Preparation of hydrated lime quality for water treatment: to reduce silica concentration from hydrated lime up to standard specification

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ABSTRACT

This research paper examines the effort of preparation of hydrated lime for water treatment matching the required quality. In order to avoid scale formation, hydrated lime quality needs the removal of silica from the lime water. Laboratory tests were conducted on lime samples and then checked for conformity with the AAWSA and AWWA standards. In this research, lime water was prepared from a 1.49% silica concentration of limestone, so much preferable. One of the most practical strategies for reducing silica content in hydrated lime was ion exchange. 2 M NaOH and 0.1 M HCl were dosed in limewater with different dosing amounts. The optical absorption value of silica in final solutions of limewater was recorded by UV-Visible spectrophotometer, and the results found 0.042, 0.132, 0.121, 0.05, 0.688 and 0.21. All these absorbance values are equivalents to less than 0.5% silica concentration lime water, which is adequate for water treatment, hence matching the standards. Among dosages amounts, the optimum dose of sodium hydroxide was 10 mL of 2 M NaOH.

Keywords: Hydrated lime; Silica; Silica reduction; Ion exchange; Scaling

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1. Introduction

Some of the general hydrates limed properties of minimum needs for water treatment. Physical properties lime is associated in nursing in odorous white powder that is soluble in water [1]. Hydrate lime must be whitish, dry, precisely powdered, and free of lumps or extraneous matter, with consistent particle size. Caustic lime $Ca(OH)_2$ is one of the principal elements of hydrated lime, and work its chemical properties is very important. Hydrate lime is incredibly finely divided powder ensuing from the association of burnt lime, consisting basically of calcium hydroxide was antecedently referred to as lime calcium hydroxide shall not have but sixty-two percent accessible unslaked lime, that is, like 81.9% caustic lime [2]. Impurities-hydrate lime shall not contain any soluble material or organic compounds in proportions capable of producing dangerous or damaging impacts on the wellbeing of this intense water which has been adequately treated with a lime product [3].

Hydrated lime is used to control the hydrogen ion concentration in the drink and is used at various phases of the process. These include adjusting the hydrogen ion concentration in water to prepare it for treatment, as well as countering "red water" by neutralizing acid water and minimizing acid water degradation of pipes as well as mains. Carbonic acid gas is present in abundance in the corrosive seas. Lime converts greenhouse gas emissions into Ca carbonate, which acts as a protective coating on the inside of water mains. Lime is combined with alum or iron salts to coagulate suspended particles that occur during the elimination of moisture in the air from "raw water". It helps to maintain the proper concentration of hydrochloric acid for a variety of natural process settings. Waste material is treated with lime in certain sewage treatment plants to help sludge thicken on pressure filters [4]. Clarification and adsorption, as well as ion-exchange procedures, have all proved successful in removing silica. Furthermore, chemical clarification and electrocoagulation processes are classified under clarification. One of the most extensively used methods for removing silica from water is chemical clarifying. Typical pretreatment methods and chemicals removal silica by precipitation (Lime ($Ca(OH)_2$ and soda ash ($NaCO_3$)), coagulation (sodium hydroxide ($NaOH$), alum ($Al_2(SO_4)_3$), iron salts: ferric chloride and ferric sulphate) and flocculation (polyelectrolytes (cationic, anionic, and nonionic) [5,6].

Coagulation is largely mediated by two mechanisms: charge neutralization of negative particles through sorption of positively charged soluble aluminium species and particle enmeshment in precipitated $Al(OH)_3$ [7]. In the charge neutralization mechanism, cationic species are electrostatically adsorbed or form a complex with negatively charged silica in water. Adsorption of oppositely charged ions lowers the zeta potential and finally induces silica instability. Because a high coagulant dose might produce charge reversal and re-stabilization, a low coagulant dose is suggested for charge neutralization mechanisms. Silica is frequently absorbed or encapsulated in metal hydroxide precipitates and eliminated using sedimentation in the hydroxide precipitation process. An increase in the amount of solid precipitate improves silica removal [8–10].

By using the flocculation of polymers, colloidal silica is removed. The polymer is also absorbed on silica particles by hydrogen bonding or attraction of electrostatics which is bridge components of silica particles.

