the full scale coagulation, flocculation process and can be conducted for a wide range of conditions.

The data obtained from several raw water samples conducted throughout the study were provided and past data was collected in Kalu Ganga and Kelani Ganga represent in Appendices A and B respectively. These tables present the results of testing the performance of Aluminium Sulphate (Alum) and Poly Aluminium Chloride (PACL) on the clarity of both Kalu Ganga and Kelani Ganga water samples at different levels of turbidity.

4.3 Turbidity of the Raw Water in Kalu Ganga and Kelani Ganga

Turbidity of the raw water varies every day depending on upstream activities and conditions. Figures 4.1 and 4.2 show the raw water parameters Turbidity and colour in Kalu Ganga and Kelani Ganga respectively.

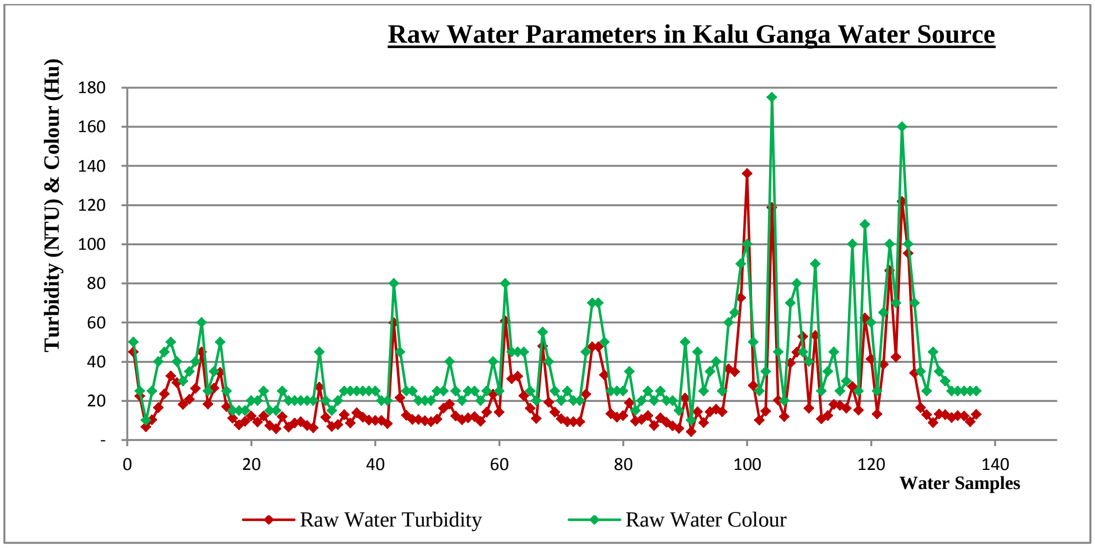


Figure 4.1: Raw Water Parameters in Kalu Ganga in the year 2010 and 2011

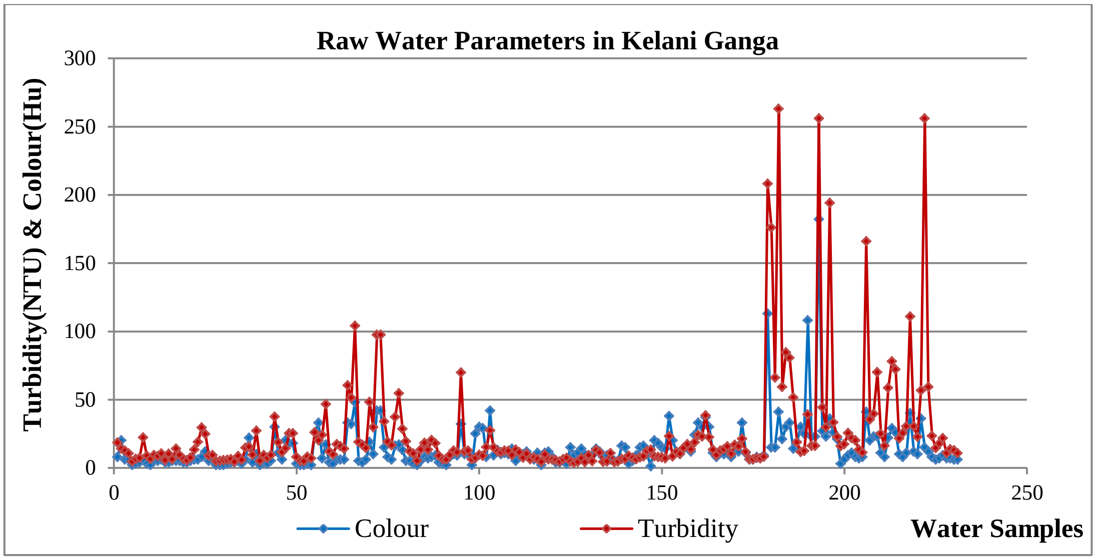


Figure 4.2: Raw Water Parameters in Kelani Ganga in the year 2014 and 2015

4.4 Experimental Jar Tests Results

The comparative performance of Alum and PACL at six turbidity levels viz. 0-10 NTU, 11-20 NTU, 21-40 NTU, 41-60NTU,61-80NTU, and 81-140NTU are tabulated in Appendix C and D for the coagulants of Aluminium Sulphate and Poly Aluminium Chloride separately. These Appendices summarized the jar test results which were done in the Kadana Water Treatment Plant using the Kalu Ganga water source.

Similarly, Jar tests performance data was taken from Biyagama Water Treatment Plant and the turbidity was analysed at turbidity levels of 0-15NTU, 16-30NTU and 31-85NTU. The jar tests were done by using both Aluminium Sulphate and Poly Aluminium Chloride using the Kelani Ganga and results are shown in the Appendix E.

4.5 Coagulant Performance

All the results were taken at the optimum dosage of coagulant as it is one of the most important parameters in coagulation-flocculation process, which determine the optimum operational condition for the performance of metal salt coagulants. The poor flocculation performance may be caused by either the insufficient coagulant dosage or overdosing. For this reason, determining of the optimum dosage is important to reduce the chemical cost and sludge formation.

Coagulant performance variations were determined graphically using Scatter Chart of Microsoft Exel. These diagrams consist of format trend lines of constant removal to plot against Turbidity (NTU) (x-axis) and coagulant concentration (ppm) (y-axis).

4.5.1 Coagulant Performance in Kalu Ganga water

Comparative Performance of alum and PACL

The comparative performance of alum and PACL at four initial turbidity levels, viz, 18.3 NTU, 39.2 NTU, 72.5 NTU, and 136 were tested and tabulated in Tables 4.3 to 4.6.

Table 4.3	**Turbidity**	**Colour**	**pH**	**Alkalinity**	**Temp ^0C**	
Raw Water	18.3	40	6.3	24	26.8	
Jar Number	**1**	**2**	**3**	**4**	**5**	**6**
Alum Dose (ppm)	7.5	8	8.5	9	9.5	10
Turbidity (NTU)	3.19	2.44	2.03	2.24	2.17	2.44
Turbidity Reduction %	82.6	86.7	88.9	87.8	88.1	
PH	6.3	6.3	6.3	6.3	6.3	6.3
Colour (Hu)	5	5-2.5	5	2.5	2.5	2.5
FSI	C	D	E	E	E	E
PACL Dose (ppm)	2.5	3	3.5	4	4.5	5
Turbidity (NTU)	4.52	3.47	2.33	2.47	2.45	4.1
Turbidity Reduction %	75.3	81.0	87.3	86.5	86.6	
PH	6.3	6.3	6.3	6.3	6.3	6.2
Colour (Hu)	7.5	5	2.5	2.5	5	5-7.5
FSI	C	D	E	E	E	E

Table 4.4	**Turbidity**	**Colour**	**pH**	**Alkalinity**	**Temp ^0C**	
Raw Water	39.2	70	6.5	20	25.6	
Jar Number	**1**	**2**	**3**	**4**	**5**	**6**
Alum Dose (ppm)	12.5	13	13.5	14	14.5	15
Turbidity (NTU)	2.25	1.96	2.17	2.13	2.04	2.26
Turbidity Reduction %	94.3	95.0	94.5	94.6	94.8	94.2
PH	6.4	6.4	6.3	6.3	6.3	6.2
Colour (Hu)	7.5-5	5	5	7.5-5	7.5-5	7.5-5
FSI	E	E	E	E	E	E
PACL Dose (ppm)	4	4.5	5	5.5	6	6.5
Turbidity (NTU)	3.96	2.89	2.43	2.1	3.79	5.61
Turbidity Reduction %	89.9	92.6	93.8	94.6	90.3	85.7
PH	6.1	6.1	6.1	6.1	6.1	6.1
Colour (Hu)	7.5	5	5	2.5	5	7.5
FSI	D	E	F	G	E	D

Table 4.5	**Turbidity**	**Colour**	**pH**	**Alkalinity**	**Temp ^{0}C**	
Raw Water	72.5	90	6.5	15.5	26.2	
Jar Number	**1**	**2**	**3**	**4**	**5**	**6**
Alum Dose (ppm)	13.5	14	14.5	15	15.5	16
Turbidity (NTU)	3.65	2.84	2.49	2.62	2.85	2.78
Turbidity Reduction %	95.0	96.1	96.6	96.4	96.1	
PH	6.4	6.3	6.3	6.3	6.3	6.2
Colour (Hu)	10-7.5	7.5-5	7.5-5	5-2.5	7.5-5	7.5-5
FSI	E-F	E-F	E-F	E-F	E-F	E-F
PACL Dose (ppm)	5	5.5	6	6.5	7	7.5
Turbidity (NTU)	7.82	4.85	2.15	2.11	1.95	1.95
Turbidity Reduction %	95.0	96.1	96.6	96.4	96.1	96.2
PH	6.5	6.5	6.5	6.5	6.4	6.3
Colour (Hu)	15	7.5	5	5	2.5	2.5
FSI	D	E	F	G	E	D

Table 4.6	**Turbidity**	**Colour**	**pH**	**Alkalinity**	**Temp ^{0}C**	
Raw Water	136	100	6.1	15	25.4	
Jar Number	**1**	**2**	**3**	**4**	**5**	**6**
Alum Dose (ppm)	13.5	4	14.5	15	15.5	16
Turbidity (NTU)	2.26	2.32	3.06	3.42	4.13	5.67
Turbidity Reduction %	98.3	98.3	97.8	97.5	97.0	
PH	6.1	6.1	6	6	5.82	5.73
Colour (Hu)	5-2.5	5-2.5	7.5-5	7.5-5	7.5-5	10-7.5
FSI	E-F	E-F	E-F	E-F	E-F	E-F
PACL Dose (ppm)	4.5	5	5.5	6	6.5	7
Turbidity (NTU)	32.6	20.3	8.75	6.02	2.26	2.77
Turbidity Reduction %	76.0	85.1	93.6	95.6	98.3	
PH	6	6	6.1	6	6	6
Colour (Hu)	50	30	15	10	2.5	2.5
FSI	D	E	F	G	G	G

Experiments were carried out to observe the performance of the two types of coagulants on the clartity of raw water samples at different levels of turbidity. The effects of increasing coagulant dosages on water samples were determined. These tables show the increased removal of water impurities with an increase in the dose of both types of coagulants. However, the PACL produced the lowest water impurities. PACL produced better results than either of the alum coagulants.

