

## Dephosphorization of Wastewater by Fly Ash from Phuket Incineration Plant

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### ABSTRACT

*Dephosphorization of wastewater was carried out by using fly ash from Phuket Incineration Plant which contained a high amount of water-soluble calcium ion (54.26% of its dry weight). The highest capacity in removing orthophosphate was when calcium concentration level was 331.40 grams per gram of orthophosphate for non-turbid wastewater, and 165.70 grams per gram for wastewater with a turbidity of 80 NTU, a pH of 10 and a contact time of 30 minutes. The turbidity of the synthetic wastewater resulted in better removal of orthophosphate.*

*The absorption capacity of phosphorus by fly ash from Phuket Incineration Plant, calculated with Freundlich's equation, was 158.63 mg of orthophosphate per gram of fly ash.*

*The experiment on raw wastewater from frozen seafood industry revealed that less orthophosphate was removed from wastewater from the production process and the total industry wastewater than from synthetic wastewater. Because raw wastewater contained more chemical substances than synthetic wastewater, calcium concentrations varied from 1,657-16,570 mg/l. It was also found that the amount of orthophosphate removed from raw wastewater was not the same as that from synthetic wastewater. However, in the production process, sulfate was added. As a result, less orthophosphate was removed from wastewater from the production process.*

**Key words:** Dephosphorization, Fly ash, Phuket Incineration Plant, Frozen seafood industry

## INTRODUCTION

Water pollution is one of the major environmental hazards in Thailand. The tribulation showing the major case of increased nutrients are from domestic, agricultural wastewater and leachate. Phosphorus is likely to accumulate in the sediments due to its shallowness. Phosphorus is a good fertilizer for enhancing the growth of fecal coliform as well as phytoplanktons and algae. The presence of excessive amount of phytoplanktons and algae would result in coloring and smelling of water, reducing clarity of water and decrease of dissolved oxygen. Consequently, these will harm fish production and cause potential risk to public.

Chemical treatment is widely used for the removal of phosphorus. Lime, alum and ferric chloride are the common percipients used for phosphorus removal. The phosphorus removal by them was highly efficient. Biological phosphorus removal has also been successfully applied (Ugurlu and Salman, 1998). Adsorption is one of the techniques which is comparatively more useful and economical for such removal. The application of low-cost and easily-available materials in wastewater treatment has been widely investigated during recent years.

Fly ash is a waste product. The use of fly ash in wastewater treatment has been studied extensively in recent years and the results of laboratory investigations showed that fly ash is a good absorbent for the removal of phosphorus from wastewater. Wongsiri et al., (2000) used fly ash from Mae Moh power plant, Lampang, Thailand for removal of phosphate from aqueous solution and found that a  $\text{PO}_4^{-3}$  removal efficiency was over 90%. Yamada et al., (2000) using fly ash from different coal-fired power plants in Japan, the Philippines and Thailand for removal of phosphate from aqueous solution found a  $\text{PO}_4^{-3}$  removal efficiency of 90%. Ugurlu and Salman (1998) used fly ash from power plant in Turkey for removal of phosphate from aqueous solution and found a  $\text{PO}_4^{-3}$  removal efficiency was in excess of 99%. These three researches showed that lignite fly ash has a high  $\text{PO}_4^{-3}$  removal efficiency.

Therefore in the present study, an attempt was made to investigate the phosphate removal potential of fly ash from Phuket Incineration Plant by determining optimum conditions for highest removal of phosphate from wastewater.

## MATERIALS AND METHODS

Fly ash sample was collected from Phuket Incineration Plant in the southern part of Thailand.

### **The highest removal of $\text{PO}_4^{-3}$ of synthetic wastewater by the use of fly ash from Phuket Incineration Plant.**

*Correlation between concentration of  $\text{Ca}^{2+}$  and highest removal of  $\text{PO}_4^{-3}$*

1, 2, 5 and 10 gram (concentration of  $\text{Ca}^{2+}$  1,657, 3,314, 8,285 and 16,570 mg/l in fly ash analyzed by Inductively-Coupled Plasma-Optical Emission Spectrometer) of fly ash sample was suspended into a 500 ml of non-turbid and turbid

80 NTU (by Hyflow Super Cells) synthetic wastewater, containing 10 mg/l of  $\text{PO}_4^{-3}$  and synthetic wastewater was mixed 125 rounds/minute for various contact times (5-30 min). Then residual  $\text{PO}_4^{-3}$  content in each filtrate was analyzed by spectrophotometer.

