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Investigation of the performance of Mushroom as a natural coagulant for reducing turbidity of local clay suspensions

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Abstract: Great interest has been given in the last few years for issues related to environmental protection and safety. This included the use of safe methods for wastewater treatment. One of these methods is the use of natural materials instead of chemicals. Mushroom is used in the present study as a natural flocculent with different dosages for treating synthetically prepared suspension of different concentrations of local clay which is collected from Egypt's River sides. The parameters studied are: pH, mushroom dose, clay dose, settling time and turbidity are determined. Results showed that a maximum turbidity removal of 96.5% is obtained at pH of 6.7 and optimum dose of 0.4 g/L of mushroom and 4000 TSS. By using 0.4 g/l of mushroom, about 17.3 NTU of turbidity remained from an initial turbidity of 100 NTU, while 4.28% of turbidity remains for 400 NTU of initial turbidity. This occurs after 120 minutes. A high turbidity removal of 96.5% with 22 NTU residual turbidity for 320 NTU of initial turbidity, while the lowest is 82.2% for an initial turbidity of 101 NTU.

Keywords: Clay, Flocculation, Suspension, Turbidity, Mushroom

I. INTRODUCTION

Water is very essential for life and it is important that it be pure and healthy. The most important problems faced by living organisms is water turbidity. Turbidity is the amount of cloud or impurity in the water [1]. This can vary from a river full of mud and silt where it is impossible to see through the water (high turbidity), to spring water that appears crystal clear (no turbidity at all) or clear (low turbidity) [2] [3]. Turbidity can be caused by silt, sand and clay; bacteria and other germs; chemical precipitates [4][5]. It is very important to check the turbidity of the domestic water supply, as these supplies often undergo some type of water treatment that can be affected by turbidity [6][7]. High turbidity will also fill tanks and pipes with mud and silt, and can damage valves and taps.

For removing turbidity of water, many types of coagulants are used [8] [9]. Those are divided to chemical or non-chemical coagulants. Also, it could be divided to synthetic or natural coagulants [10] [11]. Polymeric coagulants are expensive and considered a problem for overall treatment process cost [12] [13]. Therefore, it is necessary to find a low- cost coagulant to decline the overall cost of turbidity removal process [14 - 16]. Flocculation and bio-flocculation processes are a combination of insoluble particles and dissolved organic materials into a high aggregate, which are removed in final stages by sedimentation and filtration [17 - 19]. Bio coagulants do not have drawbacks on the human health like chemical coagulants [20]. There are a variety of Bio coagulants like microbial polysaccharides, starches, gelatin, cellulose, chitosan glues, and alginate [21] [22].

In the present study, commercially available Mushroom is used as a flocculent for reducing the turbidity of a local clay-water suspension. The factors affecting turbidity reduction are studied, and evaluated.

II. MATERIALS AND METHOD

A. *Materials*

In the present study, locally available River Nile clay and commercial Mushroom is obtained from the local market. Sulphuric acid (H_2SO_4 75%, Sigma Aldrich) and Sodium hydroxide (NaOH 25%, Sigma Aldrich) are used for controlling the pH value.

B. *Preparation of Mushroom powder*

Fresh Mushroom is washed with distilled water, cut into slices and left to dry naturally. The dried material is ground to a fine powder, and then sieved to produce particles of mesh size 325 (aperture 45 µm). Weighed amounts of Mushrooms are used in a series of tests as coagulant/ flocculent with the required concentration. Scanning

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Electron Microscopy (SEM), Transmission Electron Microscopy (TEM) and X-ray diffractometry (XRD) techniques are used to characterize Mushroom fine powder.

C. Preparation of Clay Suspension and Procedure

A weighed mass of clay is added to one liter of distilled water and then the suspension is mixed at (300 rpm) for 60 minutes to achieve a uniform dispersion of clay particles. To complete the hydration of clay materials, the suspension is allowed to settle for about 24 hours. At the time of the experiment, the prepared stock is shacked well; the flocculent is added according to the required amount, stirred at high speed for 3 min and then at low speed for 12 min and analyzed using the turbidity meter (Model TU- 2016) and results are recorded.

Suspensions of known content of TSS (1000- 6000 ppm) are placed in a graduated cylinder and left for 10 minutes before readings are recorded. The heights of the compression zone, settling zone and clear zone are taken periodically, and recorded. Other test samples of the suspension are withdrawn periodically at a distance of 10 cm from the surface and its turbidity is measured (using a Turbidity Meter Model TU- 2016) and re-checked values are corded.

III. RESULTS AND DISCUSSION

A. Materials Characterization

1. Characterization of Mushroom

Mushroom is a natural, effortlessly obtainable and environmentally friendly product rich in plant proteins, chitin and enormous vitamins. Mushroom is a macro fungus with a characteristic fruit form. Mushroom flocculent has a chain of virtues for example non-poisonousness, richness in resources, cheapness and biodegradability.

2. SEM and TEM Analysis

Fig. 1a shows that the auricular edible mushrooms have a dark powder with more electron-dense material. The chitin structure appears as several fine loosely united leaves. The auricular powder is composed of a heterogeneous mixture of amorphous fragments with a size distribution ranging between 1 and 50 µm (Fig. 1b). Higher magnifications of some of the mushroom pieces showed that the surface of these fragments appeared to have a rough morphology (Fig. 1c).

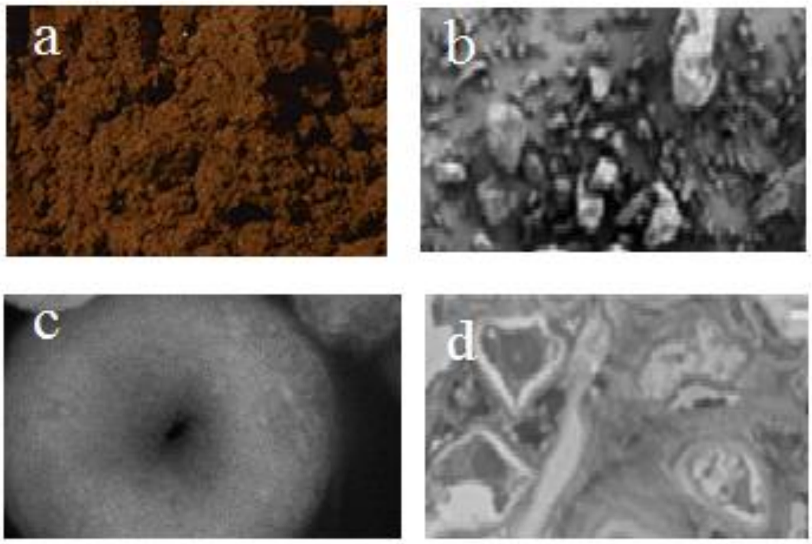

Fig. 1:Electron Microscopy Analysis of Mushroom Powders (a), Scanning Electron Microscopy (SEM) (b (for Mushroom Pieces) and c (for Mushroom powder)), Transmission Electron Microscopy (TEM) (d)

TEM analysis in Fig. 1d revealed that mushroom Powders have very similar internal structures, including circular units with a dense cell wall made of several concentric layers embedded in a heterogeneous mass of material with different textures. The darker areas in this mushroom were associated with material randomly distributed across the section, although it could be observed that the inner layers of the circular units were also highly electron dense (Fig. 1d), signifying that melanin might not have a systematic spreading shape in the mushrooms.

