Modeling of Water Turbidity Parameters in a Water Treatment Plant

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Abstract

The high cost of chemical analysis of water has necessitated various researches into finding alternative methods of determining water quality. This paper is an attempt to model the turbidity value as a water quality parameter. Mathematical models for turbidity removal were developed based on the relationships between water turbidity and other water quality criteria. Results showed that the turbidity of water is the cumulative effect of the individual parameters and/or factors affecting the system. A model equation for the evaluation and prediction of the performance of a clarifier was developed.

\[ T = T_o \cdot \left( -1.36729 + 0.03710 \cdot 10^{\lambda \cdot \text{pH}} \ldots \right) 
\]

\[ + 0.048928 \cdot t + 0.00741387 \cdot \text{alk} \]

This model will aid the predictive assessment of water treatment plant performance. The limitations of the models are as a result of insufficient variable considered during the conceptualization.

Keywords: Performance evaluation, pH, alkalinity, mathematical model, simulation

Introduction

Water that is pure is not found in nature. Even water condensing in air contains solid and dissolved gases (Tebbutt 1983). According to Tchobanoglou and Burton (1991), waste from human activities either industrial or domestic introduce even more pollutant into water bodies; therefore treatment plants are clearly important to improve quality.

According to Tchobanoglous and Burton (1991), wastes from human activities, either industrial or domestic, introduce even more pollutants than any natural sources into water bodies. Since the available water seldom meets potable specifications, a treatment plant is clearly necessary to improve the water quality.

When online, a periodic review of plant performance is undertaken to ascertain if, or otherwise, the plant works according to prediction. Both of Hammer (1973) and Cairncross (1980) agree that record-keeping and periodic reviews of plant performance are necessary decision tools when the plant requires expansion or when operational problems arise.

The aim of this paper is to model water turbidity as a function of other parameters to assess the performance of a water treatment plant over a period of time and to suggest ways of improving plant performance.

Experimental

Determination of Temperature

The temperature of the sample of water was determined with the aid of thermometer, beakers, and electrodes. The water samples were collected in beakers and the thermometer display reading, which was allowed to be steady, was recorded.

Determination of Turbidity

This involves the use of turbidimeter. The sample cells were washed with sample water then filled with the same sample. The sides of the cells were wiped with a dry cloth.
The power source of the turbid meter was switch on and adjusted to read the turbidity in NTU. The cell holder was opened and the sample cell was placed in it and the lid replaced.

Determination of pH

The pH of the sample was determined with aid of colometric comparator. Two cells were rinsed with sample water and shaken, one cell was filled to mark “B” and 10 drops of indicator were added. The second cell was filled to mark “A” and placed in the comparator on the side marked “blank”. Sliding the colorimeter through the slot in the comparator until the colour in both cells appears identical. The number in the matching colour slot is the pH.

Determination of Total Alkalinity

The total alkalinity was determined by titration. The burette was filled with alkalimetric reagent up to the zero mark. 100 ml of water was transferred to a beaker and 4 to 6 drops of helianthin indicator were added. The color changes from pink.

Modeling for Turbidity Removal

For a constant flow rate and a fixed set of conditions the suspended solids and hence, turbidity removals, are a fixed fraction of inlet suspended solid. In accordance with Belan (1988), assuming that for mildly contaminated rivers the suspended solid is linear with turbidity i.e. that the particle size and type distribution are constant over a time period.

Then Turbidity removal

\[
\frac{T_0 - T}{T_0} = k_0
\]

Where \( T \) = turbidity of clarified water

\( T_0 \) = Turbidity of aerated water

\( k_0 \) = constant

Thus \( T = T_0 k' \)

These parameters has been established to exhibit independent and cumulative effect on T

Effect of Water Temperature

Water molecules and impurity particles are in thermal Brownian motion whose intensity is directly proportional to temperature (Nikoladze, et al. 1989). It is clear that the probability of collision of individual particles with one another and their consequent aggregation depends on their relative velocities i.e. on thermal Brownian motion and therefore, on water temperature.

Again, it may be assumed that the temperature within the clarifier is constant and is equal to that of the clarified water samples.

\[
\frac{T_0 - T}{T_0} \propto t
\]

Where \( t \) = temperature in °C

Effect of Alkalinity

Turbidity removal depends on the formation of chemical floc. The equation of the overall process as simplified by Hammer (1975) is

\[
Al_2(SO_4)_3 + 3Ca(HCO_3)_2 \rightarrow 2Al(OH)_3 + 3CaSO_4 + 6CO_2
\]

Obviously, good coagulation is dependent on the presence of sufficient alkalinity (HCO_3) and therefore

\[
\frac{T_0 - T}{T_0} \propto alk
\]

Where \( alk \) = alkalinity of water in mg/l as CaCO_3

Effect of pH

Suspended matters in water are surface-charged particles. It is the function of the coagulant to neutralize the charges. Different particles types have been seen to have a particular pH at which the net charge on them is zero and coagulation optimum (Nikoladze et al. 1989). This pH is the isoelectric point (pH_{ie}). A large difference between pH of the water medium and pH_{ie} confers greater anticoagulation properties. For clay and humus pH_{ie} = 7.1 and 7.0 respectively. This effect is confirmed by graphs obtained by Tebbutt (1983) where turbidity (color) removal is
reduced as the water pH deviates from an optimum value of about 7.0.

Therefore it can be concluded that
\[(T_0 - T)/T_0 \propto 1/(\text{pH} - \text{pHis}) \quad (5)\]

Assuming pH is as 7 then pH - 7 = ∆pH has a positive value.

\[(T_0 - T)/T_0 \propto 1/(-\Delta pH) \quad (6)\]

pH = - log[H⁺], therefore a more appropriate form of the equation would be

\[(T_0 - T)/T_0 \propto 1/10^{-\Delta pH} \quad (7)\]

An expression similar to this was used by Belan (1988) to express the lime dosage required to bring about a desired change in the pH of water to pH₀ of its contaminants.