*Correlation between contact time and highest removal of  $\text{PO}_4^{-3}$*

The similar procedure as in correlation between concentration of  $\text{Ca}^{2+}$  and highest removal of  $\text{PO}_4^{-3}$  was followed in 500 ml of non-turbid and turbid 80 NTU synthetic wastewater, containing 5, 10 and 20 mg/l of  $\text{PO}_4^{-3}$  and synthetic wastewater was mixed 125 rounds/minute for various contact times (10-180 min). Then residual  $\text{PO}_4^{-3}$  content in each filtrate was analyzed by spectrophotometer.

*Correlation between pH and highest removal of  $\text{PO}_4^{-3}$*

The similar procedure as in correlation between concentration of  $\text{Ca}^{2+}$  and highest removal of  $\text{PO}_4^{-3}$  and correlation between contact time and highest removal of  $\text{PO}_4^{-3}$  was followed in 500 ml of non-turbid and turbid 80 NTU synthetic wastewater, containing 5, 10 and 20 mg/l of  $\text{PO}_4^{-3}$  at various pH from 5-10. Then residual  $\text{PO}_4^{-3}$  content in each filtrate was analyzed by spectrophotometer.

**The capacity of adsorption of  $\text{PO}_4^{-3}$  from synthetic wastewater by the use of fly ash from Phuket Incineration Plant.**

For the isotherm adsorption of  $\text{PO}_4^{-3}$  using fly ash of 1 gram and optimized conditions (from a highest removal of  $\text{PO}_4^{-3}$  of synthetic wastewater by the use of fly ash from Phuket Incineration Plant), 500 ml synthetic wastewater containing 0-50 mg/l  $\text{PO}_4^{-3}$  was used. Then residual  $\text{PO}_4^{-3}$  content in each filtrate was analyzed by spectrophotometer.

**The highest removal of  $\text{PO}_4^{-3}$  of raw wastewater by the use of fly ash from Phuket Incineration Plant.**

Raw wastewater was wastewater from production process and wastewater from total industry, frozen seafood industry and Hongyenchotivat Company so that for comparing the removal of  $\text{PO}_4^{-3}$  by using fly ash, the conditions were the same as those of synthetic wastewater.

**Orthophosphate measurement**

The samples were filtered prior to each measurement. Orthophosphate was measured according to the vanadomolybdophosphoric acid method as stated in the Standard Methods (APHA, 1998).

## RESULTS AND DISSCUSION

**Characterization of fly ash**

*Chemical composition*

Chemical composition of fly ash sample from Phuket Incineration Plant is shown in Table 1. It was found that most composition was CaO (54.26%) which is

an important composition in the removal of  $\text{PO}_4^{-3}$  (Ugurlu and Salman, 1998).

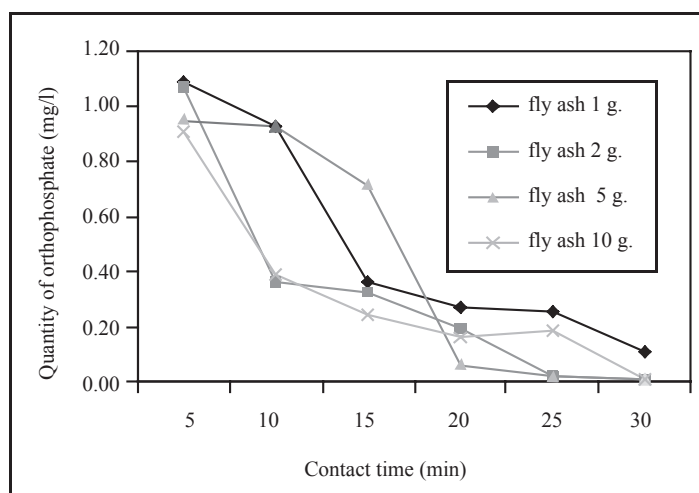
**Table 1.** Chemical composition of fly ash from Phuket Incineration Plant.

