SIMULATION OF THE CERAMIC BALL FORMATION

HAMIDAH BINTI JUSOH

BACHELOR OF CHEMICAL ENGINEERING

UNIVERSITI MALAYSIA PAHANG

HAMIDAH BINTI JUSOH BACHELOR OF CHEMICAL ENGINEERING 2013 UMP

SIMULATION OF THE CERAMIC BALL FORMATION

HAMIDAH BINTI JUSOH

Report submitted in partial fulfilment of the requirements for the award of the degree of Bachelor of Chemical Engineering

Faculty of Chemical & Natural Resources Engineering

UNIVERSITI MALAYSIA PAHANG

FEBRUARY 2013

SUPERVISOR'S DECLARATION

I hereby declare that I have checked this project and in my opinion, this project is adequate in terms of scope and quality for the award of the degree of Bachelor of Chemical Engineering.

Signature :

Name of Supervisor : DR. ANWARUDDIN HISYAM

Position :

Date :

STUDENT'S DECLARATION

I hereby declare that the work in this project is my own except for quotations and summaries which have been duly acknowledged. The project has not been accepted for any degree and is not concurrently submitted for award of other degree.

Signature :

Name : HAMIDAH BINTI JUSOH

ID Number : KA09141

Date :

DEDICATION

Special dedication to my supervisor, Dr. Anwaruddin Hisyam for your Time, Guidance, and Support.

And,

To my beloved mother (Rosnani binti Ngah) and friends, that encouraged and fully supports me throughout completing this thesis.

ACKNOWLEDGEMENT

In the name of Allah, the most Gracious and most Compassionate

First of all, thanks to Allah S.W.T for the blessing and opportunity for me to accomplish this thesis. I would like to thank and express my sincere appreciation to my supervisor, Dr Anwaruddin Hisyam for guidance and advices in every way I need to go through this study.

Besides, I would also thank to the lecturers in Faculty of Chemical and Natural Resources Engineering for their advice and support.

An honourable mention goes to all my colleagues who have provided assistance at various occasions. Their views and tips are useful indeed. Without helps of them, I would face many difficulties while doing this project.

Finally, my further gratitude goes to my family. Thank you for your love, support, and patience. I am truly blessed to have you as my family. Also to all people that directly or indirectly in helping me to completed my thesis.

SIMULATION OF THE CERAMIC BALL FORMATION

ABSTRACT

Nowadays, ceramic ball is commonly used as catalyst support in the chemical industry. However, ceramic balls production has not being widely study yet. This is because it is difficult and expensive to study the production of ceramic balls from the plant instead simulation study is necessary to carry out. Therefore, this project is carried out to develop mathematical modeling from the ceramic balls production and to validate the parameters from the experimental work data with the simulation data based on simulation software. Actually, simulation can improve the system performance by changing the model parameter. Therefore, in this project, the mass, volume and radius parameter will be study. Firstly, mathematical modeling of the ceramic ball production must be developing and then simulation model can be developing by using MATLAB software. Then, run the simulation model and identify whether the result is validate with mathematical modeling or not. If not, refers to the mathematical model back and if validate, end the simulation. From this research, it is expected to result in mathematical modeling in the ceramic ball production. By using simulation also one will reduce time, cost, and disruption of experimenting on the actual system. Then, experiments are too expensive, too dangerous, and the system to be investigated does not yet exist but by using simulation all variables can be studied and control and it is easy to manipulate the parameters.

SIMULASI DARIPADA PEMBENTUKAN BOLA SERAMIK

ABSTRAK

Pada hari ini bola seramik biasanya digunakan sebagai pemangkin sokongan dalam industri kimia. Walau bagaimanapun, pengeluaran bola seramik tidak dipelajari secara meluas lagi. Ini adalah kerana ia adalah sukar dan mahal untuk mengkaji pengeluaran bola seramik dari industri melainkan kajian simulasi adalah perlu dijalankan. Oleh itu, projek ini dijalankan untuk membentuk model matematik daripada pengeluaran bola seramik dan untuk mengesahkan parameter daripada data kerja eksperimen dengan data simulasi berdasarkan perisian simulasi. Sebenarnya, simulasi boleh meningkatkan prestasi sistem dengan menukar parameter model. Oleh itu, dalam projek ini, parameter seperti berat,isipadu dan jejari akan menjadi kajian. Pertama, pemodelan matematik berdasarkan pengeluaran bola seramik harus dibentuk dan oleh itu model simulasi boleh dijalankan dengan menggunakan perisian MATLAB. Kemudian, jalankan model simulasi dan mengenal pasti sama ada keputusan adalah tepat dengan model matematik atau tidak. Jika tidak, rujuk kepada model matematik semula dan jika disahkan, tamatkan simulasi. Daripada kajian ini, ia dijangka pembentukan dalam pemodelan matematik daripada pengeluaran bola seramik. Dengan menggunakan simulasi juga seseorang akan mengurangkan masa, kos, dan gangguan bereksperimen pada sistem sebenar. Kemudian, eksperimen adalah terlalu mahal, terlalu berbahaya, dan sistem yang akan dikaji belum wujud tetapi dengan menggunakan simulasi semua pembolehubah boleh dikaji dan dikawal dan ia adalah mudah untuk memanipulasi parameter.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF SYMBOLS

cm	Centimeter
Fin	Mass Flowrate Inlet
Fout	Mass Flowrate Outlet
g	Gram
h	Hour
m	Mass
mm	Milimeter
r	Radius
V	Volume
p	Density

LIST OF ABBREVIATIONS

EIS PACK	Eigen System Package
HIP	Hot Isostatic Processing
LINPACK	Linear System Package
MATLAB	MATrix Laboratory

CHAPTER 1

INTRODUCTION

1.1 Research Background

Ceramic ball are made from inorganic and non-metallic compounds. It is very hard, resistant to abrasion and insusceptible to all furnace atmospheres. Their shape is spherical and their rolling elements provide higher stiffness, lower thermal expansion, lighter weight, increase corrosion resistance and higher electrical resistance than steel balls. This is because they are made from a variety of ceramic materials. This is supported by Jeon (2012), which said that ceramic balls made of a variety of difference ceramic materials. The materials include alumina, alumina-zirconia, aluminium nitride, and aluminium silicate; boron nitride; and silicon carbide; and zirconia, and zirconium phosphate. Therefore, from this, supplier can choose the best material to produce ceramic ball which can be related to their application. For example, ceramic ball which used to support the catalyst bed in the reactor. It must have a characteristic of lower thermal expansion, very hard and insusceptible to all furnace atmospheres. This is because it was used to prevent the loss of catalyst downstream of reactor vessel during the high temperature and also high pressure in the reactor vessels.

In order to study and validate the parameters that involve in a ceramic ball production, a simulation process will be carried out. Actually, simulation is the use of mathematical model to recreate a situation, often repeatedly, and from this a several of possibility outcomes can be more accurately estimated. According to Harell (2000), simulation is the process of designing a model of a real system and from this model, someone will be able to conduct an experiments for the purpose either of understanding the behavior of the system or evaluating a various strategies for the operation of the system. This is because a mathematical modeling must be developing first before conduct the experiment using the simulation. This model represents the key characteristics or behaviors of the selected physical or abstract system or process. The model also represents the system itself but the simulation represents the operation of the system over time. Then, from this mathematical modeling, you can do try and error in order to select the best types of simulation for your model. Lastly, you can make a comparison between the result from the simulation and from the experimental data.

Ceramic balls production has not been widely studied yet by the researchers. This is because this topic is new and not all of us know about the ceramic balls. However, the concept of ceramic balls production has the equivalence with the crystallization process. For example, in the rate of crystal growth in which when time increase, the crystal form become bigger and bigger. So, someone will know the velocity of crystal growth form at certain time.

1.2 Problem Statement

There are a few problems involve which leads to this research in which it is difficult and expensive to study the production of ceramic balls from the plant instead simulation is necessary to carry out. This is because in order to run the experiment, one must buy the material, apparatus and many others. Then, if the result is not accurate or not efficient, one must repeat the experiment again and again until they get the accurate result. Therefore, experiment will take a long time and need more cost to buy the others material. However, by using the simulation, they can only do try and error in order to get the result and will used the simulation software only. From this, one will save the budget and also will reduce the time. Other than that, ceramic ball has not being widely study yet. Therefore, I take this opportunity to carry out this research but it is difficult to find the source in order to run the simulation.

1.3 Research Objective

The purpose of this study is to develop mathematical modeling from the production of ceramic ball. The second objective is to validate the parameters from the experimental work data with the simulation data based on the simulation software.

1.4 Research Question/Hypothesis

1.4.1: How to develop mathematical modeling from the ceramic balls production?

1.4.2: How to validate the parameters from the experimental work data with the simulation data?

1.5 Scope of the Proposed Study

In order to achieve the objective of this research, the following scopes have been identified. First, ones need to know how to develop mathematical modeling in order to run the simulation process. Then, one needs to know how to analyst and compare between the data from the simulation software with the experimental data.

1.6 Expected Outcomes

The results of this study is one will be able to develop mathematical modeling based on the parameters that involve in the ceramic ball production. Then, one can be able to study and validate the data from the experimental work data with the simulation software.

1.7 Significance of the Proposed Study

With the presence of modern technologies, this research will give many advantages to the technology, engineering and education. Firstly, it will save our time because the time scale of the dynamics of the system is not compatible with that of the experimenter. For example, it will take a millions of year to observe small changes in the development of universe, but similar change can be quickly observed via computer simulation. Then, experiments are too expensive, too dangerous or the system to be investigated does not exist yet. There are the main difficulties of the experimentation with the real system.

Besides, by doing experiment, the variables may be inaccessible. Compare to the simulation, all the variables can be studied and controlled even these that are inaccessible in the real system. Lastly, it is an easy manipulation of models. By using simulation, it is easy to manipulate the parameters of a system model, even outside the feasible range of a particular physical system.