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The crystallinity of the mushroom is determined by the XRD analysis. The XRD pattern (Fig. 2) indicated lignocellulose peaks at 2θ = 20° and 2θ = 36°, and the 2θ° closer to 20° displayed crystallinity, while the peak 2θ° = 36° showed an amorphous structure [23 - 25].

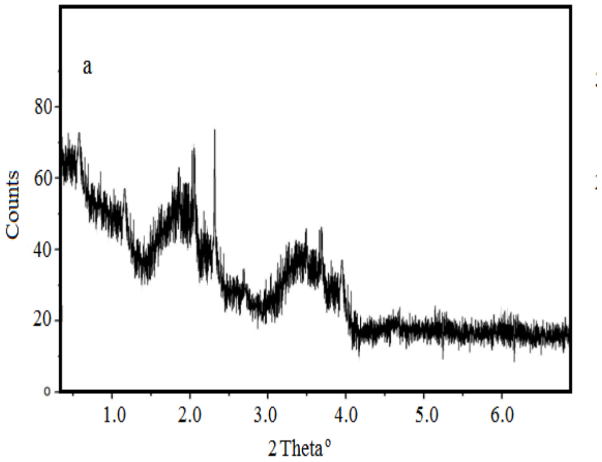

Fig. 2:XRD of Mushroom

3. *Characterization of Clay*

Clay deposits generally found in many geological regions located in the Nile Valley and Delta of Egypt. Many industries, such as the ceramics, refractories and Portland cement industries, use clay deposits as an essential component in the production processes. PA analytical Spectrometer (Axios Sequential WD-XRF, 2005) was used to determine the chemical composition of clay. The major content of the clay sample is CaO (15.5%), silica (21.25%) and alumina (7.52%). While the percent of other components is: $Fe2O3$ (1.95), $TiO2$ (0.23), MgO (0.80), and MnO (0.03). In addition, high values of $SO3$ (4.83%) and $P2O5$ (4.54%) appeared owing to the existence of gypsum and apatite. While the loss on ignition (LOI) of the clay sample was 42.90%. X-ray diffraction analysis (XRD) of the clay sample was performed by a Philips X-ray diffractometer (Mod. PW 1390). The XRD result indicated that the main components of the sample are: Goethite, gypsum, montmorillonite, fluorapatite, pyrite, calcite, and quartz contaminations (Fig. 3).

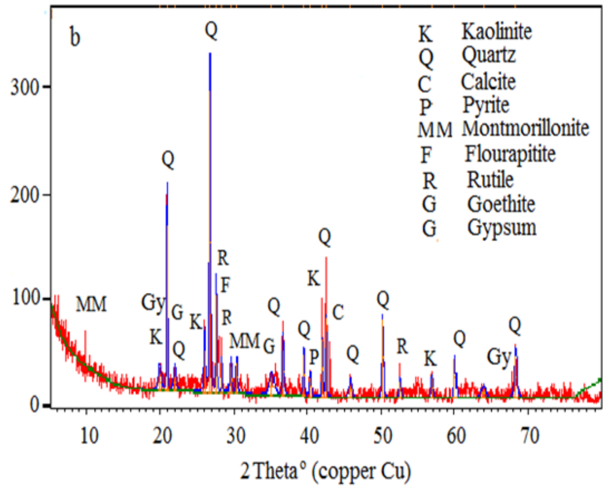

Fig. 3: X- ray Diffraction Analysis of Clay

The XRF results of Egyptian bentonite clay are shown in table (1).

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Table 1:Chemical Composition of Clay

Component	MgO	SiO_2	Fe_2O_3	Al_2O_3	TiO_2	CaO	Na_2O	K_2O	LOI Loss on ignition
XRF %	0.62	56.3	10.02	22.12	1.32	4.39	1.13	1.40	10.75

B. Effect of pH Value

Experiments are run on clay suspension of 4000 ppm with Mushroom concentration of 0.4 g/l at different values of pH. Fig. 4 indicates that minimum values of residual turbidity (best results) are accomplished at pH value of 6.7. This is followed by pH 5 and 8, while the lowest results are given at pH 3 and pH 10. Thus, values of pH around normal (neutral) are recommended for this clarification process rather than the highly alkaline or highly acidic values. Thus, the rest of experiments of this study are run at pH value 6.7.

A percentage reduction in residual turbidity of 96.5% is accomplished at pH 6.7 after 120 min., this is followed by 96.3% at pH 5. At pH 10, the percentage reduction in turbidity was 95.9. Thus, the turbidity removal is decreased or distorted when the pH is higher than 6.7 [26]. This is because the positive charges on the Mushroom-clay surface decreases as pH increases. This will contribute to the decreasing charge of both Mushroom and clay to attract the negatively charged suspended particles [2][23][27].

The high content of amine groups in Mushroom provides cationic charge at acidic pH and can destabilize colloidal suspension to promote the growth of large, rapid-settling floc that can then flocculate. Because it is a long–chain polymer with positive charges at natural water pH, Mushroom can effectively coagulate natural particulate and colloidal materials, which are negatively charged, through adsorption, charge neutralization, inter-particle bridging as well as hydrophobic flocculation [28 - 30].

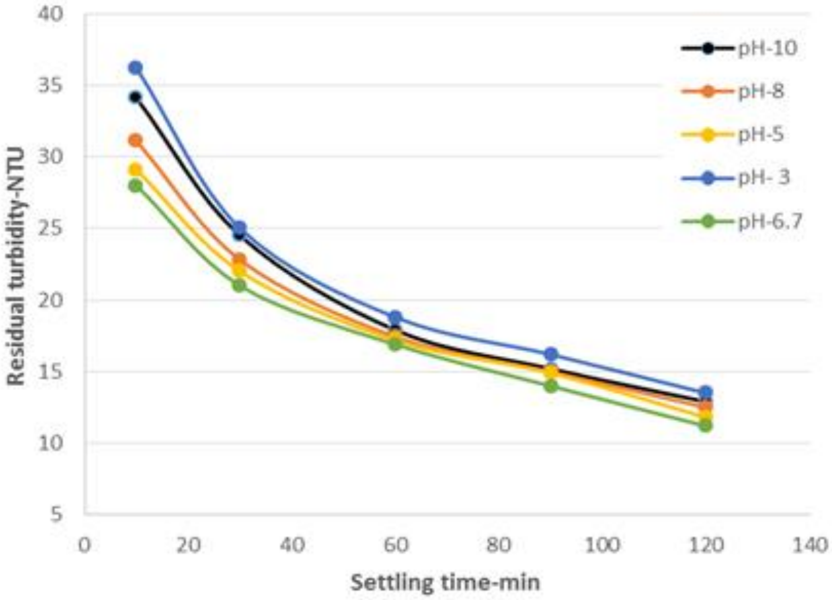

Fig. 4: Change of Residual Turbidity with pH Value (for 4000 ppm TSS and 0.4 g/l mushroom)

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C. Effect of TSS on the Value of Initial Turbidity ((No flocculent added)

Fig. 5 indicates that the Initial turbidity is higher as the initial TSS of the suspension is higher. The relation is almost linear (with R^2 value of 0.9763); implying a steady increase for initial turbidity with TSS. Thus, to obtain the amount of suspended solids present in a suspension, a TSS versus turbidity plot is developed to obtain a coefficient to relate the two.

