Removal of Chromium from Aqueous Stream Using Aluminium Oxide (Synthesized by Simple Precipitation Method) as an Adsorbent

by

Mohd Shafiq bin Ramdan

Dissertation submitted in partial fulfilment of
the requirements for the
Bachelor of Engineering (Hons)
(Chemical Engineering)

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CERTIFICATION OF APPROVAL

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Approved by,

____

(Prof. Dr. Khairun Azizi binti Azizli)

UNIVERSITI TEKNOLOGI PETRONAS
TRONOH, PERAK
January 2006

CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

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(MOHD SHAFIQ BIN RAMDAN)

ABSTRACT

Several studies have been done on discovering the potential of alumina as an adsorbent to remove heavy metal such as chromium. The purpose of this project is to analyse and study effect of initial concentration of chromium, contact time between adsorbent and chromium, and also adsorption kinetics of adsorbent. For this project, to remove chromium from aqueous stream, the potential of aluminium oxide has been explored. Aluminium oxide which was used was synthesized by simple precipitation method where it produced by reaction between aluminium chloride and ammonium hydroxide. The capability of synthesized aluminium oxide to remove chromium by adsorption was compared with commercial aluminium oxide. Based on the FESEM result, the pictures of both morphologies showed that synthesized aluminium oxide had better structure and more uniform pores than commercial aluminium oxide. Batch adsorption kinetic studies showed that the adsorption of chromium ion was strongly affected by initial chromium ion concentration. The amount of chromium ion adsorption on aluminium oxide was increased with initial chromium ion concentration which was from 20 ppm until 80 ppm. It also was found that the amount of adsorption was increased with contact time at a fixed solution pH, amount of adsorbent, initial chromium ion concentration, temperature and velocity of stirring until the equilibrium concentration was achieved at 180 minutes (3 hours). A kinetic experiment for adsorption of chromium ion on aluminium oxide was followed pseudo-second-order kinetics because of higher regression coefficients, R^2 which is 0.9776 and theoretical equilibrium sorption capacity, q_e (17.361 mg/g) was more similar with respect to experimental q_e (14.5473 mg/g). For adsorption isotherm, Langmuir adsorption equations reasonably describe the adsorption isotherm within this chromium ion concentration range. Based on the Langmuir isotherm, R^2 is 0.886. In this project, it was clearly proven that synthesized aluminium oxide was better than commercial aluminium oxide in terms of the morphology and also the capability of adsorbing chromium which adsorbed 14.5473 mg/g and 12.7326 mg/g respectively. As conclusion, considering the high capability of aluminium oxide synthesized by simple precipitation method as an adsorbent of chromium in aqueous solution via adsorption, it

is essential to encourage more researches by manipulating the morphology of aluminium oxide in order to resolve the pollution of chromium in waste water.

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CHAPTER 1

INTRODUCTION

1.1 BACKGROUND STUDY

Chromium compounds are widely used by many modern industries. As a result, a large quantity of this element has been discharged into the environment. Chromium plating, wood preserving, textile dyeing, pigmenting, chromium chemical production, pulp and paper industrial and tanning are common examples of the industry that use chromium in a bulk [1]. Thus, chromium occurs in wastewater resulting from these operations in both trivalent and hexavalent forms. The wastewater resulting from these industry processes contains high amount of chromium which is harmful for environment and human health [2].

In recent years, the development of treatment process to reduce the toxic impact of heavy metals is increasing. This is due to increasingly stringent legislation for the disposal of treated effluents in receiving streams. A lot of methods of wastewater treatment were examined and adsorption emerged as one of the most efficient technique. The use of activated carbon is still widely used. Unfortunately, it is much expensive and the regeneration of the carbon is not always possible. For the removal of heavy metals, considerable research work has been done in the search of low cost adsorbents such as red mud, coconut husk, palm pressed fibers, saw dust, etc. The latest study is the potential of raw rice husk. Risk husk is abundantly available waste byproduct of rice-milling industry in this country, Malaysia [3].

In this research, the potential of aluminium oxide, Al_2O_3 (synthesized by simple precipitation method) as adsorbent have been explored. Aluminum oxide, due to its high surface area and mechanical strength has been found suitable for applications as an adsorbent and catalyst. Laboratory batch adsorption and adsorption kinetic studies are conducted to determine the adsorption capacity of aluminum oxide.

1.2 PROBLEM STATEMENT

1.2.1 Problem Identification

There is potential hazard of chromium ions in wastewater if left untreated. Therefore, the removal of these ions is very important to ensure that the wastewater that will be sent to the main water supply does not contaminate the supply. The common method for removal of chromium ions is via adsorption, with aluminium oxide being the main choice as an adsorbent. In this research, aqueous stream containing chromium ions has been used to replace wastewater and the adsorbent's efficiency was studied for removal of chromium ions from aqueous stream. The efficiency of aluminium oxide synthesized by simple precipitation method as an adsorbent in the adsorption process for the removal of chromium from aqueous stream was studied and evaluated.

1.2.2 Significant of Study

The removal of toxic heavy metal contaminants from wastewater is currently one of the most important environmental issues being researched. Although it has been studied for many years, effective treatment options are still needed. Chemical precipitation, reduction, ion exchange, filtration, electrochemical treatment, membrane technology, reverse osmosis, evaporation removal and solvent extraction are the methods most commonly used for removing toxic metals ions from wastewater [4, 5]. However, most of these technology processes have disadvantages including incomplete metal removal, requirements for expensive equipment, monitoring system, reagent, and energy requirements or producing of toxic sludge or other disposal waste products [6].

From the problem identification, it has been stated that in this research the author will use aluminium oxide as an adsorbent for removal of chromium from wastewater. It is by far the most widely used technique for the removal of toxic metal ions from wastewater. In this research, the parameters affecting the adsorption process such as initial concentration of adsorbate was studied. The equilibrium time was evaluated based on the contact time. The adsorption kinetic was also studied to know the time dependence of adsorption on solid surfaces.

1.3 OBJECTIVES AND SCOPE OF STUDIES

In order to complete this project within the time limit and the scope given, several objectives have been identified.

1. To produce mesoporous aluminium oxide using simple precipitation method.
2. To study the effect of initial chromium concentration on adsorption of chromium from aqueous stream.
3. To study the contact time between aluminum oxide as an adsorbent and chromium as an adsorbate.
4. To study the adsorption kinetics of the aluminum oxide.

CHAPTER 2

LITERATURE REVIEW

2.1 WASTEWATER TREATMENT AND CHROMIUM CONTAMINATION

Chromium has been found in at least 115 of 1300 National Priorities List sites identified by the Environmental Protection Agency (EPA). Chromium does not occur freely in nature. The main chromium mineral is chromite. Chromium compounds can be found in waters only in trace amounts. Chromium metal is applied worldwide in amounts of approximately 20,000 tons per year. It may be polished and it does not oxidize when it comes in contact with air. Wastewater usually contains about 5 ppm of chromium [7].

Chromium exists in nature mainly in two oxidation states, Trivalent and Hexavalent. For trivalent chromium, Cr(III), it has +3 of oxidation number and it is bio element. The hydrolysis behavior of Cr(III) is complicated and it produces mononuclear species $CrOH^{2+}$, $Cr(OH)_2^{+}$, $Cr(OH)_4^{-}$, neutral species $Cr(OH)_3^{0}$, and poly-nuclear species $Cr_2(OH)_2$ and $Cr_3(OH)_4^{5+}$ [8, 9]

In life, trivalent chromium, Cr(III) is a dietary requirement for a number of organisms. The human body contains approximately 0.03 ppm of chromium. Daily intake strongly depends upon feed levels, and is usually approximately 15-200 μg, but may be as high as 1 mg. Chromium uptake is 0.5-1%, in other words very small. The placenta is the organ with the highest chromium amounts. Meanwhile, in water, Chromium is largely bound to floating particles. The LC_{50} (Lethal Concentration 50) value for chromium in sea fish lies between 7 and 400 ppm, for daphnia at 0.01-0.26 ppm, and for algae at 0.032-6.4 ppm. Most of chromium (III) compounds are water insoluble because these are largely bound to floating particles in water. Chromium (III) oxide and chromium (III) hydroxide are the only water soluble compounds. Therefore, concentrations in natural waters are limited. Cr^{3+} ions are rarely present at pH values over 5, because hydrated chromium oxide ($Cr(OH)_3$) is hardly water soluble [7]. The legal discharge limit of Cr(III) varies from 0.5 mg/l (in surface water) to 2.0 mg/l (in sewers) depending on the processing, country, and wastewater treatment methods [10].

Another oxidation states of chromium is hexavalent chromium, Cr(VI). Hexavalent chromium, Cr(VI) is a mutagenic and has +6 of oxidation number. For hexavalent chromium, Cr(VI), it exists primarily as salts of chromic acid (H_2CrO_4), hydrogen chromate ion ($HCrO_4^-$) and chromate ion (CrO_4^{2-}) depending on the pH [8, 9].

Chromium (VI) compounds are stable under aerobic conditions, but are reduced to chromium (III) compounds under anaerobic conditions. The reverse process is another possibility in an oxidizing environment. Therefore, the most common method applied for chromium (VI) control is reduction of Cr(VI) to its trivalent form in acid ($pH \approx 2.0$) and subsequent hydroxide precipitation of Cr(III) by increasing the pH to ≈9.0–10.0 using lime [6].

Hexavalent chromium is very toxic to flora and fauna. Chromium water pollution is not regarded one of the main and most severe environmental problems. Therefore, as a result, discharging chromium polluted untreated wastewater in rivers has caused environmental disasters in the past [7].

Chromium (VI) compounds are divided up in water hazard class 3, and are considered very toxic. Lime or phosphate in soils may further decrease chromium susceptibility. Air-dried soil generally contains 2-100 ppm of chromium. Chromium solubility in soil water is lower than that of other potentially toxic metals. This explains the relatively low plant uptake. Under normal conditions plants contain approximately 0.02-1 ppm chromium (dry mass), although values may increase to 14 ppm. In mosses and lichens, relatively high chromium concentrations can be found. The guideline for chromium is agricultural soils is approximately 100 ppm [7].

Hexavalent chromium is known for its negative health and environmental impact, and its extreme toxicity. It causes allergic and asthmatic reactions, is carcinogenic and is 1000 times as toxic as trivalent chromium. Health effects related to hexavalent chromium exposure include diarrhoea, stomach and intestinal bleedings, cramps, and liver and kidney damage. Hexavalent chromium is mutagenic. Toxic effects may be passed on to children through the placenta. Chromium (VI) oxide is a strong oxidant. Upon dissolution chromium acid is formed, which corrodes the organs. It may cause cramps and paralysis. The lethal dose is approximately 1-2 g. Most countries apply a legal limit of 50 ppb chromium in drinking water [7].

In industry, tanning process is one of the biggest and oldest in the world that uses chromium as the major compound in its process. Tanning process using chromium compounds is one of the most common methods for processing of hides [11]. In this process about 60% - 70% of chromium reacts with the hides. Only about 30%-40% of the chromium amount remains in the solid and liquid wastes (especially spent tanning solutions). Hence, it is important to make sure that heavy metal such as chromium has to be removed from waste water to make sure that the environment is not polluted and it can not be harmful to human health [4, 5].

From Table 2.1, it is clearly shown that chromium compounds are widely used in electroplating, metal finishing, magnetic tapes, pigments, leather tanning, wood protection, chemical manufacturing, brass, electrical and electronic equipment, catalysis and so on [12]. Contaminants from industrial wastewater rich in heavy metal ions remain an important environmental issue. Based on the Table 2.2, although control technologies have been applied to many industrial and municipal sources, the total quantity of these agents released to the environment still remains staggering [13].

Table 2.1: Industrial processes that produce aqueous effluents rich in chromium and other heavy metals

Industry source	**Al**	**Zn**	**As**	**Sn**	**Sb**	**Cd**	**Cr**	**Cu**	**Fe**	**Hg**	**Mn**	**Pb**	**Ni**	**Bi**
Automobile		X		X		X	X		X			X	X	
Petroleum refining		X	X				X	X	X			X	X	
Pulp and paper		X					X	X		X		X	X	
Textile							X							
Steel		X	X		X	X	X		X			X	X	
Organic chemicals	X	X	X	X		X	X		X	X		X		
Inorganic chemicals	X	X	X			X	X		X	X		X		
Fertilizer	X	X	X			X	X	X	X	X	X	X	X	
Plastic and synthetics									X					
Leather tanning and finishing							X							
Steel power plants		X					X							
Mining			X			X		X		X	X	X		
Acid mine drainage	X	X						X	X		X			
Metal plating		X				X	X	X						
Glass			X											
Nuclear power														X
Coal and gasoline										X		X		X

Table 2.2: Total quantity of these agents released to the environment (in 1000 metric tones/year)

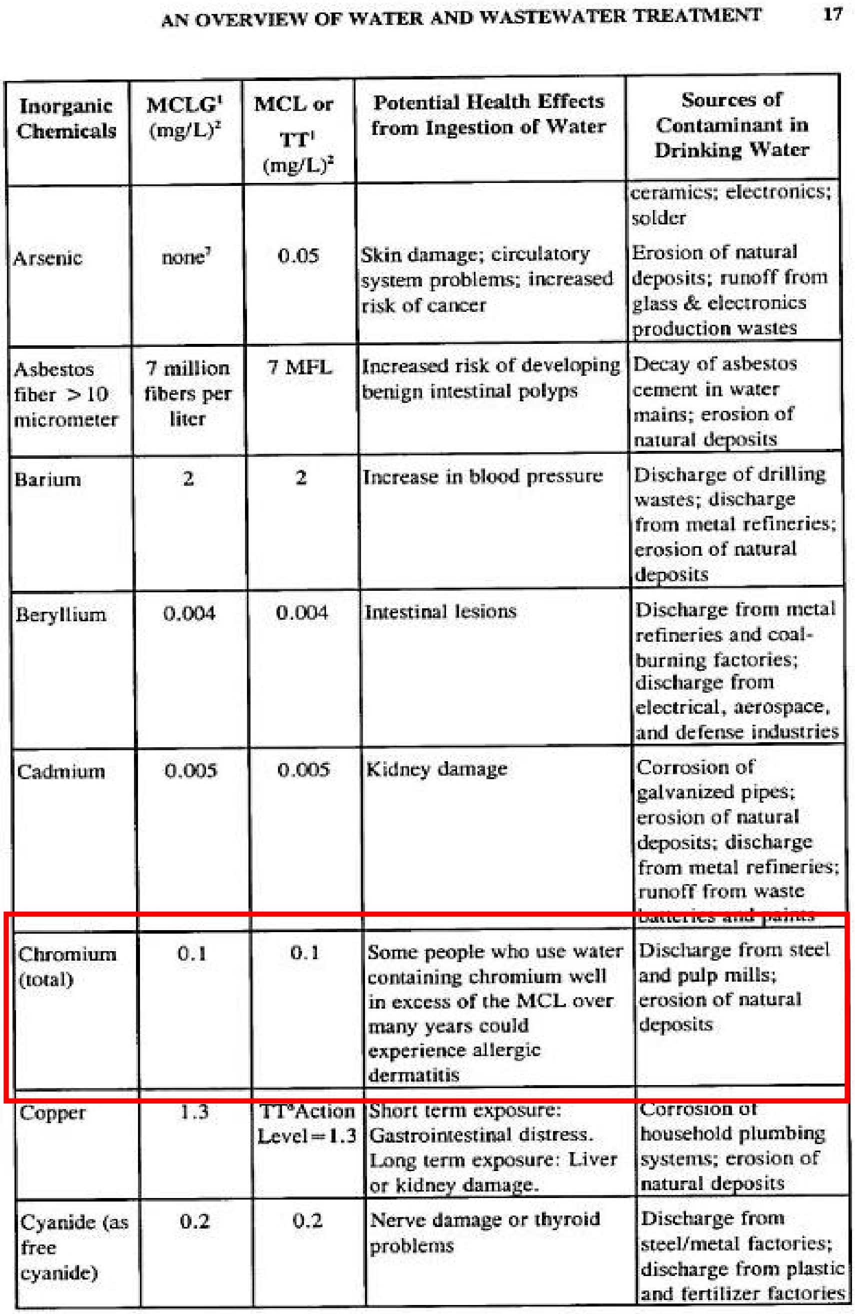
Metals	**Water**	**Air**	**Soil**
Arsenic	41	19	82
Cadmium	9.4	7.4	22
Chromium	142	30	896
Copper	112	35	954
Lead	138	332	796
Mercury	4.6	3.6	8.3
Nickel	113	56	325
Selenium	41	3.8	41
Tin	ND	6.4	ND
Zinc	226	132	1372

Chromium (VI) oxide is an example of an excellently water soluble chromium compounds, solubility = 1680 g/L. The drinking water guideline recommended by Environmental Protection Agency (EPA) in US is 100 µg/l [10].

After reviewing health effects studies, EPA sets a Maximum Contaminant Level Goal (MCLG), the maximum level of a contaminant in drinking water at which no known or anticipated adverse effect on the health of human would occur, and which allows a sufficient margin of safety. Since MCLGs consider only public health and not the limits of detection and treatment technology, sometimes the industry are set at a level which water systems can not meet. When determining an MCLG, EPA consider the risk to sensitive subpopulations such as infants, children, the elderly and those with compromised immune system of experiencing a variety of adverse health effects. Table 3 provides the summary of the NPDWRs or primary standards for drinking water [14].

The levels in Table 2.3 were established due to the fact that these contaminants can have adverse effect on human health. Thus, it is important for a wastewater treatment system to be able to remove as much contaminants as possible in compliance with the MCLG provided by the EPA.

Table 2.3: An overview of water and wastewater treatment



AN OVERVIEW OF WATER AND WASTEWATER TREATMENT 17

Inorganic Chemicals	MCLG[1] (mg/L)[2]	MCL or TT[1] (mg/L)[2]	Potential Health Effects from Ingestion of Water	Sources of Contaminant in Drinking Water
Arsenic	none[7]	0.05	Skin damage; circulatory system problems; increased risk of cancer	ceramics; electronics; solder Erosion of natural deposits; runoff from glass & electronics production wastes
Asbestos fiber >10 micrometer	7 million fibers per liter	7 MFL	Increased risk of developing benign intestinal polyps	Decay of asbestos cement in water mains; erosion of natural deposits
Barium	2	2	Increase in blood pressure	Discharge of drilling wastes; discharge from metal refineries; erosion of natural deposits
Beryllium	0.004	0.004	Intestinal lesions	Discharge from metal refineries and coal-burning factories; discharge from electrical, aerospace, and defense industries
Cadmium	0.005	0.005	Kidney damage	Corrosion of galvanized pipes; erosion of natural deposits; discharge from metal refineries; runoff from waste batteries and paints
Chromium (total)	0.1	0.1	Some people who use water containing chromium well in excess of the MCL over many years could experience allergic dermatitis	Discharge from steel and pulp mills; erosion of natural deposits
Copper	1.3	TT[8]Action Level=1.3	Short term exposure: Gastrointestinal distress. Long term exposure: Liver or kidney damage.	Corrosion of household plumbing systems; erosion of natural deposits
Cyanide (as free cyanide)	0.2	0.2	Nerve damage or thyroid problems	Discharge from steel/metal factories; discharge from plastic and fertilizer factories

(Source: Cheremisinoff, *Handbook of Water and Wastewater Treatment Technologies, Poluttion Engineering,* Butterworth-Heinemann)

2.2 ADSORPTION PROCESS

Numerous treatment methods such as ion exchange [15], reduction [16], chemical precipitation [17], membrane separations [18], electrochemical precipitation [19], photocatalytic reduction [20], adsorption [21], and biosorption [22] have been developed for chromium remediation. The precipitation, oxidation/ reduction, and lime neutralization have traditionally been the most commonly used. Although these processes are quite satisfactory in terms of purging chromium from water but they produce solid residue (sludge) containing toxic compounds whose final disposal by land filling generally with relative high costs and still a possibility of ground water contamination.

