Engineering and Technology Journal e-ISSN: 2456-3358
Volume 07 Issue 03 March-2022, Page No.-1175-1182
DOI: 10.47191/etj/v7i3.01, I.F. – 6.484

Chemical Treatment of Water Stream in a Continuous Flowing Process with Doping Technique: Calcium Hydroxide ($Ca(Oh)_2$) as a Case Study

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ABSTRACT: Water from rivers are often characterised with variable compositions influenced by the environment on the path of flow. Treatment with chemicals additives to obtain a level of purification will require repeated test to ascertain required concentrations. The complex structure of a continuous flowing river was investigated to determine required dosage with different concentrations of Calcium Hydroxide in specific volumes of the water in a gang stirrer operated at 12 rpm. The dosages and level of purity were evaluated. The results showed that the 20% alkaline stock solution was suitable for the dosing process as it gave a PH of 7.30, TDS of 38.38mg/l, Temperature of 28^0C and viscosity of 1400.7p/s. The derived optimum dose percentage from jar test analysis, introduced into a customised water treatment pilot plant was used improve the water quality with ratio controlled mechanism for a continuously flowing process by regulating the valves of the main source supply in a simple ratio flowing rates (manipulated stream) with the controlled doping valve for a regular continuous treatment. Data obtained were applied to develop a the correlation between the flow rates of the main stream and the doping concentrations in using Aspen Hysys simulation with rigorous evaluations to predict subsequent flow rates for qualitative and quantitative chemical treatment of water in a continuously flowing water purification system. The mechanism and the relationships could be used for doping other chemicals in a continuously flowing water processing.

KEY WORDS: Coagulation, Treatment, Precipitation, Simulation, Analyses, Ratio control, Valves Manipulated variables.

1.0 INTRODUCTION.

Water is a natural solvent, crucial to the sustenance of almost every living thing with interactive influence on non-biotics of nature. For humans healthy living, clean water is required even on daily basis and qualified by its Acidity level, taste, odour and transparency. Water existence is unique in nature though obtainable from many sources such as rain, brooks, rivers, haze component, dews, pools, lakes streams, rivers and ocean. Water could also be sourced from the underground like springs, boreholes and well water or formed as a result of the condensation of water vapor from the atmosphere as mist.

Rivers exchange water, materials, energy, and nutrients, in a reciprocal manner with the surrounding environment and accommodates impurities in diverse forms as a universal solvent (McCabe, 2011). They occur in three hierarchical states which could be suspended, colloidal and dissolved matters. These may be geological, anthropogenic (man-made) and depends on types and concentrations of the contaminates. The types and concentrations of natural contaminates depend on the nature of the geological materials through which the groundwater flows and quality of the recharge water and are classified as either organic , inorganic, biological or radiological. (Sharma and Bhattacharya, 2016). The sources of contaminant that many developed countries suffered from mostly is chemical discharges and industrial effluents, whereas in developing countries wastes from agricultural and municipal sources are prevalent.

The demand for water requires continuous treatment for quality and quantity supply. Water purification is therefore one of the processes where coagulant or Alkali salts, disinfectants like Chlorine are introduced to remove suspensions and colloids to achieve desired level of purity of water in reservoirs, recycled and from the direct sources when coupled with other processing methods. Methods engaged in treatment of water by the removal or reduction of contaminants to acceptable level of purity can be considered essentially on economic scale of availability, quantity and technical methods engaged in its application. Therefore, the design of any continuous liquid process is based on a full investigation of sites or source of the water with a view to understanding the sources physical, chemical and microbiological characteristics to forecast mode of treatment. The most important requirement is that it must be safe to drink or meet certain basic requirements to make it fit for domestic and industrial uses.

Water quality is inherent on the ambient conditions and may exhibit variable turbidity, clarity, power of Hydrogen and temperature. Generally, surface water sources have higher turbidity compared to groundwater sources owning to the presence of clays, silts or sand, or organic, algae, and leaf particles which may bring about seasonal changes especially when flowing on a surface. Therefore, on the basis of its application, water may be hard or soft depending on its ability to form lather readily with soap (Osei, 1985).

