

GASEOUS CORROSION IN HARD DISK DRIVE:
A COMPUTATIONAL STUDY

by

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ABSTRACT

GASEOUS CORROSIONIN HARD DISK DRIVE (HDD): A COMPUTATIONAL STUDY

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HDD is the largest digitally encoded data storage device. HDD is used to store digital data in data centers, computers and laptops. A typical HDD consists of a casing, an actuator arm, actuator axis, head, platters, power connectors, and jumper pins. The platter is made up of non-magnetic material and is covered by magnetic material, which stores the data. The magnetic heads are mounted on a moving actuator arm to read and write the data.

One of the modes of failure of a HDD is corrosion. The parts of the HDD are corroded by coming in contact with the contaminants. Sulphur bearing gases, Sulphur Dioxide (SO_2) and Hydrogen Sulfide (H_2S), are the main gaseous contaminants responsible for the corrosion in HDD in presence of certain humidity and temperature. American Society of Heating and Air-conditioning (ASHRAE) recommend an allowable

relative humidity such as 50-60% in the environment where electronic equipment is used for avoiding corrosion in the equipment.

The focus of this study is to determine the rate of corrosion computationally. A model is created which combines surface chemistry and transport species to predict the deposition rate of sulfate on platter when exposed to gaseous contaminants.

A commercially available Computational Fluid Dynamics (CFD) tool is used for the analysis to determine the rate of deposition of contaminant on the platter. Rotational speeds of the platter and humidity factors that escalate the rate of corrosion are investigated in this study.

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NOMENCLATURE

ρ	Density (kg/m^3)
k	Thermal Conductivity ($\text{W}/(\text{m}\cdot\text{K})$)
v	Velocity (m/s)
μ	Viscosity ($\text{N}/(\text{m}^2\cdot\text{s})$)
ε	Kinematic Rate of Dissipation (m^2/s^3)
\dot{m}	Mass Flow Rate (kg/sec)
Q	Heat Load (KW)
P	Power (W)
\dot{v}	Volumetric Flow Rate (cfm)
p	Pressure (Pa)
T	Temperature (K)
C_p	Specific Heat Capacity ($\text{J}/(\text{kg}\cdot\text{K})$)
R_e	Reynolds Number
l	Characteristic Length

CHAPTER 1

INTRODUCTION

1.1 Introduction to Data centers

Data center has equipment to store, process, manage and exchange digital data and information. The IT Equipment in the data center includes the storage servers to store data and compute servers to process the data along with the network equipment. Data center also houses power conversion equipment and environmental equipment to maintain operating condition [1].

These data centers have number of servers which utilizes large amount of power and tremendous heat is generated. Factors like ambient temperature, humidity, location and solar loading play important role as thermal conditions are based on ambient conditions as well as conditions inside the data center [2].

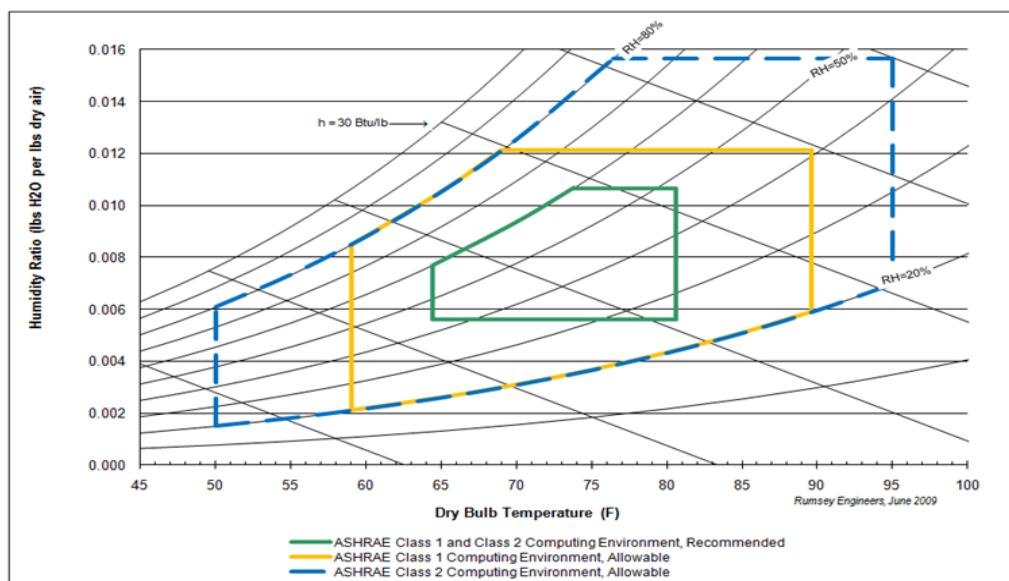


Figure 1.1: ASHRAE recommended operating conditions for data centers [3]

1.1.1 Server of the data center.

The server of the data center houses many different components, namely hard disk drive, power supply, fans, heat sinks, mother board, capacitor, VRDs, Dimms, CPU chip. It is a good practice to run the servers in class 1 and class 2 computing environment as recommended by ASHRAE.



Figure 1.2: Open compute server [4]

There are many electrical and mechanical parts in the server which are prone to fail due to several reasons. Data center operational cost increases due to frequent failures of components of the server. The design of the server itself is a reason for the failures of the components [6].

Table 1.1: Thermal specifications at server level [5].

	Server Level	Rack Level
Loading	Idle to 100%	
Inlet temperature	65°F to 95°F (35°C)	65°F to 85°F
Pressure drop within system	Intel motherboard: 0.005 to 0.24" H ₂ O AMD motherboard: 0.004 to 0.22" H ₂ O	
Total CFM requirement for above pressure levels	Intel: 12 to 103 CFM AMD: 14 to 106 CFM	Intel: 864 to 7416 CFM AMD: 252 to 1908 CFM Total: 1116 to 9324 CFM*
Fan RPM	Varies from 1120 to 7600 rpm with 10% tolerance.	
Humidity**	Approximately 30 - 65%	
Altitude	1000m (~ 3300ft)	
Dewpoint**		41.9°F minimum

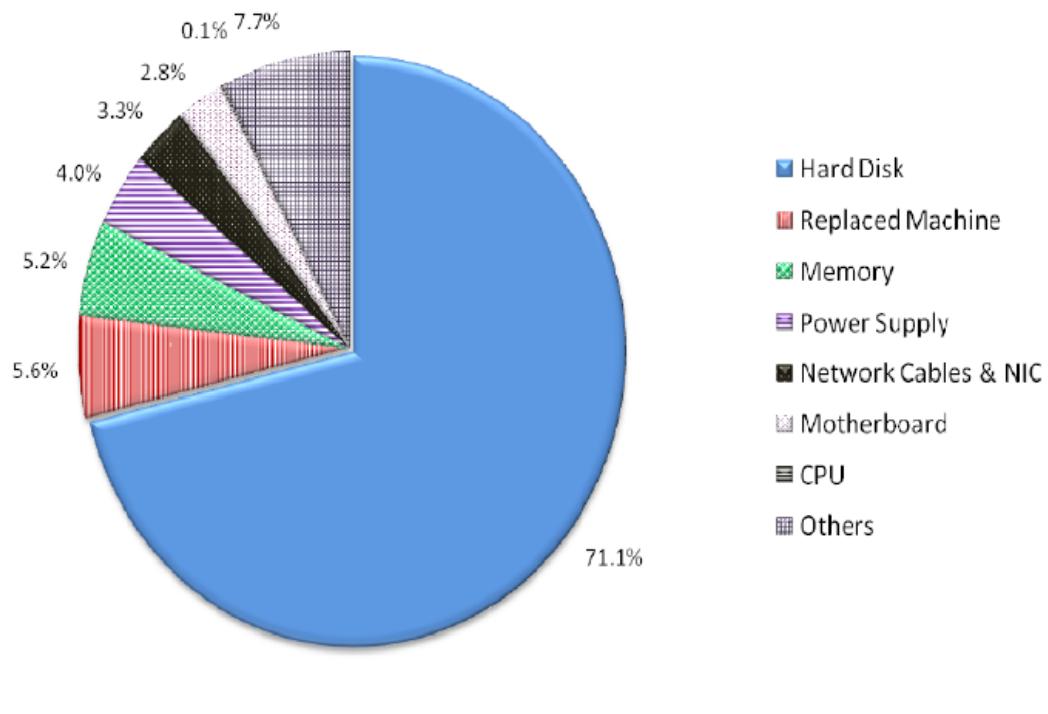


Fig 1.3: Percentage failure of hardware components of the server [6]

1.2 Introduction to Hard Disk Drive (HDD)

HDD is the largest data storage device. A hard disk drive stores digitally encoded data. In 1956 IBM introduced a HDD to store the digital data [7]. Over the period of time continues changes in HDD are made. HDD is used for storing and retrieving the data. Binary data bits are represented by the sequential changes in the magnetization. Data is read in a random-access manner. HDD stores the data even when powered off. HDD are widely used in computers, laptops and data centers for data storage. At times even more than one HDD is used in a system, the status of each HDD is provided by an indicator.

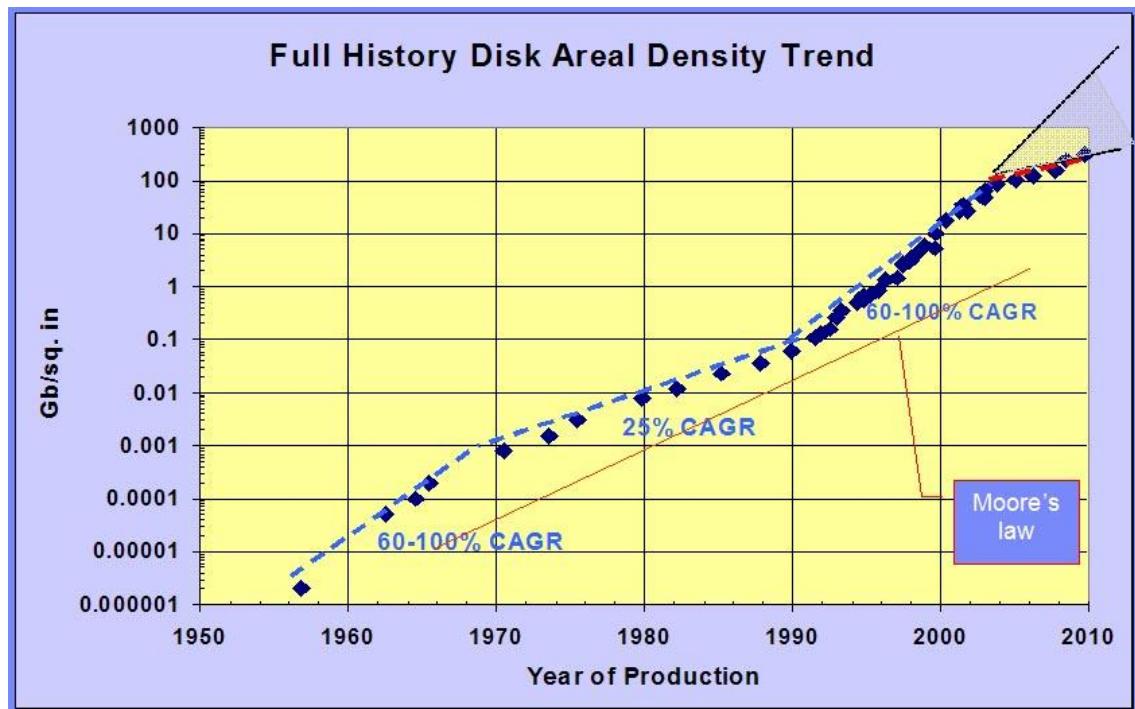


Fig 1.4: Timeline of HDD evolution [35].

A typical HDD consists of a casing, an actuator arm, actuator axis, head, spindle, platters, power connectors and jumper pins. The motherboard is connected to

the back of the hard drive through the port of cable provided at the back end of the HDD.

The HDD has the housing with the base and a cover connected to each other, a spindle motor is connected to the base and the platter rotates on the spindle with respect to the base, and an actuator rotatably connected to the base and supporting the slider with a magnetic head mounted on the front end thereof [8].

The actuator is a moving coil motor which moves the magnetic head in the desired position. The neodymium-iron-boron (NIB) magnet is supported by a metal plate and a voice coil is attached to the actuator hub and second NIB is mounted beneath this voice coil.

