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THERMAL ANALYSIS OF BEARING USED IN DISC TYPE CENTRIFUGAL SEPARATOR

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MASTER'S THESIS

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ACCEPTANCE AND APPROVAL

The thesis titled “THERMAL ANALYSIS OF BEARING USED IN DISC TYPE CENTRIFUGAL SEPARATOR”, prepared by Mürsel Onur KARADAĞ, a student of Department of Mechanical Engineering Program at Republic of Türkiye Aydın Adnan Menderes University, Graduate School of Natural and Applied Sciences, was accepted as a Master's Thesis by the jury below.

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This thesis was approved by the jury above in accordance with the relevant articles of the Aydın Adnan Menderes University Graduate Education and Examination Regulations and was approved on the .... by from the Board of Directors of the Graduate School of Natural and Applied Sciences in the .... numbered decision.

Prof. Dr. Mustafa SÜRMEN

Institute Director

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Mürsel Onur KARADAĞ

STATEMENT OF SCIENTIFIC ETHICS

I hereby declare that I composed all the information in my Master's thesis entitled "THERMAL ANALYSIS OF BEARING USED IN DISC TYPE CENTRIFUGAL SEPARATOR" within the framework of ethical behavior and academic rules, and that due references were provided and for all kinds of statements and information that do not belong to me in this study in accordance with the guide for writing the thesis. I declare that I accept all kinds of legal consequences in case of any contrary statement of what I have stated is revealed. This thesis is derived from the publication(s) for which I am the lead or co-author and whose citation information is given below.

Mürsel Onur KARADAĞ

5/03/2024

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LIST OF NOMENCLATURE

η	Efficiency
A	Square of Heat Transfer Surface
c_p	Aluminum Specific Heat
h_{air}	Heat Transfer Convection for Air
k	Heat Transfer Coefficient
L	Length of Heat Transfer Surface
P	Pressure
r_b	Radius of a bowl
R_e	Reynolds Number
t	Thickness of a fin
T_a	Environment Temperature
T_c	Max. Temperature of With Fin Oil Chamber
T_o	Beginning Temperature of With Fin Oil Chamber
T_{oil}	Max. Temperature of Lubricant, With Fin Oil Chamber
v	Speed
w	Wideness of a fin
ρ	Density
Q	Throughput rate

LIST OF ABBREVIATIONS

CAD : Computer Aided Drawing

CAE : Computer Associated Engineering

CFD : Computational Fluid Dynamics

CIP : Cleaning in Place

HMI : Human Machine Interface

MCC : Motion Control Center

MRF : Moving Reference Model

RANS : Reynolds Averaged Navier-Stokes

RNG : Renormalization Group

VFD : Variable Frequency Drive

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ÖZET

DİSK TİPİ SANTRİFÜJ SEPARATÖRLERDE KULLANILAN RULMAN ISIL ANALİZİ

Karadağ, M.O. Aydın Adnan Menderes Üniversitesi, Fen Bilimleri Enstitüsü, Makine Mühendisliği Anabilim Dalı, Yüksek Lisans Tezi, Danışman: Doç. Dr. Mustafa ASKER, Aydın, 2024.

Disk tipi santrifüjler, farklı yoğunluktaki heterojen karışımları ayırmak için yüksek *G* kuvveti kullanan makinelerdir. Bu çalışmanın amacı, disk tipi santrifüj ayırıcılarda kullanılan yağlayıcının sıcaklığını düşürmek için ısı transfer hızını arttırmaktır. Bu sayede makinede kullanılan dikey ve yatay kuvvetleri absorbe eden rulmanların bilya ve kafesleri arasındaki yağ filminin doğru bir şekilde oluşması sağlanır. Bu sayede rulmanın ömrü uzatılabilir. Yağlayıcının sıcaklığını sabit tutmak için, ısı transferini artırmak amacıyla yağ haznesine bir kanatçık eklenmiştir. Yağ hazneleri, kanatlı ve kanatsız 2 durum için aynı çalışma koşulları altında test edilmiştir. Sonuçlar, kanatçıksız yağ haznesinin 61,5°C sıcaklığa ulaştığını göstermiştir. Kanatlı durumda ise sıcaklık 53,2°C olarak ölçülmüştür. Toplam test süresi 7 saattir. Termal analiz yapılmış ve sonuçların deneysel testten elde edilenlerle benzer olduğu görülmüştür. Ayrıca, deneysel çalışma sonuçları COMSOL Multiphysics programında gerçekleştirilen analiz için girdi parametreleri olarak kullanılmıştır. Kanatlı yağ haznesi tasarımının yağlayıcı sıcaklığını sabit bir değerde tutmada başarılı olduğu ve daha da geliştirilebileceği sonucuna varılmıştır.