Consequently, chemical applications in the purification process are bound to vary as the source water changes. Under continuous operation, parameters that may be altered which also depends on the dosing mechanism includes chemical types, mixing rate, aeration level and time, filtration mechanism whose efficiency is a function of the particles sizes or by the adsorption materials administered. One of the common problems in water treatment is overfeeding or overdosing, especially with coagulants. This may not hurt the quality of water if control of coagulant concentration is not properly monitored.

Substances and colloidal particles introduced into water bodies from the environment may cause hazard to human health and harm to the ecological systems. These occur when pollutants are discharged directly or indirectly into water bodies thereby increasing the turbidity which may be caused by inorganic clay minerals in the surface water. Pollution of water could be treated by physical, biological and chemical application (Damalas and Eleftherohorinos, 2011). Impurities associated with water, which occurs as a result of pollution includes: Oxygen depleting substances, water soluble inorganic substances by micro-organisms, petroleum-based substance, radioactive substances and pathogenic organisms (Younes and Galal-Gorcher, 2000; Fawell et al., 2006).

These pollutants make most available water unsuitable and unfit for immediate consumption despite the covering of over 70% of the earth surface. Therefore One-sixth of the world population suffers from the freshwater unavailability situation for human consumption (Elimelech, 2006). The pollution of water may cause thousands of deaths, illness and poverty if infested with pollutant or poisonous chemicals. The discharge of waste or unfit water into rivers and lakes destroys aquatic life-based ecosystem which in turn disrupts the natural food chain but redistribution and dilution reduces the concentration.

The metallic impurities may be traced to the dissolved chemical salts such as gypsum $CaSO_4.2H_2O$, or limestone $CaCO_3$ from soil or rock over which water flows. Part of the measures used in the purification includes the coagulation with chemicals such as Aluminium Silicate (Alum); Use of some plant sourced coagulant from plant sources like *Moringa oleifera* in the treatment of low turbid water was reported (Eman et al., 2010; Aho and Lagasi 2012). The coagulation followed by flocculation's helps to prioritize the choice of separation techniques that may follow.

Another primary pollutant in municipal and food processing wastewaters is ammonia. During the nitrification process, hydrogen ions are released and alkalinity is consumed as the acid is neutralized. The need to maintain the proper pH, is the reason why an alkali is added to the system which also precipitating various metals into solids that can be recovered (Flomag, 2015). It kills micro -organisms in water and serves as a coagulant like most caustic agents. Caustic soda could perform similar functions, but Calcium hydroxide is significantly cheaper and economically safe. It is also known as hydated lime, caustic lime, milk of lime, calcium hydrate's for its cleaning influences in processes such as anaerobic digestion.

Treatment of water is therefore imperative either in batches or by continuous processing. To maintain regular assessment and characterisation of the most available water sources as flowing streams and rivers, a direct treatment mechanism would be most required. The presence of Ca/Mg in terms of carbonate, bicarbonate, chloride and sulfate results in hardness of water. Addition of proper chemical forms precipitation and makes it soft. Addition of $Ca(OH)_2$ forms precipitation with bicarbonate and sulphate in water as demonstrated in equations 1 and 2:

Equation:

$$Ca(HCO_3)_2 + Ca(OH)_2 \longrightarrow 2CaCO_3 + 2H_2O \quad ...1$$

$$MgSO_4 + CaCO_3 \longrightarrow Mg(OH)_2 + CaSO_4 \quad ...2$$

Therefore, formation of the Hydroxide salts as treatment could reduce the contaminant below the threshold values that would not pose serious harmful effects. Reagents of importance in water treatment that could be doped depend on the purpose of usage and recipes to be treated, hence we have: Iodine as oxidizing agent and as disinfectant to pathogenic organisms, Chlorine as strong oxidant as Hydrogen peroxide, Alum Lime as coagulants.

Precipitation is a technique of removing one or more substances from a solution by adding reagents so that insoluble solids coagulates. It is one of the simple methods to purify water The technique is used in softening water as well as for removing impurities like phosphorus, fluoride, arsenic, ferrocyanide and heavy metals, etc. (EPA US 2000; Matlock et al. 2002; Eikebrokk et al. 2006). If water is super-saturated with calcium carbonate, it will precipitate and form a layer of chemical scale on the surfaces of pipes and fixtures. A thin layer of calcium carbonate affords protection against corrosion, while excessive precipitation reduces the carrying capacity of pipes and may even lead to blocking of pipes in extreme cases.

