ISLAMIC UNIVERSITY OF TECHNOLOGY

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Design and Analysis of an Eddy Current Metal Separator in a Single Stream Solid Waste Management System

BSc Engineering (Mechanical) Thesis

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CERTIFICATE OF RESEARCH

This thesis titled **"Design and Analysis of an Eddy Current Metal Separator in a Single Stream Solid Waste Management System"** submitted by **SHAKH FAHAD AL NAQIB** (Student ID: **151404**), has been accepted as satisfactory in partial fulfillment of the requirement for the Degree of Bachelor of Science in Mechanical Engineering on March 2021.

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DECLARATION

It is hereby declared that, this thesis or any part of it has not been submitted elsewhere for the award of any degree or diploma.

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ABSTRACT

Recovery and recycling of metal items from waste sources is very important in economic and environmental aspects. The purpose of this study is to design and simulate and eddy-current metal separator which is used industrially in waste sorting plants, usually for separating the non-ferrous metal particles from other wastes. In this process repelling forces act on non-ferrous metals. The force is dependent upon the magnetic flux created by the eddy current and also on the dimensions and electric conductivity of the particles. To achieve this permanent magnet are used. Because of the force, metal particles are thrown at a trajectory from the solid material wastes. And the non-metal materials are separated before the stream of waste reaches the magnetic rotor. By adjusting the location of the magnetic rotor related to conveyor belt in accordion with the sizes of the waste particles, bigger sized particles can be separated efficiently. The design and simulation is done by a Finite Element Analysis software named Comsol Multiphysics. The software allowed us to simulate magnetic properties of the eddy current separator made of three dimensional permanent magnets. In the course of work, the magnetic flux variation around the surroundings of the machine can be analyzed. the ejection force on various particles are founded from the computed data in Comsol. The particles' induced current density and the conductivity influence can be originated. From this study, a way is founded to analyze and compare among different designs of the machine. Thus the process of making a prototype becomes much easier and the machine be much more effective. By analytical methods and finite element analysis the efficiency of the design of the machine can be tested. The paper shows a technical overview for the improvement of eddy current separation equipment so that the less conducting metals could also be recovered utterly. This study could be of great value to the recycling industries and waste sorting plants. No practical implications proved to be a limitation for this research. And for the finite element method, several practical aspects were neglected that could affect the results of the simulation. Eddy current separator, the most important machine among the machines of a solid waste management plant, can be designed and manufactured with greater efficiency from the analysis of this study. And the result of the study can be used for optimizing the design of the typical eddy current separators used by the waste sorting industries.

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INTRODUCTION

1.1 Background of The Study

Municipal wastes are both solid and liquid wastes, sources of which can be domestic, commercial or industrial. Waste quantities has been rising year by year. This presents a huge problem for municipal waste management teams specifically because legislation allows that authorities can only send limited amount of mixed wastes to disposing area. Solid wastes have wide range of variable properties in terms of composition as well as physical features such as difference in densities, moistness and heat characteristics. Thus they are very difficult to burn. Waste management mainly includes the gathering, carriage, processing, recycling or dumping of waste materials because it has served its purpose or is no longer can be used, in addition to carrying out to recover important materials from the wastes. Incorrect dumping of municipal solid waste can create unhygienic circumstances, which in turn can lead to environmental pollution and to outbursts of vector-borne diseases. Solid waste management simply denotes the entire process of handling solid waste from garbage bins to sorting plants, energy production plants or recycling industries. Recycling cannot be done for mixed materials. So it is very important to sort out various materials in different sections. Sorting of Municipal Solid Waste (MSW) is a technique of managing wastes. Sorting is done by Solid Waste Management Plants. A solid waste treatment plant is a solid waste disposal facility that combines various equipment with various sorting techniques in order to isolate valuable resources from municipal solid waste.

Wastes are collected by local municipal authorities. In some management plants, scavengers do it on refuse dumps. Other waste management plants use most advanced form of technology where machines are controlled by computers. Solid waste treatment plant comprises of several devices and different sorting methods are used to separate useful materials out from the mixed waste. In this process the wastes are separated into various components. The elements include paper and cardboards, metals, textiles, vegetable matter, plastics and rubbers. These materials are sorted by the sorting machine according to their physical or chemical properties. These devices, interconnected by conveyors, use different mechanisms in a prescribed or programmed sequence, to sort the waste. To effect wastes sorting processes such as air separation, magnetic separation, density classification etc are carried out in different sections of sophistication. Modern material recovery facilities (MRFs) generally uses electronics such as seismic sensors, colour sensors, eddy current separators, and other methods that mainly serves the purpose of increasing the efficiency to sort different materials. So mechanical waste sorting can be referred to as the method of using devices to sort wastes into their various constituents. After the processing of wastes by the MSW treatment plant, the msw can be sorted into various components according to different raw materials. These raw materials can be later processed into valuable products by corresponding recycling plants. When these sorted wastes undergo different recycling processes products like waste derived fuel can be extruded. Also there are usually high energy constituents in waste stream which can be used in power generation plants to produce energy. Other than that, the food components and some other chemicals can be utilized to produce biogas or syngas, which being later used in generating electricity as well as natural gas. To put it briefly, the plant has the potential to reduce waste pollutions and improve the environment, as well as to generate significant profits and stimulate the economy.

Recycling process can be done of aluminum, plastic, rubber, municipal solid waste (MSW) and many other materials. In recycling process many types of machines are used. Among all the machinery eddy current separator is the most important machine which is used in recycling process. And my research is about designing and simulating the machine.

For ferrous metals, magnetic separators are used as the ferrous metals are attracted or repelled by magnets. And for non-ferromagnetic metals eddy current separators are used. In an eddy-current separator usually repulsive forces are exerted on non-ferrous particles which are electrically conductive materials. Thus these non-ferrous materials are separated from the solid waste mixture stream. Eddy currents are can be stated as currents which circulate in conductors like swirling eddies in a stream. They are induced by changing magnetic fields according to Faraday's law of induction

1.1.1 List of Resources

The items found in a mixture of solid wastes and the items that are separated in a waste sorting plant or be used in a recycling industry are listed below:

List of Recyclable Items					List of Non-Recyclable Items
PAPER	**Cardboard**	**Metals**	**Glass**	**Plastics**	
❖ All office paper ❖ White paper ❖ Coloured paper ❖ Newspaper ❖ Magazines ❖ Catalogues ❖ Phonebooks ❖ Junk mail ❖ Paperboard ❖ Tissue boxes ❖ Heavy weight folders ❖ Paper towel and toilet paper rolls ❖ Food packaging ❖ Milk cartons ❖ Books ❖ Brown paper bags	❖ Cardboard ❖ Corrugated cardboard ❖ Cereal boxes ❖ Shoeboxes ❖ etc.	❖ Metal and tin beverage containers ❖ Metal and tin food containers Aluminium foil ❖ Aluminium take-out containers ❖ Aluminium pie plates and trays ❖ Kitchen cookware: metal pots, pans, tins and utensils	❖ All colours glass bottles and jars ❖ Clear glass ❖ Green glass ❖ Brown glass ❖ Blue glass ❖ Glass food containers ❖ Beer and wine bottles	❖ All plastics numbers 1-7 (Excluding #6) ❖ Food and beverage containers ❖ Screw top jars ❖ Deli-style containers ❖ Clam-shell take-out containers ❖ Plastic cups ❖ Milk jugs ❖ Soap bottles ❖ Plastic jugs: soda bottles, laundry detergent jugs	❖ Napkins ❖ Tissue paper ❖ Paper towels ❖ Wax paper ❖ Wrapping paper ❖ Bubble wrap ❖ Waxed/ waterproof cardboard ❖ Motor oil cans ❖ Metal and cardboard containers contaminated with oil based products ❖ Paint cans ❖ Light bulbs ❖ Mirror glass ❖ Window glass ❖ Ceramic or marble ❖ Crystal

Type of waste	Main products	Corresponding equipment	Final resources
Construction waste	Dust, earth, sand, stone, broken glasses, etc.	Brick production line	Bricks for building;
Green waste (biomass waste)	Tree leaves, grass, fruit shells, wood, straw, etc.	Charcoal making machine	Carbonized into charcoal powder, which can be deep processed into briquettes for BBQ;
Organic waste	Food remaining, faeces, straw, tree branches, etc.	Biogas plant	Biogas to generate electricity;
Metal	Metal products such as caps, battery, etc.	Metal plant	Sold directly or smelt for making new metal products;
Plastic waste	PET	PET fibres production line	Processed into flakes, and then processed into fibres, which can be used for making clothes, pillow inner, bolster, etc.;
	PP, PE, ABS, PS, etc.	Auto packing machine	Packed and then sold directly;
		Pyrolysis equipment	Converted into fuel oil and carbon black for higher values.

1.2 Research Problem Statement

The amount of waste generated increases over time and, in particular, with technological progress. As the technology develops, types and quantity of waste rise as there are more scopes of waste production. Electronics scrap refrigerators, televisions, and end-of-life vehicles have all contributed to significant environmental pollution. Plastic, aluminum, copper, steel, lead, permanent magnet, and residual acidic or radioactive materials are among the materials contained in waste. The study includes the separation of the metal items. ECS is a simple and efficient method for separating non-ferrous metals from wastes. Machines that works on ECS usually the core made of permanent magnets. Eddy current separation can bring renewable energy sources by extracting non-ferrous particles from waste; this method has been developed over the years in many systems. [1,2,3]

- Which type of machine or device for separating for various metals will be used is to be determined.
- Non-ferrous particles with a size of less than 5 mm are difficult to retrieve using conventional eddy current separators. [4,5]. To establish a separation, such devices depend on the eddy current force of the magnetic rotor on the non-ferrous particles.
- Unfortunately, for tiny particles, this force measures as the fifth power of the particle size. [6]

Then for that machine planning and research need to be conducted. Also, the pricing of the project must be minimalized.

1.3 Goals and Objectives of the study

Goals:

The goal of this research is to design an efficient eddy current separator for separating non-ferrous metal particles considering all the technical aspects.

Objectives:

- Design the machine using COMSOL MULTIPHYSICS

- Define the physics for the machine and surroundings of the machine
- Compute the force exerted on the non-ferrous metal items of various particle sizes and shapes
- Analyze the data

1.4 Scope and limitation of the study

Scopes:

- The magnetic flux and flux density around the eddy current metal separator has been identified
- Determining the force exerted on a non-ferrous metal particle.
- Increasing the efficiency of an eddy current metal separator

Limitations:

- The simulation was done by a finite element analysis software so, several practical aspects such as the density of the surroundings, magnetic fluxes due to other electrical equipment, air pressure and air velocity could not be determined thus neglected.

