Household Scale Clean Water Disinfection Technique with Chlorination Method

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Abstract- Disinfection is preventive efforts against the entry of pathogenic bacteria to the human body. Chlorination is one effort to give prevention with chlorine. The research objective was to determine of diffusion and mass transfer coefficients and then to develop of a chlorinated tool model. Effect of water flow rate on chlorine transport and granule size was studied to develop their relationship. The flow rates discharge used were 8 liters/minute, 14 liters/minute, and 20 liters/minute, whereas the granule sizes were 2.36 – 4.75 ml, 4.75-9.5 ml, and 9.5 - 16 ml. Diffusion coefficients and mass transfer determined by least summed of square of error. Diffusion coefficient and mass transfer used for disinfection technique was 0.4371 cm^2 $minute^{-1}$ and 0.0039-$minute^{-1}$, as well as flow rate and granule size used was 9.5 ml - 16 ml and 8 liters/minute. Experiment testing of chlorination performed to ensure of them was potentially for chlorination. Raw water chlorinated then was found of free chlorine residual and the total coliform met the quality standards based on regulation the Ministry of Health of Republic of Indonesia's number 416 of 1990 about the terms of supervision and the quality of water.

Key word: Disinfection, chlorine, total coliform, breakpoint chlorination.

1. Introduction

Disinfection is a process of annihilating microorganism which causes disease. Referring to Said (2007) disinfects which a stronghold of humans against exposure by pathogenic microorganism that caused diseases, including those viruses, bacteria and parasitic protozoan. One of them, disinfect of microorganism is being conducted by chlorine. Referring to Cheriaa et al. (2011), chlorine killed *Pseudomonas aeruginosa* effectively when the clarification process had done. Referring to Wang et al. (2010), *Escherichia coli*and *Legionella beliardensis* lost the integrity of their cell membranes at lower chlorine concentrations by chemical method. Referring to Wojcicka et al. (2007), *Brevundimonas vesicularis, Pseudomonas fluorescens,* and *Sphingomonas paucimobitis* were susceptible by chloramines as a byproduct.

Law of mass conservation declared that mass was not being created nor destroyed. Referring to Welty et al. (2004), summed between the rate mass accumulation and difference rate flux mass moved out and entered was zero. Mass in undergoes diffusion, advection and transfers mass during the process of transport (Doreswamy et al. 2012). The transport process of mass can be written as equation (1) (Zhi et al. 2004; Azarpazhooh and Ramaswamy 2010; Setyadji 2011).

$$\frac{\partial C(t)}{\partial t} = -\vartheta \frac{\partial C(t)}{\partial x} + D\frac{\partial^2 C(t)}{\partial x^2} - kC(t) \qquad (1)$$

υ as flow rate (cm/s); *D* as diffusion coefficients (cm^2 minute); *k* as mass transfer coefficients ($minute^{-1}$); *C*(*t*) as concentration (grams cm^{-3}).

An equation (1) was solved numerically by finite difference method (Mahreni and Mulyani 2002; Siswani and Kristianingrum 2006; Costa et al. 2010).

$$\frac{\partial C(t)_i}{\partial x} = \frac{C(t)_{i+1} - C(t)_{i-1}}{2.\Delta x} \qquad (2)$$

$$\frac{\partial^2 C(t)_i}{\partial x^2} = \frac{C(t)_{i+1} - 2.C(t)_i + C(t)_{i-1}}{\Delta x^2} \qquad (3)$$

Referring to Setyadji (2011), equation (2) and (3) substituted to equation (1) and its obtained equation (4).

$$\frac{\partial C(t)_i}{\partial t} = [\alpha + \beta]C(t)_{i+1} - [2.\beta + k]C(t)_i - [\alpha - \beta] \qquad (4)$$

For, $\alpha = -\frac{\vartheta}{2.\Delta x}$ and $\beta = \frac{D}{\Delta x^2}$

For i = 1 was being used as initial condition.