However, many of these approaches are slightly cost-effective or difficult to implement in developing countries. Therefore, the need exists for a treatment strategy that is simple, robust, and that addresses local resources and constraints. Sorption which includes adsorption as well as biosorption may be an effective method for removing chromium. This solves the problems of toxic sludge disposal and renders the system more economically viable, especially if low cost adsorbents are used.

Basically, adsorption is the adhesion of molecules of gas, liquid, or dissolved solids to a surface [23]. This process creates a film of the adsorbate (the molecules or atoms being accumulated) on the surface of the adsorbent. It differs from absorption, in which a fluid permeates or is dissolved by a liquid or solid [24]. The term sorption encompasses both processes, while desorption is the reverse of adsorption. Adsorption, ion exchange, and chromatography are sorption processes in which certain adsorbates are selectively transferred from the fluid phase to the surface of insoluble, rigid particles suspended in a vessel or packed in a column.

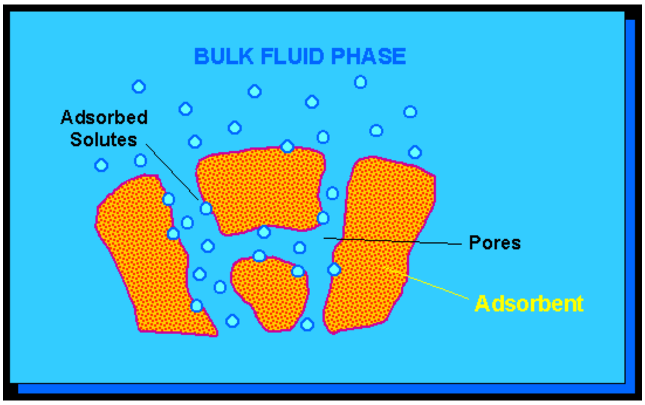


Figure 2.1: Illustration of adsorption process

Similar to surface tension, adsorption is a consequence of surface energy. Figure 2.1 shows that in a bulk material, all the bonding requirements of the constituent atoms of the material are filled by other atoms in the material. However, atoms on the surface of the adsorbent are not totally surrounded by other adsorbent atoms and therefore can attract adsorbates. The exact nature of the bonding depends on the details of the species involved, but the adsorption process is generally classified as physisorption (characteristic of weak van der Waals forces) or chemisorption (characteristic of covalent bonding) [25].

Adsorbent presents in many natural physical, biological, and chemical systems, and is widely used in industrial applications such as activated charcoal; capturing and using waste heat to provide cold water for air conditioning and other process requirements (adsorption chillers), synthetic resins; increase storage capacity of carbide-derived carbons for tunable nanoporous carbon and water purification, coconut shells, and new finding showed that fish scales also can be one of the adsorbent [26].

Adsorption is usually described through isotherms. Basically, it is the amount of adsorbate on the adsorbent as a function of its pressure (if gas) or concentration (if liquid) at constant temperature. The quantity adsorbed is nearly always normalized by the mass of the adsorbent to allow comparison of different materials.

2.2.1 Adsorption Isotherm

Adsorption isotherms are developed by exposing a given amount of adsorbate in a fixed volume of liquid to various amount of aluminium oxide. To determine the adsorption isotherm for the process, Equation 2.1 is used [27].

$$q_t = \frac{(C_0 - C_t)V}{m} \qquad \text{(Eq. 2.1)}$$

Where,

q_t = Amount of metal ion adsorbed, mg adsorbate/g adsorbent

C_0 = Initial concentration in the solution at t=0, mg/L

C_t = Final equilibrium concentration in the solution at t=t, mg/L

V = Volume of solution, L

m = Mass of adsorbent, g

2.3 ALUMINIUM OXIDE AS AN ADSORBENT

For an efficient adsorption process, the criterions of adsorbent are very significant. The followings are the selection criterions for adsorbent [25, 26]:

1. High selectivity to enable sharp separations
2. High capacity to minimize amount adsorbent needed
3. Favorable kinetic and transport properties for rapid sorption
4. Chemical and thermal stability to preserve amount and its properties
5. Hardness and mechanical strength
6. High fouling resistance
7. Capability of being regenerated - relatively low cost

Aluminium oxides and clay minerals such as kaolin are the most widespread minerals of the earth crust which are known to be good adsorbent of various metal ions, inorganic anions and organic ligands [28-32]. In general, most solid phases in natural water contain aluminium oxides. Aluminium oxides play an important role in regulating the composition of soil water, sediment-water and other natural water systems [33, 34]. Aluminium oxide, due to its high surface area and mechanical strength has found several applications as an adsorbent and catalyst.

The acid–base properties of aluminium oxide are the main reason for its wide applications. Another reason for this interest is that importance of adsorption on solid surfaces in many industrial applications in order to improve efficiency and economy.

Conventional mesoporous Al_2O_3 also known as γ-Al_2O_3 composed of a mixture of macro, meso, and micropores in rough sizes. Based on the previous researches, micropores are easily plugged by undesirable cokes that are more or less formed during adsorption process. As a result, it will disturb the diffusion of process. Besides, in adsorption process, adsorbent like existing γ-Al_2O_3 which has wider pore-size distribution are prone to rapid deactivation. Thus, it is very important to synthesize porous aluminium oxide with high surface area and narrow pore size distribution is a mesoporous region as a adsorbent to be utilized in numerous large-scale industrial processes [35].

Basically several methods have been used to synthesize aluminium oxide. Sol-gel technique is one of the methods to produce mesoporous aluminium oxide and this method is well established nowadays [36, 37]. However, in this process, aluminium alkoxides or boehmite powders that have been used as one of raw materials are expensive. To decrease the cost of producing mesoporous aluminium oxide, inexpensive salt raw materials have been used to replace aluminium alkoxides as aluminium precursor [38-41].

CHAPTER 3

METHODOLOGY

3.1 RESEARCH METHODOLOGY

Figure 3.1 shows several important methodologies that were done in this project.

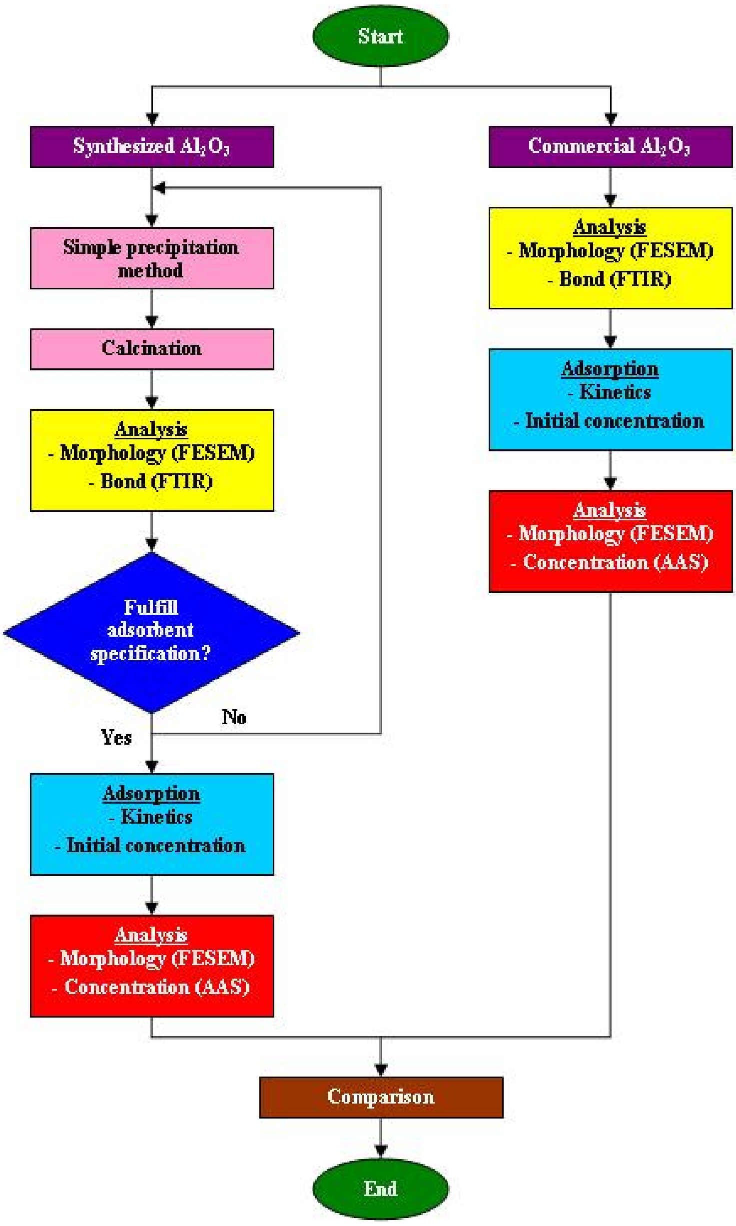


Figure 3.1: Several important methodologies in this project

3.2 PROJECT ACTIVITIES

In this project, the author had synthesized own adsorbent which was aluminium oxide by using inexpensive aluminium salt by easy precipitation method. This synthesized aluminium oxide was used as adsorbent in adsorption process. From Equation 3.1, to synthesized aluminium oxide, aluminium chloride was added with ammonium hydroxide to form aluminium hydroxide and ammonium chloride [42].

$$AlCl_3\,(aq) + 3\,NH_4OH\,(aq) \rightarrow Al(OH)_3\,(s) + 3\,NH_4Cl\,(aq) \qquad (Eq.\ 3.1)$$

Aluminium hydroxide that has been precipitated has to be dehydrated to form dehydrated aluminium hydroxide for a day (24 hours). Aluminium hydroxide dehydrated then has been grinded to increase the contact area of adsorption. After dehydrated aluminium hydroxide was grinded and powdered, it had to be calcined in the furnace at high temperature around 700°C to form aluminium oxide as shown in Equation 3.2 [43].

$$2\,Al(OH)_3 \rightarrow Al_2O_3 + 3\,H_2O \qquad (Eq.\ 3.2)$$

The adsorbent was tested by using FESEM and FTIR to observe the physical properties and its morphology. The adsorbent then was tested in a laboratory for adsorption process to check the effect of initial chromium concentration to the rate of adsorption. The study of adsorption contact time and adsorption kinetics has been conducted to ensure the effectiveness of the synthesized aluminium oxide with the commercial aluminium oxide as a control experiment.

From the simple precipitation method that was used, besides the aluminium hydroxide as the main product, ammonium chloride also was produced. Ammonium chloride as a supernate substance in this precipitation method was very useful in other industry. Industry such as agriculture (nitrogen source in fertilizers), medicine (expectorant in cough medicine), and also food (food additive) were using ammonium chloride widely. This was very important to not let any wasteful.

3.3 PRECIPITATION PROCEDURE

1. 2 Molar of $AlCl_3$ was inserted into a clean beaker.
2. About 40 mL of NH_4OH was inserted into the burette.
3. NH_4OH in the burette was added drop wise into the beaker contain $AlCl_3$ until formation of slurry was observed.
4. NH_4OH was added more into the beaker until formation of solid precipitate was observed.
5. The solid was washed with distilled water to remove any unreacted $AlCl_3$.
6. The solid moist was dried in oven at temperature of 120°C for 24 hours until complete moisture was removed.
7. The solid moist was grinded using grinder until the solid became very fine powder.
8. The grinded solid was sieved through 500-1000 micrometer mesh.
9. The solid then was calcined in the furnace at temperature of 700°C for 2 hours.
10. Al_2O_3 that was prepared was sent for FESEM and FTIR tests.

3.4 ADSORPTION PROCEDURE

Removing chromium from aqueous stream by using adsorption was conducted after the adsorbent was prepared earlier. Synthesized aluminium oxide was used as an adsorbent in this adsorption process. For every adsorption process that was done, commercial aluminium oxide was taken into consideration as control experiment. The following was the procedure for studies on removal of chromium using adsorption process:

3.4.1 Preparation of 1000 ppm of Chromium Chloride, $CrCl_3$

Parts per Million Conversions

1000 ppm = 1 g/L

Molecular Weight

Cr	= 51.996 g/mol
Cl	= 35.453 g/mol
MW of salt $CrCl_3$	= 158.355 g/mol

1 g of Cr in relation to $CrCl_3$ = 158.355/51.996
= 3.0455 g

Hence, to prepare 1000 ppm solution of Cr standard solution, 3.0455 g of $CrCl_3$ was weighted out and dissolved in 1 liter of distilled water.

Dilution Formula

$$M_1V_1 = M_2V_2 \qquad \text{(Eq. 3.3)}$$

Where,

M_1 = Concentration of Cr standard solution
V_1 = Volume of Cr standard solution
M_2 = Required Cr concentration
V_2 = Volume of new Cr concentration

Table 3.1 shows the summary of several calculation of different concentration by using dilution formula (Equation 3.3).

Table 3.1: Several calculation of different concentration

M_1	V_1	M_2	V_2
1000 ppm	2.5 mL	50 ppm	50 mL
1000 ppm	5 mL	100 ppm	50 mL
1000 ppm	4 mL	80 ppm	50 mL
1000 ppm	3 mL	60 ppm	50 mL
1000 ppm	2 mL	40 ppm	50 mL
1000 ppm	1.5 mL	30 ppm	50 mL
1000 ppm	1 mL	20 ppm	50 mL
1000 ppm	0.5 mL	10 ppm	50 mL
1000 ppm	0.25 mL	5 ppm	50 mL

`

3.4.2 Effect of Initial Chromium Concentration and Knowing Contact between Chromium and Aluminium Oxide.

1. Five conical flasks of 100 mL chromium chloride, $CrCl_3$ solutions were prepared by using the standard solution (1000 ppm) at the initial concentrations of 20 ppm, 40 ppm, 60 ppm and 80 ppm.
2. The solutions was set at pH 5 and placed over mechanical shaker at 160 rpm at 27ºC ± 2ºC. At time zero, 1.0 g of granular synthesized aluminium oxide was added to the respective conical flask.
3. 5 ml samples of each solution were withdrawn from the conical flask at known time intervals (0.5, 1.0, 1.5, 2.0, 2.5, and 3.0 hr). Contact time was used for batch tests.
4. Step 1 until 3 was repeated with the commercial aluminium oxide used as adsorbent.

3.4.3 Adsorption Kinetics of the Aluminum Oxide.

1. A conical flask of 500 mL with the concentration of 40 ppm of chromium chloride solutions were prepared by using the standard solution (1000 ppm).
2. The solutions was set at pH 5 and placed over mechanical shaker at 120 rpm at 27ºC ± 2ºC. At time zero, 1.0 g of synthesized aluminium oxide was added to the conical flask.
3. Samples were taken every 10 minutes for 3 hours. It was done to ensure the adsorption had attained equilibrium.
4. Step 1 until 3 was repeated with the commercial aluminium oxide used as adsorbent.
5. Aluminium oxide that was used was not thrown away since it was tested for FESEM.

3.5 SOURCES AND HARDWARE NEEDED

3.5.1 Apparatus

Oven, porcelain container/dish, furnace, Field Emission Scanning Electron Microscope (FESEM), Fourier Transform Infrared Spectroscopy (FTIR), Atomic Absorption Spectroscopy (AAS), mechanical shaker, bottle sample (100 mL), pipette, burette, cylinder measurement (1000 mL), volumetric flask (1000 mL), cylinder measurement (500 mL), conical flask (500 mL), filter paper, beaker (250 ml), electronic balance, dropper, and spatula.

3.5.2 Field Emission Scanning Electron Microscope (FESEM)

Conventional light microscopes use a series of glass lenses to bend light waves and create a magnified image. FESEM creates the magnified images by using electrons instead of light waves. The FESEM shows 3-dimensional images at much higher magnifications. The images are very detailed. The images created without light waves are rendered black and white [44]. It can be used to estimate the pore size of the activated carbon quantitatively. Pore entrances, clearly visible as dark irregular shapes on lighter membrane background.

3.5.3 Fourier Transform Infrared Spectroscopy (FTIR)

Fourier Transform Infrared Spectroscopy (FTIR) is a tool that recognizes types of functional groups in a molecule. FTIR is used to identify chemicals that are either organic or inorganic. By interpreting the infrared absorption spectrum, the functional groups in a molecule can be determined. FTIR spectra of pure compounds are so unique that they are called a molecular "fingerprint". Organic compounds have very rich, detailed spectra where else inorganic compounds are usually much simpler. Bonds and groups of bonds vibrate at specific frequencies. A molecule that is exposed to infrared rays absorbs infrared energy at frequencies which are specific to that molecule. FTIR spectroscopy does not require a vacuum condition since neither oxygen nor nitrogen can absorb infrared rays. FTIR analysis can be applied to small quantities of materials, whether solid, liquid, or gaseous [45].

3.5.4 Atomic Absorption Spectroscopy (AAS)

The atomic absorption spectrometry uses absorption of light of intrinsic wavelengths by atoms. All atoms are classified into those having low energies and those having high energies. The state having low energies is called the ground state and the state having high energies is called the excited state. The difference between energies in the ground state and in the excited state is fixed by the element and wavelength of light to be absorbed.

3.6 MATERIALS/ CHEMICALS

Aluminium chloride ($AlCl_3$), ammonium hydroxide (NH_4OH), distilled water, chromium chloride ($CrCl_3$), and aluminium oxide (Al_2O_3).

CHAPTER 4

RESULTS AND DISCUSSION

Based on the experiment that was conducted, there are two types of aluminium oxide that have been used. Synthesized aluminium oxide was produced experimentally and it was tested in adsorption process to be compared with commercial aluminium oxide as the controlled experiments.

4.1 TEXTURAL CHARACTERIZATION OF ALUMINIUM OXIDE

4.1.1 FTIR

A quantitative analysis of aluminium oxide was conducted by obtaining FTIR transmission spectra of samples. The adsorption capacity of aluminium oxide depends upon porosity as well as the chemical reactivity of functional groups at the surface. This reactivity creates an imbalance between forces at the surface as compared to those within the body, thus leading to molecular adsorption by the Van der Waals force.

Knowledge on surface functional groups would give insight to the adsorption capability of the synthesized aluminium oxide. FTIR spectra were collected for qualitative characterization of surface functional groups of synthesized aluminium oxide.

Figure 4.1 and Figure 4.2 shows the results of FTIR obtained for commercial and synthesized aluminium oxide respectively.