1.5 Methodology of the study:

To design and simulating the machine a finite element software is chosen. For the first step of the design, the geometry outline is drawn. Parameters were set to avoid any differential errors in the design. The geometry is then extruded to a certain point to give the optimal dimensions.

After completing the design, proper materials are then selected. According to the materials a mesh of the design is conducted. Then the simulation is prepared by the software.

The results after the simulation is given. Data can be collected from those results and further analysis of the design can be conducted.

1.6 Contribution of the study

This study mainly contributes to the Solid Waste Management Plants. The efficiency of the traditional ecs those are used in this kind of facilities can be increased significantly. Using COMSOL MULTIPHYSICS further analysis and optimization can be done for the ecs as well as other machineries those are based on eddy current. This research can be good benefit for the municipal authorities. In a developing country like ours, solid waste management plants are must for the improvement in social, economic and of course in environmental aspects. The research done is of great prominence in recycling industries as the eddy current separator is a must machine in those industries. The study might have importance in the energy production industries.

1.7 Arrangement/organization of the thesis

The paper starts with a brief introduction in chapter 1. The literature study is presented in chapter 2. In chapter 3, the research design is presented. In chapter 4, data analysis is described. The paper ends with a conclusion in chapter 5. After that references and appendices are stated.

Chapter 2

LITERATURE REVIEW

2.1 Introduction

ECS is a modern technology used in the recycling and recovery of materials that is directed toward extracting scrap materials from nonmetal substances or extracting metals from various types of scrap metals. This paper presents the ecs technology research, analyzes the design, law, benefits and disadvantages of ecs instrumentality for electromagnetic type eddy current apparatus (ECS), and so on. Supports current problems and flaws, addresses key technologies for improvement within the scrap copper separation region, and creates a fast style of the potentiality for isolation magnetic attraction metal and nonmagnetic metal at the same moment, and hence the instrumentality of sorting for the cube scrap copper.

The literature reviews for this analysis are described below.

2.2 Research Status

The regional and abroad study and deployment of ecs technologies and equipment presently fall into the following categories.

2.2.1 P. C. Rem, E. M. Beunder, A. J. van den Akker

The undulation magnetic flux formed by a position AC electromagnet is used in this modulation. The electrical type ecs arrangement consists of four parts: a perpendicularly mounted, constant speed stator, a conveyor belt, a disk, and a variation hopper. The moving phase force field created by the electrical system travels from the middle to two sections of the conveyer belt until the changing current passes through the coil that is mounted on the conveyor upper than and below. As non-magnetic metal (such as lead, aluminum, zinc, and other metals) moves through the changing force field at a specific speed. Induced eddy current is produced by the non-magnetic metal inner. Repelling force is formed on the ecm sheet (or block) as a consequence of relative velocity between the material and the magnetic field. The extent of the repelling force varies based on the characteristics of the waste products, such as electrical physical phenomena and porousness, as well as the rate and importance of magnetic flux density alteration. We can distinguish certain non-ferrous particles from the mixed material using this principle. This device has characteristics such as simple function, power efficiency, and so on. However, this type of separation device is only moderately ideal for working with coarse grain materials, and the conveyor belt movement speed should not be overly high, and it should only be used for small batch operations.

2.3 Luzheng Chen, Zheng Peng

2.3.1 Slipway type

The supplying tilted disk, permanent magnetic drum operated by a motor, and arranging loader make up the configuration of a "slipway type" ecs, which uses a drum to sort alternating pole of force. Its basic operating theory is that solid wastes are routed to the feeding segmentation and then slide down the chute's layer. The magnetic field that passes through the conductor materials is constantly shifting, causing eddy current to form within the conductor particles. This, along with contributions from momentum, gravity, force, and mechanical power, causes the motion orbits of conductor specimens to change. Various conductor specimens have various conductivities, and the magnetism effect is also variable. Even so, the shipway of such a potentiality is bent and glued, but the waste particles feeding speed cannot be controlled, and conductor particles actually collide, spray, and disperse until waste materials feeding is so great that the contact force of each other exceeds force.

2.4 Problems and deficiencies

Finally, by using ecs technology, there are certain problems and weaknesses to be mindful of.

- Available ecs equipment has flaws such as low efficacy and low separation effect, to name a few. Employees had to detach the scrap metals twice while using any tools. The complexity of the positive style, and thus the related parameters of the separation mechanism, such as feeding rate, belt velocity, and spinning velocity of the drum, are the most important reasons for this progress. This issue must be addressed in the course of the investigation.

- The new ecs technologies can be used to separate metals and nonmetals, but the separation of different types of the similar metal (for example, completely various brands of aluminum) isn't very mature.

- The fragile scrap particles can be removed using ecs technologies, while other large scrap metals (such as radiators) will be difficult to collapse. As a result, there are currently no related researches or implementations about how to isolate these scrap metals.

- Magnetically effected materials cannot be isolated using existing ecs devices. Ferrous compounds can be cleaned off by magnetic separation devices before eddy current separation. This system not only consumes time and labor, but it also increases device costs.

Chapter 3

RESEARCH/EXPERIMENTAL DESIGN

3.1 Introduction

This chapter will illustrate the research procedure which was followed to conduct the study. This will include process flow-chart, Data collection procedure and other related materials.