Anahtar Kelimeler: Rulman, Santrifüj separatör, Uzatılmış yüzeyler, Yağlama yağı, Termal analiz

ABSTRACT

THERMAL ANALYSIS OF BEARING USED IN DISC TYPE CENTRIFUGAL SEPARATOR

Karadağ, M.O. Aydın Adnan Menderes University, Institute of Natural and Applied Sciences, Department of Mechanical Engineering, Master's Thesis, Supervisor: Assoc. Dr. Mustafa ASKER, Aydin, 2024.

Disc type centrifuges are machines that use high *G* force to separate heterogeneous mixtures of different densities. The aim of this study is to increase the heat transfer rate in order to reduce the temperature of the lubricant used in disc type centrifugal separators. This provides the correct formation of the oil film between the balls and cages of the bearings that absorb the vertical and horizontal forces used in the machine. In this way the life of the bearing can be extended. To maintain a constant temperature of the lubricant, a fin was added to the oil chamber to enhance heat transfer. The oil chambers were tested under the same operating conditions for 2 cases with and without the fin. The results showed that the case without fin oil chamber reached a temperature of 61.5°C. While for the case of with fins, the temperature was measured 53.2°C. The total test duration was 7 hours. Thermal analysis was conducted, and the results were found to be similar to those obtained from the experimental test. Besides, the experimental study results were used as input parameters for the analysis which are carried out in COMSOL Multiphysics program. It has been concluded that the with fin oil chamber design is successful in maintaining the lubricant temperature at a constant value and can be further improved.

Key Words: Bearing, Centrifugal separator, Extended surfaces, Lubricant oil, Thermal analysis

1. INTRODUCTION

Mechanical separation has been a longstanding technique employed for the isolation of liquid mixtures or the extraction of solids from a liquid or liquid mixture. When the density contrast between the liquids is adequate, gravitational force can serve as an effective mechanical separation approach. With an increase in gravitational force, the required time for mechanical separation diminishes. Industrial apparatus such as decanters and separators have been devised to leverage this principle by inducing an artificial gravitational force. These machines are recognized for their substantial power demands, earning them the designation of energy-intensive equipment. The objective of this research is to explore the energy consumption factors associated with centrifugal separators and to decrease the overall energy usage by implementing specific design modifications.

1.1. Centrifugal Separators of the Disc Stack Type

The disc stack centrifuge stands out as a versatile apparatus capable of separating solid/liquid mixtures in continuous, semi-continuous, and batch configurations. Except for certain batch-operated systems, these machines can manage toxic, flammable, and volatile feeds with throughputs reaching up to 200 m3/h.

Sophisticated units of disc stack centrifuges enable the separation of liquid-liquid mixtures, achieving a three-phase separation involving two liquid phases and one solid phase. A prerequisite in all instances is a significant density distinction between the phases present in the feed.

Despite the existence of several variations, the fundamental type features an imperforate bowl encompassing an inverted stack of slender conical discs separated by spacers measuring 0.3-3 mm. The spacing between discs is influenced by viscosities and solids concentrations, favoring spacings below 1 mm. The discs, spun on a shared vertical axis, facilitate the movement of the process suspension, which is centrally fed from the top, through the annular spaces between the discs.