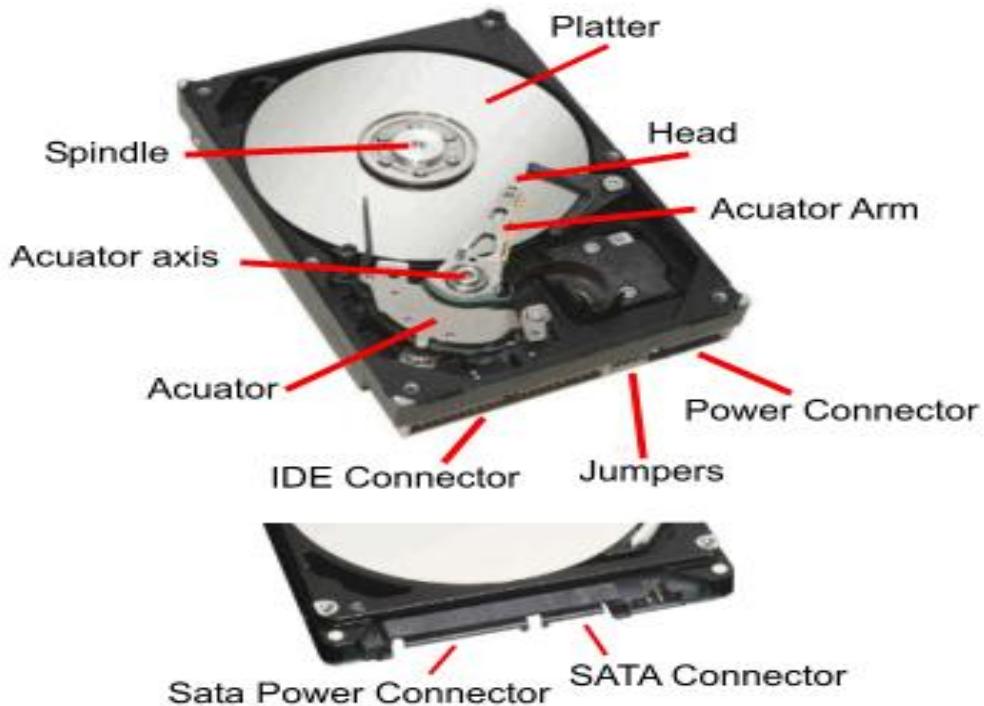


Fig 1.5: Open HDD defining the parts inside the HDD [9].

The heads of HDD fly and move radially over the surface of the spinning platters to read or write the data. The information, which is in the form of bits is converted by the heads into magnetic pulses for storing the data on the platter and reverses the process while reading [10].

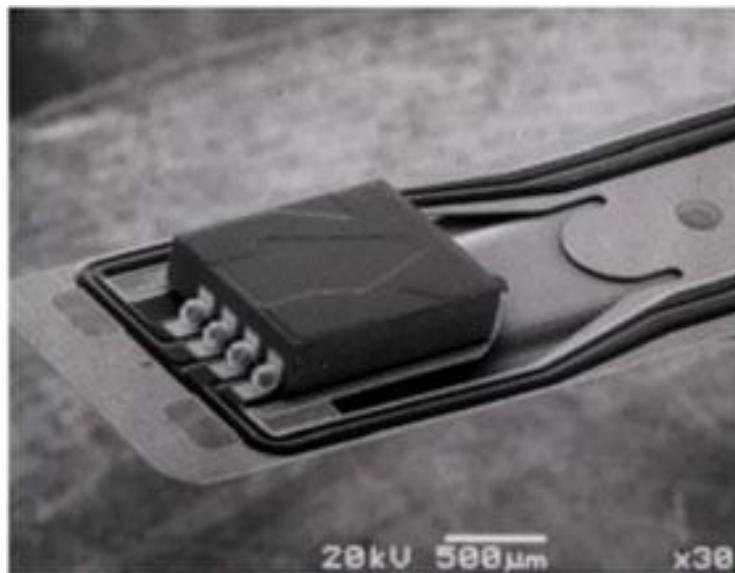


Fig 1.6: Magnetic head on actuator arm [11].

Spindle motor that turns the HDD platters, provides stable, reliable, and consistent turning power for many hours of continuous use. HDD also incorporates an intelligent circuit board, which is placed at the bottom of the base casting exposed to the outer side. The read/write heads are linked to the logic board through a flexible ribbon cable [10].

The movement of the actuator arm and the rotation of the spindle are done through the electronics controller of the HDD, which allows reading and writing on

demand from the disk controller. The feedback is accomplished through a servo feedback. The spinning of the disk also uses servo motor.

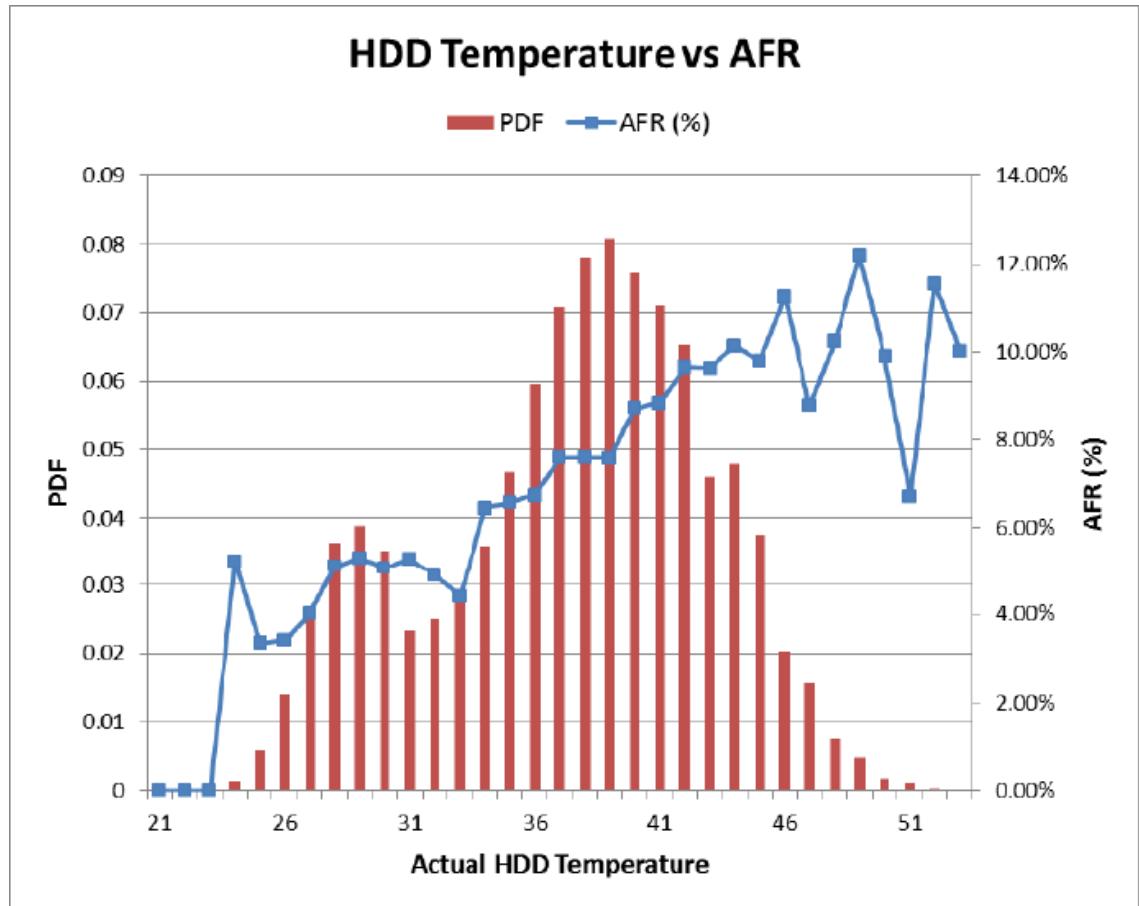


Fig 1.7: Operating temperature of HDD vs. failure rate [6]

The performance of the HDD relies on the air pressure from the outside environment for maintaining certain flying height while the platter is rotating. The pressure and contact to the environment is maintained by a small breather port. The breather port is the only place from where the outside environment can come in contact with the internal part of the HDD [12].



Fig 1.8: Working open HDD [13]

1.3 Introduction to Corrosion

Destruction of the material by reacting with the contaminants in a specific environment is called corrosion. Corrosion can occur in materials like metals, polymers and ceramics. The material is rusted when corroded releasing the ions. Corrosion mainly occurs by the exposure of the material to moisture in air. The process of corrosion is also affected by exposure to different other substances. The rate of corrosion also depends on other factors like temperature and humidity [14].

Corrosion has become a worldwide problem. Corrosion causes many problems like shutting down the plant, reducing the efficiency, loss of product, reducing the efficiency, waste of valuable resources and also reduces the technological progress.

There are different forms of corrosion depending on the pattern of the corrosion namely, Uniform corrosion, Galvanic Corrosion, Concentration Cell Corrosion, Pitting

Corrosion, Crevice Corrosion, Filiform Corrosion, Intergranular Corrosion, Stress Corrosion Cracking, Corrosion Fatigue, Fretting Corrosion, Erosion Corrosion, Dealloying, Hydrogen Damage, Corrosion in Concrete, Microbial Corrosion. Most corrosion of metals is electrochemical in nature [14].



Fig. 1.9: Effect of corrosion in pipe [16].



Fig. 1.10: Effect of corrosion in plane [16].

1.3.1 Corrosion in electronics.

The demands of electronic devices have increased significantly and so it makes it very important to maintain the reliability of the devices as changing them frequently is costly. The increased use of electronics has increased the reliability against corrosion [15].

The electronic devices have to pass from many processes from manufacturing to use that makes it more prone to corrosion. Corrosion in electronics can happen while manufacturing the device or by exposing the devices to environment while using or transporting the devices. Exposure to environment not only causes the corrosion in the devices but can also change the existing corrosion in the device that could have taken place in the manufacturing phase [15].

The combination of corrosive gas and particle deposition to the surface of the electronics cause corrosion in the electronics. The degradation of the electronic equipment is a result of electrochemical interaction of the corrosive gases and particles with the surfaces of the equipment.

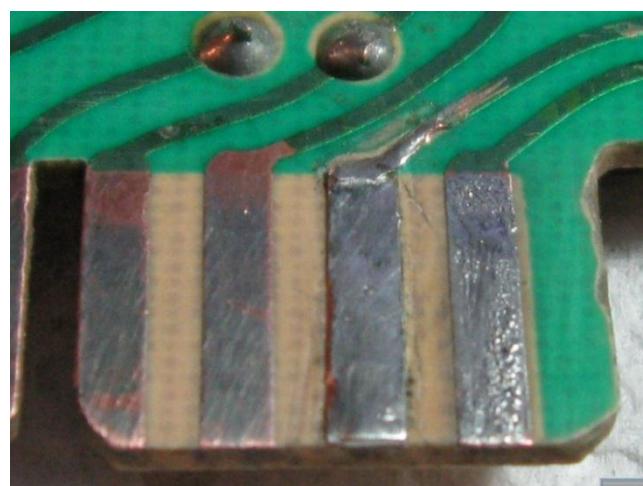


Fig 1.11: Corroded PCB [18]

Device miniaturization is also a reason for the corrosion in the electronic equipment. Gaseous agents like –Nox, Sox, O₃, H₂O₂, NH₃ along with suspended inorganic, organic acids, submicron hygroscopic ionic particles and inorganic compounds and metals in air corrode the electronic equipment [17].

1.4 Need to mitigate the corrosion in electronic equipment.

Corrosion in electronic equipment is very serious and expensive problem. The estimated damage in the electronic industry is of \$5 billion in the United States itself for equipment repairs, down time and replacement [17].

The electronic are made up of both ferrous and nonferrous metals. Chassis and support system are made up of ferrous metal whereas electron pathways are made up of nonferrous metals. Corrosion on ferrous metal is easily seen, but corrosion on nonferrous metal is rarely seen.

The intermittent defects in the electronics due to corrosion don't allow the product to work and the failure cannot be replicated. The product reacts differently under different atmospheric conditions. Increase in the electrostatic charge may blow up the circuit.

Increase in rate of corrosion results in slow deterioration, which poses threat with unpredictable consequences. Loss of 1 Pico gram of material in electronic equipment fails that equipment.

Taking into consideration the factors mentioned above it is very important to come up with the technologies and improvement in the present technologies to mitigate corrosion in electronic equipment.

1.5 Need for CFD analyses

The surface deposition rate of the contaminant can be determined using Ansys fluent. The factor affecting the deposition rate can be accounted in the CFD modeling. CFD model helps in predicting the compatibility of the design. These predictions may be determined experimentally. But, experimental testing consumes time and is expensive. This gap is bridged by extensive use of CFD software which gives us the versatility and precision in virtually simulating a test setup [2]. The focus of this study is to develop a detailed model of surface deposition of the contaminant in the HDD.

CHAPTER 2

GASEOUS CORROSION/ MOTIVATION

2.1 Introduction to gaseous corrosion

. Gaseous and particulate contaminants are responsible for corrosion in HDD.

Gaseous and particulate contaminants are identified by their size. Contaminants below 0.5 μm are gaseous contaminants whereas contaminants between 0.5 μm to 1.0 μm are particulate contaminants as specified by AHSRAE.

The types of gases that majorly cause corrosion are acidic gases such as hydrogen sulfide, sulfur and nitrogen oxides, chlorine, and hydrogen fluoride; caustic gases, such as ammonia; and oxidizing gases, such as ozone. Out of the three, acidic gases are of particular interest. Relative humidity triggers the rate of corrosion. ASHRAE suggests preferable the relative humidity be 50-60% to avoid excessive corrosion rate.