| Composition | $\text{SiO}_2$ | $\text{CaO}$ | $\text{Al}_2\text{O}_3$ | $\text{Fe}_2\text{O}_3$ | $\text{SO}_3$ | $\text{K}_2\text{O}$ | $\text{MgO}$ | $\text{Na}_2\text{O}$ |
|-------------|----------------|--------------|-------------------------|-------------------------|---------------|----------------------|--------------|-----------------------|
| Weight (%)  | 1.57           | 54.26        | 0.77                    | 1.44                    | 5.19          | 9.72                 | 1.60         | 5.74                  |

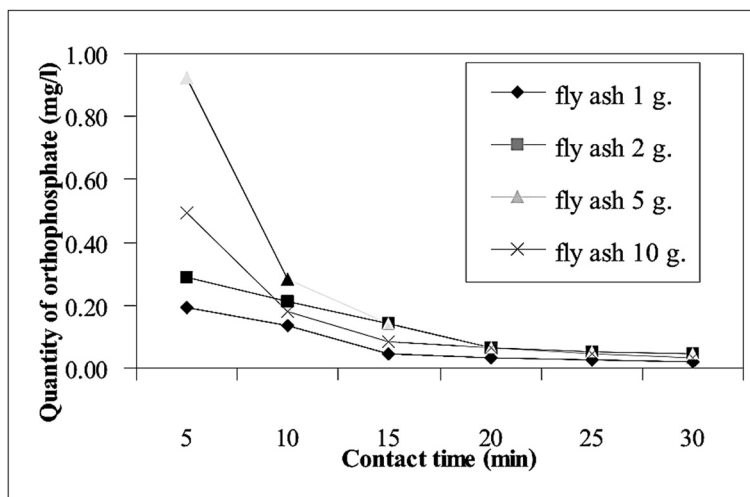
**The highest removal of  $\text{PO}_4^{-3}$  of synthetic wastewater by the use of fly ash from Phuket Incineration Plant.**

*Correlation between concentration of  $\text{Ca}^{2+}$  and highest removal of  $\text{PO}_4^{-3}$*

The results of correlation are shown in Figures 1 and 2 which present the correlation between calcium concentration and quantity of  $\text{PO}_4^{-3}$  after removal by fly ash. The graph depicted that the more calcium ion was leached out from the fly ash, the higher  $\text{PO}_4^{-3}$  removal. The  $\text{PO}_4^{-3}$  removal from non-turbid and turbid 80 NTU synthetic wastewater was highest at calcium concentration of 331.40 gram calcium per gram orthophosphate and 165.70 gram calcium per gram orthophosphate. Turbidity in synthetic wastewater seemed to have increased efficiency of  $\text{PO}_4^{-3}$  removal.



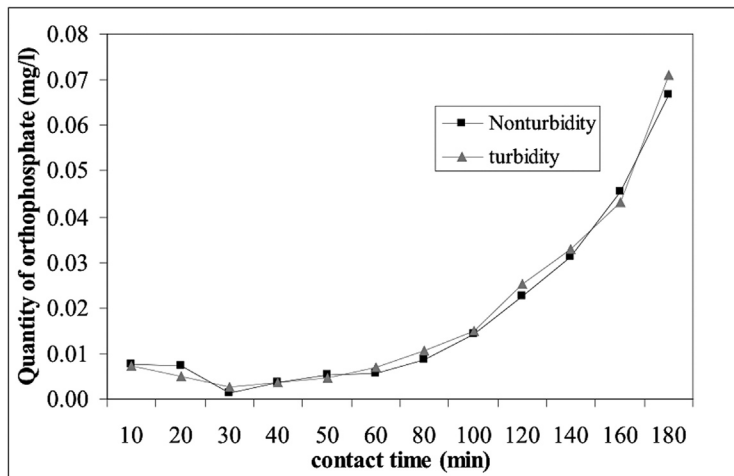
**Figure 1.** Quantity of  $\text{PO}_4^{-3}$  in non-turbid synthetic wastewater after removal by fly ash at a various concentrations of  $\text{Ca}^{2+}$ . Initial concentration of  $\text{PO}_4^{-3}$  : 10 mg/l. (fly ash 1 gram consists of concentration of  $\text{Ca}^{2+}$  1,657 mg/l.).



