VOL. 8, NO. 3, MARCH 2013 ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences

www.arpnjournals.com

FACTORS EFFECT TO THE SULFIDE GENERATION RATE IN THE TO LICH RIVER, VIETNAM

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ABSTRACT

In this paper, the water quality index (WQI) was used as an indicator to assess the pollution level of the water quality in the To Lich River. The comparison of most important factors on the sulfide generation in the open channel and pipe sewers system was presented. The result also denoted that the close relationship between Oxygen - Redox Potential (ORP) values and log {$[S^{2-}]/[SO_4^{2-}]$} by correlation coefficient $R^2 = 0.6369$. And surface water layer was the main source of To Lich River to produce sulfide by Sulfate Reducing Bacteria (SRB). The factors to affect the sulfide generation rate in the To Lich River (open channel) were organic matter (BOD_5), and environmental conditions such as ORP, pH, and temperature (T). The found model in this study for estimating the sulfide generation from the To Lich River depended on the variables such as: ORP, T, pH, BOD_5, with the correlation coefficient $R^2 = 0.9619$, as follows:

$[S^{2-}] = 0.0063 * ORP + 0.0427 * T - 4.371 * pH - 0.0012 * BOD_5 + 31.87$

Keywords: hydrogen sulfide, sulfide generation, sulfide built-up, wastewater, To Lich River.

INTRODUCTION

Hydrogen sulfide (H_2S) is a highly toxic, flammable, colorless gas that is heavier than air. H_2S is a toxic gas at relatively low concentrations and a source of odor nuisance (Beauchamp *et al*., 1984; Teodora, 1992; Guidotti, 1996; Hvitved-Jacobsen, 2001; Michael, 2003). It is produced naturally by decaying organic matter and is also a by-product of many industrial processes. H_2S generation is one of the most serious phenomena occurring during wastewater transportation. Under anaerobic conditions, Sulfate Reducing Bacteria (SRB) produce sulfide from sulfur compounds present in the sewage. It has been studied for many years. Previous studies have been developed some of empirical equations to predict sulfide build-up in pipes (Thistlethwayte, 1972; Boon, 1995; Tanaka *et al*., 2001; Harlina, 2011).

The generation of sulfide in pipes sewer is the decomposition of organic compounds containing sulfur by SRB in the sediment or slime biofilms in the wall of the sewerage. Sulfide (H_2S, HS^-, S^{2-}) appears in wastewater of sewerage under these several factors such as: pH, temperature, concentrations of organic matter and nutrients, ORP, stream velocity, surface area, retention time and so on (Pomeroy and Bowlus, 1946; Thistlethwayte, 1972; Boon, 1995; Hvitved-Jacobsen, 2001; Edwards *et al*., 2001; US-EPA, 2004; Yongsiri *et al*., 2005; Lehua Zhang *et al*., 2008).

In an aqueous medium, the ORP is an approximate measure of the equilibrium existing between the reducing and oxidizing substances in water. Previous studies reported the favorite range of ORP for SRB varies between -50 mV to -300 mV based on individual studies (Table-1).

Table-1. The favorite range of ORP for H_2S and CH_4 formation by organisms in the sewer networks.

Range of ORP	References
The favorite range of ORP for sulfide built-up by SRB	
-200 mV to -300 mV	Eliassen *et al*., 1949; Richard, 1972
-100 mV to -250 mV	Boon, 1995
-50 mV to -300 mV	Edwards *et al*., 2001
-50 mV to -250 mV	Michael, 2007
The range of ORP for circumvent of sulfide built-up by SRB	
>50 mV	Derek, 1995
≥50 mV	Faridah *et al*., 2011
The favorite range of ORP for methane production by methane producing bacteria	
-175 mV to -400 mV	Michael, 2007

The ORP values of media where sulfide is built-up usually are situated around -100 mV and -250 mV (Boon, 1995).

According to Richard (1972) and Eliassen *et al*. (1949), the ORP favors for the SRB in the range of -200 mV to -300 mV.

The typically favorite range of ORP for SRB is defined by -50 mV to -300 mV (Edwards *et al*., 2001); furthermore, ORP above 50 mV was reported to circumvent H_2S generation due to SRB (Derek, 1995).

Faridah *et al*. (2011) used the index of ORP and pH as a signal to evaluate the effectiveness of measurement of sulfide generation in the wastewater system by using chemical methods. The ORP and pH were measured as the indicators for mitigation of H_2S. The safe range of ORP and pH values is ORP≥50 mV and 8.5≤pH≤9.