$C(t)_1$ (x, t = 0) = C_0

For i = N (finite) was being used as boundary condition

C(t) (x, t) = finite

$$\frac{\partial C(t)_i}{\partial t} = 0 \qquad (5)$$

$$\frac{\partial C(t)_i}{\partial x} = \frac{C(t)_{i+1} - C(t)_{i-1}}{2.\Delta x} = 0 \qquad (6)$$

$$C(t)_{i+1=} C(t)_{i-1} \qquad (7)$$

Equation (7) substituted to equation (4) have met an equation (8) and (9) (Setyadji 2011).

$$\frac{\partial C(t)_i}{\partial t} = (2.\beta)C(t)_{i-1} - [2.\beta + k]C(t)_i \qquad (8)$$

$$C(t)_{i+1} = C(t)_i + \Delta t[(2.\beta)C(t)_{i-1} - (2.\beta + k)C(t)_i] \qquad (9)$$

C as concentration is proportional between chlorine's weights and volume of chlorine's chamber (*V*), and can be written equation (10).

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$$w(t)_{i+1} = w(t)_i + \Delta t\,[(2\beta)\,w(t)_{i-1} - (2\beta + k)\,w(t)_i] \quad (10)$$

w is weights of chlorine (grams); Δt is flow periods (minutes).

The best value of diffusion and mass transfer coefficients obtained by least sum of square of error (Budi and Sasongko 2009; Makhtur et al. 2012). The result of determine was used to develop of a chlorinated tool model.

2. MATERIAL AND METHODS

2.1 Material and Instruments

The materials and instruments used during the laboratory experiments were chlorine tablets with ingredients 60% -70% , pure water (sterilized aqua), DPD (N,N-diethyl-p-phenylenediamine), chlorine's granules were 2.36 mm – 4.75 mm, 4.75 mm – 9.5 mm and 9.5 mm – 16 mm. Chlorine pipe chamber whose diameter of ¾ inch (Figure 1), chlorine meter [HACH], oven [Memmert], water-pump by Shimizu 266 BIT, reservoir, analytical balance [Sartorius; DJ series], PVC pipes, PVC fittings, hand hacksaw, laboratory glasses, and personal computer with excel and AutoCad applications.

Figure 1 Chlorine pipe chamber

2.2 Data Collected and Method

This study was carried out in December 2013 to June 2014. Series of the measurements were carried out at the Environmental Engineering laboratory of Department of Civil and Environmental Engineering IPB and Rightful Technology laboratory in Jakarta Technical Laboratory for Environmental Health and Disease Control. Data was collected to analyze for chlorination technique. Data collected were weights of chlorine, the total coliform as MPN index/100 mL of water, and free chlorine as mg/L of Cl_2. The method is presented in Figure 2.

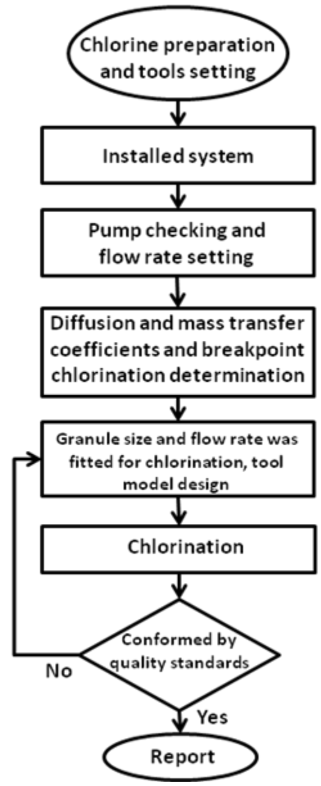

Figure 2 Method of the chlorination technique research

2.3 Experimental Procedure and Analysis

Pump discharges were arranged by valve to 8 liters/minute, 14 liters/minute and 20 liters/minute. Raw water was distributed by pumps to the chlorine pipe chamber (Figure 3).