Centrifugal forces, reaching up to 14000g, prompt the accumulation of particles on the lower surface of the discs, from where they descend towards the outer periphery of the centrifuge bowl. In batch units, the thickened solids persist in the bowl until the centrifuge's solids handling capacity is reached. At this juncture, the rotation halts, and the basket containing the trapped solids is either manually replaced or a discharge valve on the periphery of the bowl is operated manually to facilitate sediment removal. In continuous units, the flowable solids are automatically separated at periodic intervals, discharging the accumulated solids.

Figure 1.1. Automatic discharge, separator (left). Bowl group for the separator (right) (HAUS Centrifuge Technologies).

1.2. Heat transfer of Centrifugal Separators

Currently, centrifugal separators work with a bowl group, a bearing system carrying this group and an electric motor driving these 2 systems. Due to the high-speed operation (6000 rpm), the temperature of the system increases over time with the air friction and the heating of the working parts. This temperature reaches 65-70ºC in ex-proof separators. Increase in temperature can cause yield losses, spoilage of the processed product and damage to the bedding system. Generally, water is used to reduce the temperature on the drum group side. Regarding the cooling of the bearing system, the design of the oil chamber and the heat transfer with the environment are used. Since we cannot change the temperature in the environment, this thesis focuses on increasing the heat transfer and the ways in which the oil temperature can be cooled. The temperature increase parameters will be determined.

It will be determined at what level the temperature should be kept through these parameters, and criteria such as efficiency and life between the optimum operating conditions of the temperature and the standard temperature values will be observed with a design or change of designs on the machine.

1.3. Ball Bearings

These bearings are the most common type of bearings and can carry both radial and vertical loads. Ball bearing is also known as deep groove ball bearings. The inner ring is typically fixed to the rotating shaft. The outer ring is housed in a housing. That tolerance is advice for the shaft IT4. The outer ring is mounted inside the housing. That housing diameter tolerance is advice to IT6. When load is applied on the bearing, first the load transmitted from outer ring to the balls and from the ball to inner race.