Sulphur bearing gases like SO_2 (Sulphur Dioxide) and H_2S (Hydrogen Sulfide), the major gaseous contaminants, are not directly responsible for corrosion but in fact with the combination of NO_2 (Nitrogen Oxide), O_3 (Ozone) are making it more corrosive.

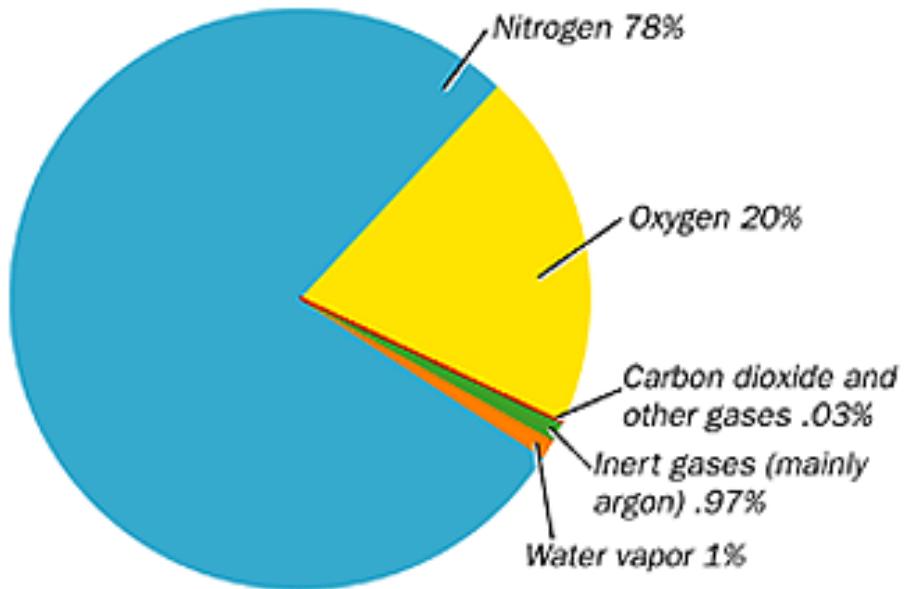


Fig 2.1: Percentage composition of air [19]

Table 2.1: List of gases present in air [20].

Constituent	Chemical symbol	Mole percent
Nitrogen	N ₂	78.084
Oxygen	O ₂	20.947
Argon	Ar	0.934
Carbon dioxide	CO ₂	0.0350
Neon	Ne	0.001818
Helium	He	0.000524
Methane	CH ₄	0.00017
Krypton	Kr	0.000114
Hydrogen	H ₂	0.000053
Nitrous oxide	N ₂ O	0.000031
Xenon	Xe	0.0000087
Carbon monoxide	CO	trace to 0.000025
Sulfur dioxide	SO ₂	trace to 0.00001
Nitrogen dioxide	NO ₂	trace to 0.000002
Ammonia	NH ₃	trace to 0.000003

2.2 Corrosion in HDD

Corrosion in any part of the HDD fails or reduces the performance of the HDD. Corrosion causes the failure of the mechanical parts inside the HDD which might result into major problems by colliding with other parts in the HDD. The eruption of any part may also result into particulate corrosion. The platter in the HDD stores the data; any damage in the platter causes the loss of the data.

2.2.1 Platter (rotating disk) of HDD.

Platter is very important part in HDD as it stores the data but it is one of the most prone parts of HDD to corrode. A platter is made up of non-magnetic material, aluminum, glass or ceramic [26]. Widely, aluminum is used to make a platter as aluminum is very rigid, light weighted and inexpensive. Both the sides of substrate are coated through magnetron sputtering which is covered by the magnetic material and also by a thin film of carbon as a protective layer against corrosion. There are few more layers on the platter with varying thickness of each layer, the top most layer is the lubricant which is 1-2nm thick, than is the overcoat 5-7 nm of thickness beneath is the magnetic layer which is about 15.25 nm in thickness, than is the under layer about 5-10 nm and the last is the substrate which is 1 mm thick [22].

When gaseous contaminants come in contact with the platter after destroying the carbon film, the magnetic layer starts corroding as the Co based magnetic layer doesn't have mechanical durability and corrosion resistivity. Air enters the HDD through the breather port when the HDD is powered on. Contaminants come in contact with the parts of HDD using air as a media [12].

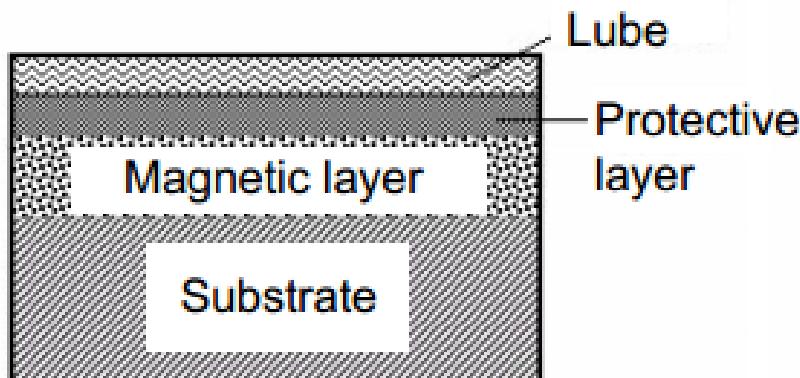


Fig 2.2: Cross-sectional structure of the HDD platter [21]

Platter is made very smooth, durable with perfect finishing as the flying head fly and move radially above the surface of the spinning platters to read and write the data.

Table 2.2: List of gaseous contaminants [23].

Gaseous matter (<0.5μm)	Source	Effect on equipment	Average species seen in Data center
Cl		Corrode power and cooling equipment	0.001ppm
H ₂ S			0.01ppm
SO ₂	Gases coming from Volcanic + air	Silver metallization	0.05ppm

Table 2.2- Continued

NO_2		Catalytic converters on automobiles in environment.	0.05ppm
Hydro Carbon	sedimentary basins		0.24 $\mu\text{g}/ \text{m}^3$
O_3	Exhaust emissions from automobiles and pollution from factories.	When comes in contact with silver blackens resulting in oxidation.	
NH_3	fossil fuel use, industry, and oceans	Readily absorbs moisture and has alkaline properties and so is corrosive.	



Fig 2.3: Corroded platter in HDD [24]

According to the study carried out by Robert J. Waltman and Andrei Khurshudov, by using atomic force microscopy for a seven day test, when slider comes in contact with the disk surface, mechanical wear takes place on both the disk and slider surfaces. Fig 2.4 shows that the 40 \AA carbon film on the slider is worn away within 2 days with the wear rate decreasing significantly thereafter. The figure also shows that after 2 days, the contact surface of the slider no longer has the protective carbon film [25].

According to the study the number of spots of corrosion is seen less with increasing the thickness of the lubricant layer. The number of spots of corrosion increases when the thickness of carbon film reduces from $\sim 50 \text{ \AA}$.

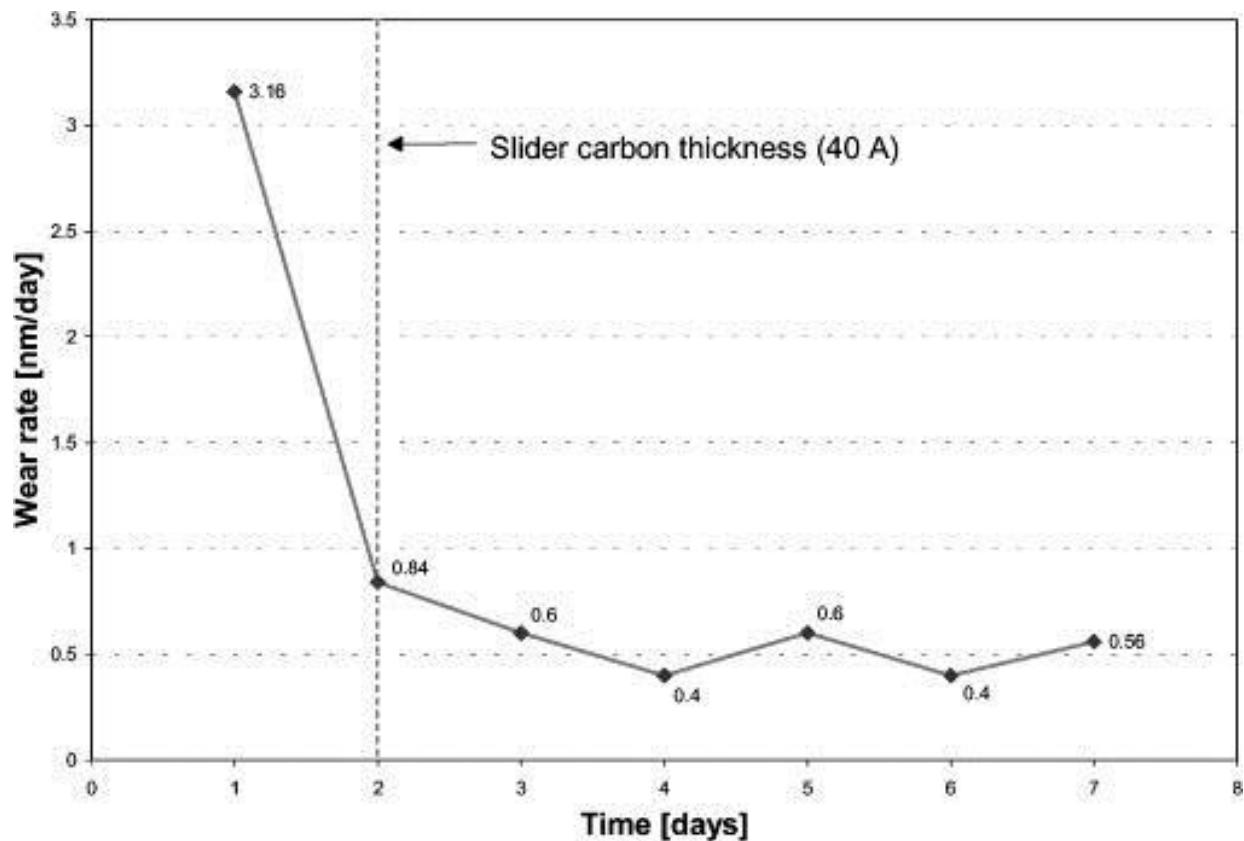


Fig. 2.4: Wear rate of platter vs. days graph [25].

Usually, the spots of corrosion are noticed at the head-disk interfaces, affecting the tribological reliability.

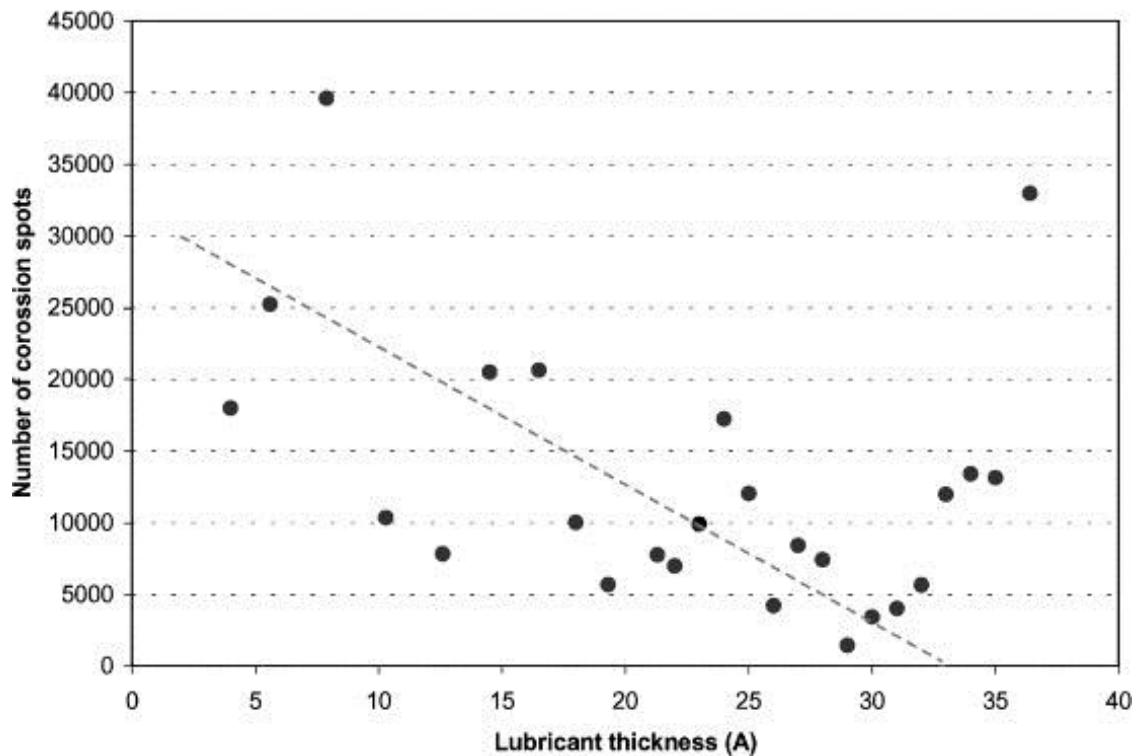


Fig 2.5: Corrosion spots vs. lubricant thickness graph [25]

2.3 Surface Chemistry on the platter

The rotating platter and the magnetic head comes in contact for writing and reading the data to/from the platter which leads to wearing of the platter surface. Thermal stiction and thermal asperity creates a small explosion on the surface of the platter which leads to leaching of the layers of the platter. Due to the leaching the cracks are formed on the surface of the platter which allows the gases and the humidity to further penetrate and cause the corrosion more intensively. Presence of water molecule in the carbon overcoat leads to leaching of the Co from the magnetic layer and through the electrochemical reaction the Co ions are precipitated in water soluble Co(OH)_2 and CoO in the presence of oxygen. Formation of sulfate corrodes the platter.

