

PERFORMANCE EVALUATION OF MULTISTAGE ADSORBER DESIGN FOR
MERCURY REMOVAL FROM PRODUCED WATER

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To my beloved family, thank you!

To my supportive lecturer, thank you.

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ABSTRACT

Management of mercury is really important as it is harmful to the environment and human, even though it exists in low concentration. In order to reduce the mercury emitting to environment, the mercury removal process needs to be developed. Adsorption is the well-known process for mercury removal due to the fact that it has low operating cost, simplicity, high efficiency, potential of adsorbent regeneration, and sludge free process. The mercury removal in the multistage adsorber is preferable compared to single stage adsorber as the total cross-sectional area increases with increasing number of adsorber stages and thus increasing the mercury removal efficiency. In this study, the design of multistage adsorber to remove $\text{CH}_3\text{Hg}(\text{II})$ and $\text{Hg}(\text{II})$ from inlet solution by using the CP adsorbents was investigated so that the optimum amount of CP adsorbent, the number of stages and the optimum contact time for selected mercury removal efficiency can be determined. Optimization of the CP-Pure amount was calculated for selected removal efficiency (i.e. 50, 60, 70, 80, and 90 %) of $\text{CH}_3\text{Hg}(\text{II})$ and $\text{Hg}(\text{II})$ ions for initial concentration of 0.6 g/m^3 treated in various inlet solution volumes. As the inlet solution volume increased, the adsorbent amount increased. The adsorbent amount also increased with increasing the removal efficiency. The treated CP adsorbents were efficient than CP-Pure adsorbent as the adsorption process only needed less amount of treated CP adsorbents to remove $\text{CH}_3\text{Hg}(\text{II})$ and $\text{Hg}(\text{II})$ at the same conditions. The optimum stage number for 99% removal of $\text{CH}_3\text{Hg}(\text{II})$ using CP-Pure adsorbent and inlet solution volume of 2.5 m^3 was four, while the total amount of the CP-Pure adsorbent was 1.64 kg (0.41 kg for each stage). For the same conditions, the same stage number was also obtained for $\text{Hg}(\text{II})$ with the CP-Pure adsorbent amount of 0.13 kg (0.09 kg for each stage). For 99% removal of $\text{CH}_3\text{Hg}(\text{II})$ and $\text{Hg}(\text{II})$ from 0.6 g/m^3 initial concentration and inlet solution volume of 2.5 m^3 , the optimum time was 2.17 and 1.25 min, respectively with four stages.

ABSTRAK

Pengurusan raksa adalah sangat penting kerana ianya berbahaya kepada sekitaran dan manusia, walupun pada kepekatan yang rendah. Untuk mengurangkan pembebasan raksa ke sekitaran, proses penyingkiran raksa perlu dibangunkan. Pejerapan adalah merupakan yang diketahui umum bagi penyingkiran raksa disebabkan kosnya yang rendah, mudah, mempunyai kecekapan yang tinggi, potensi penjanaan semula, dan proses bebas enapcemar. Penyingkiran raksa menggunakan penjerap berbilang peringkat adalah lebih baik berbanding dengan penjerap satu peringkat. Dalam kajian ini, rekabentuk penjerap berbilang peringkat bagi penyingkiran $\text{CH}_3\text{Hg}(\text{II})$ and $\text{Hg}(\text{II})$ dari larutan suapan dengan menggunakan penjerap CP telah dikaji bertujuan untuk menentukan kuantiti optimum penjerap, bilangan peringkat dan masa sentuhan optimum bagi kecekapan penyingkiran terpilih dapat ditentukan. Pengoptimuman jumlah *CP-Pure* telah dikira bagi kecekapan penyingkiran terpilih (i.e. 50, 60, 70, 80, and 90 %) ion $\text{CH}_3\text{Hg}(\text{II})$ dan $\text{Hg}(\text{II})$ untuk kepekatan awal 0.6 g/m^3 pada pelbagai isipadu larutan suapan. Kuantiti penjerap meningkat dengan kenaikan isipadu larutan suapan. Kuantiti penjerap juga meningkat dengan kenaikan kecekapan penyingkiran. Penjerap CP terawat adalah lebih cekap berbanding dengan *CP-Pure* kerana kuantiti penjerap CP terawat yang diperlukan adalah kurang bagi penyingkiran $\text{CH}_3\text{Hg}(\text{II})$ and $\text{Hg}(\text{II})$ yang dijalankan pada keadaan yang sama. Bilangan peringkat yang optimum bagi penyingkiran 99% $\text{CH}_3\text{Hg}(\text{II})$ menggunakan penjerap *CP-Pure* dan 2.5 m^3 isipadu larutan suapan ialah empat, sementara jumlah kuantiti penjerap *CP-Pure* ialah 1.64 kg (0.41 kg bagi setiap peringkat). Untuk keadaan yang sama, bilangan peringkat yang sama diperolehi bagi $\text{Hg}(\text{II})$ dengan kuantiti penjerap *CP-Pure* ialah 0.13 kg (0.09 kg bagi setiap peringkat). Untuk penyingkiran 99% $\text{CH}_3\text{Hg}(\text{II})$ dan $\text{Hg}(\text{II})$ dari kepekatan awal 0.6 g/m^3 dan 2.5 m^3 isiapdu larutan suapan, masa optimum ialah masing-masing 2.17 dan 1.25 min dengan empat peringkat.