On the other hand, if water is under-saturated with respect to calcium carbonate, any layer that may have precipitated will dissolve leaving the metal or other pipelining material exposed and subject to chemical attack (e.g. corrosion). It is therefore advisable to treat water to a slight super-saturation for protection against corrosion. A quantitative, and therefore more satisfactory way of determining the chemical stability of water is to calculate the calcium carbonate precipitation potential of the water. Calcium Carbonate Precipitation Potential (CCPP) is a parameter that gives the actual mg/l of $CaCO_3$ that would theoretically precipitate from the water. A positive CCPP of about 4 mg/l has been shown to give adequate protection against corrosion without excessive $CaCO_3$ precipitation Matlock et al., (2002).

In the administration of the different species of chemicals with varieties of functions in purifying water for domestic and industrial uses, a continuous process is most effective and abundantly capable for sufficient supply. The challenges therefore would be the administration of the reagents in the appropriate quantities while the process stream undergo thorough mixing, concentration of content, monitoring and control. The removal of phosphates is generally done by coagulant, i.e., by mixing coagulant into waste water (Xie et al. 2005).

Jar testing is a method of evaluating chemical requirement in a full-scale water treatment (Zane, 2005). The temperature, pH, turbidity, and alkalinity of the raw water were determined essentially to know the effect of after each treatment with specified concentrations of required chemicals and level of purification. This method allows adjustments in pH, variations in coagulant or polymer dose, alternating mixing speeds, or testing of different coagulant or polymer types, on a small scale in order to predict the functionality of a large-scale operation. Appropriate amount of alkali salt such as Calcium Hydroxide, or other pre-treatment chemicals, germicide (Hydrochloric acid) powder, settling activator as Aluminium Silicates are used for Water treatment to coagulate impurities, deactivates the available pathogens and microorganism and as well regulate the power of hydrogen (pH) and make the medium colourless. The major focus in this study is to study how doping mechanism could be used in domestic and industrial water treatment appropriate concentrations of chemicals (dosage) in a continuously flowing stream of water.

2.0 MATERIALS AND METHODS

One of the major rivers around Epe local government area, Lagos state, Nigeria popularly called River Temu was used as a test case of a flowing water stream. River Temu is located at the outskirt of EPE Town, Lagos State. Few activities are recorded within its environment includes bathing and washing, influx of drainages was also feasible from the road sides and from nearby crevices. Sample of River Temu was drawn into 25 L containers for Jar test analysis. The site view of river Temu is shown in Plate 1:

Plate 1: The Overview of river Temu from the main road.

2.1 Preliminary Testing of Water by Jar Testing

Ten (10), 250 ml beakers (jars) were prepared with 100 ml of stock solutions of slaked lime in the range of 5% to 45% percentage compositions of slake lime gravimetrically measured in weight per volume of river water (w/v) were dissolved and thoroughly mixed. Jar tests was conducted on gang stirrer(JLT series flocculators) with different dosages run side- by -side to simulate mixing with continuous agitation (Zane, 2005). The stirrer was operated at a speed of 12rpm for fifteen minutes, set-up is shown in plate 2. The contents of the respective beakers were allowed to settle overnight by sedimentation and the effect of the different treatment parameters such as pH, clarity, viscosity and total dissolved solids (TDS) were determined. The samples were then filtered through 0.45-micron filter respectively to determine the level of purity attained. The results from the jar test were used as a guide in determining the concentrations of chemical to be dosed into the flowing stream of water in a customised water plant.

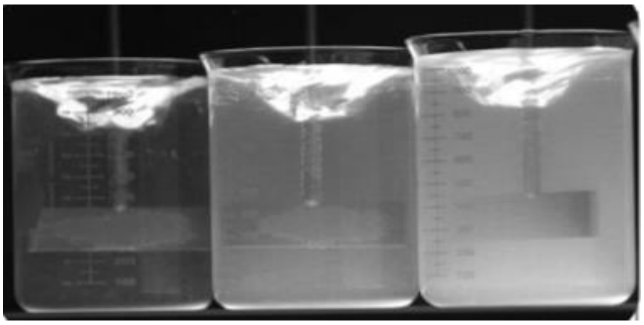

Plate 2: Jar Testing Beakers with coagulants and Stirrers

2.2 Dosing Implementation on A Process Pilot Plant.

The customised fabricated water treatment plant located at Mechanical Engineering workshop Lagos State University, had two pressure filter tanks with Sharp sands for particulate sieving and Activated Carbon Adsorber tank. Attached to the anterior was a positive displacement pump that draws water from the water reservoir while at the posterior end was a wool filter to which a ball vave tap was connected to regulate the flow rate and hence the productivity. Total dissolved and suspended solids (TDS) was determined by gravimetric analysis before and after treatment. A pictorial view of the front elevation of the pilot plant is shown in plate 3:

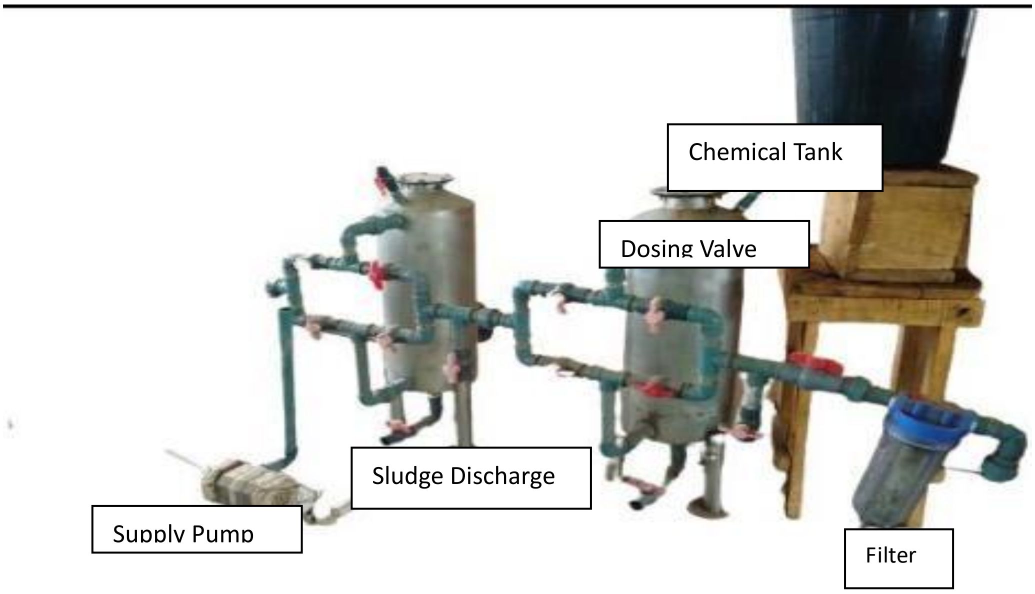

Plate 3: Pictorial view of the Water processing pilot plant

The supplying pump to the pilot plant had the flow rate capacity to be $25m^3/h$. The flowrate of the $Ca(OH)_2$ dosing was maintained at 5ml/s. Using the ratio control technique, the valves delivery capacity was regulated such that when the valve is completely opened, it was about 15± 0.5ml/s; when the valve is partially (½) opened, delivery was 10m±0.5ml/s and when the valve is minimally (¼) opened was 5± 2.0ml/s. The pattern of flow of the positive displacement pump was observed to be linear trim characteristics. The effect of doping the pilot plant with regulated $Ca(OH)_2$ dose was studied with the volume of delivery. The two flow rates were measured and the effects of their ratios computed, the manipulated flow rate was changed in constant ratio with the dosage and the doping stream.

Operational conditions of the pilot plant was introduced as boundary conditions for computer simulation of the correlations between the process stream flow rate and the corresponding dosing rate at the specified chemical concentrations. The process flow diagram used for the simulation using the Hysyss Programm simulator is presented in Figure 1: Results of the simulations were obtained for revalidation in the pilot plant and plotted for reference purposes and the estimated values were recorded and Tabulated. Results from Hysys simulation was validated with the bench analysis and so could be used for the treatment of water from streams.