1.8 Conclusion

In this research, a mathematical modeling for the validation of parameters model will be developed and one will able to analyze, validate and compare between the experimental work data with the simulation data based on the simulation software.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction to Ceramic Ball

Ceramic are defines as a class of inorganic, nonmetallic solids that are subjected to high temperature in manufacture or in use. Ceramic processing generally involves high temperatures, and the resulting materials are heat resistant or refractory. Actually, according to Indiani et.al (2012), the word of ceramic comes from the Latin word which is 'Keramos' meaning pottery or utensils made of clay which undergo sintering process. The earliest raw material used is clay. Clay is defined as a coherent and become attached when mixed with water. When wet it is easy to set up but if it is dried it becomes hard and brittle and also will maintain its shape.

Ceramic raw materials such as kaolin, feldspar and silica and other materials are mixed with a certain ratio, then processed and burned which eventually produces ceramics industry. During burning process, these materials interact with each other to form a product with different characteristics. According to Jeon (2012), Ceramics are generally produced in the form of ceramic balls, which produce alkaline water having good and soft taste to drink, when used for water purification. Ceramic ball began to be widely used for the filtration of drinking water in the 19^{th} century. Thus, the ceramic balls are used in a variety of fields for household, industry, agriculture and stockbreeding, such as water ionizers, filters for bidets, humidifiers, water purification and processing devices for washing, bathing, and the like, as well as water purifiers.

Ceramic ball also known as inert balls, catalyst support ball, alumina balls, high-alumina balls, filter material and bed support. This is supported by Rakannusa (2012), which stated that ceramic ball is also known as inert ball and catalyst support media. It was called catalyst support due to the function that acts as catalyst to prevent the problems that occur in the reactor during their operation. Therefore, ceramic ball will act as a savior to packing material and also to back up catalyst bed in order to avoid the discovery or loss of the catalyst or adsorbent materials downstream of the reactor vessels in consequence of the high pressure and temperature inside the reactor vessels during the operation. Ceramic is also an ideal filter medium because it has a small and complex pore structure. Actually, ceramic ball consist of different size, which are 3mm, 6mm, 10mm, 13mm, 19mm and 25mm. The size was arranged from layer to layer at the top and bottom of the vessel with different in the sizes of the ceramic ball. This material is slightly like the sand filter system for water purification.

It is also non-reactive and this statement was supported by Rakannusa (2012), which said that it has a unique biological application due to their nature of non-reactive to human and internal system. For example, it was been applied to internal medicine to treat several human and animal dysfunctions. In this case, it would be impossible to use steel due to the chemical present inside the human body which eventually will cause corrosion to the steel.

2.2 Raw Material in the Ceramic Ball Production

2.2.1 Feldspar

Feldspar is by far the most abundant group of minerals in the earth's crust, forming about 60% of terrestrial rocks. Most deposits offer sodium feldspar as well as potassium feldspar and mixed feldspars (IMA-NA 2012). Feldspars are primarily used in industrial applications for their alumina and alkali content. The term feldspar encompasses a whole range of materials. Most of the products we use on a daily basis are made with feldspar: glass for drinking, glass for protection, fiberglass for insulation, the floor tiles and shower basins in our bathrooms, and the tableware from which we eat. Feldspar is part of our daily life. According to Indiani et.al (2012), Feldspar is a common raw material used in glassmaking, ceramics, and to some extent as a filler and extender in paint, plastics, and rubber. In glassmaking, alumina from feldspar improves product hardness, durability, and resistance to chemical corrosion. In ceramics, the alkalis in feldspar (calcium oxide, potassium oxide, and sodium oxide) act as a flux, lowering the melting temperature of a mixture. Fluxes melt at an early stage in the firing process, forming a glassy matrix that bonds the other components of the system together.

Figure 2.1 Various types of Feldspar

(Source: Wikipedia, 2012)

Feldspar is very important in a mixture of ceramic materials. Feldspar generally expressed in the form:

$$\mathrm{KxNa1} - \mathrm{x}\left[\frac{Al}{SI3}\right]O8$$

In general there are 3 types of feldspar which are:

$$1.\,\mathrm{Arthose} = \mathrm{K}\left[\frac{Al}{SI3}\right]O8$$

$$2.\,\mathrm{Albite} = \mathrm{Na}\left[\frac{Al}{SI3}\right]O8$$

$$3.\,\mathrm{Anorthite} = \mathrm{Ca}\left[\frac{Al}{SI3}\right]O8$$

From its composition, it can be seen that Feldspar structure is not totally different with the structure of the clay, a natural silicate, pink or brown in colour and is the ceramic mineral with one of its composition is $NaAlSi_3O_8$. Feldspar is also a silicate network and among of the four silicon atoms in which replaced by aluminum atoms. At temperatures of 900^oC, Feldspar are generally stable and do not undergo a phase change.

2.2.2 Kaolin

In its natural state kaolin is a white, soft powder consisting principally of the mineral kaolinite, which, under the electron microscope, is seen to consist of roughly hexagonal, platy crystals ranging in size from about 0.1 micrometre to 10 micrometres or even larger. These crystals may take vermicular and booklike forms, and occasionally macroscopic forms approaching millimetre size are found. Kaolin as found in nature usually contains varying amounts of other minerals such as muscovite, quartz, feldspar, and anatase. In addition, crude kaolin is frequently stained yellow by iron hydroxide pigments. It is often necessary to bleach the clay chemically to remove the iron pigment and to wash it with water to remove the other minerals in order to prepare kaolin for commercial use.

When kaolin is mixed with water in the range of 20 to 35 percent, it becomes plastic (i.e., it can be molded under pressure), and the shape is retained after the pressure is removed. With larger percentages of water, the kaolin forms a slurry, or watery suspension. The amount of water required to achieve plasticity and viscosity varies with the size of the kaolinite particles and also with certain chemicals that may be present in the kaolin. Kaolin has been mined in France, England, Saxony (Germany), Bohemia (Czech Republic), and in the United States, where the best-known deposits are in the southeastern states.

Figure 2.2 Kaolin

(Source: Perpis International Co., 2012)

Kaolin is used extensively in the ceramic industry, where its high fusion temperature and white burning characteristics makes it particularly suitable for the manufacture of whiteware (china), porcelain, and refractories. The absence of any iron, alkalies, or alkaline earths in the molecular structure of kaolinite confers upon it these desirable ceramic properties. In the manufacture of white ware the kaolin is usually mixed with approximately equal amounts of silica and feldspar and a somewhat smaller amount of a plastic light-burning clay known as ball clay. These components are necessary to obtain the proper properties of plasticity, shrinkage, vitrification, etc., for forming and firing the ware. Kaolin is generally used alone in the manufacture of refractories.

Kaolin is classified into two types: first a precipitate residue which comes from the changes in the rocks. Second is the type of precipitation which nice stone and clay particles have been separated from the sediment. Kaolin derived from the preshidrotermal in which erosion occurs due to the effect of hot water contained in fractures and faults as well as the other permeable rocks. According to Sihite (2008), kaolin derived from the weathering (sedimentation) and the weathering of igneous rock that metamorpik reaction is as follows:

$KAlSiO_8 \longrightarrow HAlSi_3O_8 + KOH$ (Hydrolysis)

$HAlSiO_8 \longrightarrow HAlSi_3O_4 + 2SiO_2$ (Deslikation)

$2HAlSiO_4 + H_2O \longrightarrow (OH)_4Al_2Si_2O_5$ (Hydration)

2.2.3 Silica

Silica is one of the minerals that form perfect crystals, consisting of Crystals of silica (SiO2). Silica is the result of weathering processes contains major minerals such as Al_2O_3, Fe_2O_3, Cr_2O_3, Na_2O_3, TiO_2, K_2O. It is translucent white in colour, possess certain physical and mechanical properties.

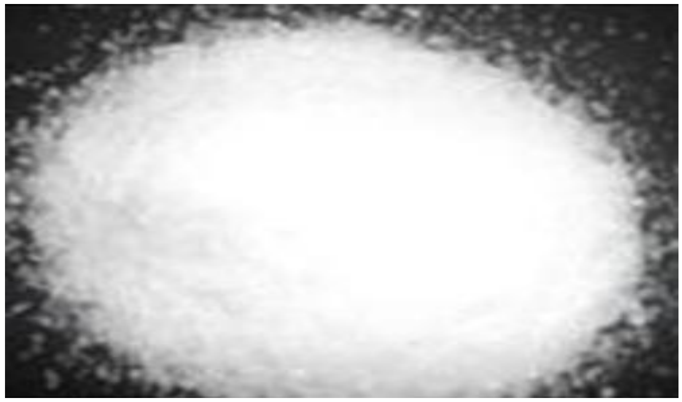

Figure 2.3 Silica Powder

(Source: Gajanad Indiamart, 2012)

Table 2.1 Differences between Feldspar, Kaolin and Silica

	Feldspar	Kaolin	Silica
Formula	$Al_2O_3.2SiO_2.2H_2O$	$K_2O.Al_2O_3.6SiO_2$	SiO_2
Plasticity	Plastic	Non Plastic	Plastic
Melting Point	1785°C	1150 °C	1710 °C
Shriveled on burning	Very discouraged	Smelted	Not discouraged

2.3 Characteristics of Ceramic Ball

Ceramic balls are one of the important advancement in the technology nowadays because they are significantly stronger and lighter than chrome balls or steel balls. Ceramic ball with silicon nitride, Si_3N_4 have very small deformation under pressure.