Electrocoagulation is a process of chemical precipitation that is different from the traditional method. An electrical current is generated between the electrodes during the electrocoagulation process and anodic oxidation aids in the formation of coagulants. When it comes to electrocoagulation, iron and aluminium electrodes are commonly used. The metallic ion generated by the electrode could be hydrolyzed to generate metal hydroxide, which can be used as flocculants or adsorbents in the removal of contaminants. Electrocoagulation has additional features against chemical precipitation: no external chemical reagent is needed, it is simple to build and operate, and it produces less sludge. Furthermore, when compared to chemical coagulation, electrocoagulation is typically a speedier procedure [11–13].

For the removal of geogenic contaminants from aqueous solutions, adsorption or ion-exchange techniques have been proven to be particularly successful. The contaminant in the majority liquid state is gathered in a tiny volume of solid material, which may either be produced and recycled in a cyclic process or disposed of safely. Adsorption of ion-exchange processes is an interesting method for removing contaminants from aqueous solutions because of their selectivity, large capacity, and resilience. When a portion of the residual silica was in nonionic form, the performance of silica extraction from super-saturated solutions was shown to be greater [14]. There is a larger danger of polymerization on the resin surface when the silica content is beyond the solubility limit. However, the presence of bicarbonate can reduce the probability of silica polymerization because of the diffuse ion-exchange zone between silica and bicarbonate. When the resin was in the form of hydroxide, silica demonstrated improved selectivity. In the precipitation, greater flow magnesium hydroxide was generated, which entraps or absorbs extra silica particles in the water. As a result of the precipitation of magnesium hydroxide within lime softening, silica will be removed by adsorption on the magnesium precipitates [15]. Silica anion exchange was discovered to be a fast and reversible process. The high-performance reverse osmosis (HERO) technology is a reverse osmosis system that is specifically developed to reduce silica scaling in water treatment. Because of its ability to tolerate high silica water, this research has rapidly attracted a lot of attention. By changing the PH of the brine, the HERO™ process enhances silica solubility up to 1,500 ppm, allowing for water recovery of more than 90%. However, divalent metal ions should be eliminated before to desalination to eliminate the production of alkaline and non-alkaline scale. This type of technology was ideally suited to wastewater treatment [16].

2. Experimental detail

2.1. Materials, apparatus and reagents

The basic materials used for hydrated lime preparation for water treatment is calcined limestone, that is, lime, CaO, sucrose, anhydrous sodium carbonate and methyl orange.

The following basic apparatus and instruments are used for the determination of silica in hydrated lime for water treatment. Muffle furnace, beakers, Whatman filter paper, platinum dishes, conical flask, bottle, Buret Clamp, pipettes, and UV spectrophotometer. The chemical reagents used in this analysis were sodium hydroxide NaOH, hydrochloric acid for the treatment of hydrated lime.

2.2. Lime analysis by titration method

The purity of both quicklime and hydrated lime can be determined using a titration technique for the detection of calcium oxide content [17] 1.5 g of calcined lime was pulverized by mortar and pestle. Then it dissolved in 200 mL of distilled water. It was swirled up to all samples dissolved. This was filtered by the Whatman filter. Now, the filtered sample was treated with 2 M NaOH and 0.1 M HCl.

2.3. Batch method

For batch method, the prepared limewater was mixed with 2 M NaOH and 0.1 M HCl for 24 h. In order to discover the best dosage that lower silica concentration in lime water, 10 mL of limewater combined with the varied volume of sodium hydroxide and maintained fixed volume of hydrochloric acid. Similarly, maintain a constant volume of sodium hydroxide and change the volume of hydrochloric acid. The final solution was tested for silica concentration using a UV spectrophotometer at the completion of each created mixture.
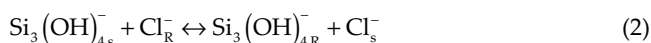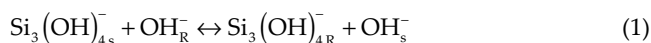
3. Result and discussions

3.1. Lime analysis results of titration

The purity of the lime can be determined by the calcium oxide concentration. The calcium oxide percentage of Type I quicklime should be at least 90%, according to SABS 459-1955, whereas the calcium oxide content of Grade I hydrated lime should be at least 68%, according to the same standard [18]. As described in Table 1, lime prepared after calcined yellowish white color limestone from Mugher cement factory source results 70% of CaO, which meets the standard specification of AAWSA standard specification that of hydrated lime for water treatment effectively.