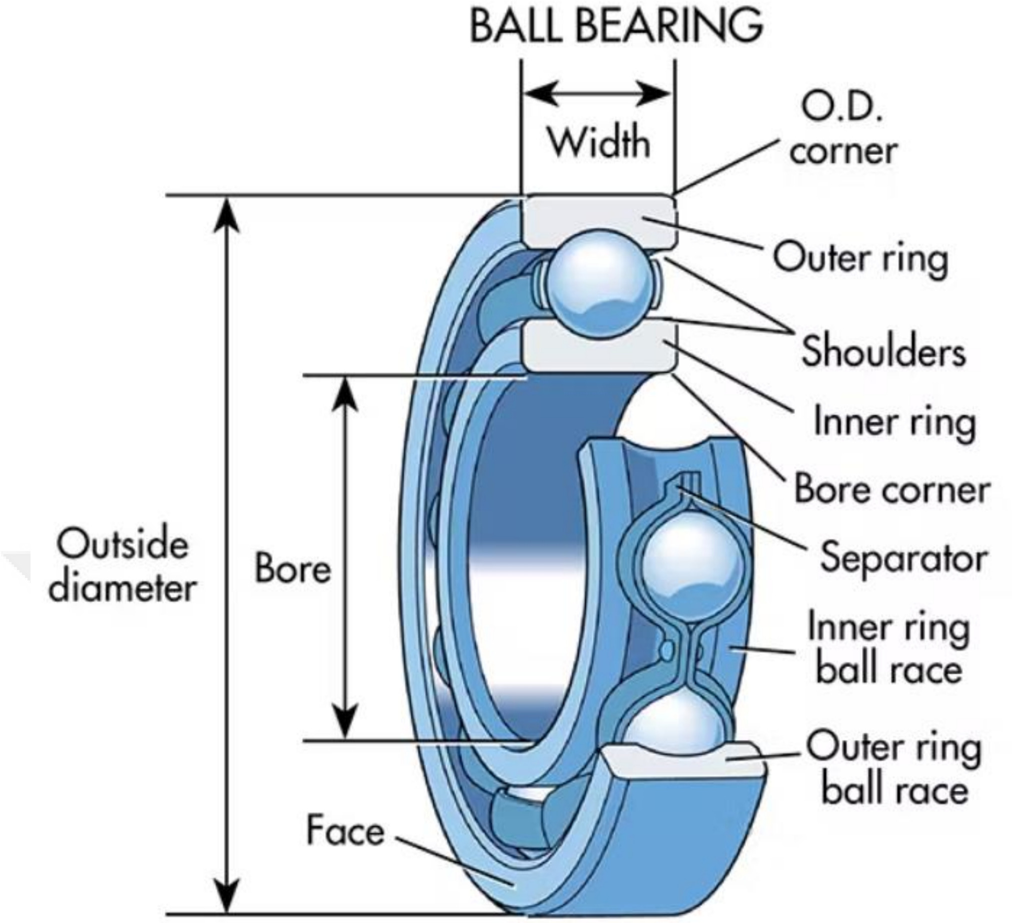

Figure 1.2. Ball bearing (SKF General Catalogue, 2003.).

The contact points between the ball and the outer ring are very small. This situation also ensures that the ball rotates smoothly. Ball bearing can be deformed for the bearing could be overloaded at a certain point caused of the contact point is too small. This will reduce the bearing shelf life. Ball bearings are used in applications where the load capacity is relatively low. This bearing is also known in SKF to 6000-7000 series. For example, 7305 BECBM or 7311 BEP.

1.3.1. Cylindrical Roller Bearings

Straight roller or cylindrical roller bearings work in cylindrical raceways and are ensure low friction, high radial load capacity and high speed. Cylindrical bearings are the point of contact between bearing and housing is a line rather than a point. The load is distributed larger space, allowing the bed to carry a bigger load. The length of the cylinder isn’t much bigger than diameter of the cylinder caused of minimizing the tendency.

These bearings are also known in SKF to NU, NJ and N series. For example, N209 ECM or NU 311 ECM.

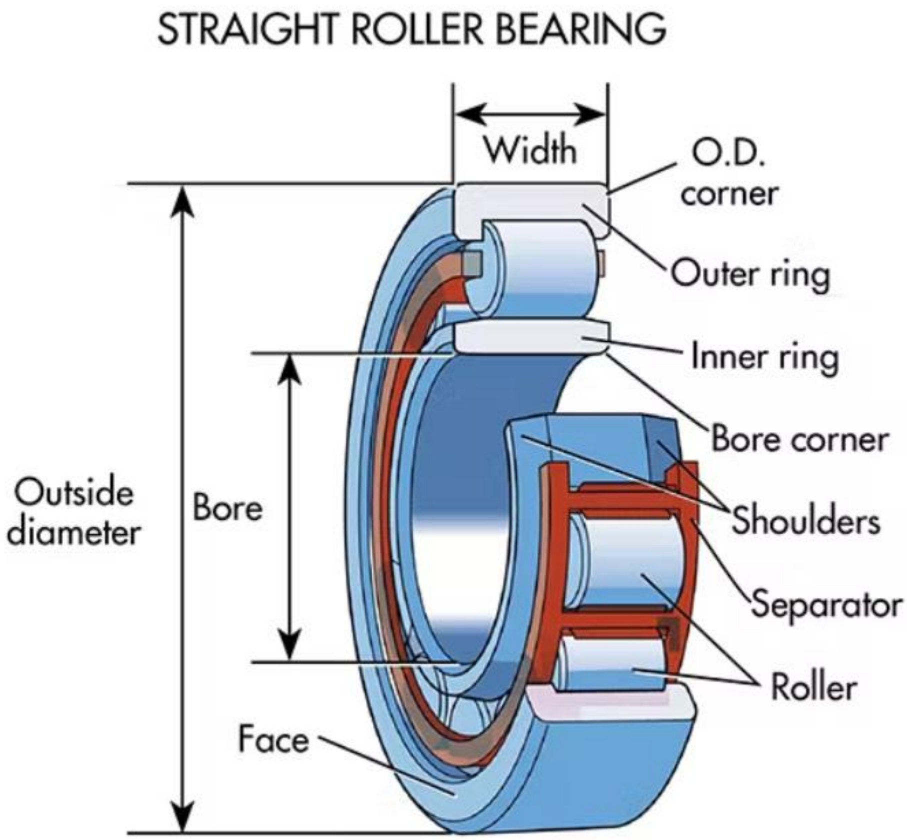

Figure 1.3. Cyclindrical bearing (SKF General Catalogue, 2003.).