Therefore, it has an excellent application in high performance precision bearings and bearing tracks. Another important aspect of ceramic balls is their extreme hardness and resistance to wear. The balls hardness will reduces the coefficient of friction present in the subassembly, so it will maximize the amount of energy that is converted to work. According to Ningbo (2012), the hardness of the ceramic balls means that they are less exposed to wear and at the same time it offers more than triple lifetimes. Therefore, it has an extremely long usable life and is ideal for components that cannot be maintained easily. Once these balls were installed in any machine or subassembly, it shows a resistance to wear unlike any other material. The material in ceramic balls shows remarkably little deformation when used in the machine. This was supported by Jeon (2012), which stated that they have less contact with the bearing retainer walls and can roll faster, so it deform less under load. Heat from friction during rolling can cause problems for metal bearings in very high speed applications which are reduced by the used of ceramics. Actually, ceramics are also more chemically resistant and can be used in wet environments where steel bearings would rust. Unfortunately, ceramics are significantly higher cost and susceptibility to damage under shock loads. Therefore, someone must be careful and thrifty when handling the ceramics materials.

Inert ball are widely used because they are inactive, so they are stable under any environment and do not hinder the catalytic reaction. Then, they are capable of withstanding a high temperature (350-1000°C) and also high pressure environment. Therefore, ceramic ball do not melt when a strong alkaline or strong acid environment is used inside the tower and it also resist impact caused by the fall when inert balls are filled. Additionally, silicon nitride is thermally stable and therefore the ceramic balls can withstand extremely high temperature. For example, the melting point of silicon nitride (1900°C) with the stainless steel (1370°C) was compared, so it is easy to see how ceramic balls have revolutionized engineering in manufactured items that are subject to extremely high temperatures. Then, others example is alumide oxide balls which consist of more than 99% wt of alpha-alumina oxide with a maximum content of 0.2% wt of silica dioxide. This composition is ideal for applications requiring extremely high crush resistance and thermal resistance. Moreover, these balls were used in high temperature environments such as steam shift operations.

There are two kinds of inert balls which are ceramic balls and also high alumina balls. For ceramic balls, it is commonly used as a filler to hold the catalyst beds in oil refining, petrochemical and natural gas. It was used in the range of 100 to 500 °C of environmental temperature. They are also a standard item which used in the desulfurization process which is removing of sulfur from the material in the hydro refining process of oil refining. Then, the other type of inert balls is high alumina balls which are used as fillers to hold the catalyst beds in petrochemical and natural gas applications with the temperature range between 100 to 1200°C. It was used as filler that holds the catalysts beds of a chemical reactor, which does not like impurities.

Figure 2.4 Ceramic ball

(Source: Tathagat Ceramic, 2012)

2.3.1 Specification of Ceramic Ball

Ceramic ball is low absorption rate, 98% corrosion alkali and acid function and can bear high temperature. It is stable molecular structure, acid and alkali-resistant, heat-resistance, good thermal stability, low water adsorption and also high compressive strength. This is supported by Rakannusa (2012) which said that ceramic ball has many advantages which are high intensity, great chemical stability and thermal stability, excellent resistance to high temperature and pressure, and also resists the corrosion from the acid, alkali and other organic solvent.

According to: Ceramic ball content percent: 17%, 25%, 65% and 95% and diameter from 3mm to 25mm.

Table 2.2 Specification of Ceramic Ball

Size		Density		Free Space	Specific Surface area	
Inches	Mm	lbs/ft^3	g/cm3	percent	ft^2/ft^3	m^2/m^3
1/8	3	90	1.44	38	350	1150
¼	6	87	1.40	40	160	520
3/8	10	86	1.38	44	120	390
½	13	86	1.38	44	80	260
¾	19	86	.37	44	50	160
1	25	84	1.34	46	40	130

Table 2.3 Chemical Analysis

Compounds	Percentage
SiO2	65-76%
Al2O3	>25%
SiO2 + Al2O3	>90%
TiO2	0.5-0.6%
Fe2O3	<1.0%
Fe leachable	0.002%
CaO	~0.3%
MgO	0.3-0.5%
K2O	1.8-2.5%
Na2O	~0.2%

Table 2.4 Physical Properties

Properties	Value
Density	2.30-2.45 g/cm3
Bulk Density	1.35-1.44 g/m3
Water absorption	0.30-0.60%
Porosity	0.60-1.10%
Crush strength	~400 N/mm^2
H2SO4 solubility	0.40%
Mohs Hardness	7-8
Thermal expansion	5.5 x 10^{-6} /°C
Catalyst poisons	None

2.4 Application of Ceramic Ball

Nowadays, ceramic balls are designed for a wide range of application which acting as carrier layers or cover layers of catalyst packing, adsorbents, molecular sieves and silica gels. Due to their excellent crush strength and high resistance to thermal stock, ceramic ball are suitable for a wide variety of industrial processes like Claus reactor. In addition, there are many organizations use ceramic ball in the water filtration and purification media. This included the water purification tool which used on its own, or in conjugation with other purification system. The ceramic ball is applied in commercial and also household application. It can be used continuously without the need for the replacement with the new one for example; a few ceramic balls which were placed in 300ml water bottle can clean the water in 8 hours.

2.4.1 INDUSTRIAL APPLICATION

Ceramic ball is widely used in many fields and is the one of the significant component in the catalyst process in the refinery, gas processing, fertilizer, petrochemical industry, environmental industry and so on. For example, it is used when refining crude, the raw material and chemically processing it into gasoline, light fuel oil, kerosene, heavy oil and many others at oil refineries complexes. Among the processes, a desulfurization process which removes sulfur in substance in consideration of the environment is done.

Due to its features that are high intensity, high chemical stability and thermal stability, it withstand high temperature and pressure during the process and also resists the corrosion, it be the covering and supporting material and also tower packing for catalyst in the reactor. The leading effects of ceramic ball are to increase the distributing spots of gas or liquid, support and protect the activated catalyst from rushing of the gas and liquid inside the reactor. This is supported by Rakannusa (2012) which state that it was used for catalyst bed support for oil refining, petrochemical and natural gas applications. It was used in fixed reactors as an inert catalyst bed support. The product is often used in fixed bed reactors where a temperature ranges of 100 °C to 500 °C.

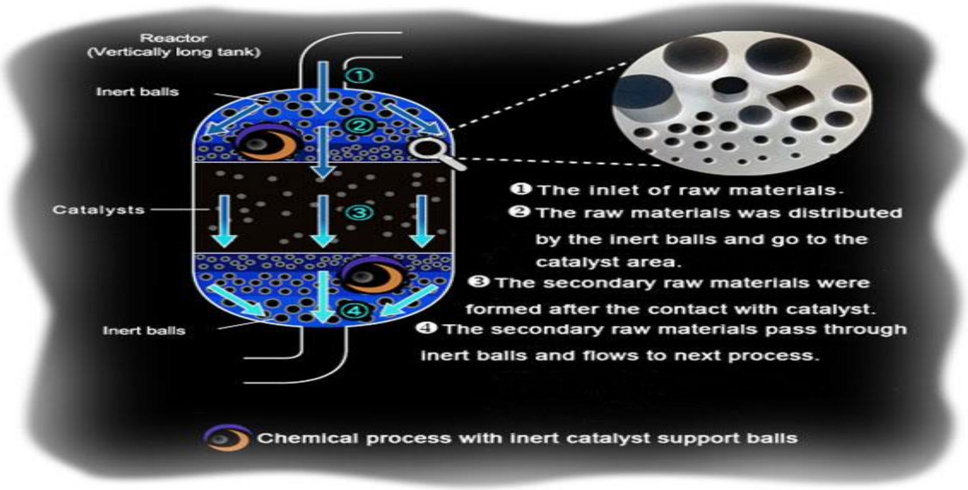

Figure 2.5 Ceramic Ball inside reactor

It also used commercially in the automotive and aircraft industry. Since the balls are extremely durable and light-weight. Ceramic balls have gained motoriety by enabling motion in commercial power-generating windmills. Considering how frequently the windmill is designed to revolve and how much stress is placed on the components, this is an excellent example of the ceramic balls value. Besides, ceramic Aerospace bearings are used in airframes as well as gyroscopes (gyros), navigation systems, flow meters, avionic instruments and other aerospace parts.

Figure 2.6 Filtration in drinking water

Ceramic balls began widely used for the filtration of drinking water in the 19th century. It has a small and complex pore structure, making it an ideal filter medium. Nowadays, many organizations are using ceramic ball in water filtration and purification media. According to Jeon (2012), ceramic balls is being used as water treatment in addition to chemicals because the municipal water contains micro-organisms and others pollutants that are washed into the water supply from the surrounding land. Then, private water supplies which taken from wells, streams, rain water collection tanks and other sources which do not get any treatment by water companies will tend to be unchlorinated, which often leads to bacteriological contamination and full of unwanted particles. Therefore, by using ceramic balls, one will be able to maintain the beneficial of minerals water by removing the harmful pollutants.

Agitator balls have suitable corrosion and density (weight) for agitation.

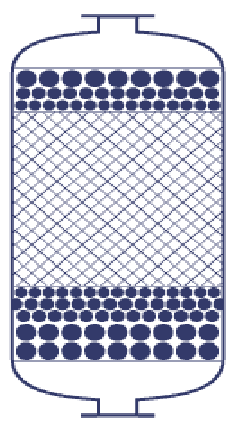

Figure 2.7 Refractory bed

It was used as refractory bed to plugs and supports in order to protect the catalyst bed from thermal impurities, so that the catalyst bed is kept intact in spite of wide pressure variation.

2.5 Production of Ceramic Ball

Ceramic ball are made of variety of different ceramic materials. These include Feldspar, Kaolin and Silica. According to Jeon (2012), in order to produce ceramic ball, firstly it was manufactured by pressing a ceramic powder binder mixture in a perform shape. After the ball was sintered, the part lines are removed via finish-grinding. Lapping and precision finishing is then used to design or grade dimensions and products specifications such as diameter, sphericity and surface finish. Hot isostatic processing (HIP) may be used after sintering for the applications that need a fully-dense material with specific material properties. HIP will produces ceramic balls with a pore-free microstructure and micron-sized grains.