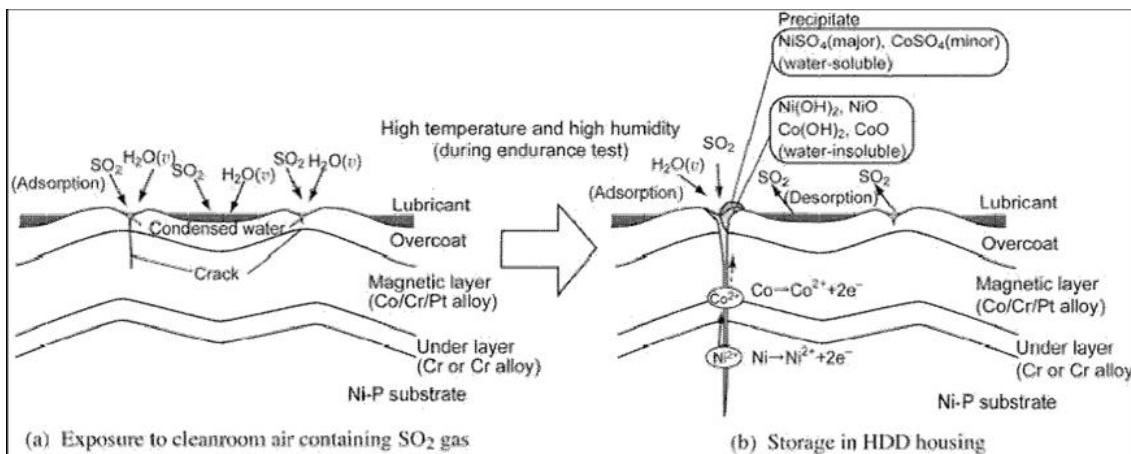


Fig 2.6: Surface reaction on the platter [22].

When sulphur Dioxide (SO_2) comes in contact, it leads the preferential adsorption of water and SO_2 to lubricating molecules. In presence of high temperature and humidity, water advances the corrosion to the magnetic layer. Sulfate is formed due to the surface reaction in presence of SO_2 and water resulting into corrosion.

Depending on the surface chemistry the following balanced surface reaction for corrosion of cobalt is designed, that produces cobalt sulfate.



2.4 Motivation

Corrosion in electronic equipment is a very serious and expensive problem.

The intermittent defects in electronics due to corrosion don't allow the product to work efficiently.

There is limited understanding on the dependency of deposition rate on humidity and subsequently corrosion. In this thesis a methodology has been discussed that's develops a better understanding of corrosion in HDD.

CHAPTER 3

Design the HDD

3.1 Geometry of the HDD

For designing the geometry of the HDD, the software Pro E is used. Pro E takes into consideration the parameters, dimensions, features, and relationships to capture intended product behavior. Pro E offers tools to enable the generation of a complete digital representation of the product and also has the ability to generate geometry of other integrated design disciplines. The geometry was then imported into Ansys.

3.2 Specifications of the geometry.

For the simplification of the CFD simulation every single part of the HDD is not designed. As mentioned previously the present study is focused on the rate of deposition of the contaminants on the rotating disk, the present geometry includes a rotating disk, and spindle, and an actuator arm mounted on the actuator axis along with the magnetic head mounted on the actuator arm.

3.2.1 Case.

The outer case houses the actuator arm assembly, along with the platter and the spindle on which the platter is mounted.

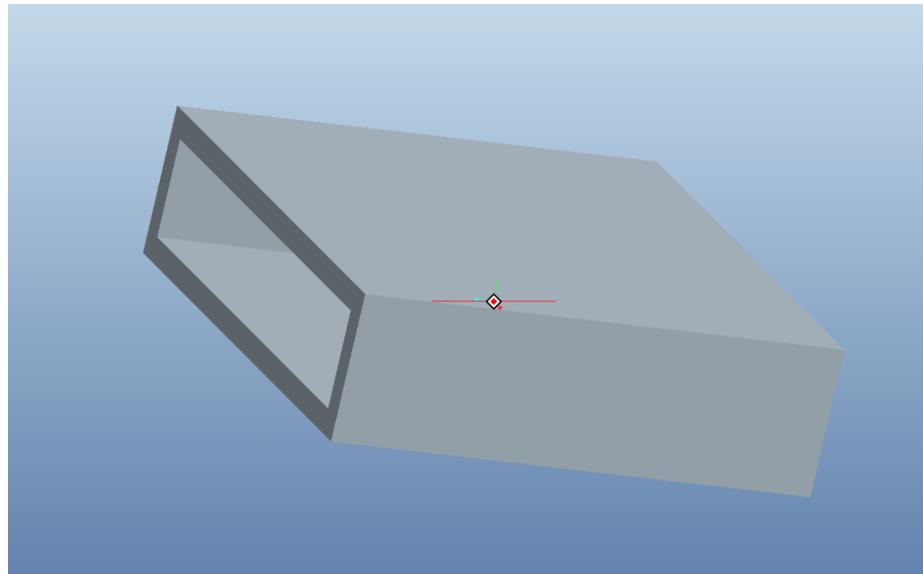


Fig 3.1: Designed case

3.2.2 Actuator Arm.

There are two actuator arms in the HDD, one is above the platter and the other one is beneath the platter. Each actuator arm carries one magnetic head.

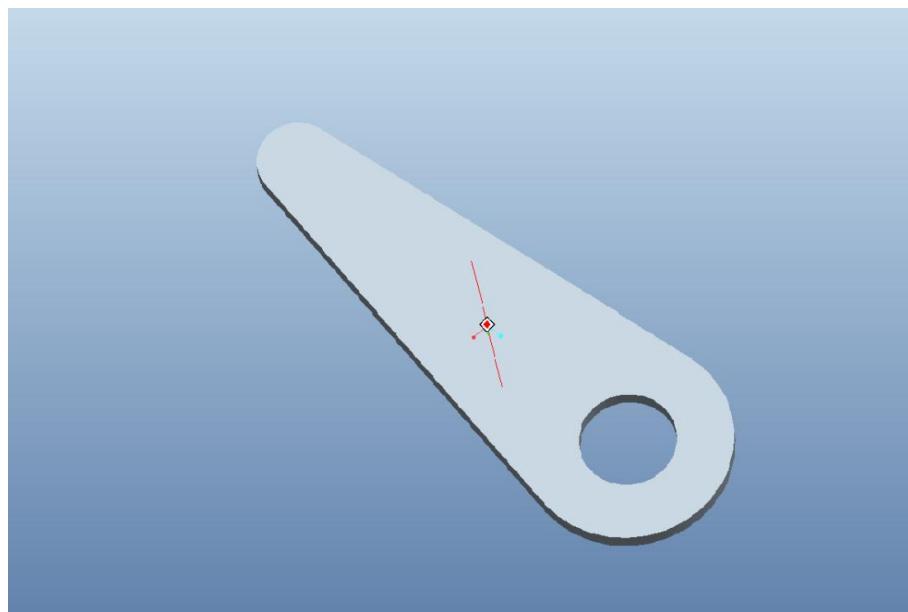


Fig 3.2: Designed actuator arm

3.2.3 Spindle for the actuator arm.

The actuator arms are mounted on the spindle and rotate according to the rotation of the spindle.

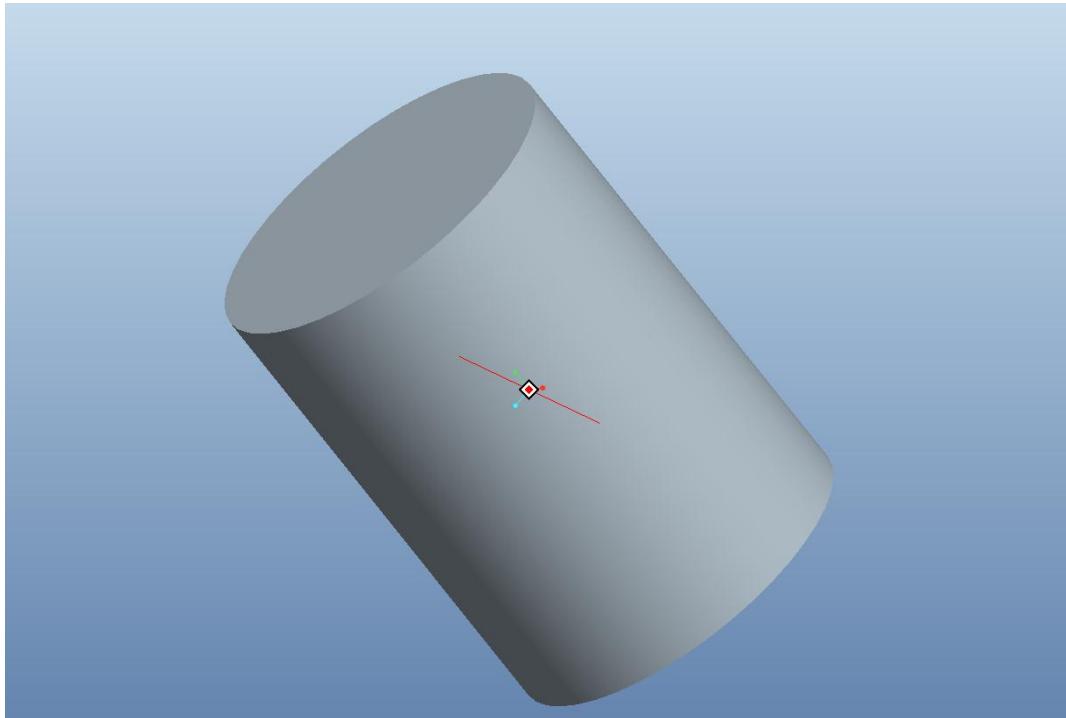


Fig 3.3: Designed spindle for the actuator arm

3.2.4 Magnetic head.

In the actuator assemble there are two magnetic heads, each on one actuator arm to perform the reading and writing on/from the rotating platter.

3.2.5 Platter.

The rotating platter rotates between the actuator arms. The outer diameter of the platter is 6 mm and the inner diameter is 1 mm. The thickness of the platter is 0.5 mm.