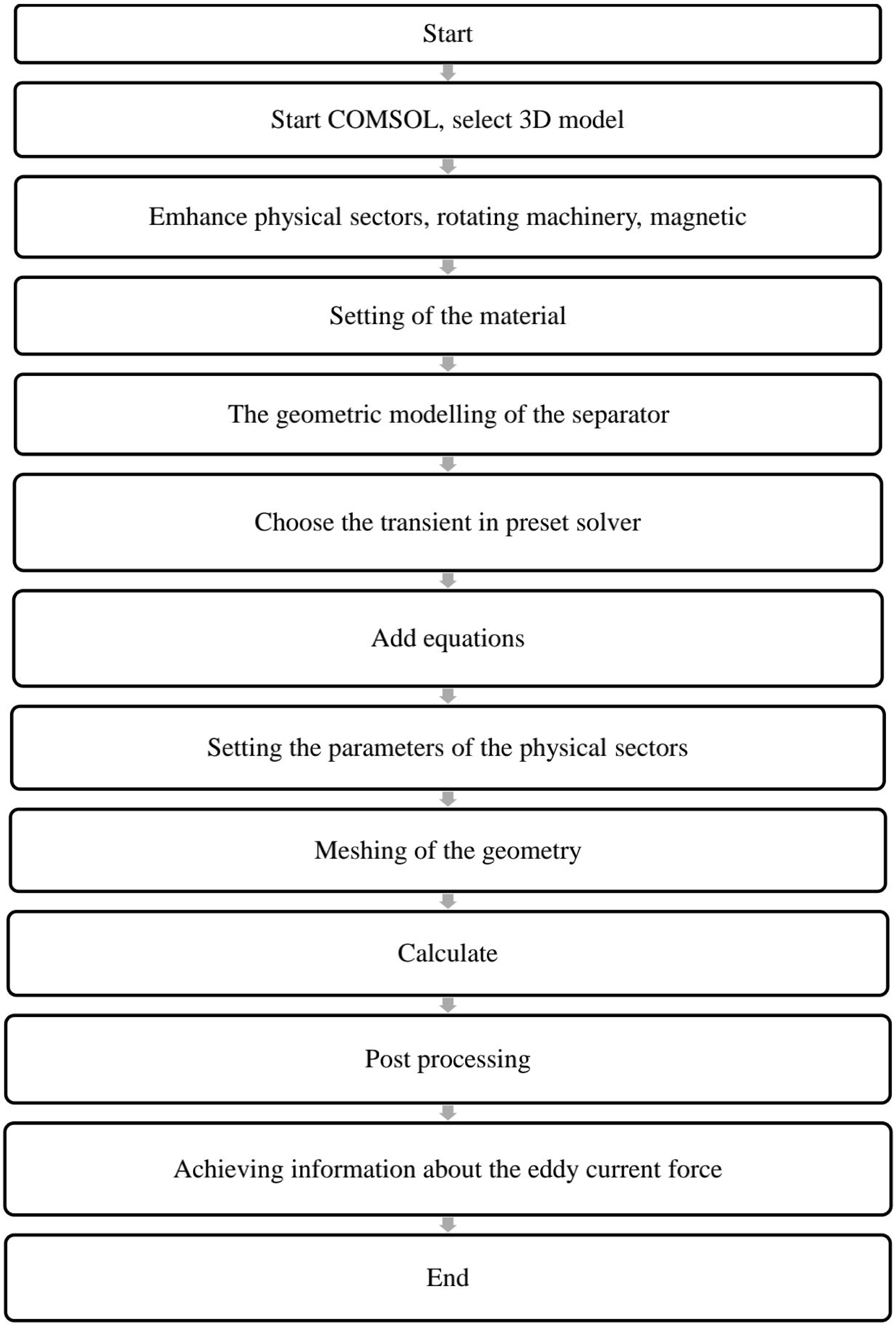
3.2 Research Design

3.2.1 Base of the study

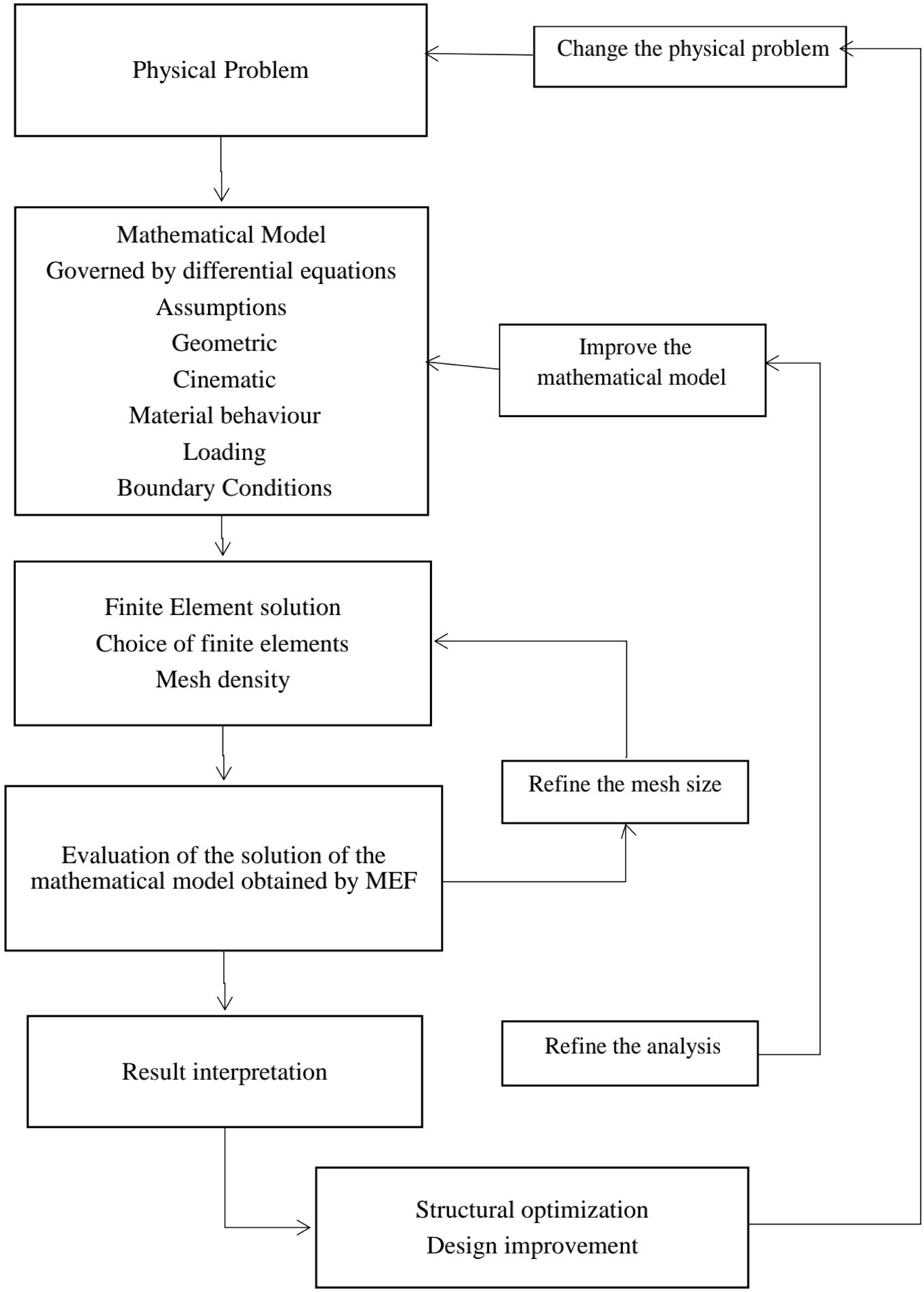
Eddy current separators are the most important piece of device for non-ferrous metals [7]. Rem and other computerized devices [8] used the linear differential equation to explain the trajectory of non-magnetic particles. The trajectory of the particles is imposed because of the force generated in a changing magnetic field based on the separation principle. On the basis of the model, a qualitative inference could be drawn that the particle's scale, shape, and conductivity influenced the separation trajectory. Meanwhile, the magnetic field intensity or magnetic flux density equation for the eddy current separator in cylindrical coordinate could be acquired.

Throughout the separation method, Zhang and Forssberg[9] proposed a measurement model for the tangential and radial forces of particles using eddy current. Lungu and Schlett[10] proposed a measurement model for the tangential and radial forces of particles induced by eddy current when they used the developed eddy current separation equipment to separate copper and aluminum from fiber optic cable. RuanJuJun[11] researched the basic theory of eddy current separation using the technique of mixing experiment and principle to solve the problem of low separation efficiency in the recycling process for discarded containers and old fridge cabinets. And in the separation process, the eddy current force model and the measurement model of flight distance for particles were recycling non-ferrous metal, with a mechanical and control cabinet structure. The magnetic roller, feeding mechanism, separating method, shell part, frame, as well as other institutions make up the mechanical's main section. The magnetic roller, which is made up of 4 pairs of NdFeB permanent magnets and is surrounded by an iron cylindrical magnetic drum, is the heart of the eddy current separator. The permanent magnets were alternately configured in the N-S-N direction. As the electrical conductivity of non-ferrous metal passes through the alternating magnetic field generated by the rotation of the magnetic roller, eddy current is produced within the metal. The eddy current generates a magnetic field that is the polar opposite of the magnetic field generated by the magnetic roller. The ecf is derived for the two magnetic fields' interaction, which include the repelling force separates non-ferrous metals from wastes. As an outcome, the purpose of separating and recycling is not formed and examined. Because of the complex separation mechanism, some separator phenomena cannot be explained by the mathematical model of ecf and flying distance established by those scholars depending on a variety of assumptions, and there are a few flaws. The computer simulation technology is completely exploited in this study in a particular approach centered on the above study. The ecf was calculated using COMSOL's finite element analysis of the magnetic roller, and the flight distance was calculated using COMSOL's joint simulation.

3.2.2 Framework of the process



3.2.3 Flowchart for COMSOL



3.3. Experimental set up

Eddy current separator can be designed in various way. The design and data that is considered for this study is been stated in the following section.

3.3.1 Eddy Current Rotor

Specific design of the ECS rotor can be defined in several ways.

3.3.1.1 Modeling of the rotor

Rotor Arrangement: High grade permanent magnets. These are rare-earth magnets, calibrated for little vibration and extensive life.

Rotor Shell: Outer shield for the covering protection of inner rotor. Material: replaceable fiberglass. It is also connected with the conveyor belt

Rotor Diameter:12 inch, 14 inch or 16 inch. Rotor diameter is set based on the power required for the size and density of non-ferrous objects those are repelled out.

Rotor Width: The greater width rotor configuration takes the product away from the belt's boundaries and holds bearings out of the magnetic field, extending the life of both rotor and belt.

Specifications:

Property/Part of the machine	Description
configuration	Eccentric set rotor; Left or Right hand drive
sleeve	Stainless steel
side plates	Removable for easy access and maintenance
motor	Variable speed with computational controller
shell	Ceramic coated, carbon fiber. Thus minimizes ferrous burnout
drum	Internal motorized drive
screw adjustment	easy belt tensioning and tracking
Lifting eyes	for easy installation/fork pockets
Particle size	typically between 3mm and 50mm

3.3.1.2 Variables and Parameters

In this study, five important factors have been taken in consideration that affect the eddy current induced on the non-ferrous metal particles. These factors are stated below:

i. Angular velocity of the magnetic rotor;
ii. Velocity of the feeding belt;
iii. Dimension of the feeding belt;
iv. Requisite of eradicating ferrous metal before the rotor;
v. Magnetic field intensity of the rotor relative to surrounding materials;

Angular velocity of the magnetic rotor:

A magnetic rotor with alternate magnetic poles (north/south) rotates within a less spinning non-metallic shield in an ECS.

This distinction is regulated by two laws:

- Faraday's Law of Induction: As conductors reach a spinning magnetic field, currents are induced;
- Lenz's Law: When induced eddy currents produce a magnetic field that opposes the magnetic field that caused it. As a result, a conductor is repelled away from the magnetic source.

A rise in the amount of polarity variate per second could theoretically improve separation performance. For example, the more the flux changes in a particular area, the more a higher reactive magnetic field in the particles is produced. Besides that, experimental results show that as the velocity of the rotor grows, the rate of change in polarity increases. This results in the actual displacement or flight distance of a non-magnetic metal particle approaches a limit. After reaching a maximum, the displacement of non-magnetic metal particles is maintained or even decreases, particularly for smaller pieces.

Velocity of the conveyor belt:

The particles are transmitted through the spinning magnetic field of the main pulley rotor by the ECS's loop. The burden depth on the conveyor belt, the dwell time in the magnetic field, and the direction of the particle when it exits the belt are all determined by the velocity of the belt.

Dwell Time:

The dwell time of the material in a spinning magnetic field is determined by the velocity of the belt. A prolonged dwell time permits the non-magnetic metal particle to consume more energy. Aluminum that is kept under a spinning magnetic field becomes very hot and anneals. When the velocity of the belt is too fast, the material is transferred too rapidly through the magnetic field, minimizing the separation effect.

Material Trajectory:

Inertia of any moving conveyor belt determines the direction of particle when it exits the belt. Higher belt speeds trigger longer predictions of transmitted content away from the head pulley while in service. In order to effectively separate non-ferrous metals using an ECS, one must first consider all of the forces acting on the ions, along with the velocity of the belt.

There are three forces acting on a particle moving along with the conveyor belt when the particle enters the rotating magnetic field of the ECS.

i. Eddy Current repulsion force generated by the Magnetic Rotor;
ii. Conveyor propulsion which is related to the velocity of the belt;
iii. Gravity;

These three forces converge to form a Resultant Force, which defines the non-ferrous metal particle's trajectory.

Forces B and C will impact all particles on the conveyor belt, while ECF a repulsion force (force A) will only effect on the non-ferrous metal particles. As a result, if all of the materials on the conveyor belt were of same dimension, form, and weight and without the Magnetic Rotor, the throw direction would not change.