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LIST OF SYMBOLS

g	-	gram
hr	-	hour
m ³	-	Cubic meter
kg	-	Kilogram
>	-	more than
Q _e	-	Amount of metal ion adsorbed at initial (mg/g)
O ₁	-	Amount of metal ion adsorbed at final (mg/g)
K _f	-	Freundlich constants denoting adsorption capacity (l ⁿ mg ¹⁻ⁿ /g)
T	-	Temperature
S	-	Entropy
P	-	Pressure
ΔG	-	Gibbs energy
G	-	Solution to be treated (kg)
C _o	-	initial pollutant concentration (g/m ³)
C _e	-	Final pollutant concentration (g/m ³)
L	-	Amount of solvent (kg)
K	-	equilibrium constant (m ³ /g)

LIST OF ABBREVIATIONS

CP	-	Coconut pith
BB	-	Black B
RR	-	Reactive Red
MPETS	-	Mercaptopropyltriethoxyl Silane
CH ₃ Hg	-	Methyl Mercury
Hg	-	Mercury
HgCl ₂	-	Mercury Chloride
CH ₃ HgCH ₃	-	Dimethyl Mercury
C ₂ H ₅ HgC ₂ H ₅	-	Diethyl Mercury
Cl ⁻	-	Chloride
HgS	-	Mercury Sulfide
HgO	-	Mercury Oxide
TLCP	-	Toxicity Characterization Leach Procedure
USEPA	-	US Environmental Protection Agency

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CHAPTER 1

INTRODUCTION

1.1 Research Background

Usually, mercury removal processes are installed either in industries or treatment processes aim to reduce the concentration of mercury. One of the most common methods from recent technologies that have been developed to remove mercury from hydrocarbon streams is the use of adsorbents. Examples are active carbon adsorbent, metal oxides or sulfide adsorbents, polymer with thiol groups and much more. Recently, the adsorption technique has been successful and widely applied to industrial and domestic water purification (Ofomaja *et al.*, 2013). Adsorption is becoming more popular because of low cost, simplicity, high efficiency, potential for regeneration and sludge free operation.

Batch adsorbers are extensively applied in the adsorption process. They often yield important kinetic and equilibrium data useful for further fixed bed studies and for predicting industrial adsorber performance. For batch adsorber design, the amount of adsorbent required to remove by a given percentage of the pollutant need to be optimized. This is to improve the efficiency of the adsorber and decrease the size of the batch adsorber and its cost (Rijith *et al.*, 2012). These are the factors that need in

order to study in designing the multistage batch adsorber. Alternatively, mercury from produced water (Hg) and natural gas condensate (CH₃Hg) can be removed by using the multi-stage batch adsorber. So, for this study, the focus will be on designing and also study the performance of the multi-stage batch adsorber. The design procedure will be attempted by prediction the optimum process parameters in batch adsorption such as number of stages, volume and amount of adsorbents. The isotherm model parameters such as capacity will be utilized in setting up the model equation from which the various parameters are optimized. The optimization of contact time for a multistage adsorber design also will be discussed. By the optimization of all the parameters, the performance of multistage adsorber can be evaluated.

