DESIGN OF TECHNOLOGICAL PROCESSES FOR THE PRODUCTION OF NANO PARTICLE COATED FILTER AID FROM BULARAFA (NIGERIAN) DIATOMITE

BY

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2000/9621EH

DEPARTMENT OF CHEMICAL ENGINEERING

SCHOOL OF ENGINEERING AND ENGINEERING TECHNOLOGY

FEDERAL UNIVERSITY OF TECHNOLOGY, MINNA, NIGERIA

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A RESEARCH PROJECT SUBMITTED TO THE DEPARTMENT OF CHEMICAL ENGINEERING, SCHOOL OF ENGINEERING AND ENGINEERING TECHNOLOGY, FEDERAL UNIVERSITY OF TECHNOLOGY, MINNA, NIGER STATE, NIGERIA

IN PARTIAL FULFILMENT OF THE REQUIREMENT FOR THE AWARD OF BACHELOR OF ENGINEERING (B. ENG.) DEGREE IN CHEMICAL ENGINEERING

OCTOBER, 2006

DECLARATION

I, Olanipekun, Saidat Ronke (2000/9621EH) declare that this project work is my original work and has never to my knowledge been elsewhere before.

Signature

03/11/2006
Date

CERTIFICATION

This is to certify that this project is the original work of Olanipekun, Saidat Ronke (2000/9621EH) carried under my supervision. I found the work adequate both in scope and quality for partial fulfilment of the requirement for the award of Bachelor of Engineering (B. Eng) in Chemical Engineering.

7/11/06

Prof. J. O. Odigure
(Project Supervisor)

Date

Dr. M.O Edoga
(Head of Department)

Date

External Examiner

Date

DEDICATION

This project is dedicated to The Almighty Allaah;

..."Verily, my Salaat (prayer), my sacrifice, my living, and my dying are for Allaah, the Lord of the 'Aalamiin (mankind, jinn and all that exists); (Holy Qur'an, Suratul Al-An'am, Chapter 6, Verse 162).

ACKNOWLEDGEMENT

The successful completion of this research work is not by my efforts at all, but by the Grace of Almighty Allah, then the contributions of my supervisor, lecturers, family members, friends, colleagues and well-wishers.

I will like to express my profound gratitude to my supervisor, Professor J. O. Odigure, for the provision of relevant materials, guidance and, most importantly, the creation of fatherly environment.

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I am highly indebted to all the members of staff of Chemical Engineering Department of Federal University of Technology most especially Prof. K. R. Onifade who has been acting as my father even before getting admission into this university.

Special appreciations go to Alhaji Folorunsho Musa Giwa and his family for their moral and financial supports.

I wish to appreciate the patience of my husband, Mal Giwa Abdulwahab, for understanding with me during this period. May Allah bless you, aamiin

My special regards go to my well wishers such as Mama AbdulSalam and my friends such as Sister Halima Olanrewaju, Sister Hauwa Isah, Sister Omolayo, Yinka and all my other classmates. My brothers and sisters in FUT Minna, jazaakumuLlaahu khayran for your encouragements.

ABSTRACT

The design of the technological process for the production of nano-particle coated filter aid was the carried out in this project. In the course of the work, Nigerian diatomite (bularafa) was used as the raw material. The material balances were carried out with the aid of Microsoft Excel and 10.00kg/hr of raw diatomite was used as the basis of the calculation while the energy balances was done using MathCAD 2000 Professional. The calciner was sized using MathCAD also and its diameter and height were found to be 0.171m and 0.256m respectively. From the calculation of the economic analysis which was carried out with the aid of MathCAD, the working capital and fixed capital investments were found not to be too big beyond what even a sole proprietor can afford. It was discovered that the total capital investment was ₦962772.65. The project was finally discovered to be profitable because investment can be recovered within one (1) year. In other word, the pay back period is 1 year.

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CHAPTER ONE

1.0 INTRODUCTION

Filtration is one of the most widely used operations in industrial processing, and diatomite has been an indispensable filter aid material for more than 60 years. Nowadays the diatomite industry faces many challenges as traditional end-use markets, especially filtration, move towards other technologies. However new applications, particularly in biotechnology could pave the way for a recovery (http://epubl.ltu.se/1402-1617/2001/009/).

Diatomite (Diatomaceous Earth or "DE") is a sedimentary rock primarily composed of the fossilized remains of unicellular fresh water plants known as Diatoms. Over the millennia the diatoms have been compressed to create one of the most effective growing mediums available. Diatomite consists of approximately 90% silicon dioxide, with the remainder of its contents being elemental minerals, which are essential for plant growth. All of these unique factors make Diatomite the premium horticultural grade medium for all growing applications (www.diatomiteusa.com/).

Diatomite consists of maximum of silicon dioxide, with the remainder of its contents being elemental minerals, which are essential for plant growth. All of these unique factors make diatomite the premium horticultural grade medium for all growing applications. Diatomite is high in silica, absorbent, porous, long lasting, environmentally friendly, ph neutral, sterilized, natural and reusable, all factors necessary for health plants, while still being cost effective for the grower. This chemical additive is used in a variety of applications, mainly as high value filter aids and functional fillers for paints and plastics. Tight quality specifications must be adhered to in order to guarantee suitability. Diatomite products are widely used as filter aids in the food and drinks industry. Further high end diatomite products are mainly used in paints. This chemical compound is used in paints as functional filler mainly for imparting a matting effect on the appearance of the paint surface. The high surface area and the pore structure of the diatomite cause an improved permeability for water vapour and a more rapid evaporation of solvents (http://www.easy2source.com/products/473/474/784/785/794/).

In Nigeria, at present, the pharmaceutical, petroleum, food and beverage industries that require the diatomite for their filtration are forced to import from the United States of America and Germany at exorbitant costs.

1.1 Aim and Objectives

The aim of this undergraduate thesis is to design the technological processes for the production of nano particle coated filter aid from diatomite. This aim will be achieved through the realization of the following objectives:

(i) acquisition of process flow sheet for the processing of diatomite;

(ii) calculation of material balances;

(iii) calculation of energy balances;

(iv) specification of the equipments involved in the processing;

(v) carrying out the economic analysis of the plant.

1.2 Scope

This work is limited to carrying out the chemical engineering design of the plant for the processing of diatomite to produce nano particle coated filter aid coated with diatomite.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Diatomite

Diatomite (diatomaceous earth, randanite, ceyssatite, or fossil flour) is a sedimentary rock consisting mainly of diatom shells. It is usually loose or weakly consolidated, and its color varies from light grey to yellowish. In various quantities there are balls (globules) of opal in diatomite, and also detrital and argillaceous minerals. Chemically diatomite on 96% consists of aqueous silica (opal).

Diatomite consists of approximately 90% silicon dioxide, with the remainder of its contents being elemental minerals, which are essential for orchid growth (http://www.tindaraorchids.com/index_tindara.htm?diatomite.htm~rbottom).

Diatomite is a material with high porosity, low density (does not sinks in water), adsorption ability, low heat and sound conductivity; it is refractory and acid proof material. Diatomite it is formed from diatomaceous silt which have accumulated in the ancient seas and lakes.

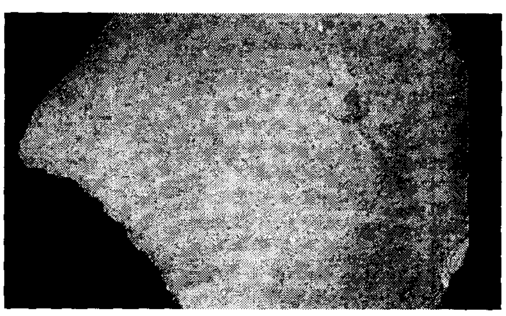


Fig. 2.1: A sample of diatomaceous earth

Diatomaceous earth, also known as DE, diatomite, diahydro, kieselguhr, kieselgur, and Celite, is a naturally occurring, soft, chalk-like sedimentary rock that is easily crumbled into a fine white to off-white powder. This powder has an abrasive feeling similar to pumice powder and is very light due to its high porosity. It is made primarily of silica and consists of fossilized remains of diatoms, a type of hard-shelled algae. It is used as a filtration aid, as a mild abrasive, as a mechanical insecticide, as an absorbent for liquids, as cat litter, and as a component of dynamite. As it is also heat resistant, it can be used as a thermal insulator (http://en.wikipedia.org/wiki/Diatomite).

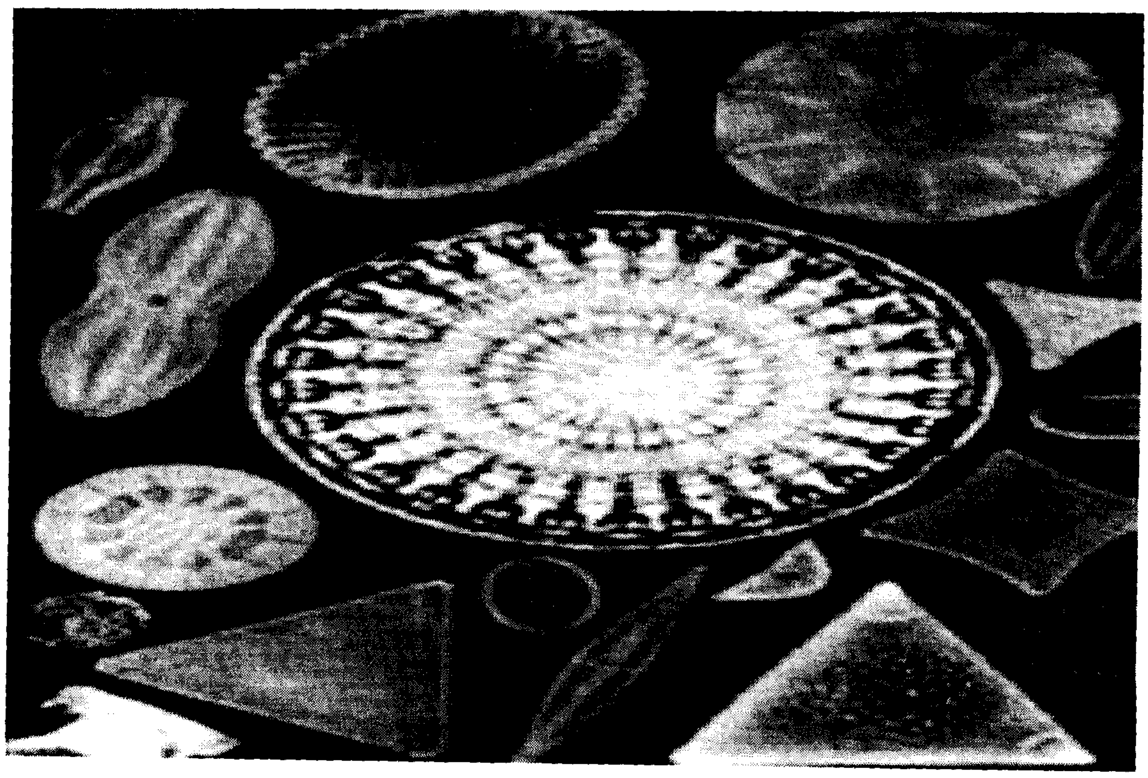


Fig. 2.2: Shapes of diatomite

2.1.1 Origin of Diatomite

Diatomite is a lightweight, white sedimentary rock formed by the accumulation of highly porous shells of Diatoms. It was used by the ancient Greeks and Romans as a lightweight, building stone. Today Diatomite, because of its superior absorbency and chemical inertness combined with very light weight, is the preferred material for industrial and domestic absorbents (http://www.supersorb.com.au/diatomite.html).

The Diatomite deposits were formed 18 million years ago when volcanoes erupted near Barraba, Northern New South Wales. The molten lava flowed to the east for 60 kilometres and new lakes formed in depressions and impounded areas within the lava field. Diatoms flourished in the nutrient rich freshwater lakes and billions of their shells sank and accumulated huge deposits of Diatomite (http://www.supersorb.com.au/diatomite.html).

Diatoms are photosynthetic single celled plants that live as plankton in lakes, rivers and oceans. Charles Darwin wrote in 1872 "Few objects are more beautiful than the minute siliceous cases of the Diatomaceae". Diatoms are vital to humankind as they make up a quarter of the earth's plant life and they produce at least a quarter of the oxygen we breathe (http://www.supersorb.com.au/diatomite.html).

2.1.2 Super absorbance of diatomite

Each granule contains millions of microscopic, hollow, perforated cylindrical shells that were produced by the ancient Diatoms, resulting in an inert, lightweight, highly porous, super absorbent material. Diatomite does not break down and become slippery when wet like other absorbent materials. 25 million Diatoms would fit in teaspoon (http://www.supersorb.com.au/diatomite.html).

2.1.3 Chemical analysis of diatomite

Table 2.1: Typical Chemical Analysis

Component	**Min %**	**Max %**
Silicon Dioxide (SiO_2)	65	80
Aluminium Oxide (Al_2O_3)	14	18
Iron Oxide (Fe_2O_3)	2.5	4
Calcium Oxide (CaO)	1.5	2.2
Potassium Oxide (K_2O)	0.9	1.2
Titanium Oxide (TiO_2)	0.65	0.85
Manganese Oxide (MnO)	0.04	0.06
Phosphorous Oxide (P_2O_5)	0.04	0.08

Source: (http://www.supersorb.com.au/diatomite.html)

2.1.4 Physical properties of diatomite

The properties of diatomite are as outlined below.