The comparative performance is summarized in Table 4.7.

Table 4.7 : Comparative Optimum Dosages of Alum and PACL

Item No	Raw Water Turbidity NTU	Optimum Dose of Alum (ppm)	Optimum Dose of PACL (ppm)	PACL /Alum Optimum Dose (%)
1	18.3	8.5	3.5	41.18
2	39.2	13.0	5.5	42.31
3	72.5	14.5	6.5	44.83
4	136	13.5	6.5	48.15

The results presented in Figure 4.3 shows the effect of Aluminium Sulphate and Poly Aluminium Chloride chemical dose on the removal efficiency of turbidity from raw water. Good removal efficiency was recorded for PACL in all ranges of turbidity than Alum. Both coagulants performed well at higher turbidities. However, PACL performed the best, as clearly shown in the graph.

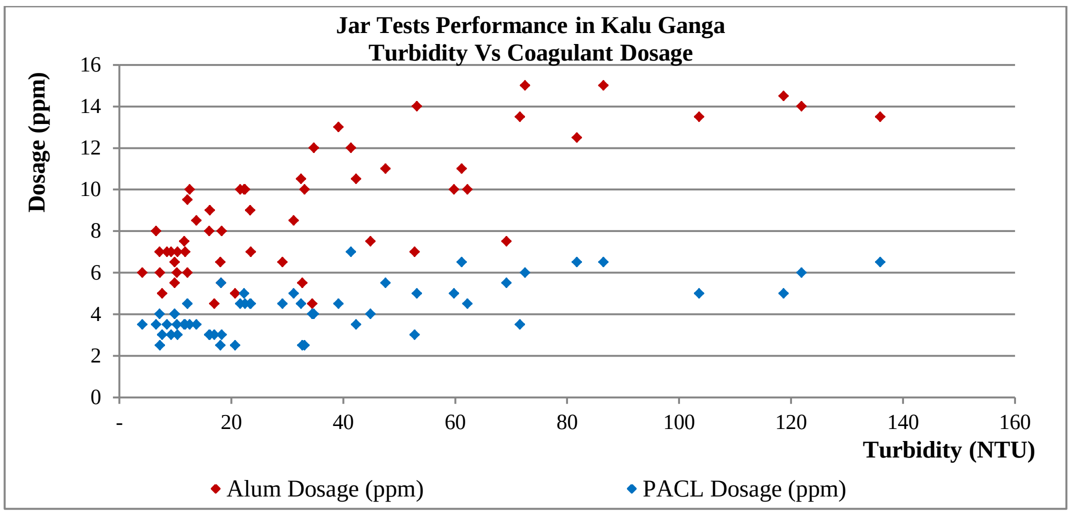


Figure 4.3: Jar Tests Performance in Kalu Ganga with Raw Water turbidity from 4.14NTU to 136NTU

Coagulant Performance in Raw Water Turbidity Levels

Turbidity Level (0-10) NTU

The level of turbidity was determined by considering turbidity ranges for raw water in Kalu Ganga, the required dosage of concentrations of coagulating chemicals for achieving. Figure 4.4 to 4.9 are given the comparison of the removal efficiency of tested coagulant in optimum dose.

As the results in Figures show, in the input turbidity (0-10) NTU (Figure 4.4) removal efficiency of both coagulants were similar with regard to turbidity and colour, but, the best turbidity removal efficiency was for PACL as the lower dose concentration than that of the Alum dosage concentration in the jar tests. In the range of 0-10NTU, PACL average optimum concentration dosage was 53% of Alum concentration dosage.

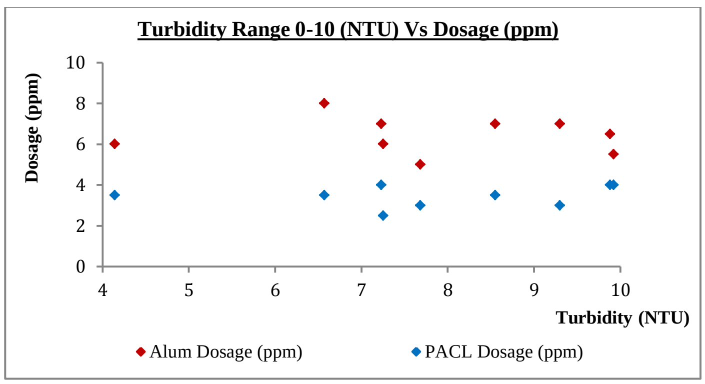


Figure 4.4: Effect of Coagulants Concentration on Turbidity in Initial Turbidity Range 0-10NTU

Turbidity Level (11-20) NTU

In the input turbidity range (11-20) NTU (Figure 4.5) the highest turbidity removal efficiency of tested coagulants were obtained as PACL than Alum and average optimum concentration dosage of PACL was 48% of Alum concentration dosage. Removal efficiency percentage was the turbidity and colour was almost equal in both coagulants in the jar tests experiments.

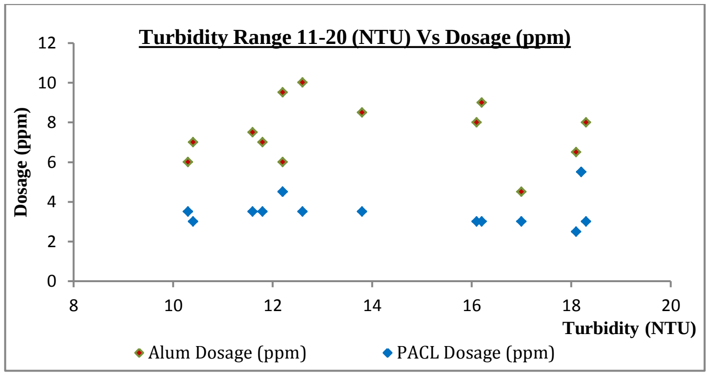


Figure 4.5: Effect of Coagulants Concentration on Turbidity in Initial Turbidity Range 11-20NTU

Turbidity Level (21-40) NTU

In the input turbidity range of 21-40NTU (Figure 4.6) the turbidity removal efficiency was obtained from PACL and the tested coagulants PACL average chemical dosage was 47% of Alum coagulant.

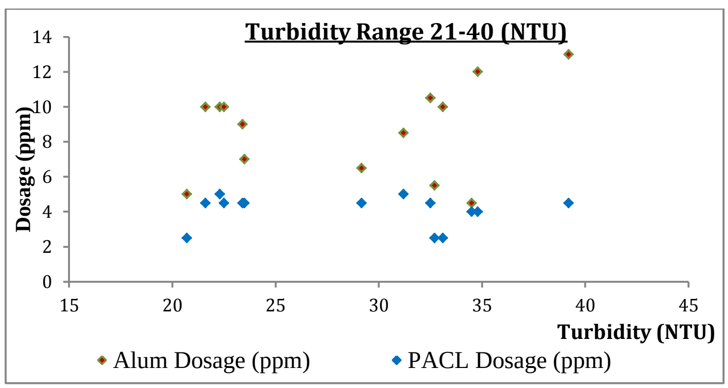


Figure 4.6: Effect of Coagulants Concentration on Turbidity in Initial Turbidity Range 21-40NTU

Turbidity Level (41-60) NTU

In the input turbidity range of 41-60NTU (Figure 4.7) removal efficiency of both coagulants were similar with regard to the turbidity and colour and in both cases turbidity removal efficiency was above 90%, but the average chemical dosage was 46% of Alum coagulant.

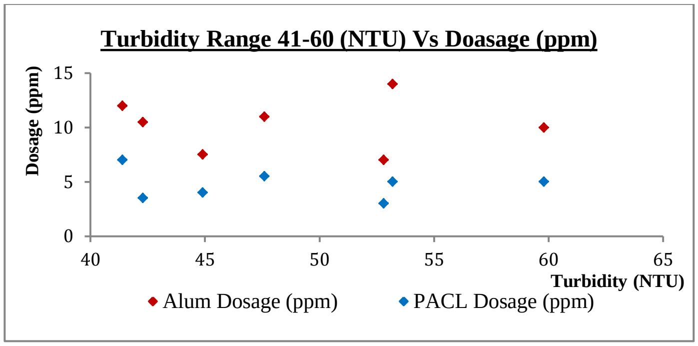


Figure 4.7: Effect of Coagulants Concentration on Turbidity in Initial Turbidity Range 41-60NTU

Turbidity Level (61-80) NTU

In the input turbidity range of 61-80NTU (Figure 4.8) removal efficiency of both coagulants was similar in regard to turbidity and colour. In both cases turbidity removal efficiency was above 90%, but the average PACL chemical dosage was 46% of Alum coagulant. This dosage was the same as the turbidity range of 41-60NTU.

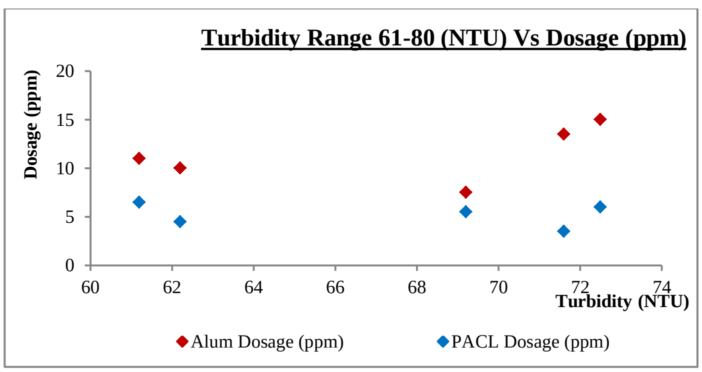


Figure 4.8: Effect of Coagulants Concentration on Turbidity in Initial Turbidity Range 41-60NTU

Turbidity Level (81-140) NTU

The input turbidity range 81-140NTU (Figure 4.9) the highest turbidity removal efficiency of PACL was 43% of the Alum.