Actually, there are various methods that have been proposed to form ceramic powder into ceramic balls. For example, Korean Patent Laid-Open Publication No. 1996-0012033 discloses spherical ceramic balls, which are formed using a compressing mould, Korean Patent Laid-open Publication No.1996-0004277 discloses ceramic balls, which are formed by spraying ceramic slurry in the form of droplets and sintering the droplets, and Korean Patent No. 153167 discloses spherical ceramic balls, which are formed by rotating or revolving a semi-sintered ceramic body in a rotary chamber composed of upper and lower halves. However, these methods have problems in that it is difficult to form truly spherical ceramic balls, and there is a limit in achieving efficient production of a great quantity of ceramic balls within a short period of time.

Therefore, Jeon (2012) introduce the production of ceramic balls using a rotary manner. This method according to the exemplary embodiment includes the following processes:

a) A formation process of growing ceramic powder to balls having a desired size by rotating a rotary chamber while supplying materials including the ceramic powder, water and a binder into the rotary chamber.

b) A drying process of drying the formed balls.

c) A sintering process of sintering the dried balls at high temperature.

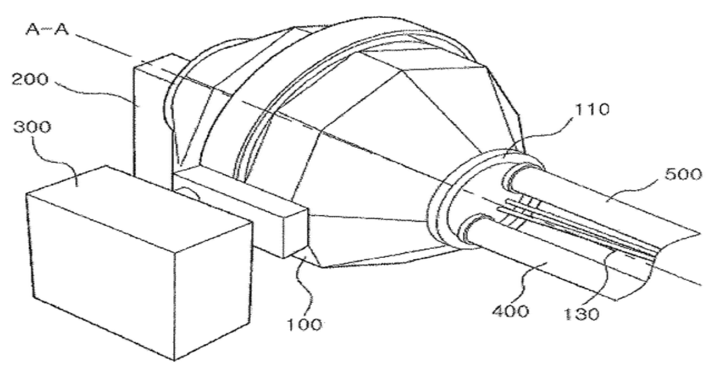

Figure 2.8 Rotary Drum

In this method, the rotary chamber is rotated with ceramic powder first introduced into the rotary chamber, and then water and or a binder are sprayed into the rotary chamber. Water and binder agglomerate the ceramic powder, and the agglomerated ceramic powder gradually increases in size, forming a spherical shape. The materials may be input to the rotary chamber by uniformly of arbitrarily dividing the total amount and inputting or multi-stage introduction manner. In order to rotate the materials including the ceramic powder, water and binder, as shown in Figure 2.8, the rotary chamber, the entirety of which is rotated about a rotary axis A-A, may be used. However, the present invention is not limited thereto, but may adopt various methods to rotate the materials, such as a method of rotating only the bottom of the chamber, a method of rotating a propeller in the chamber, a method of forwardly or reversely rotating the entirety or the bottom of the chamber while rotating the propeller and the like.

Figure 2.9 Ceramic Ball Production Process

Table 2.5 Process Description of Major Parts in Figure 2.8

Number	Description
100	Rotary Chamber
110	Inlet
130	Spray Nozzle
200	Tilt Adjuster
300	Motor
400	Heater
500	Dust Suction Port

After the ceramic balls having a desired size and strength formed, the balls are subjected to drying and sintering to form complete ceramic balls. Temperature and time for drying and sintering may vary accordingly to the kind of ceramic balls. Specifically, the drying may carried out at a temperature 80 to 200^{o}C for 5 to 20 hours, and sintering at a temperature of 900 to 1300^{o}C for 10 to 20 hours. If particularly high strength is required, coating and strength-reinforcing may be carried out. According to the kinds of ceramic balls, desired ceramic balls may also be obtained through the formation process and drying process.

CHAPTER 3

METHODOLOGY

3.1 Introduction

This research will be carried out in order to validate the parameters in the production of ceramic ball. Simulation is the best method that has been chosen to run the experiment. Simulation is chosen due to their ability to improve the system performance only by using the computer software. This process will reduce cost, save time and in a simulation, all variables can be studied and controlled. Besides, this method is choosing than the other methods due to its benefit that is easy to manipulate the parameters of a system model. Therefore, by using simulation, the designers can try out new design concepts to see what work is the best and the visualization makes it take on a realism that is like watching an actual system. There are a few simulation software that can be able to use such as MATLAB, Aspen, Scilab, and Excel. However, in this research, MATLAB will be used to validate the parameters.

3.2 Introduction to Simulation

Simulation is the process of designing a model of an actual or theoretical physical system, then the model was used on a digital computer, and analyzing the execution output. Simulation can be said as “learning by doing” because in order to learn about the system, ones must first build a model of some sort and then operate the model. This was supported by Harrell (2000), which stated that simulation as a way to reproduce the conditions of a situation by modeling, for study or testing or training. According to Maira (1997), simulation is “the modeling of a process or system in such a way that the model mimics the response of the actual system to events that take place over time”. In the others word, we can have an insight about the behavior of the actual system from the studying the behavior of modeling. Simulation is an essentially an experimentation tool in which a computer model of a new or existing system is created for the purpose of conducting experiments. This model will acts as a surrogate for the actual or real-world system. Knowledge that someone gained from the experimenting of the model can be transferred to the real system. Therefore, by using simulation, people will reduce time, cost, and disruption of experimenting on the actual system.

3.3 Mathematical Modeling

Mathematical model is the process of developing a system using mathematical concepts and language. A model may help to explain a system and to study the effects of different components, to make predictions about behavior.

Research of method consists of mathematical modeling based on principle equation including mass balance.

Input-Output=Accumulation

$$\text{Mass in} - 0 = \left[\frac{dm}{dt}\right]$$

$$\mathrm{F}\left(\frac{\mathrm{kg}}{\mathrm{h}}\right) - 0 = \left[\frac{d(vp)}{dt}\right]$$

Where:

$$\mathrm{F} = (4\prod \mathrm{pr}2)\left[\frac{dr)}{dt}\right], \quad \mathrm{V} = \left[\frac{4}{3}\prod \mathrm{r}3\right]$$

So:

$$f = \int 4\prod \rho\, r^2 dr$$

Therefore;

Mass balance:

Input-Output= Accumulation

$$\mathrm{Fin} - \mathrm{Fout} = \frac{\mathrm{dm}}{\mathrm{dt}}$$

Where Fout = 0;

$$\frac{\mathrm{dm}}{\mathrm{dt}} = \mathrm{Fin}$$

$$\mathrm{dm} = \rho dV$$

$$\mathrm{dm} = \frac{4}{3}\rho\pi r^2 dr/dt$$

$$\mathrm{dm} = \frac{4}{3}\rho\pi 3r^2 dr/dt$$

$$\mathrm{dm} = 4\pi\rho r\hat{}2\,\frac{dr}{dt}$$

$$\frac{4\rho\pi r\hat{}2dr}{dt} = \mathrm{Fin}$$

$$\frac{dr}{dt} = \frac{Fin}{4\pi\rho r\hat{}2}$$

3.4 Experimental work Methodology

Simulation comes into play during the evaluation phase. First, a model is developed for an alternative solution. As the model is run, it is put into operation for the period of time of interest. Performance statistics for example utilization and processing time are gathered and reported at the end of the run. Simulation is essentially an experimentation too in which a computer model of a new or existing system is created system is created for the purpose of conducting an experiments. The model is surrogate for the actual or real-world system. Knowledge gained from experimenting on the model can be transferred to the real system. Conducting experiments on models reduces the time, cost, and disruption of experimenting on the actual system.

The procedure for doing simulation follows the scientific method of (1) formulating a hypothesis, (2) setting up an experiment, (3) testing the hypothesis through experimentation, and (4) drawing conclusions about the validity of the hypothesis. In simulation, hypothesis is formulated about what design or operating policies work best. Then, experiment is set up in the form of a simulation model to test the hypothesis. With the model, a multiple replications of the experiment or simulation will be conduct. Finally, the simulation results will be analyze and conclusions about the hypothesis can be draw. If the hypothesis was correct, one can confidently move ahead in making the design or operational changes. The process is repeated until one are satisfied with the results**.**

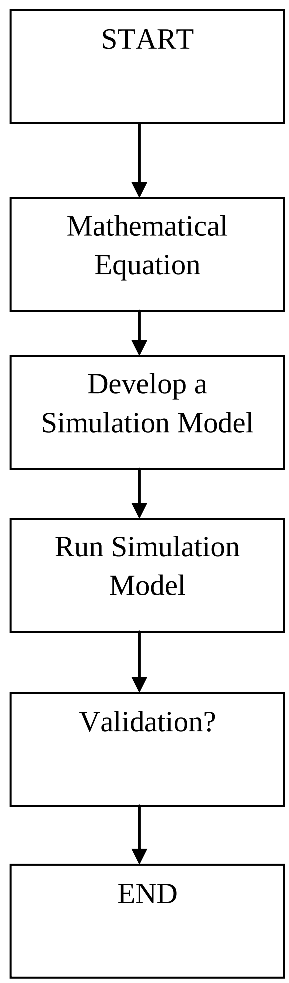

Figure 3.1 Process of Simulation Experimentation

3.4.1 MATLAB Software

In this study, MATLAB software was used. The name MATLAB stands for Matrix Laboratory. MATLAB has written originally to provide easy excess to matrix software developed by the LINPACK (Linear System Package) and EIS PACK (Eigen System Package) projects (David 2005). MATLAB is a high performance language for technical computing. It integrates computation, visualization and programming environment. Furthermore, MATLAB isa modern programming language environment: it has sophisticated data structures, contains built-in editing and debugging tools, and supports object-oriented programming. These factors make MATLAB an excellent tool for teaching and research.