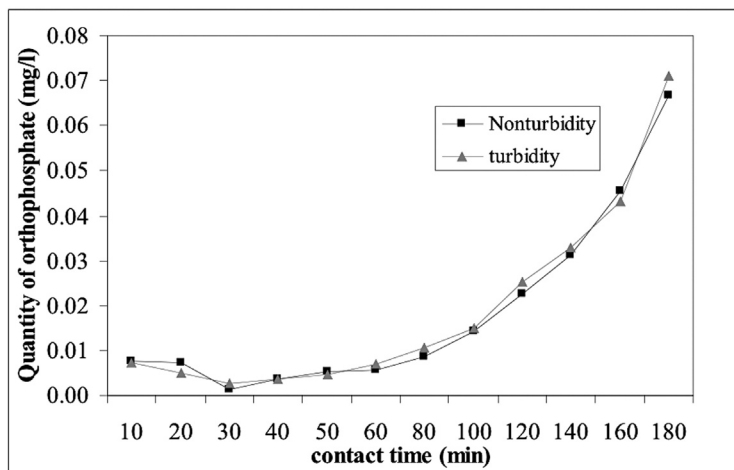
**Figure 2.** Quantity of  $\text{PO}_4^{-3}$  in turbid 80 NTU synthetic wastewater after removal by fly ash at a various concentrations of  $\text{Ca}^{2+}$ . Initial concentration of  $\text{PO}_4^{-3}$  : 10 mg/l. (fly ash 1 gram consists of concentration of  $\text{Ca}^{2+}$  1,657 mg/l.)

*Correlation between contact time and highest removal of  $\text{PO}_4^{-3}$*

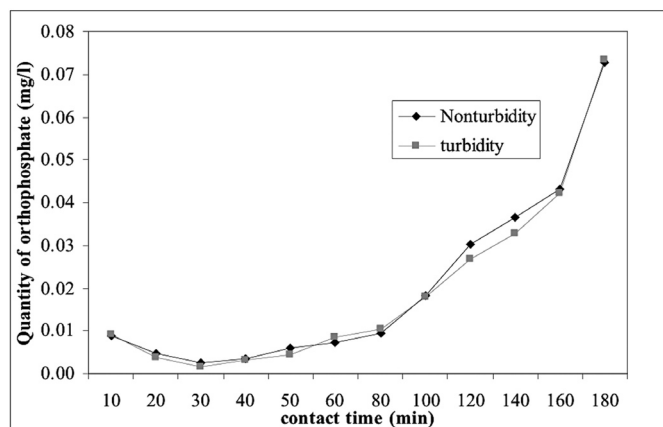
The correlation between contact time and highest removal of  $\text{PO}_4^{-3}$  is depicted in Figures 3, 4 and 5. Results of the study revealed that highest removal of  $\text{PO}_4^{-3}$  from non-turbid and turbid 80 NTU synthetic wastewater occurred at a contact time of 30 min and quantity of  $\text{PO}_4^{-3}$  from non-turbid and turbid 80 NTU synthetic wastewater after contact time of 30 min was high because the adsorption of  $\text{PO}_4^{-3}$  of fly ash from Phuket Incineration Plant was physical adsorption after which the adsorption of  $\text{PO}_4^{-3}$  could easily become desorption .



**Figure 3.** Quantity of  $\text{PO}_4^{3-}$  in non-turbid and 80 NTU turbid synthetic wastewater after removal by fly ash at various contact times. Initial concentration of  $\text{PO}_4^{3-}$  : 5 mg/l.



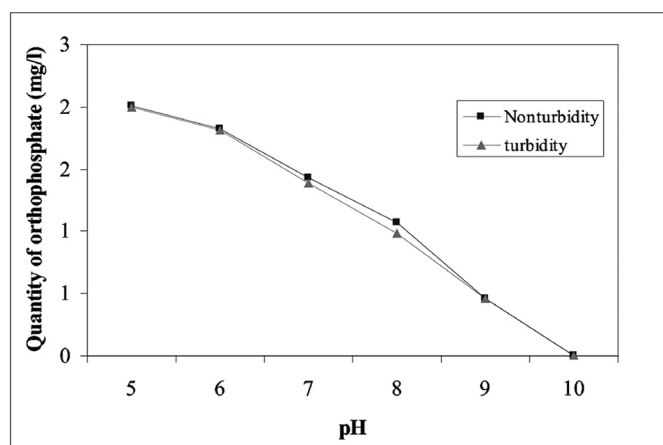
**Figure 4.** Quantity of  $\text{PO}_4^{3-}$  in non-turbid and 80 NTU turbid synthetic wastewater after removal by fly ash at various contact times. Initial concentration of  $\text{PO}_4^{3-}$  : 10 mg/l.