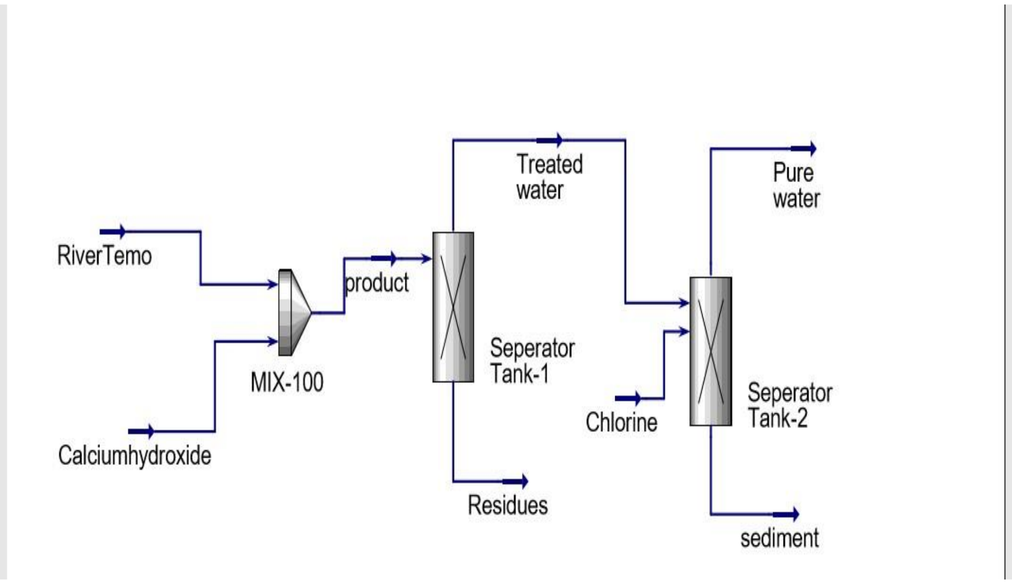

Figure 1: Process flow diagram for Hysys simulation

3.0 RESULTS AND DISCUSSIONS

The weather condition at the point of collection was 28^{0}C, the environment was cloudy and the colour was found to be pale yellow transparent liquid by visual appraisal and without any perceived odour. The pH was determined to be 5.52 (Acidic in nature). The acidity may be due to its proximity to the municipal wastes, dumping around its bank or effluents discharged from unknown source up the river path, more so, its closeness to the road side.

The viscosity of the slake lime solutions subjected to jar test for the coagulation of the particulate matter in the water samples were observed to increase as the percentage of the reagent increased. This reflected the trend of the total dissolved solids in the media which increased as the concentration of the slake lime increased as shown in Figure 1.

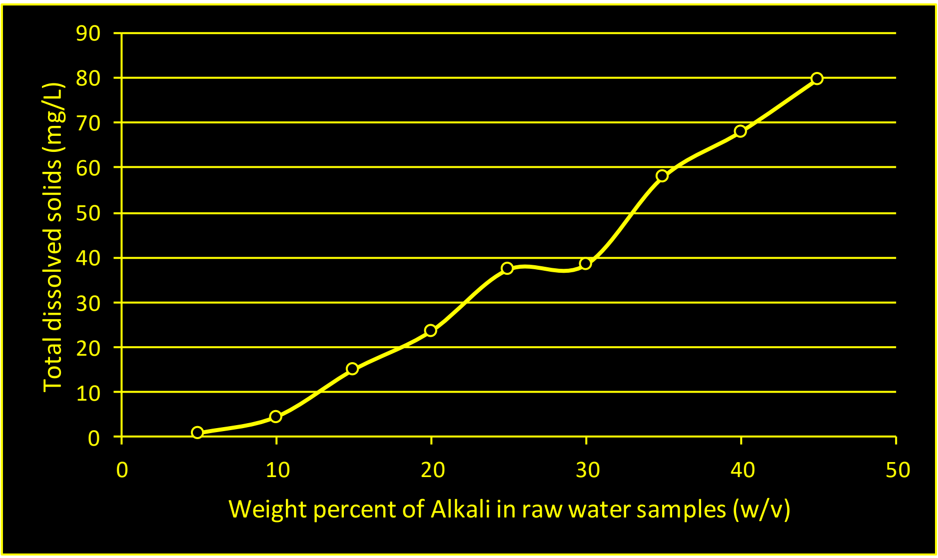

Figure 1: Effect of Alkali Concentration on media Total Dissolved Solids

A visual appraisal of the water samples on Jar testing treatment based on the colourless attributes of water and the respective outlook as shown in Plate 3 revealed that treatment of the river water with lime coagulant improved the colour of the water sample as displayed in samples 1 to 9 and comparing with the raw water sample (10). Further appraisal of the treated water based on the acidity of the media showed that the power of Hydrogen (pH) increased as the slake lime increased. The trend of the pH with respect to the product water treated is presented in Figure 2.