1.2 Problem Statement

At present, adsorption is more popular compare to other variety of method such as precipitation, electrolysis, ion exchange and many more. This is because its low cost, simplicity and high efficiency. For sure it also can save time due to high efficiency. Besides that, adsorption method is also sludge free operation. This will not involving the treatment of the sludge after the process and the cost is cut there. Due to cost of adsorbent was increase, many researches find other alternative adsorbent which is really low cost. Besides replace high cost adsorbents with agricultural waste as a new adsorbents such as coconut waste, researchers also design multistage adsorber to reduce the total amount of adsorbent that required to remove metal.

Design for multistage adsorber is preferable compare to single stage because, total cross sectional area will increase with increasing number of adsorber due to parallel connection. So, the efficiency for the adsorption of mercury process will also increase. The effluent concentration also can be minimized and the treatment goal can be determined by choosing appropriate number of adsorbents and optimum operating time. Multistage adsorber also is suitable for treatment of large amount of solution.

1.3 Significance of Study

The significance of this study is to design the multistage adsorber for mercury removal $\text{CH}_3\text{Hg(II)}$ and Hg(II) from produced water and natural gas condensate respectively. The development of a model and a program to calculate the total amount of adsorbent usage, number of stages and total contact time can be a beginning step to apply the design in industrial scale. Besides, the study of the total adsorbent amount, number of stages and contact time will lead towards improvement of efficiency in designing a multistage adsorber.

1.4 Objectives of Study

The purpose of this study are to design the multistage adsorber for mercury removal $\text{CH}_3\text{Hg(II)}$ and Hg(I) from produced water and natural gas condensate respectively by using pure coconut pith (CP) and treated CP. The design involved developing models for optimization amount of adsorbents, optimization number of stages and total adsorbents, and optimization of contact time.

1.5 Scopes of Study

These followings are the scope of the study:

- Reviewing state-of-theory in designing the multistage adsorber system.
- Studying the collected data to design the multistage adsorber design.
- Studying the optimal parameters in designing the multistage adsorber system such as total number of adsorbent, number of stages and contact time.

- The multistage adsorber design is to remove $\text{CH}_3\text{Hg}(\text{II})$ and $\text{Hg}(\text{II})$ from certain amount of inlet solution at initial concentration was $0.6\text{g}/\text{m}^3$ by using pure CP adsorbents and treated CP adsorbents.
- Models are developed during this study to calculate amount of adsorbents, optimum number of stages, and contact time. Calculation is involved.
- Developing the new design incorporating established Langmuir isotherm model, Freundlich isotherm model, and kinetic model for both $\text{CH}_3\text{Hg}(\text{II})$ and $\text{Hg}(\text{II})$.
- Few coding are written to calculate optimum number of adsorbent, optimum number of stages and contact time in MatLab 2014 software.
- MATLab and Microsoft excel are used for calculation and plotting the graphs.

1.6 Dissertation Outline

This dissertation consists of 5 chapters. Chapter 1 describes an introduction parts including background of study, problem statement, objectives, scopes, and significance of study. Chapter 2 briefly reviews the fundamental of mercury, adsorbent, adsorption and design of adsorber. Detailed methodology of new developed design are proposed in chapter 3. The findings of this study are discussed in chapter 4. Chapter 5 concludes the overall study and proposed a few recommendations for future works.

1.7 Summary

The mercury removal technologies have been widely install in many industries to reduce the concentration of mercury. The most method that have been proposed by many researchers is adsorption. Adsorption is the method that are low cost, simple, high efficiency, potential of regeneration and sludge free operation. Design for multistage adsorber is preferable compare to single stage because, total cross sectional area will increase with increasing number of adsorber due to parallel connection. This study focuses on design the multistage adsorber for $\text{CH}_3\text{Hg}(\text{II})$ and $\text{Hg}(\text{II})$ removal from produced water and natural gas condensate respectively

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