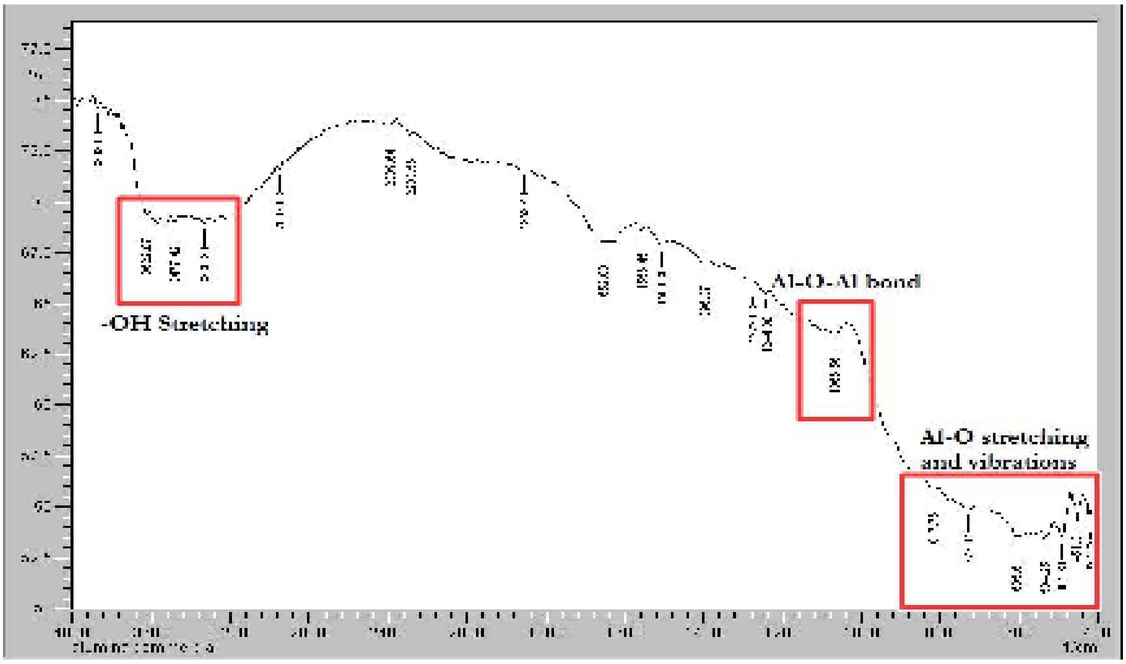


Figure 4.1: Infrared spectra of commercial aluminium oxide

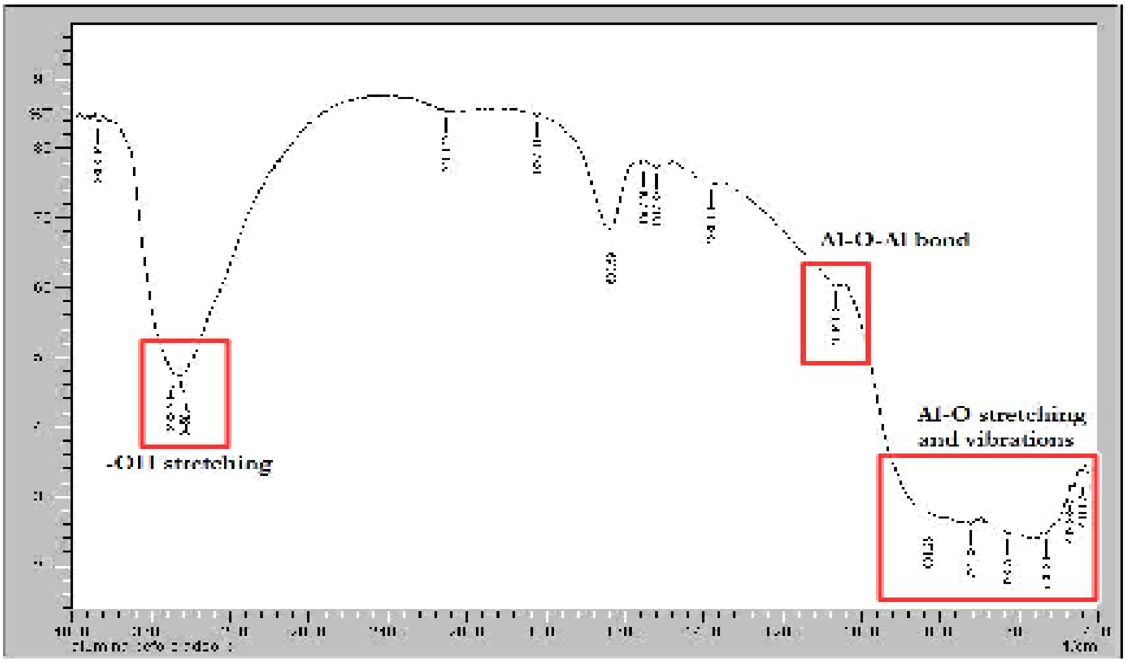


Figure 4.2: Infrared spectra of synthesized aluminium oxide

Commercial and synthesized aluminium oxide spectrums are similar and show no obvious differences between each other. The broad band at 3200-3700 cm^{-1} indicates the stretching vibration of the –OH group bonded to Al cation and peak at 1633 cm-1 corresponds to water of hydration for both types of aluminium oxide. The peak at 1065 cm^{-1} is corresponded to Al–O–Al symmetric bending stretching vibrations while bands at 462 cm^{-1} and 617 cm^{-1} mean the bending and stretching modes of AlO_6. Peak at 721 cm^{-1} and 831 cm^{-1} may be due to Al–O stretching vibrations [46].

Figure 4.3 shows the FTIR spectra of boehmite (γ-AlOOH) and it is quite similar with the FTIR analysis for synthesized aluminium oxide [46].

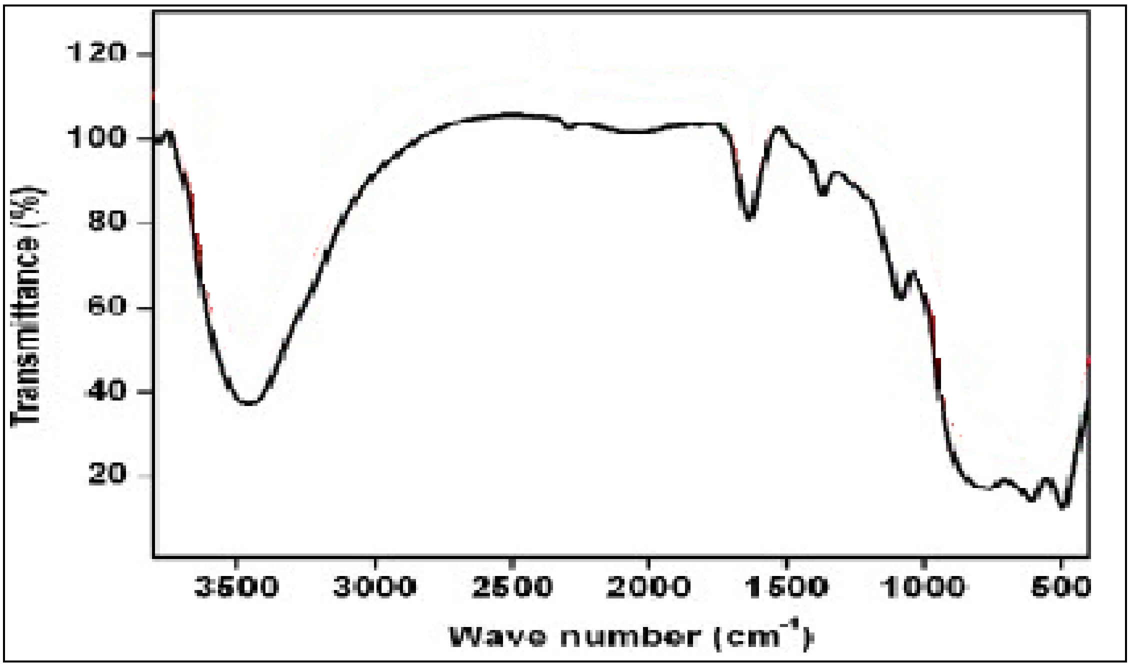


Figure 4.3: Infrared spectra of boehmite

4.1.2 FESEM

For the characterization of aluminium oxide by FESEM, the samples were examined. FESEM gives the overblown 3D images with high resolution. The images were magnified with electrons instead of light waves for 50000 and 30000 times. The images showed that there were quite a number of small pores that were important for adsorption.

Figure 4.4 shows the difference between pores existing on the commercial aluminium oxide and synthesized aluminium oxide before the adsorption process. These pores proved the capability of adsorption; however, at this stage, it was unknown whether these pores would support the maximum adsorption process.

Based on Figure 4.4, the structures of pores for synthesized aluminium oxide were more uniform than commercial aluminium oxide and it is expected to have the capability of adsorption.

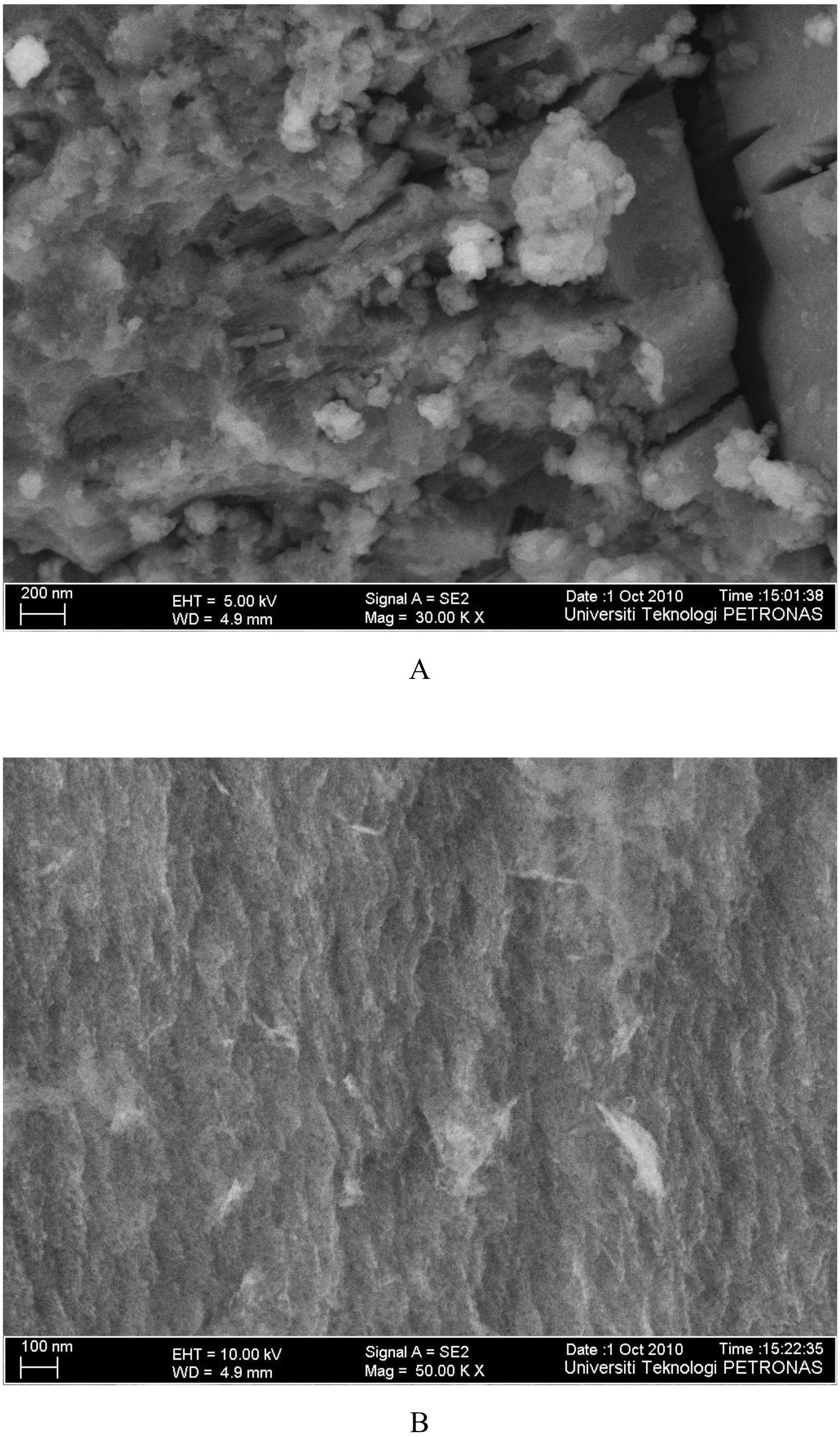


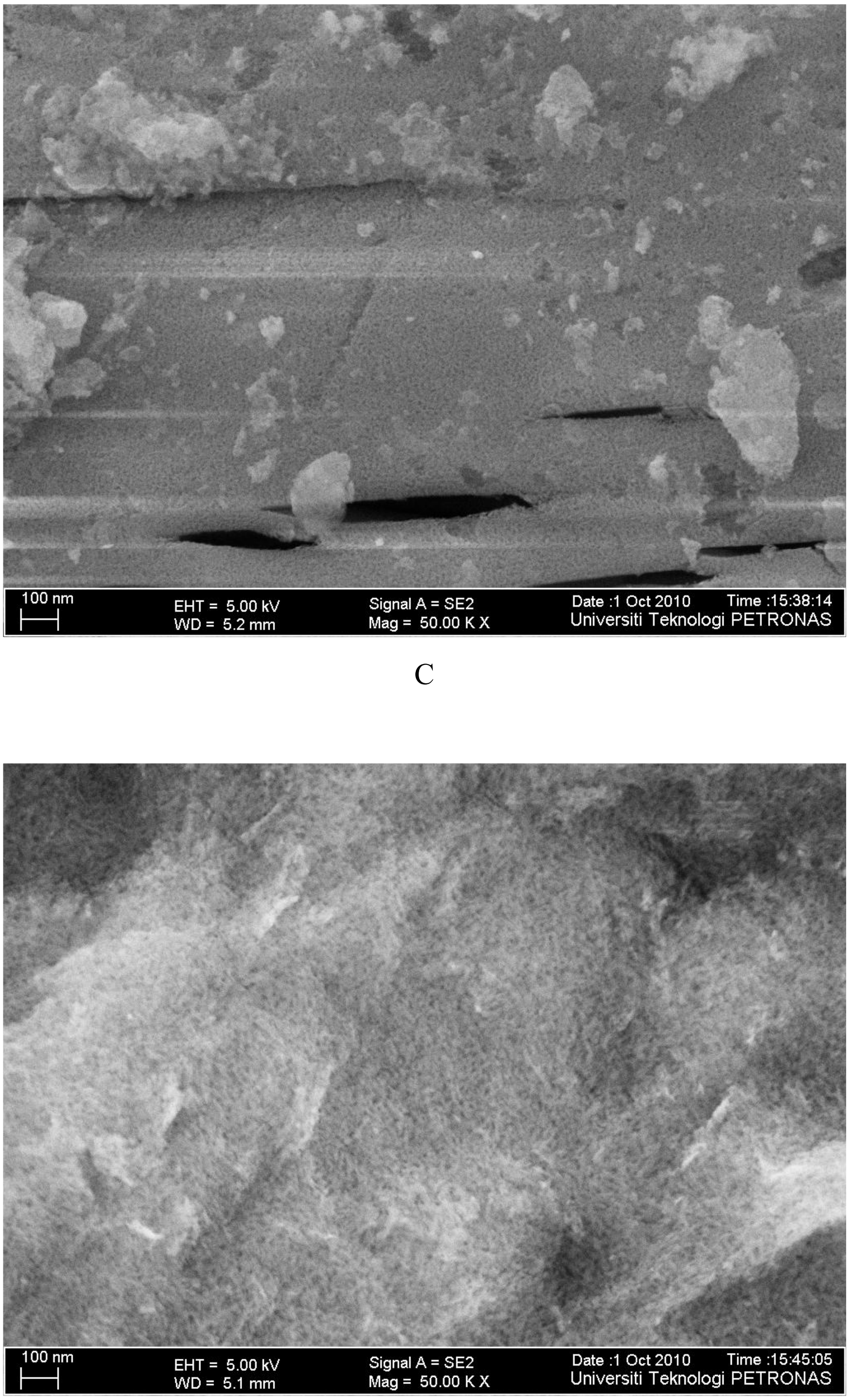
Figure 4.4: A – Commercial Aluminium Oxide, B – Synthesized Aluminium Oxide

4.2 CHARACTERIZATION OF ALUMINIUM OXIDE AFTER ADSORPTION

The adsorption process towards removal of chromium was evaluated based on the morphology of aluminium oxide after the adsorption process, contact time, effects of initial solution concentration, and the comparison of adsorption kinetics between commercial aluminium oxide and synthesized aluminium oxide.

The experiment was conducted using $CrCl_3$ aqueous solution instead of normal waste water due to time constraint and safety purpose. Figure 4.5 shows the difference between pores on the commercial aluminium oxide and synthesized aluminium oxide after adsorption process.

The morphology of both aluminium oxide showed that there were chromium adsorbed in aluminium oxide. Since synthesized aluminium oxide clearly had more uniform pores structure, it was observed that more chromium ions were adsorbed in synthesized aluminium oxide than commercial aluminium oxide.



C

D

Figure 4.5: C – Commercial Aluminium Oxide, D – Synthesized Aluminium Oxide

These images showed that the ability of the synthesized aluminium oxide to adsorb was higher due to higher number of pores. The structures were more complex with more pores that formed chambers to capture foreign ions and more uniformed. Thus, it increased the capacity of adsorption. Therefore, synthesized aluminium oxide was better adsorbent than commercial aluminium oxide.

For contact time and adsorption kinetics, Equation 4.1 expresses the chromium uptake capacity of aluminium oxide to acknowledge the amount of chromium uptake at time, t by calculating the difference between the initial and final chromium concentration and multiplying it by a volume of solution over mass of aluminium oxide used [47].

$$q_t = \frac{(C_0 - C_t)V}{m} \qquad \text{(Eq. 4.1)}$$

Where,

q_t = Amount of chromium ion adsorbed, mg/g

C_0 = Initial chromium concentration at t=0, mg/L

C_t = Chromium concentration in the solution at t=t, mg/L

V = Volume of chromium chloride solution, L

m = Amount of aluminium oxide added, g

In order to investigate the mechanism of adsorption, particularly potential rate-controlling step, the transient behavior of the chromium ion (Cr^{3+}) adsorption process was analyzed using the pseudo-first-order and pseudo-second-order. Then the adsorption equilibrium isotherm was determined.

4.3 EFFECTS OF INITIAL CHROMIUM CONCENTRATION

The effect of concentration of the chromium ion was observed by varying the chromium concentrations in the range of 20 ppm, 40 ppm, 60 ppm, and 80 ppm. The temperature and pH of solution was held constant 27ºC ± 2 ºC and pH 5 respectively. The mixture of solution and adsorbent was continuously stirred at 160 rpm. The control experiment for this adsorption was conducted by using commercial aluminium oxide instead of synthesized aluminium oxide. For evaluation in Atomic Absorption Spectroscopy (AAS), a sample of 5mL of the mixture was extracted at the time interval of 0.5, 1.0, 1.5, 2.0, 3.0 hr.

Based on Figure 4.6, by using commercial aluminium oxide, at 20 ppm, 40 ppm, 60 ppm, and 80 ppm, the amount of chromium adsorbed were 1.36272 mg/g, 2.54651 mg/g, 4.10716 mg/g and 5.50508 mg/g respectively. The amount of chromium adsorbed was higher when the concentration was increased from 20 ppm to 80 ppm.