3.1.1. Ion exchange mechanism

Since silica in lime water exists after the hydrolyzed solid, silica is found as monosilicic form. Silica removal is a sort of ion exchange that is often achieved with strong base rosin of the hydroxide kind. Due to the fact that silica is a weak acid, the exchange reaction for silica removal is shown below (Nguyen et al. [15]). From Eq. (2), mono silicic acid is reactive as follows:

$$Si_3(OH)_{4s}^- + OH_R^- \leftrightarrow Si_3(OH)_{4R}^- + OH_s^- \tag{1}$$

$$Si_3(OH)_{4s}^- + Cl_R^- \leftrightarrow Si_3(OH)_{4R}^- + Cl_s^- \tag{2}$$

Anion-exchange resins are frequently regenerated with caustic soda, NaOH, according to the reaction:

$$Si_3(OH)_{4R}^- + OH_s^- \leftrightarrow Si_3(OH)_{4s}^- + OH_R^- \tag{3}$$
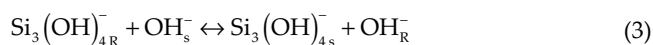
The ion exchanger (resin) is denoted by the subscript "R" whereas the mobile phase (solution) is denoted by the subscript "S". The percentages in the resin and the solution are represented in m mol/g of resin and mmol/mL of solution, respectively.

3.2. Performance of ion exchanger on silica reduction from hydrated lime

Batch tests have been conducted to investigate the effect of strong base ion exchange in the silica concentration in hydrated lime. Ion exchange with a strong foundation its interchange of anionic and cationic species is facilitated by the resin in the solution [17]. Therefore, the performance of the Strong base anion exchange on reduction of silica was studied for varied volume sodium hydroxide solution with a constant volume of hydrochloric acid solution as well as kept constant volume sodium hydroxide solution with a varied volume of hydrochloric acid solution to determine the optimum dosing. The optical absorption value of silica in the final solution of prepared hydrated lime was recorded by a single-cell holder UV-Visible spectrophotometer within the wavelength at 815 nm with room temperature using the Molydosilicate method. The concentrations of silica in the hydrated lime prepared sample were calculated from absorption data by using the Lambert-Beer equation, Eq. (12).

The relationship can be expressed as $A = \varepsilon l C$ where A is absorbance, ε is the molar extinction coefficient (which depends on the nature of the chemical and the wavelength of the light used), l is the length of the path light must travel in the solution in centimetres, and C is the concentration of a given solution.

$$A = \varepsilon l\, C \tag{4}$$

$$C = \frac{A}{\varepsilon l} \tag{5}$$

where C is the concentration (mol/L), A is absorbance value, l is the path length of cuvette which is 1 cm and ε, is molar absorptivity of silica at 815 nm, it is 46,201 mol^{-1} L cm^{-1}. The concentration of silica unit obtained in mol/L was converted to percent (%) by using Eq. (6):

$$C(\%) = \frac{\left(C(\text{mol/L})(60\text{ g/mol})\times 1,000\right)}{10,000} \tag{6}$$

Table 2 determines optimum dosing sodium hydroxide and hydrochloric acid at different volumes into lime water. These optimums were expected based on silica concentration found in lime water of AAWSA and AWWA standards for water treatment. Caustic soda (100 mg/L) reduces silica than 18 mg/L [18]. As shown in Table 2,

Table 1
Hydrated lime laboratory analysis results comparative to standards

Major oxides	Standard of silica concentration, AWWA by (%)	Standard of silica concentration, AAWSA by (%)	Lab result average (%)
CaO	≥72	≥68	70
Fe_2O_2	≤0.2	<0.5	0.2
Al_2O_3	≤0.6	<0.5	0.5
MgO	<0.4	<1	0.4

Table 2
UV spectrophotometer absorbance value of silica in hydrated lime results converted to concentration and comparison with its corresponding standards