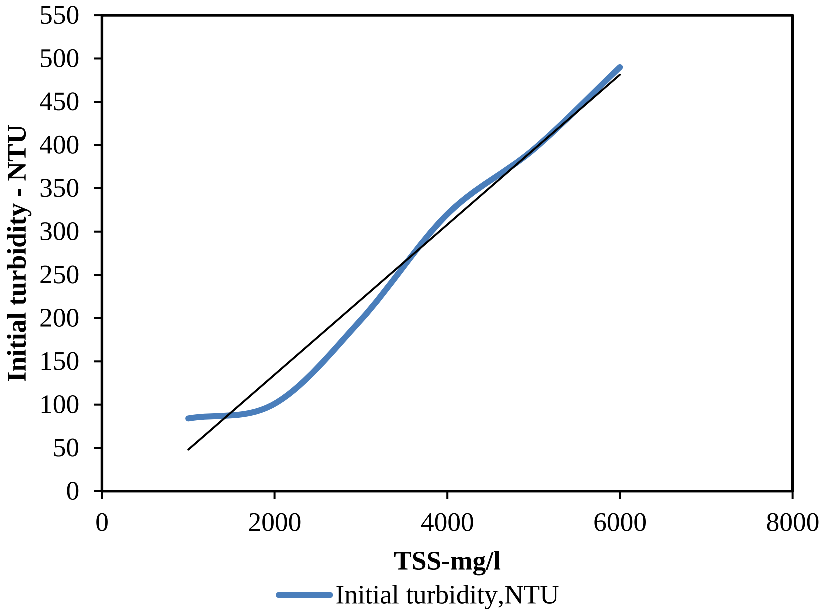

Fig. 5: Change of Initial Turbidity with TSS (at pH 6.7)

D. Effect of TSS on Residual Turbidity (NTU and % reduction in turbidity) (Mushroom Dose 0.4 g/l):

Fig. 6 shows that the percentage reduction in turbidity (solid lines) is higher in the early stages of the process and it decreases as time proceeds. Meanwhile, the percentage reduction in turbidity increases as TSS increases from 1000 to 2000 mg/l. After TSS value of 2000 mg/l the percentage reduction in turbidity decreases with increasing TSS till 4000 mg/l; after which the values of % reduction in turbidity are almost constant. This means that the performance of flocculent is not as high with higher values of initial TSS (higher than 4000 mg/l), i.e., after 4000 mg/l TSS, the efficiency of the flocculation process is reduced. This may be due to the reduction of the sweeping effect of the flocs formed. The lowest value of % reduction in turbidity (64.2%) is satisfied by a suspension of TSS value of 2000 mg/l after 10 minutes and the highest value (82.2%) was satisfied by the same suspension after 120 minutes (by the end of the process) [31][32].

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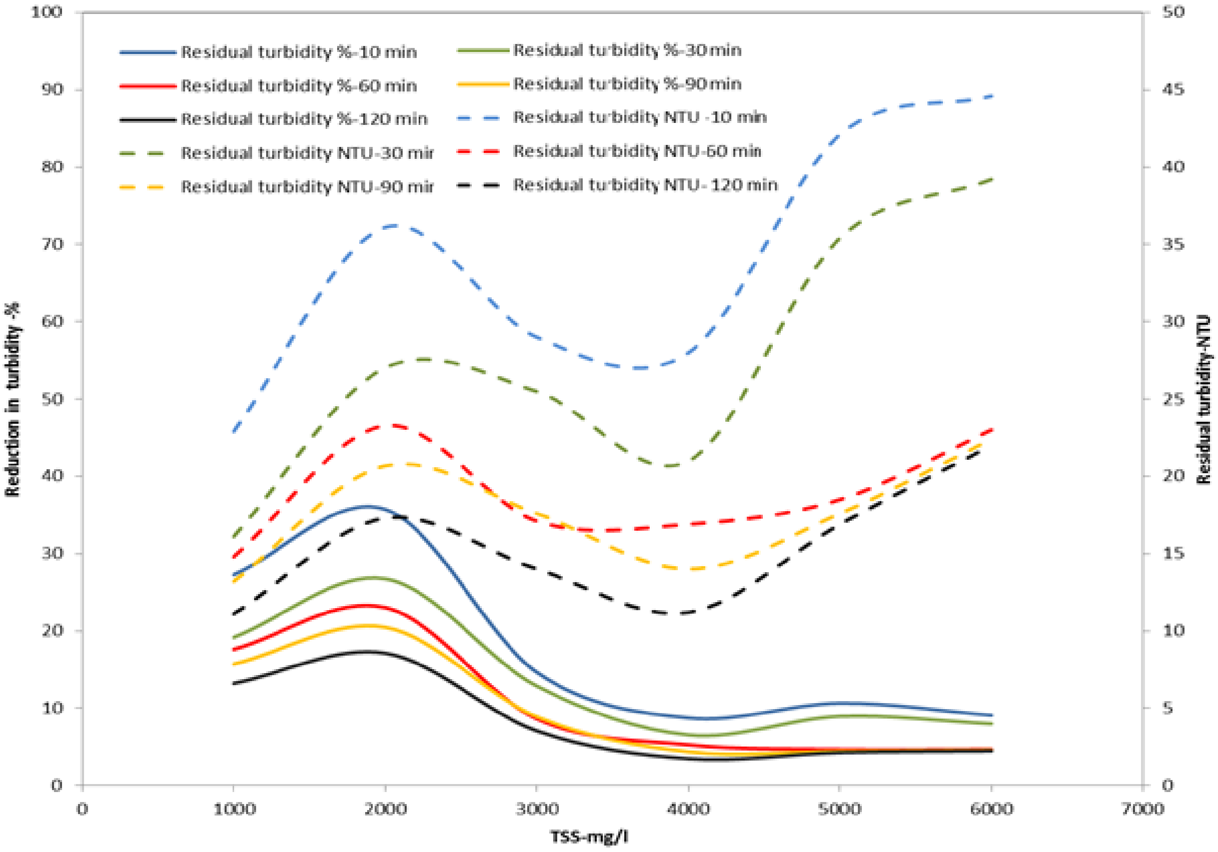

Fig. 6:Effect of TSS on Residual Turbidity (NTU) and % Reduction in Turbidity

Values of residual turbidity, NTU, (dotted lines) show an increase with increasing initial TSS till 2000 mg/l TSS after which the values of residual turbidity decrease till it reaches its lowest value at 4000 mg/l TSS and it increases again after 4000 mg/l TSS. Thus, suspensions with higher values of initial TSS (higher than 4000 mg/l) do not perform good with respect to the flocculation process and this is indicated by higher values of residual turbidity, NTU, and lower values of % reduction in turbidity[10][32][33].