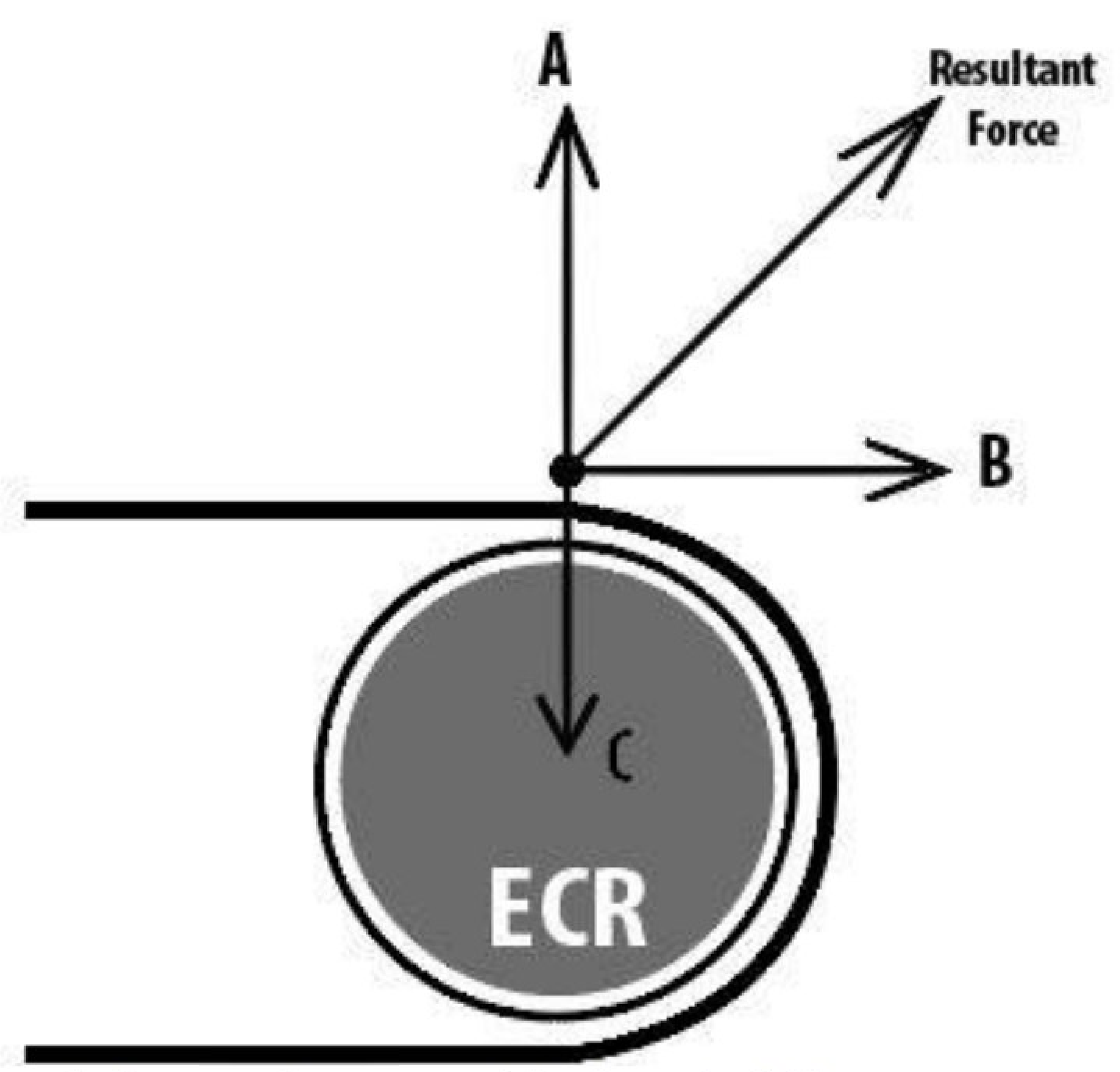


Figure 1: Forces acting on a particle above the Eddy current separator

Feed Belt Length:

The length of an Eddy Current Separator's conveyor belt differs greatly, and some argue that longer belts increase separation. The belt length is determined by the function of the belt and its relationship with the other components of the separation mechanism.

The belt essentially transfers the material into the 'separation zone', which is a spinning magnetic field. Before joining the ‘separation region,' the substance must be settled and, preferably, still on the conveyor belt for proper separation. A long belt allows the material to stabilize for a prolonged period of time.

Ferrous Metal Removal:

Given the fact that the ECS is a magnetic separation device, there is sometimes uncertainty about ferrous metal separation. An ECS consists of a belt and two pulleys, each of which is magnetic. The magnetic head pulley is the rotor that absorbs ferrous metal due to mechanics. As a result, the device will be able to distinguish between ferrous magnetic metals and non-magnetic ones. There are, however, certain drawbacks.

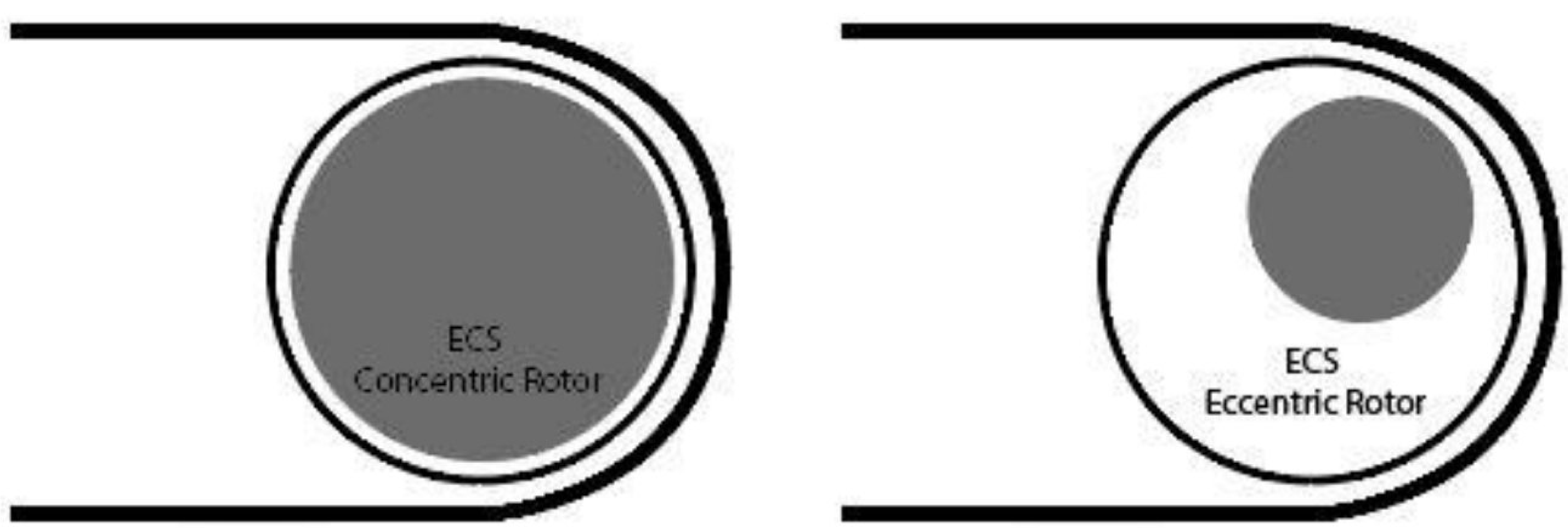


Figure 2: Difference in design between concentric and eccentric eddy current rotor

Eccentric Rotors:

A relatively small rotor is positioned in the upper portion of the non-metallic cover in the Eccentric Magnetic Rotor configuration. As a consequence, magnetic material that is drawn to the belt passes through a decreasing magnetic field until it drifts away from the belt. This ferrous metal often corrodes the non-metallic portion.

Best Practice:

A multi-phased method with separate particles recovered at various phases is needed for optimized metal recovery and separation. Leading up to the ECS, Pulley Magnets and Drum Magnets selectively and successfully retrieve exportable ferrous metals. On the ECS, which allows for non-obstructive isolation and retrieval of non-ferrous metals.

Rotor Magnetic Strength:

According to Faraday and Lenz's laws, the strongest spinning magnetic field will have a higher repellent effect. Though this is not the scenario in practical or experimental instance. The rotor of an ECS is made up of several powerful permanent magnets. The magnets are made of neodymium rare earth or ceramic ferrite and they are connected to a metal carrier.

The trajectory generated by the magnetic field is dependent on the shape and size of the permanent magnets. The dimensions of the permanent magnets that affect the magnetic field is the length around the magnetic rotor and thickness. Narrower and slimmer magnets create shallow strong magnetic fields, whereas broader and broader magnets generate stronger magnetic fields.

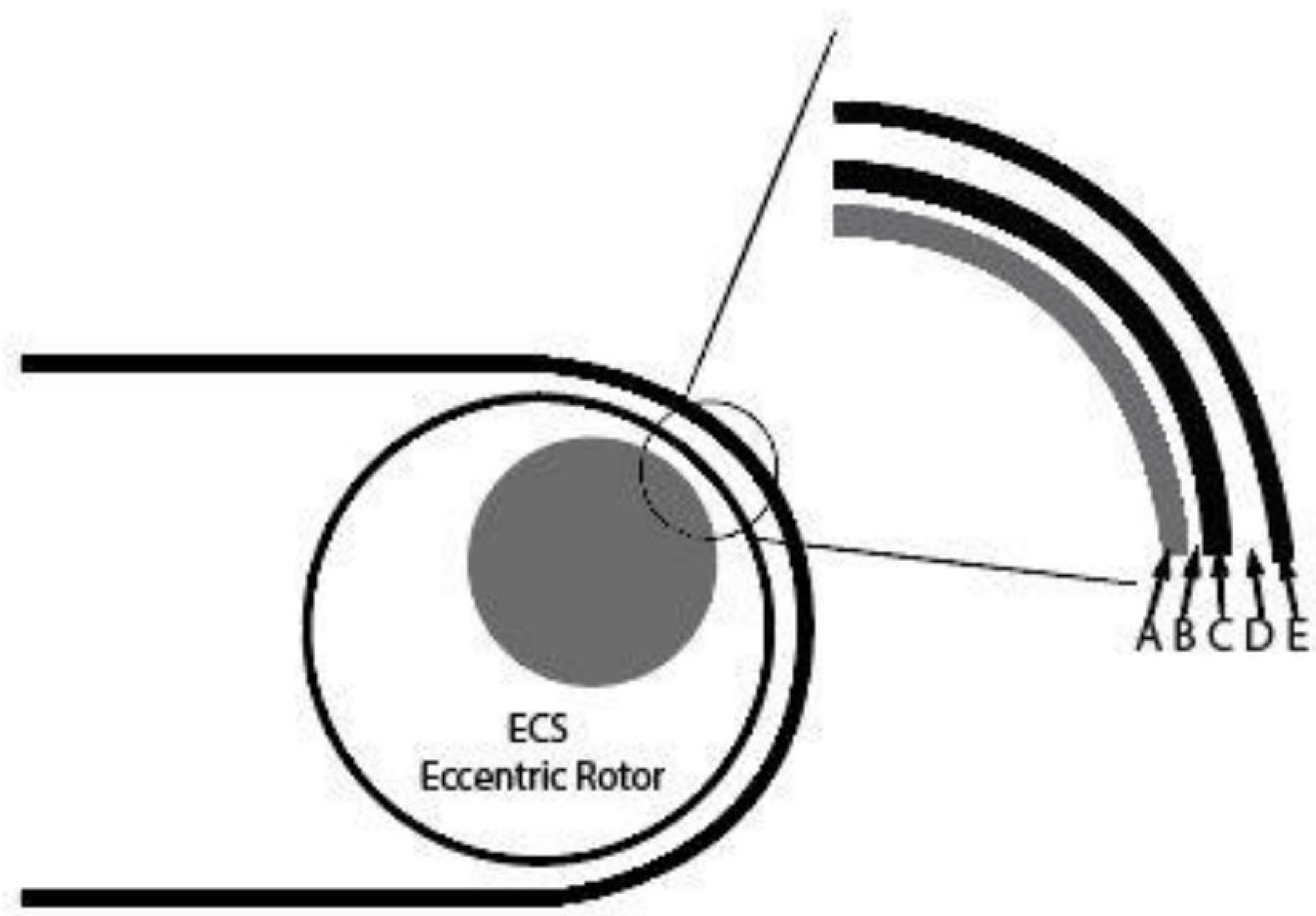


Figure 3: Materials that make the ECR. A: Magnets, B: Carbon fibre tape, C: Air gap, D: Non-metallic shell, E: Feed belt

The highest magnetic force is on the surface of the permanent magnet fixed on the holder of the magnetic rotor, regardless of whether the magnet is large or small. One important design factor is to keep the gap between the magnetic pole and the belt's surface as small as possible, since distance reduces the magnetic field significantly. Four factors have an effect on this distance:

i. Carbon fiber wrap: The magnets are mounted on the rotor's magnet container, which spins individually within the non-magnetic shield. The magnets are tightly held to the container by a tape made of carbon fiber wrapped around the rotor.

ii. The Air Gap: And when the rotor is rotating at high velocities and there is a limited level of flexing, the air distance between the top of the carbon fiber tape and the interior of the casing must be adequate to guarantee no touching.

iii. Shell Thickness: The width of the casing must be adequate to endure wear due to the strenuous operating conditions of the recycling industry;

iv. Belt Thickness: This also refers to belt length, with some implementations necessitating heavier, more durable feed belts.