Table 2.2: Physical properties

Property	Value and Description
Colour	Cream to Tan
Moisture (as packed)	0.0007
pH	7.9 - 9.4
Cation Exchange Capacity	30 meq/100gm
Water Absorption (% w/w)	80 - 130%
High Silica Content	Silica is essential for healthy plants and roots. Because diatomite is 90% silica, your orchids will receive a slow release of silica resulting in healthier more robust orchids.
Absorbency & Porosity	Diatomite is naturally very porous, and can hold 150% of its weight in water. The silica content, natural absorbency, and porous qualities result in a slow release of water and nutrients to your plants, contributing to higher yields and less watering.
Capillary Action & Lateral Movement	The porosity of the Diatomite contributes to its ability to draw water, while moving water and nutrients laterally throughout the medium, making Diatomite ideal for Hydroponics!
Air Penetration	Diatomite is multifaceted and varies in size. Because each rock is unique in shape it does not compact while in the pot. This leaves pockets, allowing air to penetrate and circulate to the root zone.
Sterilized, Non-Toxic, pH Neutral	When Diatomite is mined it is heat treated to over 600 degrees Celsius, making it completely sterile and safe for all of your planting needs. Whether you are using 100% Diatomite or you are adding it to an orchid mix it will not contribute to changes in pH.
Environmentally Friendly	Diatomite is a fossil, making it natural, safe and an environmentally conscience alternative. Our supplier has visited the mine in Australia, and we are confident that the practices used to mine Diatomite are safe and in accordance with Australian environmental guidelines.
Long Lasting, Natural & Reusable	Diatomite is inert and will not break down or decompose like other growing mediums. It is natural and completely reusable. When dry, Diatomite is extremely lightweight, making it ideal for plant shipping purposes. Because it is reusable and long lasting it is economical and cost effective for long term use.

2.1.5 Applications

Outlined below are the uses (applications) of diatomite.

2.1.5.1 Filtration

The most common use (68%) of diatomaceous earth is a filter medium, especially for swimming pools. It has a high porosity because it is made of microscopically small coffin-like hollow particles. It is used in chemistry as a filtration aid to filter very fine particles that would otherwise pass or clog filter paper. It is also used to filter water and other liquids such as beer. It can also filter syrups and sugar. Other industries such as paper, paints, ceramics, soap, and detergents use it as a filling material (http://en.wikipedia.org/wiki/Diatomite).

2.1.5.2 Abrasive

The oldest use of diatomite is as a very mild abrasive and for this purpose has been used in toothpaste and metal polishes (http://en.wikipedia.org/wiki/Diatomite).

2.1.5.3 Pest control

Diatomite is also used as an insecticide due to its abrasive properties. The fine powder abrades the cuticle, the waxy outer layer of insects' exoskeletons, causing them to dehydrate. This also works against gastropods and is commonly employed in gardening to defeat slugs. Beekeepers are apparently experimenting with it to keep small hive beetles from breeding. It is sometimes mixed with an attractant or other additives to increase its effectiveness. Medical grade diatomite is sometimes used to de-worm both animals and humans (http://en.wikipedia.org/wiki/Diatomite).

2.1.5.4 Absorbent

Its absorbent qualities make it useful for spill cleanup and the U.S. Center for Disease Control recommends it to clean up toxic liquid spills (http://en.wikipedia.org/wiki/Diatomite).

More recently, it has been employed as a primary ingredient in a type of cat litter. The type of silica used in cat litter comes from freshwater sources and does not pose a significant health risk to pets or humans (http://en.wikipedia.org/wiki/Diatomite).

In 1867, Alfred Nobel discovered that nitroglycerin could be made much more stable if absorbed in diatomiteh. He patented this mixture as dynamite (http://en.wikipedia.org/wiki/Diatomite).

2.1.6 Benefits of Using Diatomite

Diatomite is high in silica, absorbent, porous, long lasting, environmentally Friendly, pH neutral, sterilized, natural and reusable, all factors necessary for health plants, while still being cost effective for the grower (www.diatomiteusa.com/uses.html).

- **High Silica Content:** Silica is essential for healthy plants and roots. While Diatomite is approximately 85% insoluble Silica, it contains a small but significant portion that is soluble silica. Silica is essential for healthy plants and roots. Your plants will receive from Diatomite a slow release of silica resulting in healthier, more robust plants. Plant available silica has been shown in studies to stimulate Systemic Acquired Resistance (SAR) in plants which increase their resistance to disease (www.diatomiteusa.com/uses.html).
- **Absorbency & Porosity:** Diatomite is naturally very porous, and can hold 150% of its weight in water. The Silica Content, natural Absorbency, and Porous qualities result in a slow release of water and nutrients to your plants, contributing to higher yields and less watering.
- **Capillary Action & Lateral Movement:** The porosity of the Diatomite contributes to its ability to draw water, while moving water and nutrients laterally throughout the medium, making Diatomite ideal for Hydroponics! (www.diatomiteusa.com/uses.html)
- **Air Penetration:** Diatomite is multifaceted and varies in size. Because each rock is unique in shape it does not compact while in the pot. This leaves pockets, allowing air to penetrate and circulate to the root zone (www.diatomiteusa.com/uses.html).
- **Sterilized, Non-Toxic, pH Neutral:** When Diatomite is mined it is heat treated to over 600 degrees Celsius, making it completely sterile and safe for all of your planting needs. Whether you are using 100% diatomite or you are adding it to a mix of your soil it will not contribute to changes in pH.
- **Environmentally Friendly:** Diatomite is a fossil, making it natural, safe and an environmentally conscious alternative. We have visited the mine in Australia, and we are confident that the practices used to mine our product are

safe and in accordance with Australian environmental guidelines (www.diatomiteusa.com/uses.html).

- **Long Lasting, Natural & Reusable:** Diatomite is inert and will not break down or decompose like other growing mediums. It is Natural and completely reusable. When dry, diatomite is extremely lightweight, making it ideal for plant shipping purposes. Because it is Reusable and Long Lasting it is economical and cost effective for long term use (www.diatomiteusa.com/uses.html).

2.1.7 Occurrence of diatomite in Nigeria

In every continent, the deposits of diatomite are known to exist in widely diversified locations. The Geological Survey of Nigeria at the north eastern part of the country first discovered diatomite in 1924. Table 2.3 below gives the specific locations of the abundant deposits of diatomite in Nigeria (Anwar, 2004).

Table 2.3: Deposits of diatomite in Nigeria

S/No.	State	Local Government Area	Town/Village
1	Borno	Hawul	Miringa, Shani
2	Bauchi	Gamawa	Udubo
3	Gombe	Kwami	Kwami
4	Yola	Gujba	Bularafa, Abakire, Gujba, Makatari

Source: (Anwar, 2004)

2.1.7.1 Bularafa Diatomite Deposits

This covers a total area of 63.1 hectares located 6km north of Bularafa village and lies between latitudes 11° 06' and 11° 09' north of the equator and longitudes of 11° 47' and 11° 48' east of Greenwich in Gujba Local Government Area of Yobe State. GNS discovered the deposit in 1924 (Anwar, 2004).

In 1963 and 1985, NMC (the holder of the lease) carried out detailed investigations and a total of 43 Banka drill holes were drilled, 32 of which encountered diatomite at various deposits ranging from 0 – 30 metres. This investigation revealed a reserve of about 400,000 tonnes of diatomite (Anwar, 2004).

2.1.7.2 Abakire diatomite deposits

Located about 1.5km north east of Abakire village, the deposit was discovered in 1931 by Geological Survey of Nigeria, NMC investigated the site in 1987 drilling a total of 47 holes on 200 x 20m grid and 100 x 10m. An area of 200,000 square metres was demarcated as diatomite bearing. A reserve of 350,000 tonnes has been estimated for the deposit with the average thickness of 1.5 metres and overburden ratio of 0.4:1 metre (Anwar, 2004).

2.2 Diatomite Filter Aid

Diatomite has been used as a filter aid for nearly a century. The ore is a soft, friable siliceous mineral. It is composed of the skeletons of microscopic plants deposited on the bottoms of oceans and lakes after and during the Miocene Age, from 100,000 to 15,000,000 years ago. Under the microscope the particles of diatomite show up in a variety of forms: symmetrical figures resembling disks, rods, cylinders and snowflakes. It is the shape factor combined with the rigidity of the particles that makes Dicalite diatomite such an excellent raw material for the production of superior filter aids (http://www.grefco.com/Diatom_filter_aid.htm).

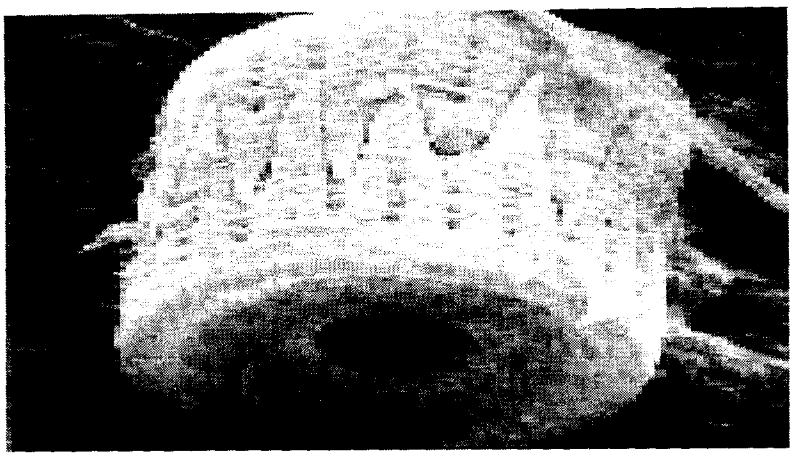
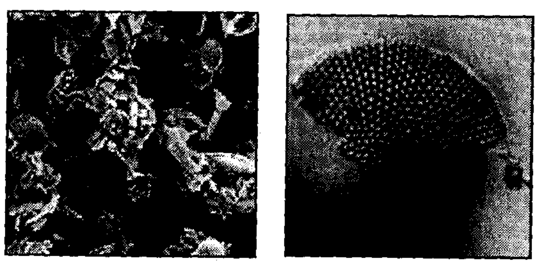


Fig. 2.3: Diatomite filter aid

Diatomaceous earth is an amorphous form of silica containing a small amount of microcrystalline material. Filter aids are processed at above 800 °C (1500 °F). Both calcined and flux-calcined diatomite filter aids are free of organic matter and are non-adsorptive.

Dicalite diatomite filter aids offer outstanding performance from the finest to the coarsest grades. These materials meet all requirements for good filter aids. This enables them to meet the exacting clarity and flow-rate demands of industrial filtration. Even more important, the user can depend on consistency and uniformity load after load (http://www.grefco.com/Diatom_filter_aid.htm).

Further, Diatomite is a chalky sedimentary rock composed of the skeletal remains of single cell aquatic plants called Diatoms. Each particle is porous and has honeycomb, rods, cone and snow flakes like structure and due to this property, Diatomite after some process is used to filter perfectly different solutions. Filtroseem is our brand name for our diatomite products, which was established in the year 1980 and since then it has become a popular brand in the market (http://www.indiamart.com/seemaminerals/).



View Of Diatomite   Structure Of Diatomite

Fig. 2.4: View and structure of diatomite

2.2.1 Uses of Filter aid

- Filter aid is used to remove the suspending impurities in microns from any liquid.
- In pharmaceuticals, it is used to filter syrups and other bulk drugs in liquid form, which is added in tablets etc.
- In oil Industries, before packing, it is used to filter oil to give it a shine and to remove any suspending impurity.
- Beer is filtered through diatomite before packing to remove molasses.

- Filter candles are made from diatomite filteraids for drinking water purification.
- Processed diatomite granules 15 to 50 mm are used in denim cloth wash, to give it shine and design. Diatomite granules are replacement of pumice stone which is used for same purpose and is imported from turkey (http://www.indiamart.com/seemaminerals/).

2.3 Nano particle

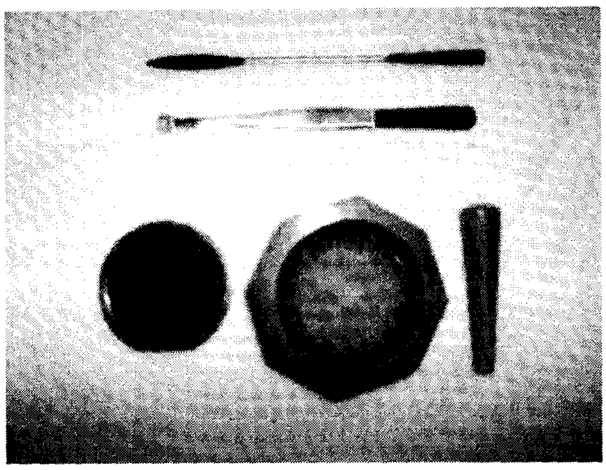


Fig. 2.5: Silicon nanopowder

A nanoparticle is a microscopic particle whose size is measured in nanometres (nm). It is defined as a particle with at least one dimension <200nm. Nanoparticles made of semiconducting material may also be labeled quantum dots if they are small enough (typically sub 10nm) that quantization of electronic energy levels occurs.