According to Michael (2007), the ORP range of a favorable environment for the production of sulfide is usually in the range from -50 mV to -250 mV. For more low ORP values, the reduction of methane dominate, ORP values ranging from -175 mV to -400 mV.

Temperature is another important factor in the microbial generation of sulfide. Since 1934, Baumgartner reported that sulfide production is greatly retarded at temperatures of 7^0C and below. The highest production rate occurred at 30^0C. According to Pomeroy and Bowlus (1946), in the interval from 15^0C to 38^0C, the sulfide generation rate to increase by an average of 7 percent per degree.

Previous studies indicated that sludge deposits and sewer growths are the major cause of prolific sulfide production in sewers. Sludge deposits and slime growths in sewers provide sites where the microbial environment can become suitable for sulfide generation. With an adequate supply of organic matter available in the deposits and growths, all the SRB need is their hydrogen acceptor (Pomeroy and Bolus, 1946; Brearsley, 1949).

Another environmental condition that affects the growth of the sulfide built-up is pH. By comparing the time necessary to reach the same sulfide concentration at various average pH values, Pomeroy and Bowlus (1946) calculated and plotted in Figure-1. The optimum appears of pH to be between 7.5 and 8.0 which near the average for the sewage throughout most of the sewer systems.

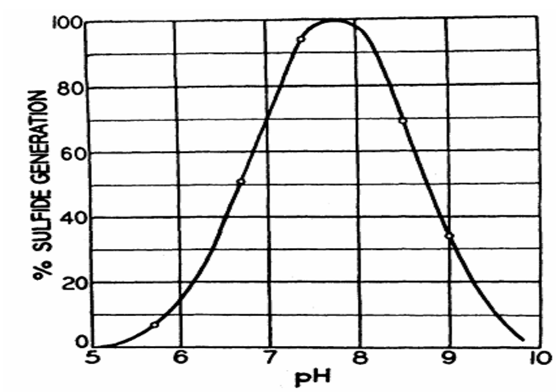

Figure-1. Relative rates of sulfide production at various pH values (Pomeroy and Bowlus, 1946).

Most of the empirical equations proposed for forecasting sulfide build-up in pipes used BOD_5 or COD as a source of organic matter, although SRB only consume soluble organic matter (Hvitved-Jacobsen *et al*., 1988 cited by Tanaka *et al*., 2001, Yongsiri C. *et al*., 2005). The equations that related the amount of sulfide build-up in the pipes sewers have been developed. These equations depended on the most important factors affected on sulfide generation. These parameters include organic matter, sulfate, temperature, and residence time (Delgado *et al*., 1998). Although pH and ORP greatly influences sulfide generation, but it is not usually taken into account in forecasting equations because the rate of sulfide formation is highest within the pH range of 6.0 to 8.5 and the ORP range of -50mV to -250 mV, which is the usual pH range and ORP of pipe sewerage. Most of the equations proposed are as follows (Boon, 1995; Pomeroy, 1959; Hvitved-Jacobsen, 1988 cited by Tanaka *et al*., 2001; Harlina *et al*., 2011):

$$\Delta S = a * C^b * 1.07^{(T-20)} * t_h * (A/V)$$

Where

ΔS = increase in S^{2-} (mg/L)
C = soluble or total COD or BOD_5
T = temperature (°C)
A = inside area of the pipe (m^2)
V = total pipe volume (m^3)
t_h = residence time (hour)
a and b = coefficients. In most equations, b = 1, and a depends on the organic matter used (COD and BOD_5) and the quality of wastewater studied.

The above equation can explain the sulfide built-up process is mainly depend on the value of COD/BOD_5, the temperature of wastewater, the retention time, and the biofilm in slime of the sludge in the wall of the pipe. This equation is only appropriate for the sulfide built-up forecasting in the pipe sewer system. Previous studies have proposed some equations for predicting sulfide production in pipe sewer that transport raw wastewater as listed in Table-2.

Table-2. Sulfide generation forecasting equation.