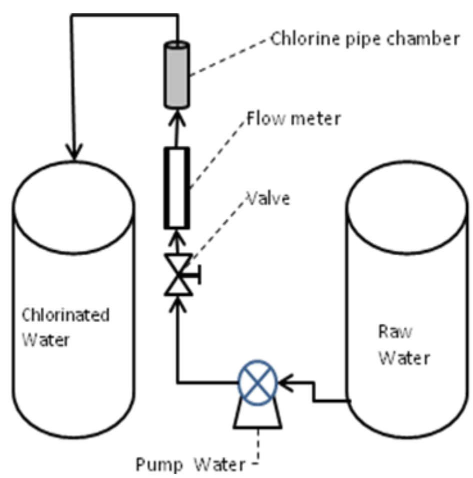

Figure 3 Flow chart of chlorination

First step, the empty chlorine pipe chamber was weighed, then put in as much of chlorine for each pipe and weighed it. Next step, the chlorine pipe chamber was installed such Figure 3. First chamber had been draining for 10 minutes, second chamber for 20 minutes and the last one for 30 minutes. Theirs dried for 24 hours then their weighed.

Diffusion and mass transfer coefficients were obtained by computation, which used solver application in Microsoft

Windows 2007. The best value was based on least sum of square of error (SSE). An equation of SSE can be written as equation (11) (Budi and Sasongko 2009; Makhtur et al. 2012).

SSE = [Simulat

Besides, the data collected to obtain a relationship of chlorine's remains percentage and time's series. Chlorine of weights remains a percentage can be written as equation (12).

Chlorine weigh

Table 1 Determination result of diffusion (*D*) and mass transfer coefficients (*k*) on rate discharges and granule sizes

Rate discharge (liter/minute)		flow periods (minutes) 10	20	30	Sum Square Error	*D* (cm^2 $minute^{-1}$)	*k* ($minute^{-1}$)
Granule size was 9.75 mm – 16 mm.							
8	Simulation (g)	9.94	10.02	7.35	-	0.4371	0.0039
	Experiment (g)	10.07	9.57	7.64	-		
	Error square	0.0172	0.2059	0.0826	0.3057		
14	Simulation (g)	8.92	8.77	8.02	-	0.4804	0.0048
	Experiment (g)	8.95	8.64	8.09	-		
	Error square	0.0009	0.0167	0.0045	0.0221		
20	Simulation (g)	7.78	7.22	5.83	-	0.6861	0.0073
	Experiment (g)	7.76	6.76	6.13	-		
	Error square	0.0002	0.2162	0.0910	0.3074		
Granule size was 4.75 mm – 9.75 mm.							
8	Simulation (g)	9.65	8.57	7.15	-	0.5935	0.0086
	Experiment (g)	9.67	8.34	7.29	-		
	Error square	0.0003	0.0544	0.0194	0.0741		
14	Simulation (g)	6.76	3.83	1.16	-	0.6755	0.0340
	Experiment (g)	6.73	3.81	1.22	-		
	Error square	0.0006	0.0004	0.0031	0.0042		
20	Simulation (g)	6.37	2.90	0.67	-	0.5552	0.0388
	Experiment (g)	6.32	2.85	0.87	-		
	Error square	0.0022	0.0021	0.0393	0.0437		

$w(t)_{i+1}$ was obtained by equation (10) and $w(t)_0$as initial weights.Breakpoint chlorination (BPC) curve which depicts relationships between dosed and the measured chlorine was made to effective chlorine dosage. Chlorine powder weighed was 0.05 grams and then was diluted by sterilized pure water. Solution was sampled to determine those concentrations and then volume as much as 1, 2, 3, 4, 5, 6 and 7 mL of solution and was put into 200 mL of raw water. Chlorinated water was allowed to 30 minutes (WHO 2004) and then was determined of chlorine concentrations.

Chlorine needed was calculated to add in a reservoir by equation (13).

$$BPC\ (gr) = \frac{V x\ [C]}{0.2}\ x\ Q\ x\ \Delta t\ x\ 2.02\ x\ 10^{-3} \qquad (13)$$

V as volume of dosage (liters); [*C*] as concentration of chlorine's solution (mg/L); *Q* as flow rate discharge (liters/ minute); Δt as flow periods (minutes); 2.02 as inversely proportional to molecules weights $Ca(OCl)_2$ and Cl_2.

Chlorination experiment was performed on flow rate discharge and granule size which potential for chlorination technique. Pump used was 14 liters/minute which was based on average rate of public dischargeand it had been working for 30 minutes. Chlorine weight needed was controlled by control charts. The control charts included were breakpoint chlorination (BPC) (equation 13), chlorine weights remain (equation 10), chlorine transported, and maximum chlorine added. Chlorinated water was sampled to measure of residual free chlorine and total coliform.