Sample No.	Ion exchanger dosage		Hydrated lime (mL)	Absorbance value of silica	Silica Conc. (%) Lab. result (UV)	Standard of hydrated lime silica conc. for water treatment	
	Volume in (mL) of 2 M NaOH	Volume in (mL) of 0.1 M HCl				AWWA Silica Conc. (%)	AAWSA Silica Conc. (%)
1	10	5	10	0.042	0.0054		
2	15	5	10	0.132	0.0168		
3	20	5	10	0.121	0.0162	≤0.5	≤1
4	10	15	10	0.05	0.0064		
5	10	10	10	0.688	0.0893		
6	10	5	10	0.21	0.027		

when dosing all amounts of 2 M NaOH with 0.1 M HCl with different volumes in prepared lime water, silica concentration was less than 0.1% in hydrated lime, which confirmed with the standard specification of both AAWSA and AWWA. The reason why silica concentration is less 0.1% was that the most silica concentration reduction was due to filtration, and the lime by itself contains less amount of silica. Since non-dissolved silica of hydrated lime was left on funnel filter and the only dissolved silica was passing through filter paper. Consequently, the silica was found with a very small amount of concentration in lime water after treatment, as shown in Fig. 1. Moreover, due to UV spectrophotometer measures molybdate-reactive soluble silica and polymeric (colloidal) silica formed from reactive silica in lime water deposits on types of equipment. That is why observed results of reactive silica were with too much small concentration as Table 2 indicates.

A small amount of caustic soda is enough for silica production, that is, not more than 150 mg/L needed for silica reduction. A retained silica quantity of 14.7 mg/L was obtained using a caustic soda, NaOH dosage of 180 mg/L [18]. From the beginning of this chapter, silica in the limestone was obtained 1.49%. Here silica amount in hydrated lime was reduced to much less than 0.5%, as results indicated in Table 2. With increasing caustic soda, silica was removal dramatically by more than 20%. NaOH increased with each increment in caustic soda dose until it reached a steady state of 200 mg/L caustic doses. The dosage was eliminated 90.6 percent of the time, with a final silica content of 3.5 mg/L, down from 37.3 mg/L at the start [18]. As can be seen from Table 2, when dosing 10 mL of 2 M NaOH and 5 mL 0.1 M

HCl results, the silica amount is 0.0054%. Silicate concentration would predominantly be reduced at this dosage. Because the decrease of silica level did not drop much when sodium hydroxide dose, NaOH was raised further, it was established that 10 mL of 2 M NaOH was the optimum dose of sodium hydroxide. In addition, because greater doses increase chemical costs, it's best to keep the precipitant dose as low as possible.

Fig. 2 shows silica concentration vs. absorbance using the different volumes of 2 M NaOH and 0.1 M HCl solution dosed in hydrated lime. In Fig. 2, the results of the experiments were matched; for each dosage of resin (ion exchange) to Eq. (12). The influence of ion exchange resin on silica content was investigated with a very good correlation coefficient.

Generally, the above all discussion is mainly interpreted the silica content that was obtained from Mugher Cement Factory limestone and its lime sample analysis. As all results indicate that Mugher Cement Factory was found to have the best quality resource for hydrated lime production. The quality of hydrated lime supplied by Derby was much inferior to the one we produced [19].

3.3. Economic considerations of lime

As Federal Democratic Republic of Ethiopia Ministry of Trade data shows, there was lime imported from other different countries. From the beginning of this research explained hydrated lime is utilized for water treatment.