The bearings used in the centrifugal separator are specially selected. NU series bearing is used according to the lettering of SKF company whose operating conditions are up to 125 degrees. The role of this bearing in the centrifugal separator meets the radial loads. The history of bearings is based on ancient times. In 1909 Dr.-Ing. Josef Kirner, one of Norma Compagnie's leading engineers.

The design improvements of cylindrical roller bearings have evolved from the history of rolling bearings, dating back to the 1870s. This period coincides with the establishment of the first bicycle factories, where the need for bearings arose. The increasing demand for ball and roller bearings in various mechanical applications led to the emergence of companies specializing in the construction and design of rolling bearings. Since the early stages of the industry, the energy-efficient properties of roller bearings have been apparent. In a research study carried out in New York in 1905, W.P. Graham from Syracuse University compared the energy consumption of two similar streetcars - one equipped with sliding bearings and the other with roller bearings. The results showed a 52% decrease in energy consumption when using roller bearings.

In Germany, Cannstatt obtained a patent for an innovative invention: the cylindrical roller bearing. The bed structure included raceways with a crowned design, which effectively prevented detrimental edge stresses on the cylinder ends. Bearings developed in subsequent years, featuring appropriately sized short rollers that were both produced and meticulously guided amidst variations, resulting in numerous advantages. Kirner was aware of these benefits, and despite facing opposition from many expert colleagues, he advocated for the implementation of such bearings in Germany. In 1914, SKF, which is based in Gothenburg, Sweden, acquired fifty percent of Norma's shares, forming a collaborative alliance within the SKF Group.

A bearing is a component of a machine that provides relative movement only in desired directions. Reduces friction between moving parts. The design of a radial bearing can provide free rotation about a selected axis, for example. There are many different ways to classify bearings, however, the division often depends on the type and type of operation. lubrication. Radial, axial and axial-radial are the most frequently mentioned in the section made according to the process type.

The centrifugal separator consists of liquid lubricated bearings that take axial and radial loads, can operate up to 125 degrees and are adapted to high speeds. There are 2 clues in the centrifugal separator that we discussed in the thesis. One of them is the NU series bearing that takes the radial load, the 7 series takes the axial load and has 2 working backs. The speed required for the lubricant to start the lubrication process with centrifugal force is 3000 rpm. On top of that, a non-lubrication to drive and an oil-free power will result in deformation of the prolonged operating regime. Therefore, the centrifugal separator should not be operated at low speed for a long time. This will also damage the bearing, contaminating the lubricant and shortening it will change its characteristic.

In centrifugal separators, one of the shares of low process efficiency belongs to the lubricant. For example, even when the centrifuge separator does not process the product, the current drawn is very high as it brings the entire bowl group to operating speed. The lubricant starts to heat up with the temperature resulting from the friction force caused by this high current. At high speeds, if no coolant is sent from the outside, the drum group will also start to heat up and the temperature will inevitably increase towards the bearing system starting from the top. Temperature differences occur on a process basis. For this reason, improving the cooling system will reduce the temperature of the lubricant and thus extend its life. One of the most important conditions for optimum operation of the centrifugal separator is stable lubrication. In this way, the bearing elements will be able to work stably and the vibration and noise level will always remain at the desired levels.

The centrifuge apparatus is also used for phase separations, such as gas-liquid separation. Although the designs are different from those of the centrifugal disc stack separator, the underlying principle of mechanical separation remains essential. (Kefalas and Margaris, 2009) explored a separation device commonly used for mixtures like air and water. They modeled a novel centrifugal phase separator and conducted diverse CFD analyses. This section comprises of an inlet and an outlet volute, which are connected to a cylindrical tower to ensure that centrifugal forces maintain an equal phase separation. The analysis, which utilized different mesh structures and resolutions, yielded tangible results when employing the RNG k-ε turbulence model. To enhance the correlation of experimental data with the analysis, a genuine centrifugal phase separator was used as a reference to provide a geometrically accurate 3D model.

