

# CHAPTER I

## INTRODUCTION

### 1.1 State of Problem

Removal of heavy metal ions is of particular interest in the recent hazardous waste management due to their severe toxicity to all living organisms including human being. Their high solubility in aquatic environments makes them accumulate in soil and the food chain (Mukherjee, 2007). Most techniques for soil decontamination are considerably expensive (Pavel and Gavrilesco, 2008). The accumulation of heavy metals in the environment still remains an unsolved problem in several developed and developing countries (Harmens *et al.*, 2004) including Thailand (Patungtod *et al.*, 2006).

Numerous treatment techniques are now available for removing heavy metal ions from aqueous solutions. They include chemical precipitation, solvent extraction, ion exchange, membrane processes, and electrowinning. However, these mentioned techniques are not considered to be economically feasible for treating large volumes of wastewaters containing heavy metals at low levels due to the high operational cost, which results from large volumes of chemicals and/or high energy consumption (Gupta *et al.*, 2000; Kurniawan *et al.*, 2006). Lime precipitation has been found to be one of the most effective heavy metal removal techniques, if the heavy metal concentration is higher than 1000 mg/L; however, it still requires a large amount of lime and produces a large quantity of residue (Kurniawan *et al.*, 2006). Treatment of a large volume of dilute wastewater with solvent extraction leads to the loss of the solvent and the high cost of the energy (Fillipi *et al.*, 1998). In ion exchange, the resins used are susceptible to fouling by high suspended solids and an initial metal concentration greater than 100 mg/L is required to achieve complete removal (Kurniawan *et al.*, 2006). Although electrolytic processes have a great advantage of the possibility of the metal recovery in a pure solid form, most of them are ineffective at low heavy metal concentrations due to the low mass-transfer rate, leading to high energy consumption (Elsherief, 2003). Although membrane processes, such as reverse osmosis (RO), are technically suitable for treating dilute waste solutions, their

permeability decreases over the time due to the membrane fouling. As environmental regulations tighten, new techniques are needed for removing metal ions from a dilute wastewater as a polishing step after the conventional separation process (Qu *et al.*, 2009; Doyle, 2003; Fang and Yang, 2010). For example, the allowable limits for cadmium in industrial effluent discharged into a watercourse legislated by the pollution control department of Thailand and Singapore are 0.03 mg/L (Notification the Ministry of Science, Technology and Environment, 1996) and 0.1 mg/L (National Environment Agency, 2000), respectively.

In removing trace heavy metal ions from a dilute wastewater with large volume, ion flotation or ion foam fractionation appears to be particularly promising (Wang *et al.*, 2008; Doyle, 2003; Perry and Green, 2007). The foam fractionation of ions called “ion foam fractionation” is similar to ion flotation but uses an excess of surfactant or a proper frother to produce stable foam (Rubio *et al.*, 2002). Ion foam fractionation was found to offer high metal removal ( $\approx 100\%$ ) at a low feed metal concentration (50 mg/L) with both low chemical and energy costs (Kurniawan *et al.*, 2006). Foam fractionation is based on the selective adsorption or attachment of materials onto the surfaces of foam or froth generated by gas bubbles rising through a solution (Prudich, 2007). This process offers many advantages for the treatment of industrial wastewaters compared to other treatment processes, including low space and energy requirements, simple plant design, operation, and scale-up, and low capital and operating costs (Wong *et al.*, 2001).

Most of studies of ion foam fractionation were in lab scale with a single stage and batch mode of operation while a few of them were carried out in continuous mode. The main problem of ion foam fractionation is that nearly complete removal ( $>99\%$ ) always yields a large volume of foamate with a low heavy metal enrichment ratio while dry foam always comes with low heavy metal removal efficiency (Qu *et al.*, 2008; Scorzelli *et al.*, 1999; Polat and Erdogan, 2007). Only one study focused on process design to reduce the interstitial liquid or liquid hold-up in the foam (Kinoshita *et al.*, 2007). The separation efficiency of multistage foam fractionation for the recovery of cetylpyridinium chloride (CPC), a cationic surfactant, from water was found to be much higher than that in a single-stage system, especially in terms of the enrichment ratio and % recovery of the CPC (Boonyasuwat *et al.*, 2005). Further

development of ion foam fractionation equipment and processes is still needed to improve the separation efficiency by reducing liquid hold-up in the foam without causing foam collapse. In this study, continuous multistage foam fractionation with bubble-cap trays was developed for the removal of trace heavy metals.

## 1.2 Objectives

The main objective of this study was to assess the operational parameters affecting the process performance and to elucidate the process mechanism of continuous multistage foam fractionation with bubble-cap trays for removal of trace heavy metals in simulated wastewater. The overall objectives of this work were as follows:

1. To demonstrate continuous multistage ion foam fractionation with bubble-cap trays for the removal of Cd as a model heavy metal at ppm concentration levels from simulated wastewater.
2. To study the effects of operational parameters of the continuous multistage ion foam fractionation on the separation efficiency of Cd and surfactant.
3. To investigate the effects of added ions on the separation efficiency of Cd.

## 1.3 Scope of Work

In this study, sodium dodecyl sulphate (SDS) was used to generate the foam and cadmium was used as a model heavy metal to be removed from simulated wastewater at ppm levels. The surface tension isotherm of SDS of the system was measured to investigate the surfactant adsorption behaviour. The operational zone of the studied multistage ion foam fractionator was constructed for selecting optimum zone for running the ion foam fractionation experiments. The separation performance of the continuous multistage ion foam fractionation was investigated by varying operational parameters: feed SDS/Cd molar ratio, air flow rate, feed flow rate, foam height, and feed Cd concentration.

Inorganic salts including NaCl, NaNO<sub>3</sub>, Na<sub>2</sub>SO<sub>4</sub>, KNO<sub>3</sub>, Mg(NO<sub>3</sub>)<sub>2</sub>, and Ca(NO<sub>3</sub>)<sub>2</sub> were used to investigate their chemical interferences in the separation

efficiency of cadmium at a feed Cd concentration of 10 mg/L. The surface tension isotherms of SDS with various concentrations of different added salts in the presence and absence of 10 mg/L of Cd were used to determine the effects of both added cations and anions on the Cd adsorption on the foam surface in order to correlate with the separation efficiency of cadmium.

To obtain a better understanding of ion foam fractionation by mechanistic modelling of the process, a bubble size distribution in a rising foam and the fraction of collapsed foam returned to column should be measured (Stevenson *et al.*, 2008; Martin *et al.*, 2010). However, for foams with a polydispersed structure, the bubble size distributions obtained by image analysis of photographs taken through a transparent column wall may not be representative of bubble size distributions within the bulk (Stevenson *et al.*, 2008; Cheng and Lemlich, 1983) due to statistical planar sampling bias (Stevenson *et al.*, 2010). Consequently, bubble size measurement and process modelling were not carried out in this study.