E. Dependence of Percentage Reduction in Turbidity on Initial Turbidity of Suspension

Values of percentage reduction in turbidity at the end of experiments (120 minutes) are calculated from the results obtained for suspensions with different values of initial turbidity, NTU. Fig. 7 shows that the relation is linear (with R2 value 0.7181). Thus percentage reduction in turbidity is higher as the suspension is more turbid. The slope of the line is 0.0291 which indicates that the percentage reduction in turbidity does not increase sharply with increasing initial turbidity of suspension [34 – 38].

Thus, the value of initial turbidity does not have a pronounced effect on Mushroom flocculation efficiency of clay suspension; which means that the turbidity remaining after the tests was similar for tests on different initial turbidity levels. As a result, the percentage of turbidity removal increases with increasing initial turbidity. For example, after 120 minutes of settling, there was 17.13 % of the initial turbidity remaining (corresponding to 82.8 % reduction) in the test that had an initial turbidity of 100 NTU, while the test with an initial turbidity of 400 NTU had 4.28 % turbidity remaining (corresponding to 95.7% reduction) [39][40]. The highest percentage removal of 96.5% after 120 minutes of settling was observed with the initial turbidity of 320 NTU, and the lowest was 82.8% for the initial turbidity of 101 NTU. However, the absolute level of turbidity after 120 minutes of settling generally increases with increasing initial turbidity. Fig. 8 shows the relation between the values of absolute residual turbidity (NTU) and percentage of turbidity removal for suspensions with different values of initial turbidity. The values of percentage of turbidity removal did not show great variation regardless of the residual turbidity, while the absolute level of the initial turbidity varied widely. Thus, it could be concluded that the rate of settling of flocculent varies with the value of initial turbidity; i.e., with the initial concentration of suspension [41][42].

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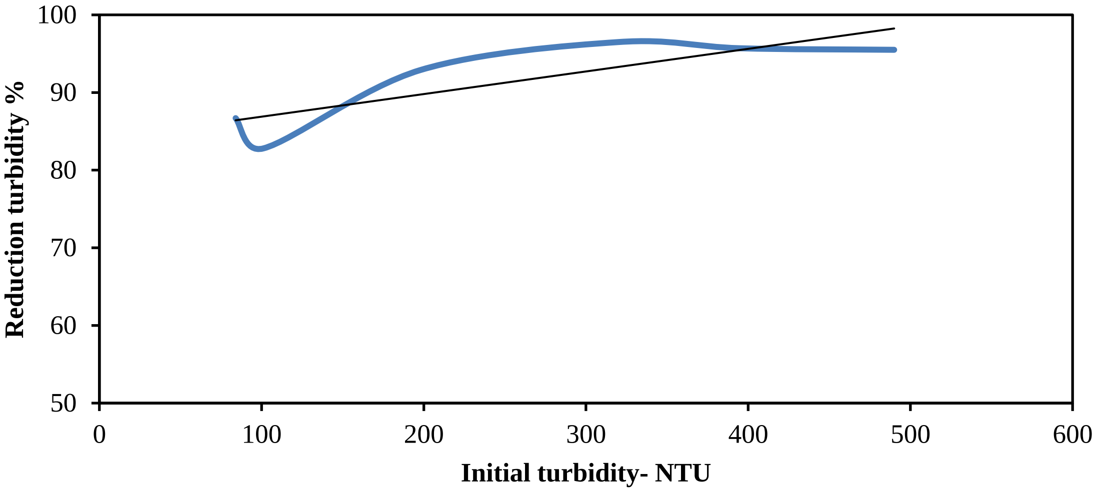

Fig. 7:Dependence of Percentage Reduction in Turbidity on Initial Turbidity

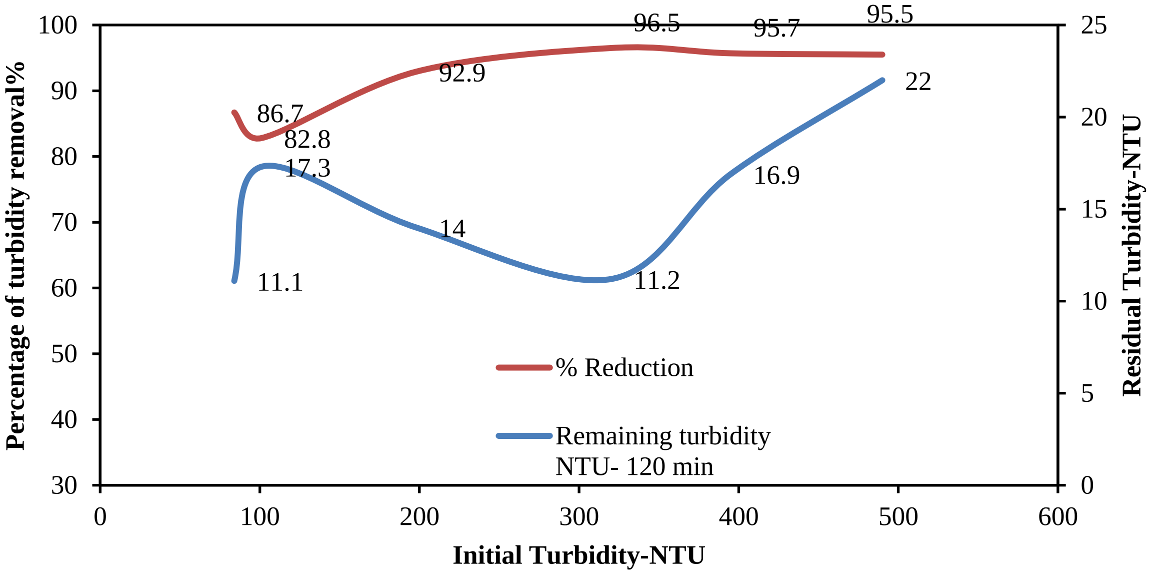

Fig. 8:Change of percentage turbidity reduction and residual turbidity, Absolute residual turbidity (NTU) vs. percentage of turbidity removal %

Fig. 9 declares that the remaining turbidity, in NTU, increased with increasing initial turbidity. The most effective turbidity removal process was obtained with the highest initial turbidity tested, 490 NTU, with (22 NTU) turbidity remaining after 120 minutes of settling. The least effective removal process was found with the lowest initial turbidity tested, 84 NTU, with (11.1NTU) remaining after 120 minutes of settling [43 – 45]