Nanoparticles are of great scientific interest as they are effectively a bridge between bulk materials and atomic or molecular structures. A bulk material should have constant physical properties regardless of its size, but at the nano-scale this is often not the case. Size-dependent properties are observed such as quantum confinement in semiconductor particles, surface plasmon resonance in some metal particles and superparamagnetism in magnetic materials. Semi-solid and soft nanoparticles have been manufactured. A prototype nanoparticle of semi-solid nature is the liposome.

The properties of materials change as their size approaches the nanoscale. For example, the bending of bulk copper (wire, ribbon, etc.) occurs with movement of copper atoms/clusters at about the 50 nm scale. Copper nanoparticles smaller than 50 nm are considered super hard materials that do not exhibit the same malleability and ductility as bulk copper.

The interesting and sometimes unexpected properties of nanoparticles are partly due to the aspects of the surface of the material dominating the properties in lieu of the bulk properties. The percentage of atoms at the surface of a material becomes significant as the size of that material approaches the nanoscale. For bulk materials larger than one micrometre the percentage of atoms at the surface is minuscule relative to the total number of atoms of the material. Suspensions of nanoparticles are possible because the interaction of the particle surface with the solvent is strong enough to overcome differences in density, which usually result in a material either sinking or floating in a liquid.

Nanoparticles often have unexpected visible properties because they are small enought to scatter visible light rather than absorb it. For example gold nanoparticles appear deep red to black in solution.

At the small end of the size range, nanoparticles are often referred to as clusters. Metal, dielectric, and semiconductor nanoparticles have been formed, as well as hybrid structures (e.g., core-shell nanoparticles). Nanospheres, nanorods, and nanocups are just a few of the shapes that have been grown. Semiconductor quantum dots and nanocrystals are types of nanoparticles. Such nanoscale particles are used in biomedical applications as drug carriers or imaging agents. Various types of liposome nanoparticles are currently used clinically as delivery systems for anticancer drugs and vaccines.

Nanoparticle characterization is necessary to establish understanding and control of nanoparticle synthesis and applications. Characterization is done by using a variety of different techniques, mainly drawn from materials science. Common techniques are electron microscopy [TEM, SEM], Atomic Force Microscopy [AFM], dynamic light scattering [DLS], X-Ray Photoelectron Spectroscopy [XPS], powder X-Ray Diffractometry [XRD], and Fourier transform infrared spectroscopy [FTIR].

Besides research purposes, nanoparticles have already been used for commercial purposes. Refrigerators and washing machines are coated with silver nanoparticles which kill micro-organisms. This ensures that food will stay fresh for a very long time and clothes are cleaned thoroughly.

Nanoparticle research is currently an area of intense scientific research, due to a wide variety of potential applications in biomedical, optical, and electronic fields. The National Nanotechnology Initiative of the United States government has driven huge amounts of state funding exclusively for nanoparticle research (http://en.wikipedia.org/wiki/Nanoparticle).

2.4 Production of Diatomite

2.4.1 Processing technologies for the production of diatomite

During its early development period, diatomite was processed almost exclusively by hand. It was taken from the beds in blocks and dried, and subsequently shipped in this form. The first mill or plant for processing natural diatomite was constructed in the early 1900s. Today, diatomite is typically mined by open-pit quarrying techniques using conventional, heavy duty earth moving equipment then transferred to a processing plant. At the plant, three different processes are used to manufacture the many different diatomite products depending on the desired characteristics (www.ima-eu.org).

2.4.1.1 Natural Grades

The crude ore is milled, dried at relatively low temperatures and classified to remove extraneous matter and to produce a variety of different particle-size grades. These natural powders, consisting primarily of amorphous silica, are generally off-white in colour (www.ima-eu.org).

2.4.1.2 Calcined Grades

These products are produced from the natural material by calcination, or sintering, at higher temperatures usually in excess of 900°C in a rotary kiln. After calcination, the diatomite is further processed into products with selected particle size ranges that can include filter aids, multifunctional fillers and aggregates. During calcination any organics and volatiles are removed and the colour typically changes from off-white to tan or pink (www.ima-eu.org).

2.4.1.3 Flux-calcined grades

These products are also produced from the natural material by calcining in a rotary kiln. Temperatures in excess of 900°C are used in the presence of a flux such as soda ash (sodium carbonate). During flux-calcination the diatoms further increase in particle size though agglomeration, and in many instances become bright white in colour depending upon the conditions chosen. Further milling and air separation control the final particle size distribution to produce filter aids of relatively high permeability and fine white multifunctional fillers (www.ima-eu.org).

2.4.2 Process description

Most diatomite deposits are found at or near the surface and can be mined by open pit methods or quarrying. Diatomite mining is all open pit, normally using some combination of bulldozers, scraper-carriers, power shovels, and trucks to remove overburden and the crude material. In most cases, fragmentation by drilling and blasting is not necessary. The crude diatomite is loaded on trucks and transported to the mill or to stockpiles. Figure 2.6 shows a typical process flow diagram for diatomite processing (Kadey, 1983).

The processing of uncalcined or natural-grade diatomite consists of crushing and drying. Crude diatomite commonly contains as much as 40 percent moisture, and in many cases contains over 60 percent. Primary crushing to aggregate size (normally done by a hammer mill) is followed by simultaneous milling-drying (Kadey, 1983).

For filtration uses, natural grade diatomite is calcined by heat treatment in gas-or fuel oil-fired rotary calciners, with or without a fluxing agent. Typical calciner operating temperatures range from 650° to 1200°C (1200° to 2200°F). For straight-calcined grades, the powder is heated to the point of incipient fusion in large rotary calciners, and thus, in the strict technical sense, the process is one of sintering rather than calcining. The material exiting the kiln then is further crushed and milled. Straight calcining is used for adjusting the particle size distribution for filter aid applications in which medium flow rates are required. The product of straight calcining has a pink color, which is caused by the oxidation of iron in the raw material and becomes more intense with increasing iron oxide content aids (Kadey, 1983). The diatomite is then passed to the moulding machine to be moulded into bottled shape. Finally, the mould of the diatomite is coated with graphite (as wound) and connected to the mains as shown in Figure 2.7 below.

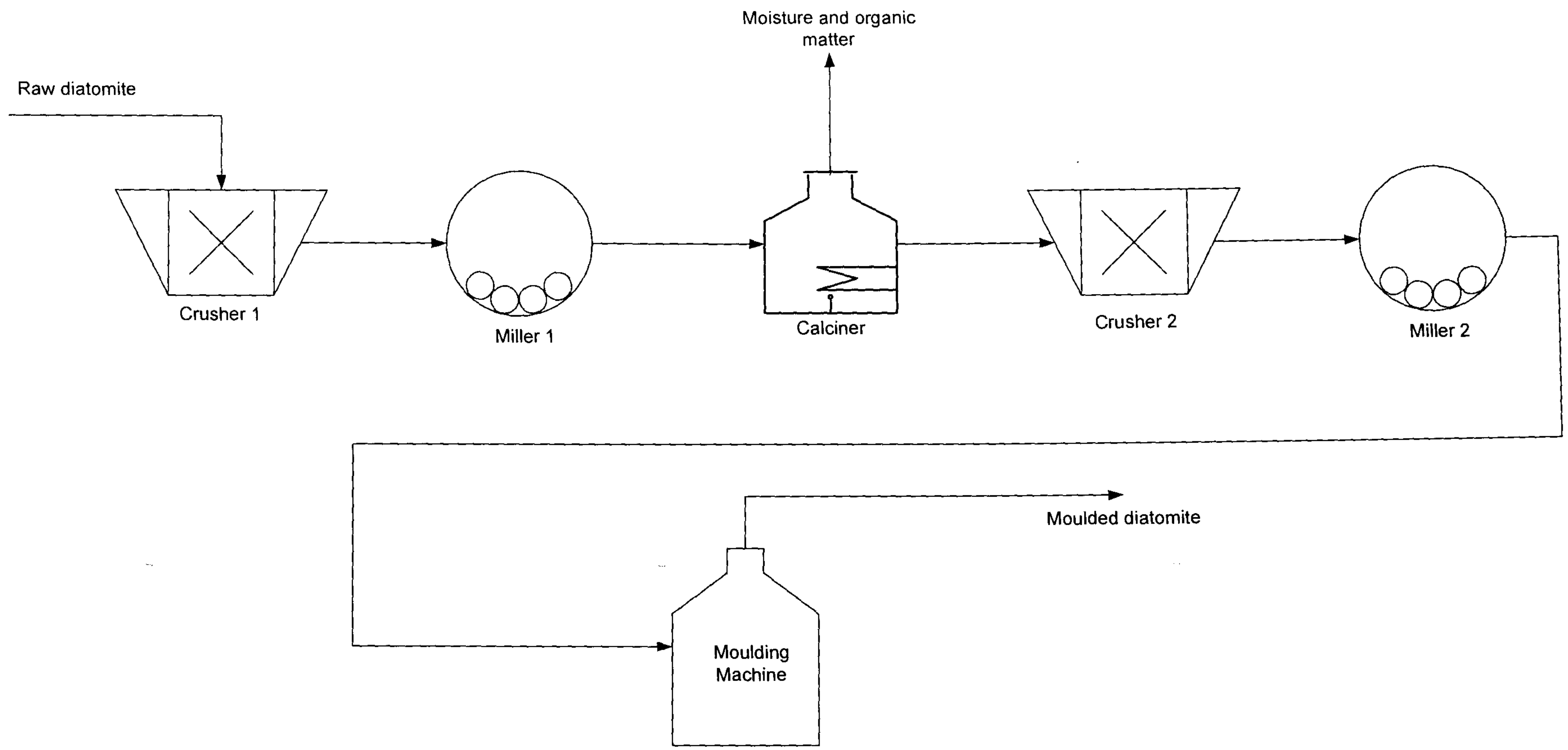


Figure 2.6: Process flow diagram for the production of nano particle coated diatomite.

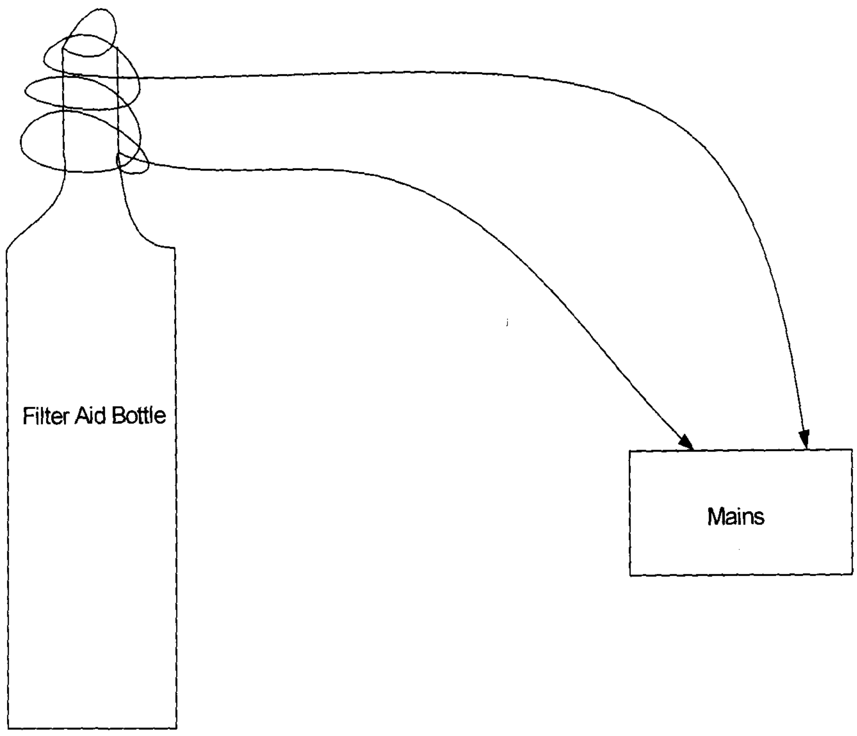


Figure 2.7: Coating of the mould of diatomite (filter aid)with graphite (nano particle)

CHAPTER THREE

3.0 MATERIAL BALANCES, ENERGY BALANCES, SPECIFICATION OF EQUIPMENT AND ECONOMIC ANALYSIS

3.1 Material Balaances

Basis = 10.00 kg/hr of raw diatomite

Composition of raw bularafa diatomite

Comp.	wt%
Diatomite	55.90
Moisture	40.00
Organic Matter	4.10
Total	100.00

Unit 1: Crusher
Operation: Particle size reduction of diatomite
Assumption: 100% material recovery

	Unit Input		Unit Addition		Unit Loss		Unit Output	
Comp	kg/hr	wt%	kg/hr	wt%	kg/hr	wt%	kg/hr	wt%
Diatomite	5.59	55.90	0.00	#DIV/0!	0.00	#DIV/0!	5.59	55.90
Moisture	4.00	40.00	0.00	#DIV/0!	0.00	#DIV/0!	4.00	40.00
Organic Matter	0.41	4.10	0.00	#DIV/0!	0.00	#DIV/0!	0.41	4.10
Total	10.00	100.00	0.00	#DIV/0!	0.00	#DIV/0!	10.00	100.00

Unit 2: Miller
Operation: Grinding of crushed diatomite
Assumption: Milling to uniform size was achieved