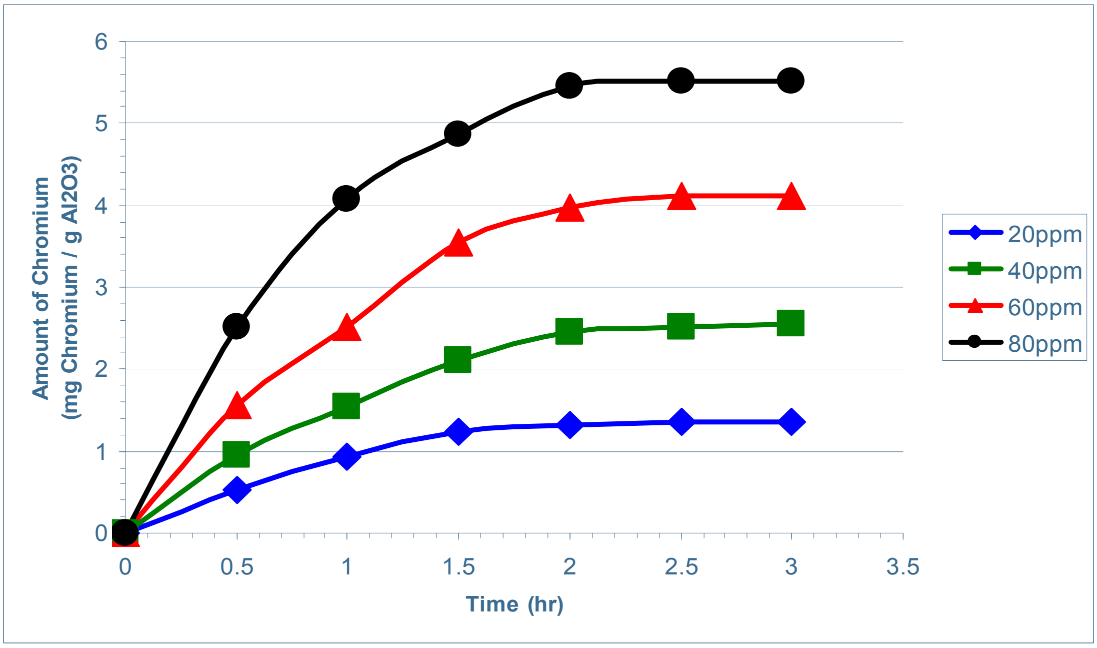


Figure 4.6: Effect of chromium initial concentration by using commercial aluminium oxide

Figure 4.7 shows the amount of chromium adsorbed by using synthesized aluminium oxide with different initial concentrations of chromium which were at 20 ppm, 40 ppm, 60 ppm, and 80 ppm. Based on the Figure 4.7, the amount of chromium adsorbed are 1.76272 mg/g, 2.90946 mg/g, 4.57716 mg/g and 6.10508 mg/g respectively with the initial concentrations.

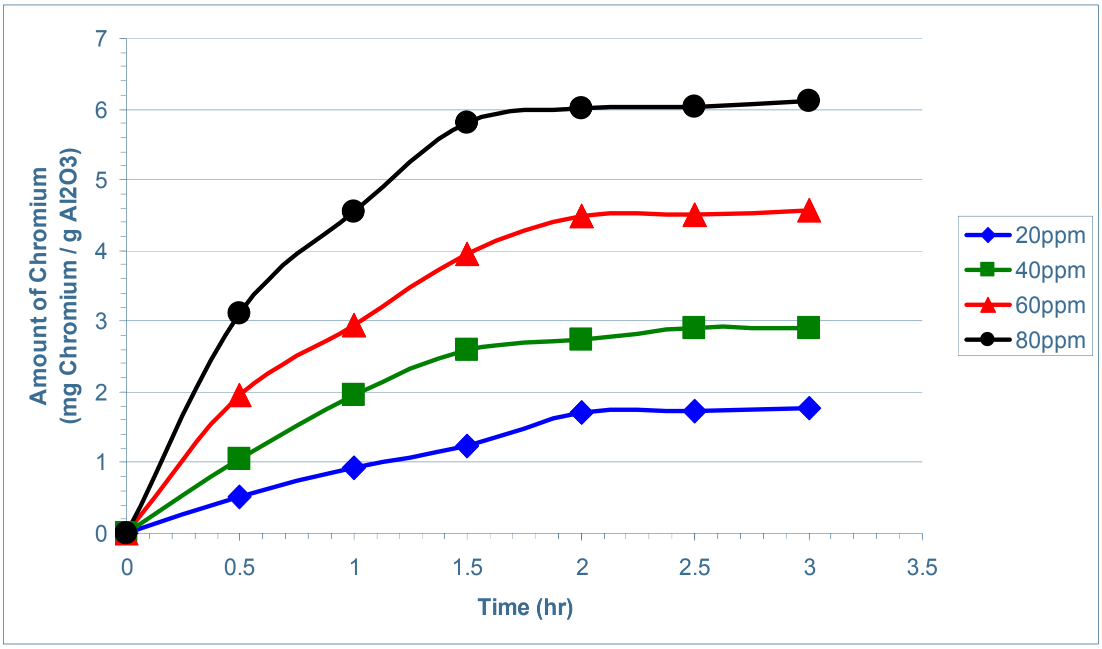


Figure 4.7: Effect of chromium initial concentration by using synthesized aluminium oxide

From this plot, it is obvious that the amount of chromium adsorbed by using synthesized aluminium oxide is higher than commercial aluminium oxide. Besides, it is clearly observed that initial concentration of chromium have effects on the adsorption process.

Initially, the active surface sites of the adsorbent are rapidly occupied with the chromium ions. This is because in the beginning, active surface sites are vacant and are readily available to be occupied by chromium ions.

Chromium ions interacted easily with the active sites where more chromium ions were adsorbed. In other words, more chromium ions were removed from the aqueous solution [48]. The scenario of the rapid interaction between chromium ions and adsorbent active sites increases the amount of chromium adsorbed onto the adsorbent. Therefore, the trend approaching 1.5 hours has higher slope, indicating that adsorption is faster.

Towards 2 hours, the amount of chromium started to reduce and became constant till it reached 3 hours, indicating that the process has reached the end of adsorption process. This is due to the surface of adsorbent been saturated with the chromium ions. Since the amount of adsorbent used was constant at 1.0 g, the active surface sites were limited. Therefore, the adsorption of chromium onto the adsorbent was also limited. The more chromium ions accumulated onto the adsorbents, the lower the numbers of vacant active sites. As a result, this shows that the initial concentration of the solutions affects the adsorption capacity of the chromium ions onto the aluminium oxide.

4.4 EFFECT OF CONTACT TIME

Figure 4.8 represents a plot of the amount of chromium ion adsorbed (mg/g) versus contact time for commercial aluminium oxide with fixed initial concentration of chromium which was 40 ppm. The temperature and pH of solution were held constant 27ºC ± 2 ºC and pH 5 respectively. The mixture of solution and adsorbent were continuously stirred at 160 rpm. From these plots, it was found that the amount of adsorption (mg of adsorbate per gram of adsorbent) at equilibrium was attained within 3 hours (180 minutes). The amount of chromium adsorbed at equilibrium was approximately 12.7326 mg/g.

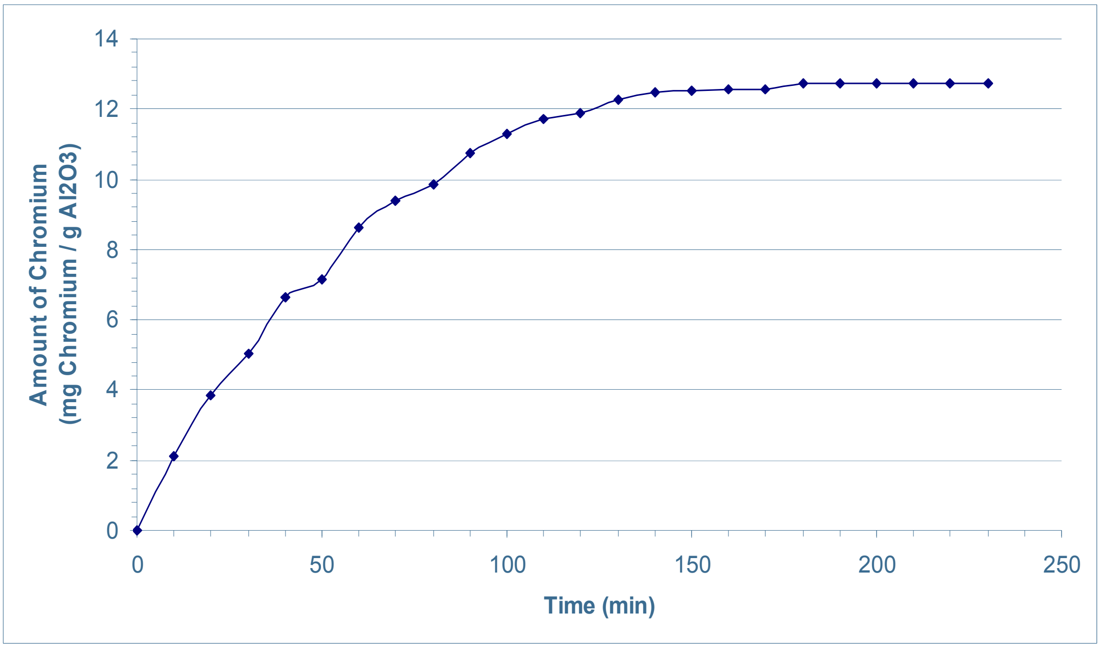


Figure 4.8: The contact time of chromium ion adsorption using commercial aluminium oxide

The same adsorption process was conducted but using different adsorbent. Commercial aluminium oxide was replaced by synthesized aluminium oxide. Figure 4.9 represents the amount of chromium ion adsorbed (mg/g) by synthesized aluminium oxide at similar parameters. For these plots, it was found that the amount of adsorption (mg of adsorbate per gram of adsorbent) at equilibrium was attained within 3 hours (180 minutes). The amount of chromium adsorbed at equilibrium was approximately 14.5473 mg/g.

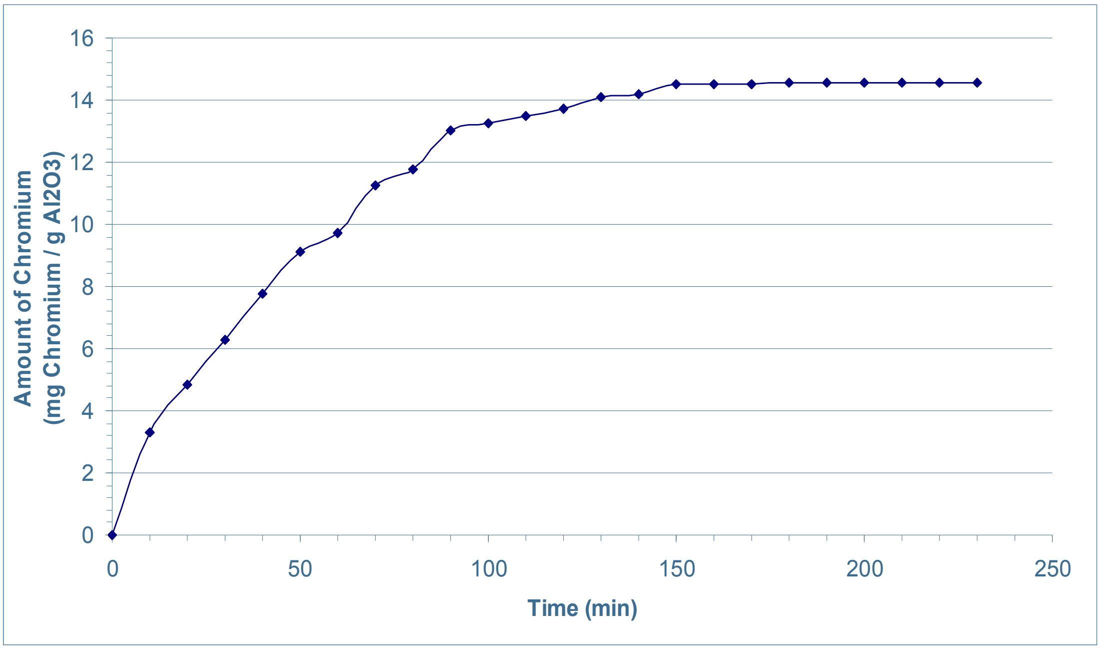


Figure 4.9: The contact time of chromium ion adsorption using synthesized aluminium oxide

In order to investigate the contact time and mechanism of adsorption, particularly potential rate-controlling step, the transient behavior of the chromium ion (Cr^{3+}) adsorption process was analyzed using the pseudo-first-order and pseudo-second-order.

4.4.1 Lagergren Pseudo-First-Order Kinetics

The chromium ion adsorption kinetics following the pseudo-first-order model is given by Equation 4.2 [47]

$$\frac{dq}{dt} = K_1(q_e - q_t) \qquad \text{(Eq 4.2)}$$

Where,

q_e = Amount of metal ion adsorbed at t=0, mg/g

q_t = Amount of metal ion adsorbed at t=t, mg/g

K_1 = Adsorption rate constant (min^{-1})

Integrating Equation 4.2 for the boundary conditions t=0 to t=t and q=0 to $q=q_t$ gives the Equation 4.3

$$\log(q_e - q_t) = \log q_e - \frac{K_1 t}{2.303} \qquad \text{(Eq. 4.3)}$$

Thus, the rate constant, K_1 (min^{-1}) can be obtained from the plot of log ($q_e - q_t$) versus time t which is shown in Figure 4.10 (commercial aluminium oxide) and Figure 4.11 (synthesized aluminium oxide) with poor linear regression coefficient, R_1 of 0.972 and 0.9258 respectively.

For adsorption of chromium using commercial aluminium oxide, the rate constant, K_1 was 0.0279 min^{-1}. Meanwhile, for adsorption of chromium using synthesized aluminium oxide, the rate constant, K_1 was 0.0341 min^{-1}

Based on the poor linear regression coefficient for both adsorbent, it is clear that this adsorption does not follow pseudo-first-order model.

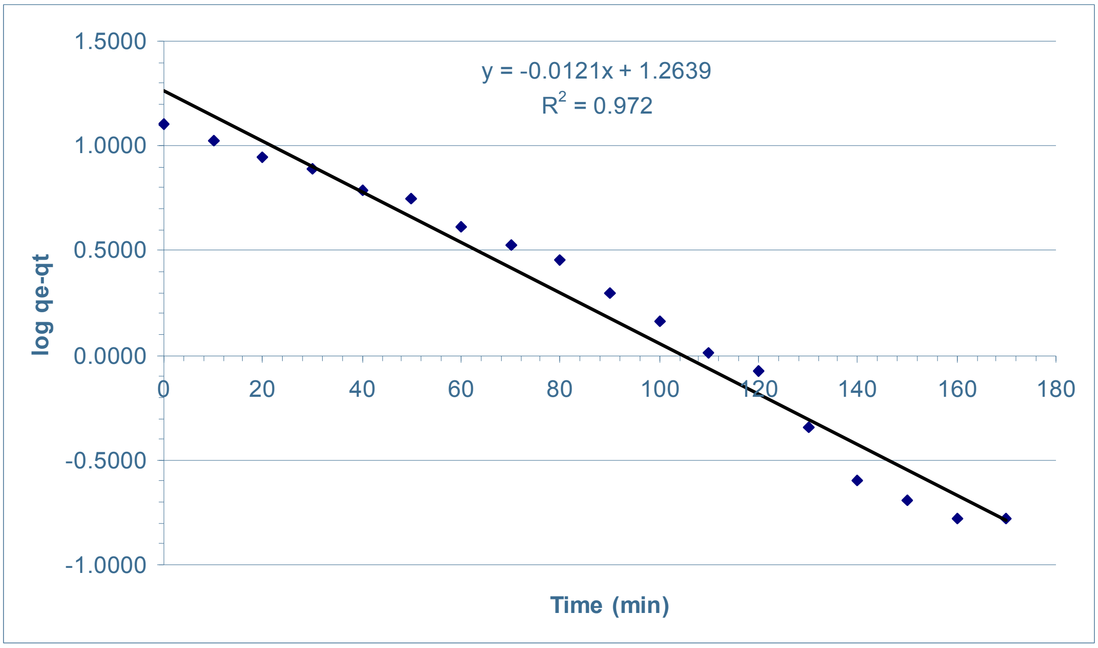


Figure 4.10: Pseudo-first-order model for chromium adsorption using commercial aluminium oxide

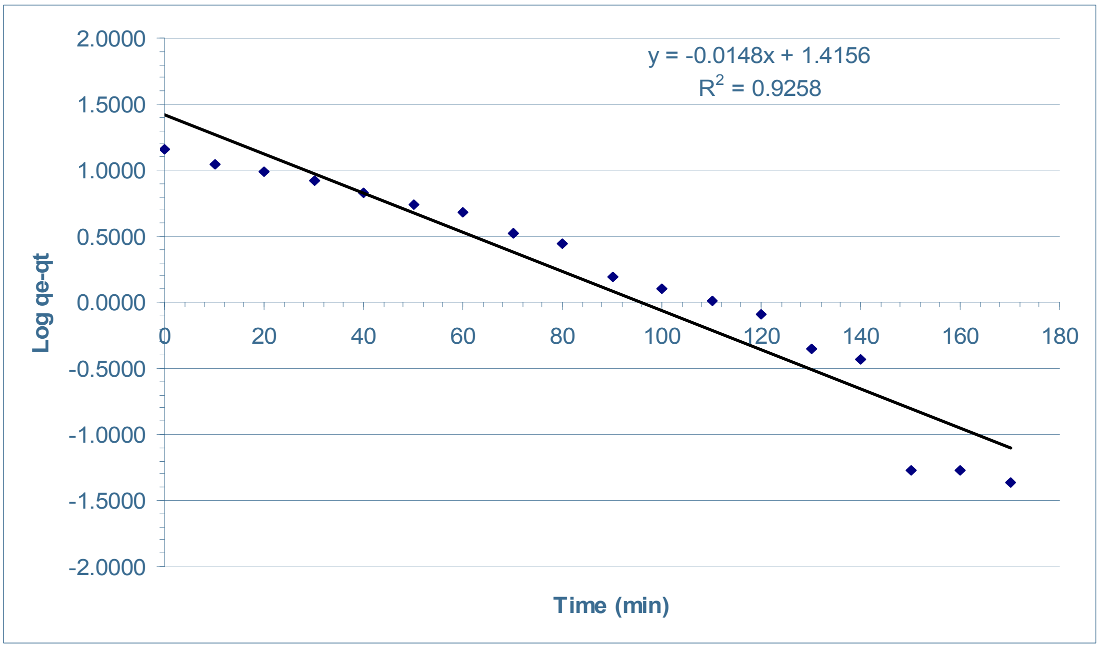


Figure 4.11: Pseudo-first-order kinetics model for chromium adsorption using synthesized aluminium oxide

4.4.2 Lagergren Pseudo-Second-Order Kinetics

The adsorption data was then analyzed in terms of pseudo-second-order mechanism, described by Equation 4.4 [47]

$$\frac{dq}{dt} = K_2(q_e - q_t)^2 \qquad \text{(Eq. 4.4)}$$

Where,

K_2 = Pseudo-second-order rate constant, g/mg.min

Integrating Equation 4.4 for the boundary conditions t=0 to t=t and q=0 to $q=q_t$ gives Equation 4.5

$$\frac{t}{q_t} = \frac{1}{K_2 q_e^2} + \frac{1}{q_e} t \qquad \text{(Eq. 4.5)}$$

A plot between t/q_t versus t gives the value of the constants, K_2 (g/mg.hr) and also q_e (mg/g). The constant, K_2 shown in Equation 4.6, is used to calculate the initial adsorption rate, h at $t \rightarrow 0$,

$$h = K_2 q_e^2 \qquad \text{(Eq. 4.6)}$$

Thus, the rate constant, K_2, initial adsorption rate, h and predicted amount of chromium ions adsorbed, q_e can be calculated from the plot of t/q_t versus time t by using Equation 4.5. Figure 4.12 and Figure 4.13 represent the kinetic plots between t/q_t versus time t for chromium adsorption at fixed initial chromium concentrations, adsorbent dosages, solution pH and temperature, but using different type of aluminium oxide. High regression coefficients, R_2 suggest that the adsorption experiment follows pseudo-second-order kinetics. The initial sorption rate is $h = K_2 q_e^2$.