A dosing rate of the slake lime was obtained from the jar test analysis and was estimated to contain 37.36mg/l for 20% batch solution and it gave the most effective coagulation and flocculation with a pH closer to 7.0 The alkali is fed by gravity to delivers 5ml/s continuously to have a ratio control valve operation in the dosing. Application of slake lime or other coagulant may not be desirable beyond certain concentration as further percentage increased the quantity and it may not be desired because of the possible depositions and blockage of pipes. Observations made about each sample were put together in Table 1:

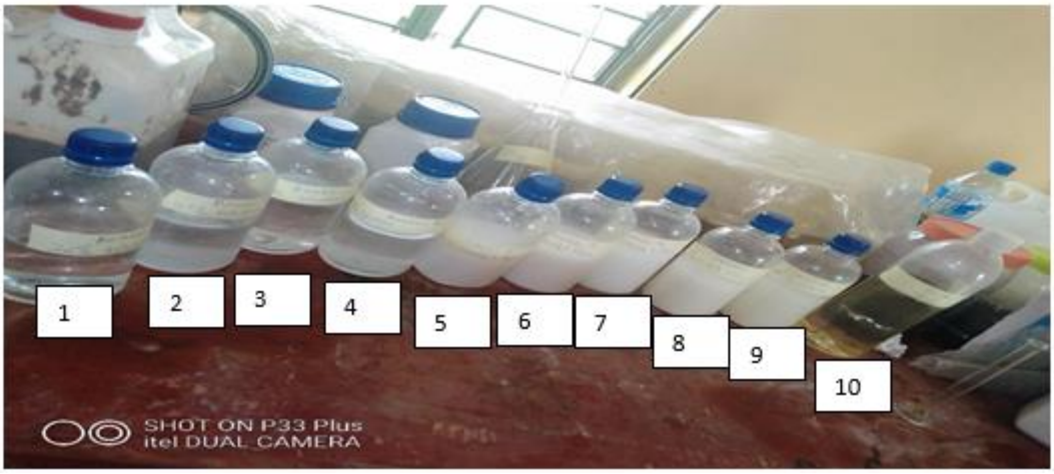

Figure 3: Physical appearance of results obtained before, durring and after dosing

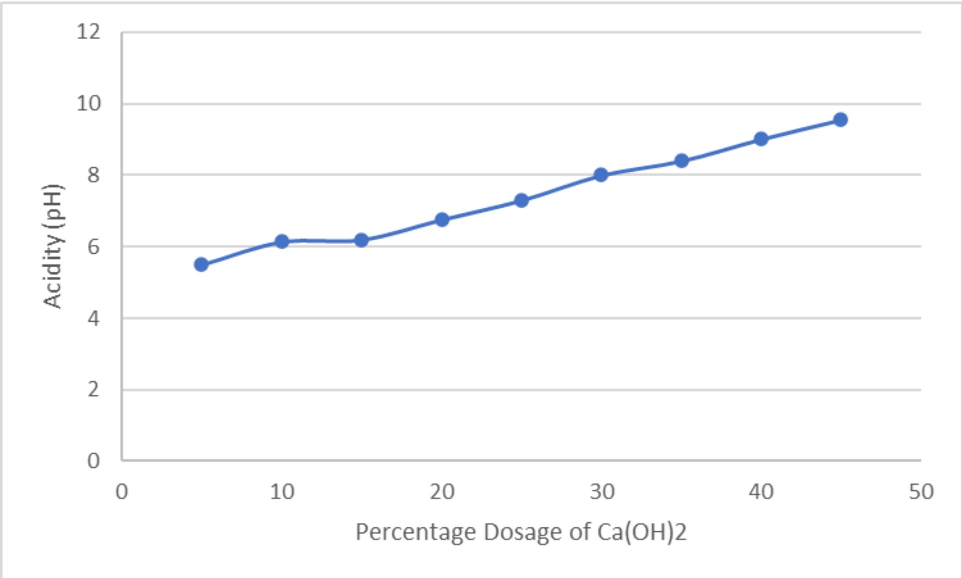

Figure 2: is the graph showing relationship between Alkali dose and pH.