	Unit Input		Unit Addition		Unit Loss		Unit Output	
Comp	kg/hr	wt%	kg/hr	wt%	kg/hr	wt%	kg/hr	wt%
Diatomite	5.59	55.90	0.00	#DIV/0!	0.00	#DIV/0!	5.59	55.90
Moisture	4.00	40.00	0.00	#DIV/0!	0.00	#DIV/0!	4.00	40.00
Organic Matter	0.41	4.10	0.00	#DIV/0!	0.00	#DIV/0!	0.41	4.10
Total	10.00	100.00	0.00	#DIV/0!	0.00	#DIV/0!	10.00	100.00

Unit 3: Calciner
Operation: Calcination of diatomite
Assumptions: (1) The moisture is removed
(2) The organic matter is burnt away

	Unit Input		Unit Addition		Unit Loss		Unit Output	
Comp	kg/hr	wt%	kg/hr	wt%	kg/hr	wt%	kg/hr	wt%
Diatomite	5.59	55.90	0.00	#DIV/0!	0.00	0.00	5.59	100.00
Moisture	4.00	40.00	0.00	#DIV/0!	4.00	90.70	0.00	0.00
Organic Matter	0.41	4.10	0.00	#DIV/0!	0.41	9.30	0.00	0.00
Total	10.00	100.00	0.00	#DIV/0!	4.41	100.00	5.59	100.00

Unit 4: Crusher
Operation: Size reduction of calcined diatomite
Assumptions: 100% material recovery

	Unit Input		Unit Addition		Unit Loss		Unit Output	
Comp	kg/hr	wt%	kg/hr	wt%	kg/hr	wt%	kg/hr	wt%
Diatomite	5.59	100.00	0.00	#DIV/0!	0.00	#DIV/0!	5.59	100.00
Moisture	0.00	0.00	0.00	#DIV/0!	0.00	#DIV/0!	0.00	0.00
Organic Matter	0.00	0.00	0.00	#DIV/0!	0.00	#DIV/0!	0.00	0.00
Total	5.59	100.00	0.00	#DIV/0!	0.00	#DIV/0!	5.59	100.00

Unit 5: Miller
Operation: Grinding of crushed calcined diatomite
Assumptions: Milling to uniform size is achieved

	Unit Input		Unit Addition		Unit Loss		Unit Output	
Comp	kg/hr	wt%	kg/hr	wt%	kg/hr	wt%	kg/hr	wt%
Diatomite	5.59	100.00	0.00	#DIV/0!	0.00	#DIV/0!	5.59	100.00
Moisture	0.00	0.00	0.00	#DIV/0!	0.00	#DIV/0!	0.00	0.00
Organic Matter	0.00	0.00	0.00	#DIV/0!	0.00	#DIV/0!	0.00	0.00
Total	5.59	100.00	0.00	#DIV/0!	0.00	#DIV/0!	5.59	100.00

Unit 6: Moulding Machine
Operation: Moulding of diatomite into bottled shape
Assumptions: 3.00 % of the diatomite is lost in this unit
Each bottle weight 1 kg at the rate of 5 bottles per hour

	Unit Input		Unit Addition		Unit Loss		Unit Output	
Comp	kg/hr	wt%	kg/hr	wt%	kg/hr	wt%	kg/hr	wt%
Diatomite	5.59	100.00	0.00	#DIV/0!	0.17	100.00	5.42	100.00
Moisture	0.00	0.00	0.00	#DIV/0!	0.00	0.00	0.00	0.00
Organic Matter	0.00	0.00	0.00	#DIV/0!	0.00	0.00	0.00	0.00
Total	5.59	100.00	0.00	#DIV/0!	0.17	100.00	5.42	100.00

3.2 Energy Balances

Since there is no data for the heat capacity of the diatomite, the heat capacities of its components

to evaluate its own heat capacity. Outlined below are the heat capacities of the components of

diatomite

$$C_{pSiO2} = (3.65 + 0.0240 \cdot T) \cdot \frac{cal}{mol \cdot K}$$

$$C_{pAl2O3} = \left(22.08 + 0.008971 \cdot T - \frac{522500}{T^2}\right) \cdot \frac{cal}{mol \cdot K}$$

$$C_{pCaO} = \left(10.00 + 0.00484 \cdot T - \frac{108000}{T^2}\right) \cdot \frac{cal}{mol \cdot K}$$

$$C_{pMgO} = \left(10.86 + 0.001197 \cdot T - \frac{208700}{T^2}\right) \cdot \frac{cal}{mol \cdot K}$$

$$C_{pFe2O3} = \left(24.72 + 0.01604 \cdot T - \frac{423400}{T^2}\right) \cdot \frac{cal}{mol \cdot K}$$

$$C_{pTiO2} = \left(11.81 + 0.00754 \cdot T - \frac{41900}{T^2}\right) \cdot \frac{cal}{mol \cdot K}$$

$$C_{pK2O} = \left(69.26 + 0.00821 \cdot T - \frac{2331000}{T^2}\right) \cdot \frac{cal}{mol \cdot K}$$

$$C_{pNa2O} = \left(63.78 + 0.001171 \cdot T - \frac{1678000}{T^2}\right) \cdot \frac{cal}{mol \cdot K}$$

$$C_{pH2O} = \left[11.2964 + 47.212 \cdot 10^{-2} \cdot T + \left(-133.88 \cdot 10^{-5}\right) \cdot T^2 + 1314.2 \cdot 10^{-9} \cdot T^3\right] \cdot 0.239 \cdot \frac{cal}{mol \cdot K}$$

The composition of each component in the diatomite is given as :

$$comp := \begin{pmatrix} 75.2 \\ 14.88 \\ 4.79 \\ 1.99 \\ 1.11 \\ 0.39 \\ 0.3 \\ 0.2 \\ 1.14 \end{pmatrix} \cdot \%$$

The heat capacity of diatomite can be taken to be the sum of the heat capacities of the components as shown below:

$$C_{pcalciner} = \left[(3.65 + 0.0240 \cdot T) \cdot comp_1 + \left(22.08 + 0.008971 \cdot T - \frac{522500}{T^2}\right) \cdot comp_2 \ldots \right.$$
$$+ \left(10.00 + 0.00484 \cdot T - \frac{108000}{T^2}\right) \cdot comp_3 \ldots$$
$$+ \left(10.86 + 0.001197 \cdot T - \frac{208700}{T^2}\right) \cdot comp_4 \ldots$$
$$+ \left(24.72 + 0.01604 \cdot T - \frac{423400}{T^2}\right) \cdot comp_5 \ldots$$
$$+ \left(11.81 + 0.00754 \cdot T - \frac{41900}{T^2}\right) \cdot comp_6 \ldots$$
$$+ \left(69.26 + 0.00821 \cdot T - \frac{2331000}{T^2}\right) \cdot comp_7 \ldots$$
$$+ \left(63.78 + 0.001171 \cdot T - \frac{1678000}{T^2}\right) \cdot comp_8 \ldots$$
$$+ \left[\left[11.2964 + 47.212 \cdot 10^{-2} \cdot T + \left(-133.88 \cdot 10^{-5}\right) \cdot T^2 + 1314.2 \cdot 10^{-9} \cdot T^3\right] \cdot 0.239\right] \cdot comp_9 \ldots$$
$$\left. + \left(2.673 + 0.002617 \cdot T - \frac{116900}{T^2}\right) \right] \cdot \frac{cal}{mol \cdot K}$$

The heat capacity of the combustible and the water present are given as:

$$C_{pcombustible} = \left(2.673 + 0.002617 \cdot T - \frac{116900}{T^2}\right) \cdot \frac{cal}{mol \cdot K}$$

$$C_{pwater} = \left[\left[11.2964 + 47.212 \cdot 10^{-2} \cdot T + \left(-133.88 \cdot 10^{-5}\right) \cdot T^2 + 1314.2 \cdot 10^{-9} \cdot T^3\right] \cdot 0.239\right] \cdot \frac{cal}{mol \cdot K}$$

Temperature, $T := (1000 + 273) \cdot K$

Mass of material in the calciner, $M_{calciner} := \begin{pmatrix} 5.59 \\ 4.00 \\ 0.41 \end{pmatrix} \cdot \frac{kg}{hr}$

Molecular weights of the components in the diatomite is given as

$$mw_{dc} := \begin{pmatrix} 60.06 \\ 101.94 \\ 56.08 \\ 40.32 \\ 159.7 \\ 79.9 \\ 94.2 \\ 61.994 \\ 18.02 \end{pmatrix} \cdot \frac{kg}{mol}$$

Molecular weight of materials in the calciner is are thus given as: diatomite,

$$mw := \begin{pmatrix} mw_{dc} \cdot comp \\ 12 \cdot \frac{kg}{mol} \\ 18 \cdot \frac{kg}{mol} \end{pmatrix}$$

Number of mole of the materials:

$$n_{calciner} := \overrightarrow{\left(\frac{M_{calciner}}{mw}\right)} \qquad n_{calciner} = \begin{pmatrix} 0.084 \\ 0.333 \\ 0.023 \end{pmatrix} \frac{kmol}{hr}$$

Given that the calcination temperature is, $T = 1.273 \times 10^3 K$ and the reference temperature to be

$$T_r := 298 \cdot K$$

The temperature difference is calcualated as $\Delta T := T - T_r$

$$\Delta T = 975\ K$$

The heat capacity capacity of the materials in the calciner at the temperature of $T = 1.273 \times 10^3 K$ is calculated as:

$$T := T \cdot K^{-1}$$

$$C_{pcalciner} := \left[\begin{aligned} &(3.65 + 0.0240 \cdot T) \cdot comp_1 + \left(22.08 + 0.008971 \cdot T - \frac{522500}{T^2}\right) \cdot comp_2 \ldots \\ &+ \left(10.00 + 0.00484 \cdot T - \frac{108000}{T^2}\right) \cdot comp_3 \ldots \\ &+ \left(10.86 + 0.001197 \cdot T - \frac{208700}{T^2}\right) \cdot comp_4 \ldots \\ &+ \left(24.72 + 0.01604 \cdot T - \frac{423400}{T^2}\right) \cdot comp_5 \ldots \\ &+ \left(11.81 + 0.00754 \cdot T - \frac{41900}{T^2}\right) \cdot comp_6 \ldots \\ &+ \left(69.26 + 0.00821 \cdot T - \frac{2331000}{T^2}\right) \cdot comp_7 \ldots \\ &+ \left(63.78 + 0.001171 \cdot T - \frac{1678000}{T^2}\right) \cdot comp_8 \ldots \\ &+ \left[\left[11.2964 + 47.212 \cdot 10^{-2} \cdot T + \left(-133.88 \cdot 10^{-5}\right) \cdot T^2 + 1314.2 \cdot 10^{-9} \cdot T^3\right] \cdot 0.239\right] \cdot comp_9 \ldots \\ &+ \left(2.673 + 0.002617 \cdot T - \frac{116900}{T^2}\right) \ldots \\ &+ \left[11.2964 + 47.212 \cdot 10^{-2} \cdot T + \left(-133.88 \cdot 10^{-5}\right) \cdot T^2 + 1314.2 \cdot 10^{-9} \cdot T^3\right] \cdot 0.239 \end{aligned} \right] \cdot \frac{cal}{mol \cdot K}$$

$$C_{pcalciner} = 317.462 \frac{cal}{mol \cdot K}$$

$$C_{pcalciner} = 1.329 \frac{kJ}{mol \cdot K}$$

The heat, Q, of the calciner is thus calculated as:

$$Q_{calciner} := \sum \left(n_{calciner} \cdot C_{pcalciner} \cdot \Delta T \right)$$

$$Q_{calciner} = 570.397 \frac{kJ}{hr}$$

3.3 Specification of Equipment

Molecular weights — Densities

$$\begin{pmatrix} \text{Diatomite} \\ \text{Moisture} \\ \text{"Organic Matter"} \end{pmatrix} \qquad mw = \begin{pmatrix} 66.519 \\ 12 \\ 18 \end{pmatrix} \frac{kg}{mol} \qquad \rho := \begin{pmatrix} 2622.32 \\ 995 \\ 2260 \end{pmatrix} \cdot \frac{kg}{m^3}$$

3.3.1 Specification of crusher 1

Amount

$$\begin{pmatrix} \text{Diatomite} \\ \text{Moisture} \\ \text{"Organic Matter"} \end{pmatrix} \qquad m' := \begin{pmatrix} 5.59 \\ 4.00 \\ 0.41 \end{pmatrix} \cdot \frac{kg}{hr}$$

The average density is calculated as:

$$\rho_{av} := \frac{m'}{\sum m'} \cdot \rho$$

$$\rho_{av} = 1.957 \times 10^3 \frac{kg}{m^3}$$

The total mass of the components is given as:

$$M := \sum \overrightarrow{(m')} \qquad M = 8.766 \times 10^4 \frac{kg}{yr}$$

The volumes of the components are calculated as:

$$V := \frac{M}{\rho_{av}} \qquad V = 5.111 \times 10^{-3} \frac{m^3}{hr}$$

Assuming a clearance of $V_c := 15\% \cdot V$

$$V_c = 7.667 \times 10^{-4} \frac{m^3}{hr}$$

The actual volume of the crusher is then equal to

$$V_{crusher\_1} := V + V_c$$

$$V_{crusher\_1} = 0.141 \frac{m^3}{day}$$

Assuming the crusher to be cylindrical, mathematically, the volume is given as

$$V_{crusher\_1} = \pi \cdot R_{crusher\_1}{}^2 \cdot H_{crusher\_1}$$

and, since,

$$R_{crusher\_1} = \frac{D_{crusher\_1}}{2}$$

$$V_{crusher\_1} = \pi \cdot \left(\frac{D_{crusher\_1}}{2}\right)^2 \cdot H_{crusher\_1}$$

$$V_{crusher\_1} = \pi \cdot \frac{D_{crusher\_1}^{\;2}}{4} \cdot H_{crusher\_1}$$