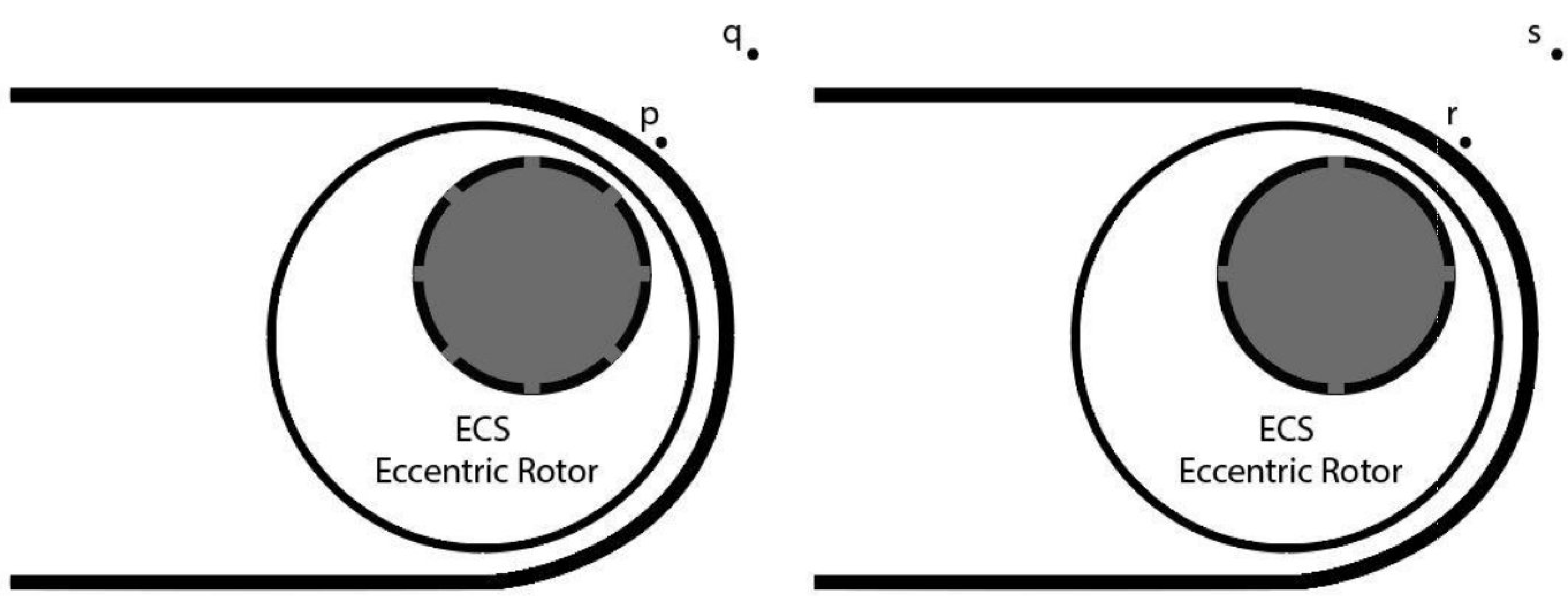


Figure 4: Both of these eddy current separator eccentric rotor has the same configuration. But there is a difference in the design and number of the permanent magnets those make the rotor. Left side rotor has short magnets. Right side rotor has long magnets. This results in a change in magnetic force. Such as, magnetic force at p for the short magnets are greater than the magnetic force at r for the long magnets. Oppositely, Magnetic force at q for the short magnets is less than the magnetic force at s for the long magnets.

3.4 Expected Outcomes

There is some mm in length between the position of highest magnetic power and the top of the belt due to the carbon fiber tape, the air distance between the external casing, the width of the casing, and the depth of the belt. The next step is to evaluate the predicted output of rotors with small or large magnets after these parameters have been set. Because of the influence of a shallow or deep magnetic field, categorizing a magnetic rotor as "solid" or "weak" is largely based on the position of the calculation used to justify the designation. The following scenario states such:

Rotor Design	On the surface of the belt	10mm above the surface of the belt
Rotor 1: Made of rare earth neodymium magnets in short size but of remarkable strength with narrow field lines	Strongest	Weakest
Rotor 2: Made of Ferrite magnets in long size but of standard strength with deep field lines	Weakest	Strongest

3.5 Types of methods

The simulation model of the key physical phenomena existing in ecs is the method followed in this article. By evaluating the strength of the repulsive magnetic field generated in each of the phenomena by the changing magnetic field provided by the permanent magnet rotating drum, the trajectory distance of the components of the mixed materials to be separated is determined.

The rotating velocity of both the magnet container and the conveyor belt, the direction of the collector, the materials scale, and the arrangement of the materials on the conveyor belt were all included in this numerical analysis for the context of an industrial separator. This form of challenge was solved using the COMSOL Multiphysics computing method.

In linear areas, the key methods for resolving partial differential equations in non-linear media especially for the inductor material are as follows.

- Finite Difference Method (FDM)
- Finite Element Method (FEM)
- Finite Volume Method (FVM)
- Analytical Method (AM)
- Integral Border Method (MI)

Among these methods, The FEM is the most widely used since it is well suited to the interpretation of complicated geometries and the analysis of nonlinear material behavior, the numerical finite methods restrict the differential equation process resolution in the field of analysis to that of a mathematical equations system whose formulations lead to derivation of electromagnetic field lines, thus taking into consideration the boundary conditions. [12]

The installation measures 180 centimeter x 50 centimeter x 120 centimeter and weights roughly 320 kg. It is made up of a four-pivot frame that supports a three-stage electrical circuit as well as a four-pole magnetic rotating drum that is driven by a three-stage electric motor by a belt. Other single-other electric motor of the geared motor type is used in the system, which drives the conveyor belt, which drives the mixture of particles to be retrieved.

3.6 Mathematical modeling

The drum rotation with angular velocity produces a changing magnetic flux near the separator. Magnetic flux density model compositions can be used to suit a variety of situations. as per the extensions in cylindrical coordinates (r, z) the formulae mentioned below [13]

$$Br = \sum_{m=0}^{\infty} bm \left(\frac{r}{R}\right)^{-(2m+1)p-1} \sin(2m+1)\, p(\phi - \omega_l t) \qquad (1)$$

$$B\phi = \sum_{m=0}^{\infty} -bm\left(\frac{r}{R}\right)^{-(2m+1)p-1} \cos(2m+1)\, p(\phi - \omega_l t) \qquad (2)$$

$$\mathrm{Bz} = 0 \qquad (3)$$

where bm represents the Fourier coefficient, which is influenced by the magnetic field strength and radius (r), and R is the magnetic rotor's radius [13].

Maxwell's equation of magnetic conservation:

$$\nabla \cdot \vec{\mathrm{B}} = 0 \qquad (4)$$

$$\mathrm{B} = \nabla \mathrm{XA} \qquad (5)$$

Faraday's law states:

$$\nabla\, X\, E = -\frac{\partial B}{\partial t} \qquad (6)$$

Ohm's Law:

$$\mathrm{J} = \sigma E \qquad (7)$$

Here J is the eddy current density and E is the particle's electrical conductivity [13]. As a consequence, we get the below mentioned equation:

$$\nabla\, X\, J = -\sigma \cdot \frac{\partial B}{\partial t} \qquad (8)$$

Ampere's law:

$$\nabla\, X\, \mathrm{H} = J \qquad (9)$$

here H represents the magnetic field generated by the permanent magnets.

The induced current is expressed by

$$\mathrm{J} = -\sigma\left(\frac{\partial A}{\partial t} + \nabla \cdot \varphi\right) \qquad (10)$$

Laplace's Equation:

$$\nabla^2 \varphi = 0 \quad (11)$$

The boundary condition can be used to achieve the solution of Equation (11) for. A repelling force F is produced by the interaction of electromagnetic field and eddy currents in non-ferrous metals with a volume V, as demonstrated by:

$$F = \iiint_v J \, X \, B dV \quad (12)$$

The force between a particle and the permanent magnets can be obtained from this equation. Thus, the separation force is expressed by:

$$F = H^2 \left(\frac{np}{2}\right) * \left(\frac{m\sigma}{\rho s}\right) \quad (13)$$

In our study, The electromagnetic force is obtained using the basis of the Maxwell's law, which relate the basic electromagnetic variables. With the aid of COMSOL applications, these calculations can be resolved using the finite element method (FEM).

3.7 COMSOL Design and Simulation:

To design and simulate the model of the eddy current separator, below mentioned steps were followed in this study.