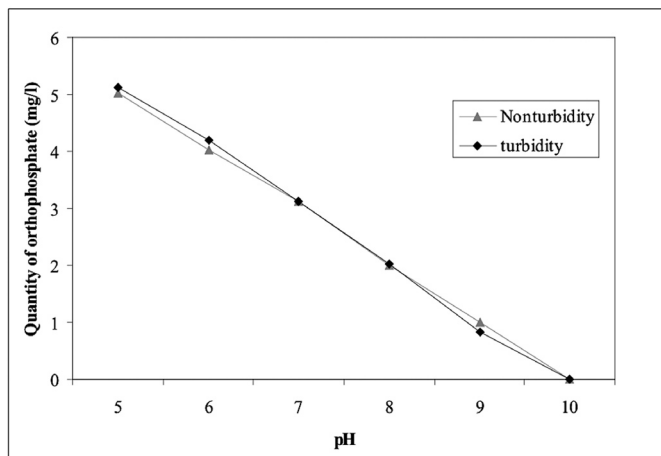
**Figure 5.** Quantity of  $\text{PO}_4^{-3}$  in non-turbid and 80 NTU turbid synthetic wastewater after removal by fly ash at various contact times. Initial concentration of  $\text{PO}_4^{-3}$  : 20 mg/l.

*Correlation between pH and highest removal of  $\text{PO}_4^{-3}$*

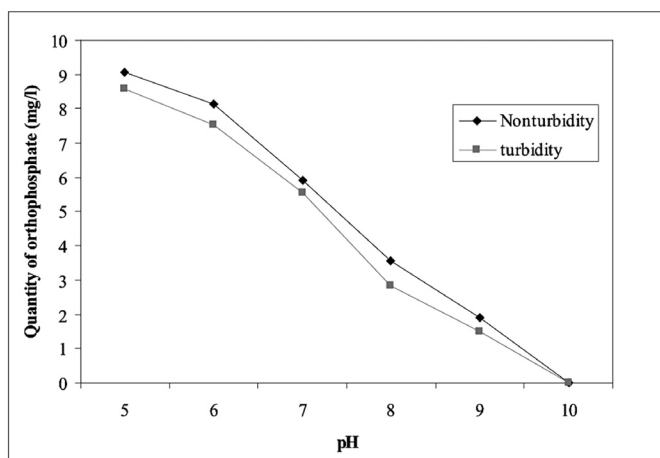
The correlation between pH and highest removal of  $\text{PO}_4^{-3}$  is shown in Figures 6, 7 and 8. Results of study revealed that highest removal of  $\text{PO}_4^{-3}$  from non-turbid and turbid 80 NTU synthetic wastewater occurred at pH 10 and quantity of  $\text{PO}_4^{-3}$  from non-turbid and turbid 80 NTU synthetic wastewater after contact time of 30 min was low when pH was high because the synthetic wastewater was adjusted by acid but the medium around particles of fly ash was alkaline. When  $\text{PO}_4^{-3}$  came near particles of fly ash, it became  $\text{Ca}_5(\text{PO}_4)_3\text{OH}$ , precipitated and was removed from wastewater (Wongsiri et al., 2000).



**Figure 6.** Quantity of  $\text{PO}_4^{-3}$  in non-turbid and 80 NTU turbid synthetic wastewater after removal by fly ash at various pH. Initial concentration of  $\text{PO}_4^{-3}$  : 5 mg/l.



**Figure 7.** Quantity of  $\text{PO}_4^{-3}$  in non-turbid and 80 NTU turbid synthetic wastewater after removal by fly ash at various pH. Initial concentration of  $\text{PO}_4^{-3}$  : 10 mg/l.



**Figure 8.** Quantity of  $\text{PO}_4^{-3}$  in non-turbid and 80 NTU turbid synthetic wastewater after removal by fly ash at various pH. Initial concentration of  $\text{PO}_4^{-3}$  : 20 mg/l.

