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Assessment of Drinking Water Treatment, Disinfection and Disinfection by Products

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Abstract

Disinfection By-Products (DBPs) have heterogeneous structures, which are suspected carcinogens as a result of reactions between Natural Organic Matter and oxidants/disinfectants such as chlorine. Because of variability in DBPs characteristics, eliminate completely from drinking water by single technique is impossible and it have been considered as toxic contaminants of water. Disinfection By-product is another problem available in water supply treatment in the distribution system. The objective of this study was evaluating the performance of Jimma town water distribution networks of water treatment plant. Hence, the study was addressed, efficiency of conventional water treatment plant unit, chlorination and disinfection and disinfection by-product. To evaluate the water treatment plant simulation WatPro v4, tool was applied for disinfection and treatment plant performance. As per the discussion held with the Jimma water supply and sewerage authority and field visit, the major factors of water loss were identified. As per the calculation result, the treatment plant efficiency of the town was estimated as 69.75%. In case of giardia and viruses reduction (22.6% and 75.34%), that was the results obtained from the treatment plant simulation did not obey the surface water treatment rule. Despite its small amount, disinfection by products has been found in the town's water treatment plant. As per the calculation obtained; the contact time of the water system did not meet the contact time requirement because 0.476<1. In general, the current water distribution network and treatment plant of Jimma town were in poor performance and were not conducted adequate water to the various demand categories of the town. Hence, it is important to rehabilitate and the treatment plant of the town in order to fulfill the required need.

Keywords: Chlorination • Disinfection and Disinfection By-product • performance • treatment plant unit • Wat Pro v4

Introduction

The raw water from the surface water, lake or reservoir had been drawn into the plant through intake structure to be treated that delivered to the distribution system to reach or satisfy the customers. Mostly the major unit processes that make up the conventional treatments of surface water are the intake (screening; coagulation/ flocculation; sedimentation; filtration, and disinfection [1]. The coagulation and flocculation treatment unit process are used to remove color, turbidity, algae and other microorganisms from surface waters. The addition of a chemical coagulant to the water causes the formation of a precipitate, or flocs, which entraps these impurities. Iron and aluminum can also be removed under suitable conditions as coagulants, but the most commonly used coagulants are aluminum sulphate and ferric sulphate, although other coagulants are available and this coagulation categories as primary coagulants and coagulant aids. The primary coagulants are used to cause particles to become destabilized and begin to clump together which used, to add density to slow-settling flocs or toughness so that the flocs will not break up in the following processes. Salts of Aluminum or iron are the most commonly used coagulant chemicals in water treatment because they are effective, relatively low cost, available, and easy to handle, store, and apply. The common design parameters that affect the efficiency of coagulation are mixing intensity and detention time [2]. The common problems usually occur in coagulation process are under or over dosing, mixing of insufficient energy, fouling or clogging of injectors or diffusers and side reactions. Most of the time coagulation and flocculation inter counter as the pre-chlorination for surface water treatment plant and it may not be for ground water, whereas chlorination were common for both surface and ground water sources typically require disinfection to eliminate or inactivate microbiological populations. The application of disinfecting agents to a potable water supply has been practiced for over a century and was recognized as one of the most successful examples of public health protection. Historically, chlorine was the disinfectant used, but more recently, other chemicals such as chlorine dioxide, chloramines, and ozone have been used to purify water. Water treatment plants perform two kinds of disinfection (primary and secondary) disinfection and the primary disinfection achieves the desired level of

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microorganism kill or inactivation whereas, secondary disinfection maintains a disinfectant residual in the finished drinking water to prevent regrowth of microorganisms as water passes through the distribution system. Water treatment plants are use different chemicals for the two kinds of disinfection that might affect chemicals in the residuals and this primary disinfection occurs early in the source water treatment, prior to sedimentation or filtration [3]. Although no residuals are generated during this treatment step, the disinfectant used (e.g. chlorine) or disinfection by-products may be present in the WTP residual waste streams (e.g. filter backwash). Secondary disinfection occurs at the end of source water treatment, at the finished drinking water clear either well. This disinfection step is used to maintain a disinfectant residual in the finished drinking water to prevent regrowth of microorganisms but this process does not result in residuals generation; however, water from the clear well may be used to backwash filters [4]. As a result, disinfectant added to the finished drinking water may become part of the filter backwash. Chlorine and chloramines are effective secondary disinfectants and when chlorine is added to water, it produces nascent oxygen, which kills the bacteria which is cheap and most reliable and when dissolved it's in water, chlorine gas quickly forms Hypochlorous acid (HOCl), which in turn, dissociates into hypochlorite ion (OCl)

Materials and Methods

Study area description

The study area was found in Jimma town, which located at the distance of 3450 km west of Finfinnee at between 9°5'N and 36°33'E. Based on the 1:50,000 scale topographic map of the Ethiopian mapping authorities, the elevation of the town varies between 1760 and 2180 masl and with a total area of 3580 ha.