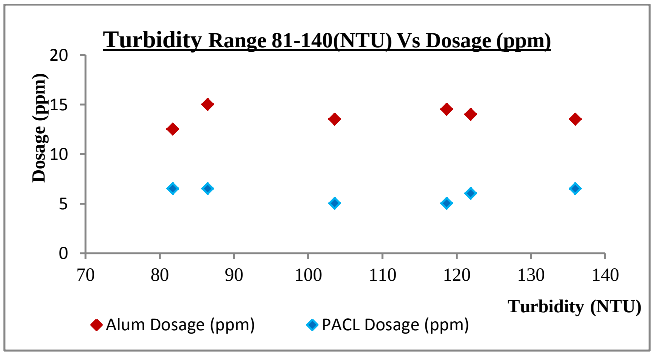


Figure 4.9: Effect of Coagulants Concentration on Turbidity in Initial Turbidity Range 81-140NTU

To sum up, in the coagulation process, Poly Aluminium Chloride is better than the high turbidity of the raw water source in Kalu Ganga. However, this experiment indicated that the higher turbidity water was a better performance in PACL than that of lower turbidity water with low concentration of the chemical as illustrated in Figure 4.11.

4.5.2 Coagulant Performance in Kelani Ganga

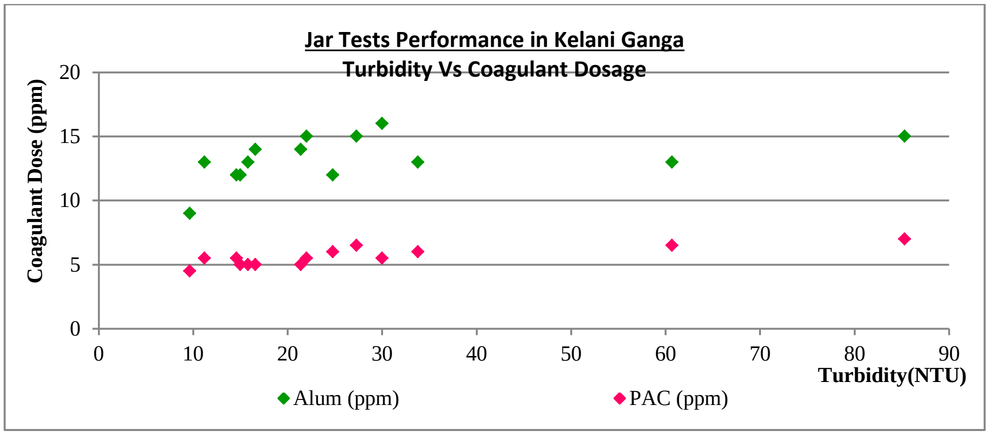


Figure 4.10: Jar Tests Performance in Kelani Ganga with Raw Water turbidity from 9.66 NTU to 85.3NTU

The Figure 4.12 shows the variation in the range of turbidity 9.66 NTU to 85.3 NTU. According to the above figure the optimum dosages of alum and PACL were 9.0 ppm and 4.5 ppm for raw water turbidity 9.66 NTU.

As per the above graph, the optimum dosage of PACL for the sample with 85.3 NTU turbidity was 7.0 ppm. For the similar, optimum dosage of alum was 15.0 ppm. Accordingly, coagulant of the above water sample was more efficient with PACL performance.

Performance of turbidity removal of raw water is demonstrated in Figure 4.12. This figure shows, raw water turbidity removal by coagulant was efficient in the high turbidity raw water. In addition, it shows high turbidity raw water consumed less coagulant than low turbidity water in the removal of turbidity.

To sum up in the coagulation process, Poly Aluminium Chloride is better than the high turbidity of the raw water source in Kelani Ganga.

In the range of various turbidity levels of 0-15NTU, 16-30NTU, and 31-85NTU, were tested for the optimum dosage ratio with both the coagulant PACL & Alum. According to the test results requirements of PACL compared with Alum were 43.2%, 39%, and 47.6% respectively in the Kelani Ganga water source.

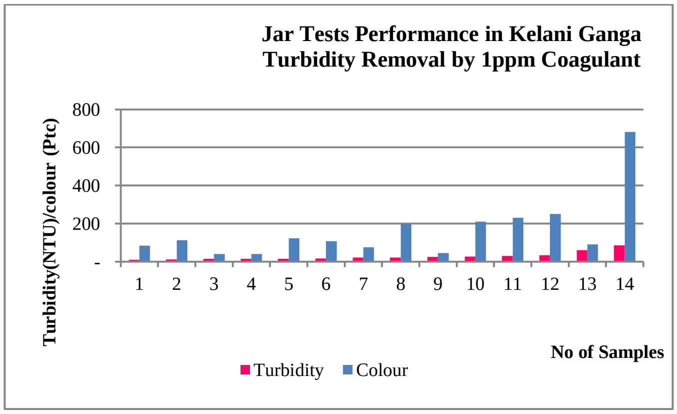


Figure 4.11: Raw Water Parameters in Kelani Ganga

Performance of turbidity removal of raw water in Kelani Ganga is indicated in Figure 4.15. This figure shows that raw water turbidity removal by coagulant was efficient in the high turbidity raw water. In addition, it shows high turbidity raw water consumed less coagulant than low turbidity water to remove turbidity.

4.6 Flocs Size Analysis

During the experiment, it was noted that in the PACL treatment flocs formed larger in sizes and flocs settled faster than the alum. This could be due to the great effect of PACL hydrolysis as compared to that of alum.

The observed floc quality for PACL and Alum varied depending on dosage. The flocs were observed to change from a pin point flocs to fluffy flocs in the case of PACL.

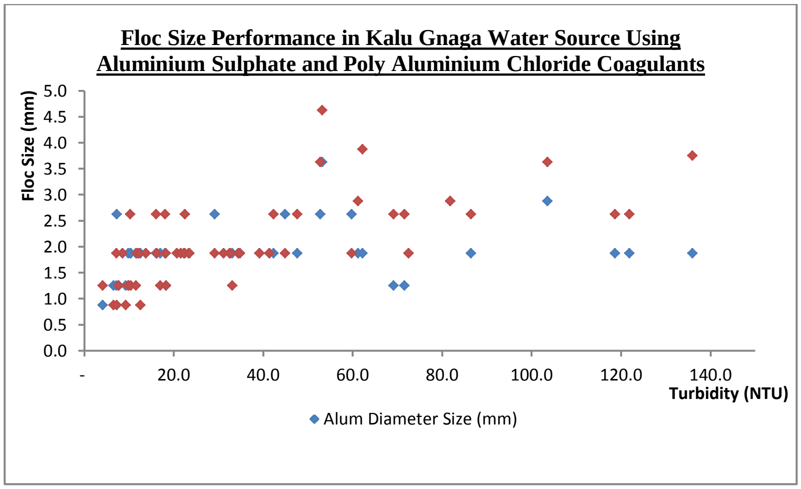


Figure 4.12: Floc Size Formation Using Aluminium Sulphate and Poly Aluminium Chloride in Kalu Ganga

Figure 4.16 shows the floc size formation by using alum and PACL in Kalu Ganga water source. This figure shows, the generated floc size was higher with PACL than with Alum under the same concentration of coagulants. In the jar tests, flocs were generated faster and larger size with a smaller dosage of PACL than of Alum. This indicates that of the PACL has a higher hydrolysis characteristic than alum.

pH Test

Testing of the raw water's pH was undertaken before and after water treatment with both coagulants. But there were no significant changes in the resultant pH, as seen in the experimental data tabulated in Table 4.1 and Table 4.2 in the Kalu Ganga.

4.7 Factors affecting the effectiveness and efficiency of coagulants

The most effective coagulants for the treatment were examined for the both water sources. Raw water characteristics, particularly the raw water turbidity and colour affect the required coagulant dosage with the type of coagulant. The literature review showed that raw water alkalinity and water temperature are the most important raw water quality variables for selecting a particular coagulant. Sufficient coagulant must be added to destabilize suspended colloids and/or to create a good settling floc for effective treatment to occur. However, for the water examined in this research, raw water pH is less important for determining the appropriate coagulant dosage in both Kalu Ganga and Kelani Ganga.

4.8 Financial Analysis

Potable water treatment process costs vary depending on the quality of the raw water and the treatment process. The total treatment cost includes cost of chemicals, transport, storage, manpower, energy, etc.

This research was carried out in the two water treatment plants at Kandana and Biyagama and these two plants are operated as conventional water treatment process.

At Kandana Treatment Plant, chemical procurement data collected for the period 2008 to 2016 showed that during 2009 to 2011 they have shifted to using PACL instead of Alum, and reverted back to Alum in 2011. The study shows a significant cost reduction in the treatment chemical cost when using PACL. The annual chemical cost is indicated in Tables 4.3 and 4.4, and Fig 4.13. These data show that there is a 32% (average) cost reduction when using PACL instead of alum.