3. RESULT AND DISCUSSION

3.1 Determination of diffusion coefficient (*D*) and mass transfer coefficient (*k*)

Granule size was 2.36 mm - 4.75 mm							
Rate discharge (liter/minute)		flow periods (minutes)			Sum Square Error	*D* (cm^2 $minute^{-1}$)	*k* ($minute^{-1}$)
		10	20	30			
8	Simulation (g)	3.68	1.18	0.15	-	0.5350	0.0517
	Experiment (g)	3.56	1.27	0.45	-		
	Error square	0.0147	0.0084	0.0894	0.1125		
14	Simulation (g)	1.77	0.60	-0.11	-	0.3610	0.0751
	Experiment (g)	1.42	0.64	0.14	-		
	Error square	0.1236	0.0012	0.0645	0.1893		

The result of computation on mass transfer coefficients (*k*) rose when flow rate discharge was increased. Mass transfer was occurred of chlorine to soluble or reacts within water (Rohim 2006; Said 2007; Sarbatly and Duduku 2009; Setiawan et al. 2013) and also was eroded by water or both of them. Transport of mass was strongly influenced by flow rate discharge (Welasih 2006). Table 1 shows the coefficients of mass transfer up within granule size was decreased.

Diffusion coefficient (*D*) rose when flow rate discharge had risen for granule of 9.5 mm – 16 mm and fluctuated for 4.74 mm – 9.5 mm, thus down for 2.36 mm – 4.75 mm. A coefficient diffusion affected by temperature, pressure, substances compound, and nature of solvent (Mortimer 2008). Referring to Connell (1993), coefficient diffusion was inversely proportional to the diameter of molecules and the others declared as a root square of molecule's weights. Referring to Wati and Budiman – Sastrowardoyo (2007), density was inversely proportional to the diffusion coefficient. Table 1 shows the coefficients of mass transfer increases and it the meanings of chlorine transfer rises. Chlorine transported from solids to liquids in chlorine pipe chamber, and it was causing of density increased. Thereby, diffusion coefficient declined.

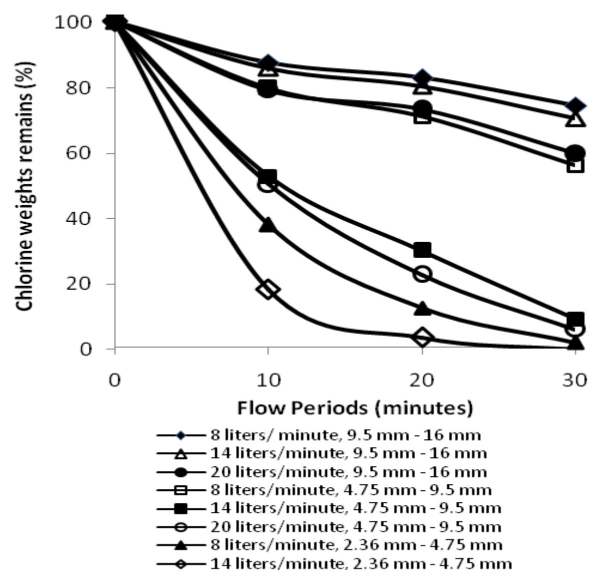

Figure 4 Percentage of chlorine weights remains on influenced by flow rate discharge and granule size.

3.2 The influence of flow rate discharges and granule sizes on weight change

Figure 4 shows of chlorine weights remain declines when water flow rate discharge rises for common granule size. Flow rate discharge is multiplying between the velocity and crossed sectional square. So, flow discharge rises to causes velocity increases. Change velocity generates momentum whose makes forces (Geankoplis 1993). Forces made chlorine eroded. Besides, chlorine is soluble or reacts within part of water (Patnaik 2002). Flow discharge of water rose to make chlorine's weight declined. It's caused more freshly water was solved.

Figure 4 shows of granule size's declines when chlorine's weights increases for common flow rate discharge. Surfaces area increased when granule size was being shrinking. Referring to Geankoplis (1993), Surfaces area increased that caused of collision regions was enlarged. Consequently, chlorine fragmentation was being formed and carried off by water. The rate of flux out mass is strongly influenced by region's space contact (Welty *et al*. 2004).