3.7.1 Designing the geometry:

First the outlines were drawn as shown in the figure below

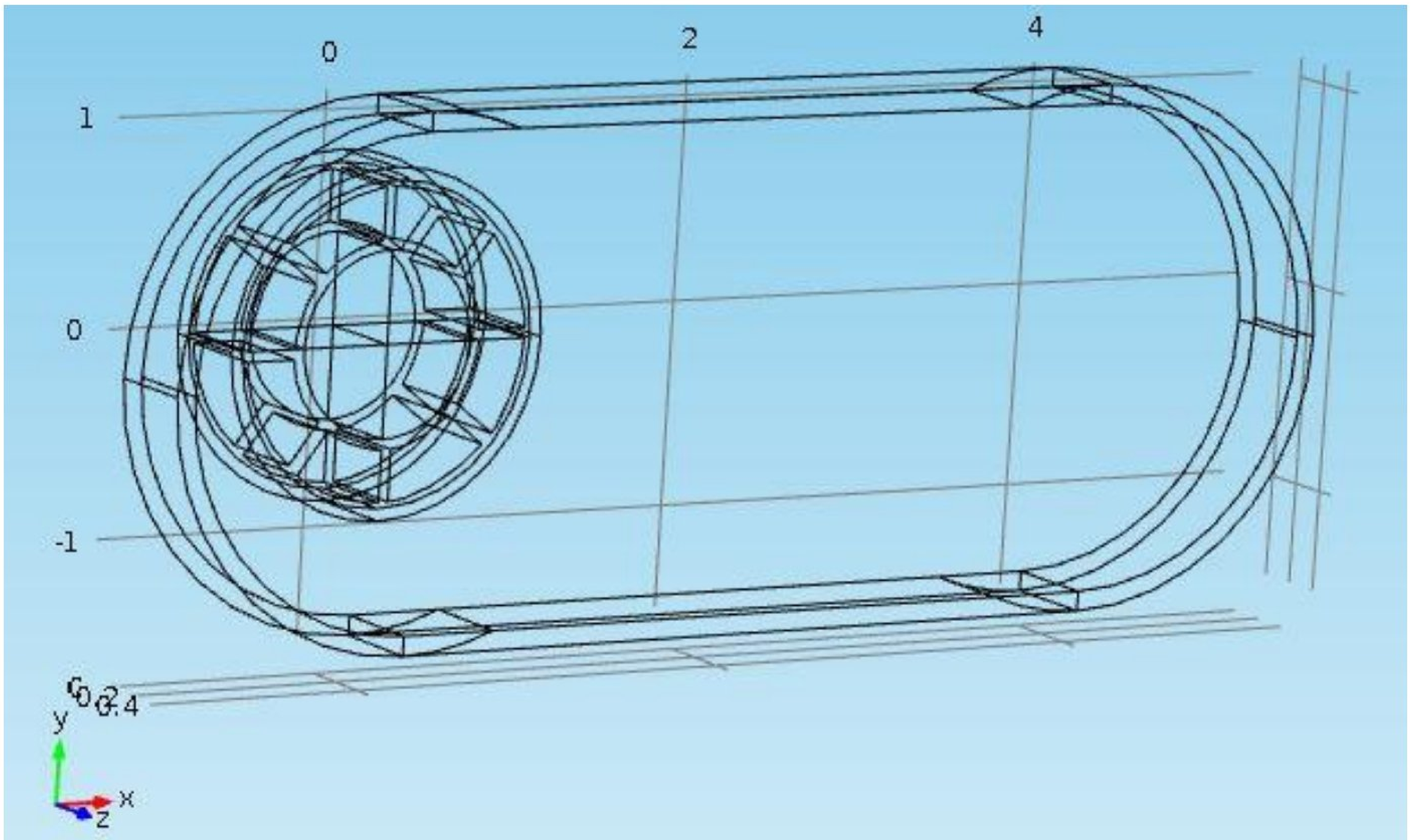


Figure 5: Outlines of the geometry

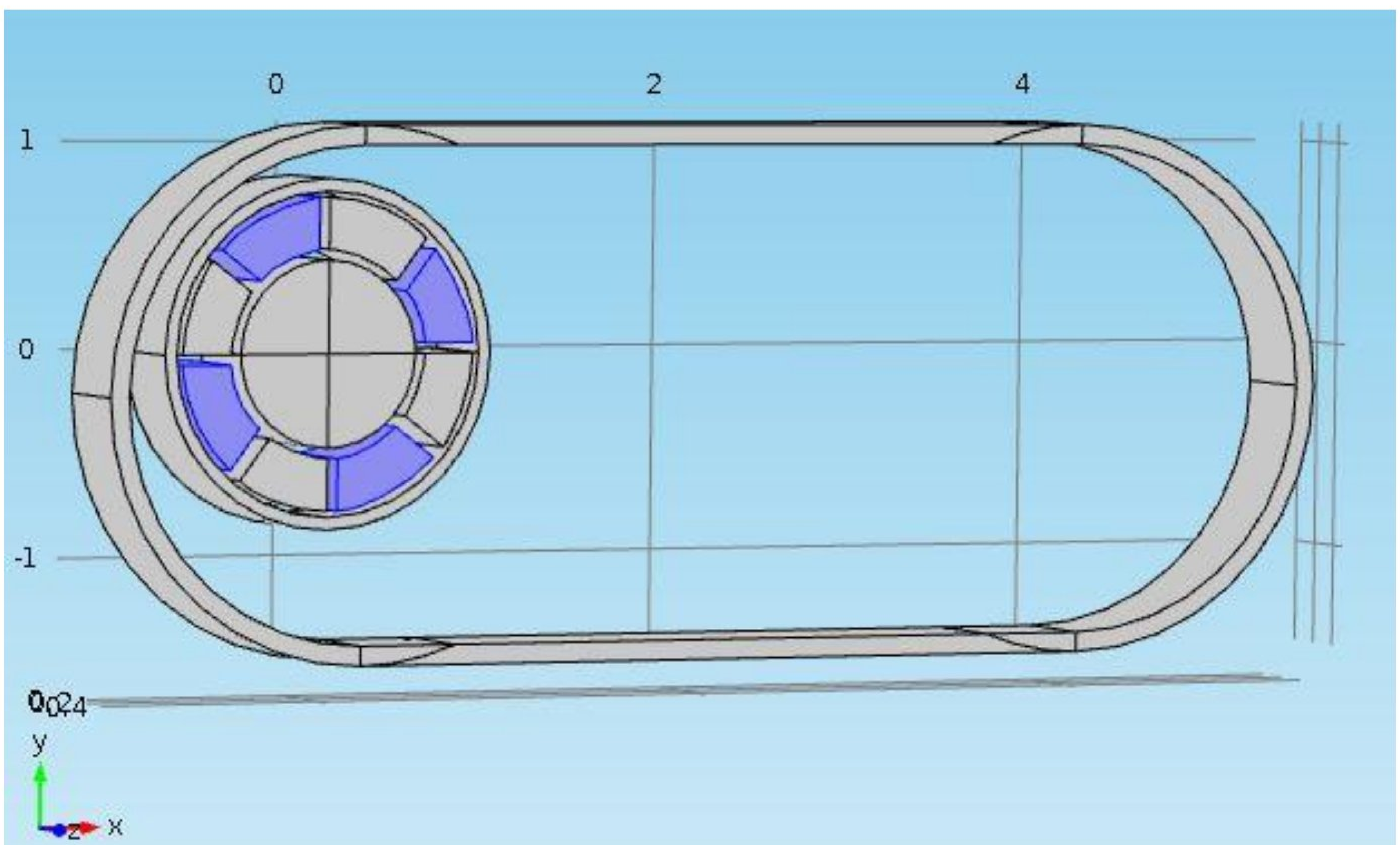


Figure 6: model of the final geometry. blue blocks indicate the south poles of the permanent magnets