No.	Equations	Sources
1	$\Delta S = 0.0265 * COD^{0.5} * 1.07^{(T-20)} * t_h * (A/V)$	Harlina, 2011
2	$\Delta S = 1.5 * 10^{-3} (COD-50)^{0.5} * 1.07^{(T-20)} * t_h * (A/V)$	Hvitved-Jacobsen, 1988 (†)
3	$\Delta S = 1.52 * 10^{-3} * BOD_5 * t_h * \{(1 + 0.004 * D)/D\}$	Boon, 1995 (††)
4	$\Delta S = 0.0026 * 10^{-6} * E_{BOD} * t_h * \{(1 + 0.01 * D)/D\}$	Pomeroy, 1959 (†††)

(†) cited by Tanaka, 2001
(††) t_h in min and D (diameter) in cm
(†††) E_{BOD} stands for effective BOD_5: $E_{BOD} = BOD_5 * 1.07^{(T-20)}$

In the open channel condition the above mentioned equations may be not appropriate for the forecasting of sulfide built-up by the reasons as follows:

- In the open channel condition, the wastewater has affected by the environmental condition (atmosphere) due to the transfer of temperature and other gases such as O_2, CO_2, CH_4… between the atmosphere and wastewater. Most gases transfer between the liquid phase and gas phase complies with the theory of two-films by Liss (1974).
- By the easily connections of discharger into the open channel, thus in the open channel normally has many additional discharger. In the To Lich River have more than ten of open channel, and dischargers, and hundreds of small sewers discharge into this river. (Ha Noi People's Committee, 2005; JICA, 2007; Tran Yem *et al*., 2009). Thus, the water in the To Lich River (open channel) has continuous changes due to the influence of the additional discharge, as well as affects the retention time of the wastewater.
- By the stratification of the wastewater in the open channel, the temperature and ORP in the surface of wastewater is normally higher than the bottom layer.

To Lich River is one of four major sewerage rivers in Ha Noi City (Figure-2). Wastewater in To Lich River is mainly domestic wastewater and a partly industrial wastewater and leads to the pollution of this water body and ambient air in riparian areas. The amount of sulfide generation from To Lich River water was estimated of equivalent 1, 702.3 tons SO_2 per year (about 2.14% of industrial source of Hanoi City) (Nguyen Xuan Hai *et al*., 2010).

Currently, there are some studies on wastewater and drainage system in the To Lich River, in Hanoi, Vietnam (Ha Noi People's Committee, 2005; JICA, 2007; Tran Yem *et al*., 2009; Nguyen Xuan Hai *et al*., 2010; Nguyen Huu Huan *et al*., 2012). However, most of the above mentioned studies have problems in term of assessment of the factors governing of sulfide formation in the To Lich River. It is one of the toxic gas can affect to the people and causing damage to the drainage system of Hanoi. Therefore, this paper refers to evaluate the factors governing the formation of sulfide in wastewater in open channel conditions (To Lich River).

METHODS

Sampling and preservation methods: The water samples were collected and stored in accordance with TCVN 6663 - 14:2000.

Methods of analysis of water samples: The water quality analysis methods are applied as shown in Table-3.

Table-3. Analysis methods.

No.	Parameters	Methods
1	pH	TCVN 6492-1999 pH - Determination
2	TSS	TCVN 4560-1988 Determination of total suspended solid
3	TDS	TCVN 6053-1995 Determination of total dissolved solid
4	COD	TCVN 6491-1999 Determination of COD
5	BOD_5	TCVN 6001-1995 Determination of BOD (5 days)
6	H_2S	TCVN 4567-1988 Determination of sulfur, sulfate
7	NH_4^+	TCVN 5988-1995 Determination of ammonium - Distillation and titration method
8	DO	TCVN 4564-1988 Determination of dissolved oxygen
9	Fe	TCVN 6177-1996 Determination of iron - Spectrometric method
10	As	TCVN 6626-2000 Determination of arsenic - Atomic absorption method.
11	ORP	Determination of oxidation - reduction potential (ORP) by Mettler Toledo MX 300
12	Total N	Total Kjeldahl Nitrogen - Kjeldahl method
13	Total P	TCVN 8563-2010 Determination of total phosphorus by colorimeter method
14	Coliform	TCVN 6187-1-1996 Detection and enumeration of organisms thermotolerant coliform organisms and presumptive Escherichia coli

TCVN: Stands for Vietnamese national standard

Methods of evaluation water quality index (WQI): Evaluation of WQI method by the guideline of Department of Environment Pollution Control, Ministry of Natural Resources and Environment, Vietnam (DEPC, 2011), includes 6 indicators such as: TSS, BOD_5, N_{total}, P_{total}, As and Coliform. The rating scale of surface water pollution index as follows:

- Good quality : WQIo ≤ 50
- Not polluted : 50 < WQIo ≤ 100
- Light polluted : 100< WQIo ≤ 200
- Polluted : 200< WQIo ≤ 300
- Heavy polluted : WQIo > 300