Typical uses of MATLAB include:

a. Math and computation
b. Algorithm development
c. Modeling, simulation and prototyping
d. Data analysis, exploration and visualization
e. Scientific and engineering graphics
f. Application development, including graphical user interface building.

Table 3.1 Attribute for Plot

SYMBOL	COLOR
K	Black
R	Red
B	Blue
G	Green
C	Cyan
M	Magenta
Y	Yellow

(Source: David, 2005)

Advantages of using MATLAB:

1. It is very easy for a beginner in computer programming.
2. It comes with well-written manuals.
3. It is powerful graphics and ease of use. The programming environment is interactive, you can interface your MATLAB program to C and Fortran routines.
4. It also has a large number of additional application toolboxes for doing maths and analysis, data acquisition, signal processing, control design, finance and economics and simulation.

CHAPTER 4

RESULT AND DISCUSSION

4.1 Introduction

This chapter will discuss in detail the result of the simulation of analysis of ceramic ball production for the selected parameter. Factorial design method will be used to define significant parameters, firstly develop mathematical modeling from the ceramic ball production and then select the best method to carry out the study. Only significant parameter will be considered for further investigations which are radius, volume and mass.

4.2 Experimental Result

According to Jeon (2012), about 36 hour is needed in order to produce about 2 cm of ceramic ball. Density for this ceramic ball is 2.6g/cm^3. Therefore from this value, the volume, mass and inlet flowrate of the ceramic ball production can be calculated as shown below:

Time,t = 36h;

Radius, r = 2cm;

Density, ρ = 2.6 g/cm^3;

Volume,V = $\frac{4}{3}\pi r^{\wedge}3$

$= \frac{4}{3}\pi(2)^{\wedge}3$

=33.51cm^3

Mass,m = ρV

=2.6 $\frac{g}{cm^{\wedge}3}$ (33.51cm^3)

=87.13g

Flowrate inlet, F_{in} = $\frac{m}{t} = \frac{87.13g}{36h}$

=2.42$\frac{g}{h}$

4.2.1 Relationship between Radius and Time

In this case, the size or radius of ceramic ball is described by an equation of:

Mass balance:

Input-Output= Accumulation

$$\text{Fin} - \text{Fout} = \frac{\text{dm}}{\text{dt}}$$

Where Fout = 0;

$$\frac{\text{dm}}{\text{dt}} = \text{Fin}$$

$$\text{dm} = \rho dV$$

$$\text{dm} = \frac{4}{3}\rho\pi r^2 dr/dt$$

$$\text{dm} = \frac{4}{3}\rho\pi 3r^2 dr/dt$$

$$\text{dm} = 4\pi\rho r\text{^}2\frac{dr}{dt}$$

$$\frac{4\rho\pi r\text{^}2dr}{dt} = \text{Fin}$$

$$\frac{dr}{dt} = \frac{Fin}{4\pi\rho r\text{^}2}$$

In this equation, the term r is the ceramic ball radius, Fin is the inlet or mass flowrate of the raw material which consist of feldspar, kaolin and silica while *p* is the density of ceramic ball. The equation above then was input to the MATLAB software for further analysis according to the steps outlined for the ordinary differential equation (ODE) pattern. Figure 4.1 show the result in which radius of ceramic ball increase with the increasing time.

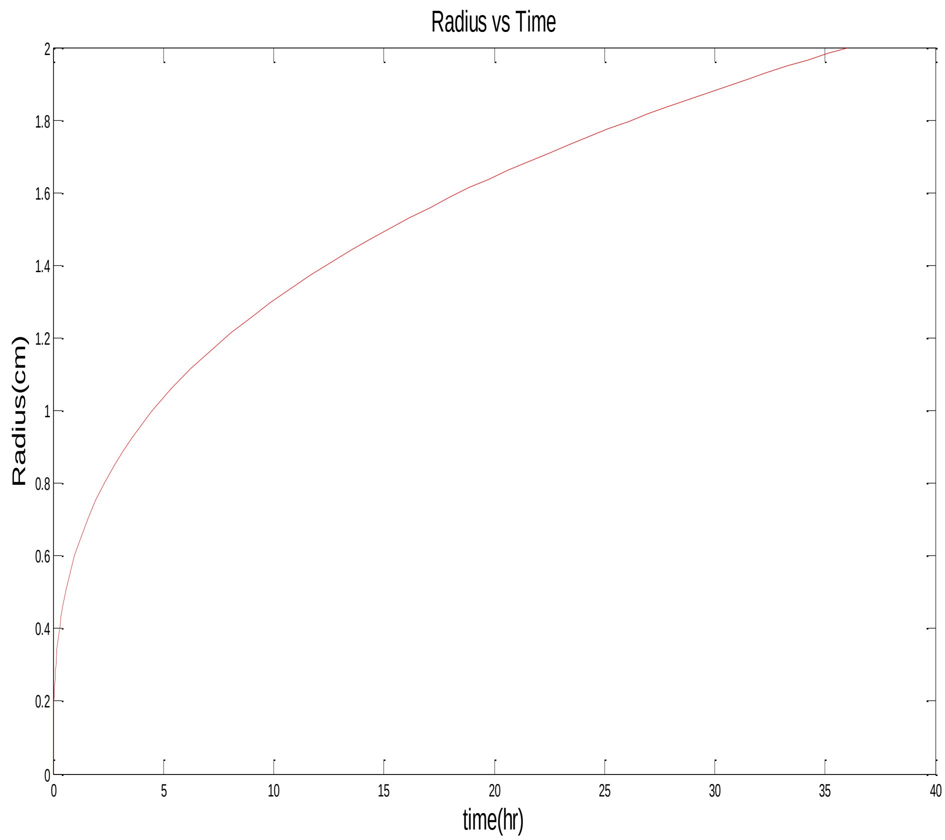

Figure 4.1 Graph of Radius versus Time

4.2.2 Relationship between Volume and Time

From the previous equation, the volume of ceramic ball can also be studied based on the equation of density which is:

p=mass/volume

Therefore;

$$\frac{dm}{dt} = \text{Fin}$$

$$\frac{d(V\rho)}{dt} = \text{Fin}$$

$$\frac{dV}{dr} = \frac{\text{Fin}}{\rho}$$

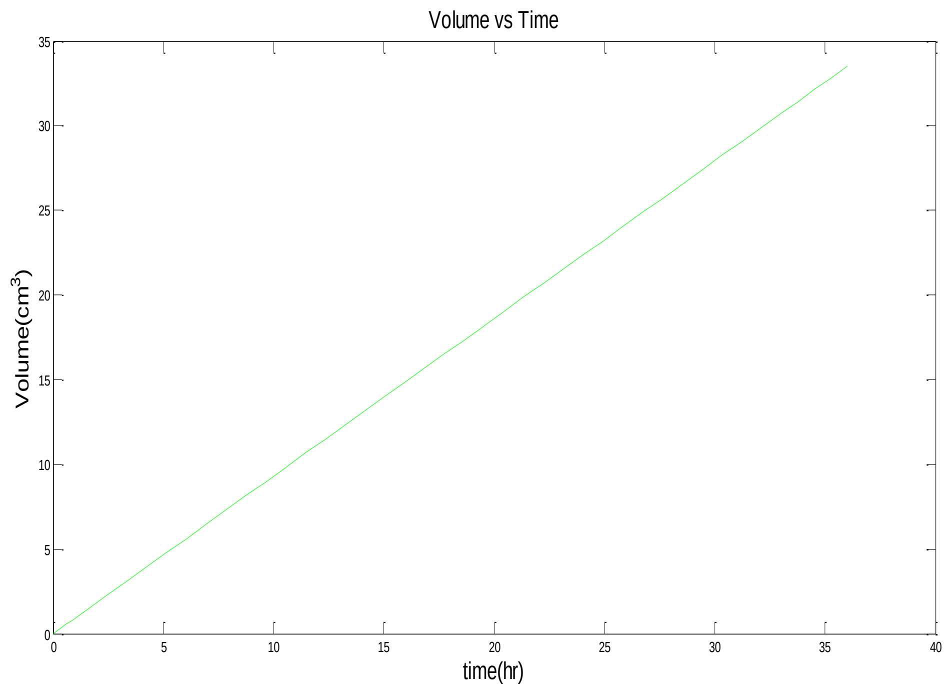

Figure 4.2 Graph of Volume versus Time

Graph above show that as time increase, volume of ceramic ball also increase which is in straight line.

4.2.3 Relationship between Mass and Time

$$\frac{dm}{dt} = \text{Fin}$$

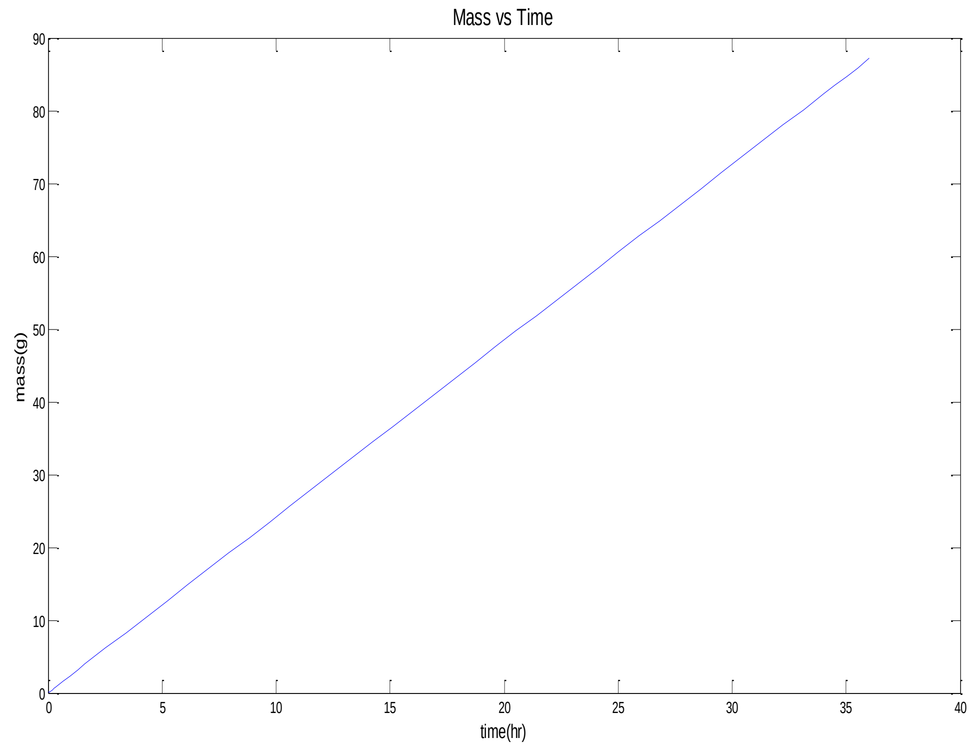

Figure 4.3 Graph of Mass versus Time

Graph above show the straight line or linear pattern for the mass versus time. This also known as flowrate which is mass divide by time.