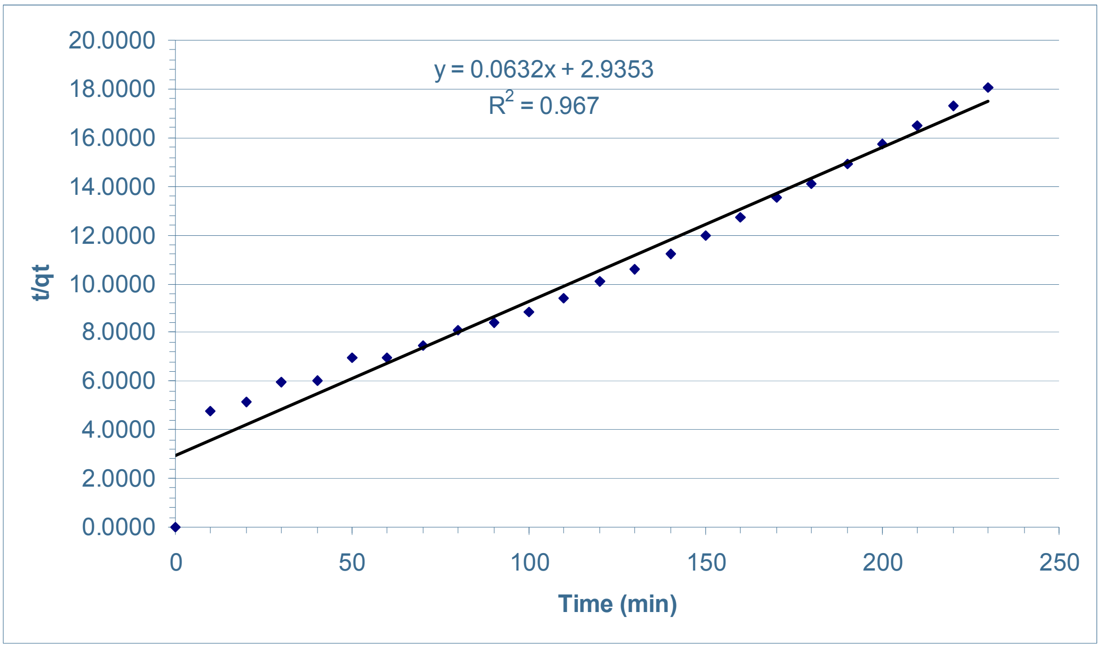


Figure 4.12: Pseudo-second-order kinetics model for chromium adsorption using commercial aluminium oxide

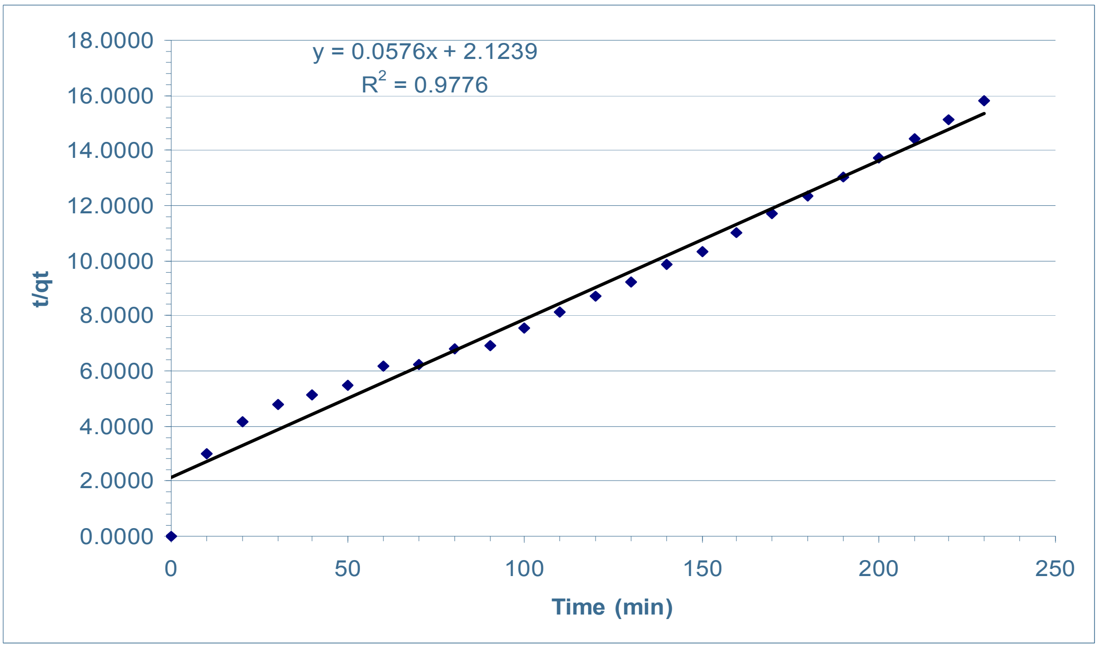


Figure 4.13: Pseudo-second-order kinetics model for chromium adsorption using synthesized aluminium oxide

All parameters including the correlation coefficients, R_2, the pseudo-second-order rate constant, K_2 and K_1, theoretical and also experimental equilibrium sorption capacity, q_e, were calculated and tabulated in Table 4.1. Theoretical and experimental equilibrium sorption capacity in pseudo-second-order kinetics is more similar if to be compared with pseudo-first-order. Higher correlation coefficients with respect to fitted pseudo first-order reaction model suggest that adsorption of chromium ion on aluminium oxide follows the pseudo-second-order kinetics. It also suggests that the chromium ion adsorbed process is due to chemisorptions. The assumption is that the rate-limiting step might be chemisorptions involving valence forces through sharing or exchange of electrons between adsorbent and adsorbate [47]. As the correlation coefficients are very high as shown in Table 4.1, it might also be assumed that adsorption of chromiun ions occurred through chemisorption.

Table 4.1: Summary of Lagergren pseudo-order kinetics based on contact time

Kinetics model	**Adsorbent**	**R^2**	**K_2 (g/mg.min)**	**q_e (theoretical) (mg/g)**	**q_e (experimental) (mg/g)**
Second	Commercial Al_2O_3	0.9670	0.00136	15.823	12.7326
Second	Synthesized Al_2O_3	0.9776	0.00156	17.361	14.5473
Kinetics model	**Adsorbent**	**R^2**	**K_1 (min^{-1})**	**q_e (theoretical) (mg/g)**	**q_e (experimental) (mg/g)**
First	Commercial Al_2O_3	0.9720	0.0279	18.361	12.7326
First	Synthesized Al_2O_3	0.9258	0.0341	26.038	14.5473

4.5 ADSORPTION EQUILIBRIUM ISOTHERM

The most appropriate method in designing the adsorption systems is to have an idea on adsorption isotherm. Therefore the adsorption equilibrium data were fitted for Langmuir-2 and Freundlich isotherms within chromium ion concentration range 20 ppm, 40 ppm, 60 ppm, and 80 ppm, respectively. Linear regression was used to determine the most fitted isotherm.

4.5.1 Freundlich Adsorption Isotherm

The Freundlich adsorption isotherm, which assumes that adsorption takes place on heterogeneous surfaces, can be expressed as per Equation 4.7 [47]

$$\ln q_e = \ln K_f + \frac{1}{n}(\ln C_e) \qquad \text{(Eq. 4.7)}$$

Where,

q_e = Amount of chromium adsorbed at equilibrium time

C_e = Equilibrium concentration of chromium ion in solution.

K_f = Capacity of the adsorption

n = Rate of the adsorption

The capacity and rate of adsorption can be calculated from the intercept and slope of plot between ln q_e and ln C_e. Figure 4.14 shows result on Freundlich isotherm fittings for commercial aluminium oxide with R^2 is 0.969. Freundlich constants such as adsorption capacity, K_f, and rate of adsorption, n, were calculated from these plots which were 0.1955 and 0.981, respectively.

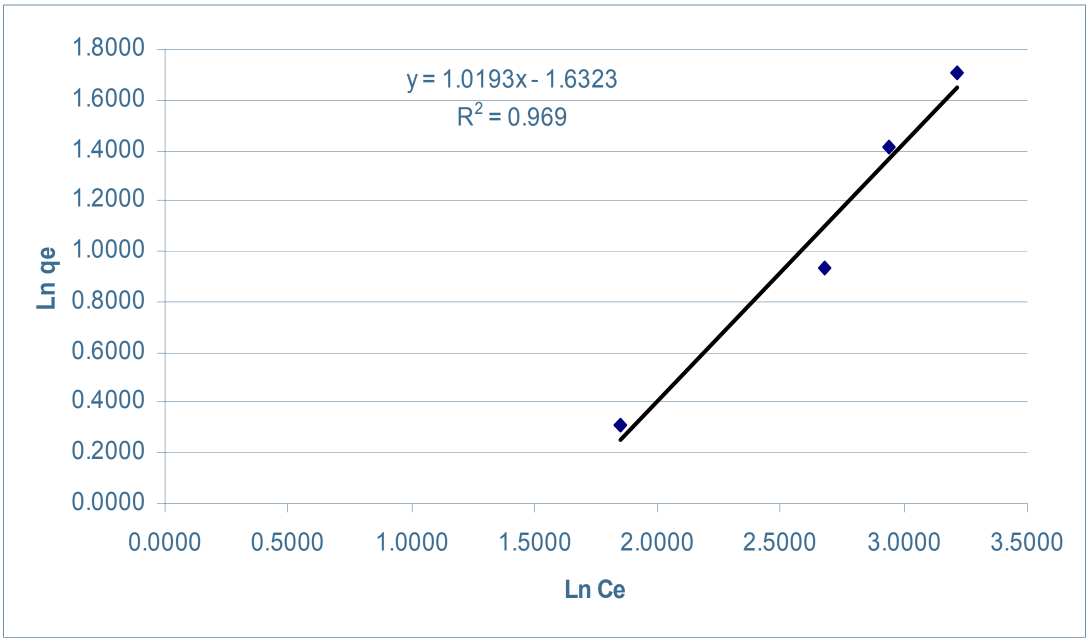


Figure 4.14: Freundlich isotherm plot for commercial aluminium oxide

For synthesized aluminium oxide, the result on Freundlich isotherm fittings for this adsorbent is shown in Figure 4.15 with R^2 is 0.8794. For this adsorbent, the value of adsorption capacity, K_f, and rate of adsorption, n, were calculated to be 1.0253 and 1.819, respectively.

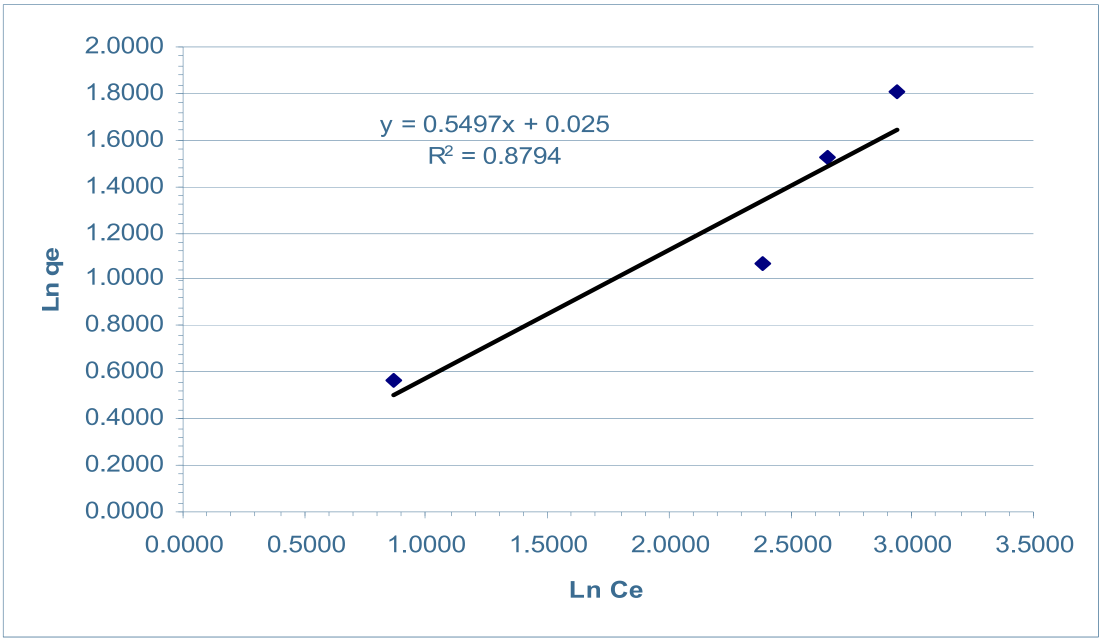


Figure 4.15: Freundlich isotherm plot for synthesized aluminium oxide

4.5.2 Langmuir-2 Adsorption Isotherm

Also, Langmuir-2 isotherm equation was tested with the same chromium ion concentration range. The linearized form of Langmuir-2 can be written as shown in Equation 4.8 [47]

$$\frac{1}{q_e} = \left(\frac{1}{K_a q_m}\right)\frac{1}{C_e} + \frac{1}{q_m} \qquad \text{(Eq. 4.8)}$$

Where,

q_m = Maximum adsorption capacity

K_a = Values for Langmuir-2

These two values are predicted from the plot between $1/q_e$ versus $1/C_e$ which is shown in Figure 4.16 for commercial aluminium oxide adsorbent. The maximum adsorption capacity of Cr^{3+}, q_m and constant related to the binding energy of the sorption system, K_a is calculated which are 51.02 mg/g and 0.004239, respectively.

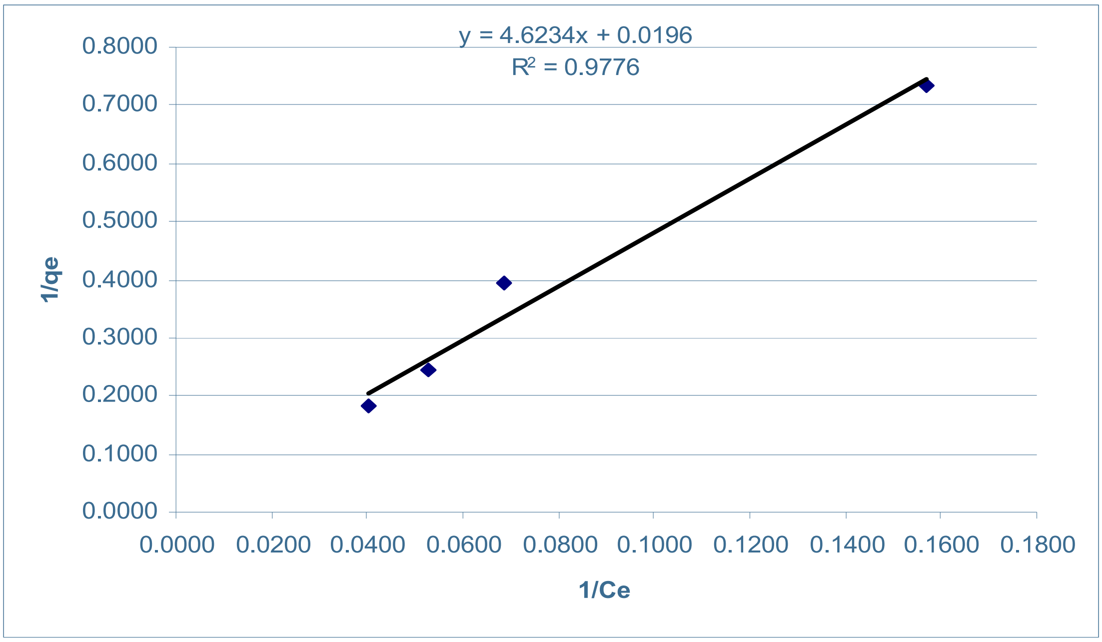


Figure 4.16: Langmuir-2 isotherm plot for commercial aluminium oxide

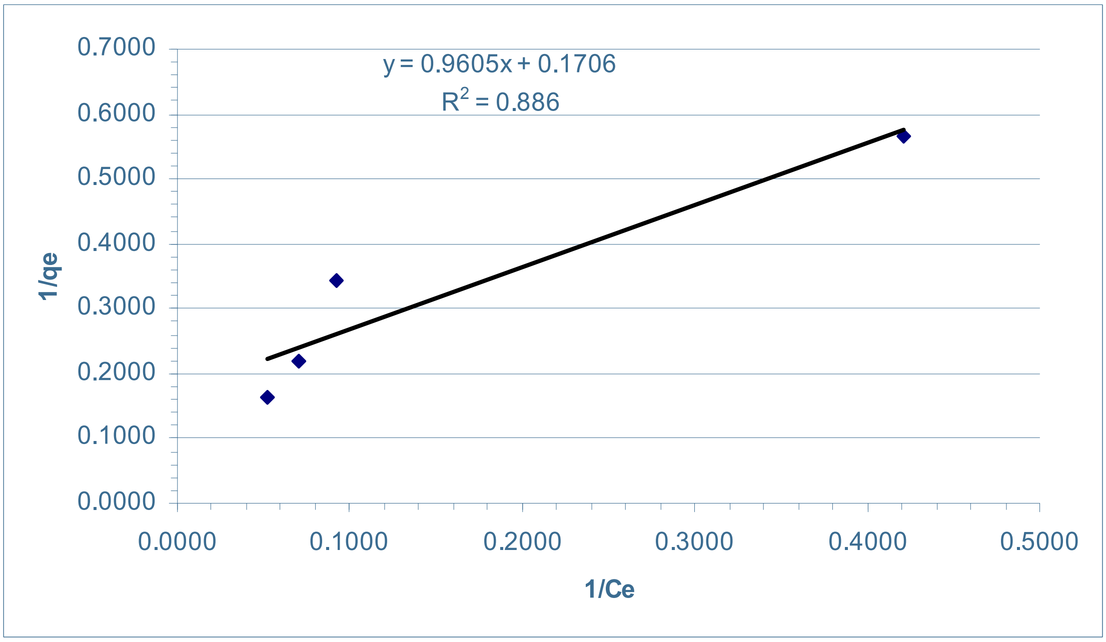


Figure 4.17: Langmuir-2 isotherm plot for synthesized aluminium oxide

Figure 4.17 shows the Langmuir-2 adsorption isotherm for synthesized aluminium oxide adsorbent. The maximum adsorption capacity of Cr^{3+}, q_m and constant related to the binding energy of the sorption system, K_a is calculated which are 5.862 mg/g and 0.1776, respectively.