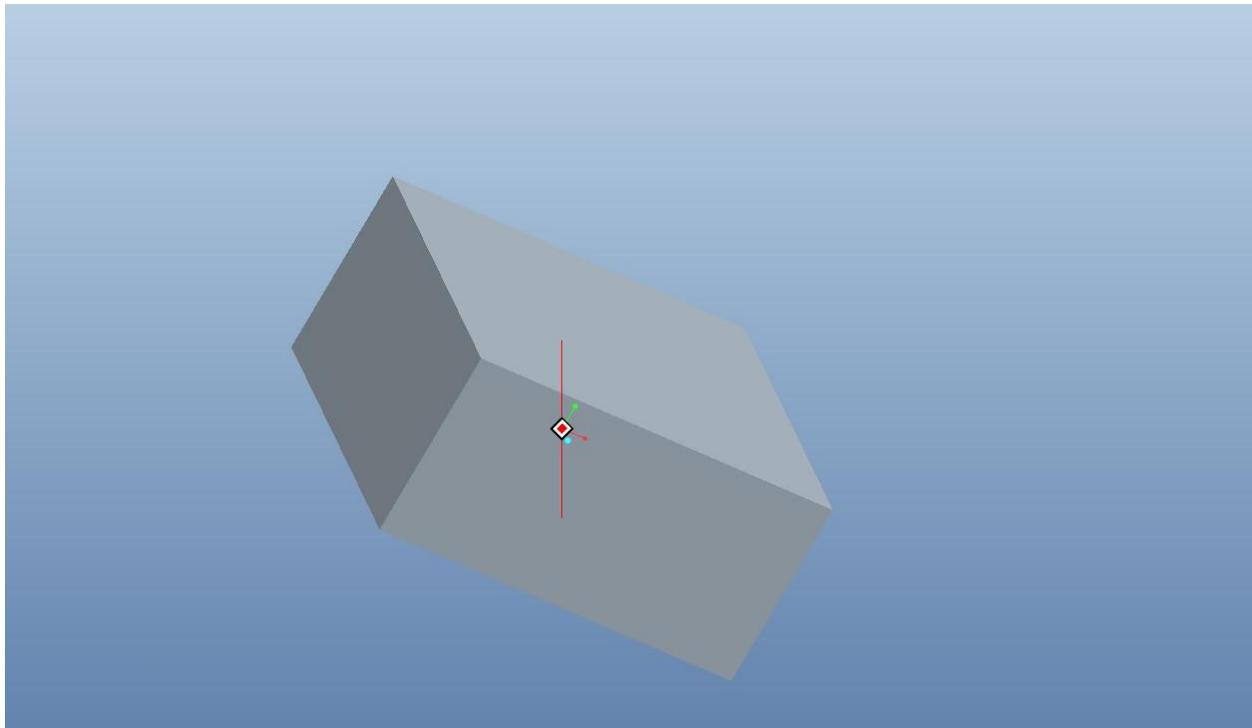


Fig 3.4: Designed head

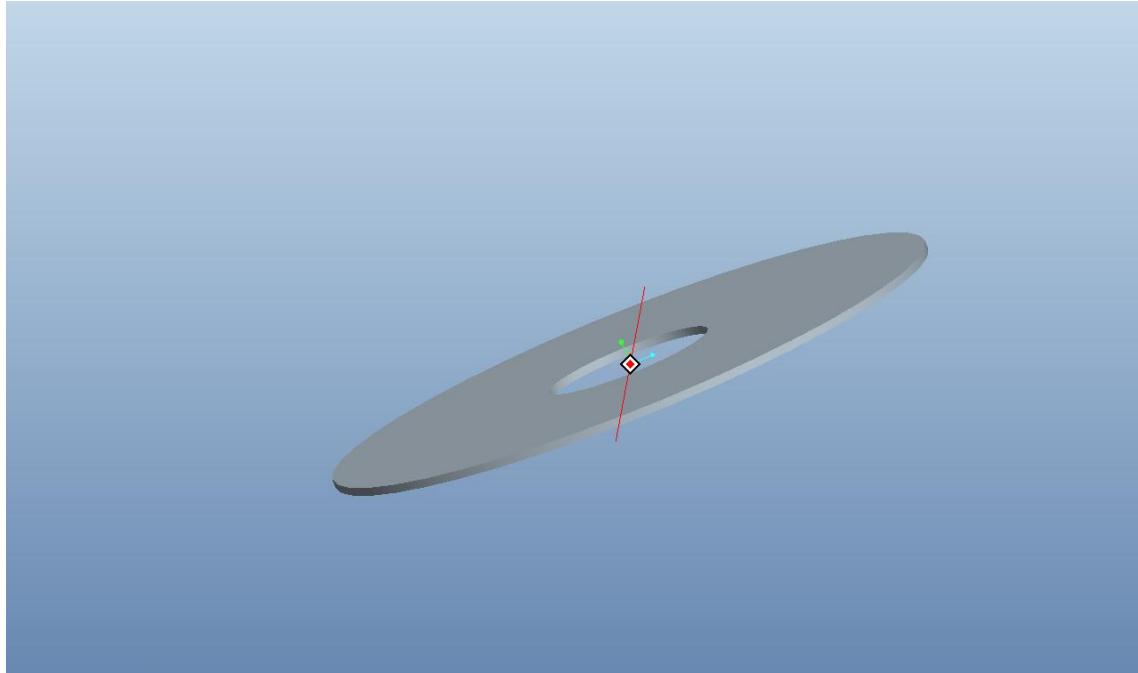


Fig 3.5: Designed platter.

3.2.6 Spindle for the platter.

The platter is mounted on the spindle and the rotation of the platter depends on the rotation of this spindle. The diameter of the spindle is 1 mm.

3.2.7 Breather Port

At the bottom of the case a breather port is provided through which the atmosphere communicates to the HDD. For the CFD simulation inlet and outlet needs to be specified, for which reason the breather port is divided into two halves where one half serves as inlet and the second half serves as outlet

3.2.8 Assembly.

All the parts mentioned above are assembled to give a complete geometry for the CFD simulation.

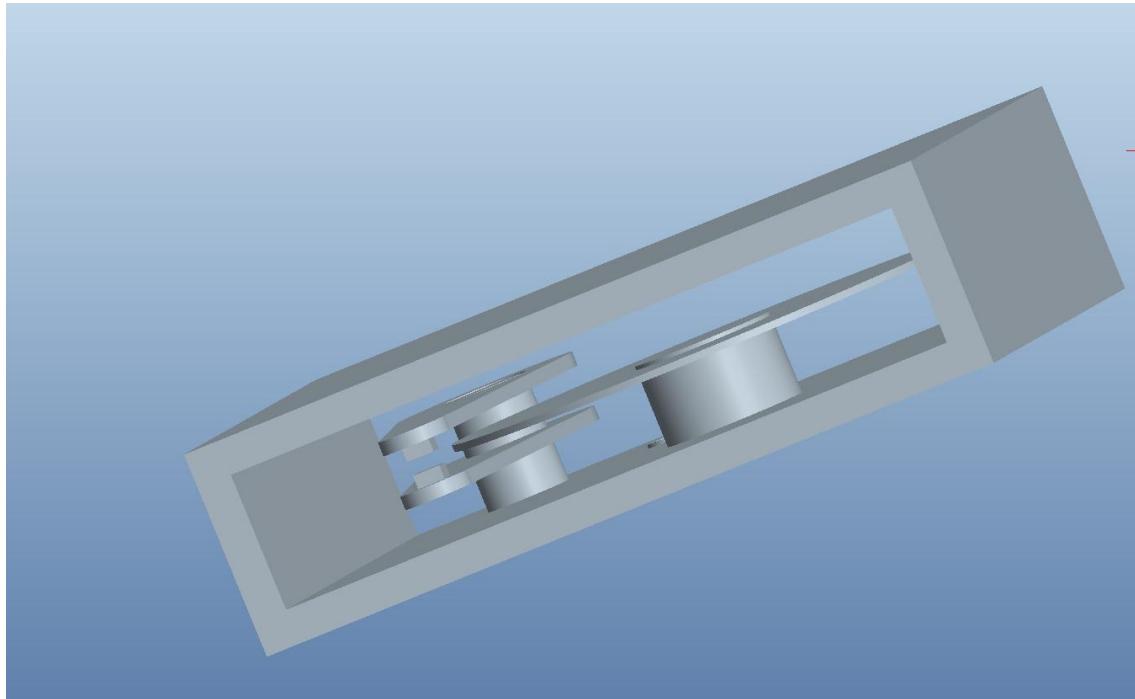


Fig 3.6: Designed assembly.

CHAPTER 4

Computational Fluid Dynamics (CFD) Analysis

4.1 Introduction to CFD

CFD deals with the numerical simulation and analysis of fluid flow, heat transfer characteristics and pressure characteristics. Computational fluid dynamics uses numerical methods to predict, simulate and analyze distribution of velocity, pressure, temperature and other variables throughout the calculation domain. The calculations in CFD are based on the boundary conditions and the calculations are done in a computer. CFD is used for various applications such as data center industries, systems with high heat loads, telecommunication industry, and several more [2].

CFD is a bridge between pure theory and pure experiment. CFD discretize the problem based on the numerical parameters to solve the problem. Experimental work is costlier than CFD. When compared to conducting an experiment, CFD is very fast as we can simulate many cases in specific time period. A numerical prediction is used for the generation of a mathematical model which represents the physical domain of interest to be solved and analyzed [2].

4.2 Governing Equations

The four differential equations namely conservation of mass, conservation of momentum, conservation of energy and conservation of chemical species commonly

known as governing equations are used to solve the numerical solution for heat transfer and fluid flow based problems.

The conservation of mass is given by:

$$\frac{\partial \rho}{\partial x} + \nabla \cdot (\rho u) = 0$$

The conservation of momentum is given by:

$$\frac{\partial}{\partial t}(\rho u) + \nabla \cdot (\rho uu) = \nabla \cdot (\mu \text{grad } u) - \frac{\partial p}{\partial x} + B_x + V_x$$

The conservation of energy is given by:

$$\nabla \cdot (\rho uh) = \nabla \cdot (k \text{grad } T) + S_h$$

The conservation for chemical species is given by:

$$\frac{\partial}{\partial t}(\rho Y_i) + \nabla \cdot (\rho \vec{V} Y_i) = -\nabla \cdot J_i + R_i + S_i$$

4.3 Global Computational Domain

The governing equations are solved in the computational domain. The control volume is defined as the closed volume within a finite region of flow. The boundary conditions for the solution domain are fixed to obtain the solution of the equations. The boundary conditions are ambient temperature, mass flow at inlet and outlet, fluid viscosity, density, velocity, pressure, and other environmental conditions. The major steps in CFD is defining the geometry of the problem, dividing the volume into discrete cells also called as meshing, applying boundary conditions and finally solving the governing equations [2].

In the present study the tool Ansys Fluent is used for its capability of solving the species transport reaction and very well defined post processing. Mixing and

transportation of the chemical species can be solved by Ansys Fluent by solving the conservation equations. Chemical species reaction and mixing along with surface deposition/ reaction models are present in Ansys Fluent. Free surface and multiphase models for gas-liquid, gas-solid, and liquid-solid flows, steady-state and transient flows, Inviscid, laminar and turbulent flows, ideal and real gases, convection, radiation and heat transfer are few more capabilities of the Ansys Fluent.

4.4 Turbulence Modeling

The type of the flow can be laminar, transient or turbulent depending on the Reynolds number. Turbulent flow is defined as a flow regime characterized by irregular fluctuations in all directions [28].

- laminar when $Re < 2300$
- transient when $2300 < Re < 4000$
- turbulent when $4000 < Re$

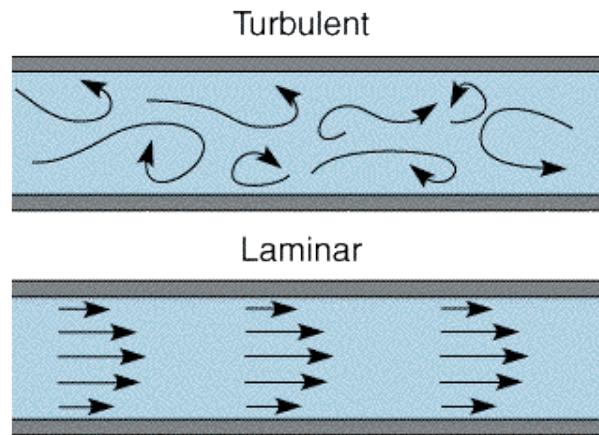


Figure 4.1: Graphical representation of laminar vs. turbulent flow [33]

4.4.1 K-Epsilon Turbulence Model

K-Epsilon turbulence model is also commonly known as two equation model and is widely used for turbulent flow modeling. This model solves using two variables, the kinetic energy of turbulence (k) and the dissipation rate of kinetic energy of turbulence (ε). Two transport equations namely Kinetic energy of turbulence (k) and the dissipation rate of kinetic energy of turbulence are solved [29]. In the present study K-Epsilon turbulence model is used.

The following are the transport equations [30]:

$$\frac{\partial(\rho k)}{\partial t} + \frac{\partial \rho k u_i}{\partial x_i} = \frac{\partial}{\partial x_i} \left[\left(\mu + \frac{\mu_t}{\sigma_k} \right) \frac{\partial k}{\partial x_i} \right] + G_k + G_b - \rho \varepsilon$$
$$\frac{\partial(\rho \varepsilon)}{\partial t} + \frac{\partial \rho \varepsilon u_i}{\partial x_i} = \frac{\partial}{\partial x_i} \left[\left(\mu + \frac{\mu_t}{\sigma_k} \right) \frac{\partial \varepsilon}{\partial x_i} \right] + C_{1s} \frac{\varepsilon}{k} (G_k + C_{3s} G_b) - C_{2s} \rho \frac{\varepsilon^2}{k}$$

4.5 Modeling of the HDD

The geometry of the HDD is imported in Ansys for the simulation purpose. The HDD is meshed in Ansys. For the accuracy of the converged solution many parameters are taken care of while meshing the geometry. Ansys Fluent uses unstructured meshes in order to enable more complex geometries compared to conventional, multi-block structured meshes. Ansys Fluent is capable of handling triangular, quadrilateral, tetrahedral, hexahedral, pyramid, wedge, and polyhedral elements. The maximum cell skewness of the mesh is maintained below 0.98 for better solution [31] as a rule of thumb.