According to Indiani et.al (2012), the composition of raw material in the ceramic ball production as shown below:

Table 4.1 Composition for the Raw Material

Raw Material	Composition
Feldspar	35%
Kaolin	35%
Silica	30%

(Source: Indiani, 2012)

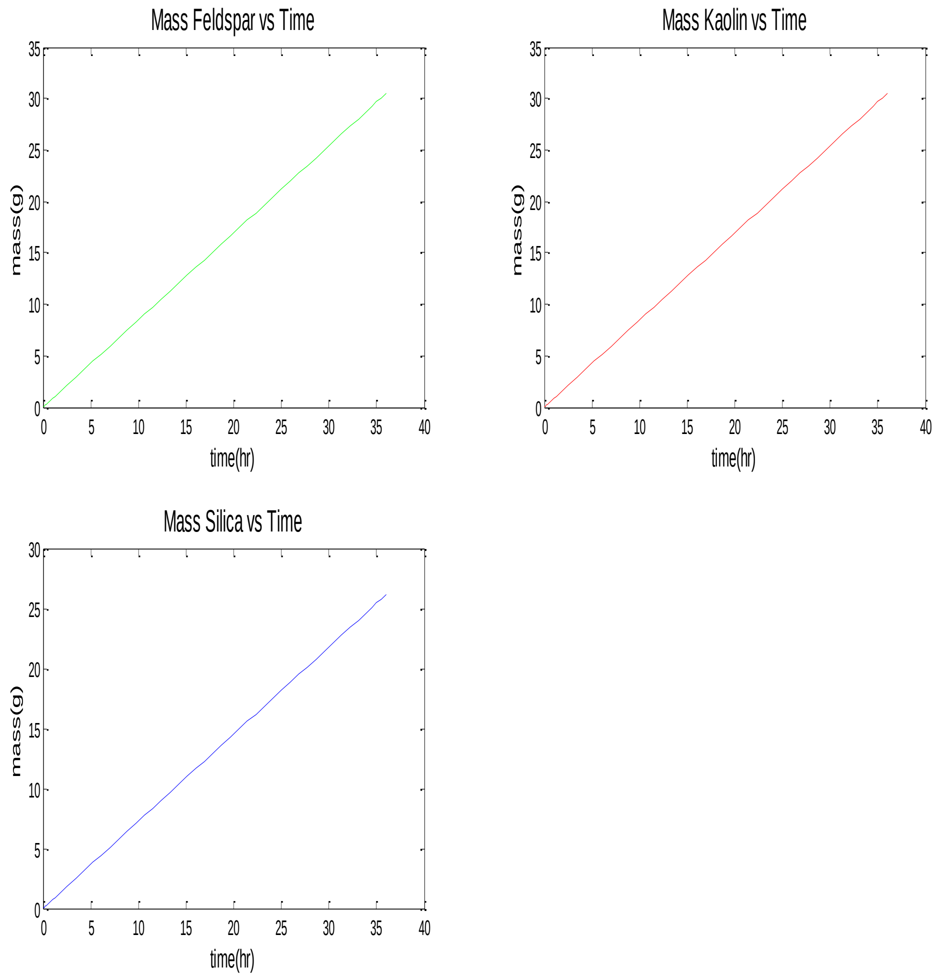

Figure 4.4 Graph of Mass of Feldspar versus Time, Mass of Kaolin versus Time, and Mass of Silica versus Time.

Figure 4.4 show the graph for the mass of each of the raw material versus time. It also shows the straight line in which mass increase linearly with the increasing time.

4.3 Discussion

4.3.1 Simulation Design Result

Basically, empirical model that were developed are statistically valid and sound. All the models were significant thus indicated that the term selected to estimate the factor effects were correct.

Particle size distribution depends on the processing parameters. Figure 4.1 show the graph of radius versus time to indicate how many time is needed in order to produce a certain size of ceramic ball. It shows that as time increase, sizes of ceramic ball also increase. This situation is correct according to Jeon (2012) in which the raw materials combine with the water and were placed in a rotary drum and then it was sprayed at 10m/s towards the ceramic powder through a nozzle rotated at 20rpm with the rotary axis A-A tilted at an angle of 20^{o}C to grow ceramic grains to a certain diameter. Then the process was repeated again until it produces a required size of ceramic ball. Therefore, the final ceramic balls had excellent particle size distribution.

The size of the formed spherical ceramic balls has various diameters ranging, but not limited to, which is from 0.5 to 100mm. Generally, the diameter ranges from 1 to 50mm but in this case, 2cm or 20mm radius was chosen. The result obtained from this study as shown in figure 4.1 is same with the experiment value which is 36 hour needed to form 2cm ceramic ball. Actually, while run the experiment, there are some conventional problems occurs in which the ceramic balls have non-uniform particle size distribution, making it difficult to obtain ceramic ball which having a desired particle size for a specific time. Therefore, a correct method and apparatus needed to produce truly spherical ceramic balls with uniform particle size distribution and this will waste time and cost. Compare to the simulation, in which it is easy to know the ceramic balls size for a certain time.

From figure 4.2, the volume of the ceramic ball is increase linearly with the increasing time. This is because there is no change in the volume of ceramic ball due to the constant or same amount of the mass of ceramic ball.

Mass of ceramic ball also increases linearly with the increasing time as shown in figure 4.3 and figure 4.4. The mass inserted to the rotary drum is same, so there will be no change occurs but it increases in a straight line as time increase. According to Jeon (2012), according to embodiments of the present invention, ceramic powder is formed into ceramic balls through a rotation method, so that the mass production is possible and substantially truly spherical ceramic balls can be obtained. Other than that, the composition of the materials input may be varied as needed. If the viscosity of the ceramic powder is high as in loess balls, the powder may be formed using water without a separate binder, whereas when producing low viscosity chloride balls, a binder is add to the powder. It should noted that the material input to the chamber are not limited to a specific kind or amount and the new ceramic powder or water and binder may be manually or automatically supplied into the chamber in the course of the formation process according to viscosity of the powder material. However in this study a specific range of raw material was chosen which 35% of Feldspar, 35% of Kaolin and 30% of Silica.

CHAPTER 5

CONCLUSION

5.1 Introduction

This chapter describes conclusions and recommendation for future study based on the current research work. Factorial method of mathematical modeling and MATLAB software were the main approaches that had been used for evaluating the parameters in the ceramic balls production. The result obtained from this simulation is same as the experimental value as shown in the figure above. However, simulation is more advantages compare to the experiment based on the time and cost production.

5.2 Conclusion

This project has proven that parameters in the ceramic balls production have been easily study. Then, the objective is achieved in which the mathematical modeling for the ceramic ball production has been developing and the parameters in the ceramic balls production were validated. Therefore, one will also reduce time and cost, all variables can be studied and control and lastly it is easy to manipulate the parameters.

5.3 Recommendation for Future Work

The following recommendations are very useful for future studies:

1. Relationship between size or amount of ceramic ball produce and processing variables such as Temperature and mill speed shall be investigated due to it affect the value of response.

2. Due to the time and data constraint, simulation was done in range of investigation. For future study, simulation should be done for whole process parameters.

3. This research should be widely study and applied in the industry in order to improve experimental performance and also to save budget.

REFERENCES

Aimi bin Abdul Ghafar, (2010), Optimizing crushing Processing Parameter of Oil Palm Shell Charcoal, *Journal from Faculty of Mechanical Engineering,* UTM,Johor:, 37, 1-38.

A.P.T.M.J.Lamberts., (2007), Numerical Simulation of Ballistic impacts on Ceramic Material, *Journal from Eindhoven University of Technology*, 4, 1-5.

Ceramic Ball, (2012), *Article from Rakannusa Corporation (M) Sdn. Bhd*. (Rakannusa), Gebeng, Pahang.

Data Sheet of Ceramic Ball, (2012), *Article from Ningbo Tianyi Chemical Industries (T.C.I) Co*,Ltd., Ningbo City, China.

David, H., (2005), Introduction to MATLAB for Engineering Students, *Journal from Nourthen University*, 51, 1-52.

Faimon, J.,and Nehyba,S., (2004), The formation of spherical clay balls on the slopes of sandpit quarry, the Rudice-Sec(Czech Republic), *Journal from Institute of Geological Sciences*, Masaryk University, 611 37 Brno. Kolerska 2, Czech Republic: Elsevier, 17, 23-40.

Feldspar. What is Feldspar?, (2012), *Journal from Industrial Minerals Association (IMA-NA)*, Suite 301 Washington, DC 20006 (202) 457-0200, North America.

G. Dmitri, V.Oleg, and J.D.S. William., (1998), Simulation of Grinding in a Shaker Ball Milk, *Journal from University of Calgary*, Calgary, Alberta, Canada T2N 1N4: Elsevier, 9, 63-72.