VOL. 8, NO. 3, MARCH 2013 ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences

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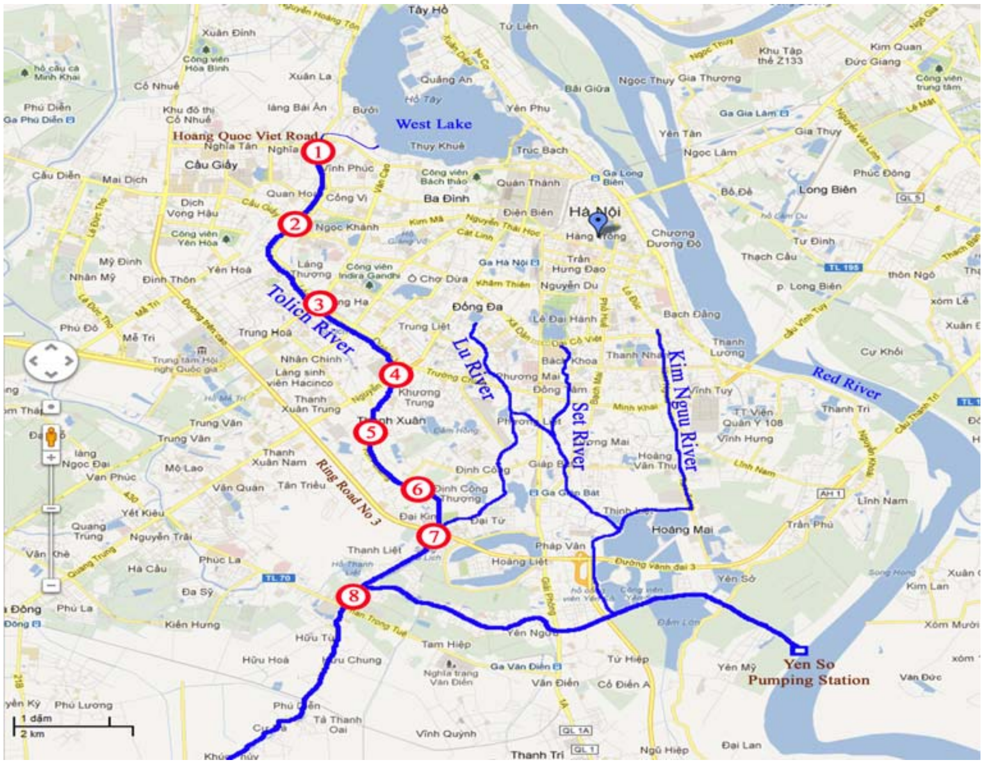

Figure-2. Sampling map.

RESULTS AND DISCUSSIONS

The sediment quality in the To Lich River

The sediment quality in the To Lich River is shown in Table-4. The density of the sediment is relatively high, organic matter content changes within widely ranges. This is because over a period of several years, the annual sediment dredging in the To Lich River. Therefore the changes in sediment quality also changes. However, the values of ORP of sediment still shows increasing trend downstream, caused by the flow of the river as downstream as the high water level, so as the dominant of reduction process. The ORP values change from -311 mV to -429 mV, which is out of the favorite range of ORP (Table-1) for the sulfide built-up by SRB (Eliassen *et al.*, 1949; Richard, 1972 Boon, 1995; Edwards *et al.*, 2001; Michael, 2007). With the range of ORP in sediment environment of the To Lich River is not adequate for sulfide built-up that is favorable for reducing methane organic compounds (Michael, 2007).

The soluble sulfate concentration ($SO_4^{2-}{}_{Ext}$) of river sediments varies in range of 3.270 to 8.126 mg/100 g (equivalent dry weight of sediment) with tends to increase in the end of To Lich River. It is available source of sulfur for the activity of organisms in the sulfur cycle in wastewater in the To Lich River.

Table-4. Sediment content in the To Lich River (equivalent dry weight).