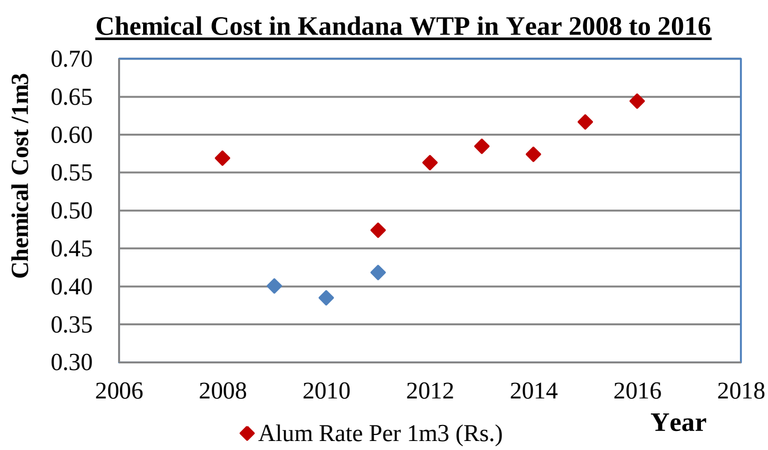


Figure 4.13: Comparison chemical cost in Kandana WTP in Year 2008 to2016

Table 4.8 : Chemical Cost of the Kandana Water Treatment Plant from Year 2008 to Year 2016										
Year	**Coagulant**	**Monthly Production (m3)**	**Alum (Tonnes)**	**Lime (Tonnes)**	**PACL (Tonnes)**	**Alum Cost(Rs.) *[1]**	**Lime Cost (Rs.) *[2]**	**PACL Cost (Rs.) *3**	**Total Cost (Rs.)**	**Rate Per 1m3 (Rs.)**
2008	**Alum**	15,329,880	166	99	-	6,238,125	2,485,000	-	8,723,125	0.57
2011		12,905,224	106	86	-	3,975,000	2,140,750	-	6,115,750	0.47
2012		22,046,898	247	126	-	9,253,125	3,161,250	-	12,414,375	0.56
2013		24,108,072	288	132	-	10,785,000	3,310,750	-	14,095,750	0.58
2014		25,452,430	292	146	-	10,961,250	3,648,250	-	14,609,500	0.57
2015		32,304,033	397	202	-	14,887,500	5,038,250	-	19,925,750	0.62
2016		39,846,694	488	296	-	18,281,250	7,392,500	-	25,673,750	0.64
		171,993,231	**1,984**	**1,087**	**-**	**74,381,250**	**27,176,750**	**-**	**101,558,000**	**0.59**
2009	**PACL**	17,511,666	-	74	78	-	1,914,250	5,099,900	7,014,150	0.40
2010		18,334,369	-	85	76	-	2,109,750	4,947,150	7,056,900	0.38
2011		6,728,419	-	32	31	-	800,000	2,015,000	2,815,000	0.42
		42,574,454	**-**	**191**	**186**	**-**	**4,824,000**	**12,062,050**	**16,886,050**	**0.40**

Table 4.9 : Annual Cost Saving by Using PACL instead of Alum as per Table 4.3				
Description	**Monthly Production (m3)**	**Rate Per 1m^3 (Rs.)**	**Monthly Treatment Cost (Rs.)**	**Yearly Treatment Cost (Rs.)**
Water Treatment by Alum	3,750,000	0.59	2,212,500.00	26,550,000.00
Water Treatment by PACL	3,750,000	0.40	1,500,000.00	18,000,000.00
*Annual saving by using PACL instead of Alum				**8,550,000.00**

Note: The cost analysis is based on present (Year 2017) market prices.

***[1] - Alum Cost Rs.37,500.00/Tonne** ***[2] - Lime Cost Rs. 25,000.00/Tonne** ***[3] – PACL Cost Rs.65, 000/Tonne**

4.9 Questionnaire Survey Analysis

The objective of the questionnaire survey were,

(a) To assess the acceptability of PACL compared to Alum, among the treatment plant operating staff and other officers

(b) to seek information about issues, if any that need to be addressed if a decision is made to change from Alum to PACL

To identify the effective factors on coagulants, the questionnaire survey has been carried out of the users of water treatment. The survey was conducted at plant's operated personals who were knowledgeable of the treatment process in the WTPs. Engineers, Chemists and Plant Technicians.

A set of questionnaire was distributed to the personals. Among them 21 experts were commented base on the selection of the best performance coagulant. The questionnaire survey and questionnaire survey analysis are presented in Appendices F and G respectively. These comments were analyzed and graphically presented in Figure 4.14.

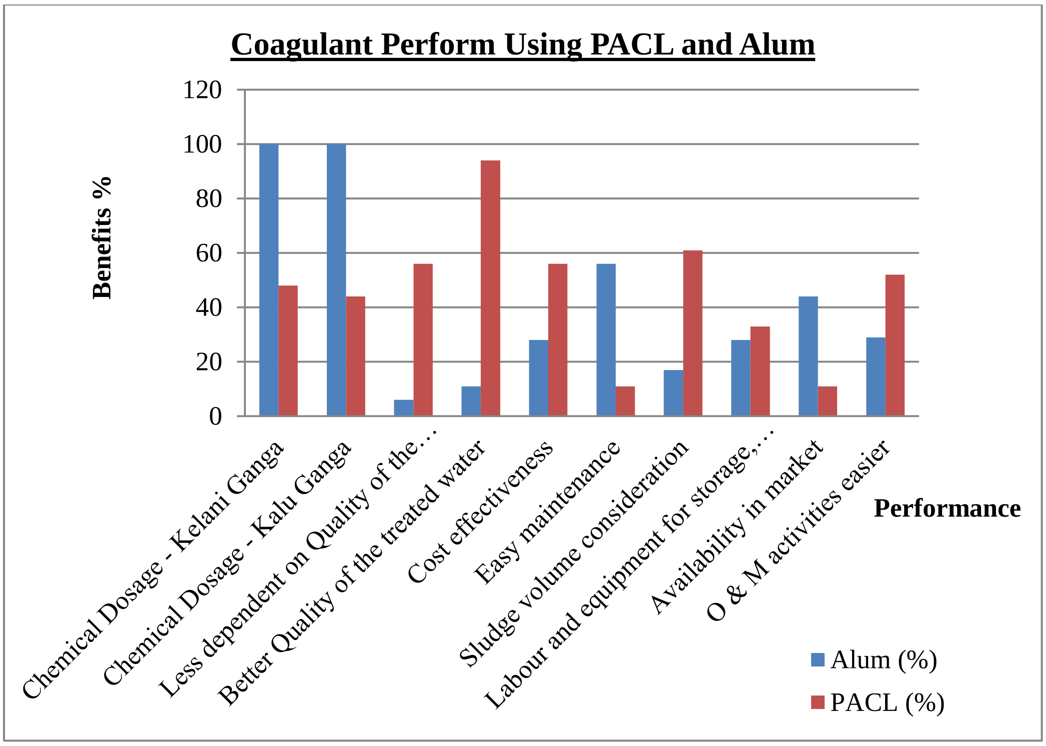


Figure 4.14: Coagulant Perform Using PACL and Alum

4.9.1 Requirement of the coagulant dosages for water treatment

The test results data show that the dosage of PACL required for raw water treatment was less than alum at both low and high turbidities. Past researchers have stated that the PACL required for water treatment is 60% less than that of alum. However, my study found that PACL achieved from 43% to 53% of the dosage of alum required to remove turbidity in the Kalu Ganga water source. Similarly, this from 39% to 47.6% is in the Kelani Ganga water source. In comparison PACL required only 50% of dosage of alum for water treatment.

4.9.2 The benefits expected from using PACL and Alum

The benefits expected from using PACL and alum are presented in figure 4.15.

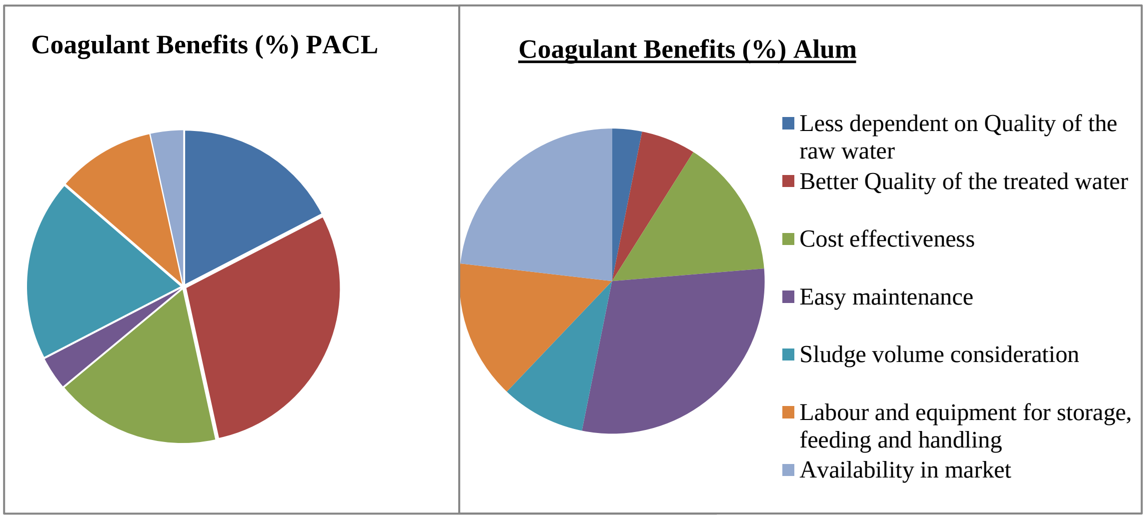


Figure 4.15: Benefits Expected From Using PACL and Alum

- Less dependent on Quality of the raw water

  Almost 56% of respondents opined that optimum PACL dose is less than alum for same raw water quality.

- Better Quality of the treated water

  With regard to the quality of treated water, PACL performed better than alum. 94% of respondents stated that PACL perform better than alum while 11% disagreed.

- Cost effectiveness

  PACL chemical cost is more than alum. However, in terms of indirect cost PACL is more economical. 56% of respondents agreed the PACL is more cost effective than alum while 27% disagreed.

- Easy maintenance

  The coagulation process covers and depends from chemical supply to sludge disposal of utilization. However, the majority of respondents (56%) were in favour of alum.

- Sludge volume consideration

  All coagulants produce sludge in the form of metal hydroxide together with coloured and colloidal matter removal from the raw water in the treatment. 61% of the despondence opined that PACL produces less sludge than alum while 17% considered alum to produce less sludge.

- Availability in market

  PACL and alum are imported mainly from India and China respectively to Sri Lanka, as these are the least cost options. Presently, there are shortages for alum in the market due to production restrictions. 44% respondents considered alum to be available in the market and 11% thought it was not available. This is probably because they were ignorant of the market situation.

- Labour and equipment for storage, feeding and handling

  Labour and equipment for storage, feeding and handling is reduced when using PACL than alum in treatment process. 33% of the respondents agreed that labour and equipment for storage, feeding and handling were less for PACL as opposed to 27% for alum.

4.9.3 The percentage of turbidity reduced efficiency by using alum and PACL

According to the experiments, both PACL and Alum could achieve more than 90% turbidity removal. Most of the respondents said that the turbidity removal percentage is in between 75-100%. This is more or less in agreement with my study results.

4.9.4 Coagulant type which makes O & M activities easier

Questionnaire survey results stated that the 52.4% and 28.6% said O&M activities were easier with PACL and Alum respectively..