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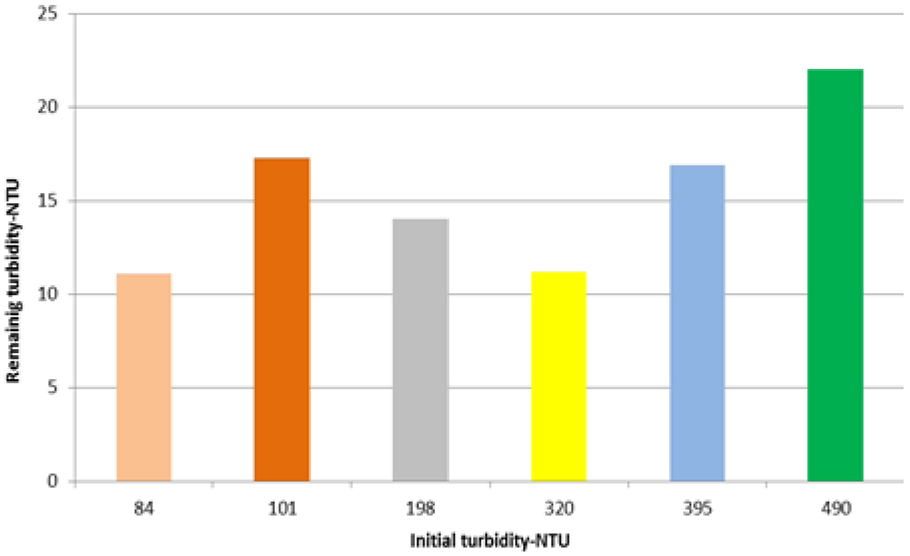

Fig. 9:Dependence of Residual Turbidity on Initial Turbidity for Suspensions

F. Studying of the Rate of Settling

Experiments are run on clay suspension of 4000 mg/l TSS, treated with 0.4 gm/l Mushroom dose at pH value of 6.7. Suspensions are left to settle and the height of clear, settling and compression zones are measured periodically. Fig. 10 shows the experimental setup for this test.

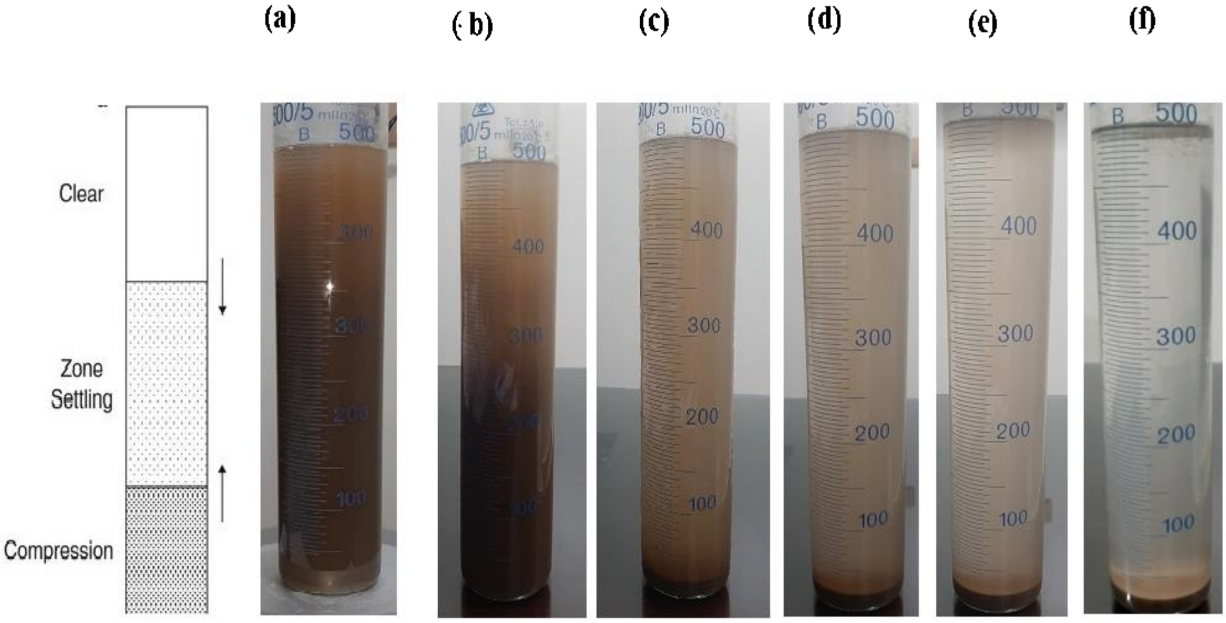

Fig. 10:Change of Clay Particles Distribution during Flocculation and Sedimentation

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The results of this test are represented graphically in Fig. 11 for the change of height of clear zone with time. Examination of this figure shows that the height of the clear zone increases sharply in the early stages of clarification but this increase is slight after 95 minutes of clarification. In other words, the rate of clarification is high in the early stages of the clarification process than at the end of the process. For example, an increase in the height of 100 % and 61.6 % is noticed in the time period from 8 to 30 minutes and from 60 to 95 minutes, respectively, compared to 2.06 % in the time period 95 to 121 minutes [46] [47]. These ratios were calculated from the experimental results given in Table 2.

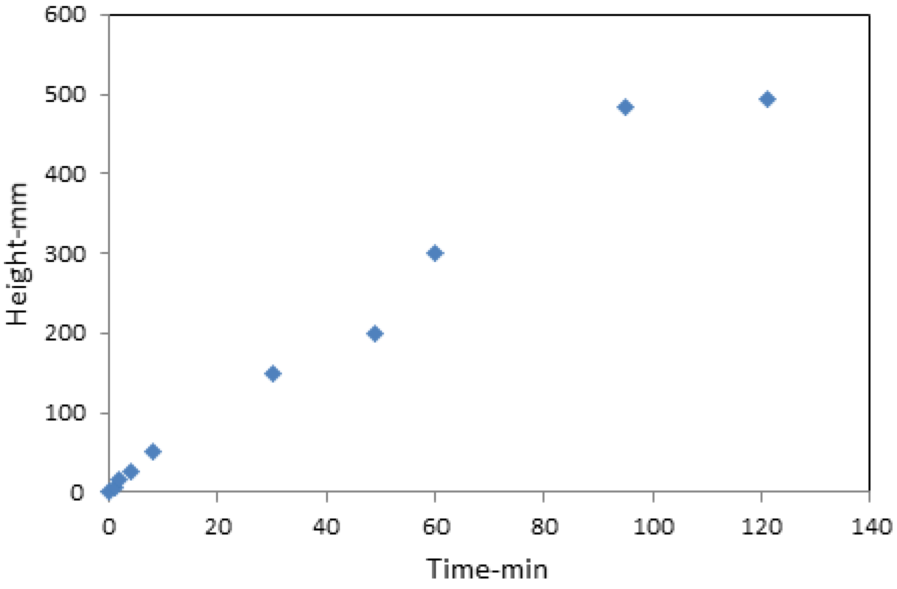

Fig. 11:Change of Height of Clear Zone with Time

Table 2:Change of Height of Different Zones with Time

Time, min	Compression Zone, mm	Settling zone, mm	Clear Zone, mm
0	3	497	0
1	5	490	5
2	5	480	15
4	5	470	25
8	5	445	50
17	5	395	100
30	5	345	150
49	5	295	200
60	5	195	300
95	5	10	485
121	5	0	495

Fig. 12 shows the change of the heights of both the clear zone and settling zone. As expected, an increase in the height of the clear zone corresponds to a decrease in the height of the settling zone (Fig. 13) and both express the rate of clarification under the specified conditions given for this test. The height of the compression zone is not pronounced due to a smaller volume of clay used in suspension compared to the volume of water [48] [49].