Table 1: Effects of Calcium Hydroxide Concentrations on water samples

Quantity dose (%)	Temp C	Visual observations	Inference
5	**29**	Cloudy solution formed which took a while for the solution to settle down .	Clear particles floating on top i.e impurities present
10	**29.5**	Cloudy mixture formed ,took a while to settle down, also there was an exothermic reaction	Colloids formed.

15	**27**	Exothermic reaction formed which led to the emission of fumes	Formation of flocs
20	28	Formation of white blanket on the liquid surface	Formation of bubbles
25	28	While adding the stock solution of $Ca(OH)_2$ there was an emission of white fumes with chocking smell	No coagulation formed
30	**29**	There was a quick settling of sediments in the mixture	Flocs formed.
35	30.5	Exothermic reaction occurred	Formation of white fluffy granules, was emission of more fumes compared to other stock solutions
40	31.5	Exothermic reaction occurred during the preparation of the stock solution	No coagulation formed
45	31.5	Exothermic reaction occurred	Formation of white fluffy granules

The results from the process plant at regulated flowrates when the dosing valve is completely opened gave a PH result of 7.20 and when partially opened PH of 6.10 was recorded. Hence, the 20% batch solution obtained from the jar tests demonstrated to be the most suitable dosage. This indicated that the water was acidic in nature and needed to be neutralized and purified by coagulation and subsequent screening to obtain desired level of purity. The total dissolved solid (TDS) of 37.36mg/l was evaluated for the treated water which was within the admissible threshold value(EPA and WHO).

The relationship between the doping process stream and the main stream water supply is presented in Figure 4:

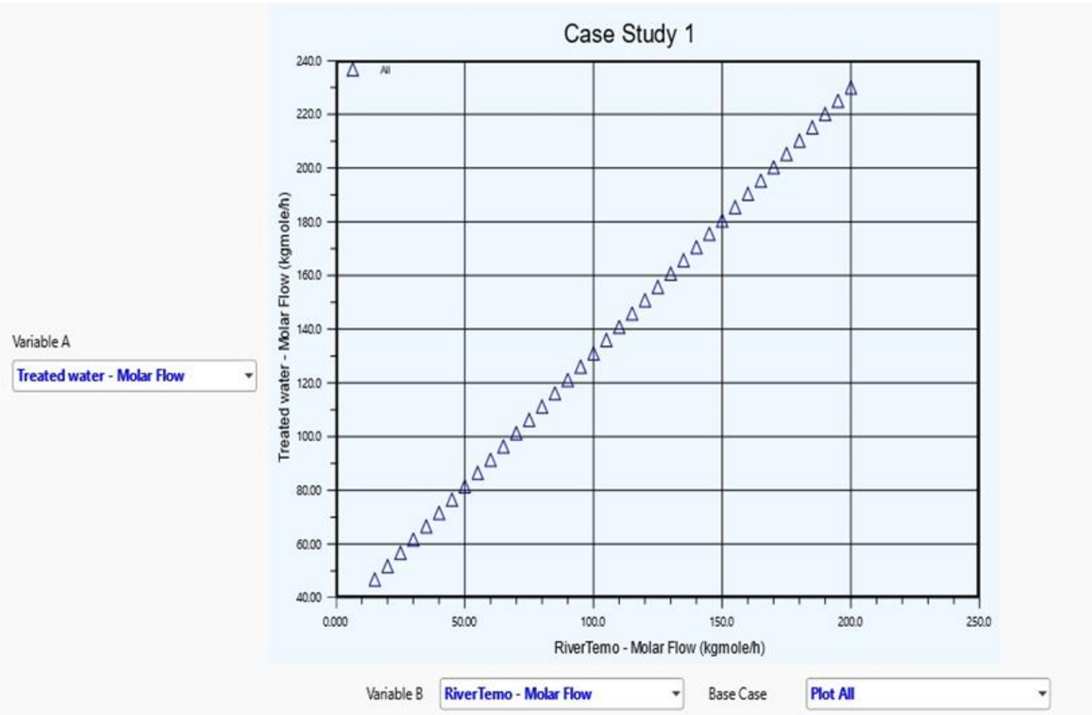

Figure 4: Case Study simulation 1

The best dose recommended for the coagulation and ph regulation of the source water as obtained from the laboratory analysis was the 20% clake lime stock solution with a PH of 7.20 obtained when $Ca(OH)_2$ is dissolved in 80ml of distilled water. Final analysis of the water obtained from the pilot plant is presented in Table 2

Table 2.