Existing water treatment plant

The existing Water treatment plant of Jimma town for drinking water is treated and then by the aid of water distribution networks it was conveyed to the consumers' points end. The design of the treatment plant was having pre-treatment unit of horizontal roughing filtration unit and rapid sand filtration unit [5]. The chemicals like alum, lime and chlorine were added to the water following its sequences (coagulation, flocculation, sedimentation, filtration and chlorination). One of the popular methods of disinfection used for the town water treatment is disinfection by chlorine which has a great power of killing the diseases causing organisms (pathogens) but chlorination has its own side effect by emerging disinfection by-product. Thus, instead of chlorine if chlorine dioxide is used the amount of disinfection by- product is hugely reduced (Figure 1).

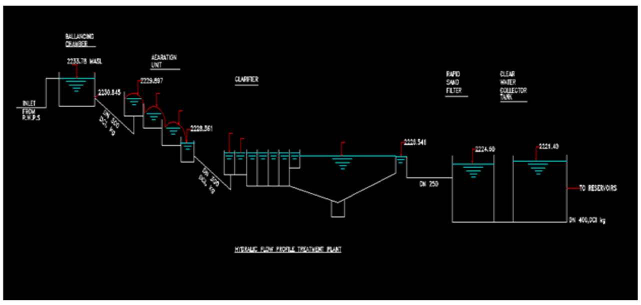

Figure 1. Jimma WTP layout.

Water treatment simulation: WatPro

WatPro is a useful program for analyzing and designing a water treatment system. With this program, an engineer can create a simulation of a water treatment plant and predict water quality given specific parameters [6]. It is a steady state water treatment modeling program, with a focus on disinfection and disinfection by-products. Although other aspects of water treatment processes are supported, these are of lesser significance within the package's scope. The information in this section is taken from the WatPro user guide. WatPro 4.0 used raw water quality parameters to simulate water treatment i.e. pH, turbidity, residual chlorine, and chemical dosages (e.g. Alum, ferric chloride, lime, ammonia) and design and operating characteristics of process tanks, WatPro accurately simulates plant operation. WatPro was required for simulation of water treatment to: identify the formation of DBPs (e.g. THMs, HAAs, chlorite, chlorate, calculate contact time for any location in the treatment system, and compare inactivation of viruses and Giardia by chlorine, ozone, chlorine dioxide and chloramines [7].

Input data used for treatment plant simulation

The necessary data that are required for drinking water treatment simulation are characteristics of water, water treatment plant layout, and chemicals requires. Those data were obtained from the office of Jimma town water supply office and used as an input for WatPro. The other data like water quality (PH, turbidity, residual chlorine) were taken from the laboratory technician of the town's water supply. According to the Jimma town water service office there is no sufficient laboratory equipment for the analysis of DBPs (TTHMs, HAA5s, chromite and the like) and no giardia and viruses problem occurred out there. However, this study was identified the existence of disinfection by-product and giardia and viruses by WatPro v4.0, using the data obtained from the Jimma town water service office.

Simulation and evaluation of disinfection processes

A water treatment simulation has been established for the disinfection (Chlorination) process in water treatment plant of the town [8-10].

The simulation of chlorination has been performed using the water treatment simulator WatPro v4 tool and the three-inactivation parameters have been designated by the simulator tool to assess the disinfection accomplishment: total giardia reduction, total virus reduction, total crypto reduction.

The advantages of simulation analysis are obtaining a useful method to establish a broad understanding of the operating performance of the disinfection process.