For both adsorption processes which used commercial and synthesized aluminium oxide, they follow Langmuir-2 adsorption isotherm because both adsorptions have higher regression coefficients, R^2 with respect to R^2 from Freundlich adsorption isotherm. R^2 of commercial and synthesized aluminium oxide for Langmuir-2 adsorption isotherm are 0.9776 and 0.886 respectively.

Langmuir was the first to propose a coherent theory of adsorption onto flat surface based on kinetic viewpoint. There is a continual process of bombardment of molecules onto the surface and a corresponding evaporation (desorption) of the molecules from the surface to maintain zero rate of accumulation at the surface at equilibrium. The surface of adsorption that follows Langmuir model is assumed to be homogenous that indicates surfaces energy is constant over all sites. Adsorbed atoms or molecules are adsorbed at definite and localized sites where only one atom/molecule can accommodate those sites [47].

On the other hand, Freundlich model assumed that surface of adsorption is heterogeneous in the sense that the adsorption energy is distributed. Surface topography is patchwise where sites having same adsorption energy are grouped together into one patch. Adsorption energy can be defined as the energy of interaction between adsorbate and adsorbent. However, each patch is independent from each other, that there is no interaction between patches. Freundlich further assumed that on each patch, only one adsorption site can be adsorbed adsorbate molecule. Hence, the Langmuir model may be applicable for the description of equilibrium of each patch [47].

CHAPTER 5

CONCLUSION AND RECOMMENDATION

Batch adsorption kinetic studies show that the adsorption of chromium ion (Cr^{3+}) was strongly affected by initial chromium ion concentration. The amount of chromium ion (Cr^{3+}) adsorption on aluminium oxide (Al_2O_3) increases with initial chromium ion concentration.

It has also been found that the amount of adsorption (mg of adsorbate per gram of adsorbent) increases with increasing contact time and equilibrium is attained within 180 minutes (3 hours) at a fixed solution pH (approximately pH 5), amount of adsorbent (1.0 g), initial chromium ion concentration (40 ppm), temperature (27°C ± 2 ºC) and also continuously stirred at 160 rpm.

Kinetic experiments clearly indicate that adsorption of chromium ion (Cr^{3+}) on aluminium oxide followed pseudo-second-order kinetics. For adsorption isotherm, Langmuir adsorption isotherm equations reasonably describe the adsorption isotherm within this chromium ion concentration range which is from 20 ppm until 80 ppm.

In this project, it was clearly proven that synthesized aluminium oxide was better than commercial aluminium oxide in terms of the morphology and also the capability of adsorbing chromium. The potential of aluminium oxide synthesized by simple precipitation method as an adsorbent for the removal of chromium from aqueous solution was shown. Since synthesized aluminium oxide was feasible and reliable, it is recommended to focus more to improve its adsorption capacity.

For further studies, it is recommended to investigate the effect of different pH and temperature of solution and also amount of adsorbent used towards adsorption of chromium. It is important to find out the optimum pH, temperature and adsorbent used for the effective adsorption process in order to manipulate the adsorption process.

In short, considering the high capability of aluminium oxide synthesized by simple precipitation method as an adsorbent of chromium in aqueous solution via adsorption, it is essential to encourage more researches by manipulating the morphology of aluminium oxide in order to resolve the pollution of chromium in waste water.

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APPENDICES

APPENDIX 1 – ADSORPTION CHROMIUM DATA USING COMMERCIAL ALUMINIUM OXIDE

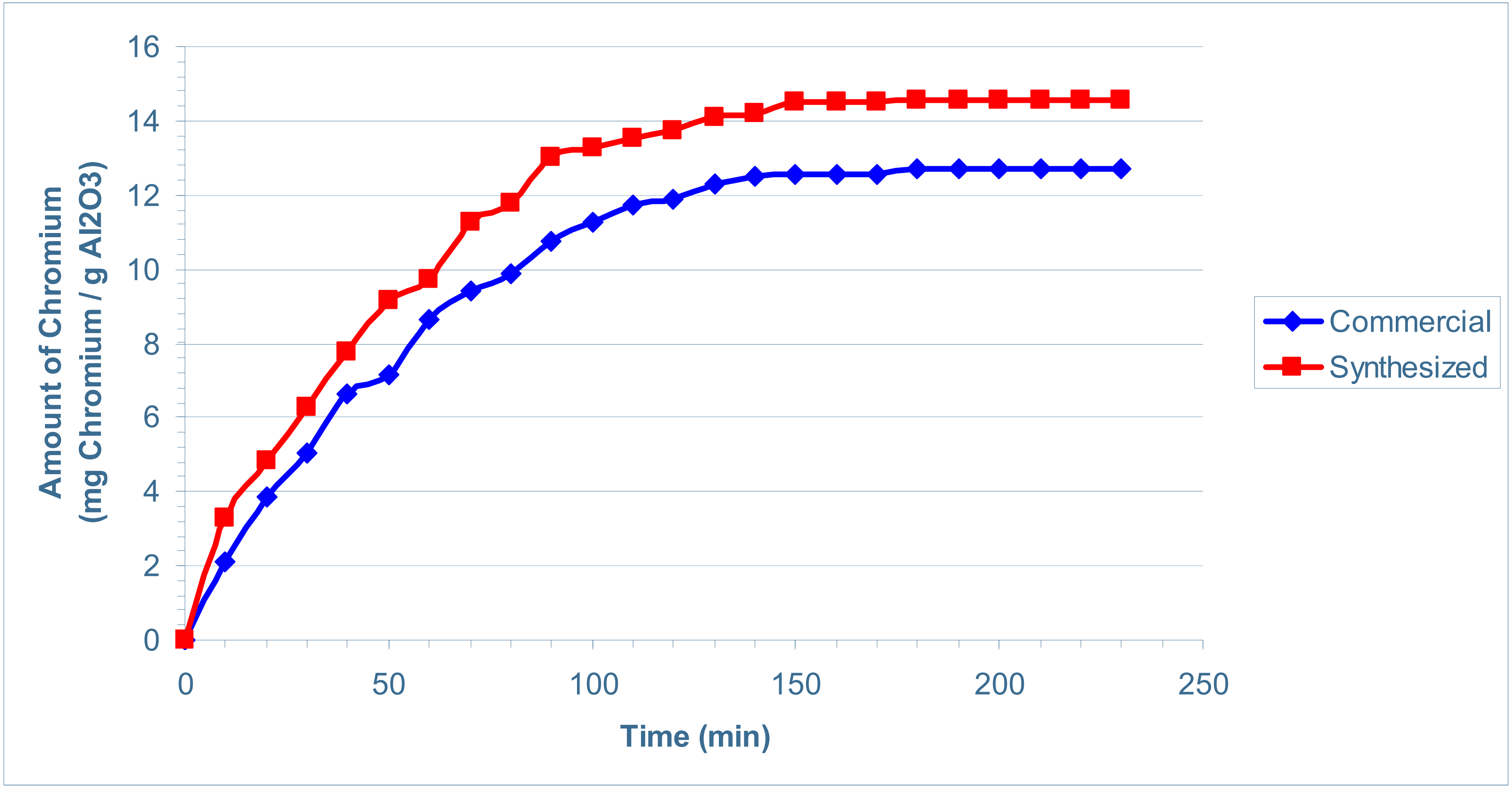
Initial Concentration (ppm)	Time (hr)	Concentration (mg/L)	V (L)	m (g)	q (mg/g)	ln Ce	ln qe	1/Ce	1/qe
20	0	20	0.1	1	0	2.9957	#NUM!	0.0500	#DIV/0!
	0.5	14.8185	0.1	1	0.51815	2.6959	-0.6575	0.0675	1.9299
	1	10.7621	0.1	1	0.92379	2.3760	-0.0793	0.0929	1.0825
	1.5	7.628	0.1	1	1.2372	2.0318	0.2129	0.1311	0.8083
	2	6.9044	0.1	1	1.30956	1.9322	0.2697	0.1448	0.7636
	2.5	6.5113	0.1	1	1.34887	1.8735	0.2993	0.1536	0.7414
	3	**6.3728**	0.1	1	**1.36272**	**1.8520**	**0.3095**	**0.1569**	**0.7338**
40	0	40	0.1	1	0	3.6889	#NUM!	0.0250	#DIV/0!
	0.5	30.4839	0.1	1	0.95161	3.4172	-0.0496	0.0328	1.0509
	1	24.5391	0.1	1	1.54609	3.2003	0.4357	0.0408	0.6468
	1.5	18.9865	0.1	1	2.10135	2.9437	0.7426	0.0527	0.4759
	2	15.5278	0.1	1	2.44722	2.7426	0.8950	0.0644	0.4086
	2.5	14.9432	0.1	1	2.50568	2.7043	0.9186	0.0669	0.3991
	3	**14.5349**	0.1	1	**2.54651**	**2.6766**	**0.9347**	**0.0688**	**0.3927**
60	0	60	0.1	1	0	4.0943	#NUM!	0.0167	#DIV/0!
	0.5	44.3	0.1	1	1.57	3.7910	0.4511	0.0226	0.6369
	1	34.8	0.1	1	2.52	3.5496	0.9243	0.0287	0.3968
	1.5	24.4378	0.1	1	3.55622	3.1961	1.2687	0.0409	0.2812
	2	20.256	0.1	1	3.9744	3.0085	1.3799	0.0494	0.2516
	2.5	18.839	0.1	1	4.1161	2.9359	1.4149	0.0531	0.2429
	3	**18.9284**	0.1	1	**4.10716**	**2.9407**	**1.4127**	**0.0528**	**0.2435**
80	0	80	0.1	1	0	4.3820	#NUM!	0.0125	#DIV/0!
	0.5	54.9135	0.1	1	2.50865	4.0058	0.9197	0.0182	0.3986
	1	39.2183	0.1	1	4.07817	3.6691	1.4056	0.0255	0.2452
	1.5	31.3952	0.1	1	4.86048	3.4467	1.5811	0.0319	0.2057
	2	25.4026	0.1	1	5.45974	3.2349	1.6974	0.0394	0.1832
	2.5	24.931	0.1	1	5.5069	3.2161	1.7060	0.0401	0.1816
	3	**24.9492**	0.1	1	**5.50508**	**3.2168**	**1.7057**	**0.0401**	**0.1817**

Initial Concentration (ppm)	Time (min)	Concentration (mg/L)	V (L)	m (g)	q (mg/g)	log (qe-qt)	t/qt
40	0	40	0.5	1	0	1.1049	0.0000
	10	35.7811	0.5	1	2.10945	1.0263	4.7406
	20	32.2623	0.5	1	3.86885	0.9476	5.1695
	30	29.9605	0.5	1	5.01975	0.8872	5.9764
	40	26.712	0.5	1	6.644	0.7845	6.0205
	50	25.664	0.5	1	7.168	0.7454	6.9754
	60	22.7409	0.5	1	8.62955	0.6131	6.9529
	70	21.2197	0.5	1	9.39015	0.5241	7.4546
	80	20.2833	0.5	1	9.85835	0.4585	8.1149
	90	18.5204	0.5	1	10.7398	0.2995	8.3800
	100	17.4534	0.5	1	11.2733	0.1641	8.8705
	110	16.5877	0.5	1	11.7062	0.0113	9.3968
	120	16.2266	0.5	1	11.8867	-0.0727	10.0953
	130	15.4419	0.5	1	12.2791	-0.3434	10.5871
	140	15.0412	0.5	1	12.4794	-0.5966	11.2185
	150	14.9432	0.5	1	12.5284	-0.6901	11.9728
	160	14.8673	0.5	1	12.5664	-0.7794	12.7324
	170	14.8699	0.5	1	12.5651	-0.7760	13.5296
	180	14.5349	0.5	1	12.7326	#NUM!	14.1370
	190	14.5349	0.5	1	12.7326	#NUM!	14.9224
	200	14.5349	0.5	1	12.7326	#NUM!	15.7078
	210	14.5349	0.5	1	12.7326	#NUM!	16.4932
	220	14.5349	0.5	1	12.7326	#NUM!	17.2785
	230	14.5349	0.5	1	12.7326	#NUM!	18.0639

APPENDIX 2 – ADSORPTION CHROMIUM DATA USING SYNTHESIZED ALUMINIUM OXIDE

Initial Concentration (ppm)	Time (hr)	Concentration (mg/L)	V (L)	m (g)	q (mg/g)	ln Ce	ln qe	1/Ce	1/qe
20	0	20	0.1	1	0	2.9957	#NUM!	0.0500	#DIV/0!
	0.5	14.8185	0.1	1	0.51815	2.6959	-0.6575	0.0675	1.9299
	1	10.7621	0.1	1	0.92379	2.3760	-0.0793	0.0929	1.0825
	1.5	7.628	0.1	1	1.2372	2.0318	0.2129	0.1311	0.8083
	2	2.9044	0.1	1	1.70956	1.0662	0.5362	0.3443	0.5849
	2.5	2.6513	0.1	1	1.73487	0.9751	0.5509	0.3772	0.5764
	3	**2.3728**	0.1	1	**1.76272**	**0.8641**	**0.5669**	**0.4214**	**0.5673**
40	0	40	0.1	1	0	3.6889	#NUM!	0.0250	#DIV/0!
	0.5	29.4839	0.1	1	1.05161	3.3838	0.0503	0.0339	0.9509
	1	20.5391	0.1	1	1.94609	3.0223	0.6658	0.0487	0.5139
	1.5	13.9865	0.1	1	2.60135	2.6381	0.9560	0.0715	0.3844
	2	12.5278	0.1	1	2.74722	2.5280	1.0106	0.0798	0.3640
	2.5	11.0134	0.1	1	2.89866	2.3991	1.0642	0.0908	0.3450
	3	**10.9054**	0.1	1	**2.90946**	**2.3893**	**1.0680**	**0.0917**	**0.3437**
60	0	60	0.1	1	0	4.0943	#NUM!	0.0167	#DIV/0!
	0.5	40.4821	0.1	1	1.95179	3.7009	0.6687	0.0247	0.5124
	1	30.4866	0.1	1	2.95134	3.4173	1.0823	0.0328	0.3388
	1.5	20.4378	0.1	1	3.95622	3.0174	1.3753	0.0489	0.2528
	2	15.0493	0.1	1	4.49507	2.7113	1.5030	0.0664	0.2225
	2.5	14.839	0.1	1	4.5161	2.6973	1.5076	0.0674	0.2214
	3	**14.2284**	0.1	1	**4.57716**	**2.6552**	**1.5211**	**0.0703**	**0.2185**
80	0	80	0.1	1	0	4.3820	#NUM!	0.0125	#DIV/0!
	0.5	48.8596	0.1	1	3.11404	3.8890	1.1359	0.0205	0.3211
	1	34.6021	0.1	1	4.53979	3.5439	1.5129	0.0289	0.2203
	1.5	21.8736	0.1	1	5.81264	3.0853	1.7600	0.0457	0.1720
	2	19.8743	0.1	1	6.01257	2.9894	1.7939	0.0503	0.1663
	2.5	19.6332	0.1	1	6.03668	2.9772	1.7979	0.0509	0.1657
	3	**18.9492**	0.1	1	**6.10508**	**2.9418**	**1.8091**	**0.0528**	**0.1638**

Initial Concentration (ppm)	Time (min)	Concentration (mg/L)	V (L)	m (g)	q (mg/g)	log (qe-qt)	t/qt
40	0	40	0.5	1	0	1.1628	0.0000
	10	33.3785	0.5	1	3.31075	1.0506	3.0205
	20	30.3274	0.5	1	4.8363	0.9873	4.1354
	30	27.4839	0.5	1	6.25805	0.9185	4.7938
	40	24.4752	0.5	1	7.7624	0.8315	5.1530
	50	21.7321	0.5	1	9.13395	0.7335	5.4741
	60	20.5391	0.5	1	9.73045	0.6828	6.1662
	70	17.4852	0.5	1	11.2574	0.5172	6.2181
	80	16.4299	0.5	1	11.78505	0.4413	6.7883
	90	13.9865	0.5	1	13.00675	0.1877	6.9195
	100	13.4667	0.5	1	13.26665	0.1074	7.5377
	110	12.9846	0.5	1	13.5077	0.0169	8.1435
	120	12.5278	0.5	1	13.7361	-0.0909	8.7361
	130	11.7844	0.5	1	14.1078	-0.3570	9.2148
	140	11.6437	0.5	1	14.17815	-0.4328	9.8743
	150	11.0134	0.5	1	14.4933	-1.2676	10.3496
	160	11.0117	0.5	1	14.49415	-1.2745	11.0389
	170	10.9912	0.5	1	14.5044	-1.3675	11.7206
	180	10.9054	0.5	1	14.5473	#NUM!	12.3734
	190	10.9054	0.5	1	14.5473	#NUM!	13.0608
	200	10.9054	0.5	1	14.5473	#NUM!	13.7483
	210	10.9054	0.5	1	14.5473	#NUM!	14.4357
	220	10.9054	0.5	1	14.5473	#NUM!	15.1231
	230	10.9054	0.5	1	14.5473	#NUM!	15.8105


16
14
12
10
8
6
4
2
0
0
50
100
150
200
250
Amount of Chromium
(mg Chromium / g Al2O3)
Time (min)
Commercial
Synthesized

APPENDIX 3 – MATERIAL and SAFETY DATA SHEET (MSDS)

Material Safety Data Sheet

Venfloc 2000, polyaluminium chloride solution, Morton material

ACC# 01478

Section 1 - Chemical Product and Company Identification

MSDS Name: Venfloc 2000, polyaluminium chloride solution, Morton material
Catalog Numbers: AC345690000
Synonyms:
Company Identification:

Acros Organics N.V.
One Reagent Lane
Fair Lawn, NJ 07410

For information in North America, call: 800-ACROS-01
For emergencies in the US, call CHEMTREC: 800-424-9300

Section 2 - Composition, Information on Ingredients

CAS#	Chemical Name	Percent	EINECS/ELINCS
Not available	Venfloc 2000, polyaluminium chloride solution		unlisted

Section 3 - Hazards Identification

EMERGENCY OVERVIEW

Not available.
Target Organs: Eyes, skin.

Potential Health Effects

Eye: Causes eye irritation.
Skin: Causes skin irritation. May be harmful if absorbed through the skin.
Ingestion: May cause irritation of the digestive tract. May be harmful if swallowed. Ingestion of large amounts may cause nausea and vomiting, rigidity or convulsions. Continued exposure can produce coma, dehydration, and internal organ
Inhalation: May cause respiratory tract irritation. May be harmful if inhaled.
Chronic: Not available.

Section 4 - First Aid Measures

Eyes: Flush eyes with plenty of water for at least 15 minutes, occasionally lifting the upper and lower eyelids. Get medical aid.
Skin: Get medical aid. Flush skin with plenty of water for at least 15 minutes while removing contaminated clothing and shoes.
Ingestion: Do not induce vomiting. Get medical aid. Wash mouth out with water.
Inhalation: Remove from exposure and move to fresh air immediately. If not breathing, give artificial respiration. If breathing is difficult, give oxygen. Get medical aid.
Notes to Physician: Treat symptomatically and supportively.

Section 5 - Fire Fighting Measures

General Information: As in any fire, wear a self-contained breathing apparatus in pressure-demand, MSHA/NIOSH (approved or equivalent), and full protective gear.
Extinguishing Media: Use water spray, dry chemical, carbon dioxide, or chemical foam.
Flash Point: Not available.
Autoignition Temperature: Not available.
Explosion Limits, Lower: Not available.
Upper: Not available.
NFPA Rating: Not published.