Taking the ratio of height of the crusher to its diameter to be

$$\frac{H_{crusher\_1}}{D_{crusher\_1}} = k$$

$$H_{crusher\_1} = k \cdot D_{crusher\_1}$$

then,

$$V_{crusher\_1} = \pi \cdot \frac{D_{crusher\_1}^{\;2}}{4} \cdot \left(k \cdot D_{crusher\_1}\right)$$

Making Dcrusher the subject of the formula with the aid of MathCAD yields,

$$D_{crusher\_1} = \begin{bmatrix} \frac{1}{(\pi \cdot k)} \cdot \sqrt[3]{4} \cdot \left(V_{crusher\_1} \cdot \pi^2 \cdot k^2\right)^{\left(\frac{1}{3}\right)} \\ \frac{-1}{(2 \cdot \pi \cdot k)} \cdot \sqrt[3]{4} \cdot \left(V_{crusher\_1} \cdot \pi^2 \cdot k^2\right)^{\left(\frac{1}{3}\right)} + \frac{1}{2} \cdot i \cdot \frac{\sqrt{3}}{(\pi \cdot k)} \cdot \sqrt[3]{4} \cdot \left(V_{crusher\_1} \cdot \pi^2 \cdot k^2\right)^{\left(\frac{1}{3}\right)} \\ \frac{-1}{(2 \cdot \pi \cdot k)} \cdot \sqrt[3]{4} \cdot \left(V_{crusher\_1} \cdot \pi^2 \cdot k^2\right)^{\left(\frac{1}{3}\right)} - \frac{1}{2} \cdot i \cdot \frac{\sqrt{3}}{(\pi \cdot k)} \cdot \sqrt[3]{4} \cdot \left(V_{crusher\_1} \cdot \pi^2 \cdot k^2\right)^{\left(\frac{1}{3}\right)} \end{bmatrix}$$

Assuming $k := 1.5$

$$D_{crusher\_1} := \begin{bmatrix} \frac{1}{(\pi \cdot k)} \cdot \sqrt[3]{4} \cdot \left(V_{crusher\_1} \cdot hr \cdot \pi^2 \cdot k^2\right)^{\left(\frac{1}{3}\right)} \\ \left|\frac{-1}{(2 \cdot \pi \cdot k)} \cdot \sqrt[3]{4} \cdot \left(V_{crusher\_1} \cdot hr \cdot \pi^2 \cdot k^2\right)^{\left(\frac{1}{3}\right)} + \frac{1}{2} \cdot i \cdot \frac{\sqrt{3}}{(\pi \cdot k)} \cdot \sqrt[3]{4} \cdot \left(V_{crusher\_1} \cdot hr \cdot \pi^2 \cdot k^2\right)^{\left(\frac{1}{3}\right)}\right| \\ \left|\frac{-1}{(2 \cdot \pi \cdot k)} \cdot \sqrt[3]{4} \cdot \left(V_{crusher\_1} \cdot hr \cdot \pi^2 \cdot k^2\right)^{\left(\frac{1}{3}\right)} - \frac{1}{2} \cdot i \cdot \frac{\sqrt{3}}{(\pi \cdot k)} \cdot \sqrt[3]{4} \cdot \left(V_{crusher\_1} \cdot hr \cdot \pi^2 \cdot k^2\right)^{\left(\frac{1}{3}\right)}\right| \end{bmatrix}$$

$$D_{crusher\_1} = \begin{pmatrix} 0.171 \\ 0.171 \\ 0.171 \end{pmatrix} m$$

The real part is taken as the diameter of the crusher. Therefore,

$$D_{crusher\_1} := D_{crusher\_1_1} \qquad D_{crusher\_1} = 0.171\,m$$

$$H_{crusher\_1} := k \cdot D_{crusher\_1} \qquad H_{crusher\_1} = 0.256\,m$$

The area is calculated to be

$$A_{crusher\_1} := 2\pi \cdot \frac{D_{crusher\_1}}{2} \cdot H_{crusher\_1} + 2\pi \cdot \left(\frac{D_{crusher\_1}}{2}\right)^2 \qquad A_{crusher\_1} = 0.183\,m^2$$

3.3.2 Specification of miller 1

Amount

$$\begin{pmatrix} \text{Diatomite} \\ \text{Moisture} \\ \text{"Organic Matter"} \end{pmatrix} \qquad m' := \begin{pmatrix} 5.59 \\ 4.00 \\ 0.41 \end{pmatrix} \cdot \frac{kg}{hr}$$

The average density is calculated as:

$$\rho_{av} := \frac{m'}{\sum m'} \cdot \rho \qquad \rho_{av} = 1.957 \times 10^3 \frac{kg}{m^3}$$

The total mass of the components is given as:

$$M := \sum \overrightarrow{(m')} \qquad M = 8.766 \times 10^4 \frac{kg}{yr}$$

The volumes of the components are calculated as:

$$V := \frac{M}{\rho_{av}} \qquad V = 5.111 \times 10^{-3} \frac{m^3}{hr}$$

Assuming a clearance of $V_c := 15\% \cdot V$

$$V_c = 7.667 \times 10^{-4} \frac{m^3}{hr}$$

The actual volume of the miller is then equal to

$$V_{miller\_1} := V + V_c$$

$$V_{miller\_1} = 0.141 \frac{m^3}{day}$$

Assuming the miller to be cylindrical, mathematically, the volume is given as

$$V_{miller\_1} = \pi \cdot R_{miller\_1}^2 \cdot H_{miller\_1}$$

and, since,

$$R_{miller\_1} = \frac{D_{miller\_1}}{2}$$

$$V_{miller\_1} = \pi \cdot \left(\frac{D_{miller\_1}}{2}\right)^2 \cdot H_{miller\_1}$$

$$V_{miller\_1} = \pi \cdot \frac{D_{miller\_1}^2}{4} \cdot H_{miller\_1}$$

Taking the ratio of height of the miller to its diameter to be

$$\frac{H_{miller\_1}}{D_{miller\_1}} = k$$

$$H_{miller\_1} = k \cdot D_{miller\_1}$$

then,

$$V_{miller\_1} = \pi \cdot \frac{D_{miller\_1}^2}{4} \cdot \left(k \cdot D_{miller\_1}\right)$$

Making Dmiller the subject of the formula with the aid of MathCAD yields,

$$D_{miller\_1} = \begin{bmatrix} \frac{1}{(\pi \cdot k)} \cdot \sqrt[3]{4} \cdot \left(V_{miller\_1} \cdot \pi^2 \cdot k^2\right)^{\left(\frac{1}{3}\right)} \\ \frac{-1}{(2 \cdot \pi \cdot k)} \cdot \sqrt[3]{4} \cdot \left(V_{miller\_1} \cdot \pi^2 \cdot k^2\right)^{\left(\frac{1}{3}\right)} + \frac{1}{2} \cdot i \cdot \frac{\sqrt{3}}{(\pi \cdot k)} \cdot \sqrt[3]{4} \cdot \left(V_{miller\_1} \cdot \pi^2 \cdot k^2\right)^{\left(\frac{1}{3}\right)} \\ \frac{-1}{(2 \cdot \pi \cdot k)} \cdot \sqrt[3]{4} \cdot \left(V_{miller\_1} \cdot \pi^2 \cdot k^2\right)^{\left(\frac{1}{3}\right)} - \frac{1}{2} \cdot i \cdot \frac{\sqrt{3}}{(\pi \cdot k)} \cdot \sqrt[3]{4} \cdot \left(V_{miller\_1} \cdot \pi^2 \cdot k^2\right)^{\left(\frac{1}{3}\right)} \end{bmatrix}$$

Assuming $k := 1.5$

$$D_{miller\_1} := \begin{bmatrix} \frac{1}{(\pi \cdot k)} \cdot \sqrt[3]{4} \cdot \left(V_{miller\_1} \cdot hr \cdot \pi^2 \cdot k^2\right)^{\left(\frac{1}{3}\right)} \\ \frac{-1}{(2 \cdot \pi \cdot k)} \cdot \sqrt[3]{4} \cdot \left(V_{miller\_1} \cdot hr \cdot \pi^2 \cdot k^2\right)^{\left(\frac{1}{3}\right)} + \frac{1}{2} \cdot i \cdot \frac{\sqrt{3}}{(\pi \cdot k)} \cdot \sqrt[3]{4} \cdot \left(V_{miller\_1} \cdot hr \cdot \pi^2 \cdot k^2\right)^{\left(\frac{1}{3}\right)} \\ \frac{-1}{(2 \cdot \pi \cdot k)} \cdot \sqrt[3]{4} \cdot \left(V_{miller\_1} \cdot hr \cdot \pi^2 \cdot k^2\right)^{\left(\frac{1}{3}\right)} - \frac{1}{2} \cdot i \cdot \frac{\sqrt{3}}{(\pi \cdot k)} \cdot \sqrt[3]{4} \cdot \left(V_{miller\_1} \cdot hr \cdot \pi^2 \cdot k^2\right)^{\left(\frac{1}{3}\right)} \end{bmatrix}$$

$$D_{miller\_1} = \begin{pmatrix} 0.171 \\ 0.171 \\ 0.171 \end{pmatrix} m$$

The real part is taken as the diameter of the miller. Therefore,

$$D_{miller\_1} := D_{miller\_1_1} \qquad D_{miller\_1} = 0.171\,m$$

$$H_{miller\_1} := k \cdot D_{miller\_1} \qquad H_{miller\_1} = 0.256\,m$$

The area is calculated to be

$$A_{miller\_1} := 2\pi \cdot \frac{D_{miller\_1}}{2} \cdot H_{miller\_1} + 2\pi \cdot \left(\frac{D_{miller\_1}}{2}\right)^2 \qquad A_{miller\_1} = 0.183\,m^2$$

3.3.3 Specification of calciner

Amount

$$\begin{pmatrix} \text{Diatomite} \\ \text{Moisture} \\ \text{"Organic Matter"} \end{pmatrix} \qquad m' := \begin{pmatrix} 5.59 \\ 4.00 \\ 0.41 \end{pmatrix} \cdot \frac{kg}{hr}$$

The average density is calculated as:

$$\rho_{av} := \frac{m'}{\sum m'} \cdot \rho \qquad \rho_{av} = 1.957 \times 10^3 \frac{kg}{m^3}$$

The total mass of the components is given as:

$$M := \sum \overrightarrow{(m')} \qquad M = 8.766 \times 10^4 \frac{kg}{yr}$$

The volumes of the components are calculated as:

$$V := \frac{M}{\rho_{av}} \qquad V = 5.111 \times 10^{-3} \frac{m^3}{hr}$$

Assuming a clearance of $V_c := 15\% \cdot V$

$$V_c = 7.667 \times 10^{-4} \frac{m^3}{hr}$$

The actual volume of the calciner is then equal to

$$V_{calciner} := V + V_c$$

$$V_{calciner} = 0.141 \frac{m^3}{day}$$

Assuming the calciner to be cylindrical, mathematically, the volume is given as

$$V_{calciner} = \pi \cdot R_{calciner}^2 \cdot H_{calciner}$$

and, since,

$$R_{calciner} = \frac{D_{calciner}}{2}$$

$$V_{calciner} = \pi \cdot \left(\frac{D_{calciner}}{2}\right)^2 \cdot H_{calciner}$$

$$V_{calciner} = \pi \cdot \frac{D_{calciner}^2}{4} \cdot H_{calciner}$$

Taking the ratio of height of the calciner to its diameter to be

$$\frac{H_{calciner}}{D_{calciner}} = k$$

$$H_{calciner} = k \cdot D_{calciner}$$

then,

$$V_{calciner} = \pi \cdot \frac{D_{calciner}^2}{4} \cdot \left(k \cdot D_{calciner}\right)$$

Making $D_{calciner}$ the subject of the formula with the aid of MathCAD yields,

$$D_{calciner} = \begin{bmatrix} \frac{1}{(\pi \cdot k)} \cdot \sqrt[3]{4} \cdot \left(V_{calciner} \cdot \pi^2 \cdot k^2\right)^{\left(\frac{1}{3}\right)} \\ \frac{-1}{(2 \cdot \pi \cdot k)} \cdot \sqrt[3]{4} \cdot \left(V_{calciner} \cdot \pi^2 \cdot k^2\right)^{\left(\frac{1}{3}\right)} + \frac{1}{2} \cdot i \cdot \frac{\sqrt{3}}{(\pi \cdot k)} \cdot \sqrt[3]{4} \cdot \left(V_{calciner} \cdot \pi^2 \cdot k^2\right)^{\left(\frac{1}{3}\right)} \\ \frac{-1}{(2 \cdot \pi \cdot k)} \cdot \sqrt[3]{4} \cdot \left(V_{calciner} \cdot \pi^2 \cdot k^2\right)^{\left(\frac{1}{3}\right)} - \frac{1}{2} \cdot i \cdot \frac{\sqrt{3}}{(\pi \cdot k)} \cdot \sqrt[3]{4} \cdot \left(V_{calciner} \cdot \pi^2 \cdot k^2\right)^{\left(\frac{1}{3}\right)} \end{bmatrix}$$