The quality of effluent treated water quality was employed to determine differences in water quality among the three processes. DBPs (THM and HAA) formation potentials in water effluents were used to discover the convenience of each disinfection process (Figure 2).

manganese as well as other organic constituents in the raw water, it cannot expect capacity of the clarifiers to hold more than this. However, only 2,846 m^3 of clean water every day in the distribution system (the current plant capacity). However, the treatment plant efficiency of the town can be estimated as below;

$$\text{plant efficiency rate} = \frac{\text{water consumed}}{\text{water produced}} \times 100$$

Results and Discussions

Performance of unit processes for water treatment plant

Flocculation: As per the design report document of DH Consultant, the total volume of flocculator for eight units was 720 m^3 and the detention time of the units was found to be 30 minutes. This time was found with in the maximum recommended design range of 20-30 minutes. Thus, flocculation time does not result flocs to settle and form scum on the walls and bottoms of the flocculator [13]. The mixing energy (velocity gradient) from the design report was 86.1 s^{-1}. It was exist within the recommended design range of 45-90 s^{-1}. The head loss of the entire unit was 0.098 m, which was less than 0.35-0.5 m design range. Thus, partial of the design parameters were within the recommended design ranges. This indicates that there was sufficient mixing and dispersion of coagulant chemicals with the raw water. By using the equation (2.2), the flocculation basin capability was found to be 34,560 m^3/d. This, shows that the capacity of flocculation was greater than the current maximum water demand of the town (34,560 m^3/d>6584.16 m^3/d). Therefore, Flocculation chamber exists in a good performance, which expressed in supplementary result obtained from WatPro v4 (Figure 3).

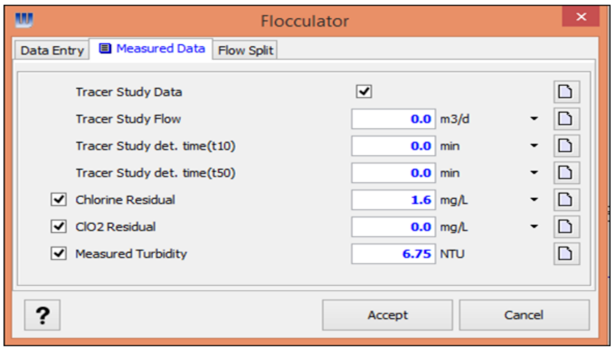

Figure 3. Data entry window of flocculator generated by WatPro 4.0.

Sedimentation

The two rectangular sedimentation basins have total surface area of 120 m^2. The detention time (from the design report) was 4 hours. This detention time was much higher than the design value 3 hours. This indicated the flocculated water spent more time than the required design and the plant was operated at around half of the design flow to the sedimentation basins. From the equation (3.10), sedimentation capability was found to be 3,000 m^3/d. This shows that the sedimentation basin performs less than that of the maximum day demand of the town (6584.16 m^3/d). Operators reported routine removal of sludge from sedimentation basins was not being practiced. The sludge was being removed once in three months' time. The sludge deposit in the settling basin was almost half of the total depth. This indicated that too much floc was being accumulated at the bottom of the basin for longer time and become septic causing the sludge to bulk. This could result short-circuiting that limits sedimentation performance. However, the result obtained from WatPro v4 simulator [14]. Therefore, proper adjustment of hydraulic loading and scheduling of the sludge removal cycle is essential [15-17].

Filtration

The filtration rate (from the design report of DH Consultant) was averaged 3.5 m/h this shows that the filters were operated at less than the recommended design loading rate 5-15 m/hr range. The lower filter-loading rate decreased the potential of filter performance. This means the filters could be operated at higher loading rates and they can produce more filtered water than the present quantity. From the equation (2.3), the filtration capability was 4,354.56 m^3/d. Hence, in case of cope up with the maximum water demand of the town filter basin was not perform in a good condition. Therefore, the proper adjustment of the filter loading rate and the capability of filtration is the most crucial in order to enhance the potential of filter performance and delivers the amount of water demanded by the town population [18].

Chlorine contact time

As per the information suggested under section (2.6 e) and using the equation (2.5), the result of chlorine contact time was 4.8 mg-min/l. Thus, the result was less than the required contact time of 6 mg-min/l. Therefore, the result shows that the chlorine added was poorly performed because chlorine contact time was less than the standard value i.e. 4.8>6 mg-min/l. This means to inactivate viruses and bacteria using free chlorine, the disinfection treatment required before the first customer must be at least 6 milligrams- minutes per liter (6 mg-min/L). Therefore, in case of disinfection by chlorine the chlorine contact time was not enough to inactivate pathogens since the contact time achieved was less than that of the contact time required mean that disinfection efficiency was poorly performed. Therefore, the required contact time value of 6 mg-min/l, it is necessary to adjust the free chlorine residual concentration or the chlorine contact time [19].