No.	Density	COD	BOD_5	N_{Total}	As	$SO_4^{2-}{}_{Ext.}$	Organic matter	Fe	ORP
		g/kg	g/kg	g/kg	mg/100g	mg/100g	%	mg/100g	mV
1	2.589	165	40	3.6	69	4805	8.0	951	-311
2	2.399	143	30	6.6	11	3270	12.7	434	-362
3	2.412	122	34	10.2	41	4487	11.2	476	-392
4	2.625	128	37	4.3	37	5616	7.8	676	-350
5	2.655	179	32	3.3	10	8126	4.8	853	-408
6	2.754	242	61	3.4	111	7490	5.8	1220	-425
7	2.781	257	50	3.7	114	7560	6.9	1011	-429
8	2.615	236	48	4.2	98	7320	7.2	850	-415

The water quality in the to Lich River

Results of water quality analysis in the To Lich River are presented in Table-5. The WQI in the To Lich River shows that water is heavily polluted. Which cause high levels of pollution indicator of coliform and BOD_5 (Table-6). The WQI in the To Lich River depends on microbial pollution indicators (coliforms) and organic matter (BOD_5), with the range varies from 530 to 620, and it is larger than around two times of the highest value in the recommended scale by Ministry of Natural resources and Environment of Vietnam. Values of WQI decrease from sample No 1 to No 4, and then to be more stable at the end of the To Lich River (Figure-3).

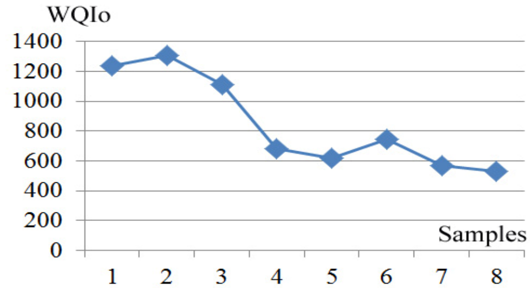

Figure-3. WQI in the To Lich River.

Table-5. Water quality in the To Lich River.

No.	Parameter	Unit	Water samples (Figure-2)							
			1	2	3	4	5	6	7	8
1	As	mg/L	0.00556	0.00679	0.00643	0.00728	0.00681	0.00717	0.00917	0.00906
2	BOD_5	mgO_2/L	57.6	58.28	66.46	57.6	54.4	48	69.2	52.64
3	Coliform	MPN/100 ml	240.000	360.000	280.000	140.000	120.000	170.000	100.000	92.000
4	TSS	mg/L	226	286	312	296	289	272	228	290
5	N_{Total}	mg/L	32.48	28.34	31.36	27.22	30.24	29.34	29.68	26.32
6	P_{Total}	mg/L	1.66	1.55	1.75	1.48	1.41	1.43	1.43	1.46
7	S^{2-}	mMol/L	0.143	0.279	0.298	0.277	0.301	0.150	0.191	0.163
8	SO_4^{2-}	mMol/L	0.237	0.396	0.365	0.376	0.364	0.209	0.195	0.169
9	$Lg[S^{2-}]/[SO_4^{2-}]$	-	-0.218	-0.153	-0.089	-0.133	-0.082	-0.144	-0.010	-0.016
10	ORP	mV	-216	-218	-220	-218	-224	-226	-232	-226
11	Fe	mg/L	0.36	1.16	1.1	0.94	0.96	0.88	1.78	1.08
12	As	mg/L	0.00556	0.00679	0.00643	0.00728	0.00681	0.00717	0.00917	0.00906
13	pH	-	7.21	7.2	7.19	7.2	7.18	7.23	7.21	7.21
14	COD	mgO_2/L	100.5	97.3	140.2	136.2	118.4	98.6	135.2	82.8
15	DO	mgO_2/L	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01

Table-6. WQI in the To Lich River.

No.	WQI_i						WQI_0
	TSS	BOD_5	N_{Total}	P_{Total}	As	Coliform	
1	67.3	93.3	48.1	69.2	3.6	678.4	1241
2	85.2	94.4	41.9	64.6	1.6	1017.6	1305
3	93.0	107.7	46.4	72.9	1.5	791.5	1113
4	88.2	93.3	40.3	61.7	1.7	395.7	681
5	86.1	88.1	44.8	58.8	1.6	339.2	619
6	81.1	77.8	43.4	59.6	1.2	480.5	744
7	67.9	112.1	43.9	59.6	2.1	282.7	568
8	86.4	85.3	39.0	60.8	2.1	260.1	534

VOL. 8, NO. 3, MARCH 2013 ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences

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The factors effect to the sulfide generation rate in the To Lich River

The relationship between sulfide and ORP

The relationship between ORP and concentration of sulfide (mMolS / L) in the To Lich River is shown in Figure-4. The ORP decreased from upstream to the downstream of the river. The concentration of sulfide has a trend to increase from the sample No. 1 to No 5, then decreased and relatively stable in the downstream of the To Lich River. The ORP values in the surface water of To Lich River change in the range of -216 to -232 mV; this range is favorable for the sulfide built-up. But in the downstream of To Lich River, the concentration of sulfide shown a decreased tend and stable at the end. That can be explain along the To Lich River have many additional sources of wastewater and may present of inhibitors, or reaction of sulfide with metals such as iron and metal heavy (Nguyen Thi Lan Huong *et al.*, 2007) and precipitated in the form of metal sulfide (Smith, 1923).