Assuming $k := 1.5$

$$D_{calciner} := \begin{bmatrix} \frac{1}{(\pi \cdot k)} \cdot \sqrt[3]{4} \cdot \left(V_{calciner} \cdot hr \cdot \pi^2 \cdot k^2\right)^{\left(\frac{1}{3}\right)} \\ \left|\frac{-1}{(2 \cdot \pi \cdot k)} \cdot \sqrt[3]{4} \cdot \left(V_{calciner} \cdot hr \cdot \pi^2 \cdot k^2\right)^{\left(\frac{1}{3}\right)} + \frac{1}{2} \cdot i \cdot \frac{\sqrt{3}}{(\pi \cdot k)} \cdot \sqrt[3]{4} \cdot \left(V_{calciner} \cdot hr \cdot \pi^2 \cdot k^2\right)^{\left(\frac{1}{3}\right)}\right| \\ \left|\frac{-1}{(2 \cdot \pi \cdot k)} \cdot \sqrt[3]{4} \cdot \left(V_{calciner} \cdot hr \cdot \pi^2 \cdot k^2\right)^{\left(\frac{1}{3}\right)} - \frac{1}{2} \cdot i \cdot \frac{\sqrt{3}}{(\pi \cdot k)} \cdot \sqrt[3]{4} \cdot \left(V_{calciner} \cdot hr \cdot \pi^2 \cdot k^2\right)^{\left(\frac{1}{3}\right)}\right| \end{bmatrix}$$

$$D_{calciner} = \begin{pmatrix} 0.171 \\ 0.171 \\ 0.171 \end{pmatrix} m$$

The real part is taken as the diameter of the calciner. Therefore,

$D_{calciner} := D_{calciner_1}$ $\qquad D_{calciner} = 0.171\,m$

$H_{calciner} := k \cdot D_{calciner}$ $\qquad H_{calciner} = 0.256\,m$

The area is calculated to be

$$A_{calciner} := 2\pi \cdot \frac{D_{calciner}}{2} \cdot H_{calciner} + 2\pi \cdot \left(\frac{D_{calciner}}{2}\right)^2 \qquad A_{calciner} = 0.183\,m^2$$

3.3.4 Specification of crusher 2

Amount

$$\begin{pmatrix} \text{Diatomite} \\ \text{Moisture} \\ \text{"Organic Matter"} \end{pmatrix} \qquad m' := \begin{pmatrix} 5.59 \\ 0.00 \\ 0.00 \end{pmatrix} \cdot \frac{kg}{hr}$$

The average density is calculated as:

$$\rho_{av} := \frac{m'}{\sum m'} \cdot \rho \qquad \rho_{av} = 2.622 \times 10^3 \frac{kg}{m^3}$$

The total mass of the components is given as:

$$M := \sum \overrightarrow{(m')} \qquad M = 4.9 \times 10^4 \frac{kg}{yr}$$

The volumes of the components are calculated as:

$$V := \frac{M}{\rho_{av}} \qquad V = 2.132 \times 10^{-3} \frac{m^3}{hr}$$

Assuming a clearance of $V_c := 15\% \cdot V$

$$V_c = 3.198 \times 10^{-4} \frac{m^3}{hr}$$

The actual volume of the crusher is then equal to

$$V_{crusher\_2} := V + V_c$$

$$V_{crusher\_2} = 0.059 \frac{m^3}{day}$$

Assuming the crusher to be cylindrical, mathematically, the volume is given as

$$V_{crusher\_2} = \pi \cdot R_{crusher\_2}^{2} \cdot H_{crusher\_2}$$

and, since,

$$R_{crusher\_2} = \frac{D_{crusher\_2}}{2}$$

$$V_{crusher\_2} = \pi \cdot \left(\frac{D_{crusher\_2}}{2}\right)^2 \cdot H_{crusher\_2}$$

$$V_{crusher\_2} = \pi \cdot \frac{D_{crusher\_2}^{\ 2}}{4} \cdot H_{crusher\_2}$$

Taking the ratio of height of the crusher to its diameter to be

$$\frac{H_{crusher\_2}}{D_{crusher\_2}} = k$$

$$H_{crusher\_2} = k \cdot D_{crusher\_2}$$

then,

$$V_{crusher\_2} = \pi \cdot \frac{D_{crusher\_2}^{\ 2}}{4} \cdot \left(k \cdot D_{crusher\_2}\right)$$

Making Dcrusher the subject of the formula with the aid of MathCAD yields,

$$D_{crusher\_2} = \begin{bmatrix} \frac{1}{(\pi \cdot k)} \cdot \sqrt[3]{4} \cdot \left(V_{crusher\_2\_2} \cdot \pi^2 \cdot k^2\right)^{\left(\frac{1}{3}\right)} \\ \frac{-1}{(2 \cdot \pi \cdot k)} \cdot \sqrt[3]{4} \cdot \left(V_{crusher\_2} \cdot \pi^2 \cdot k^2\right)^{\left(\frac{1}{3}\right)} + \frac{1}{2} \cdot i \cdot \frac{\sqrt{3}}{(\pi \cdot k)} \cdot \sqrt[3]{4} \cdot \left(V_{crusher\_2} \cdot \pi^2 \cdot k^2\right)^{\left(\frac{1}{3}\right)} \\ \frac{-1}{(2 \cdot \pi \cdot k)} \cdot \sqrt[3]{4} \cdot \left(V_{crusher\_2} \cdot \pi^2 \cdot k^2\right)^{\left(\frac{1}{3}\right)} - \frac{1}{2} \cdot i \cdot \frac{\sqrt{3}}{(\pi \cdot k)} \cdot \sqrt[3]{4} \cdot \left(V_{crusher\_2} \cdot \pi^2 \cdot k^2\right)^{\left(\frac{1}{3}\right)} \end{bmatrix}$$

Assuming $k := 1.5$

$$D_{crusher\_2} := \begin{bmatrix} \frac{1}{(\pi \cdot k)} \cdot \sqrt[3]{4} \cdot \left(V_{crusher\_2} \cdot hr \cdot \pi^2 \cdot k^2\right)^{\left(\frac{1}{3}\right)} \\ \left| \frac{-1}{(2 \cdot \pi \cdot k)} \cdot \sqrt[3]{4} \cdot \left(V_{crusher\_2} \cdot hr \cdot \pi^2 \cdot k^2\right)^{\left(\frac{1}{3}\right)} + \frac{1}{2} \cdot i \cdot \frac{\sqrt{3}}{(\pi \cdot k)} \cdot \sqrt[3]{4} \cdot \left(V_{crusher\_2} \cdot hr \cdot \pi^2 \cdot k^2\right)^{\left(\frac{1}{3}\right)} \right| \\ \left| \frac{-1}{(2 \cdot \pi \cdot k)} \cdot \sqrt[3]{4} \cdot \left(V_{crusher\_2} \cdot hr \cdot \pi^2 \cdot k^2\right)^{\left(\frac{1}{3}\right)} - \frac{1}{2} \cdot i \cdot \frac{\sqrt{3}}{(\pi \cdot k)} \cdot \sqrt[3]{4} \cdot \left(V_{crusher\_2} \cdot hr \cdot \pi^2 \cdot k^2\right)^{\left(\frac{1}{3}\right)} \right| \end{bmatrix}$$

$$D_{crusher\_2} = \begin{pmatrix} 0.128 \\ 0.128 \\ 0.128 \end{pmatrix} m$$

The real part is taken as the diameter of the crusher. Therefore,

$D_{crusher\_2} := D_{crusher\_2_1}$ $D_{crusher\_2} = 0.128\,m$

$H_{crusher\_2} := k \cdot D_{crusher\_2}$

$H_{crusher\_2} = 0.192\,m$

The area is calculated to be

$$A_{crusher\_2} := 2\pi \cdot \frac{D_{crusher\_2}}{2} \cdot H_{crusher\_2} + 2\pi \cdot \left(\frac{D_{crusher\_2}}{2}\right)^2 \qquad A_{crusher\_2} = 0.102\,m^2$$

3.3.5 Specification of miller 2

Amount

$$\begin{pmatrix} \text{Diatomite} \\ \text{Moisture} \\ \text{"Organic Matter"} \end{pmatrix} \qquad m' := \begin{pmatrix} 5.59 \\ 0.00 \\ 0.00 \end{pmatrix} \cdot \frac{kg}{hr}$$

The average density is calculated as:

$$\rho_{av} := \frac{m'}{\sum m'} \cdot \rho \qquad \rho_{av} = 2.622 \times 10^3 \frac{kg}{m^3}$$

The total mass of the components is given as:

$$M := \sum \overrightarrow{(m')} \qquad M = 4.9 \times 10^4 \frac{kg}{yr}$$

The volumes of the components are calculated as:

$$V := \frac{M}{\rho_{av}} \qquad V = 2.132 \times 10^{-3} \frac{m^3}{hr}$$

Assuming a clearance of $V_c := 15\% \cdot V$

$$V_c = 3.198 \times 10^{-4} \frac{m^3}{hr}$$

The actual volume of the miller is then equal to

$$V_{miller\_2} := V + V_c$$

$$V_{miller\_2} = 0.059 \frac{m^3}{day}$$

Assuming the miller to be cylindrical, mathematically, the volume is given as

$$V_{miller\_2} = \pi \cdot R_{miller\_2}^{2} \cdot H_{miller\_2}$$

and, since,

$$R_{miller\_2} = \frac{D_{miller\_2}}{2}$$

$$V_{miller\_2} = \pi \cdot \left(\frac{D_{miller\_2}}{2}\right)^{2} \cdot H_{miller\_2}$$

$$V_{miller\_2} = \pi \cdot \frac{D_{miller\_2}^{2}}{4} \cdot H_{miller\_2}$$

Taking the ratio of height of the miller to its diameter to be

$$\frac{H_{miller\_2}}{D_{miller\_2}} = k$$

$$H_{miller\_2} = k \cdot D_{miller\_2}$$

then,

$$V_{miller\_2} = \pi \cdot \frac{D_{miller\_2}^{2}}{4} \cdot \left(k \cdot D_{miller\_2}\right)$$

Making Dmiller the subject of the formula with the aid of MathCAD yields,

$$D_{miller\_2} = \begin{bmatrix} \frac{1}{(\pi \cdot k)} \cdot \sqrt[3]{4} \cdot \left(V_{miller\_2} \cdot \pi^{2} \cdot k^{2}\right)^{\left(\frac{1}{3}\right)} \\ \frac{-1}{(2 \cdot \pi \cdot k)} \cdot \sqrt[3]{4} \cdot \left(V_{miller\_2} \cdot \pi^{2} \cdot k^{2}\right)^{\left(\frac{1}{3}\right)} + \frac{1}{2} \cdot i \cdot \frac{\sqrt{3}}{(\pi \cdot k)} \cdot \sqrt[3]{4} \cdot \left(V_{miller\_2} \cdot \pi^{2} \cdot k^{2}\right)^{\left(\frac{1}{3}\right)} \\ \frac{-1}{(2 \cdot \pi \cdot k)} \cdot \sqrt[3]{4} \cdot \left(V_{miller\_2} \cdot \pi^{2} \cdot k^{2}\right)^{\left(\frac{1}{3}\right)} - \frac{1}{2} \cdot i \cdot \frac{\sqrt{3}}{(\pi \cdot k)} \cdot \sqrt[3]{4} \cdot \left(V_{miller\_2} \cdot \pi^{2} \cdot k^{2}\right)^{\left(\frac{1}{3}\right)} \end{bmatrix}$$

Assuming $k := 1.5$

$$D_{miller\_2} := \begin{bmatrix} \frac{1}{(\pi \cdot k)} \cdot \sqrt[3]{4} \cdot \left(V_{miller\_2} \cdot hr \cdot \pi^2 \cdot k^2\right)^{\left(\frac{1}{3}\right)} \\ \frac{-1}{(2 \cdot \pi \cdot k)} \cdot \sqrt[3]{4} \cdot \left(V_{miller\_2} \cdot hr \cdot \pi^2 \cdot k^2\right)^{\left(\frac{1}{3}\right)} + \frac{1}{2} \cdot i \cdot \frac{\sqrt{3}}{(\pi \cdot k)} \cdot \sqrt[3]{4} \cdot \left(V_{miller\_2} \cdot hr \cdot \pi^2 \cdot k^2\right)^{\left(\frac{1}{3}\right)} \\ \frac{-1}{(2 \cdot \pi \cdot k)} \cdot \sqrt[3]{4} \cdot \left(V_{miller\_2} \cdot hr \cdot \pi^2 \cdot k^2\right)^{\left(\frac{1}{3}\right)} - \frac{1}{2} \cdot i \cdot \frac{\sqrt{3}}{(\pi \cdot k)} \cdot \sqrt[3]{4} \cdot \left(V_{miller\_2} \cdot hr \cdot \pi^2 \cdot k^2\right)^{\left(\frac{1}{3}\right)} \end{bmatrix}$$

$$D_{miller\_2} = \begin{pmatrix} 0.128 \\ 0.128 \\ 0.128 \end{pmatrix} m$$

The real part is taken as the diameter of the miller. Therefore,

$$D_{miller\_2} := D_{miller\_2_1} \qquad D_{miller\_2} = 0.128\,m$$

$$H_{miller\_2} := k \cdot D_{miller\_2} \qquad H_{miller\_2} = 0.192\,m$$

The area is calculated to be

$$A_{miller\_2} := 2\pi \cdot \frac{D_{miller\_2}}{2} \cdot H_{miller\_2} + 2\pi \cdot \left(\frac{D_{miller\_2}}{2}\right)^2 \qquad A_{miller\_2} = 0.102\,m^2$$