**The capacity of adsorption of  $\text{PO}_4^{-3}$  from synthetic wastewater by the use of fly ash from Phuket Incineration Plant.**

Langmuir's and Freundlich's adsorption isotherm models were used in these evaluations. Both equations relate the equilibrium solid phase concentration  $C_s$ , with the liquid phase concentration,  $C_e$ . The Langmuir equation is defined as:

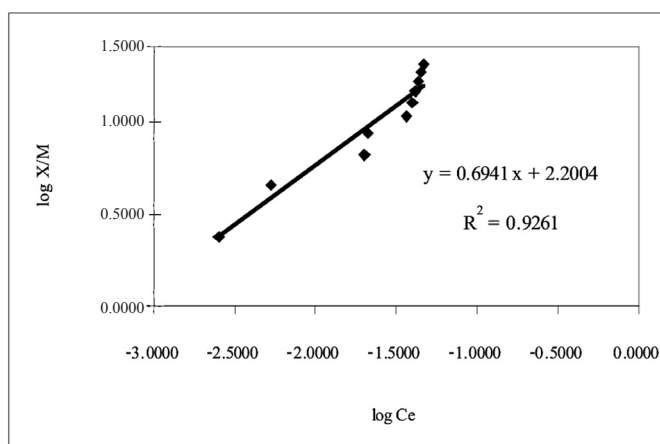
$$C_s = \frac{x}{m} = \frac{(abC_e)}{(1+bC_e)}$$

The Freundlich equation is defined as:

$$C_s = \frac{x}{m} = K_F C_e^{1/n}$$



The isotherm adsorption experiments were performed to calculate the  $\text{PO}_4^{-3}$  removal capacity of individual fly ash from Phuket Incineration Plant. The plot of the experimental data of  $\text{PO}_4^{-3}$  removal showed straight line for fly ash examined. Assuming that the  $\text{PO}_4^{-3}$  removal reaction is in accord with Freundlich's adsorption isotherm, the results are shown in Figure 9.



**Figure 9.** Adsorption  $\text{PO}_4^{-3}$  isotherm using fly ash from Phuket Incineration Plant at pH 10.

The complete elimination of  $\text{PO}_4^{-3}$  from synthetic wastewater was possible with the use of smaller amount of fly ash from Phuket Incineration Plant, compared with that from Mae Moh power plant, Thailand, the Philippines and Japan. The capacity of fly ash from Phuket Incineration Plant, compared with Mae Moh power plant, Thailand, the Philippines and Japan is shown in Table 2.

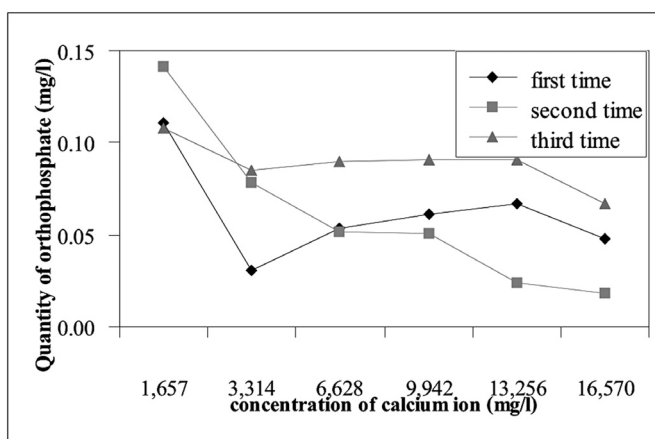
**Table 2.** The capacity of fly ash from Phuket Incineration Plant compared with Mae Moh power plant, Thailand, the Philippines and Japan.

| Fly ash                   | Adsorption of $\text{PO}_4^{-3}$ Capacity (mg/g) |
|---------------------------|--------------------------------------------------|
| Phuket Incineration Plant | 158.63                                           |
| Thailand Unit-1           | 144.00                                           |
| Thailand Unit-5           | 31.50                                            |
| Philippines               | 15.60                                            |
| Japan (Isogo)             | 15.60                                            |
| Japan (Takehara)          | 70.80                                            |