In these data, Unit prices per ton of hydrated lime were incremented by 15% per year. As information obtained from AAWSA, the unit price in 2019 was $200, and in 2020 it will
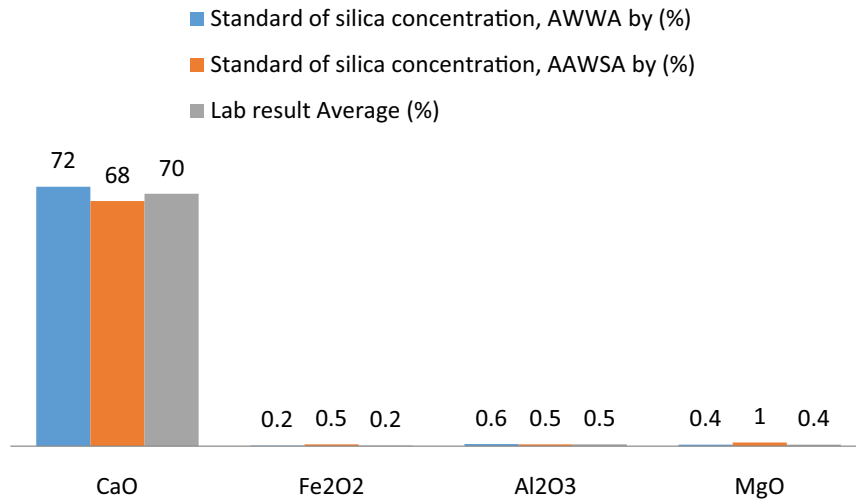
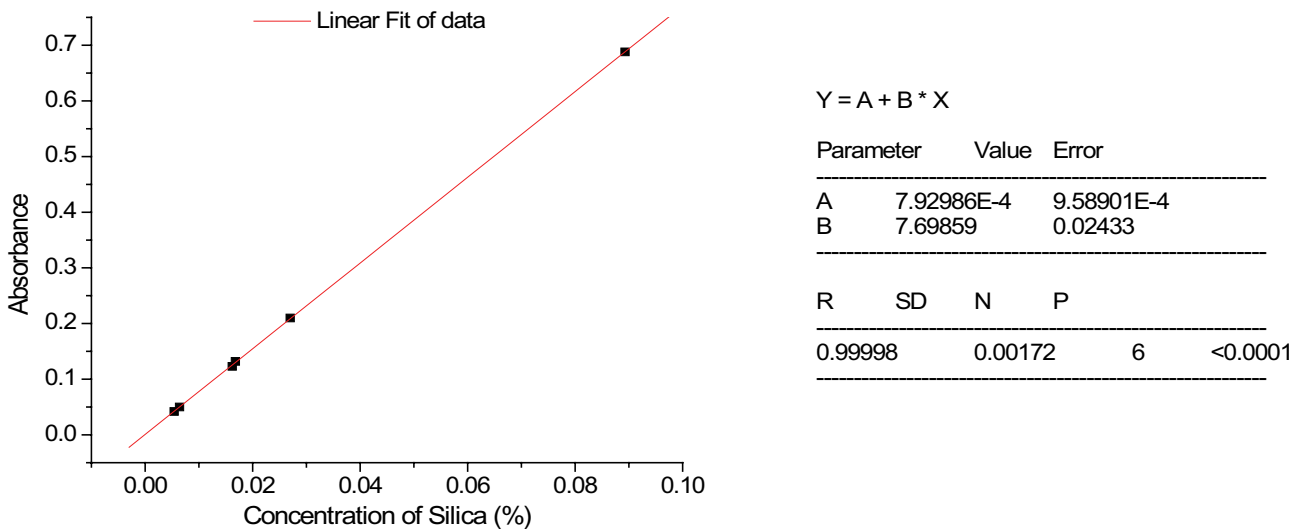Fig. 1. Hydrated lime laboratory analysis results comparative to standards.

Fig. 2. Experimental data fitted for different dosages of ion-exchange into hydrated lime.

become \$230. Similarly, in 2021 unit price becomes \$264.5. FOB cost of price (USD) = Unit price × total weight (ton).

Fig. 3 reveals the trend that as long as time (y) increases, the total cost was also directly increased because the unit price cost was incremented by 15% per year. In addition to this, as Table 3 shows, there was a cost for transportation for importing hydrated lime so much expensive than a local product of hydrated lime. From these data, it is possible to decide or estimate the cost for importing hydrated lime after the coming five years will be required a very large dollar to import rather than the quality problem of locally manufactured products [19]. Therefore producing hydrated lime in Ethiopia widely is very crucial for saving high currency.

Lime is also used in large numbers in water treatment, and the need for lime for road construction is expected to rise. Domestic production of lime is currently insufficient to meet demand (maximum 4,500 tons per year), and getting supplies has proven challenging due to cement manufacture taking precedence.