The relationship between log ($[S^{2-}]/ [SO_4^{2-}]$) and ORP

Delgado *et al*. (1999) indicated that in the pipe sewer ORP is the most important factor related to the logarithm of the sulfide/sulfate ratio according to the following equation:

$$ORP = - 28.53 * \log ([S^{2-}]/ [SO_4^{2-}]) - 208$$

The applying Delgado's equation to calculate the ORP in the To Lich River is not adequate. By this experiment, in the To Lich River, the relationship between ORP and logarithm of the sulfide/sulfate ratio comply with the following equation ($R^2 = 0.6369$, Figure-5):

$$ORP = - 61{,}173* \log ([S^{2-}]/ [SO_4^{2-}]) - 228.97$$

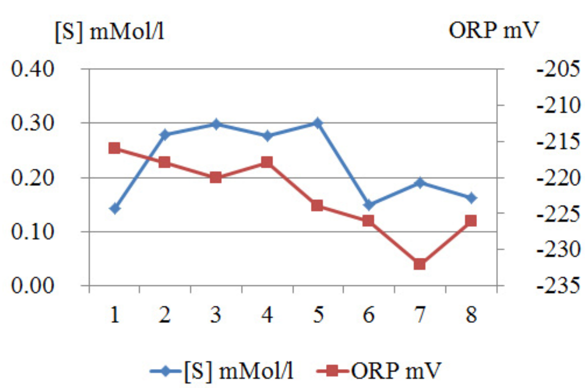

Figure-4. Sulfide vs. ORP in the To Lich River.

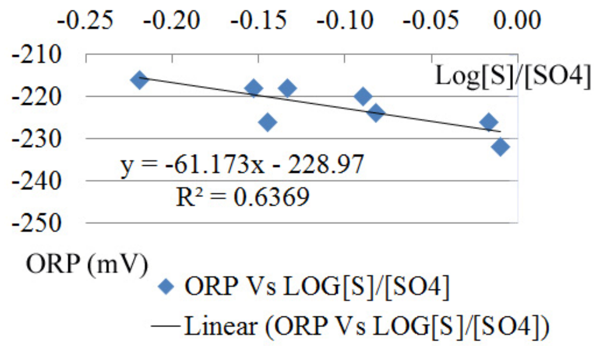

Figure-5. Log $[S^{2-}]/ [SO_4^{2-}]$ vs. ORP in the To Lich River.

The relationship between sulfide and pH values

Although the variation range of pH value is not large, but also shows the trend of the pH decreases when the sulfide content increases, and the pH increases while the concentration of sulfide decreases. For the section of river from sample of No. 6 to the end (sample No. 8), the pH value tends to increase, the main reason can be explain that, in this section of the river receives the additional wastewater source from Thuong Dinh Industrial Zone. Furthermore, the additional wastewater source has high concentration of the heavy metal, thus the precipitation of sulfide and heavy metal such as As, Cd, Pb … is occurred (Nguyen Thi Lan Huong *et al*., 2007). The concentration of Fe and as in the downstream of To Lich River with tends of increasing, it may contributed to the causing of decreased of sulfide concentration in this river. Consequently, when the pH increased at the end of the river, the sulfide concentration is decreased (Figure-6).

The relationship between sulfide and temperature

Temperature is an important factor in the microbial generation of sulfide (Baumgartner, 1934; Pomeroy and Bowlus, 1946). Baumgartner (1934) reported that the highest production rate of H_2S built-up occurred at around of 30^0C. In this experiment, the range of temperature in the To Lich River varies from 28.8 ^{0}C to 32.5^0C and favorites for sulfide generation. The pick of sulfide concentration occurs in the sample No. 5, with the temperature around 30^0C (Figure-7).

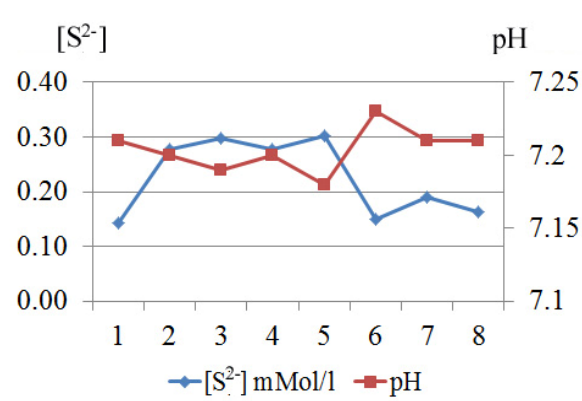

Figure-6. Sulfide vs. pH in the To Lich River.