3.3 Chlorination and Prototype Tool Design

Chlorine needed as disinfect was determined by breakpoint chlorination (BPC). Referring to Rosyidi (2010), BPC was accomplished by chlorine addition which to oxidized all of water compounds included of ammonia to convert nitrogen gases (Figure 5). Consequently, chlorine was declined.

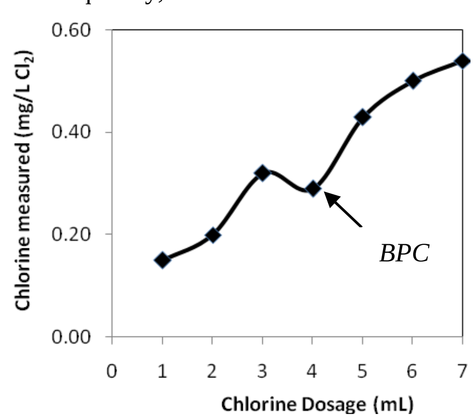

Figure 5 Breakpoint chlorination of raw water

Chlorine required for breakpoint chlorination (BPC) was calculated by equation (13). Dosage used was 4 mL or 0.004 liters that it acquired 0.51 grams of chlorine to a reservoir filled by flow rate discharge 14 liters/minute during 30 minutes. Referring to White (2010), if chlorine added when it had been exceeding of BPC point, the next addition of chlorine to result up free chlorine residual (FCR) linearly. Figure 6 was shown of experiment resulted which it was exceeded.

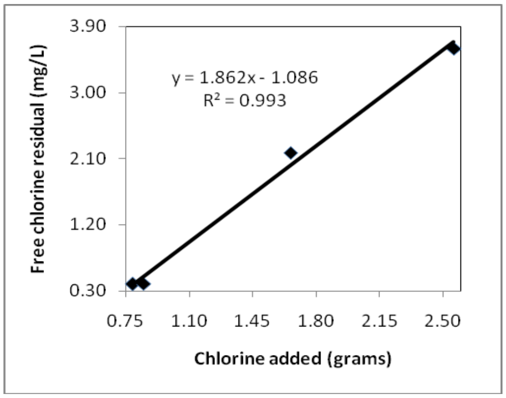

Figure 6 Chlorine added when it had been exceeding of BPC point.

The positive linear correlation has R-Sq value 99.33% and their correlation has value of 0.9967. Referring to Ministry of Health of Republic of Indonesia (1990), maximum FCR value is 0.5 mg /L. Result of interpolation with maximum chlorine added was 0.8518 grams so FCR was being fulfilled.

Chlorination experiment was performed which potentially used of chlorine's granules and flow rate discharge. There was 9.5 mm – 16 mm and 8 liters /minute. Theirs slightly shrank of chlorine's weights. Second, trends linearly graph was extrapolated to equation (10) (Figure 8), so that the ratio of raw water and chlorine added was leveling off. Chlorination experiment carried out of rate discharge on 14 liters/minute. Consequently, chlorine pipe chamber has been modified (Figure 7) and error rate level was obtained on Table 2.

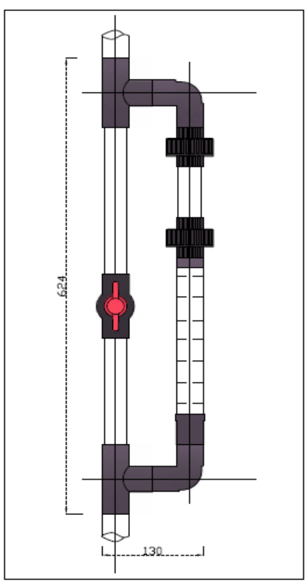

Figure 7 Prototype of chlorination tool model, code of AYH-01

Table 2 Error rate level of prototype model

No	Chlorine's weight remains		Error
	Simulation	Experiment	(%)
1	2.38	2.42	1.65
2	2.27	2.21	2.71
3	2.34	2.28	2.63
Average of error (%)			2.33

Control chart of chlorination was made by computation (Figure 8). Chlorine transported was obtained by difference of chlorine's weights between initial and remains. Initial weight used was 3.06 grams of chlorine.