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It is noticed in Fig. 13 that the slope of both lines is almost the same (value of m); but with different signs (one is + ve and the other is – ve). This is because as the clear zone increases the settling zone decreases at the same rate [18][50 - 52].

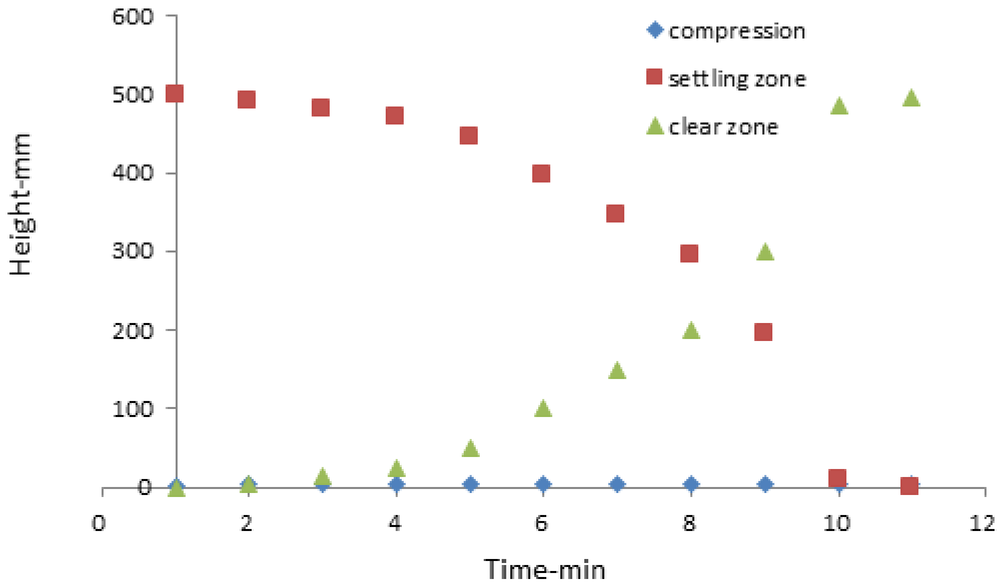

Fig. 12:Change of the Heights of Clear, Settling and Compression Zone

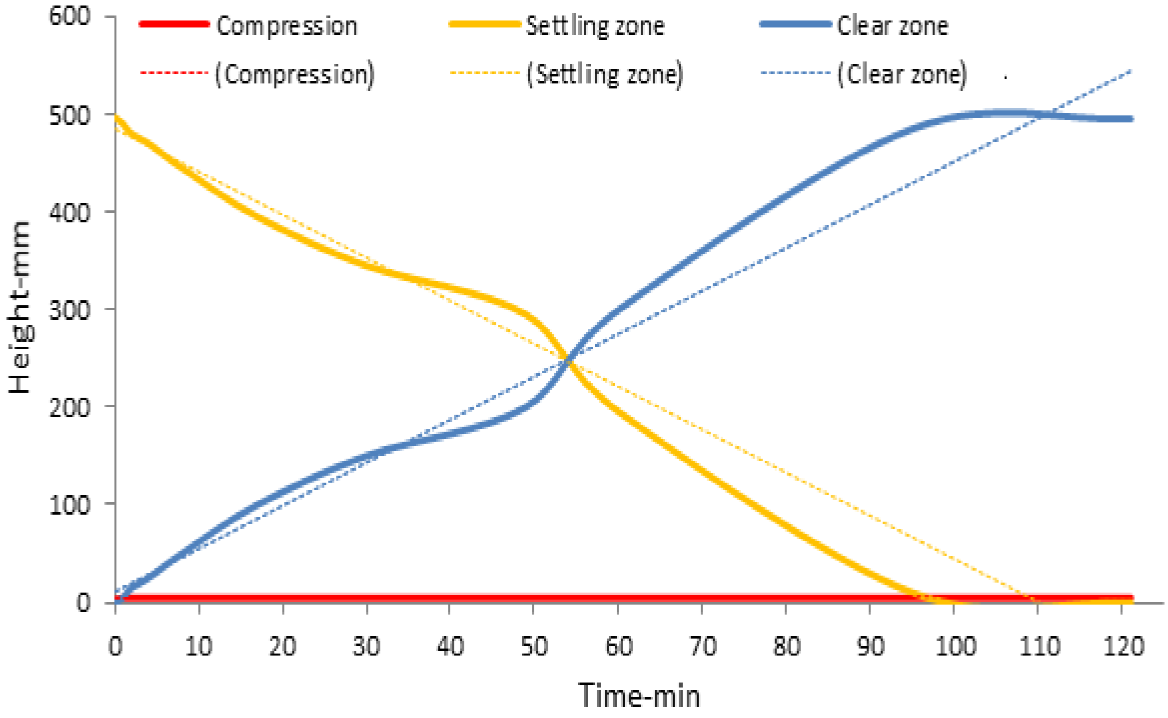

Fig. 13:Change of the Heights of both the Clear Zone and Settling Zone

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IV. CONCLUSIONS

The following conclusions are obtained from the present work:

- ✓ A percentage reduction in residual turbidity of 96.5% is accomplished at pH 6.7 after 120 min., this is followed by 96.3% at pH 5 and 96% at pH 8 (for 4000 ppm clay concentration and 0.4g/L of mushroom).

- ✓ The lowest value of % reduction in turbidity (64.2%) is satisfied by a suspension of 2000 mg/l TSS after 10 minutes and the highest value (82.8%) was satisfied by the same suspension after 120 minutes (by the end of the process).

- ✓ After 120 minutes of settling, there was 17.13% of the initial turbidity remaining (corresponding to 82.8 % reduction) in the test that had an initial turbidity of 100 NTU, while the test with an initial turbidity of 400 NTU had 4.28% turbidity remaining (corresponding to 95.7% reduction); using 0.4 g/L of mushroom

- ✓ Using Mushroom concentration of 0.4g/L, the highest percentage removal of 96.5% after 120 minutes of settling, was observed with the initial turbidity of 320 NTU, and the lowest was 82.8% for the initial turbidity of 101 NTU. However, the absolute level of turbidity after 120 minutes of settling generally increases with increasing initial turbidity

    - ○ The most effective turbidity removal process was obtained with the highest initial turbidity tested, 490 NTU, with (22 NTU) turbidity remaining after 120 minutes of settling at 6000 ppm clay concentration and 0.4 g/L of mushroom. The least effective removal process was found with the lowest initial turbidity tested, 84 NTU, with (11.1NTU) remaining after 120 minutes of settling at 1000 ppm clay concentration and 0.4 g/L of mushroom.

    - ○ Using a clay suspension of concentration 4000 ppm and Mushroom dose of 0.4g/L, an increase of 100% and 61.6 % is noticed in the height of Clear Zone at time periods from 8 to 30 minutes and from 60 to 95 minutes, respectively, compared to 2.06 % in the time period 95 to 121 minutes.