4.9.5 Time required for floc perfomation

During the experiments, it was noted that PACL flocs formed rapidly and the floc size was large. It needs a short time to react and settle down. This could be due to the greater ease of PACL hydrolysis as compared that of alum. According to the literature, PACL emits polyhydroxides with long molecular chains and greater electrical charges in the solution, thus maximizing the physical action of flocculation.

4.9.6 More economical chemical for water treatment

Overall treatment cost is reduced by PACL with respect to pre- and post- pH adjustment, sludge treatment, solid disposal, transport, shipping, storage, labor cost etc. PACL is typically 1.7 times of alum price. However, lower doses of the PACL coagulant and lower and pre- and post- treatment alkali doses can still make its use economical. More than 86% personnel agreed that PACL is more economical than Alum.

4.9.7 The equipment required to be installed to use of PACL

The use of PACL may necessitate modifying the dosage equipment such as storage tanks, pumps, piping and fittings, valves and accessories, providing dust extractors to prevent some problems like corrosion, and pallets for storage.

5. CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

This research was aimed at identifying an alternative coagulant for removing turbidity from water by evaluating aluminium sulphate (alum) and poly aluminium chloride (PACL). The following conclusions were drawn based on the observations, analyses and findings.

The benefits of PACL relative to alum have been investigated as a function of pH,raw water composition, and mixing conditions.

1. Effectiveness

i) PACL is a more effective coagulant than alum for removing turbidity from raw water.

- The removal efficiency of turbidity and colour is more or less the same with both the coagulants, PACL & Alum, but under lower concentration of turbidity and colour the PACL dosage needed is less compared to that of Alum.
- In the experimental tests, the range of turbidity from 4.14 NTU to 136 NTU, PACL was more effective than Alum. Further, under increasing turbidity, PACL produced the better performance with the least dosage.

ii) PACL can rapid coagulation at different turbidity levels.

- The various turbidity levels such as 0-10NTU, 11-20NTU, 21-40NTU, 41-60NTU, 61-80NTU, and 81-140NTU were tested for the optimum dosage ratio with both the coagulant PACL & Alum. According to the test results requirements of PACL compared with Alum were 53%, 48%, 47%, 46%, 46% and 43% respectively in the Kalu Ganga water source while the requirement of PACL compared with Alum at turbidity levels 0-15NTU, 16-30NTU, and 31-85NTU were 43.2%, 39%, and 47.6% respectively in the Kelani Ganga water source.
- Accordingly, turbidity removal was more effective in the case of high turbidities of the raw water with PACL than with Alum.

iii) Higher content of active ingredient

- PACL and alum contains an aluminium content equivalent to 28% and 16% as Al_2O_3, respectively. This is 57% higher than alum thereby requiring as an absolute minimum 2/5 the chemical storage capacity at the treatment plant.

iv) pH changes by coagulants

- The changes in pH are not significantly different in the case of both coagulants as shown in the results of the Kalu Ganga raw water. With the addition of lime, the required dosage of PACL is less compared to Alum.

v) Flocs generation by coagulants

- The generated floc size was higher with PACL than with Alum at the optimum dose of coagulants. In the jar tests, flocs were generated faster and were larger in size with a smaller dosage of PACL than of Alum.
  PACL produced the fastest settling floc when rapid mix conditions were correctly controlled.

2. Cost

i) The average optimum coagulant dosage ratio obtained between PACL & Alum is 47% in the Kalu Ganga water. The present market value of PACL is 1.7 times higher than that of Alum. When considering the total treatment cost including cost of lime, transport, storage, labour (man power), etc. there is a saving in using PACL than Alum.The cost for cogulant usage for production also analysed that shows PACL cost is lesser than Alum. Therefore considering all factors , using PACL is more economical than using Alum.

ii) The National Water Supply & Drainage Board imports PACL and Alum in powder form and chip form respectively. Therefore, in the case of PACL, there is no need of agitators for long time mixing, which reduces power consumption and labour cost compared with Alum. This is also a benefit in terms of cost saving in water treatment.

3. Operational Factors:

i) This study tried to highlight the importance of technical and economic feasibility of using PACL coagulant as a substitute for Alum. The present study identified some of the effective factors for decision making and the relative importance of each of them was indicated under the responses comments of water treatment experts to a series of questions.

ii) The Questionnaire Survey revealed that the overall performance is much higher of PACL than Alum. Further, the experts commented that large flocs sizes could appear in the process with a smaller dosage of the PACL than of Alum. In addition, experts gave their opinion on providing the dust extractors to prevent some problems like corrosion, and pallets for storage when using PACL.

iii) In the questionnaire survey, some professionals opined that PACL solidified due to moisture caused by long-term storage. To prevent this, good stock management is necessary; sufficient amounts of chemicals should be available for a one-month period. Coagulants should be dated on receipt and used in rotation on a first come first issue basis.

4. Availability

At present, NWSDB faces a problem with the continuous supply of Alum due to the banned imposed on the production of Aluminum Sulphate in China due to health and environmental hazards. This situation arised in several times. Accordingly, it is better to use Poly Aluminium Chloride as an alternative to alum.

5.2 Recommendations

This study examined the efficacy of Alum and PACL that is used in the purification of water. From an engineering point of view, Poly Aluminum chloride (PACL) was found to be an acceptable alternative coagulating agent for drinking water purification and for the removal of turbidity and colour.

A coagulant should be selected for improving treated water quality and treatment plant performance for optimizing coagulation so as to minimize operating cost. Treatment using PACL produced excellent results as measured by the higher turbidity and colour removal, rapid formation of flocs and the shorter time for sedimentation. In addition to improvements in coagulant performance with PACL, benefits can be derived in other areas of plant operations such as reduced sludge, decreased filtering time leading to lower volumes of filter waste and backwash waste.

The results of the experiment showed that the dosage of PACL required for river water treatment was less than that of alum, thus showing that the overall cost of using PACL could be less than that of alum, for similar raw water characteristics.

Further Studies

Substituting coagulants require that all the possible technical, economical, social and environmental impacts to be considered. Each situation must be analyzed and evaluated. Coagulation problems may occur for different raw water in different conditions.

Further research and development activities are required in relate to the technical, economical, social and environmental impacts.

This study can be further enhanced with;

1. Additional jar tests with different natural raw water should be conducted to verify the observations in this study for general use in other parts of the country. It is useful to extend the study to reservoirs too.
2. The turbidity and settled coagulation flocs were tested and analysed in this study. This should be extended to check the settling time of the flocs and flocs density.
3. It is useful to investigate and compare the quantity and quality of the sludge generated by using both coagulants.
4. Considerable amounts of waste water are produced in water treatment plants due to backwashing of rapid sand filters and their release to natural water sources. Further research is recommended into the waste water quality and quantity for testing the effectiveness of both PACL and Alum coagulants.

REFERENCES

[1].	Central Pollution Control Board, (MINISTRY OF ENVIRONMENT AN FORESTS) Website : www.cpcb.nic.in
[2].	SK Al-Dawery and OH Al-Joubori(2012),"Preparation and Usage of Polyaluminium Chloride as a Coagulating Agent"
[3].	N. Kumar and Dr. N. Balasundaram,(2017), International Journal of Applied Engineering Research, 12(12) 3253-3262.
[4].	Bulletin of Environment, Pharmacology and Life Sciences, (2014), Selecting the optimal coagulant in turbidity removal and organic carbon of surface water using AHP, vol 3[6]May 2014:78-88
[5].	David J.Pernitsky(2003), Coagulation, Alberta
[6].	Ali Daryabeigi Zand and Hassan Hoveidi,(2015), Comparing Aluminium Sulfate and Poly -Aluminium Chloride (PAC) Performance in Turbidity Removal from Synthetic Water, Journal of Applied Biotechnology Reports
[7].	Anthony S. Greville, "How to Select a Chemical Coagulant and Flocculant"(1997), Alberta Water & Wastewater Operators Association, 22th Annual Seminar March 11- 14, 1997
[8].	WHO Guidelines for Drinking-water Quality, Fourth Edition,(2011) World Health Organization
[9].	John C. Crittenden, R. Rhodes Trussell, David W. Hand, Kerry J. Howe, George Tchobanoglous,(2012), MWH's Water Treatment Principles and Design Third Edition
[10].	AWWA,(1940) Water Quality and Treatment, A Hand Book of Public Water Supplies, Third Edition, McGRAW-HILL Book Company
[11].	David J. Pernitsky and James K.Edzwald (2006), Selection of alum and polyaluminium coagulants:Principles and applications, Journal of Water Supply:Research and Technology –AQUA,55.2
[12].	Syed R Qasim, Edward M. Motley, Guang Zhu, (2004), Water Works Engineering, Planning, Design and Operation, Published by Asoke K.Ghosh
[13].	Yi Geng,(2005), Application of Floc Analysis for Coagulation Optimization of Split Lake Water Treatment Plant, Master of Thesis
[14].	John Gregory and Jinming Duan, (2001), Hydrolyzing metal salts as coagulants,73(12):2017-2026
[15].	Samuel D.Faust and Osman M. Aly,(1998), Chemistry of Water Treatment,2nd Edition, Published by Taylor & Francis Group
[16].	S. D. Freese, D L Trollip and D J Nozaic,(2003), Manual for Testing of Water and Wastewater Treatment Chemicals

[17].	Coagulants, Polyelectrolytes, and Coagulant Aids,(2001), Chapter 8, EM 1110-1-4012
[18].	Patrick Niquette, Frédéric Monette, Abdelkrim Azzouz and Robert Hausler,(2004), Impacts of Substituting Aluminum-Based Coagulants in Drinking Water Treatment, Water Research, 39(3) 303–310
[19].	Tardat-Henry M. 1989. Évolution des dérivés de l'aluminum utilisés commeagents coagulants. Sci. Tech.Eau 22(4):297–304.
[20].	Chartré A. 2002. Personal communication. Ville de Longueuil, Quebec, Canada
[21].	Sauvageau C. 2002. Personal communication. Ville de L'As-somption, Quebec, Canada.
[22].	Exall KN, van Loon GW. 2000. Using coagulants to remove organic matter. J. AWWA 92(11):93–102
[23].	Simpson AM, Hatton W, Brockbank M. 1988. Aluminum,its use and control, in potable water. Environ. Tech.Lett. 9:907–916.
[24].	Mojtaba Fazeli, Mastaneh Safari, Tavakol Ghobaee,(2014),Bulletin of Environment, Pharmacology and Life Sciences, 3(6) 78-88
[25].	WHO. 1998. Guidelines for drinking-water quality. WHO, Second edition, Addendum to Vol. 1 and Vol. 2. Recommendations. Geneva.
[26].	Health Canada. 1996. Aluminum dans l'eau potable. Government of Canada. Prepared by the Sous-committee federal-provincial sur l'eau potable. 54 p
[27].	FPSDW (Federal–Provincial Subcommittee on Drinking Water). 2001. Summary of guidelines for Canadian drinking water quality. FPSDW of the Federal–Provincial–Territorial Committee on Environmental and Occupational Health. Canada. 7 p.
[28].	NWSDB/ Specification for Aluminium Sulphate (2013)
[29].	Project Profile on Aluminium Sulphate,(2011),Tanstia-FNF
[30].	Water Treatment Manual,(2002), Coagulation, flocculation & Clarification, Environmental Protection Agency
[31].	Peter Gebbie, (2001)Using Polyaluminium Coagulants in Water Treatment, 64th Annual Water Industry Engineer's and Operators' Conference