The efficiency of the centrifugal separator's bowl is reduced due to the high-speed rotation. The air friction generated between the bowl and the upper case of the separator can be theoretically reduced by creating a vacuum environment, which is not possible due to the industrial design of the separator. The air friction generated between the bowl and the upper case of the separator can be theoretically reduced by creating a vacuum environment, which is not possible due to the industrial design of the separator. However, the windage effect can still be examined.

Centrifuge technology includes various designs, such as tubular bowls, chamber bowls, imperforate baskets, disc stack separators, and decanters, which are used in diverse applications (Sutherland, 2009). Although decanters and separators share similarities, their primary designs differ significantly. The decanter has a horizontally rotating bowl and is commonly used for separating mixtures with high solid content. In contrast, separators have a bowl that rotates vertically and has a distinct shape, which is specifically used for mixtures with low solid content. Decanters have more extensive literature on design and calculations compared to separators. One of the primary objectives of this study is to analyze the differences between separators and decanters.

Due to the low knowledge about the bearing of centrifugal separators, the calculation part was incomplete. It is inevitable that this deficiency will create a negative perception in the designs to be made. Along with this thesis, it is a preliminary study for the design and life calculation of the bearings.

1.4. Mechanical Parts

The contact of the mechanical parts leads to an increase in the temperature of the lubricant and also to fouling. In this work, the friction temperature of a bearing element must be calculated. In this way, the lubricant used to slow down this temperature increase is important. This lubricant prevents the increase in temperature of the bearing element and provides its elongation and protection from mechanical deformations. Likewise, the feature of the lubricant ensures the working conditions of the bearing element and optimum efficiency from the work done.

Harris conducted a thorough analysis of rolling bearings, specifically addressing ball-raceway contact variables. The analysis employed the simplifying assumption of an isothermal Newtonian lubricant. A comparison of the analytical findings with experimental data from Shevchenko, Bolan, Poplawski, and Mauriello showed that the calculation of ball-raceway contact is more precise than the solution derived using outer raceway control theory. Kagan proposed an alternative approach based on the theory of dynamical systems, using Turing systems (diffusion-reaction systems) to explain spatial and temporal patterns caused by friction. (Wu and Tan, 2010)

The bearing system consists of a vertical shaft, bearings and lubrication equipment. It is also inside the bearing elements in rubber wedges used to meet vertical loads. Both horizontal and vertical forces act on the system. Bearings that meet these forces must be cooled with a correct lubricant and the operating conditions must be optimized. The main reasons for the heat occurring can be expressed as follows. (Bolat D. and Gedik K., 2016)

- Friction
- Belt system
- Gear system
- Direct system

Each bearing has its own elements and these elements have a theme within themselves. For example, in the gear drive transmission mechanism, an electric motor drives a horizontal shaft, this drive turns the horizontal gear and with a vertical gear embedded in this gear, the system reaches high speeds. However, due to the bearing, seals and mechanical parts in this system, the temperature will continue to increase with each passing day. The operation of the lubricant is very important here and must effectively cool every bearing part used. The rate of contamination and deterioration of the characteristics of the lubricant is higher and its efficiency is lower than the belt system due to the excess transfer element used. Likewise, high speeds are achieved thanks to a belt drive system, an electric motor, a pulley driven by this motor and the power transferred from this pulley to the vertical shaft by belt. The temperature of the bearing elements increases as soon as they start working, likewise, the temperature of the belt increases due to friction and the environment will continue to warm. Heat transfer with the environment will also come into play here and will prevent the temperature of the bearing elements from increasing excessively with the lubricant. In systems with direct drive mechanism, the motor shaft operates as the vertical shaft of the centrifuge separator and the bearing elements have been simplified. In this way, less mechanical losses and temperature increases will be observed, so that the bearing problems and part deformation of the lubricant will be minimized in optimum operating conditions.