Contact tank

As per the information suggested under section (2.6 e) and by using the equation (2.5), the result of contact tank was 24 mg-min/l. Thus, this value shows that contact tanks were used a contact time of 24 mg-min/l to disinfect drinking water prior to distribution. Therefore, the required contact time for chlorine contact tank requires 24 mg-min/l to meet the disinfection efficiency.

Contact time for water system

As described clear under 2.7 sub sections and in equation (2.7), the result of inactivation ratio for water supply system of the town was 0.476. This shows that the value gained (inactivation ratio) was less than the contact time requirement (0.476<1) mean that disinfection efficiency of water system exists in poor condition. Accordingly, this value was complied with the surface water treatment rules i.e. inactivation ratio must be greater than 1 (one) to ensure contact time for water system efficient. Therefore, from such findings the water system did not meet the required contact time so that it performs poorly.

Existing plant efficiency

In the same way, as discussed under section (2.8) and equation (2.8), the result for the existing plant efficiency was 69.75%. This indicates that treatment plant of the town performs its duty at efficiency rate of 69.75%. Since the plant performs poorly, it is inevitable that the health life of the people exposed too many problems. Therefore, the existing treatment plant efficiency of the town is almost not in good performance to ensure the drinking water quality of the town.

Treatment requirements

According to the surface water treatment rules, all community and noncommunist public water systems that use a surface water source or a ground water, direct influence of surface water must achieve a minimum of 99.9% (3-log) removal and/or inactivation of Giardia cysts, and a minimum of 99.99% (4-log) removal and/or inactivation of viruses. However, as the result obtained from the treatment plant simulated by WatPro shows that the result obtained was lower than that of the standard stated above. Thus, result from the WatPro for Giardia reduction and/inactivation is 22.6% (log^{-3}) and for viruses removal and/inactivation is 75.34% (log^{-4}). Therefore, such result complies with the treatment requirements i.e. surface water treatment rule so that in case of giardia, viruses, and crypto inactivation and/removal the treatment plant of the town not exist in a good performance. Therefore, for various amount of disinfectants, the following are the results tabulated (Table 2).

Disinfect Dosage (mg/L)	Giardia Reduction (Log (10))	Virus Reduction (log (10))	Crypto Reduction (log(10))
6	22.5643	75.3254	2
6.09444	22.7747	75.3254	2
6.13889	22.9882	75.3254	2
7.58333	23.183	75.3254	2
9.02778	23.4024	75.3254	2
10.4722	23.6027	75.3254	2
11.9167	23.8055	75.3254	2
13.3611	23.9881	75.3254	2
14.8056	24.196	75.3254	2
16.25	24.3832	75.3254	2

Table 2. Inactivation.

Hence, from the above table it is the fact that the amount of disinfectant can affect the reduction and/inactivation of Giardia (log^{-3}) but for the reduction and/inactivation of viruses (log^{-4}) and for crypto reduction it is almost constant. Hence, it is advised that in order to increase the reduction/or inactivation of giardia the disinfectant dosage should be enhanced. The following graph (Figure 4 shows more details of the above statement).

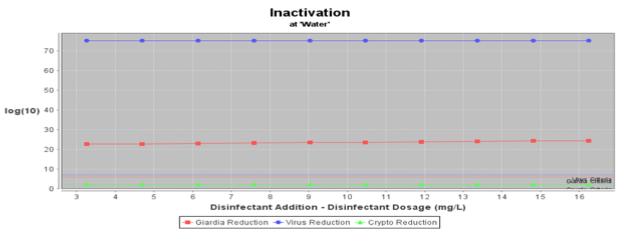

Figure 4. Inactivation graph.

Disinfection By-Product (DBP) formation

While chlorine has been effective for reducing most microbial pathogens to safe levels, it reacts with naturally occurring matter in the water to form Trihalomethanes (THMs) and Haloacetic Acids (HAAs) as Disinfection By-Products (DBPs).

Therefore, as the result obtained from the WTP simulation the values of those DBPs are tabulated as below (Table 3).