[32].	Peter Gebbie, (2005) A DUMMY'S GUIDE TO COAGULANTS, 68th Annual Water Industry Engineer's and Operators' Conference
[33].	Michael Dalton,(2008),Potable Water Coagulant Trials Utilizing Polyaluminium Chlorhydrate, 33rd Annual Qld Water Industry Operations Workshop
[34].	Specification for Poly Aluminium Chloride for Human Consumption (NWSDB)
[35].	Marten Soderlund, stig Gunnarss, (2010) Process for the production of polyaluminium salts, EP 2158160 A1
[36].	Gulbrandsen Technologies http://www.hbsshbkj.com/AdminFrom/eWebEditor/uploadfile/20110126153712607.pdf
[37].	20th WEDC Conference(1994), Affordable Water Supply and Sanitation, Poly aluminium chloride as an alternative coagulant
[38].	Edzwald JK, Tobiason JE. 1999. Enhanced coagulation: US requirements and a broader view. Water Sci. Technol.40(9):63–70.
[39].	R. S. Parde and V. C. Renge,(2012), Comparative Evaluation of Surface Water Treatment by Using Different Coagulating Agents, International Journal of Advanced Engineering Technology E-ISSN 0976-3945 IJAET/Vol.III/ Issue IV/Oct.-Dec., 2012/86-88

Appendices

Appendix A	-	Raw Water Quality in Kalu Ganga in Year 2010 and Year 2011
Appendix B	-	Raw Water Quality in Kelani Ganga in Year 2015 and Year 2016
Appendix C	-	Treated Water Quality Using Aluminium Sulphate in Kalu Ganga Water Source
Appendix D	-	Treated Water Quality Using Poly Aluminium Chloride in Kalu Ganga Water Source
Appendix E	-	Treated Water Quality Using Alumnium Sulphate and Poly Aluminium Chloride in Kelani Ganga Water Source
Appendix F	-	Questionnaire Survey
Appendix G	-	Questionnaire Survey Analysis

Appendix - A

Raw Water Quality in Kalu Ganga in Year 2010 and Year 2011

Sample No	Raw Water Parameter		
	pH	Colour	Turbidity
1	4.14	7.11	10
2	6.57	7.2	10
3	7.23	6.9	20
4	7.25	6.9	15
5	7.68	6.5	15
6	8.55	6.9	20
7	9.3	6.9	20
8	9.88	6.9	25
9	9.92	7.1	20
10	10.3	7.1	25
11	10.4	6.9	20
12	11.6	6.9	25
13	11.8	7.1	25
14	12.2	6.8	25
15	12.2	6.9	25
16	12.6	6.7	25
17	13.8	6.5	25
18	16.1	6.7	25
19	16.2	7	25
20	17	6.5	25
21	18.1	6	30
22	18.2	6.3	25
23	18.3	6.8	40
24	20.7	6.3	35
25	21.6	6.7	45
26	22.3	6.6	25
27	22.5	6.5	45

Sample No	Raw Water Parameter		
	pH	Colour	Turbidity
28	23.4	6.9	40
29	23.5	6.5	45
30	29.17	6.3	40
31	31.2	6.7	45
32	32.5	6.6	45
33	32.7	6.1	50
34	33.1	6.3	50
35	34.5	6.5	50
36	34.8	6.5	65
37	39.2	6.5	70
38	41.4	6.3	60
39	42.3	6.5	70
40	44.9	6.7	50
41	47.6	6.3	70
42	52.8	6.5	45
43	53.2	6.5	80
44	61.2	6.9	80
45	62.2	6.5	80
46	69.2	6	90
47	71.6	6.7	90
48	72.5	6.5	90
49	81.8	6.4	90
50	86.5	6.5	100
51	103.6	6.5	140
52	118.7	6.4	175
53	121.9	6.3	160
54	136	6.1	100

Appendix –B

Raw Water Quality in Kelani Ganga in Year 2015 and Year 2016

Sample No	Raw Water Parameter		
	pH	Colour	Turbidity
1	6.8	8	18.5
2	6.9	20	13.9
3	6.8	6	12.5
4	6.9	6	10.6
5	6.9	2	4.6
6	6.8	3	6.4
7	6.9	4	7.3
8	6.8	6	22.1
9	6.8	3	8.9
10	6.9	2	6.4
11	6.9	5	9.29
12	6.8	5	8.65
13	6.8	6	10.5
14	6.9	4	5.6
15	6.8	4	10.3
16	6.7	5	6.23
17	6.8	5	14
18	6.7	5	9.31
19	6.9	4	6.5
20	7	4	5.52
21	6.9	5	7.34
22	6.9	6	13.2
23	6.8	6	18.91
24	6.6	8	29.4
25	6.5	12	24.7
26	6.8	5	8.79
27	6.6	6	9.25
28	6.7	2	4.89
29	6.8	2	5.15
30	6.7	2	5.55
31	6.8	3	5.85
32	6.7	4	6.37
33	7	4	4.51
34	6.9	5	8.52
35	6.5	3	5.87
36	6.6	6	14.7
37	6.9	22	15.5
38	6.9	4	9.59
39	6.6	10	27.1
40	6.9	2	5.07

Sample No	Raw Water Parameter		
	pH	Colour	Turbidity
41	6.9	4	9.36
42	6.7	3	7.25
43	6.8	5	9.21
44	6.6	30	37.5
45	6.9	11	18.6
46	6.8	6	11.36
47	6.7	20	14.3
48	6.6	18	25.2
49	6.6	18	25.2
50	6.7	3	7.85
51	6.7	2	5.01
52	6.6	2	4.97
53	6.6	3	8.22
54	6.7	2	6.87
55	6.9	26	26
56	6.7	33	20.1
57	6.7	7	24.2
58	6.6	17	46.5
59	6.7	4	11.9
60	6.7	3	9.7
61	6.8	6	17.2
62	6.6	6	15.8
63	6.7	6	14.1
64	6.6	33	60.4
65	6.7	32	51.2
66	6.3	48	104
67	6.9	5	19
68	6.9	5	19
69	6.7	4	16.8
70	6.6	6	14.5
71	6.9	19	48.2
72	6.8	10	29.8
73	6.9	42	97.5
74	6.9	42	97.5
75	6.9	15	34
76	6.8	8	19.1
77	6.9	6	16.6
78	6.7	16	37.3
79	6.7	17	54.6
80	6.8	13	28.5

Sample No	Raw Water Parameter		
	pH	Colour	Turbidity
81	6.8	5	19.5
82	6.7	5	12.1
83	6.8	3	10.5
84	6.8	2	5.2
85	6.9	5	13.2
86	6.8	8	18.2
87	6.7	7	13.3
88	6.9	8	20.4
89	6.6	9	18
90	6.9	4	8.84
91	6.9	3	6.18
92	6.9	2	5.98
93	6.9	8	9.21
94	6.9	10	12.5
95	6.9	9	11.4
96	6.7	32	69.7
97	6.5	10	11.8
98	6.6	10	12.5
99	6.9	2	6.2
100	6.9	25	7.12
101	0	0	0
102	6.9	30	9.5
103	7	29	8.9
104	6.7	8	15.2
105	6.9	42	27.4
106	7.1	9	15
107	6.6	13	12.2
108	6.5	10	11.5
109	6.7	11	12.5
110	6.8	10	12.4
111	6.8	10	12.4
112	6.7	14	9.35
113	6.9	5	13.4
114	6.9	11	11.5
115	6.6	10	7.37
116	6.8	12	10.26
117	6.7	8	6.32
118	6.9	6	7.37
119	6.5	11	6.42
120	6.6	2	4.51

Sample No	Raw Water Parameter		
	pH	Colour	Turbidity
121	6.5	11	9.79
122	6.5	12	6.37
123	6.6	8	5.96
124	6.4	4	5.67
125	6.7	4	4.72
126	6.8	5	6.31
127	6.9	3	7.31
128	6.9	3	7.31
129	6.8	15	4.69
130	6.4	9	3.71
131	6.8	11	4.44
132	6.9	14	6.89
133	6.7	10	4.12
134	6.8	8	9.25
135	6.8	9	4.89
136	6.7	14	13
137	6.6	12	11.1
138	6.6	8	4.35
139	6.8	9	4.71
140	6.8	6	10.7
141	6.8	5	4.22
142	6.7	5	4.71
143	6.7	16	6.47
144	6.7	15	6.47
145	6.8	3	8.8
146	6.7	5	7.25
147	6.5	9	6.35
148	6.5	15	7.62
149	6.6	16	8.35
150	6.5	10	12.26
151	6.5	1	13.2
152	6.5	20	8.3
153	6.5	18	8.02
154	6.5	15	7.73
155	6.5	14	6.95
156	6.6	38	23.22
157	6.6	20	8.32
158	6.5	12	11.43
159	6.5	10	10.31
160	6.4	14	14.52