Section 6 - Accidental Release Measures

General Information: Use proper personal protective equipment as indicated in Section 8.
Spills/Leaks: Absorb spill with inert material (e.g. vermiculite, sand or earth), then place in suitable container.

Section 7 - Handling and Storage

Handling: Avoid breathing dust, mist, or vapor. Avoid contact with skin and eyes.
Storage: Store in a cool, dry place. Store in a tightly closed container. Store at around 20°C. Do not store in metal containers.

Section 8 - Exposure Controls, Personal Protection

Engineering Controls: Facilities storing or utilizing this material should be equipped with an eyewash facility and a safety shower. Use adequate ventilation to keep airborne concentrations low.
Exposure Limits

Chemical Name	ACGIH	NIOSH	OSHA - Final PELs
Venfloc 2000, polyaluminium chloride solution	none listed	none listed	none listed

OSHA Vacated PELs: Venfloc 2000, polyaluminium chloride solution: No OSHA Vacated PELs are listed for this chemical.
Personal Protective Equipment
Eyes: Not available.
Skin: Wear appropriate protective gloves to prevent skin exposure.
Clothing: Wear appropriate protective clothing to prevent skin exposure.
Respirators: Follow the OSHA respirator regulations found in 29 CFR 1910.134 or European Standard EN 149. Use a NIOSH/MSHA or European Standard EN 149 approved respirator if exposure limits are exceeded or if irritation or other symptoms are experienced.

Section 9 - Physical and Chemical Properties

Physical State: Liquid
Appearance: blue
Odor: odorless
pH: 1.4
Vapor Pressure: Not available.
Vapor Density: Not available.

Evaporation Rate: Not available.
Viscosity: <10 mPa.s 20 deg C
Boiling Point: 105 deg C
Freezing/Melting Point:<-30 deg C
Decomposition Temperature: Not available.
Solubility: Miscible.
Specific Gravity/Density: Not available.
Molecular Formula: Not applicable.
Molecular Weight: Not available.

Section 10 - Stability and Reactivity

Chemical Stability: Stable under normal temperatures and pressures.
Conditions to Avoid: Incompatible materials, temperatures above 40°C, do not freeze.
Incompatibilities with Other Materials: Metals.
Hazardous Decomposition Products: Hydrogen chloride.
Hazardous Polymerization: Will not occur.

Section 11 - Toxicological Information

RTECS#:
No CAS#s in product.
LD50/LC50:

Carcinogenicity:

Epidemiology: No data available.
Teratogenicity: No data available.
Reproductive Effects: No data available.
Mutagenicity: No data available.
Neurotoxicity: No data available.
Other Studies:

Section 12 - Ecological Information

No information available.

Section 13 - Disposal Considerations

Chemical waste generators must determine whether a discarded chemical is classified as a hazardous waste. US EPA guidelines for the classification determination are listed in 40 CFR Parts 261.3. Additionally, waste generators must consult state and local hazardous waste regulations to ensure complete and accurate classification.
RCRA P-Series: None listed.
RCRA U-Series: None listed.

Section 14 - Transport Information

	US DOT	**Canada TDG**
Shipping Name:	Not regulated as a hazardous material	No information available.
Hazard Class:		
UN Number:		

Packing Group:	

Section 15 - Regulatory Information

US FEDERAL

TSCA
Venfloc 2000, polyaluminium chloride solution is not listed on the TSCA inventory. It is for research and development use only.

Health & Safety Reporting List
None of the chemicals are on the Health & Safety Reporting List.

Chemical Test Rules
None of the chemicals in this product are under a Chemical Test Rule.

Section 12b
None of the chemicals are listed under TSCA Section 12b.

TSCA Significant New Use Rule
None of the chemicals in this material have a SNUR under TSCA.

CERCLA Hazardous Substances and corresponding RQs
None of the chemicals in this material have an RQ.

SARA Section 302 Extremely Hazardous Substances
None of the chemicals in this product have a TPQ.

Section 313 No chemicals are reportable under Section 313.

Clean Air Act:
This material does not contain any hazardous air pollutants.
This material does not contain any Class 1 Ozone depletors.
This material does not contain any Class 2 Ozone depletors.

Clean Water Act:
None of the chemicals in this product are listed as Hazardous Substances under the CWA.
None of the chemicals in this product are listed as Priority Pollutants under the CWA.
None of the chemicals in this product are listed as Toxic Pollutants under the CWA.

OSHA:
None of the chemicals in this product are considered highly hazardous by OSHA.

STATE

California Prop 65

California No Significant Risk Level: None of the chemicals in this product are listed.

European/International Regulations

European Labeling in Accordance with EC Directives

Hazard Symbols:
XI

Risk Phrases:
R 36/38 Irritating to eyes and skin.

Safety Phrases:
S 26 In case of contact with eyes, rinse immediately with plenty of water and seek medical advice.
S 37/39 Wear suitable gloves and eye/face protection.
S 28A After contact with skin, wash immediately with plenty of water
.

WGK (Water Danger/Protection)

Canada - DSL/NDSL
None of the chemicals in this product are listed on the DSL or NDSL list.

Canada - WHMIS
WHMIS: Not available.
This product has been classified in accordance with the hazard criteria of the Controlled Products

Regulations and the MSDS contains all of the information required by those regulations.
Canadian Ingredient Disclosure List

Section 16 - Additional Information

MSDS Creation Date: 8/11/1999
Revision #4 Date: 3/28/2008

Material Safety Data Sheet

Aluminium Oxide

ACC# 88309

Section 1 - Chemical Product and Company Identification

MSDS Name: Aluminium Oxide
Catalog Numbers: A/2392
Synonyms: Aluminum Oxide; Morin Dyed; Alumina.
Company Identification:

Fisher Scientific
1 Reagent Lane
Fair Lawn, NJ 07410

For information, call: 201-796-7100
Emergency Number: 201-796-7100
For CHEMTREC assistance, call: 800-424-9300
For International CHEMTREC assistance, call: 703-527-3887

Section 2 - Composition, Information on Ingredients

CAS#	Chemical Name	Percent	EINECS/ELINCS
1344-28-1	Aluminum oxide	100	215-691-6

Section 3 - Hazards Identification

EMERGENCY OVERVIEW

Appearance: white solid.
Caution! May cause mechanical eye and skin irritation. May cause respiratory tract irritation. May cause lung damage.
Target Organs: Lungs.

Potential Health Effects

Eye: Dust may cause mechanical irritation.
Skin: Dust may cause mechanical irritation. Low hazard for usual industrial handling.
Ingestion: Ingestion of large amounts may cause gastrointestinal irritation. Expected to be a low ingestion hazard.
Inhalation: May cause respiratory tract irritation. May cause lung damage.
Chronic: Chronic inhalation of fine dusts may cause lung damage.

Section 4 - First Aid Measures

Eyes: Flush eyes with plenty of water for at least 15 minutes, occasionally lifting the upper and lower eyelids. Get medical aid.
Skin: Flush skin with plenty of water for at least 15 minutes while removing contaminated clothing and shoes. Get medical aid if irritation develops or persists. Wash clothing before reuse.
Ingestion: If victim is conscious and alert, give 2-4 cupfuls of milk or water. Never give anything by mouth to an unconscious person. Get medical aid.
Inhalation: Remove from exposure and move to fresh air immediately. If not breathing, give artificial respiration. If breathing is difficult, give oxygen. Get medical aid.

Notes to Physician: Treat symptomatically and supportively.

Section 5 - Fire Fighting Measures

General Information: As in any fire, wear a self-contained breathing apparatus in pressure-demand, MSHA/NIOSH (approved or equivalent), and full protective gear.
Extinguishing Media: Substance is noncombustible; use agent most appropriate to extinguish surrounding fire.
Flash Point: Not applicable.
Autoignition Temperature: Not applicable.
Explosion Limits, Lower: Not available.
Upper: Not available.
NFPA Rating: Not published.

Section 6 - Accidental Release Measures

General Information: Use proper personal protective equipment as indicated in Section 8.
Spills/Leaks: Vacuum or sweep up material and place into a suitable disposal container. Avoid generating dusty conditions.

Section 7 - Handling and Storage

Handling: Wash thoroughly after handling. Wash thoroughly after handling. Use with adequate ventilation. Minimize dust generation and accumulation. Avoid prolonged or repeated contact with skin. Avoid contact with eyes. Do not ingest or inhale.
Storage: Store in a tightly closed container. Store in a cool, dry, well-ventilated area away from incompatible substances.

Section 8 - Exposure Controls, Personal Protection

Engineering Controls: Use adequate general or local exhaust ventilation to keep airborne concentrations below the permissible exposure limits.
Exposure Limits

Chemical Name	ACGIH	NIOSH	OSHA - Final PELs
Aluminum oxide	10 mg/m3 TWA (particulate matter containing no asbestos and <1% crystalline sili ca)	none listed	15 mg/m3 TWA (total dust); 5 mg/m3 TWA (respirable fraction)

OSHA Vacated PELs: Aluminum oxide: 10 mg/m3 TWA (total dust); 5 mg/m3 TWA (respirable fraction)
Personal Protective Equipment
Eyes: Wear appropriate protective eyeglasses or chemical safety goggles as described by OSHA's eye and face protection regulations in 29 CFR 1910.133 or European Standard EN166.
Skin: Wear appropriate gloves to prevent skin exposure.
Clothing: Wear appropriate protective clothing to prevent skin exposure.
Respirators: Follow the OSHA respirator regulations found in 29 CFR 1910.134 or European Standard EN 149. Use a NIOSH/MSHA or European Standard EN 149 approved respirator if exposure limits are exceeded or if irritation or other symptoms are experienced.

Section 9 - Physical and Chemical Properties

Physical State: Solid
Appearance: white
Odor: Odorless.
pH: Not available.
Vapor Pressure: Negligible.
Vapor Density: Not available.
Evaporation Rate: Not available.
Viscosity: Not available.
Boiling Point: 2980 deg C
Freezing/Melting Point:2000 deg C
Decomposition Temperature: Not available.
Solubility: Negligible in water.
Specific Gravity/Density:4.0 (water=1)
Molecular Formula:Al_2O_3
Molecular Weight:101.9612

Section 10 - Stability and Reactivity

Chemical Stability: Stable.
Conditions to Avoid: Incompatible materials.
Incompatibilities with Other Materials: Reacts with chlorine trifluoride or ethylene oxide. Exothermic reaction above 200C with halocarbon vapors produces toxic hydrogen chloride and phosgene.
Hazardous Decomposition Products: Hydrogen chloride, phosgene.
Hazardous Polymerization: Has not been reported.

Section 11 - Toxicological Information

RTECS#:
CAS# 1344-28-1: BD1200000
LD50/LC50:
Not available.

Carcinogenicity:
CAS# 1344-28-1: Not listed by ACGIH, IARC, NTP, or CA Prop 65.

Epidemiology: No information available.
Teratogenicity: No information available.
Reproductive Effects: No information available.
Mutagenicity: No information available.
Neurotoxicity: No information available.
Other Studies:

Section 12 - Ecological Information

No information available.

Section 13 - Disposal Considerations

Chemical waste generators must determine whether a discarded chemical is classified as a hazardous waste. US EPA guidelines for the classification determination are listed in 40 CFR Parts

261.3. Additionally, waste generators must consult state and local hazardous waste regulations to ensure complete and accurate classification.
RCRA P-Series: None listed.
RCRA U-Series: None listed.

Section 14 - Transport Information

	US DOT	Canada TDG
Shipping Name:	Not regulated as a hazardous material	No information available.
Hazard Class:		
UN Number:		
Packing Group:		

Section 15 - Regulatory Information

US FEDERAL

TSCA
CAS# 1344-28-1 is listed on the TSCA inventory.
Health & Safety Reporting List
None of the chemicals are on the Health & Safety Reporting List.
Chemical Test Rules
None of the chemicals in this product are under a Chemical Test Rule.
Section 12b
None of the chemicals are listed under TSCA Section 12b.
TSCA Significant New Use Rule
None of the chemicals in this material have a SNUR under TSCA.
CERCLA Hazardous Substances and corresponding RQs
None of the chemicals in this material have an RQ.
SARA Section 302 Extremely Hazardous Substances
None of the chemicals in this product have a TPQ.
Section 313
This material contains Aluminum oxide (CAS# 1344-28-1, 100%),which is subject to the reporting requirements of Section 313 of SARA Title III and 40 CFR Part 373.
Clean Air Act:
This material does not contain any hazardous air pollutants.
This material does not contain any Class 1 Ozone depletors.
This material does not contain any Class 2 Ozone depletors.
Clean Water Act:
None of the chemicals in this product are listed as Hazardous Substances under the CWA.
None of the chemicals in this product are listed as Priority Pollutants under the CWA.
None of the chemicals in this product are listed as Toxic Pollutants under the CWA.
OSHA:
None of the chemicals in this product are considered highly hazardous by OSHA.
STATE
CAS# 1344-28-1 can be found on the following state right to know lists: New Jersey, Pennsylvania, Minnesota, Massachusetts.

California Prop 65

California No Significant Risk Level: None of the chemicals in this product are listed.

European/International Regulations
European Labeling in Accordance with EC Directives
Hazard Symbols:
Not available.

Risk Phrases:

Safety Phrases:

WGK (Water Danger/Protection)
CAS# 1344-28-1: 0
Canada - DSL/NDSL
CAS# 1344-28-1 is listed on Canada's DSL List.
Canada - WHMIS
WHMIS: Not available.
This product has been classified in accordance with the hazard criteria of the Controlled Products Regulations and the MSDS contains all of the information required by those regulations.
Canadian Ingredient Disclosure List
CAS# 1344-28-1 is listed on the Canadian Ingredient Disclosure List.

Section 16 - Additional Information

MSDS Creation Date: 12/12/1997
Revision #5 Date: 3/15/2007

Material Safety Data Sheet

Ammonium hydroxide water solution, >5.7N but < 14N NH_4OH (>10% but <25% as ammonia, NH_3)

ACC# 01260

Section 1 - Chemical Product and Company Identification

MSDS Name: Ammonium hydroxide water solution, >5.7N but < 14N NH_4OH (>10% but <25% as ammonia, NH_3)
Catalog Numbers: AC390070000, AC390070010, AC390070025, A470-1, A470-250, A470-500, A512-4, A512-4EA, A512-500
Synonyms: Ammonium hydrate; Ammonia solution; Ammonia water; Aqueous ammonia; Aqua ammonia.
Company Identification:

Fisher Scientific
1 Reagent Lane
Fair Lawn, NJ 07410

For information, call: 201-796-7100
Emergency Number: 201-796-7100
For CHEMTREC assistance, call: 800-424-9300
For International CHEMTREC assistance, call: 703-527-3887

Section 2 - Composition, Information on Ingredients

CAS#	Chemical Name	Percent	EINECS/ELINCS
7732-18-5	Water	76-90	231-791-2
7664-41-7	Ammonia	10-24	231-635-3

Section 3 - Hazards Identification

EMERGENCY OVERVIEW

Appearance: colorless liquid.
Danger! Causes eye and skin burns. Causes digestive and respiratory tract burns. Harmful if swallowed.
Target Organs: Eyes, skin, mucous membranes.

Potential Health Effects

Eye: Contact with liquid or vapor causes severe burns and possible irreversible eye damage. Lachrymator (substance which increases the flow of tears).
Skin: Causes severe skin irritation. Causes skin burns. May cause deep, penetrating ulcers of the skin. Contact with the skin may cause staining, inflammation, and thickening of the skin.
Ingestion: Harmful if swallowed. May cause severe and permanent damage to the digestive tract. Causes gastrointestinal tract burns. Causes throat constriction, vomiting, convulsions, and shock.
Inhalation: Effects may be delayed. Causes severe irritation of upper respiratory tract with coughing, burns, breathing difficulty, and possible coma.
Chronic: Prolonged inhalation may cause respiratory tract inflammation and lung damage. Prolonged or repeated exposure may cause corneal damage and the development of cataracts and glaucoma.

Section 4 - First Aid Measures

Eyes: In case of contact, immediately flush eyes with plenty of water for a t least 15 minutes. Get medical aid immediately.
Skin: In case of contact, immediately flush skin with plenty of water for at least 15 minutes while removing contaminated clothing and shoes. Get medical aid immediately. Wash clothing before reuse.
Ingestion: If swallowed, do NOT induce vomiting. Get medical aid immediately. If victim is fully conscious, give a cupful of water. Never give anything by mouth to an unconscious person.
Inhalation: If inhaled, remove to fresh air. If not breathing, give artificial respiration. If breathing is difficult, give oxygen. Get medical aid.
Notes to Physician: After inhalation exposure, observe for 24 to 72 hours as pulmonary edema may be delayed.

Section 5 - Fire Fighting Measures

General Information: As in any fire, wear a self-contained breathing apparatus in pressure-demand, MSHA/NIOSH (approved or equivalent), and full protective gear. During a fire, irritating and highly toxic gases may be generated by thermal decomposition or combustion. Use water spray to keep fire-exposed containers cool. Contact with metals may evolve flammable hydrogen gas. Containers may explode when heated. Approach fire from upwind to avoid hazardous vapors and toxic decomposition products. Ammonium hydroxide itself is non-combustible. However concentrated ammonia solutions may give off ammonia vapours. Ammonia gas is generally not considered a serious fire or explosion hazard because ammonia/air mixtures are difficult to ignite. A relatively high concentration of ammonia gas must be present in order for ignition to occur. However, a large and intense energy source may cause ignition and/or explosion in a confined space.
Extinguishing Media: Use extinguishing media most appropriate for the surrounding fire.
Flash Point: Not available.
Autoignition Temperature: Not applicable.
Explosion Limits, Lower: Not available.
Upper: Not available.
NFPA Rating: (estimated) Health: 3; Flammability: 0; Instability: 0

Section 6 - Accidental Release Measures

General Information: Use proper personal protective equipment as indicated in Section 8.
Spills/Leaks: Absorb spill with inert material (e.g. vermiculite, sand or earth), then place in suitable container. Neutralize spill with a weak acid such as vinegar or acetic acid. Avoid runoff into storm sewers and ditches which lead to waterways. Clean up spills immediately, observing precautions in the Protective Equipment section. Provide ventilation. Approach spill from upwind.

Section 7 - Handling and Storage

Handling: Wash thoroughly after handling. Remove contaminated clothing and wash before reuse. Do not get in eyes, on skin, or on clothing. Keep container tightly closed. Discard contaminated shoes. Do not breathe vapor. Use only with adequate ventilation.
Storage: Do not store in direct sunlight. Store in a tightly closed container. Store in a cool, dry, well-ventilated area away from incompatible substances. Corrosives area. Isolate from oxidizing materials and acids. Walls, floors, shelving, fittings, lighting and ventilation systems in storage area should be made from carbon steel or stainless steel which do not react with ammonium hydroxide.

Section 8 - Exposure Controls, Personal Protection

Engineering Controls: Use process enclosure, local exhaust ventilation, or other engineering controls to control airborne levels below recommended exposure limits. Facilities storing or utilizing this material should be equipped with an eyewash facility and a safety shower.