Disinfect Dosage (mg/L)	TTHMs (ug/L)	HAA5 (ug/L)	Chlorite (ug/L)
6	0.071695	1.45429	0
4.09444	0.082012	1.92986	0
6.13889	0.090041	2.3829	0
7.58333	0.096706	2.82023	0
9.02778	0.102097	3.249404	0
10.4722	0.106796	3.66928	0
11.9167	0.110798	4.08421	0
13.3611	0.114425	4.4929	0
14.8056	0.117346	4.901108	0
16.25	0.120056	5.30447	0

Table 3. DBPs.

From the Table 3, the result (numerical value) of disinfection by product tabulated indicates that there was the existence of disinfection by product (disease causing pathogens) in treatment plant of the town. Thus, as the disinfectant dosage increases the value of Trihalomethanes and Haloacetic acid increases except that of chlorite. So that their (disinfection by-product) existence may causes many effects on the health life of the population. Therefore, the performance of treatment plant of the town did not exist in a good manner to treat drinking water to keep the health life of the people. For more precise the above table was illustrated by the following graph (Figure 5).

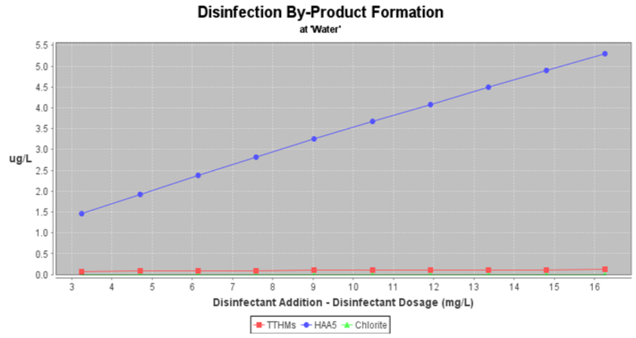

Figure 5. DBPs graph.

The ongoing implemented treatment processes including chlorination have been evaluated and simulated using WatPro 4.0 simulator for JWTP. Treatment processes evaluation was based on DBPs generation potential and disinfection effectiveness. Output summary for the treated water was presented in Figure 6. Health risk factor made DBPs have highest criteria values. Hence, DBPs generation potential is crucial in the safety of water disinfection assessment mandates.

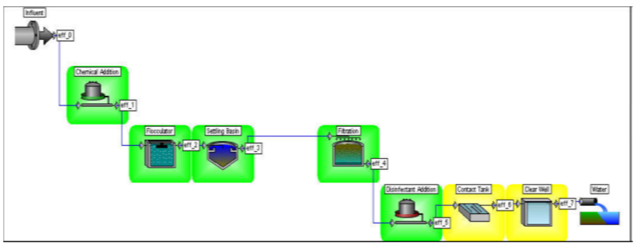

Figure 6. Water treatment steps of JWTP using process simulator WatPro 4.0

Effluent treated water quality obtained through the simulation of current chlorination process shows that this disinfection technique may involve serious flaws. Operation conditions like temperature, pH and contact time may have considerable influence on the disinfection success of chlorination respecting pathogens elimination. Regarding to DBPs generation, these factors have low or no significant impacts. The temperature of the treated water was considered 20°C for simulation purposes during all treatment plant steps. Moreover, the water treatment simulator software WatPro v4 has no temperature and time retention control tool specific for chlorination contact tank.

Conclusion

The current capacities of raw water pumps deliver the water to the treatment plant was 2851.2 m^3/d. In contrarily the current maximum water demand of the town was 6584.16 m^3/d.

This shows that the current raw water pump capacity did not satisfy the required peak daily water demand of the town.

The major capability of unit process of the treatment plant was found. However, except that of sedimentation and filtration basin (their capacity is less than the current peak daily demand i.e. 3000 $m^3/d < 6584.16$ m^3/d and 4354.56 $m^3/d < 6584.16$ m^3/d) the other units have enough capacity because their capabilities greater than the current maximum day demand of the town.

The contact time of water system of the town was found that it is less than that of inactivation ratio i.e. 0.467<1.

Thus, this indicates that less effective measurements of disinfection process.

The treatment plant performs its duty at a rate of 69.75%; this indicates that the existing treatment plant efficiency of the town is almost not in a good performance to ensure the drinking water quality of the town. The disinfection by-product was formed in water distribution system since the chlorine is used in treatment plant. Inactivation and/removal of giardia and viruses computed were less than that of the surface water treatment rule standards. In general, it was summarized that the current water distribution network and treatment plant of Jimma town was in poor performance and did not conducted adequate water to the various demand categories of the town.

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