G.I.Ricki., (2008), Introduction to Simulation, *Journal from Oklahoma State University Stillwater*, OK 74078, U.S.A, 2,17-18.

Harell, D.C., Ghosh, D.B.K., and Bowden, D.R, (2000), Simulation Using Promodel, *Journal of McGraw-Hill Higher Education*, United States of America.

Indiani, E., and Umiati, N.A.K., (2012), Keramik Porselen Berbasis Feldspar sebagai Bahan Isolator Listrik, *Journal from Universitas Diponegoro*, Semarang Indonesia, 2, 83-85.

Jeon, H.T., (2012), Production Method for a Truly Spherical Ceramic Ball by means of Rotational Method and a Device Therefor, *Journal of United States Patent Application Publication*, 20120098170.

Lamberts, A.P.T.M.J., (2007), Numerical simulation of Ballistic impacts on ceramic material, *Journal of Eindhoven University of Technology*: Eindhoven, 5,3-8.

Liang, H., Yun , L., Hiroshima, A., and Jie, G., (2012), The influence of the processing parameters on the formation of iron thin films on alumina balls by mechanical coating technique, *Journal of The University of Chiba*, 1-33, Yayoi-cho, Inage-ku, Chiba, 263-8522,Japan: Elsevier, 7,1169-1176.

Maira, A., (1997), Introduction to Medeling and Simulation, *Journal from State University of New York* ,Binghamton, NY 13902-6000, U.S.A.,12, 1-13.

Sihite, D.R., (2008), Pembuatan dan Karakterisasi Bahan Keramik Berpori dengan Aditif Sekam Padi yang Digunakan sebagai Filter Gas Buang, *Journal from Universitas Sumatera Utara*, Medan..

Zhong, L.Y., Wu, B.L., Zhang, L .M., and Song, J.g., (2007), Influence of milling time on the performance of ceramic ball grinding media prepared from refractory waste, *Journal from University of Technology*, Guilin 541004, China: Material Science Poland, 5,130-135.

APPENDICES

APPENDIX A

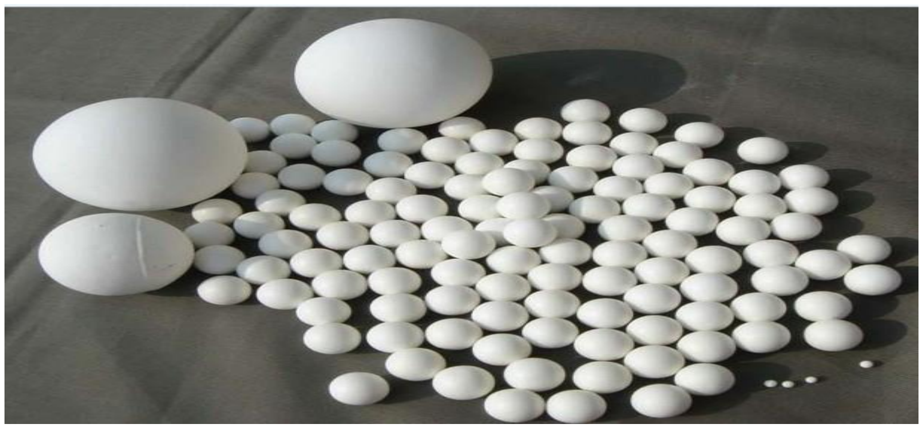

Figure A-1 Pictures of Ceramic Ball

Figure A-2 Process in Ceramic Ball Production

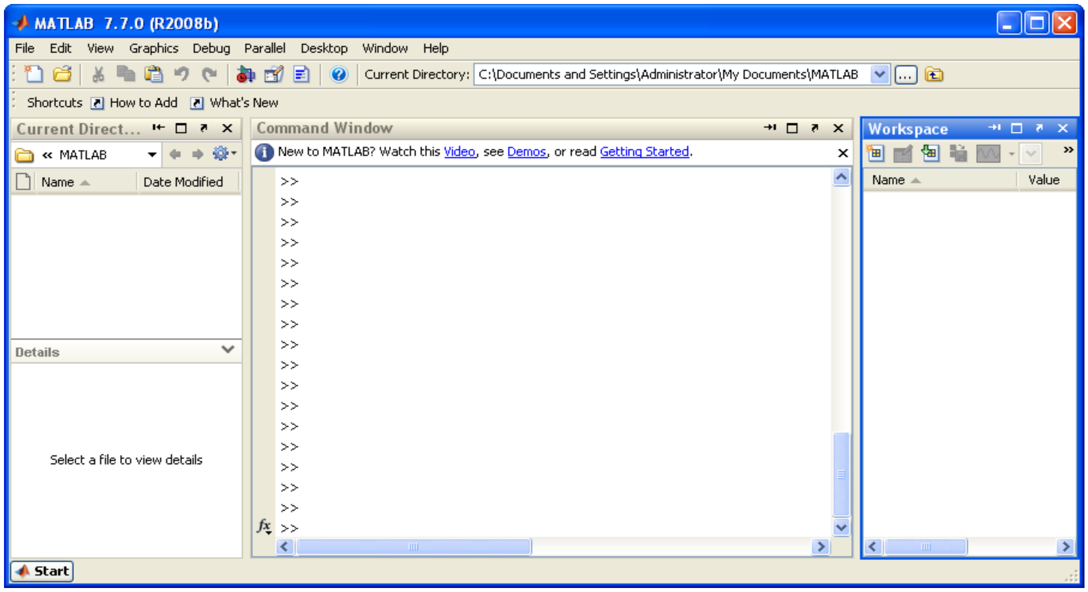

Figure A-3 Example of MATLAB

>> title('Graph of y = sin(3pi x)')
>> xlabel('x axis')
>> ylabel('y-
axis')

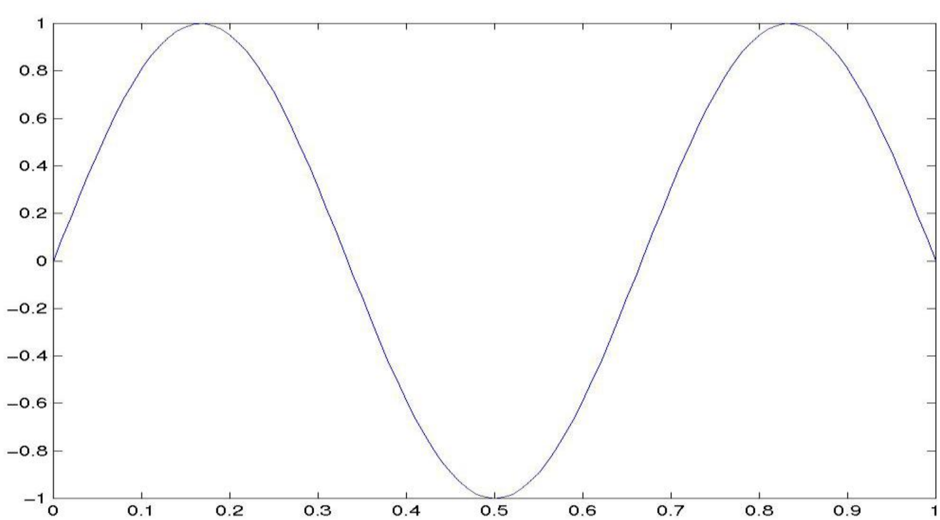

Figure A-4 Basic Plot and Labelling MATLAB

```
function new
clear
clc

t0= [0 , 36];
r0=1e-10;
[t,r]=ode45(@new,t0,r0)
plot(t,r,'r')

 xlabel('time(hr)','Fontsize',16)
 ylabel('Radius(cm)','Fontsize',16)
 title('{Radius vs Time}','Fontsize',16)

function dr = new(t,r)
Fin=2.42;
rho=2.6;
pi=3.14;
dr = Fin/(4*pi*rho*r^2)
```

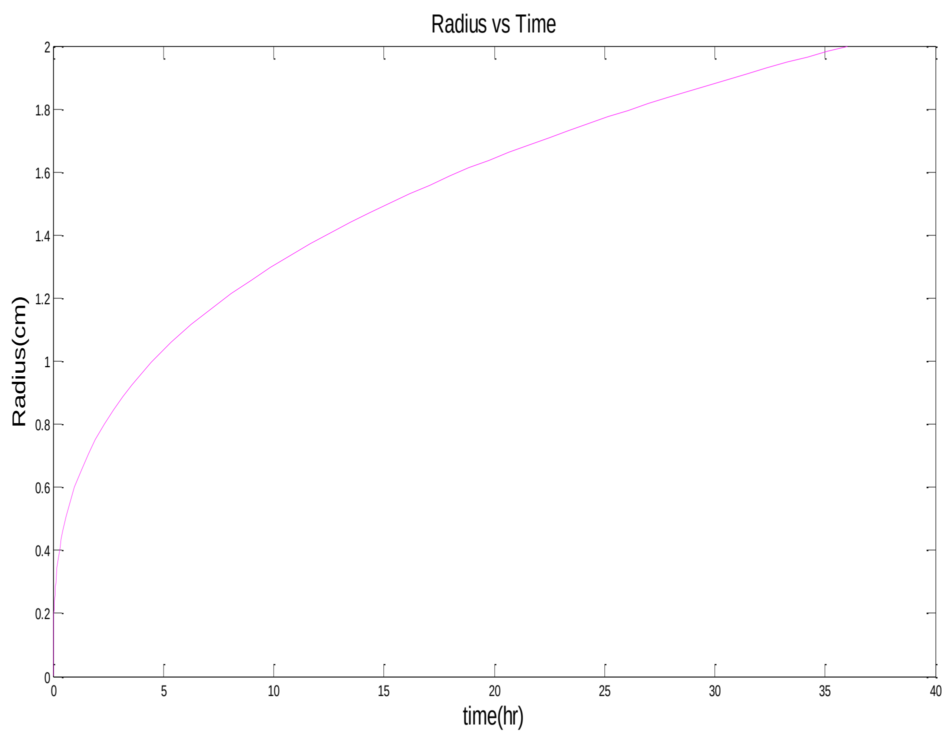

Figure A-5 Coding Code and the Graph of Radius versus Time

```
function new
clear
clc

t0= [0  36];
v0=0;
[t,v]=ode45(@volume,t0,v0)
plot(t,v,'g')

 xlabel('time(hr)','Fontsize',16)
 ylabel('Volume(cm^3)','Fontsize',16)
 title('{Volume vs Time}','Fontsize',16)

function dv = volume(t,v)
Fin=2.42;
rho=2.6;
dv = Fin/(rho)
```