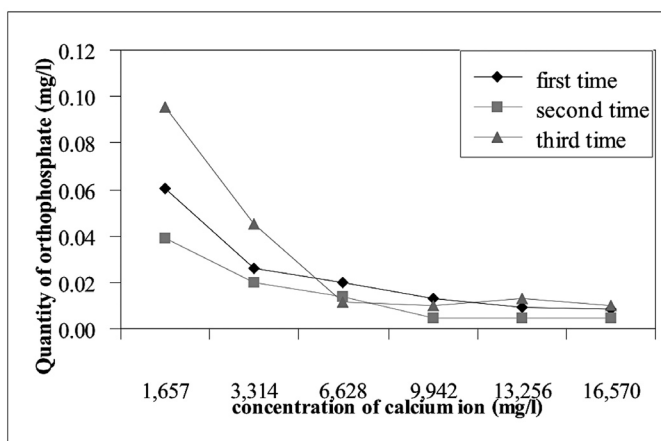
#### The highest $\text{PO}_4^{-3}$ removal of raw wastewater by the use of fly ash from Phuket Incineration Plant.

The  $\text{PO}_4^{-3}$  removal by the use of fly ash from Phuket Incineration Plant in raw wastewater from production process, total industry, frozen seafood industry and Hongyenchotivat Company suggested that quantity of  $\text{PO}_4^{-3}$  after removal by fly

ash for production process wastewater was 0.5883 mg/l (Figure 10) and quantity of  $\text{PO}_4^{-3}$  after removal by fly ash for total industry wastewater was 1.0376 mg/l (Figure 11) which were higher than removal of  $\text{PO}_4^{-3}$  by fly ash from synthetic wastewater because raw wastewater contained high concentration of chemical substances such as bicarbonate and sulfate. So, the concentration of  $\text{Ca}^{2+}$  was changed from 1,657-16,570 mg/l. The  $\text{PO}_4^{-3}$  removal of wastewater from production process and wastewater from total industry was similar to condition of synthetic wastewater. But in production process of frozen sea food industry, the sulfate was added, so the  $\text{PO}_4^{-3}$  removal from production process was low because sulfate reacted with  $\text{Ca}^{2+}$  and  $\text{CaSO}_4$  was formed.



**Figure 10.** Quantity of  $\text{PO}_4^{-3}$  after removal  $\text{PO}_4^{-3}$  by fly ash for production process wastewater.



**Figure 11.** Quantity of  $\text{PO}_4^{-3}$  after removal  $\text{PO}_4^{-3}$  by fly ash for total industry wastewater.

## CONCLUSION

Fly ash from Phuket Incineration Plant contains water-soluble Ca ions which can react with  $\text{PO}_4^{-3}$  in water to become crystalline form. This was the major reaction involved in the  $\text{PO}_4^{-3}$  removal. A highest  $\text{PO}_4^{-3}$  removal was achieved at alkalinity of pH 10 and a contact time of 30 min. Turbidity in synthetic wastewater increased efficiency of  $\text{PO}_4^{-3}$  removal. A complete elimination of  $\text{PO}_4^{-3}$  from synthetic wastewater was possible with the use of smaller amount of fly ash from Phuket Incineration Plant as compared to Mae Moh power plant, Thailand, the Philippines and Japan.

$\text{PO}_4^{-3}$  removal by the use of fly ash from Phuket Incineration Plant in raw wastewater was higher than removal of  $\text{PO}_4^{-3}$  by fly ash from synthetic wastewater because raw wastewater contained high concentration of chemical substance. So, the concentration of  $\text{Ca}^{2+}$  should be increased in raw wastewater.

## ACKNOWLEDGEMENTS

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## REFERENCES

- APHA, AWWA and WEF. 1998. Standard methods for the examination of water and wastewater. 20 th ed. Maryland : American Public Health Association.
- Ugurlu, A., and B. Salman. 1998. Phosphorus removal by fly ash. *Environmental International* 24:991-998.
- Wongsiri, B.P., K. Haraguchi, and K. Yamada. 2000. Dephosphorization from aqueous solution by fly ash from Mae Moh power plant. Symposium on Mineral, Energy and Water Resource of Thailand.
- Yamada, K., K. Haraguchi, and C. Gacho. 2003. Removal of phosphate from aqueous solution by crystallization using fly ash (Online). Available from: <http://www.flyash.info>.

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