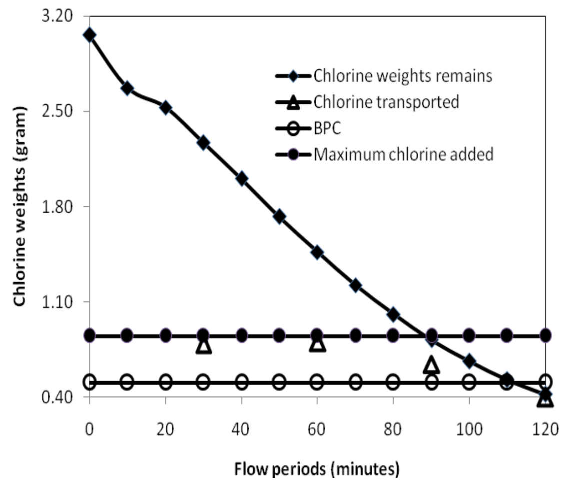

Figure 8Control chart of chlorination by initial weights was 3.06 grams of chlorine.

Free chlorine residual measured was 0.40 mg/L and the total coliform was zero. Chlorine transported to a reservoir calculated was 0.85 grams that conformed by maximum chlorine added. Chlorine transported to a reservoir between at 90 to 120 minutes was not exceeded of BPC's point, but these conditions still had formed chloramines. The disinfection of bacteria was succeeded by chloramines (Li et al. 2005; Wojcicka et al. 2007). Referring to Said (2007), chloramines were killed bacteria, but it was less powerful compared by free chlorine.

Raw water added a lot of bacteria and then sampled contain 1600 per 100 mL of water. Furthermore, the total coliform was zero when it had chlorinated. Initial weights used 3.16 grams of chlorine and it transported to the reservoir was 0.88 grams which it exceeds on maximum chlorine added in, even though FCR found was 0.39 mg/L. It caused difference both of chlorine transported between added and no added of bacteria used to kill them.

4. CONCLUSION

The conclusions of this research are:

1. Granule size of 9.5 mm – 16 mm and 8 liters/minute as well as a prototype of the AYH-01 model recommended for disinfection technique.
2. The error rate of the prototype model was 2.33%.

3. Chlorinated water met by the standard based on Ministry of Health of Republic of Indonesia' number 416 of 1990 about the terms of supervision and the quality of water.

REFERENCES

[1] Azapazhooh E; Ramaswamy HS. 2010. Evaluation of diffusion and azuara models for mass transfer kinetics during microwave osmotic dehydration of apples under continuous flow medium-spray conditions. Drying Technology. 28(1): 57 - 67

[2] Budi FS & Sasongko SB. 2009. Koefisien transfer massa pada proses ekstraksi kayu manis (Cinnamomum Burmanni). Jurnal Reaktor. 12(4): 232 – 238.

[3] Cheriaa J, Abouda Y, Rouabhia M, Nefzi M, Bakhrouf A. 2011. Efficiency of primary chlorination, clarification and final disinfection on Pseudomonas aeruginosa under laboratory conditions in raw water. Journal of Water Supply. 60(2): 101–108.

[4] Connell DW, Miller GJ. 1995. Kimia dan Ekotoksikologi Pencemaran. Koestoer Y, penerjemah; Sahati, Editor. Jakarta (ID): Penerbit Universitas Indonesia.

[5] Costa DP, de Matos Silva F, Romualdo KV, da Silva Neto AJ, Câmara LDT. 2010. International Review of Chemical Engineering (I.RE.CH.E.). Special Section on "XIII Computational Modeling Meeting. 2(6): 772-778.

[6] Doreswamy HS, Janardhan RCL, Sudheendra SR. 2012. An Analytical Solution of One-dimensional Advection-Diffusion Equation in a Porous Media in Presence of Radioactive Decay. Global Journal of Pure and Applied Mathematics. 8 (2): 113-124.

[7] Geankoplis CJ. 1993. Transport Processes and Unit Operations. Third Edition. New Jersey (USA): Prentice – Hall International Inc.