Appendix -C

Treated Water Quality Using Aluminium Sulphate in Kalu Ganga Water Source

Sample No	Raw Water Parameters				Treated Water Parameters by Aluminium Sulphate				
	Turbidity Range	**Turbidity (NTU)**	**PH**	**Colour (Hu)**	**Alum Dosage (ppm)**	**Turbidity (NTU)**	**pH**	**Colour (Hu)**	**Diameter Type**
1	0-10	4.14	7.11	10	6	2.3	6.9	7.5	C
2		6.57	7.2	10	8	2.16	7	5	D
3		7.23	6.9	20	7	2.02	6.9	2.5	D
4		7.25	6.9	15	6	1.6	6.9	5	F
5		7.68	6.5	15	5	2.07	6.4	2.5	D
6		8.55	6.9	20	7	1.85	6.9	5	E
7		9.3	6.9	20	7	1.65	6.9	2.5	D
8		9.88	6.9	25	6.5	1.73	6.9	2.5	E
9		9.92	7.1	20	5.5	1.12	7	2.5	D
10	11-20	10.3	7.1	25	6	2.12	6.9	5	E
11		10.4	6.9	20	7	1.38	6.8	2.5	E
12		11.6	6.9	25	7.5	1.92	6.9	5	E
13		11.8	7.1	25	7	1.64	7	5	E
14		12.2	6.8	25	6	1.67	6.7	2.5	E
15		12.2	6.9	25	9.5	1.82	6.3	2.5	E
16		12.6	6.7	25	10	1.38	6.6	2.5	E
17		13.8	6.5	25	8.5	2.05	6.4	5	E
18		16.1	6.7	25	8	1.88	6.3	2.5	E
19		16.2	7	25	9	1.93	6.8	2.5	E
20		17	6.5	25	4.5	2.93	6.5	2.5	E
21		18.1	6	30	6.5	1.92	6	2.5	E
22		18.2	6.3	25	5.5	2.28	6.3	2.5	E
23		18.3	6.3	40	8.5	2.03	6.3	5	E
24	21 -40	20.7	6.3	35	5	2.87	6.3	2.5	E
25		21.6	6.7	45	10	1.94	6.6	2.5	E
26		22.3	6.6	25	10	2.79	6.3	5	E
27		22.5	6.5	45	10	1.59	6.3	2.5	E
28		23.4	6.9	40	9	1.71	6.9	2.5	E
29		23.5	6.5	45	7	4.32	6.1	5	E
30		29.17	6.3	40	6.5	2.48	6.3	2.5	F
31		31.2	6.7	45	8.5	1.82	6.3	2.5	E
32		32.5	6.6	45	10.5	1.38	6.2	2.5	E
33		32.7	6.1	50	5.5	2.05	6.1	5	E
34		33.1	6.3	50	10	2.68	6.2	5	E
35		34.5	6.5	50	4.5	1.92	6.5	2.5	E
36		34.8	6.5	65	12	1.43	6.2	2.5	E
37		39.2	6.5	70	13	1.96	6.4	5	E

Sample No	Turbidity Range	Turbidity (NTU)	PH	Colour (Hu)	Alum Dosage (ppm)	Turbidity (NTU)	pH	Colour (Hu)	Diameter Type
38	41-60	41.4	6.3	60	12	1.76	6.2	2.5	E
39		42.3	6.5	70	10.5	1.86	6.46	2.5	E
40		44.9	6.7	50	7.5	3.63	6.4	5	F
41		47.6	6.3	70	11	1.93	6.1	2.5	E
42		52.8	6.5	45	7	1.32	6.3	2.5	F
43		53.2	6.5	80	14	3.08	6.2	5	F
44	61-80	61.2	6.9	80	11	2.02	6.4	5	E
45		62.2	6.5	80	10	3.12	6.2	5	E
46		69.2	6	90	7.5	3.26	6.9	5	D
47		71.6	6.7	90	13.5	3.65	6.8	10	D
48		72.5	6.5	90	14.5	2.49	6.3	5	F
49	81-140	81.8	6.4	90	12.5	2.96	5.76	5	E
50		86.5	6.5	100	15	3.36	6.2	5	E
51		103.6	6.5	140	13.5	2.49	6.2	5	E
52		118.7	6.4	175	14.5	1.78	6.1	2.5	E
53		121.9	6.3	160	14	2.28	6.2	2.5	E
54		136	6.1	100	13.5	2.26	6.1	2.5	E

Appendix D

Treated Water Quality Using Poly Aluminium Chloride in Kalu Ganga Water Source

	Raw Water Parameters				Treated Water Parameters by Poly Aluminium Chloride				
	Turbidity Range	Turbidity (NTU)	PH	Colour (Hu)	PACL Dosage (ppm)	Turbidity (NTU)	pH	Colour (Hu)	Diameter Type
1	0-10	4.14	7.11	10	3.5	2.3	6.9	6.9	D
2		6.57	7.2	10	3.5	2.25	7.1	5	C
3		7.23	6.9	20	4	2.88	6.9	5	E
4		7.25	6.9	15	2.5	3.63	7.1	5	C
5		7.68	6.5	15	3	1.73	6.9	2.5	D
6		8.55	6.9	20	3.5	3.11	6.7	5	E
7		9.3	6.9	20	3	2.8	6.9	5	C
8		9.88	6.9	25	4	2.98	6.4	5	D
9		9.92	7.1	20	4	3.21	6.9	5	D
10	11-20	10.3	7.1	25	3.5	1.91	6.9	5	F
11		10.4	6.9	20	3	2.6	6.9	5	D
12		11.6	6.9	25	3.5	2.64	6.8	5	D
13		11.8	7.1	25	3.5	2.23	6.9	5	E
14		12.2	6.8	25	4.5	2.39	6.9	5	E
15		12.2	6.9	25	4.5	2.39	6.9	5	E
16		12.6	6.7	25	3.5	3.33	6.9	5	C
17		13.8	6.5	25	3.5	3.32	6.7	5	E
18		16.1	6.7	25	3	2.15	6.7	5	F
19		16.2	7	25	3	2.89	6.6	5	E
20		17	6.5	25	3	3.55	6.5	5	D
21		18.1	6	30	2.5	2.53	6.5	5	F
22		18.2	6.3	25	5.5	3.01	6	5	E
23		18.3	6.3	40	3.5	2.33	6.3	5	D
24	21 -40	20.7	6.3	35	2.5	2.24	6.6	2.5	E
25		21.6	6.7	45	4.5	3.11	6.9	2.5	E
26		22.3	6.6	25	5	2.68	6.5	5	E
27		22.5	6.5	45	4.5	2.37	6.42	2.5	F
28		23.4	6.9	40	4.5	3.62	5.92	5	E
29		23.5	6.5	45	4.5	3.62	5.92	5	E
30		29.17	6.3	40	4.5	3.18	6.1	5	E
31		31.2	6.7	45	5	2.84	6.7	2.5	E
32		32.5	6.6	45	4.5	3.48	6.5	5	E
33		32.7	6.1	50	2.5	2.32	6.1	5	E
34		33.1	6.3	50	2.5	2.64	6.7	5	D
35		34.5	6.5	50	4	2.42	6.3	5	E
36		34.8	6.5	65	4	2.42	6.3	5	E
37		39.2	6.5	70	5	2.43	6.1	5	F

	Raw Water Parameters				Treated Water Parameters by Poly Aluminium Chloride				
	Turbidity Range	Turbidity (NTU)	PH	Colour (Hu)	PACL Dosage (ppm)	Turbidity (NTU)	pH	Colour (Hu)	Diameter Type
38	41-60	41.4	6.3	60	7	3.93	6.9	5	E
39		42.3	6.5	70	3.5	2.84	6.3	2.5	F
40		44.9	6.7	50	4	3.48	6.5	5	E
41		47.6	6.3	70	5.5	1.71	6.3	2.5	F
42		52.8	6.5	45	3	3.76	6.3	5	F
43		53.2	6.5	80	5	2.72	6.3	5	F
44	61-80	61.2	6.9	80	6.5	2.84	6.3	5	E
45		62.2	6.5	80	4.5	2.8	6.4	5	E
46		69.2	6	90	5.5	2.07	6	5	F
47		71.6	6.7	90	3.5	3.58	6.7	2.5	F
48		72.5	6.5	90	6.5	2.11	6.5	5	G
49	81-140	81.8	6.4	90	6.5	2.96	5.76	5	E
50		86.5	6.5	100	6.5	2.95	6.3	5	F
51		103.6	6.5	140	5	3.12	6.2	5	F
52		118.7	6.4	175	5	1.73	6	2.5	F
53		121.9	6.3	160	6	2.24	6.5	2.5	F
54		136	6.1	100	6.5	2.26	6	2.5	G

Appendix -E

Treated Water Quality Using Alum and PACL in Kelani Ganga Water Source

Sample No	Raw Water Parameter			Settled Water Parameter							
				Aluminium Sulphate				Poly Aluminium Chloride			
	Raw Water Turbidity Range	Turbidity	Colour	Dosage (ppm)	Turbidity	PH	Colour	Dosage (ppm)	Turbidity	PH	Colour
1	0-15	9.66	84	9	2.52	6.84	23	4.5	2.03	6.86	20
2		11.2	112	13	2.13	6.65	25	5.5	1.88	6.86	22
3		14.6	40	12	2.34	6.98	10	5.5	2.08	6.96	10
4		15	40	12	4.47	6.93	20	5	1.86	7.2	10
5	16-30	15.8	123	13	2.54	6.41	15	5	2.03	6.83	15
6		16.6	108	14	2.32	6.89	24	5	2.16	6.75	26
7		21.4	75	14	2.64	6.82	10	5	2.12	6.94	10
8		22	198	15	2.96	6.81	40	5.5	2.75	6.94	33
9		24.8	45	12	3.19	6.83	10	6	1.59	7.17	5
10		27.3	211	15	2.98	6.87	24	6.5	2.58	6.96	12
11		30	231	16	3.18	6.94	27	5.5	2.81	7.25	26
12	31-85	33.8	251	13	4.52	6.59	41	6	3.31	7.45	29
13		60.7	90	13	4.99	6.68	20	6.5	4.02	7.02	20
14		85.3	682	15	10.2	6.64	113	7	3.58	7	44

Appendix – F

Questionnaire Survey

Name :

Position :

Present Work Place :

Previous Work Place :

Poly Aluminium Chloride as an alternative to Alum as a coagulant in Water Treatment

1. Have you used chemical coagulants in water treatment?
   - i) Yes
   - ii) No

2. Which coagulant you are familiars in the water treatment process?
   - i) Aluminium Sulphate (Alum)
   - ii) Poly Aluminium Chloride (PACL)
   - iii) Both

3. How many years of experience do you have in Water Treatment Plants?
   - i) < 2 years
   - ii) 2 – 5 years
   - iv) 6 – 10 years
   - v) >10 years