3.3.6 Specification of moulding machine

Amount

$$\begin{pmatrix} \text{Diatomite} \\ \text{Moisture} \\ \text{"Organic Matter"} \end{pmatrix} \qquad m' := \begin{pmatrix} 5.59 \\ 0.00 \\ 0.00 \end{pmatrix} \cdot \frac{kg}{hr}$$

The average density is calculated as:

$$\rho_{av} := \frac{m'}{\sum m'} \cdot \rho \qquad \rho_{av} = 2.622 \times 10^3 \frac{kg}{m^3}$$

The total mass of the components is given as:

$$M := \sum \overrightarrow{(m')} \qquad M = 4.9 \times 10^4 \frac{kg}{yr}$$

The volumes of the components are calculated as:

$$V := \frac{M}{\rho_{av}} \qquad V = 2.132 \times 10^{-3} \frac{m^3}{hr}$$

Assuming a clearance of $V_c := 15\% \cdot V$

$$V_c = 3.198 \times 10^{-4} \frac{m^3}{hr}$$

The actual volume of the moulding_machine is then equal to

$$V_{moulding\_machine} := V + V_c$$

$$V_{moulding\_machine} = 0.059 \frac{m^3}{day}$$

Assuming the moulding_machine to be cylindrical, mathematically, the volume is given as

$$V_{moulding\_machine} = \pi \cdot R_{moulding\_machine}{}^2 \cdot H_{moulding\_machine}$$

and, since,

$$R_{moulding\_machine} = \frac{D_{moulding\_machine}}{2}$$

$$V_{moulding\_machine} = \pi \cdot \left(\frac{D_{moulding\_machine}}{2}\right)^2 \cdot H_{moulding\_machine}$$

$$V_{moulding\_machine} = \pi \cdot \frac{D_{moulding\_machine}{}^2}{4} \cdot H_{moulding\_machine}$$

Taking the ratio of height of the moulding_machine to its diameter to be

$$\frac{H_{moulding\_machine}}{D_{moulding\_machine}} = k$$

$$H_{moulding\_machine} = k \cdot D_{moulding\_machine}$$

then,

$$V_{moulding\_machine} = \pi \cdot \frac{D_{moulding\_machine}{}^2}{4} \cdot \left(k \cdot D_{moulding\_machine}\right)$$

Making Dmoulding_machine the subject of the formula with the aid of MathCAD yields,

Assuming that $V_{mould} := V_{moulding\_machine}$

$$D_{mould} = \begin{bmatrix} \frac{1}{(\pi \cdot k)} \cdot \sqrt[3]{4} \cdot \left(V_{mould} \cdot \pi^2 \cdot k^2\right)^{\left(\frac{1}{3}\right)} \\ \frac{-1}{(2 \cdot \pi \cdot k)} \cdot \sqrt[3]{4} \cdot \left(V_{mould} \cdot \pi^2 \cdot k^2\right)^{\left(\frac{1}{3}\right)} + \frac{1}{2} \cdot i \cdot \frac{\sqrt{3}}{(\pi \cdot k)} \cdot \sqrt[3]{4} \cdot \left(V_{mould} \cdot \pi^2 \cdot k^2\right)^{\left(\frac{1}{3}\right)} \\ \frac{-1}{(2 \cdot \pi \cdot k)} \cdot \sqrt[3]{4} \cdot \left(V_{mould} \cdot \pi^2 \cdot k^2\right)^{\left(\frac{1}{3}\right)} - \frac{1}{2} \cdot i \cdot \frac{\sqrt{3}}{(\pi \cdot k)} \cdot \sqrt[3]{4} \cdot \left(V_{mould} \cdot \pi^2 \cdot k^2\right)^{\left(\frac{1}{3}\right)} \end{bmatrix}$$

Assuming $k := 1.5$

$$D_{mould} := \begin{bmatrix} \frac{1}{(\pi \cdot k)} \cdot \sqrt[3]{4} \cdot \left(V_{mould} \cdot hr \cdot \pi^2 \cdot k^2\right)^{\left(\frac{1}{3}\right)} \\ \left|\frac{-1}{(2 \cdot \pi \cdot k)} \cdot \sqrt[3]{4} \cdot \left(V_{mould} \cdot hr \cdot \pi^2 \cdot k^2\right)^{\left(\frac{1}{3}\right)} + \frac{1}{2} \cdot i \cdot \frac{\sqrt{3}}{(\pi \cdot k)} \cdot \sqrt[3]{4} \cdot \left(V_{mould} \cdot hr \cdot \pi^2 \cdot k^2\right)^{\left(\frac{1}{3}\right)}\right| \\ \left|\frac{-1}{(2 \cdot \pi \cdot k)} \cdot \sqrt[3]{4} \cdot \left(V_{mould} \cdot hr \cdot \pi^2 \cdot k^2\right)^{\left(\frac{1}{3}\right)} - \frac{1}{2} \cdot i \cdot \frac{\sqrt{3}}{(\pi \cdot k)} \cdot \sqrt[3]{4} \cdot \left(V_{mould} \cdot hr \cdot \pi^2 \cdot k^2\right)^{\left(\frac{1}{3}\right)}\right| \end{bmatrix}$$

$$D_{mould} = \begin{pmatrix} 0.128 \\ 0.128 \\ 0.128 \end{pmatrix} m$$

$$D_{moulding\_machine} := D_{mould}$$

The real part is taken as the diameter of the moulding_machine. Therefore,

$$D_{moulding\_machine} := D_{moulding\_machine_1} \qquad D_{moulding\_machine} = 0.128\,m$$

$$H_{moulding\_machine} := k \cdot D_{moulding\_machine} \qquad H_{moulding\_machine} = 0.192\,m$$

The area is calculated to be

$$A_{moulding\_machine} := 2\pi \cdot \frac{D_{moulding\_machine}}{2} \cdot H_{moulding\_machine} + 2\pi \cdot \left(\frac{D_{moulding\_machine}}{2}\right)^2$$

$$A_{moulding\_machine} = 0.102\,m^2$$

Summary of specification of equipment

$$Equipment := \begin{pmatrix} \frac{V_{crusher\_1}}{\frac{m^3}{hr}} & \frac{D_{crusher\_1}}{m} & \frac{H_{crusher\_1}}{m} & \frac{A_{crusher\_1}}{m^2} \\ \frac{V_{miller\_1}}{\frac{m^3}{hr}} & \frac{D_{miller\_1}}{m} & \frac{H_{miller\_1}}{m} & \frac{A_{miller\_1}}{m^2} \\ \frac{V_{calciner}}{\frac{m^3}{hr}} & \frac{D_{calciner}}{m} & \frac{H_{calciner}}{m} & \frac{A_{calciner}}{m^2} \\ \frac{V_{crusher\_2}}{\frac{m^3}{hr}} & \frac{D_{crusher\_2}}{m} & \frac{H_{crusher\_2}}{m} & \frac{A_{crusher\_2}}{m^2} \\ \frac{V_{miller\_2}}{\frac{m^3}{hr}} & \frac{D_{miller\_2}}{m} & \frac{H_{miller\_2}}{m} & \frac{A_{miller\_2}}{m^2} \\ \frac{V_{moulding\_machine}}{\frac{m^3}{hr}} & \frac{D_{moulding\_machine}}{m} & \frac{H_{moulding\_machine}}{m} & \frac{A_{moulding\_machine}}{m^2} \end{pmatrix}$$

$$Equipment = \begin{pmatrix} 0.0058777 & 0.1708741 & 0.2563111 & 0.1834562 \\ 0.0058777 & 0.1708741 & 0.2563111 & 0.1834562 \\ 0.0058777 & 0.1708741 & 0.2563111 & 0.1834562 \\ 0.0024515 & 0.1276677 & 0.1915015 & 0.1024099 \\ 0.0024515 & 0.1276677 & 0.1915015 & 0.1024099 \\ 0.0024515 & 0.1276677 & 0.1915015 & 0.1024099 \end{pmatrix}$$

3.4 Economic Analysis

3.4.1 Purchased Equipment Cost

3.4.1.1 Purchase cost of crusher 1

Given that,

$M\_S := 1100 \qquad F_m := 1.00 \qquad F_p := 1.00 \qquad F_c := F_m \cdot F_p \qquad \text{Naira} := \frac{1}{130} \cdot \text{Dollar}$

$$PC_{crusher\_1} := \left(\frac{M\_S}{280}\right) \cdot \left[101.9 \cdot \left(\frac{D_{crusher\_1}}{ft}\right)^{1.066} \cdot \left(\frac{H_{crusher\_1}}{ft}\right)^{0.802} \cdot F_c\right] \cdot \text{Dollar}$$

$PC_{crusher\_1} = 187.989 \text{ Dollar}$

3.4.1.2 Purchase cost of miller 1

Given that,

$M\_S := 1100 \qquad F_m := 1.00 \qquad F_p := 1.00 \qquad F_c := F_m \cdot F_p$

$$PC_{miller\_1} := \left(\frac{M\_S}{280}\right) \cdot \left[101.9 \cdot \left(\frac{D_{miller\_1}}{ft}\right)^{1.066} \cdot \left(\frac{H_{miller\_1}}{ft}\right)^{0.802} \cdot F_c\right] \cdot \text{Dollar}$$

$PC_{miller\_1} = 187.989 \text{ Dollar}$

3.4.1.3 Purchase cost of calciner

$Q_{calciner} = 570.397 \frac{kJ}{hr} \qquad M\_S := 1100 \qquad F_m := 0.00 \qquad F_p := 0.00 \qquad F_c := 1 + F_m + F_p$

$$PC_{calciner} := \left(\frac{M\_S}{280}\right) \cdot \left[5520 \cdot \left[\frac{Q_{calciner}}{\left(10^6 \cdot \frac{BTU}{hr}\right)}\right]^{0.83} \cdot F_c\right] \cdot \text{Dollar}$$

$PC_{calciner} = 42.119 \text{ Dollar}$

3.4.1.4 Purchase cost of crusher 2

Given that,

$M\_S := 1100 \qquad F_m := 1.00 \qquad F_p := 1.00 \qquad F_c := F_m \cdot F_p$

$$PC_{crusher\_2} := \left(\frac{M\_S}{280}\right) \cdot \left[101.9 \cdot \left(\frac{D_{crusher\_2}}{ft}\right)^{1.066} \cdot \left(\frac{H_{crusher\_2}}{ft}\right)^{0.802} \cdot F_c\right] \cdot Dollar$$

$$PC_{crusher\_2} = 109.057\ Dollar$$

3.4.1.5 Purchase cost of miller 2

Given that,

$M\_S := 1100 \quad F_m := 1.00 \quad F_p := 1.00 \quad F_c := F_m \cdot F_p$

$$PC_{miller\_2} := \left(\frac{M\_S}{280}\right) \cdot \left[101.9 \cdot \left(\frac{D_{miller\_2}}{ft}\right)^{1.066} \cdot \left(\frac{H_{miller\_2}}{ft}\right)^{0.802} \cdot F_c\right] \cdot Dollar$$

$$PC_{miller\_2} = 109.057\ Dollar$$

3.4.1.6 Purchase cost of moulding machine

Given that,

$M\_S := 1100 \quad F_m := 1.00 \quad F_p := 1.00 \quad F_c := F_m \cdot F_p$

$$PC_{moulding\_machine} := \left(\frac{M\_S}{280}\right) \cdot \left[101.9 \cdot \left(\frac{D_{moulding\_machine}}{ft}\right)^{1.066} \cdot \left(\frac{H_{moulding\_machine}}{ft}\right)^{0.802} \cdot F_c\right] \cdot Dollar$$

$$PC_{moulding\_machine} = 109.057\ Dollar$$

The total cost of equipment is thus given as:

$$PC_{equipment} := PC_{crusher\_1} + PC_{miller\_1} + PC_{calciner} + PC_{crusher\_2} + PC_{miller\_1} + PC_{moulding\_machine}$$

$$PC_{equipment} = 824.201\ Dollar$$

$$PC_{equipment} = 1.071 \times 10^{5}\ Naira$$

Estimation of Total Capital Investment

I. Direct Costs

A. Equipment + installation + instrumentation + piping + electrical + insulation + painting

1. **Purchased equipment cost (PEC),** 15-40% of fixed capital investment

As calculated, $PEC := PC_{equipment}$ $PEC = 1.071 \times 10^5$ Naira

2. **Installation, including insulation and painting,** 25-55% of purchased equipment cost

Assuming $Insta := 53\% \cdot PEC$ $Insta = 5.679 \times 10^4$ Naira

3. **Instrumentation and controls, installed,** 6-30% of purchased equipment cost

Assume $Instr := 30\% \cdot PEC$ $Instr = 3.214 \times 10^4$ Naira

4. **Piping installed,** 10-80% of purchased equipment cost

Assume $Pip := 78\% \cdot PEC$ $Pip = 8.357 \times 10^4$ Naira

5. **Electrical, installed,** 10-40% of purchased equipment cost

Assume $Elect := 40\% \cdot PEC$ $Elect = 4.286 \times 10^4$ Naira

So, the cost of equipment, installation, instrumentation, piping, electrical, insulation and painting is given as