$$\eta = \frac{(T_{out} n)}{(T_{in} n)} * 100 \quad (1.1)$$

1.5. Lubricants oils

Lubricants are thought to have first appeared with the invention of the wheel. With the invention of the wheel, the use of lubricants became inevitable. The main reason for this is friction. Friction causes an increase in the temperature between the parts and accordingly the formation of deformations. For the first time in history, animal and vegetable oils were used as lubricants. Towards the end of the 1800s, crude oil was also used as a lubricant.

However, it is not used as a lubricant due to the pollutants contained in crude oil and its unsuitability for lubrication. When the refining of crude oil began, there was a great opportunity for improvement for lubricants. In this way, the lubricants used in many industrial industries have evolved and started to be used. It is seen today as two different types of synthetic and mineral oils. If it is obtained from a petroleum-based raw material, it is called mineral oil, if it is produced from a synthetic-based raw material, it is called synthetic oil. It is known that vegetable oils are also used in some exceptional cases. We can list the main reasons for using lubricant equipment in industrial machinery as follows .

- reduce friction
- To create resistance to corrosion
- create control temperature
- To provide sealing

Synthetic oils have much better viscosity and thermal permeability than mineral oils. Synthetic oils, which are more costly, are preferred in many industrial sectors.

Both mineral and synthetic oils are used for the centrifugal separators we will discuss. Oil change period is foreseen as 1 year when synthetic based oil is used, while this period decreases to 6 months when mineral oil is used. Even this situation allows us to see the difference between the 2 types of oil. The oils to be discussed in this study are CLP 100 and ISO VG 68. CLP 100 is a mineral oil with a viscosity of 100 cSt at 40ºC. ISO VG 68 is a synthetic oil with a viscosity of 65 cSt at 40ºC.

2. LITERATURE REVIEW

The first inventor of centrifugal machines was the Swedish Gustav de Laval. The first centrifuge machine he invented during this period was aimed at separating cream from milk. This centrifuge machine, which is a manually rotated equipment, has evolved to its current position over the years with developing technology. In this process, GEA, a German company, emerged as a rival to Gustav de Laval, the founder of Alfa Laval. Most of the market share is divided between these 2 brands. While Alfa Laval focused on the marine sector, GEA aimed to work in more specific areas.

Centrifugal separator manufacturers have made significant improvements in design, stability, and operating cost reductions. These improvements are key elements in increasing market share, and technological advancements have made them easier to achieve.

By increasing the material quality, preference of centrifugal separators are escalated. Operating temperature is one of the biggest factors of the overall performance of centrifugal separators and advanced water-cooling systems made the drive system and bowl group able to run at a lower temperature. Reduced bearing temperature, changes the lubricant viscosity and affects the operating performance of bearings. Bearing life is also another factor that can be improved to make better machinery. Unlike thermal analysis of rolling bearings, thermal analysis of plain bearings or machine parts has been done in various studies. Therefore, very limited experimental studies are available in thermal analysis of rolling bearings. (Takabi and Khonsari, 2013, 23). To be an example, in the study of Ochia named “Two-Phase Flow CFD Analysis of Temperature Effects on Oil Supplied to Small Diameter Trunk Bed with Oil Feeding Groove” (Ochiai, 2018) they prepared a sample setup for bedding and heat transfer analysis.

and heat transfer and analysis. To establish the boundary conditions for the calculations, the inlet velocity was adjusted based on the oil supply quantity obtained from experimental findings. (Peeters and Weis, 2004, 24) explored the correlation between pool depth and internal washing at the shore of a solid bowl pitcher centrifuge. The oil temperature at the inlet remained constant at 50°C, which is consistent with the experimental setting. The outlet was configured exclusively for counterflow in the liquid phase, and the counterflow temperature was set to 25°C, mirroring the experimental environment. The shaft was programmed to rotate at 5800 rpm, and the thermal boundary condition of the rotating shaft was set to the mean temperature at the shaft surface wall, as determined through experiments. The aim of the analysis was to determine the heat flux on the shaft surface (Tarawneh and Wilson, 2009).