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REFERENCES

[1] Sobsey, M. D., Stauber, C. E., Casanova, L. M., Brown, J. M. & Elliott, M. A. 2008, Point of use household drinking water filtration: a practical, effective solution for providing sustained access to safe drinking water in the developing world. Environmental Science and Technology 42 (12), 4261–4267.

[2] Ansari, S., Alavi, J. & Yaseen, Z. M. 2018b, Performance of full-scale coagulation-flocculation/DAF as a pre-treatment technology for biodegradability enhancement of high strength wastepaper-recycling wastewater. Environmental Science and Pollution Research, 25 (34), 33978–33991.

[3] Yaseen, Z. M., Zigale, T. T., Kumar, R., Salih, S. Q., Awasthi, S., Tung, T. M., Al-Ansari, N. & Bhagat, S. K. 2019, Laundry wastewater treatment using a combination of sand filter, bio-char and teff straw media. Scientific Reports 9 (1), 1–11.

[4] Vijayaraghavan, G., Sivakumar, T. & Kumar, A. V. 2011, Application of plant based coagulants for waste water treatment. International Journal of Advanced Engineering Research and Studies 1 (1), 88–92.

[5] Lee, C. S., Robinson, J. & Chong, M. F. 2014, A review on application of flocculants in wastewater treatment. Process Safety and Environmental Protection 92 (6), 489–508. http://dx.doi.org/10.1016/j.psep.2014.04.010.

[6] Al Doury, M. & Al Samerrai, H. 2019, Treatment of al doura oil refinery wastewater turbidity using magnetic flocculation. Tikrit Journal for Engineering Sciences 26, 1–8.

Print ISSN 2682-3993
Online ISSN 2682-4000

[7] Bhagat, S. K., Tung, T. M. & Yaseen, Z. M. 2020, Development of artificial intelligence for modeling wastewater heavy metal removal: state of the art, application assessment and possible future research. Journal of Cleaner Production 250, 119473. http://dx.doi.org/10.1016/j. jclepro.2019.119473.

[8] Tzoupanos, N. D. & Zouboulis, A. I. 2008, Coagulation-flocculation processes in water/wastewater treatment: the application of new generation of chemical reagents. In: 6th IASME/WSEAS International Conference on Heat Transfer, Thermal Engineering and Environment (HTE'08), August 20th–22nd, Rhodes, Greece, pp. 309–317.

[9] Ibrahim, A. 2019, Effect of the horizontal perforated plates on the turbidity removal efficiency in water treatment plant of Tikrit university. Tikrit Journal of Engineering Sciences 26 (4), 38–42.

[10] Choy, S. Y., Prasad, K. M. N., Wu, T. Y., Raghunandan, M. E. & Ramanan, R. N. 2014, Utilization of plant-based natural coagulants as future alternatives towards sustainable water clarification. Journal of Environmental Sciences 26 (11), 2178–2189. http://dx.doi.org/10.1016/j. jes.2014.09.024.

[11] Gippel, C. J. 1995, Potential of turbidity monitoring for measuring the transport of suspended solids in streams. Hydrological Processes 9 (1), 83–97.

[12] Jayalakshmi, G., Saritha, V. & Dwarapureddi, B. K. 2017, A review on native plant based coagulants for water purification. International Journal of Applied Environmental Sciences 12 (3), 469–487.

[13] Alavi, J., Ewees, A. A., Ansari, S., Shahid, S. & Mundher, Z. 2021, A new insight for real – time wastewater quality prediction using hybridized kernel – based extreme learning machines with advanced optimization algorithms. Environmental Science and Pollution Research 0123456789. https://doi.org/10.1007/s11356-021-17190-2.

[14] Iqbal, A., Hussain, G., Haydar, S. & Zahara, N. 2019, Use of new local plant-based coagulants for turbid water treatment. International Journal of Environmental Science and Technology 16 (10), 6167–6174.

[15] Al-Doury, M. M. I. & Alwan, M. H. 2019, Phenol removal from synthetic wastewater using batch adsorption scheme. Tikrit Journal of Engineering Sciences 26 (3), 31–36.

[16] Shihab, A. S. & Ahmad, A. M. 2020, Performance study of tube settlers in removing low turbidity from the Tigris river water using a bench scale model. Tikrit Journal of Engineering Sciences 27 (4), 1–7.

[17] Muthuraman, G. & Sasikala, S. 2014, Removal of turbidity from drinking water using natural coagulants. Journal of Industrial and Engineering Chemistry 20 (4), 1727–1731.

[18] Kumar, V. 2020, Partial replacement of alum by using natural coagulant aid to remove turbidity from institutional wastewater. International Journal of Integrated Engineering 12 (4), 241–251.

[19] Mehr, A. D. & Akdegirmen, O. 2021, Estimation of urban imperviousness and its impacts on flashfloods in Gazipasa, Turkey, Knowledge-Based Engineering and Sciences 2 (1), 9–17.

[20] Wan Mohtar, W. H. M., Abdul Maulud, K. N., Muhammad, N. S., Sharil, S. & Yaseen, Z. M. 2019, Spatial and temporal risk quotient based river assessment for water resources management. Environmental Pollution 248, 133–144. https://doi.org/10.1016/j.envpol.2019. 02.011.

[21] Kakoi, B., Kaluli, J. W., Ndiba, P. & Thiong'o, G. 2016, Banana pith as a natural coagulant for polluted river water. Ecological Engineering 95, 699–705. http://dx.doi.org/ 10.1016/ j.ecoleng. 2016.07.001.

[22] Chhipi-Shrestha, G., Beauchamp, N., Sadiq, R. & Rodriguez, M. 2020, Investigating unregulated disinfection byproduct reduction efficiencies in drinking waters using zirconium oxychloride, a novel coagulant. Journal of Water Process Engineering 37, 101496.

[23] Bina, B., Mahdinezhad, M. H., Nikaein, M. & Movahedian, A. H. 2009, Effectiveness of chitosan as natural coagulant aid in treating turbid waters. Iranian Journal of Environmental Health and Scientific Engineering 6 (4), 247–252.

[24] Asadollah, S. B. H. S., Sharafati, A., Motta, D. & Yaseen, Z. M. 2020, River water quality index prediction and uncertainty analysis: a comparative study of machine learning models. Journal of Environmental Chemical Engineering 9, 104599.

[25] Li, M., Cheng, J., Zou, F., Zhang, C., Wang, M., Li, Y., Gu, J. & Yan, M. 2020, Effects of pre-oxidation on residual dissolved aluminum in coagulated water: a pilot-scale study. Water Research 190, 116682. https://doi.org/10.1016/j.watres.2020.116682.

Print ISSN 2682-3993
Online ISSN 2682-4000

[26] Misbahuddin, M. & El-Rehaili, A. 1995, Phosphorus removal from trickling filter effluents by Fly Ash. Journal of King Saud University – Engineering Sciences 7 (2), 185–197. http://dx.doi.org/ 10.1016/s1018-3639(18)30626-3.

[27] Fatoki, O. S. & Ogunfowokan, A. O. 2002, Effect of coagulant treatment on the metal composition of raw water. Water SA 28 (3). http://dx. doi.org/10.4314/wsa.v28i3.4897.