This design refers to an eccentric eddy current separator

3.7.2 Defining the physics and creating mesh:

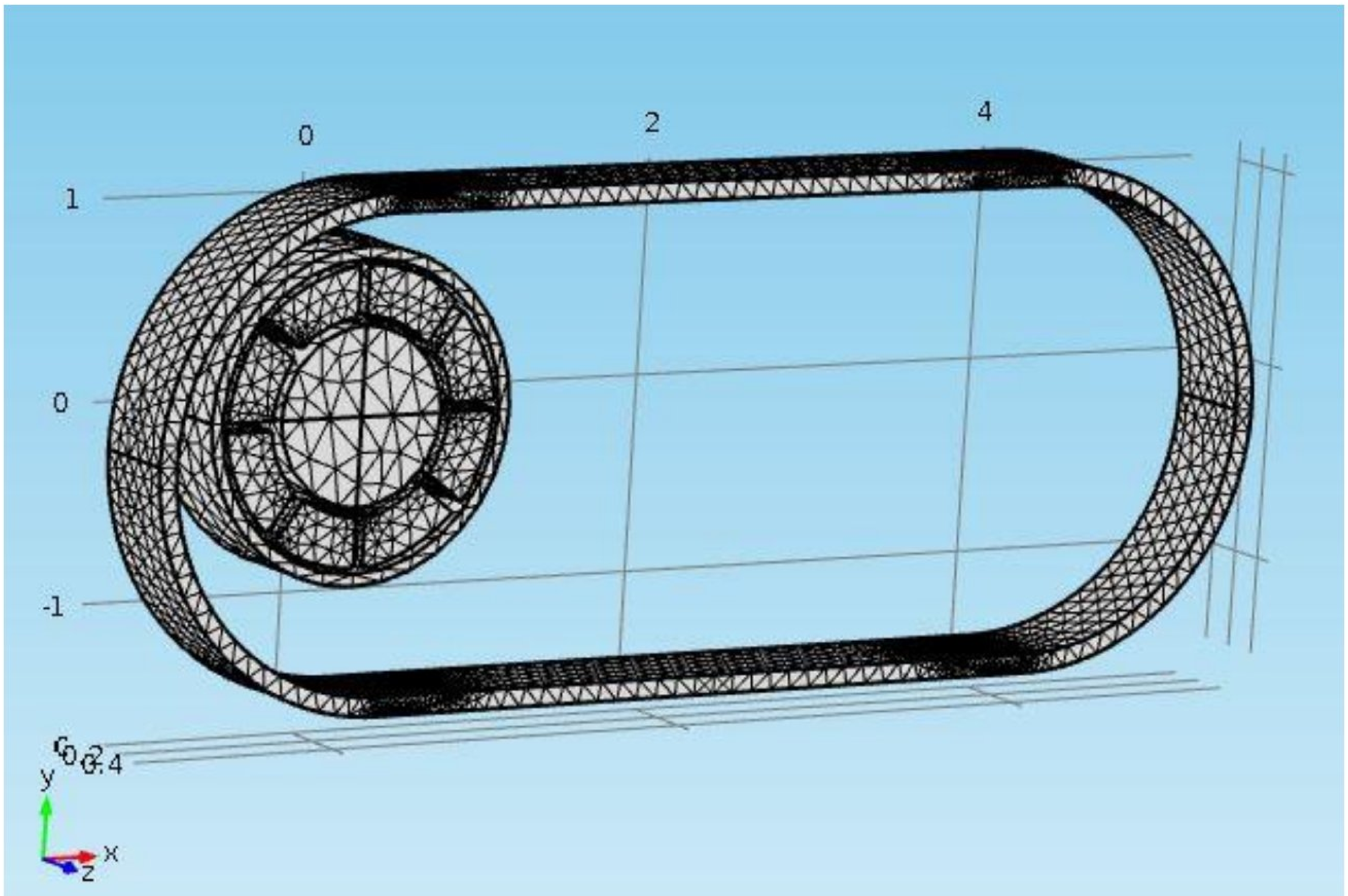


Figure 6: Mesh of the model

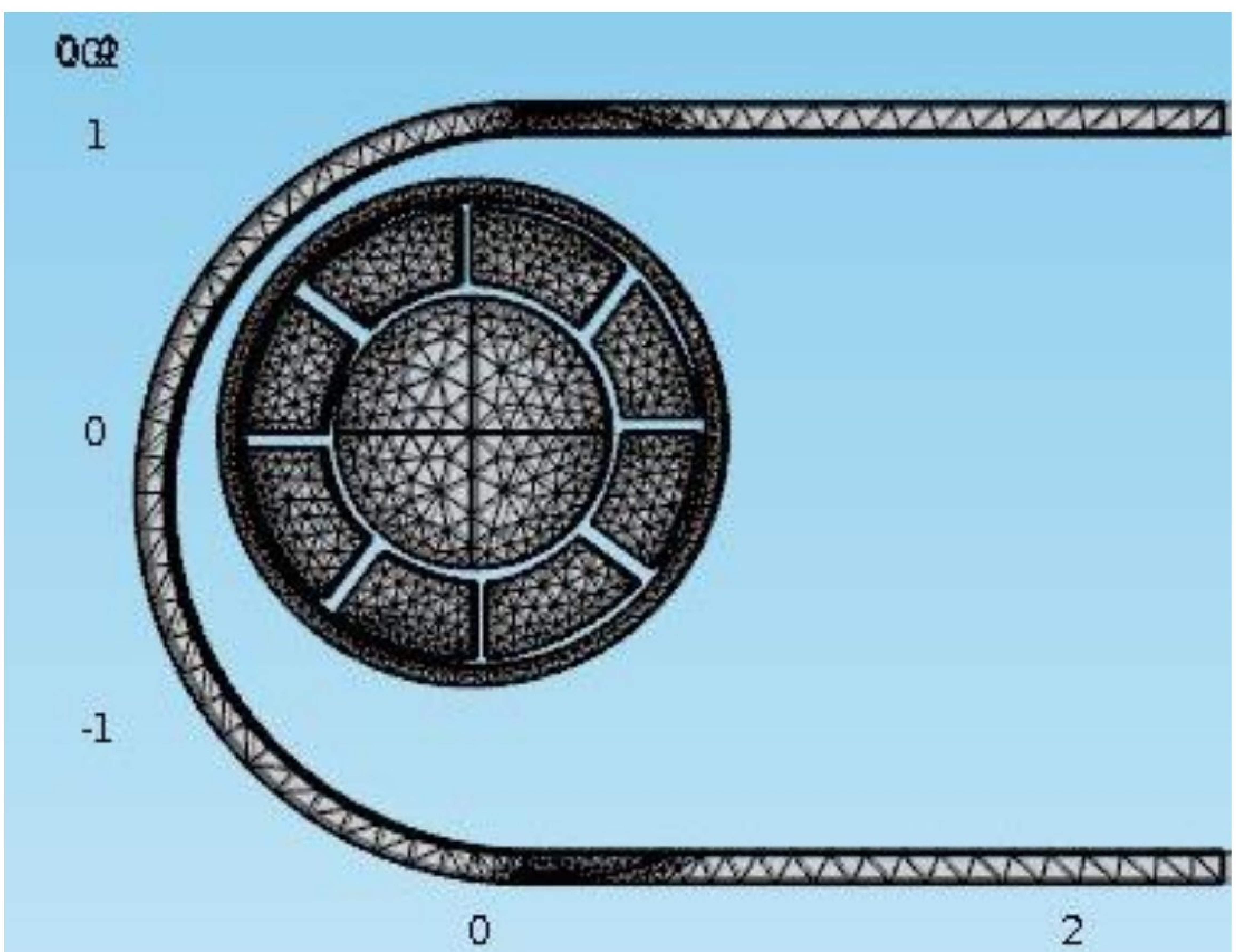


Figure 8: Mesh of the ECS rotor

Relatively coarse meshed are of less permeability and finer meshes denotes materials with higher permeability. This is the conveyor belt, and this is the rotor. Inside it are the permanent magnets of alternating poles. Surroundings is air.

3.7.3 Simulation:

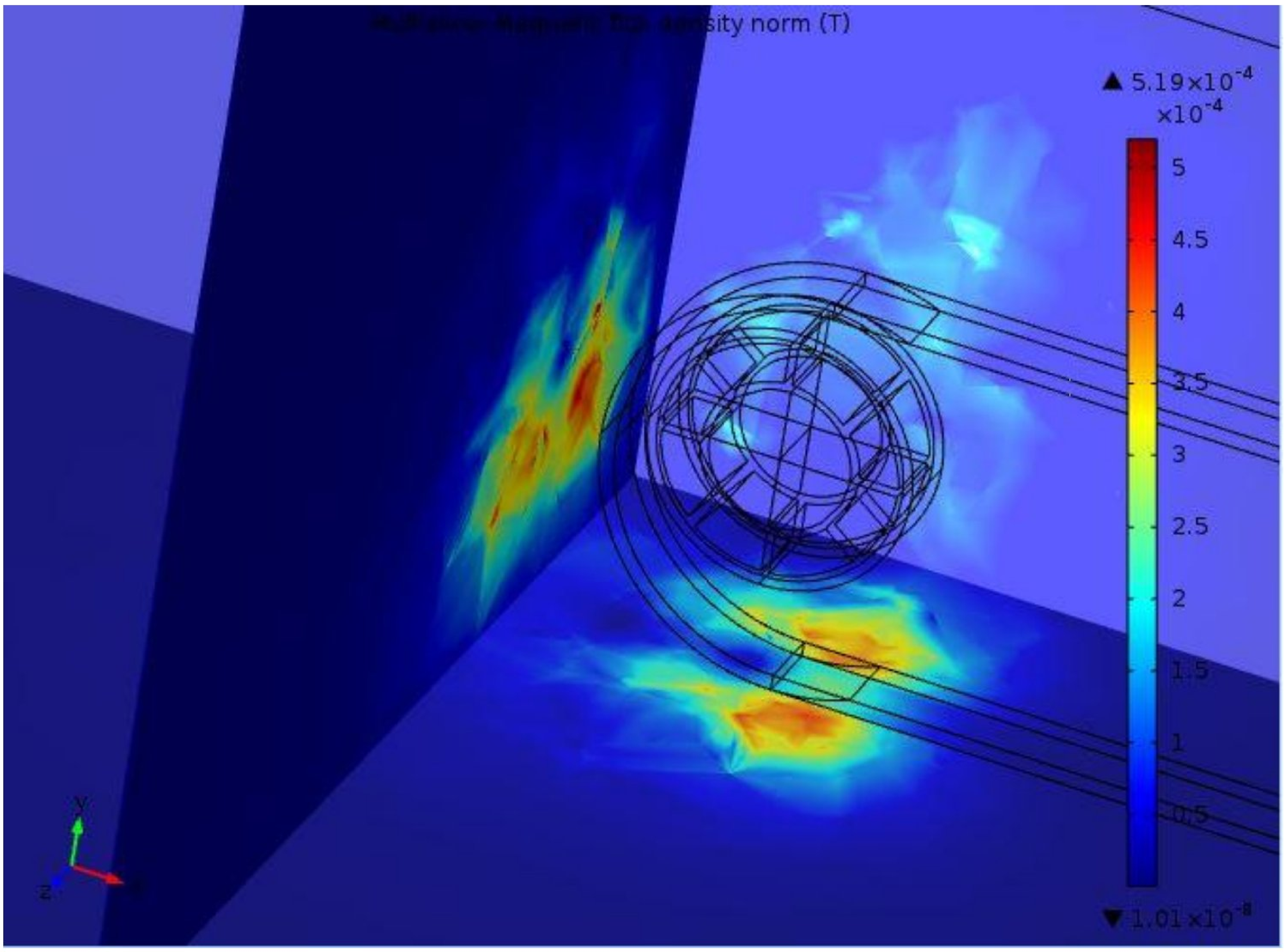


Figure 9: Magnetic Flux density at a certain distance

Two planes near the eddy current separator surface were taken. Supposing, the non-ferrous materials be placed on these planes. The COMSOL Multiphysics software allows me to determine the magnetic flux density on any point of this plane. We can see that the magnetic flux density is relative to the distance of the plane. The less the distance the more will be the flux density. Where the color is reddish, it means that the magnetic flux is much denser in that section. Blue areas denote less dense magnetic flux. And we know that force is directly proportional to Magnetic Flux Density. From this simulation we can gather data for various non-ferrous materials. Using these data in the before mentioned equations, we can calculate the force and trajectory acting on a particle.

Chapter 4

DATA ANALYSIS AND DISCUSSION

4.1 Introduction

This chapter will illustrate the collected data and the implications of it.

4.2 Model Description Data

The following data table represents the description details of the eddy current separator model that has been design and simulated in COMSOL Multiphysics software.

Parameters	Values
No. of poles	2p = 6
Magnetisation of permanent magnet (NdFeB)	1.33 T
Air breach	16 mm
Positioning of magnets	On the surface
Magnet width	25 mm
Mechanical gap of magnets	30 degree
Polar phase	45 degree
Radius of magnets next to the air gap	80 mm
Radius of magnets next to the rotor	50 mm
Axial dimension of magnets	100 mm
Axial rotor dimension	225 mm
Rotor diameter	160 mm

Comment	Used materials	The mechanical set
Material	Copper	Stationary
North pole of the magnet	Neodymium	Motion in rpm
Br = 1.32 T radial constituent South pole of the magnet	Neodymium	Motion in rpm
Br = −1.32 T radial constituent cylinder head	Soft iron without losses	Motion in rpm

4.3 Data Collected

Mesh components	Value
Assembly of solid objects	5
Domains	12
Boundaries	67
Points	60
No. of domain elements	2180
No. of boundary elements.	390
Excellent quality elements	97.014%
Average quality of the elements	1.215%
Minimum quality of the elements	0.648%

4.3.1 Experimental Result

Comment	Used materials	The mechanical set
Material	Copper	Stationary
North pole of the magnet	Neodymium	Motion in rpm
Br = 1.32 T radial constituent South pole of the magnet	Neodymium	Motion in rpm
Br = −1.32 T radial constituent cylinder head	Soft iron without losses	Motion in rpm

4.3.2 Comparison among particles

Material	Conductivity, σ ($10^{-8}/\Omega m$)	Density, ρ (10^3 Kg/m^3)ρ	σ/ρ (10^3 m$^2/\Omega$Kg)
Aluminium(Al)	0.35	2.7	13.0
Copper (Cu)	0.59	8.9	6.7
Silver(Ag)	0.63	10.5	6.0
Zinc (Zn)	0.17	7.1	2.4
Gold (Au)	0.44	19.4	2.26
Lead (Pb)	0.05	11.3	0.4