[8] Li L, Kaymak B, Haas CN. 2005. Validition of batch disinfection kinetics of Escherichia coli inactivation by monochloramine in a continous flow system. Environmental Engineering Science. 22(5): 567 – 5777.

[9] Mahreni, Mulyani S. 2002. Pemodelan sistem ekstraksi padat cair tipe unggun tetap. Seminar nasional Fundamental dan Aplikasi Teknik Kimia 2002; 31 Oktober – 1 November 2002; Surabaya. Indonesia. Surabaya (ID): ITS. hal 1-8.

[10] Makhtur AK, Rahul, Majumders CB; Gautam SB; McNaught J. 2012. Modelling and kinetic aspect of a BTEX contamined air-treating biofilter. International Journal of Environmental Studies. 69(3): 475-489.

[11] Mortimer, RG. 2008. Physical Chemistry. Third Edition. California (USA): The Benjamin/Cummings Publishing Company, Inc.

[12] Patnaik P. 2002. Handbook of Inorganic Chemicals. New York (USA): McGraw-Hill.

[13] Rohim M. 2006. Analisis penerapan metode kaporitisasi sederhana terhadap kualitas bakteriologi air PMA [tesis]. Semarang (ID): Universitas Diponegoro.

[14] Said NI. 2007. Disinfeksi Untuk Proses Pengolahan Air Minum. Jurnal Air Indonesia. 3(1): 15 – 28.

[15] Sarbatly RHJ, Duduku H. 2007. Free chlorine residual content within the drinking water distribution system. International Journal of Physical Sciences. 2(8): 196 - 201.

[16] Setiawan D, Sibarani J, Suprihatin IE. 2013. Perbandingan efektivitas disinfeksi kaporit, Hidrogen Peroksida dan Pereaksi Fenton (H_2O_2/Fe^{2+}). Jurnal Cakra Kimia. 1(2): 16 – 24.

[17] Setyadji M. 2011. Model matematika penentuan koefisien perpindahan massa dan difusivitas aksial Zirkonium pada proses adsorpsi secara fixed bed kromatografi. Prosiding Seminar Nasional ke-17 Teknologi dan Keselamatan PLTN serta Fasilitas Nuklir; 01 Oktober 2011; Yogyakarta. Indonesia . Yogyakarta (ID): hal.622 -633.

[18] Siswani ED, Kristianingrum S. 2006. Penentuan koefisien perpindahan massa pada ekstraksi minyak kemiri (lewat model matematika). Jurnal Kimia. 5(5): 41 – 49.

[19] Wang Y, Claeys L, der Ha DV, Verstraete W, Boon N. 2010. Effects of chemically and electrochemically dosed chlorine on Escherichia coli and Legionella beliardensis assessed by flow cytometry. Appl Microbiol Biotechnol (2010). 87:331–341.

[20] Wati, Budiman - Sastrowardoyo P. 2007. Difusi Cobalt dalam Na-Bentonit dan Ca-Bentonit. Jurnal Teknologi Pengolahan Limbah. 10(2): 53 – 61.

[21] Welasih T. 2006. Penentuan koefisien perpindahan massa liquid solid dalam kolom packed bed dengan metode adsorpsi. Jurnal Teknik Kimia. 1(1): 15 – 20.

[22] Welty JR, Wicks CE, Wilson RE, Rorrer G. 2004. Dasar-dasar Fenomena Transport. Volume ke-1. Gunawan P. penerjemah; Lemeda S. editor. Jakarta (ID): Penerbit Erlangga. Terjemahan dari: Fundamentals of Momentum, Heat, and Mass Transfer. Ed ke-4.

[23] [WHO] World Health Organization. 2004. Guidelines for drinking water quality. Third Edition. Volume 1. Geneva.

[24] Wojcicka l, Hofmann R, Baxter C, Andrews RC, Auvrey I, Liere J, Miller T, Chauret C, Baribeau H. 2007. Journal of Water Supply. 56(2): 137 – 150.

[25] Zhi QD, Singh VP; Bengtsson L. 2004. Numerical solution of fractional advection-dispersion equation. Journal of Hydraulic Engineering. 130 (5): 422-431

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