Introducing constants into equations 3, 4 and 7
\[(T_0 - T)/T_0 = k_1/10^{-\Delta pH} \quad (8)\]
\[(T_0 - T)/T_0 = k_2t \quad (9)\]
\[(T_0 - T)/T_0 = k_3\text{alk} \quad (10)\]

The values of these constants may be determined using the least – square method for multiple regression, adapted from Stroud (1995).

The various effects of pH, temperature and alkalinity on turbidity removal may also be combined in a product and exponential manner since no evidence exists to suggest the relationship used. Following the same premise as before, a possible second model equation could also be developed.

\[T = k_0(T_0.10^{k_1 \Delta pH}, t^{k_2}\text{alk}^{k_3}) \quad (61)\]

Comparison of the models results indicates their extent of validity. The constants k₀, k₁, k₂, k₃ could be obtained from the solution of the 4 x 4 matrix generated.

The Polymath3, a software package was used to find the coefficients in both models (Himmelblau,1996). The developed models are presented below.

\[T = T_0 \cdot \left(1.36729 + 0.03710 \cdot 10^{k_1 \text{pH}} \ldots \right) + 0.048928 \cdot t + 0.00741387 \text{alk} \]

\[T = \left(2.20673 \cdot 10^{-11} \cdot T_0 \cdot 10^{0.045606 \text{pH}} \cdot 5.35007 \cdot \text{alk}^{1.55099}\right)\]

The graphical error analysis technique was then used as the criteria for selecting the ‘best-fit’ model.

Other factors, such as organic content, do exert influence on turbidity removal; so their contribution can be accounted for by the introduction of corrective coefficients.

Assuming that hydrodynamic conditions are approximately constant, the influences of temperature, pH and alkalinity on the turbidity of water in a clarifier basin maybe additive or multiplicative (Lucey 2000). However, a change in one will cause dis-equilibrium in the overall turbidity. Such changes may be accounted for by the various constants. Using the additive model

\[(T_0 - T)/T_0 = k_0 + k_1/10^{-\Delta pH} + k_2t + k_3\text{alk} \quad (11)\]

From which

\[T = T_0(1 - k_0 + k_1/10^{-\Delta pH} + k_2t + k_3\text{alk}) \quad (12)\]

1 – k₀ is a constant, say k₀

\[T = T_0(k_0 + k_1/10^{-\Delta pH} + k_2t + k_3\text{alk}) \quad (13)\]

Results

The results of the various experimental methods are as presented in Table 1.

Table 1. Experimental values of some water quality parameters

<table>
<thead>
<tr>
<th>Weeks</th>
<th>T₀</th>
<th>T</th>
<th>t</th>
<th>pH</th>
<th>alk</th>
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<tr>
<td>1</td>
<td>1.5</td>
<td>1.25</td>
<td>27.75</td>
<td>0.1</td>
<td>23.8</td>
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<tr>
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<td>1</td>
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<td>0.1</td>
<td>21</td>
</tr>
<tr>
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<td>1</td>
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<td>0.1</td>
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<tr>
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<td>1.5</td>
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<td>0</td>
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<tr>
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<td>0.1</td>
<td>23.29</td>
</tr>
<tr>
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<td>2</td>
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<td>0.4</td>
<td>23.75</td>
</tr>
<tr>
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<tr>
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<tr>
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<tr>
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<td>26.15</td>
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</table>

The simulated results from the models are presented in Fig. 1.
Discussion

Results from Table 1 shows that turbidity in the treated water fell short of standards (5NTU max.) on one occasion (5.75 NTU), but the mean value of 1.56NTU is well within the guideline values (WHO, 1985). The cause of this is most likely the high $T_o$ and the consequent overloading of the clarifier. This may also suggest that the clarifier was overdue for desludging.

Mathematical modeling of the clarifier’s performance based on additive and multiplicative models using the pre-determined parameters gave equations 1 and 2 respectively.

\[
T = T_o \cdot \left( -1.36729 + 0.03710 \cdot 10^{-3 \cdot pH} + 0.048928 \cdot t + 0.00741387 \cdot alk \right)
\]

\[
T = 2.20673 \cdot 10^{-11} \cdot T_o \cdot 10^{-0.045606 \cdot pH} \cdot t^{5.35007} \cdot alk^{1.55099}
\]

Simulation results of the models showed that model 1 to a large extent would give a better turbidity prediction. It showed also that factors affecting turbidity values are mainly independent in operation. The turbidity of water is the cumulative effect of the individual parameters/factors affecting the system.

From model 1, the change in turbidity caused by one of the independent variables is the cumulative effects of the individual contributions of $T_o$, t and alk. In model 2, the difference in turbidity is expressed as a synergy or interdependence of these variables. The nature of the model 1 equation gives turbidity change a dimensionless significance. Therefore, $k_2$ the coefficient of temperature ‘t’ will have a unit of $1/°C$. It could be defined as the change in ratio of inlet and outlet turbidity caused by changing the temperature of the clarifier by 1°C.

The Discrepancy between the experimental and simulated values could be attributed to the constraints in formulating the model discussed above. The number of variables considered was quite small; influence of human activities and contaminations’ had an impact on the coagulation and settling processes. These and many others need to be considered to enhance the reliability of the model.

Conclusion

A model equation was developed for the evaluation and prediction of the clarifier’s performance.

The limitations of the models are as a result of insufficient variables considered during the conceptualization.

References

Lucey, T. 2000. Quantitative Techniques, 5th ed. ELST?, NY,