Above data obtained from the AAWSA that of local hydrated lime product was produced at Derba Cement Factory. The results from Table 4 and the calculation shows that utilizing locally produced hydrated lime have an annual saving of 2,328,780 Birr cost advantages for only AAWSA than utilizing imported hydrated lime. This result may also indicate that the total cost of saving after the coming five years, a minimum of 11,643,900 Birr, will be saved for only AAWSA. In addition to these results shows hydrated lime consumption again as a whole in Ethiopia for water treatment becomes cost effective whenever a used local product of hydrated lime. There is no hydrated lime production for water treatment in Mugher Cement Factory. But as this research result shows, there was convenient limestone that can be used to prepare hydrated lime for water treatment.
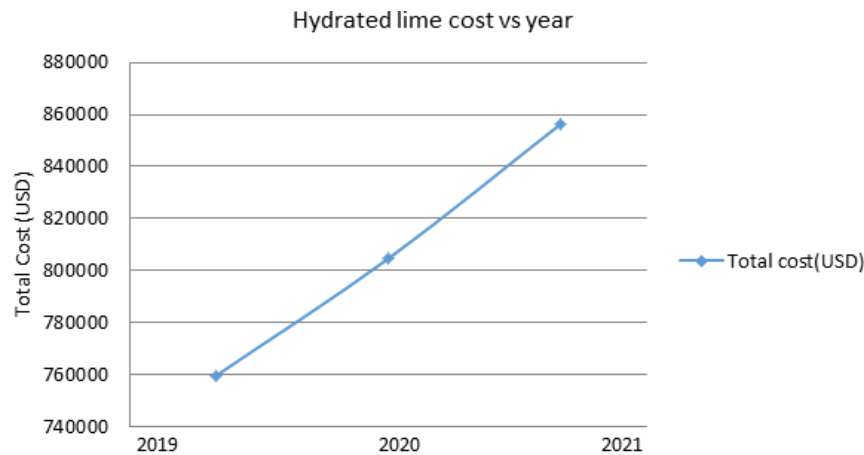
Fig. 3. Cost of hydrated lime imported for Addis Ababa Water Treatment.

Table 3
Data of hydrated lime product imported for Addis Ababa Water & Sewerage Authority for water treatment

Year*	Imported hydrated lime (ton)	FOB cost of price (USD)	Cost freight (USD)	Cost insurance (USD)	Cost inland transport (USD)	Total cost (USD)
2019	1,500	300,000	147,000	24,500	288,000	759,500
2020	1,500	345,000	147,000	24,500	288,000	804,500
2021	1,500	396,750	147,000	24,500	288,000	856,250

FOB: Free on Board (Freight on Board);
*European Calendar;
Source: AAWSA – Addis Ababa Water & Sewerage Authority.

Table 4
Cost comparison of imported hydrated lime and local product of hydrated lime for water treatment per year

Year	Imported hydrated lime unit cost in Birr per Quintal	A local product of hydrated lime unit cost in Birr per Quintal	Total lime consumption of AAWSA per year (Quintal)
2020	886.23	–	6,000
2021	–	498.1	6,000

Unit cost-saving = Cost of utilize imported hydrated lime – cost of utilize local hydrated lime;
Unit cost saving = 886.23 – 498.1 = 388.13 (Birr/Q_t);
Annual saving = 388.13 Birr/Q_t × 6,000Q_t = 2,328,780 Birr
Source: AAWSA – Addis Ababa Water & Sewerage Authority.

For hydrated lime production at Mugher Cement Factory, the following assumption is used below; this assumption is based Standard specification of limestone oxides. Particularly this research focused on silica content limestone. Less than 1% of silica concentration can use for preparations of hydrated lime for water treatments. According to chemical analysis of limestone was carried out in Mugher Cement Factory quality control and assurance laboratory shows there was limestone which contains 1.49% silica concentration which is suitable for preparation of hydrated lime. Tables 3 and 4 indicate that it was costly to import hydrated lime. Therefore when hydrated lime is manufactured for water treatment in Mugher Cement Factory, it may be possible to replace imported hydrated lime with hydrated lime produced there. Besides saving costs, this will increase the market of the Mugher cement factory.