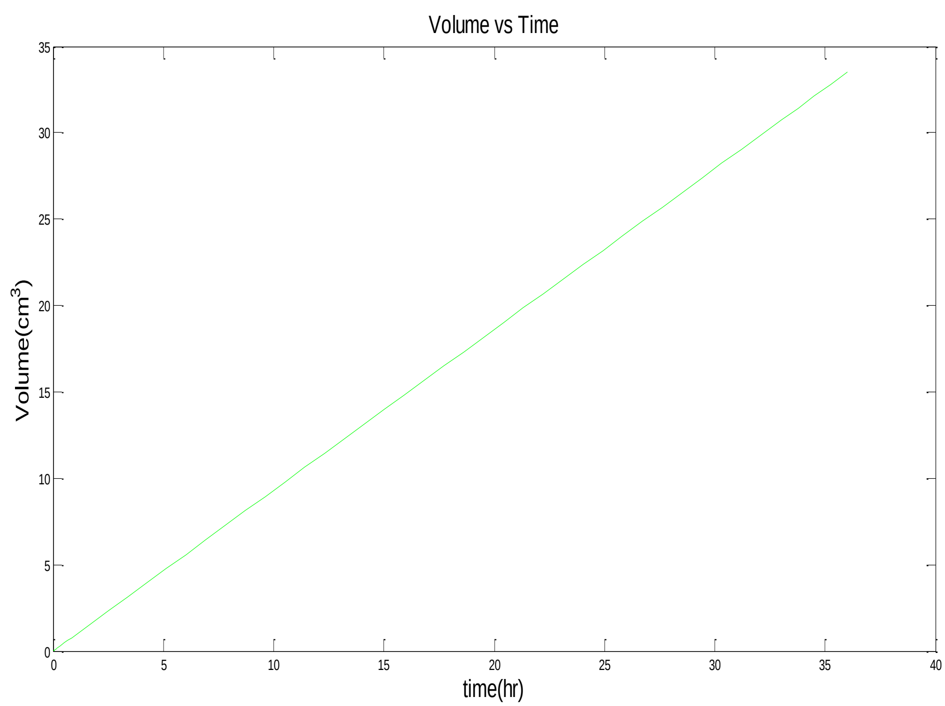

Figure A-6 Coding Code and the Graph of Volume versus Time

```
function new
clear
clc
global Fin
t0= [0 , 36];
m0=0;
Fin=2.42;
[t,m]=ode45(@massa,t0,m0)
mtotal=m;
mfeld=0.35*m;
mkaol=0.35*m;
msil=0.3*m;


figure(1)
plot(t,m,'b')

 xlabel('time(hr)','Fontsize',12)
 ylabel('mass(g)','Fontsize',12)
 title('{Mass vs Time}','Fontsize',14)

 figure(2)
 subplot(2,2,1)
 plot(t,mfeld,'g')
 xlabel('time(hr)','Fontsize',12)
 ylabel('mass(g)','Fontsize',12)
 title('{Mass Feldspar vs Time}','Fontsize',14)

 subplot(2,2,2)
 plot(t,mkaol,'r')
 xlabel('time(hr)','Fontsize',12)
 ylabel('mass(g)','Fontsize',12)
 title('{Mass Kaolin vs Time}','Fontsize',14)

 subplot(2,2,3)
 plot(t,msil,'b')
 xlabel('time(hr)','Fontsize',12)
 ylabel('mass(g)','Fontsize',12)
 title('{Mass Silica vs Time}','Fontsize',14)


function dm = massa(t,m)
global Fin
dm = Fin
```

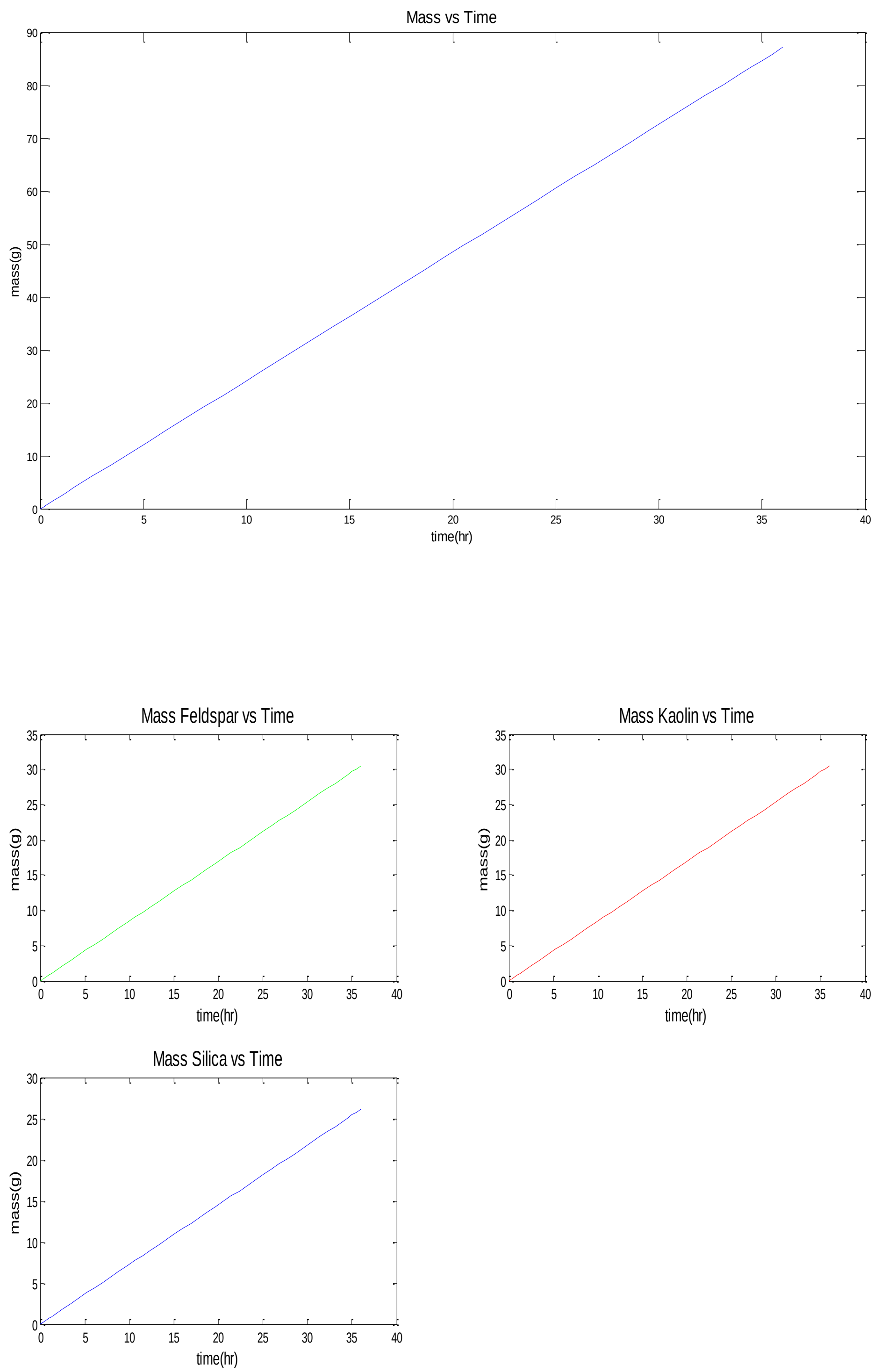

Figure A-7 Coding Code and the Graph of Mass versus Time

Radius, r = 2cm;

Density, ρ = 2.6 g/cm^3;

Volume,V = $\frac{4}{3}\pi r\text{^}3$

$= \frac{4}{3}\pi(2)\text{^}3$

=33.51cm^3

Mass,m = ρV

=2.6 $\frac{g}{cm\text{^}3}$ (33.51cm^3)

=87.13g

Flowrate inlet, F_{in} = $\frac{m}{t} = \frac{87.13g}{36h}$

=2.42$\frac{g}{h}$

Figure A-8 Calculation to find Volume, Mass and Mass Flowrate

APPENDIX B

Table B.1 Basic Arithmetic Operators

SYMBOL	OPERATION	EXAMPLE
+	Addition	2+3
-	Substraction	2-3
*	Multiplication	2*3
/	Division	2/3

Table B.2 Symbol for the Line Colour in MATLAB

SYMBOL	COLOR
K	Black
R	Red
B	Blue
G	Green
C	Cyan
M	Magenta
Y	Yellow

Table B.3 Ordinary Differential Equation (ODE) in MATLAB

Solver	Implicit/Explicit	Accuracy
Ode45	Explicit	4^{th} order, medium accuracy
Ode23	Explicit	$2^{nd}/3^{rd}$ order, low accuracy
Ode113	Explicit	Very accurate (13^{th} Order)
Ode15s	Implicit	Anything from 1^{st}-5^{th} order
Ode23s	Implicit	Low accuracy (but may be more stable than ODE15s)
Ode23tb	Implicit	Low accuracy (but may be more stable than ODE15s)