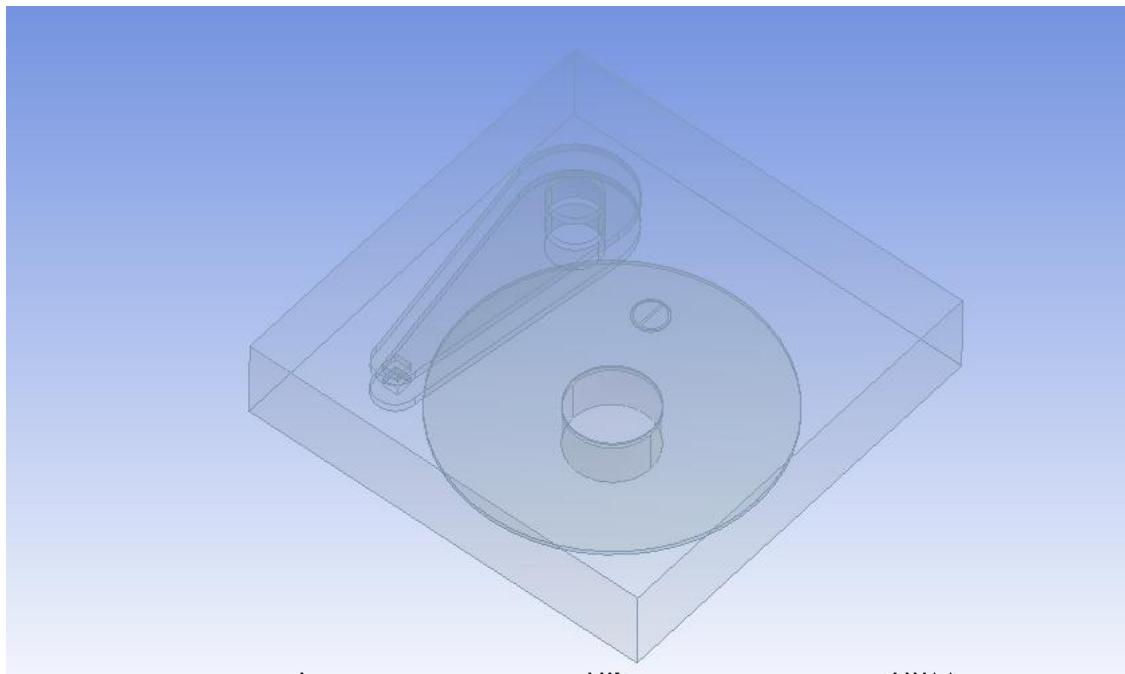


Fig 4.2: Designed HDD in Ansys Fluent.

In the present geometry the numbers of elements are 4.5 million, 91194 nodes are present, maximum skewness is 0.94 and the average aspect ratio is 1.85. Tetrahedral mesh is used.

It is very important for accurate solution to have a proper mesh, for the reason while starting the simulation it is necessary to check the mesh and maintain the right scale units for the mesh.

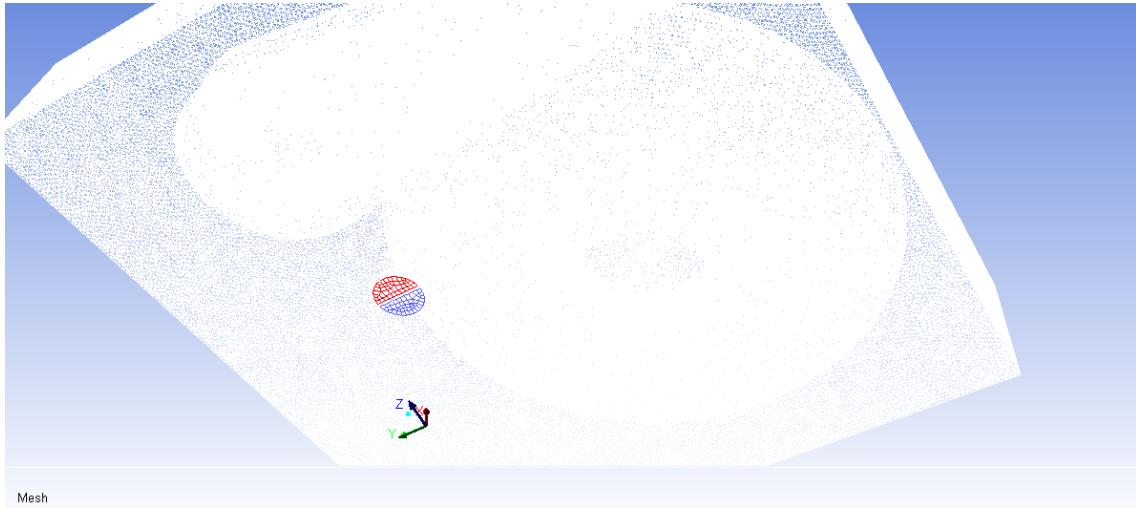


Fig 4.3: Meshed HDD

4.6 Solution setup

4.6.1. Solver

In both, Density based solver and Pressure based solver momentum equations are used to get the velocity field. Controlled volume based technique is used in both the solvers. The governing integral equations for conservation of mass and momentum, energy and scalars are solved by both the solvers. Algorithm that belongs to projection method is employed by the pressure-based solver. The density based solver solves the governing equations simultaneously [27].

A decoupled chemistry calculation starts from converged steady-state solution. The solution can be obtained from models like species transport, non-premixed, partially-premixed. The premixed combustion model, valid for turbulent, subsonic flows is available with the pressure based solver. For the present case steady state pressure based solver is used.

4.6.2. Solution model

In the chemical species model energy is turned on as the energy is employed for the species reaction to take place. For the flow type as K-Epsilon turbulent model is chosen. The species transport model is activated. The local mass fraction of each species is predicted by Ansys Fluent, by taking into consideration the convection diffusion equation for the specie. The mass fraction of the species must be unity, for which reason the Nth mass fraction is determined as one minus the sum of the N-1 solved mass fraction. The Nth specie is the one in abundance so it's chosen last [27]. Several elementary physic-chemical processes like chemical reaction and adsorption of gas-phase species on the surface, adsorption of gases from the surface back to the gas phase takes place while modeling the reaction.

The reaction rate of gas-phase reaction is based on basis of volumetric and rate of destruction and creation of chemical species in the species conservation equation. The source and sink of the chemical species in gas phase as well as on the reacting surface is created by wall surface reactions. The rate of adsorption and desorption in surface reaction is governed by the chemical kinetics and diffusion to and from the surface [31].

There is certain loss of mass due to the deposition reaction of the specie for which the mass reaction is enabled in the model. The robustness and the convergence speed is controlled by the aggressiveness factor, by varying the value between 0 to 1, where 0 is most robust resulting in slow convergence. The effect of the enthalpy transport due to the species diffusion in the energy equation is accounted by the diffusion the diffusion energy source contributing to energy balance for the case of Lewis numbers far from the unity. Stefan-Maxwell equation is activated by the Full Multicomponent Diffusion, which computes the diffusive fluxes of all

species in the mixture to all concentration gradients. Heavy molecules are diffused less rapidly and light molecules are diffused more rapidly toward heated surfaces by Thermal Diffusion.

4.6.3. Material properties.

Every species involved in the reaction has to be defined for Ansys Fluent to take into consideration while simulating the reaction. Properties for the mixture material and also for its constituent species are to be defined. The species involved in the reaction has to be defined as fluid material. The mixture material is the set of the species involved in the reaction and the list of rules governing their interaction. The mixture material consists of the constituent species defined as fluid materials, along with the physical properties like density, viscosity, specific heat, etc. It also has the diffusion coefficients for individual species in the mixture. Many common mixture materials are stored in the Ansys Fluent data base, but if the desired mixture material is not present in the data base it can be defined [31].

For the present study the mixture materials is defined along with the properties of the materials that are not stored in the Ansys Fluent Data base. For the present case the chemical reaction used is:



The material properties of H_2O , SO_2 and H_2 are copied from the Fluent Data Base where as the properties of CoSO_4 and CoO is defined. Cobalt is not defined as the fluid material instead it is defined as the solid as platter is solid.

In the present study few properties are defined as Kinetic Theory as the ideal gas law is enabled. By choosing the Kinetic Theory the Ansys Fluent compute using the empirically based expression and no further inputs are needed. The Characteristic length and Energy parameters have to be defines when using Kinetic theory along with Degrees of freedom if required.

The species defined are divided into broad categories depending on their role in the reaction. The categories in which they are divided are gas-phase specie, the site specie and the solid specie. The gas phase species include all the gases involved in the reaction no matter whether as the source or as the product, the site specie includes the sites involved in the reaction and the solid species are the one that usually deposits. For the present study H₂, H₂O and SO₂ are defined as the gas-phase species, CoO is defined as the site specie and CoSO₄ is defined as the solid specie. The Characteristic length and Energy parameters for the solid materials are always 0 and also the degree of freedom is 0. The entropy and enthalpy are defined according to nature of the reaction.

Table 4.1: Material specifications of the species [32]

Name	Cobalt oxide	Cobalt sulfate	Hydrogen	Humidity	Sulphur dioxide	Cobalt
Type of species	Site	Solid	Gas-phase	Gas-phase	Gas-phase	
Chemical formula	CoO	CoSO ₄	H ₂	H ₂ O	SO ₂	Co
Density(kg/m3)	6440	3710	0.08189	-	2.77	8862
Specific heat(j/kg-k)	123.4	123.4	Kinetic theory	Kinetic theory	Kinetic theory	420
Thermal Conductivity(w/m-k)	0.16	Kinetic theory	Kinetic theory	Kinetic theory	Kinetic theory	100
Viscosity(kg/m-s)	2.1e-05	Kinetic theory	Kinetic theory	Kinetic theory	Kinetic theory	-
Molecular weight(kg/kmol)	74.93	154.99	2.01594	18.01534	64.0648	-

Table 4.1- Continued

Standard state enthalpy(j/kgmol)	-237.9	-888.3	0	-2.41e+08	-2.96e+08	-
Standard state entropy(j/kgmol-k)	53	118	130579.1	188696.4	248098.3	-
Reference temperature(K)	298.15	298.15	298.15	298.15	298.15	-
L-J Characteristic length(angstrom)	-	0	2.92	2.605	4	-
L-J parameter(K)	-	0	38	572.4	100	-
Degree of freedom	-	-	5	18	8	-

4.6.4. Reaction.

The reactions in which the defined species participate are to be created in the Ansys Fluent. Through the solution of the convection-diffusion equation, local mass fraction of each species is predicted by Ansys FLUENT. After creating the reaction the modifications can be done taking care of the reaction mechanics. The set of reactions, including the reaction type, stoichiometry and rate constants are defined in the mixture materials. The sources and sinks of the chemical species in the gas-phase and the reacting surface are defined through wall surface reactions. The source term is the rate of creation and destruction of the species in the conservation equation. Diffusion to and from the surface along with the chemical kinetics governs rate of adsorption and desorption. The rate of reaction is defined on a volumetric basis [31].

Multiple numbers of reactions can be defined in the reaction drop down dialog box. Every reaction has an individual ID to identify. The reactions can be defined as volumetric, wall

surface or particle surface. For the present case the reaction is wall surface type. Total number of reactants and products are defined. For the present case there are three reactants, namely, Cobalt Oxide, Humidity and Sulphur Dioxide and two products namely Cobalt Sulfate and Hydrogen depending on the equation defined previously. The stoichiometry of the species involved in the reaction, either reactant or product is non-zero. Arrhenius expression is used to compute the forward rate constant with help of inputting pre-exponential factor, temperature exponent, activation energy and universal gas constant.

4.6.5. Cell zone and Boundary conditions.

Cell zone consists of fluids and solids. Ansys FLUENT allows solving the problems involving moving parts. The zone type of every zone has to be checked or re-defined if needed before setting up any cell zone or boundary conditions. The flow around the moving part plays interesting role. The flow around the moving parts can be modeled as a steady state problem with respect to moving frame. Moving parts such as rotating blades, moving walls, impellers can be modeled in Ansys Fluent. In cell zones after the moving reference frame is activated, the equations of the motion are modified to incorporate the additional acceleration terms which occur due to the transformation from the stationary to the moving reference frame. The entire computational domain can be referred as one single moving reference frame. Two formulations are to be addressed when using moving reference frame, namely absolute velocity formulation and relative velocity formulation which appears in momentum equation. Every zone is associated with the boundary condition. The cell zone and boundary conditions can be copied to other similar zones [27].

All the active equations are solved in fluid zone. Type of fluid material is defined for the fluid zone. An appropriate material property has to be assigned to the fluid zone. For species transportation the material can be specified as mixture or a fluid. The care should be taken that the fluid zone should not be contiguous. Ansys Fluent allows setting source or fixed values of scalar quantities. The reaction option can be turned on and the reaction mechanism can be selected for modeling the species transport with reaction [27].

Boundary conditions need to be defined for inlets and outlets, walls, pole and internal face. Different parameters can be defined in the inlet boundary condition;

The gradients are selected for better convergence of the results. Along with the gradients discretization scheme is to be selected in Solution method task page. Second order accuracy is chosen as it gives better result for the species transport reactions. Taylor series expansion is used for second order upwind scheme. Velocity boundary condition can be defined, stating the inlet velocity of the fluid, velocity specification method, reference frame and the initial pressure at the inlet. The inlet temperature of the fluid can be defined. The mole fraction of the gas species selected previously can be defined in the inlet boundary condition depending on the role they play in the reaction mechanics. For the present case the mole fraction of sulphur dioxide and water is specified depending on the relative humidity percentage involved in the reaction. Saturation temperature table is used to derive the mole fraction of the inlet species at a specified 301.15 K inlet temperature. The inlet velocity in the present case is fixed to 0.7 m/s and the inlet pressure is 20 Pa. The static pressure at the flow outlets and other scalar conditions are defined by the pressure outlet boundary conditions. The flow velocity and pressure at the outlet are not known prior to the simulation so they cannot be specified in the outlet boundary condition dropdown box. The specific loss coefficient and ambient static

pressure and temperature at the outlet vent are modeled by the outlet vent boundary conditions. Turbulent parameters can be defined in the inlet and outlet boundary condition dropdown box [27].