Eddy Current (A/mm2)	Particles	1 mm	2 mm	3 mm	4 mm	5 mm
	Aluminium(Al)	40	50	52	55	58
	Copper (Cu)	60	68	73	90	98
	Silver(Ag)	80	90	98	100	108
	Zinc (Zn)	17	19	22	27	34
	Gold (Au)	45	60	65	70	78
	Lead (Pb)	4	4.6	5	6	8

4.4 Data analysis and Presentation

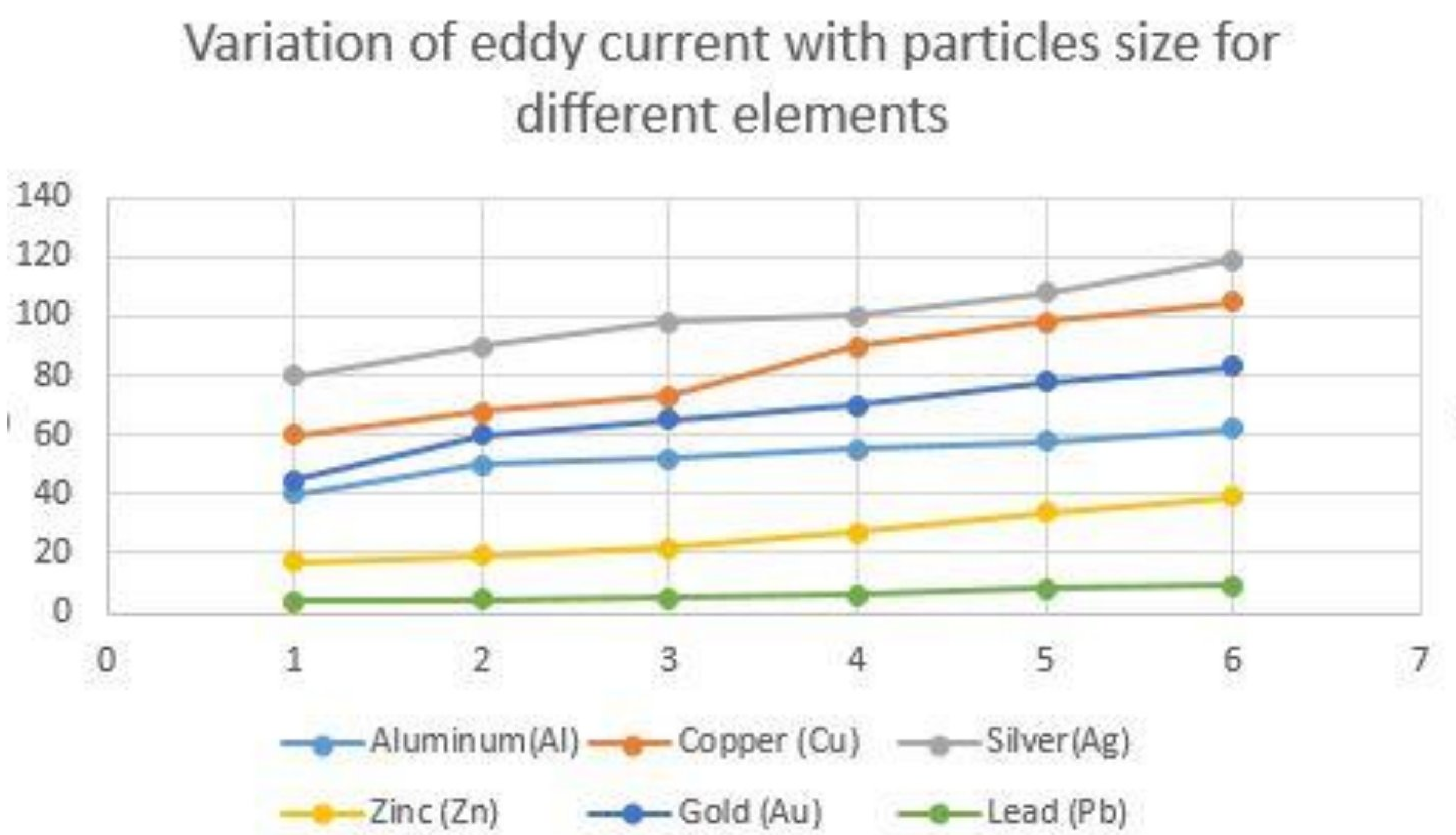


Figure 10: Variation in eddy current induced in different particles

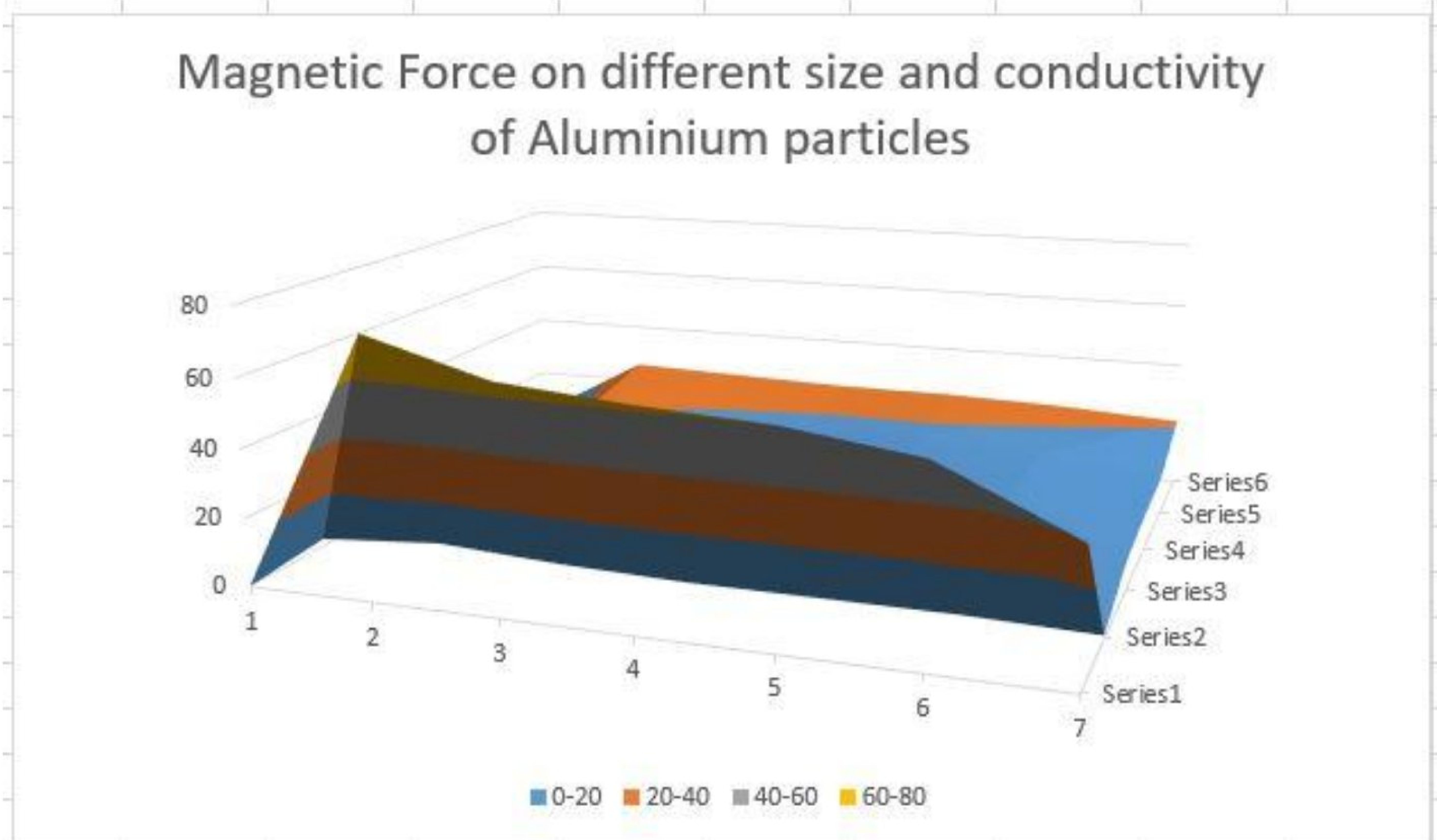


Figure 11: Magnetic force on aluminium particles of different sizes and conductivity

4.4 Discussion

The repulsive forces exerted on block-shaped particles in the stream of an eddy current separator and a rotor disc is measured using Maxwell's electromagnetism equations. A variety of assumptions were used to simplify the complex repulsive force expressions. The measurements of repulsive forces were found to be related to the magnetic structure of an eddy current separator in this aspect. It can be linked to a specific model of rotor disc by the use of a performance factor I, that can be used to select the appropriate magnetic strip proportions for a specified channel diameter. Repulsive-force tests in a rotor disc were used to assess the feasibility of the theoretical procedure.

Chapter 5

CONCLUSION AND RECOMMENDATION

5.1 Summary

From the results of simulation, the magnetic characteristics surrounding eddy current separator can be known. This three dimensional analysis gives us nearly the similar types of result as of practical implications. Although there had been several limitations in research, the overall importance of the study cannot be neglected. This project can be further implemented in making industrial machineries. In optimization of the typical eddy current separators and improving the efficiency of these type of machineries this study can be of great value.

5.2 Conclusion

Despite the numerous models used for the eddy current technique, the issue of non-ferrous metals trajectory distance to retrieve from major pollutants remains a concern. The calculation of the detachment angle of the particles in the effective separation region is used to optimize this size. based on preliminary results. This system is capable of separating items as large as a.35-liter drink can. The optimal operating point is determined by many controllable variables, including the speed rotating of either the magnetic drum or the conveyor, the collector orientation, the mixture scale, and the arrangement of the mixture on the conveyor. Through numerically computing the magnetic field that each conductor is exposed and analyzing the effects of induced eddy currents, the behavior of materials of various properties and sizes in the context of a variable magnetic field can be effectively observed. This research used a multi-physical approach. It has shown that its simulation method, which is focused on the elementary discretization of physical domains, can model the most complex structures of eddy-current separators in various operating conditions relevant to their implementation to non-ferrous waste management.

5.3 Recommendation

In a developing country like ours, solid waste management plants are must for the improvement in social, economic and of course in environmental aspects. Sorted wastes can be further used for recycling as well as energy production. Lastly, Wastes are not actually waste; if used in a proper way, waste can be turned into treasure. Thus, for the development it is recommended that this study should be approached for further researches and practical implementation.

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