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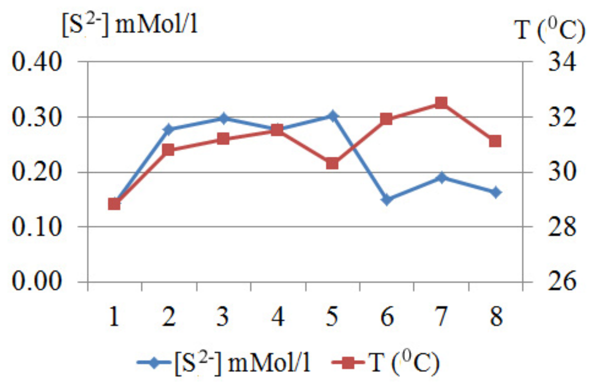

Figure-7. Sulfide vs. temperature in the To Lich River.

The relationship between sulfide and COD, BOD_5

Previous studies on the relationship between the concentration sulfide and the organic matter (COD, BOD_5) shown closely relationship in the wastewater system (Delgado *et al*., 1999; Edwards *et al*., 2001). In the case of To Lich River also shown close relationship, when the values of COD or BOD_5 increase, the concentration of sulfide also increases and vice versa (Figure-8).

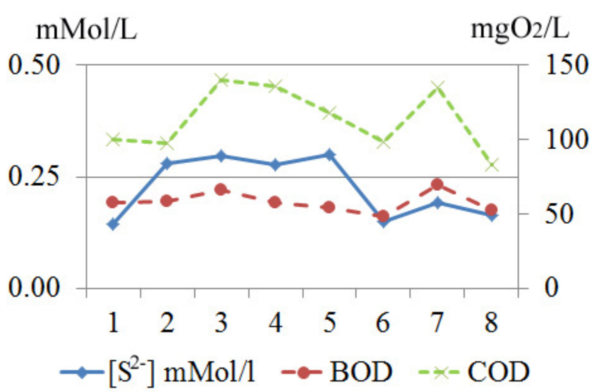

Figure-8. Sulfide vs. COD, BOD_5 in the To Lich River.

The model of sulfide generation rate in the To Lich River

Water of To Lich River is mainly domestic and partly industrial wastewater. It causes pollution of water body and ambient air in riparian areas (Tran Yem *et al*., 2009; Nguyen Xuan Hai *et al*., 2010; Nguyen Huu Huan *et al*., 2012). In the open channel condition such as To Lich River, the previous equations for pipe sewers are not adequate for the forecasting of H_2S built-up by the reasons as follows:

- To Lich is open channel, thus the wastewater in the river is effected from the environmental conditions (meteorological conditions such as temperature, wind velocity…) due to the transfer of temperature and other gases such as O_2, CO_2, CH_4 and so on, between the air phase and liquid phase. Most gases transfer between the liquid and gas in the atmosphere complies with the theory of two-films by Liss (1974).
- The basin of the To Lich River was divided so many drainage sub-basin; thus, the To Lich River has many points of discharger into the river. Along the To Lich River is around 13.5 km, has more than ten of open channel, and dischargers, and hundreds of small sewers discharge into this river. Therefore, the water in this river has to continuous changes due to the influence of the additional discharge, as well as affects the retention time of the wastewater in the river (Ha Noi People's Committee, 2005; JICA, 2007; Tran Yem *et al*., 2009).
- By the stratification of the wastewater in the open channel, the temperature and ORP in the surface of wastewater in the open channel is normally larger than the bottom layer. The H_2S built-up mainly occur in the surface water layer of the To Lich River because of environmental conditions (ORP and pH) are adequate. The bottom water layer and sediment layer of the To Lich River have the ORP value is too low (less than -300 mV) (Table-7) and is not favorable for the sulfide built-up by SRB. At this low ORP condition, the methane (CH_4) formation process is dominated (Eliassen *et al*., 1949; Boon, 1995; Derek, 1995; Edward *et al*., 2001; Michael, 2007; and Faridah *et al*., 2011). Most previous studies report on the pipe networks, the sites to produce sulfide in the biofilms of slimes by depositing of sludge in the wall of pipes (Henry, 1961; Santry, 1963). In the case of To Lich River, due to the media condition of ORP, the main sites in the flows of river to produce sulfide is surface water layer.