Boundary conditions for the pre-defined walls are also to be defined. For rotating boundary condition the rotational axis origin and rotational axis direction are to be defined along with the rotational speed. The thermal parameter has to be defined along with the reaction if the reaction is to be simulated on the particular wall. For the present case the reaction is enabled on the platter in the boundary condition dialogue box and the rotational speed of the platter and the spindle is mentioned along with the thermal parameters of the fluid. The rotational axis origin and the rotational axis direction are also specified. The gravitational force direction is specified on the axis in the operational condition dropdown box along with the operational pressure and the operational temperature is fixed to 328.15 K.

4.7 Solution parameters

A well-defined solution technique is employed to obtain a converged solution as there is high degree of coupling between the momentum equations due to high influence of rotational term. Distribution of the rotational speed is set up in the field due to high degree of rotation which introduces large radial pressure gradient, driving the flow in the axial and radial directions [31].

An appropriate scheme has to be selected in solution method dialogue box for better convergence. Quite a few options are available for selecting the scheme for pressure-velocity coupling methods, namely, SIMPLE, SIMPLEC, PISO, and Coupled depending on the properties they offer. For the present study coupled scheme is used. In the coupled scheme all

the equations for phase velocity corrections and shared pressure corrections are solved simultaneously. Mass transfer terms and lift forces are incorporated into general matrix by this method. This scheme is most suitable for steady state situations. This scheme is not available if slip velocity is enabled for mixture multiphase model [27]. Under relaxation factors can be varied within the range for better convergence.

CHAPTER 5

Results and Discussion

In the present study the rate of deposition of the sulfate on the platter is investigated. The present study is done on the cobalt layer of the platter supposing a crack has been formed on the top layers of the platter through which the contaminants and the humidity comes in contact with the magnetic layer of the platter.

For determining the rate of deposition of sulfate on the rotating platter two different cases were employed, where in case 1 the relative humidity (RH) was varied and in case 2 the rotational speed of the platter was varied to study the effect of change in humidity and change in rotational speed of the platter on the deposition rate of sulfate on the platter. In both the cases same convergence procedure was followed to find the optimum result.

5.1 Case 1: Effect of Relative Humidity

For investigating case 1 the RH was varied from 30%, 40%, 50%, 60% and 70%. The rotational speed of the platter in this case was kept constant to 7200 RPM. The inlet temperature was kept constant to 301.15° K and the operational temperature was kept constant to 328.15° K.

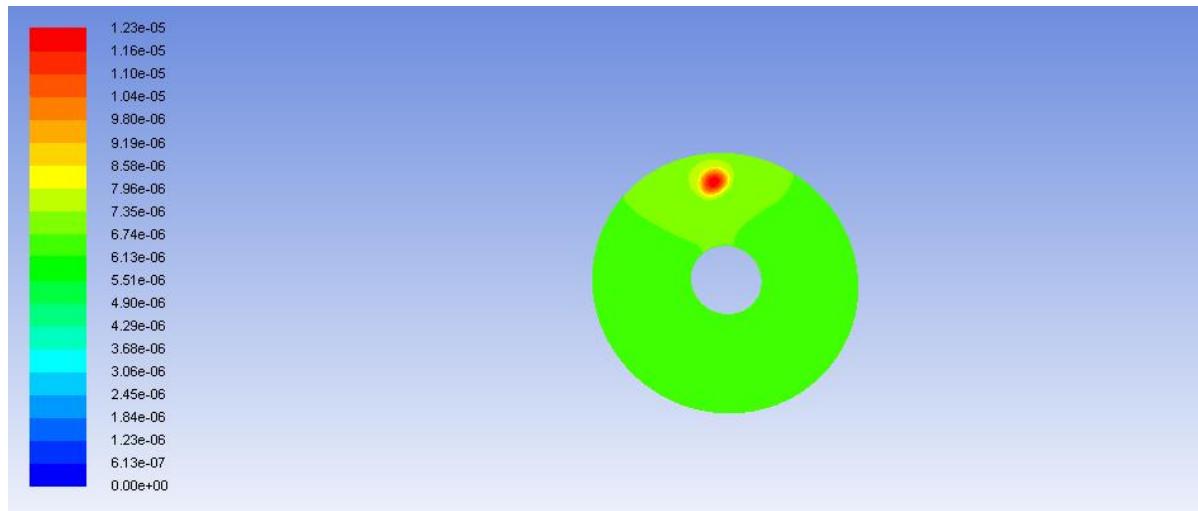


Fig 5.1: Rate of deposition of sulfate on the platter at 30% RH

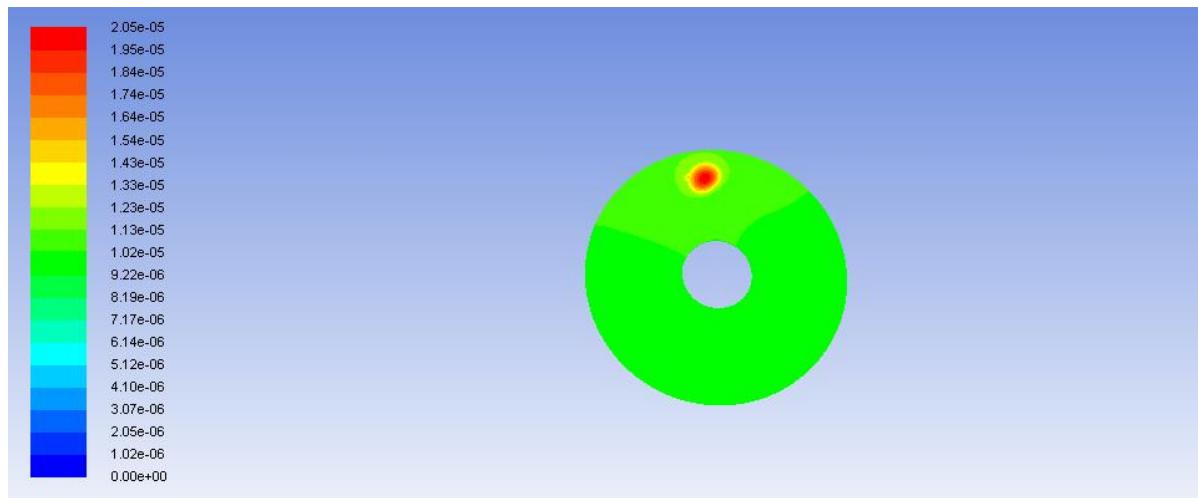


Fig 5.2: Rate of deposition of sulfate on the platter at 50% RH

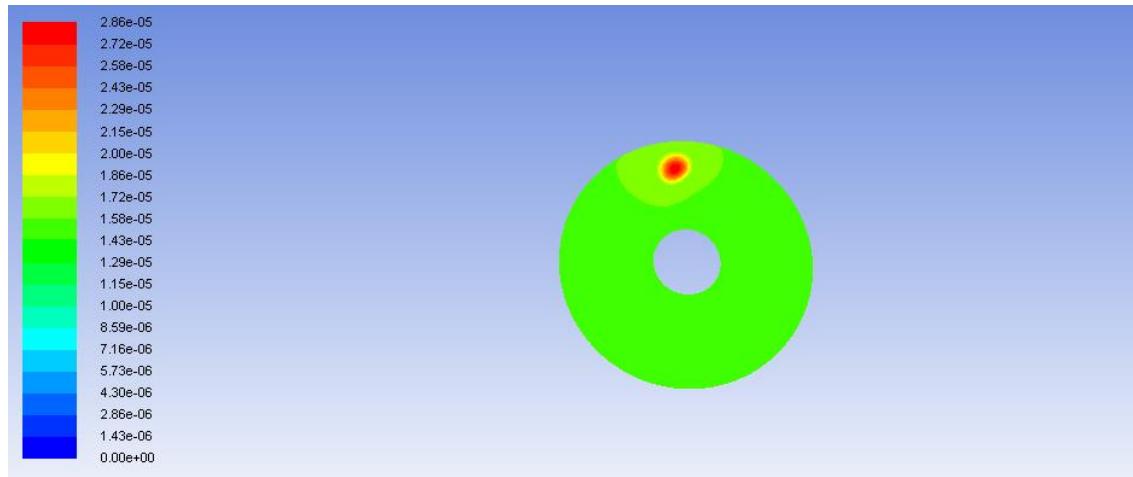


Fig 5.3: Rate of deposition of sulfate on the platter at 70% RH

Table 5.1: RH vs. maximum deposition rate

Sr. No.	RH%	Maximum Deposition rate(Kg/m ² -s)*10 ⁻⁰⁶	Maximum Deposition rate(Å/month)* 10 ⁹
1.	30	12.25	1.36
2.	40	16.41	1.83
3.	50	20.04	2.28
4.	60	24.66	2.75
5.	70	28.63	3.19

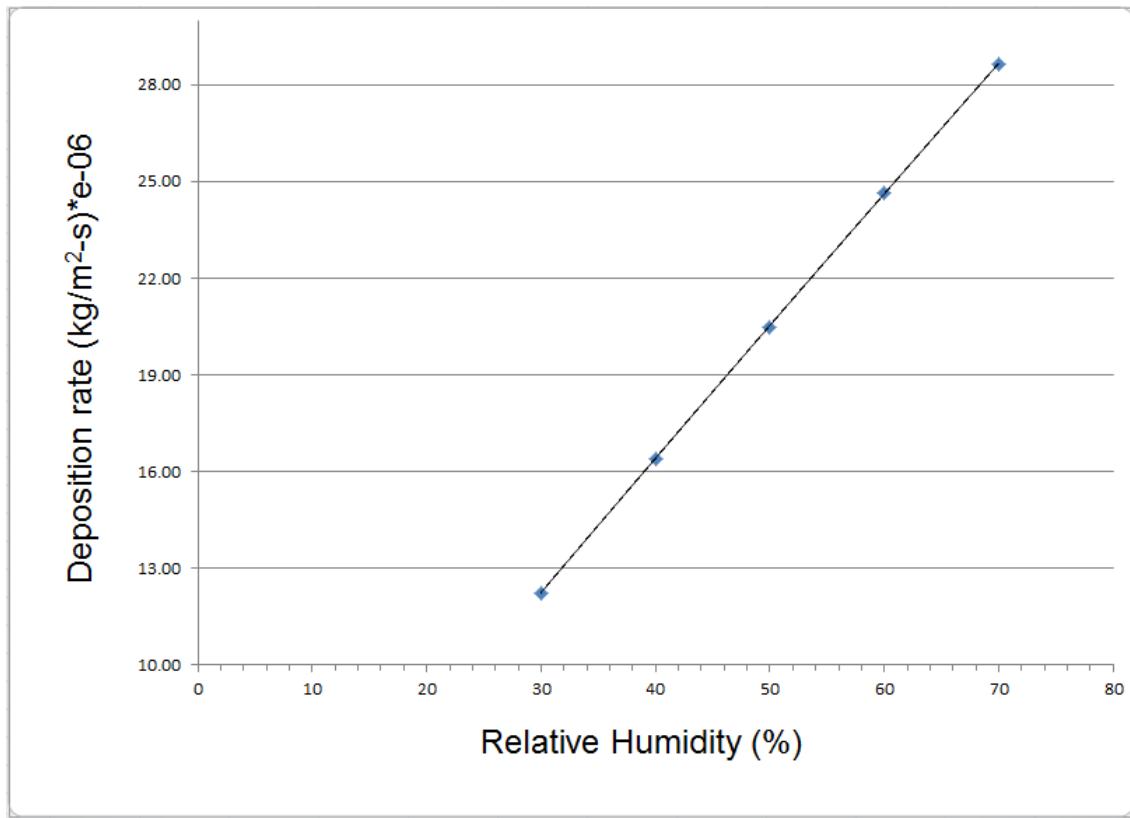


Fig 5.4 Deposition rate of sulfate vs. RH

5.2 Case 2: Effect of Rotational Speed

For investigating case 2 the rotational speed of the platter was varied from 5400 RPM, 7200 RPM, 10000 RPM and 14000 RPM. The RH in this case was kept constant to 50%. The inlet temperature was kept constant to 301.15° K and the operational temperature was kept constant to 328.15° K .