4. How long have you been working at the present Treatment Plant?
   - i) < 2 years
   - ii) 2 – 5 years
   - iii) 6 – 10 years
   - iv) >10 years

5. What is the capacity of your Water Treatment Plant you are presently working?
   - i) < 10,000 m^3/day
   - ii) 10,000 -20,000 m^3/day

iii) 20,000 -50,000 m^3/day
iv) > 50,000 m^3/day

6. What is the type of coagulant that you presently use?

i) Aluminium Sulphate (Alum)
ii) Poly Aluminium Chloride (PACL)
iii) Any others – Please specify …………………………

7. What is the most preferable type of coagulant according to your experience?

i) Aluminium Sulphate (Alum)
ii) Poly Aluminium Chloride (PACL)
iii) Any others – Please specify …………………………

8. What do you think about the coagulant dosage for the two chemicals?

i) Aluminium Sulphate and Poly Aluminium Chloride Dosages are equal.
ii) Approximately Half of Aluminium sulphate dosage is equal to Aluminium Chloride dosage
iii) Approximately Half Aluminium Chloride of dosage is equal to Aluminium sulphate dosage
iv) Other
If other Ratio, please specify
………………………………………………………………………………………

9. How did you answer the above question (Question 8)

i) I have used both chemicals in treatment plants
ii) I have learnt/ read about it
iii) I have heard other chemists/operators talk about it
iv) I do not know, I just guessed

10. If you like to use Alum, what are the benefits you expect by using Alum Other than the Poly Aluminium chloride ? (prefer 1 or more, please tick)

i) Less dependent on Quality of the raw water
ii) Better Quality of the treated water
iii) Cost effectiveness
iv) Easy maintenance
v) Sludge volume consideration

vi) Labour and equipment for storage, feeding and handling
vii) Availability in market

11. If you like to use Poly Aluminium Chloride, what are the benefits you expect by using Poly Aluminium Chloride Other tahan the Alum? (prefer 1 or more, please tick)

    i) Less dependent on Quality of the raw water
    ii) Better Quality of the treated water
    iii) Cost effectiveness
    iv) Easy maintenance
    v) Sludge volume consideration
    vi) Labour and equipment for storage, feeding and handling
    vii) Availability in market

12. How much turbidity is reduced on average as a percentage, when using the following coagulants?

    - Aluminium Sulphate — 0-25% ☐ 26- 50% ☐ 51-75% ☐ 75-100% ☐
    - Poly Aluminium Chloride — 0-25% ☐ 26- 50% ☐ 51-75% ☐ 75-100% ☐
    - I do not know

13. What do you think about the organic matter removal by Aluminium Sulphate and Poly Aluminium Chloride?

    i) Aluminium Sulphate (Alum) is better
    ii) Poly Aluminium Chloride (PACL) is better
    iii) Both are equal
    iv) I do not know

14. Which coagulant makes the O&M activities easier?

    i) Aluminium Sulphate (Alum)
    ii) Poly Aluminium Chloride (PACL)

15. Are any changes in equipment required to change over from Alum to PACL?

   i) Aluminium Sulphate (Alum)
      ………………………………………………

   ii) Poly Aluminium Chloride (PACL)
      ……………………………………………….

16. What are the personnel (Man power) requirements for setting up both coagulants in the plant?
   i) Aluminium Sulphate (Alum)
      ……………………………………………………………….
   ii) Poly Aluminium Chloride (PACL)
      ……………………………………………………………….

17. What is the time required to floc preformation for both chemical?

   i) Aluminium Sulphate (Alum)
      ……………………………………………………………….
   ii) Poly Aluminium Chloride (PACL)
      ……………………………………………………………….

18. What is the more economical chemical out of these two chemicals?

   i) Aluminium Sulphate (Alum)
      ……………………………………………………………….
   ii) Poly Aluminium Chloride (PACL)
      ……………………………………………………………….

19. Are there any equipment (Dust extractors, chemical stirrers; etc) required to be fixed to use Aluminium Sulphate (Alum)/Poly Aluminium Chloride ?

   i) Aluminium Sulphate (Alum)
      ……………………………………………………………….
   ii) Poly Aluminium Chloride (PACL)
      ……………………………………………………………….

20. What do you think about the Floc formation Efficiency when both chemicals are compared?

    i) Aluminium Sulphate (Alum) produces less sludge than PACL
    ii) Poly Aluminium Chloride (PACL) produces less sludge than Alum

21. How is the availability of Aluminium Sulphate (Alum)/Poly Aluminium Chloride in the market? Please mention, whether there was any shortage in the recent past or at present?

    i) Aluminium Sulphate (Alum)
    ……………………………………………………………..
    ii) Poly Aluminium Chloride (PACL)
    ……………………………………………………………..

22. Were there any complaints from the operators or neighbours when using either of the chemicals? If yes, please give details

    i) Aluminium Sulphate (Alum)
    ii) Poly Aluminium Chloride (PACL)

Appendix -G

Poly Aluminium Chloride as an alternative to Alum as a coagulant in Water Treatment

<u>Questionnaire Survey Analysis</u>

The conclusions of the questionnaire survey analysis are as follows:

1. Questions 01 to 04
   - Regarding the coagulants familiarization, period of experience in WTP, and period of working in the present.

     All respondents were aware of both coagulants. Out of the total, 21 numbers of persons, approximately 50%, used Alum or PACL.

2. Questions 05 and 06
   - Consisted of the capacity of WTP presently working and the type of coagulant t presently used.

     61% plants are using Alum while 56% plants are using PACL. The DGM (Western Province) said that, in the Western Province, seven WTPs are in operation under NWSDB. However, only two WTPs use PACL.
     Details of Western province WTPs details are shown in the following table:

	Water Treatment Plant	***Source***	***Production (m^3/day)***	***Coagulant Used***
01	*Ambatale (Old)*	*Kelani Ganga*	*180,000*	*Alum*
02	*Ambatale (New)*	*Kelani Ganga*	*292,500*	*Alum*
03	*Kalatuwawa*	*Kalatuwawa Reservoir*	*90,000*	*PACL*
04	*Labugama*	*Labugama Reservoir*	*45,000*	*Alum*
05	*Bambukuliya*	*Ma Oya*	*36,000*	*Alum*
06	*Kandana*	*Kalu Ganga*	*127,000*	*Alum*
07	*Kethhena*	*Kalu Ganga*	*56,000*	*PACL*

3. Question 07
   - Relevant to the most preferable type of coagulant

     Three persons out of 21 prefer to use Alum. The others are willing to use PACL (18/21). The majority of the people know about PACL and its effectiveness in the treatment process.

4. Questions 08 and 09
   - What do you think about the coagulant dosage of the two chemicals?

     In the survey 13/21 said that approximately 50% of Alum dosage is required compared with PACL for the water treatment process, whereas only one preferred Alum and PACL in equal doses.

5. Questions 10 and 11
   - The benefits expected from using Alum rather than Poly Aluminium Chloride and Poly Aluminium Chloride rather than Alum

     Comparison of coagulant benefits as a percentage % are presented in the following table:

	Description	***Coagulant Benefits (%)***	
		Alum	***PACL***
1	*Less dependent on Quality of the raw water*	*5.6*	*55.6*
2	*Better Quality of the treated water*	*11.1*	*94.4*
3	*Cost effectiveness*	*27.8*	*55.6*
4	*Easy maintenance*	*55.6*	*11.1*
5	*Sludge volume consideration*	*16.7*	*61.1*
6	*Labour and equipment for storage, feeding and handling*	*27.8*	*33.3*
7	*Availability in market*	*44.4*	*11.1*

6. Question 12
    - The percentage of turbidity reduced efficiency by using Alum and PACL

      Most of them were of the opinion that between 75 and 100% efficiency could be achieved by using both coagulants. Very few persons were of the opinion that 51-75% efficiency could be obtained from Alum.

7. Question 13
    - The organic matter removal by Alum and PACL

      Eleven persons (11/21) accepted that more organic matter could be removed with PACL rather than with Alum whereas seven persons (7/21) disagreed..

8. Question 14
    - Coagulant type which makes O&M activities easier.

      The 28.6% and 52.4% said O&M activities were easier with Alum and PACL respectively. However, some of them stated that PACL was more corrosive than Alum.

9. Question 15
    - Any changes in the equipment required to change over from Alum to PACL

      About 80% commented that PACL is a corrosive agent. Therefore, the equipment should be replaced with non- corrosive materials.

10. Question 16
    - The personnel (manpower) required for setting up both coagulants in the plant.

      Seven participants replied that high manpower was required for Alum while one participant said that high manpower was required for PACL. Six participants said the same manpower was required for both chemicals.

11. Question 17

- The time required for floc preformation in both chemicals.

  The respondents said that floc formation time was faster with PACL; the others had not commented on the comparison.

12. Question 18

- The more economical chemical of these two chemicals.

  All participants, except three, commented that PACL was more economical than Alum. They formed a percentage of 85.7%. Among them, one had said that "Considering present market prices, Alum is more economical even though the dosage required is considerably high. But, considering shipping, transport and storage cost PACL is more economical. And, also less lime was needed with PACL".

13. Question 19

- Any equipment (dust extractors, chemical stirrers, etc) required to be fixed to use Aluminium Sulphate (Alum)/Poly Aluminium Chloride

  Most of the participants had mentioned that dust extractors were needed when using PACL. They commented about the need for special equipment such as dust extractors and chemical stirrers to control corrosion caused by PACL dust. Six out of 21 had commented that they were needed for both chemicals; 4/21 did not answer.

14. Question 20

- Floc Formation Efficiency when both chemicals are compared.

  Among the respondents 81% accepted that less sludge is produced with PACL. About 19% disagreed; others did not respond.

15. Question 21

- The availability of Alum/PACL in the market and any shortage in the recent past or at present

The respondents commented in different ways. Seventeen persons said that both chemicals were available in the market whereas two persons out of the total commented that PACL was less available in the market.

DGM (Supplies) and Manager (Supplies) commented that both chemicals were available in the market. However, recently Alum imports from China was suspended because some factories were closed down by the Chinese Government owing to some environmental problem.

16. Question 22

- Any complaints from the operators or neighbours when using either of the chemicals

Most of the respondents replied that with regard to Alum there were no complaints, but PACL caused corrosion due to dust, solidifying due to moisture, difficulty in breathing due to dust, and difficulty in storing for long periods. To prevent this they proposed eliminating dust accumulation when handling PACL.