Sample description	Temperature	pH	TDS	Odour	Viscosity (poise)
Sample E	28^0C	7.30	37.36 Mg /L	NIL	1400.7

4.0 CONCLUSION

The demand for good water with increasing needs and population could be met by continuous processing of available flowing river to improved supply for domestic and industrial needs. Laboratory Jar testing for chemical applications in water treatment was successfully used for determining chemical dosages for purifying raw water. Alkaline dosing in water treatment was successfully used in continuous fashion to purify water from a flowing river as coagulant, flocculates and pH regulation was possible with doping. The variation and complex compositions associated with flowing water can be countered with the application of ratio control concept and correlations developed from the Hysyss simulation to minimizing the regular jar testing often needed before chemical application. This concept could be extended to other water treatment reagents in a continuous process.

REFERENCES

1. Aho, I.M. and Lagasi, J.E. (2012) A New Water Treatment System Using Moringa oleifera Seed. American Journal of Scietific and Industrial Research, 3, 487-492
2. Damalas,C.A and Eleftherohorinos, I.G(2011). Pesticide Exposure ,safety issues and Risk Assessment indicators .International journal of environment research and Public health
3. Eikebrokk B, Juhna T, Østerhus SW (2006) Water treatment by enhanced coagulation—operational status and optimization issues. Techneau D 5(3):1
4. Elimelech M (2006). The global challenge for adequate and safe water. J Water Supply Res Technol AQUA 55:3–10
5. Eman, N.A., Suleyman, A.M., Hamzah, M.S., Zahangir, Md.A. and Salleh, M.R.M. (2010). Production of Natural Coagulant from Moringa oleifera Seed for Application in Treatment of Low Turbidity Water. Journal of Water Resource and Protection, 2, 259-266. http://dx.doi.org/10.4236/jwarp.2010.23030
6. EPA ,(2000).The history of drinking water treatment ,Environmental protection Agency
7. Farhaoui, M. and Derraz, M. (2016) Review on Optimization of Drinking Water Treatment Process. Journal of Water Resource and Protection, 8, 777-786. http://dx.doi.org/10.4236/jwarp.2016.88063
8. Fawell J., Bailey K., Chilton J., Dahi E., Fewtrell L., Magara Y., (2006) Fluoride in drinking-water. World Health Organization, Published by IWA Publishing, London
9. Flomag, (2015). The Role of Alkalinity in Aerobic Wastewater Treatment Plants: Magnesium Hydroxide vs. Caustic Soda. Martin Marietta Magnesia Specialties, LLC <www.magnesiaspecialties.com> accessed 6th Dec 2021
10. Frik Scutte (Editor) 2006. HANDBOOK FOR THE OPERATION OF WATER TREATMENT WORKS. Water Utilisation Division Department of Chemical Engineering University of Pretoria. ISBN 1-77005-428-6 Republic of South Africa.
11. Matlock M.M., Howerton B.S., Atwood D.A., (2002) Chemical precipitation of heavy metals from acid mine drainage. Water Res 36(19):4757–4764
12. McCabe, D. J., (2011). Rivers and Streams: Life in Flowing Water. *Nature Education Knowledge* 3(10):19
13. Osei Yaw Ababio, (2015) New school chemistry ,for senior secondary schools.Sixth edition.
14. Sharma1 S.and. Bhattacharya A (2016). Drinking water contamination and treatment techniques. Applied Water Science <https://www.researchgate.net/publication/306243509>
15. Xie W, Wang Q, Ma H, Ohsumi Y and Ogawa H.I., (2005). Study on phosphorus removal using a coagulation system. Process Biochem 40(8):2623–2627
16. Younes .M. and Galal-Gorcher (2000). Pesticides in drinking water –A case study. Food and Chemical toxicology WHO(2010).
17. Zane Satterfield, P. E, (2005). Jar Water Testing THE NATIONAL ENVIRONMENTAL SERVICES CENTER. at West Virginia University, P.O. Box 6064, Morgantown, WV 26506-6064 Tech Brief • Jar Testing, Spring, Vol. 5, Issue 1