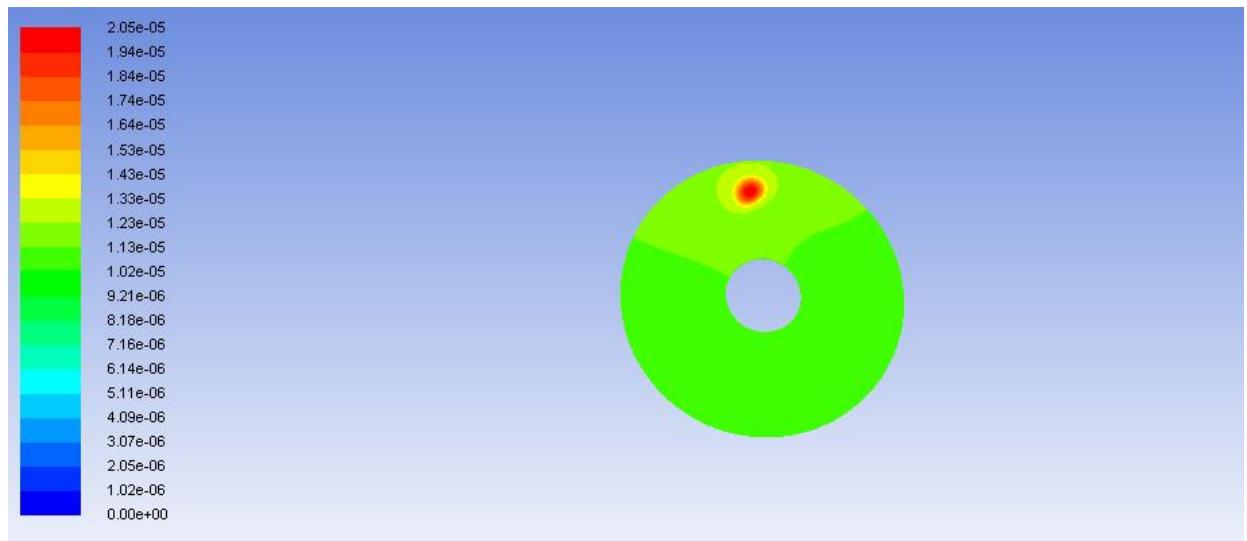


Fig 5.5: Rate of deposition of sulfate on the platter at 5400 RPM

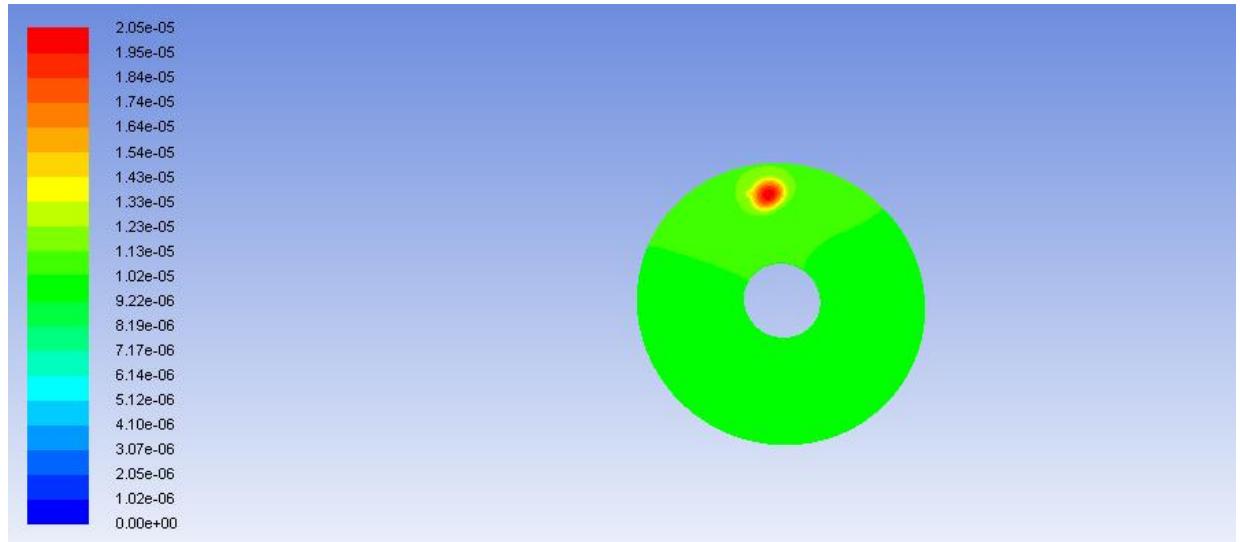


Fig 5.6: Rate of deposition of sulfate on the platter at 7200 RPM

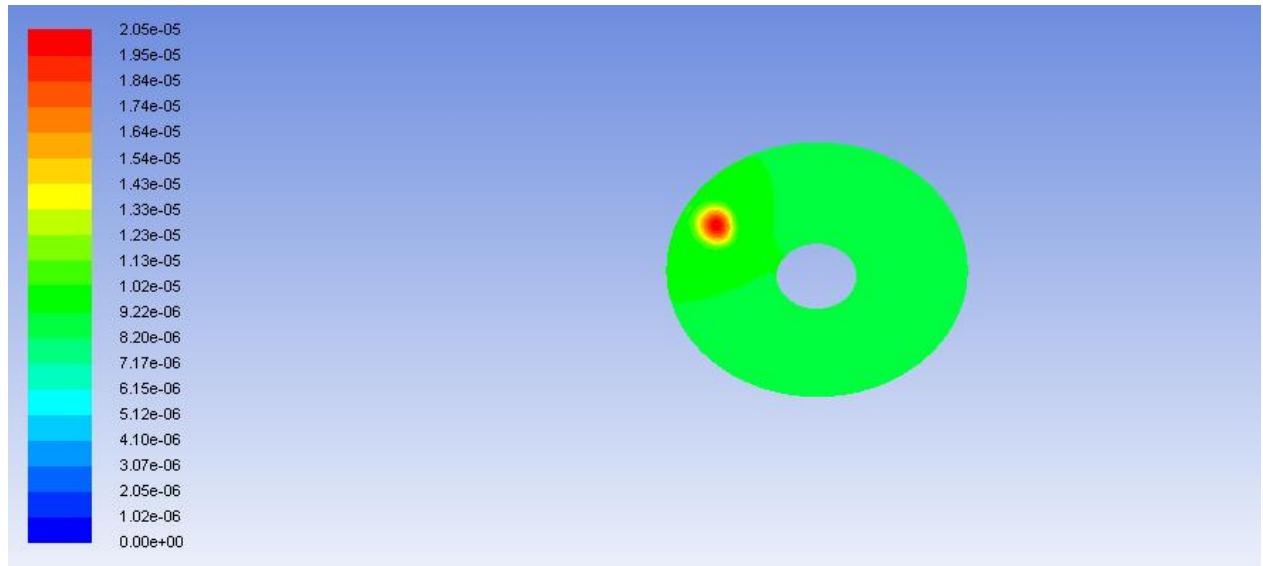


Fig 5.7: Rate of deposition of sulfate on the platter at 14000 RPM

Table 5.2: Rotational speed vs. maximum deposition rate

Sr. No.	Rotating Speed(RPM)	Maximum Deposition rate($\text{Kg/m}^2\cdot\text{s}$) * 10^{-6}	Maximum Deposition rate(\AA/month) * 10^9
1.	5400	20.453	2.282
2.	7200	20.462	2.283
3.	10000	20.486	2.285
4.	14000	20.499	2.286

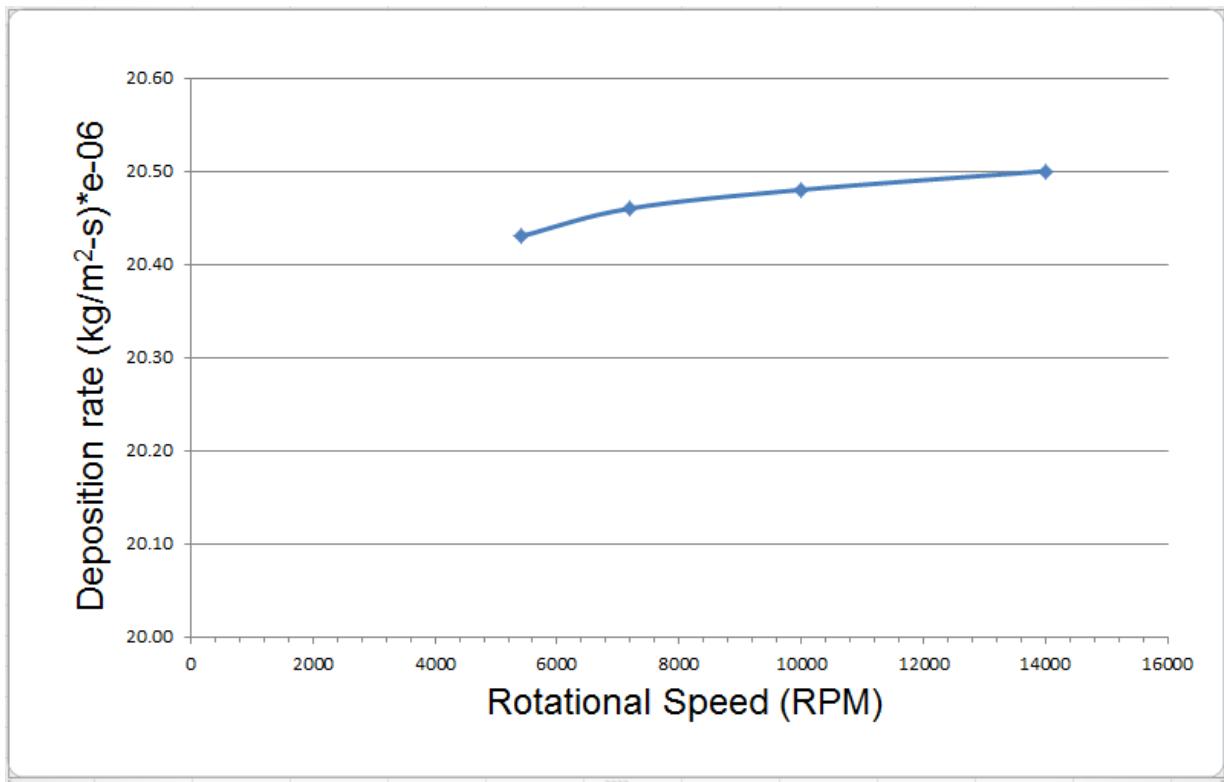


Fig 5.8: Deposition rate of sulfate vs. rotational speed

5.3 Conclusion

Following conclusions are made from the results obtained from the simulations:

- A contamination modeling for platter of HDD (surface deposition rate) has been formulated in ANSYS Fluent.
- It is clearly evident from the results that there is significant contamination in data storage system like HDD, under certain environmental conditions.
- As expected, Relative Humidity has an adverse effect in the deposition rate of the sulfate on the Hard Disk Drive platter.

- Interestingly, Rotational Speed of the platter did not have any significant effect in deposition rate of the sulfate on the Hard Disk Drive platter.

APPENDIX A

RELATION BETWEEN $\text{kg/m}^2\text{-s}$ AND \AA/month

The unit $\text{kg/m}^2\cdot\text{s}$ is first converted into $\mu\text{g/cm}^2\cdot\text{h}$ and then to convert $\mu\text{g/cm}^2\cdot\text{h}$ to $\text{\AA}/\text{month}$ following procedure is followed.

Consider silver sulfate (Ag_2S) the only corrosion product with density 7.23 g/cm^3 [34].

$$\begin{aligned} 1 \mu\text{g} &\equiv \frac{2 \times 107.9 + 32}{32} \mu\text{g of Ag}_2\text{S} \\ &\equiv 7.74 \times 10^{-6} \text{ g of Ag}_2\text{S} \\ &\equiv \frac{7.74 \times 10^{-6}}{7.23} \text{ cm}^3 \text{ of Ag}_2\text{S} \\ &\equiv 1.07 \times 10^{-6} \text{ cm}^3 \text{ of Ag}_2\text{S} \end{aligned}$$

$$\begin{aligned} 1 \mu\text{g/cm}^2\cdot\text{h} &\equiv 1.07 \times 10^{-6} \text{ cm/h} \\ &\equiv 1.07 \times 10^{-6} \times 10^8 \text{ \AA/h} \\ &\equiv 107 \times 24 \times 30 \text{ \AA/30 days} \\ &\equiv 7.7 \times 10^4 \text{ \AA/30 days} \end{aligned}$$

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BIOGRAPHICAL INFORMATION

Hardik Shah has received his Bachelor of Technology degree in Mechatronics Engineering from Ganpat University, India in May 2011. He completed his Master of Science degree in Mechanical Engineering from University of Texas at Arlington, USA in May 2013.

Hardik Shah has done his Engineering Training from Mercedes Benz, India.

Hardik Shah has been involved in number of projects at UT Arlington in Contamination group from gaseous to particulate corrosion in data center and hard disk drives. His research area includes gaseous corrosion in data center and hard disk drives. He has worked on finding the gaseous corrosion rate on copper and silver coupons using environmental chamber. He has also worked on system impedance of servers and fan characterization. He has studied the impact of inlet temperature on server power using environmental chamber.