Table 5 shows the comparison between methods of water treatment with their advantage and disadvantage, as it can be seen the limestone water treatment is promising with its cost effective and not hazardous to the environment.

4. Conclusions

The effort of preparation of hydrated lime for water treatment matching the required quality is directly related to the concentration of its silica. Silica reduction from hydrated lime was examined by using the ion exchange method. The optical absorbance of silica concentration was

Table 5
Comparing limestone water and conventional methods of water treatment

No.	Conventional (chemical) methods	Advantages	Disadvantages	References
1	Coagulation and flocculation	Chemicals with a positive charge are added to the water. The positive charge of these chemicals neutralizes the negative charge of dirt and other dissolved particles in the water. When this occurs, the particles bind with the chemicals and form larger particles, called floc.	Requires adjunction of non-reusable chemicals (coagulants, flocculants, aid chemicals); Physicochemical monitoring of the effluent (pH); Increased sludge volume generation (management, treatment, cost); Low removal of arsenic.	[20]
2	Flotation froth flotation	Integrated physicochemical process; Different types of collectors (nonionic or ionic); Efficient for removal of small particles and can remove low-density particles, which would require long settling periods; Useful for primary clarification; Metal selective; Low retention time; Used as an efficient tertiary treatment in the pulp and paper industry; *Mechanisms*: true flotation, entrainment and aggregation.	High initial capital cost; Energy costs; Maintenance and operation costs no negligible; Chemicals required (to control the relative hydrophobicities between the particles and to maintain proper froth characteristics); Selectivity is pH-dependent.	[21]
3	Chemical oxidation Simple oxidation Ozone Hypochlorite treatment Hydrogen peroxide	Chemical oxidation; Simple oxidation; Ozone; Hypochlorite treatment; Hydrogen peroxide.	Chemicals required; Production, transport and management of the oxidants (other than ozone); Pretreatment indispensable; Efficiency strongly influenced by the type of oxidant; Short half-life (ozone); A few dyes are more resistant to treatment and necessitate high ozone doses; Formation of (unknown) intermediates; No diminution of chemical oxygen demand values or limited effect (ozone); No effect on salinity (ozone); Release of volatile compounds and aromatic amines (hypochlorite treatment); Generates sludge.	[22]
4	Chemical precipitation	Technologically simple (simple equipment); Integrated physicochemical process; Both economically advantageous and efficient; Adapted to high pollutant loads; Very efficient for metals and fluoride elimination; Not metal selective; Significant reduction in the chemical oxygen demand.	Chemical consumption (lime, oxidants, H_2S, etc.); Physicochemical monitoring of the effluent (pH); Ineffective in the removal of the metal ions at low concentration; Requires an oxidation step if the metals are complexed; High sludge production, handling and disposal problems (management, treatment, cost).	[23]
5	Limestone	Limited solubility – cannot over-treat – Can install years of treatment capacity. • Can store on-site without loss; • Not hazardous; • Less than 20% of the cost of lime and caustic alternatives.	When exposed to acidic water containing Al and Fe^{3+}, solids quickly form. • Solids foul limestone aggregate, greatly decreasing its effectiveness	

determined by a UV spectrophotometer at the wavelength of 815 nm at room temperature. The research proves that NaOH with HCl reduced the silica concentration from lime water. For the present application, when dosing of 2 M NaOH with 0.1 M HCl with different volumes in prepared lime water could be the optimum solution for water treatment. Significantly, when dosing 10 mL of 2 M NaOH and 15 mL 0.1 M HCl results the silica amount were 0.0054%, 0.0168%, 0.0162%, 0.0064%, and 0.027%. From these, 0.0054% was prominently optimum dosage. Generally, in material science, when materials are affected by external influences, their properties might be changed. Due to the dosage of sodium hydroxide in lime water, silica concentration is reduced. The deposition character of silica in hydrated lime on the surface of tubes during application of hydrated lime for water treatment also similarly will be reduced.

Recommendation

For the future study, the researchers will characterize the materials by using devices like X-Ray diffraction (XRD), Scanning electron microscope (SEM) and Ultraviolet-visible spectrophotometer (UV-Vis).

Disclosure

The research was performed as a part of the employment of the authors from Universities Ethiopia.

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