Exposure Limits

Chemical Name	ACGIH	NIOSH	OSHA - Final PELs
Water	none listed	none listed	none listed
Ammonia	25 ppm TWA; 35 ppm STEL	25 ppm TWA; 18 mg/m3 TWA 300 ppm IDLH	50 ppm TWA; 35 mg/m3 TWA
Ammonium hydroxide	none listed	none listed	none listed

OSHA Vacated PELs: Water: No OSHA Vacated PELs are listed for this chemical. Ammonia: No OSHA Vacated PELs are listed for this chemical. Ammonium hydroxide: No OSHA Vacated PELs are listed for this chemical.

Personal Protective Equipment

Eyes: Wear chemical splash goggles and face shield.

Skin: Wear appropriate protective gloves to prevent skin exposure.

Clothing: Wear appropriate protective clothing to prevent skin exposure.

Respirators: Follow the OSHA respirator regulations found in 29 CFR 1910.134 or European Standard EN 149. Use a NIOSH/MSHA or European Standard EN 149 approved respirator if exposure limits are exceeded or if irritation or other symptoms are experienced.

Section 9 - Physical and Chemical Properties

Physical State: Liquid
Appearance: colorless
Odor: strong odor - ammonia-like
pH: 13.6
Vapor Pressure: > 112.5 mm Hg @ 20 deg C
Vapor Density: 0.59 (air=1)
Evaporation Rate: Not available.
Viscosity: Not available.
Boiling Point: 27 deg C
Freezing/Melting Point:-34.9 deg C
Decomposition Temperature: Not available.
Solubility: Soluble.
Specific Gravity/Density:0.92
Molecular Formula:NH_4OH
Molecular Weight:35.04

Section 10 - Stability and Reactivity

Chemical Stability: Stable under normal temperatures and pressures. Ammonium hydroxide is actually a solution of ammonia in water. Therefore the flammable properties of ammonia apply.

Conditions to Avoid: High temperatures, confined spaces, Ammonia solutions are corrosive to copper, zinc, aluminum and their alloys..

Incompatibilities with Other Materials: Strong oxidizing agents, acids, acrolein, halogens, mercury, hypochlorite, silver nitrate, acrylic acid, dimethyl sulfate, silver oxide.

Hazardous Decomposition Products: Nitrogen oxides (NOx) and ammonia (NH_3).

Hazardous Polymerization: Will not occur.

Section 11 - Toxicological Information

RTECS#:
CAS# 7732-18-5: ZC0110000
CAS# 7664-41-7: BO0875000
CAS# 1336-21-6: BQ9625000
LD50/LC50:
CAS# 7732-18-5:
Oral, rat: LD50 = >90 mL/kg;
.

CAS# 7664-41-7:
Inhalation, mouse: LC50 = 4230 ppm/1H;
Inhalation, mouse: LC50 = 4600 mg/m3/2H;
Inhalation, rabbit: LC50 = 7 gm/m3/1H;
Inhalation, rat: LC50 = 2000 ppm/4H;
Inhalation, rat: LC50 = 18600 mg/m3/5M;
Inhalation, rat: LC50 = 7040 mg/m3/30M;
Skin, rat: LD50 = 112000 mg/m3/15M;
Skin, rat: LD50 = 71900 mg/m3/30M;
Skin, rat: LD50 = 4840 mg/m3/60M;
.

CAS# 1336-21-6:
Draize test, rabbit, eye: 250 ug Severe;
Draize test, rabbit, eye: 44 ug Severe;
Oral, rat: LD50 = 350 mg/kg;
.

Carcinogenicity:
CAS# 7732-18-5: Not listed by ACGIH, IARC, NTP, or CA Prop 65.
CAS# 7664-41-7: Not listed by ACGIH, IARC, NTP, or CA Prop 65.
CAS# 1336-21-6: Not listed by ACGIH, IARC, NTP, or CA Prop 65.

Epidemiology: No information found
Teratogenicity: No information found
Reproductive Effects: No information found
Mutagenicity: No information found
Neurotoxicity: No information found
Other Studies:

Section 12 - Ecological Information

Ecotoxicity: Fish: Rainbow trout: LC50 = 0.008 mg/L; 24 Hr.; Unspecified
Fish: Fathead Minnow: LC50 = 8.2 mg/L; 96 Hr.; Unspecified
Fish: Bluegill/Sunfish: LC50 = 0.024-0.093 mg/L; 48 Hr.; Unspecified
Water flea Daphnia: EC50 =0.66 mg/L; 48 Hr.; 22 degrees C

Section 13 - Disposal Considerations

Chemical waste generators must determine whether a discarded chemical is classified as a hazardous waste. US EPA guidelines for the classification determination are listed in 40 CFR Parts 261.3. Additionally, waste generators must consult state and local hazardous waste regulations to ensure complete and accurate classification.
RCRA P-Series: None listed.

RCRA U-Series: None listed.

Section 14 - Transport Information

	US DOT	Canada TDG
Shipping Name:	AMMONIA SOLUTIONS	AMMONIA SOLUTIONS
Hazard Class:	8	8(9.2)
UN Number:	UN2672	UN2672
Packing Group:	III	III

Section 15 - Regulatory Information

US FEDERAL

TSCA
CAS# 7732-18-5 is listed on the TSCA inventory.
CAS# 7664-41-7 is listed on the TSCA inventory.
CAS# 1336-21-6 is listed on the TSCA inventory.

Health & Safety Reporting List
None of the chemicals are on the Health & Safety Reporting List.

Chemical Test Rules
None of the chemicals in this product are under a Chemical Test Rule.

Section 12b
None of the chemicals are listed under TSCA Section 12b.

TSCA Significant New Use Rule
None of the chemicals in this material have a SNUR under TSCA.

CERCLA Hazardous Substances and corresponding RQs
CAS# 7664-41-7: 100 lb final RQ; 45.4 kg final RQ CAS# 1336-21-6: 1000 lb final RQ; 454 kg final RQ

SARA Section 302 Extremely Hazardous Substances
CAS# 7664-41-7: 500 lb TPQ

SARA Codes
CAS # 1336-21-6: immediate, delayed.

Section 313
This material contains Ammonia (CAS# 7664-41-7, 10-24%),which is subject to the reporting requirements of Section 313 of SARA Title III and 40 CFR Part 373.

Clean Air Act:
This material does not contain any hazardous air pollutants.
This material does not contain any Class 1 Ozone depletors.
This material does not contain any Class 2 Ozone depletors.

Clean Water Act:
CAS# 7664-41-7 is listed as a Hazardous Substance under the CWA. CAS# 1336-21-6 is listed as a Hazardous Substance under the CWA.
None of the chemicals in this product are listed as Priority Pollutants under the CWA.
None of the chemicals in this product are listed as Toxic Pollutants under the CWA.

OSHA:
CAS# 7664-41-7 is considered highly hazardous by OSHA.

STATE
CAS# 7732-18-5 is not present on state lists from CA, PA, MN, MA, FL, or NJ.
CAS# 7664-41-7 can be found on the following state right to know lists: California, New Jersey, Pennsylvania, Minnesota, Massachusetts.
CAS# 1336-21-6 can be found on the following state right to know lists: California, New Jersey, Pennsylvania, Massachusetts.

California Prop 65

California No Significant Risk Level: None of the chemicals in this product are listed.

European/International Regulations

European Labeling in Accordance with EC Directives

Hazard Symbols:

C

Risk Phrases:

R 34 Causes burns.

Safety Phrases:

S 26 In case of contact with eyes, rinse immediately with plenty of water and seek medical advice.

S 36/37/39 Wear suitable protective clothing, gloves and eye/face protection.

S 45 In case of accident or if you feel unwell, seek medical advice immediately (show the label where possible).

WGK (Water Danger/Protection)

CAS# 7732-18-5: No information available.
CAS# 7664-41-7: 2
CAS# 1336-21-6: 2

Canada - DSL/NDSL

CAS# 7732-18-5 is listed on Canada's DSL List.
CAS# 7664-41-7 is listed on Canada's DSL List.
CAS# 1336-21-6 is listed on Canada's DSL List.

Canada - WHMIS

This product has a WHMIS classification of D1B, E.

This product has been classified in accordance with the hazard criteria of the Controlled Products Regulations and the MSDS contains all of the information required by those regulations.

Canadian Ingredient Disclosure List

CAS# 7664-41-7 is listed on the Canadian Ingredient Disclosure List.
CAS# 1336-21-6 is listed on the Canadian Ingredient Disclosure List.

Section 16 - Additional Information

MSDS Creation Date: 6/22/1999
Revision #11 Date: 2/11/2008

Material Safety Data Sheet

Chromium(III) chloride hexahydrate

ACC# 00449

Section 1 - Chemical Product and Company Identification

MSDS Name: Chromium(III) chloride hexahydrate
Catalog Numbers: AC213360000, AC213360050, AC213365000
Synonyms: Chromic chloride.
Company Identification:

Acros Organics N.V.
One Reagent Lane
Fair Lawn, NJ 07410

For information in North America, call: 800-ACROS-01
For emergencies in the US, call CHEMTREC: 800-424-9300

Section 2 - Composition, Information on Ingredients

CAS#	Chemical Name	Percent	EINECS/ELINCS
10060-12-5	Chromium(III) chloride hexahydrate	98	unlisted

Section 3 - Hazards Identification

EMERGENCY OVERVIEW

Appearance: dark green crystalline powder.
Danger! Causes burns by all exposure routes. Harmful if swallowed, inhaled, or absorbed through the skin. Cancer hazard.
Target Organs: Kidneys, liver, respiratory system, gastrointestinal system, eyes, skin.

Potential Health Effects
Eye: Causes eye burns.
Skin: Harmful if absorbed through the skin. Causes skin burns.
Ingestion: Harmful if swallowed. Causes gastrointestinal tract burns.
Inhalation: Harmful if inhaled. Causes chemical burns to the respiratory tract.
Chronic: May cause liver and kidney damage. May cause cancer in humans. Adverse reproductive effects have been reported in animals. Laboratory experiments have resulted in mutagenic effects.

Section 4 - First Aid Measures

Eyes: Immediately flush eyes with plenty of water for at least 15 minutes, occasionally lifting the upper and lower eyelids. Get medical aid imme diately.
Skin: Get medical aid immediately. Immediately flush skin with plenty of water for at least 15 minutes while removing contaminated clothing and shoes.
Ingestion: Do not induce vomiting. Get medical aid immediately. Call a poison control center.
Inhalation: Get medical aid immediately. Remove from exposure and move to fresh air immediately. If breathing is difficult, give oxygen. Do not use mouth-to-mouth resuscitation if victim ingested or inhaled the substance; induce artificial respiration with the aid of a pocket mask equipped with a one-way valve or other proper respiratory medical device.
Notes to Physician: Treat symptomatically and supportively.

Section 5 - Fire Fighting Measures

General Information: As in any fire, wear a self-contained breathing apparatus in pressure-demand, MSHA/NIOSH (approved or equivalent), and full protective gear.
Extinguishing Media: Use foam, dry chemical, or carbon dioxide.
Flash Point: Not available.
Autoignition Temperature: Not available.
Explosion Limits, Lower: Not available.
Upper: Not available.
NFPA Rating: (estimated) Health: 3; Flammability: 1; Instability: 1

Section 6 - Accidental Release Measures

General Information: Use proper personal protective equipment as indicated in Section 8.
Spills/Leaks: Vacuum or sweep up material and place into a suitable disposal container. Wear a self contained breathing apparatus and appropriate personal protection. (See Exposure Controls, Personal Protection section). Avoid generating dusty conditions. Provide ventilation. Do not let this chemical enter the environment.

Section 7 - Handling and Storage

Handling: Minimize dust generation and accumulation. Do not get in eyes, on skin, or on clothing. Do not ingest or inhale. Use only in a chemical fume hood.
Storage: Store in a cool, dry place. Store in a tightly closed container. Corrosives area.

Section 8 - Exposure Controls, Personal Protection

Engineering Controls: Facilities storing or utilizing this material should be equipped with an eyewash facility and a safety shower. Use only under a chemical fume hood.
Exposure Limits

Chemical Name	ACGIH	NIOSH	OSHA - Final PELs
Chromium(III) chloride hexahydrate	none listed	none listed	none listed
Chromic chloride	none listed	none listed	5 æg/m3 TWA (listed under Chromium (VI) compounds).2.5 æg/m3 Action Level (as Cr.); 5 æg/m3 TWA (as Cr, Cancer hazard - See 29 CFR 1910.1026) (listed under Chromium (VI) compounds).

OSHA Vacated PELs: Chromium(III) chloride hexahydrate: No OSHA Vacated PELs are listed for this chemical. Chromic chloride: No OSHA Vacated PELs are listed for this chemical.
Personal Protective Equipment
Eyes: Wear appropriate protective eyeglasses or chemical safety goggles as described by OSHA's eye and face protection regulations in 29 CFR 1910.133 or European Standard EN166.
Skin: Wear appropriate protective gloves to prevent skin exposure.
Clothing: Wear appropriate protective clothing to prevent skin exposure.
Respirators: A respiratory protection program that meets OSHA's 29 CFR 1910.134 and ANSI Z88.2 requirements or European Standard EN 149 must be followed whenever workplace conditions

warrant respirator use.

Section 9 - Physical and Chemical Properties

Physical State: Crystalline powder
Appearance: dark green
Odor: none reported
pH: 2 - 3 (5% aq.sol.)
Vapor Pressure: Not applicable.
Vapor Density: Not available.
Evaporation Rate: Not applicable.
Viscosity: Not applicable.
Boiling Point: Not available.
Freezing/Melting Point:83 deg C
Decomposition Temperature: Not available.
Solubility: Soluble.
Specific Gravity/Density: Not available.
Molecular Formula:$Cl_3Cr.6H_2O$
Molecular Weight:266.44

Section 10 - Stability and Reactivity

Chemical Stability: Moisture sensitive.
Conditions to Avoid: Incompatible materials, dust generation, excess heat, exposure to moist air or water.
Incompatibilities with Other Materials: Strong oxidizing agents.
Hazardous Decomposition Products: Hydrogen chloride, carbon monoxide, carbon dioxide.
Hazardous Polymerization: Has not been reported.

Section 11 - Toxicological Information

RTECS#:
CAS# 10060-12-5: GB5450000
CAS# 10025-73-7: GB5425000
LD50/LC50:
CAS# 10060-12-5:
    Oral, rat: LD50 = 1790 mg/kg;
.

CAS# 10025-73-7:
    Inhalation, mouse: LC50 = 31500 ug/m3/2H;
    Inhalation, mouse: LC50 = 31.5 mg/m3;
    Oral, rat: LD50 = 440 mg/kg;
.

Carcinogenicity:
CAS# 10060-12-5: Not listed by ACGIH, IARC, NTP, or CA Prop 65.
CAS# 10025-73-7:

- **ACGIH:** Not listed.
- **California:** carcinogen, initial date 2/27/87 (listed as Chromium (VI) compounds).
- **NTP:** Known carcinogen (listed as Chromium (VI) compounds).
- **IARC:** Group 1 carcinogen (listed as Chromium (VI) compounds).

Epidemiology: Tumorigenic effects have been reported in experimental animals.Considered to be a carcinogen in humans according to IARC.
Teratogenicity: Teratogenic effects have occurred in experimental animals.
Reproductive Effects: Adverse reproductive effects have occurred in experimental animals.
Mutagenicity: Mutagenic effects have occurred in humans.
Neurotoxicity: No information available.
Other Studies:

Section 12 - Ecological Information

Ecotoxicity: No data available. No information available.
Environmental: No information available.
Physical: No information available.
Other: Do not empty into drains.

Section 13 - Disposal Considerations

Chemical waste generators must determine whether a discarded chemical is classified as a hazardous waste. US EPA guidelines for the classification determination are listed in 40 CFR Parts 261.3. Additionally, waste generators must consult state and local hazardous waste regulations to ensure complete and accurate classification.
RCRA P-Series: None listed.
RCRA U-Series: None listed.

Section 14 - Transport Information

	US DOT	**Canada TDG**
Shipping Name:	CORROSIVE SOLID, TOXIC, N.O.S.	CORROSIVE SOLID, TOXIC, N.O.S.
Hazard Class:	8	8
UN Number:	UN2923	UN2923
Packing Group:	III	III

Section 15 - Regulatory Information

US FEDERAL

TSCA
CAS# 10060-12-5 is not on the TSCA Inventory because it is a hydrate. It is considered to be listed if the CAS number for the anhydrous form is on the inventory (40CFR720.3(u)(2)).
CAS# 10025-73-7 is listed on the TSCA inventory.
Health & Safety Reporting List
None of the chemicals are on the Health & Safety Reporting List.
Chemical Test Rules
None of the chemicals in this product are under a Chemical Test Rule.
Section 12b
None of the chemicals are listed under TSCA Section 12b.
TSCA Significant New Use Rule
None of the chemicals in this material have a SNUR under TSCA.
CERCLA Hazardous Substances and corresponding RQs
None of the chemicals in this material have an RQ.
SARA Section 302 Extremely Hazardous Substances
CAS# 10025-73-7: 1 lb lower threshold TPQ; 10000 lb upper threshold TP Q

SARA Codes

CAS # 10060-12-5: immediate, delayed.

Section 313

This material contains Chromic chloride (listed as Chromium (VI) compounds), -%, (CAS# 10025-73-7) which is subject to the reporting requirements of Section 313 of SARA Title III and 40 CFR Part 373.

Clean Air Act:

This material does not contain any hazardous air pollutants.
This material does not contain any Class 1 Ozone depletors.
This material does not contain any Class 2 Ozone depletors.

Clean Water Act:

None of the chemicals in this product are listed as Hazardous Substances under the CWA.
None of the chemicals in this product are listed as Priority Pollutants under the CWA.
None of the chemicals in this product are listed as Toxic Pollutants under the CWA.

OSHA:

None of the chemicals in this product are considered highly hazardous by OSHA.

STATE

CAS# 10060-12-5 is not present on state lists from CA, PA, MN, MA, FL, or NJ.
CAS# 10025-73-7 can be found on the following state right to know lists: New Jersey, Pennsylvania, Minnesota, (listed as Chromium (VI) compounds), Massachusetts.

California Prop 65

WARNING: This product contains Chromic chloride, listed as `Chromium (VI) compounds', a chemical known to the state of California to cause cancer.
California No Significant Risk Level: None of the chemicals in this product are listed.

European/International Regulations

European Labeling in Accordance with EC Directives

Hazard Symbols:

C

Risk Phrases:

R 20/21/22 Harmful by inhalation, in contact with skin and if swallowed.
R 34 Causes burns.

Safety Phrases:

S 26 In case of contact with eyes, rinse immediately with plenty of water and seek medical advice.
S 36/37/39 Wear suitable protective clothing, gloves and eye/face protection.
S 45 In case of accident or if you feel unwell, seek medical advice immediately (show the label where possible).

WGK (Water Danger/Protection)

CAS# 10060-12-5: No information available.
CAS# 10025-73-7: No information available.

Canada - DSL/NDSL

CAS# 10025-73-7 is listed on Canada's DSL List.

Canada - WHMIS

This product has a WHMIS classification of D2A, D2B.
This product has been classified in accordance with the hazard criteria of the Controlled Products Regulations and the MSDS contains all of the information required by those regulations.

Canadian Ingredient Disclosure List

CAS# 10060-12-5 is not listed on the Canadian Ingredient Disclosure List.
CAS# 10025-73-7 is listed on the Canadian Ingredient Disclosure List.

Section 16 - Additional Information

MSDS Creation Date: 9/02/1997

Revision #7 Date: 2/21/2008