[28] Elsayed, E. M., Nour El-Den, A. A., Elkady, M. F. & Zaatout, A. A. 2020 Comparison of coagulation performance using natural coagulants against traditional ones. Separation Science and Technology, 1–9. http://dx.doi.org/10.1080/01496395.2020.1795674.

[29] Lanan, F. A. B. M., Selvarajoo, A., Sethu, V. & Arumugasamy, S. K. 2020 Utilisation of natural plant-based fenugreek (Trigonella foenumgraecum) coagulant and okra (Abelmoschus escluentus) flocculant for palm oil mill effluent (POME) treatment. Journal of Environmental Chemical Engineering 9 (1), 104667.

[30] Bhatia, S., Othman, Z. & Ahmad, A. L. 2007, Coagulation–flocculation process for POME treatment using Moringa oleifera seeds extract: optimization studies. Chemical Engineering Journal 133 (1–3), 205–212. http://dx.doi.org/10.1016/j.cej.2007.01.034.

[31] Ravikumar, K. & Sheeja, A. K. 2012, Water clarification using Moringa oleifera seed coagulant. In: 2012 International Conference on Green Technologies (ICGT). IEEE, pp. 64–70.

[32] Salvato, J. A., Nemerow, N. L. & Agardy, F. J. 2003, Noninfectious and noncommunicable diseases and conditions associated with the environment, including air, water, and food. Environmental Engineering, 229–259.

[33] Šćiban, M., Klašnja, M., Antov, M. & Škrbić, B. 2009, Removal of water turbidity by natural coagulants obtained from chestnut and acorn. Bioresource Technology 100 (24), 6639–6643.

[34] Yin, C.-Y. 2010, Emerging usage of plant-based coagulants for water and wastewater treatment. Process Biochemistry 45 (9), 1437–1444. http://dx.doi.org/10.1016/j.procbio.2010.05.030.

[35] Abidin, Z. Z., Mohd Shamsudin, N. S., Madehi, N. & Sobri, S. 2013, Optimisation of a method to extract the active coagulant agent from jatropha curcas seeds for use in turbidity removal. Industrial Crops and Products 41, 319–323. http://dx.doi.org/10.1016/j.indcrop.2012. 05.003.

[36] Rak, A. E. & Ismail, A. A. M. 2012, Cassia alata as a potential coagulant in water treatment. Research Journal of Recent Sciences 1 (2), 28–33.

[37] Patale, V. & Pandya, J. 2012, Mucilage extract of Coccinia indica fruit as coagulant-flocculent for turbid water treatment. Asian Journal of Plant Science and Research 2 (4), 442–445.

[38] Okoro, B. U., Sharifi, S., Jesson, M., Bridgeman, J. & Moruzzi, R. 2021, Characterisation and performance of three Kenaf coagulation products under different operating conditions. Water Research 188, 116517.

[39] Al-Sulttani, A. O., Al-Mukhtar, M., Roomi, A. B., Farooque, A., Khedher, K. M. & Yaseen, Z. M. 2021, Proposition of new ensemble data-intelligence models for surface water quality prediction. IEEE Access 9, 108527–108541.

[40] Khaleefa, O. & Kamel, A. H. 2021, On The evaluation of water quality index: case study of Euphrates River, Iraq. Knowledge-Based Engineering and Sciences 2 (2), 35–43.

[41] Siswoyo, E., Tanjung, D. S. & Jalaly, M. J. H. 2021, Development of Natural Coagulant for Turbidity Removal Created from Marine Product Solid Waste. In: IOP Conference Series: Earth and Environmental Science. IOP Publishing, p. 12038.

[42] Nhut, H. T., Hung, N. T. Q., Lap, B. Q., Han, L. T. N., Tri, T. Q., Bang, N. H. K., Hiep, N. T. & Ky, N. M. 2021, Use of Moringa oleifera seeds powder as bio-coagulant for the surface water treatment. International Journal of Environmental Science and Technology 18 (8), 2173–2180.

[43] Nougbodé, Y. A. E. I., Agbangnan, C. P., Koudoro, A. Y., Dèdjiho, C. A., Aïna, M. P. Mama, D. & Sohounhloué, D. C. K. 2013, Evaluation of the Opuntia dillenii as natural coagulant in water clarification: case of treatment of highly turbid surface water. Journal of Water Resource and Protection 05 (12), 1242–1246. http://dx.doi.org/10.4236/jwarp.2013.512133.

[44] Ghawi, A. H. 2017, Using natural coagulant to remove turbidity and heavy metal from surface water treatment plant in Iraq. International Journal of Engineering Technology and Scientific Innovation 2 (1), 1851–2456.

Print ISSN 2682-3993
Online ISSN 2682-4000

[45] Zainol, N. A., Bakar, S. N. S., Zailani, S. N., Ghani, A. A. & Sohaimi, K. S. A. 2020, Surface Water Treatment with Natural Starches as Coagulant via Coagulation Process. In: IOP Conference Series: Materials Science and Engineering. IOP Publishing, p. 12048.

[46] Kim, B. M., Lee, H. Y. & Ahn, J.-H. 2020, Optimization of initial turbidity and coagulant concentration to remove turbidity using Moringa Oleifera seed. Journal of Korean Society of Environmental Engineers 42 (2), 47–54. http://dx.doi.org/10.4491/ksee. 2020.42.2.47.

[47] Xue, J., Peldszus, S., Van Dyke, M. I. & Huck, P. M. 2021, Removal of polystyrene microplastic spheres by alum-based coagulation/flocculation-sedimentation (CFS) treatment of surface waters. Chemical Engineering Journal 422, 130023.

[48] Kurniawan, S. B., Abdullah, S. R. S., Imron, M. F., Said, N. S. M., Ismail, N., Hasan, H. A., Othman, A. R. & Purwanti, I. F. 2020, Challenges and opportunities of biocoagulant/bioflocculant application for drinking water and wastewater treatment and its potential for sludge recovery. International Journal of Environmental Research and Public Health 17 (24), 9312.

[49] Sasikala, S. & Muthuraman, G. 2017, Turbidity removal from surface water by natural coagulants and its potential application. Iranica Journal of Energy and Environment. http://dx.doi.org/10.5829/idosi.ijee.2017.08.01.11.

[50] Choy, S. Y., Prasad, K. N., Wu, T. Y., Raghunandan, M. E. & Ramanan, R. N. 2016, Performance of conventional starches as natural coagulants for turbidity removal. Ecological Engineering 94, 352–364. http://dx.doi.org/10.1016/j.ecoleng.2016.05.082.

[51] Leiknes, T., Ødegaard, H. & Myklebust, H. 2004, Removal of natural organic matter (NOM) in drinking water treatment by coagulation– microfiltration using metal membranes. Journal of Membrane Science 242 (1–2), 47–55.

[52] Ge, J., Guha, B., Lippincott, L., Cach, S., Wei, J., Su, T.-L. & Meng, X. 2020, Challenges of arsenic removal from municipal wastewater by coagulation with ferric chloride and alum. Science of the Total Environment 725, 138351.