$CA := PEC + Insta + Instr + Pip + Elect$

$CA = 3.225 \times 10^5$ Naira

B. Buildings, process and auxiliary, 10-70% of purchased equipment cost

Assume $Build := 70\% \cdot PEC$ $Build = 7.5 \times 10^4$ Naira

C. Service facilities and yard improvements, 40-100% of purchased equipment cost

Assuming $Servi := 90\% \cdot PEC$ $Servi = 9.643 \times 10^4$ Naira

D. Land, 1-2% of fixed capital investment or 4-8% of purchased equipment cost)

Assuming $Lan := 7\% \cdot PEC$ $Lan = 7.5 \times 10^3$ Naira

Thus, the direct cost is equal to

$Direct\_Cost := CA + Build + Servi + Lan$ $Direct\_Cost = 5.014 \times 10^5$ Naira

II. Indirect costs: expenses which are not directly involved with material and labour of actual installation of complete facility (15-30% of fixed capital investment)

A. Engineering and supervision, 5-30% of direct cost

Assuming $Engin := 30\% \cdot Direct\_Cost$ $Engin = 1.504 \times 10^5$ Naira

B. Construction expense and contractor's fee, 6-30% of direct cost

Assuming $Const := 15\% \cdot Direct\_Cost$ $Const = 7.522 \times 10^4$ Naira

C. Contingency, 5-15% of direct cost

Assuming $Conti := 15\% \cdot Direct\_Cost$ $Conti = 7.522 \times 10^4$ Naira

Thus, indirect cost is equal to

$Indirect\_Cost := Engin + Const + Conti$ $Indirect\_Cost = 3.009 \times 10^5$ Naira

III. Fixed Capital Investment:

Fixed capital investment = Direct cost + Indirect cost

$Fixed\_CI := Direct\_Cost + Indirect\_Cost$ $Fixed\_CI = 8.023 \times 10^5$ Naira

IV. Working Capital, 11-20% of fixed capital investment

Assuming $Working\_C := 20\% \cdot Fixed\_CI$ $Working\_C = 1.605 \times 10^5$ Naira

3.4.2 V. Total Capital Investment (TCI):

Total capital investment to be Fixed capital investment + Working capital

Assuming $TCI := Fixed\_CI + Working\_C$ $TCI = 9.628 \times 10^5$ Naira

Estimation of Total Product Cost:

I. Manufacturing Cost = Direct production cost + Fixed charges + Plant overhead cost

A. Fixed Charges, 10-20% of total product cost)

i. Depreciation, This depends on life period, salvage value and method of calculation

- about 13% of FCI for machinery and equiupment and 2-3% of building value for buildings

Assuming $Depre := 10\% \cdot Fixed\_CI + 3\% \cdot Build$ $Depre = 8.248 \times 10^4$ Naira

ii. Local Taxes, 1-4% of fixed capital investment

Assuming $Tax := 4\% \cdot Fixed\_CI$ $Tax = 3.209 \times 10^{4} Naira$

iii. Insurance, 0.4-1% of fixed capital investment)

Assuming $Insur := 1\% \cdot Fixed\_CI$ $Insur = 8.023 \times 10^{3} Naira$

iv. Rent, 8-12% of value of fixed capital investment

Assuming $Ren := 12\% \cdot Fixed\_CI$ $Ren = 9.628 \times 10^{4} Naira$

Thus, fixed charges is given as

$$Fixed\_Charges := Depre + Tax + Insur + Ren$$

$$Fixed\_Charges = 2.189 \times 10^{5} Naira$$

3.4.3 B. Direct Production Cost (Operating Cost):

Fixed charges is 10-20% of total product cost

Assuming $Fixed\_Charges = 20\% \cdot TPC$

making total product cost, TPC, the subject of the formula,

$$TPC = \frac{FC}{20\%}$$

$$TPC := \frac{Fixed\_Charges}{20\%} \qquad TPC = 1.094 \times 10^{6} Naira$$

i. Raw materials, 10-50% of total product cost)

Assuming

$Raw\_mat := 50\% \cdot TPC$ $Raw\_mat = 5.472 \times 10^{5} Naira$

ii. Operating Labour (OL), 10-20% of total product cost

Assuming $OperL := 20\% \cdot TPC$ $OperL = 2.189 \times 10^{5} Naira$

iii. Direct Supervisory and Clerical Labour (DS & CL), 10-25% of OL

Assuming $DireS := 20\% \cdot OperL$ $DireS = 4.377 \times 10^{4} Naira$

iv. Utilities, 10-20% of total product cost

Assuming $Util := 20\% \cdot TPC$ $Util = 2.189 \times 10^{5} Naira$

v. Maintenance and repairs (M & R), 2-10% of fixed capital investment

Assuming $Maint := 2\% \cdot Fixed\_CI$ $Maint = 1.605 \times 10^{4} Naira$

vi. Operating Supplies, 10-20% of M & R or 0.5-1% of FCI

Assuming $OperS := 20\% \cdot Maint$ $OperS = 3.209 \times 10^3$ Naira

vii. Laboratory Charges, 10-20% of OL

Assuming $Lab := 20\% \cdot OperS$ $Lab = 641.848$ Naira

viii. Patent and Royalties, 0-6% of total product cost

Assuming $Paten := 0.1\% \cdot TPC$ $Paten = 1.094 \times 10^3$ Naira

Thus, direct production cost is

$$DPC := Raw\_mat + OperL + DireS + Util + Maint + OperS + Lab + Paten$$

$$DPC = 1.05 \times 10^6 \text{ Naira}$$

C. Plant Overhead Costs, 50-70% of operating labour, supervision, and maintenance or 5-15% of total product cost); includes for the following: general plant upkeep and overhead, payroll overhead, packaging, medical services, safety and protection, restaurants, salvage, laboratories, and storage facilities.

Considering the plant overhead cost to be 55% of OL, DS & CL and M & R

Therefore,

$$Plant\_Overhead := 55\% \cdot (OperL + DireS + Maint) \qquad Plant\_Overhead = 1.533 \times 10^5 \text{ Naira}$$

Manufacture cost = Direct production cost + Fixed charges + Plant overhead cost

$$Manuf := DPC + Fixed\_Charges + Plant\_Overhead \qquad Manuf = 1.422 \times 10^6 \text{ Naira}$$

II. General Expenses = Administrative costs + distribution and selling costs + research

and development costs

A. Administrative costs, 2-6% of total product cost

Assuming $Admin := 2\% \cdot TPC$ $Admin = 2.189 \times 10^4$ Naira

B. Distribution and Selling Costs, 2-20% of total product cost; includes costs for sales offices, salesmen, shipping, and advertising.

Assuming $Distr := 20\% \cdot TPC$ $Distr = 2.189 \times 10^5$ Naira

C. Research and Development Costs, about 5% of total product cost

Assuming $Resea := 5\% \cdot TPC$

$Resea = 5.472 \times 10^4 Naira$

D. Financing (Interest), 0 - 10% of total capital investment

Assuming $Interest := 10\% \cdot TCI$ $Interest = 9.628 \times 10^4 Naira$

Thus, general expenses,

$Gener := Admin + Distr + Resea + Interest$ $Gener = 3.918 \times 10^5 Naira$

III. Total Product Cost = Manufacture Cost + General Expenses

$TProdC := Manuf + Gener$

$TProdC = 1.814 \times 10^6 Naira$

3.4.4 V. Gross Earnings/Income (Revenue Expectations):

The selling price of the product is

$$Selling\_price := 337.9 \cdot \frac{Naira}{kg}$$

$$Quantity\_Produced := 5 \cdot \frac{kg}{hr}$$

$$day := 7 \cdot hr$$

Assuming that the attainment is $Attainment := 240 \cdot day$

Total income = Selling price x quantity of product manufactured

Assume $Total\_income := Selling\_price \cdot Quantity\_Produced \cdot Attainment$

$Total\_income = 2.838 \times 10^6 Naira$

Gross income = Total income - Total Product Cost

That is, $Gross\_income := Total\_income - TPC$

$Gross\_income = 1.744 \times 10^6 Naira$

Tax rate = 15% of gross income, $Tax\_rate := 15\%$

$Taxes := 45\% \cdot Gross\_income$ $Taxes = 7.848 \times 10^5 Naira$

Net profit = Gross income - Taxes

$Net\_profit := Gross\_income - Taxes$

$Net\_profit = 9.592 \times 10^5 Naira$

Calculation of Rate of Return:

$$Rate\_of\_return = \frac{Net\_profit}{Total\_CI} \cdot 100\%$$

Therefore,

$$Rate\_of\_return := \frac{Net\_profit}{TCI} \cdot 100\% \qquad Rate\_of\_return = 99.628\%$$

3.4.5 Pay-Back Period

The pay-back period is calculated as the reciprocal of the rate of return.

Therefore,

$$Pay\_back\_period := \frac{1}{Rate\_of\_return} \cdot yr \qquad Pay\_back\_period = 1\ yr$$

Summary of purchase cost of equipment

$$Purchase\_Equipment\_Cost := \begin{pmatrix} PC_{crusher\_1} \\ PC_{miller\_1} \\ PC_{calciner} \\ PC_{crusher\_2} \\ PC_{miller\_2} \\ PC_{moulding\_machine} \end{pmatrix}$$

$$Purchase\_Equipment\_Cost = \begin{pmatrix} 24438.62 \\ 24438.62 \\ 5475.52 \\ 14177.4 \\ 14177.4 \\ 14177.4 \end{pmatrix} Naira$$

$$\begin{pmatrix} \frac{Working\_C}{Naira} \\ \frac{Fixed\_CI}{Naira} \\ \frac{Rate\_of\_return}{\%} \\ \frac{Pay\_back\_period}{yr} \end{pmatrix} = \begin{pmatrix} 160462.11 \\ 802310.54 \\ 99.63 \\ 1 \end{pmatrix}$$

CHAPTER FOUR

4.0 RESULTS AND DISCUSSION

4.1 Results

The results obtained from the design are as tabulated in the tables below.

Table 4.1: Results of material balances

	Input (kg/hr)		Output (kg/hr)	
Unit	In	Addition	Loss	Out
Crusher 1	10.00	0.00	0.00	10.00
Miller 1	10.00	0.00	0.00	10.00
Calciner	10.00	0.00	4.41	5.59
Crusher 2	5.59	0.00	0.00	5.59
Miller 2	5.59	0.00	0.00	5.59
Moulding Machine	5.59	0.00	0.17	5.42

Table 4.2: Results of specification of equipment

Unit	Volume (m^3)	Diameter (m)	Height (m)	Area (m^2)
Crusher 1	0.0058777	0.170874	0.256311	0.183456
Miller 1	0.0058777	0.170874	0.256311	0.183456
Calciner	0.0058777	0.170874	0.256311	0.183456
Crusher 2	0.0024515	0.127668	0.191502	0.10241
Miller 2	0.0024515	0.127668	0.191502	0.10241
Moulding Machine	0.0024515	0.127668	0.191502	0.10241

Table 4.3: Results of purchase cost of equipment

Unit	Cost (₦)
Crusher 1	24438.62
Miller 1	24438.62
Calciner	5475.52
Crusher 2	14177.40
Miller 2	14177.40
Moulding Machine	14177.40

Table 4.4: Results of economic analysis

Economic Description	Value
Working Capital	₦160462.11
Fixed Capital	₦802310.54
Total Capital	₦962772.65
Rate of Return	99.63%
Pay Back Period	1year

4.2 Discussion of Results

Tables 4.1 to 4.4 show the results of this technological process design. The result of material balances, specification of equipment, cost of equipment and economic analysis are shown in Tables 4.1, 4.2, 4.3 and 4.4 respectively.

As shown in Table 4.1, the mass in and out of the units were observed to vary as the raw material traveled along the plant and as it was being processed. For instance, with the basis of 10.00kg/hr of diatomite which was passed into the crusher 1, the same mass of 10.00 kg/hr came out of the unit because there was 100% material recovery. That is, there was not any loss in this unit. But in the cs of the calciner where the calcinations took place, the mass of the material leaving was 5.59kg/hr in contrast to the 10.00kg/hr that entered the calciner. The reason for the reduction in mass of the material was due to the material loss from the calcinations reaction.

Table 4.2 show the sizes of the equipment used for the production. It was discovered that the plant required very small sized units of equipment because the production rate was also not too big.

The costs of the pieces of equipment were calculated and it was found that the prices of the equipment were not the same even though some of them had the same size. This is because each piece of the equipment has its own special component which allowed it to perform its functions effectively.

Finally, from the calculation of the economic analysis, the working capital and fixed capital investments were found not to be too big beyond what even a sole proprietor can afford. It was discovered that the total capital investment was ₦962772.65.

In conclusion, the project was finally discovered to be profitable because investment can be recovered within one (1) year. In other word, the pay back period is 1 year.

CHAPTER FIVE

5.0 CONCLUSION AND RECOMMENDATION

5.1 Conclusion

The calculation of the economic analysis, the working capital and fixed capital investments were found not to be too big beyond what even a sole proprietor can afford. It was discovered that the total capital investment was ₦962772.65.

In conclusion, the project was finally discovered to be profitable because investment can be recovered within one (1) year. In other word, the pay back period is 1 year.

5.2 Recommendation

It is recommended that this plant should be sited in Minna so that it can be used for the treatment of water in Minna metropolis.

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