Some of previous studies in the pipe sewer, the sources of sulfur for the SRB is sulfate (Beardsley, 1949; Richard, 1972), but some studies reported that the sulfur source from the organism matters, thus some experiment equation is not consider the concentration of sulfate (Boon, 1995; Hvitved-Jacobsen *et al*., 1988 cited by Tanaka *et al.,* 2001; and Harlina *et al*., 2011). Pomeroy and Bowlus (1946) review the sulfate concentration would not to be expected to have much effect on the rate of sulfide production in sewers. In the case of To Lich Rive, the sulfate concentration is very low (Table-5), thus can be consider this factor is not important to impact the H_2S built-up.

Table-7. The stratification of ORP in the To Lich River.

Media	Water and sediment samples (Figure-2)							
	1	2	3	4	5	6	7	8
Surface water layer (0.25 m)	-216	-218	-220	-218	-224	-226	-232	-226
Bottom water layer (> 1m)	-298	-320	-345	-326	-329	-362	-350	-312
Sediment layer	-311	-362	-392	-350	-408	-425	-489	-415

The observed concentration of sulfide in the To Lich River has a close relationship with the organic matter measured as BOD_5 and other media conditions of temperature (T), pH and ORP of wastewater in the To Lich River. And which also allows forecasting the concentration of S^{2-} in wastewater to be found by measuring the ORP and T, pH and BOD_5 of the bulk wastewater. By using regression line, the equation found is (with the correlation coefficient $R^2 = 0.9619$):

$$S^{2-} = 0.0063 * ORP + 0.0427 * T - 4.371 * pH - 0.0012 * BOD_5 + 31.87 \quad (1)$$

By using equation (1), the forecasted sulfide concentrations present the close relationship with the observed values in the To Lich River (Figure-9).

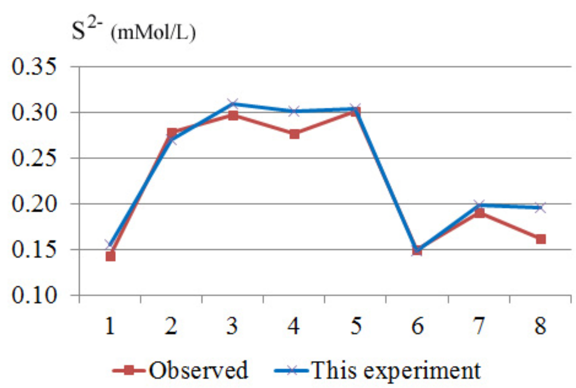

Figure-9. Concentration of **s**ulfide by forecasting in this experiment vs. observed value in the To Lich River.

CONCLUSIONS

a) The WQI in the To Lich River shows that water is very heavily polluted. The range of WQI in the To Lich River varies from 530 to 620 and it is about twofold than the highest value in the recommended sclae by Ministry of Natural Resources and Environment of Vietnam. The WQI dominate by mainly pollution indicator such as coliform and BOD_5.
b) The media of sulfide generation in To Lich River is not the layer of sediment as well as bottom water layer. Due to the media condition of ORP, the main sites in the To Lich River to produce sulfide by SRB is surface water layer.
c) Most of the previous equations to forecast the sulfide built-up in the pipe sewer cannot be apply in the open channel condition such as To Lich River, the form of above mentioned equation as follows:

$$\Delta S = a * C^b * 1.07^{(T-20)} * t_h * (A/V)$$

d) A close relationship between ORP and log ($[S^{2-}]/[SO_4^{2-}]$) in the To Lich River has been found, which allows determine the S^{2-} concentration in wastewater indirectly by measuring the ORP and sulfate of the bulk wastewater. The equation is:

$$ORP = - 228.97-61.173* \log ([S^{2-}]/ [SO_4^{2-}])$$

With $R^2 = 0.6369$

e) The concentration of sulfide in the To Lich River has a close relationship with the BOD_5 and other media conditions such as temperature, pH and ORP of wastewater in the To Lich River. And which also allows forecasting the concentration of S^{2-} in wastewater by measuring the ORP, T, pH and BOD_5 of the bulk wastewater. The equation is:

$S^{2-} = 0.0063 * ORP + 0.0427 * T - 4.371 * pH - 0.0012 * BOD_5 + 31.87$, with $R^2 = 0.9619$

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