Under lubrication, the mean temperature on the shaft surface was found to be 52.5°C, while the transition condition was recorded at 50.5°C. The thermal boundary condition for the bearing surface was provided by external convection heat transfer. The task involved specifying the bearing thickness, heat transfer coefficient between the external wall of the bearing and the ambient air, heat conductivity of the bearing, and the specific heat of the bearing. Lubricant is the main element in centrifugal separators. In order to lubricate the bearings used in the bearing system and to keep the vibration level of the system at a certain value, the lubricant must be kept in the separator under continuous and optimum operating conditions. Machine dimensions change depending on the machine capacity, and this change affects the choice of the bearing. With the increase in machine size, the bedding system differentiates and the amount of oil to be used increases in direct proportion to this growth. Each element that increases is seen as a heat source and acts as a factor increasing the temperature of the lubricant. Oil change period is predicted as 6000 hours in today's but it is recommended to be changed 250 hours after first started caused of contaminant parts include oil chamber bearing and metal parts. centrifuge separators. Of course, this period varies according to working conditions and environmental conditions. This time can be increased with an effective cooling system and correct operation. Centrifugal separators have 3 different drives as gear, belt and direct drive and their own bearing systems for these systems. It is the lowest energy efficient drive system due to the excess of the transmission organs used in the gear drive system and the large number of bearings. Consequently, this system is no longer preferred due to the high number of elements that can contaminate the lubricant and increase its temperature. A belt driven separator has lower energy losses and is considered today as a preferred system with a simplified bearing system. Air friction due to the high rotation speed constitutes the biggest share of the temperature increase in the separators used.

The pursuit of efficiency has become a major challenge among machine builders these days. With the rising energy costs, a new factor has been brought to the competition between centrifugal separator manufacturers. Centrifugal separators are equipment commonly used for tons of applications across industries, from foods to industrial liquids. Separating the mixtures into phases in order to collect valuable resources such as cream of milk and fish oil is the main purpose of these centrifuge machines. From an engineering point of view, centrifugal separators are difficult to manufacture, so there are expensive solutions for various processes. Even if the purchasing cost of the separator is ignored, the running cost of centrifugal separators is very high compared to other machines in a process.

Many studies have been carried out to reduce these operating costs and to extend the operating life of the machine. The temperature increase during the operation of the system is undesirable and large amounts of water is consumed to prevent this.

One of the reasons for the occurrence of this temperature is the bearing system, and when this system lubricant contacts, the oil gets hot and loses its characteristic properties over time. In this way, reducing the negative effects of temperature on the bearing, reducing the oil temperature and keeping it away from contaminants comes to mind as the most important factor increasing the life of the bearing system. (Min and Shuyun, 2016) made a precise analysis and calculation of thermal contact resistance. Improvement of the thermal transfer model of the mattress. (Takabi and Khonsari, 2013, 24) developed a cannon carrying the mathematical model of frictional heat generation, heat transfer and transient temperature distribution;

Experiments were conducted for different speeds and loads to validate the model. (Li and Shin, 2004) The thermomechanical modeling approach is suggested for replicating the stiffness of the bearing, temperature distributions, and thermal expansions. The outcomes highlight the interplay between the dynamic and thermal characteristics of high-speed spindle systems. The process of achieving thermal equilibrium within the high-speed spindle system is dynamic. It occurs as the temperature increases, causing thermal elastic deformations in the bearing components. As a result, the geometric dimensions of the bearings are reciprocally affected. These deformations alter the geometric dimensions of the bearings, which in turn affects preload, heat generation, and stiffness. The heat generation in the bearings is closely correlated with the viscosity of the lubricant. This viscosity undergoes changes due to temperature fluctuations, which inevitably cause a temperature rise in the lubricant. This rise in temperature alters the heat generation of the bearings during the thermal equilibrium process.

The interaction between temperature rise and thermal deformation also modifies thermal boundary conditions, including convective coefficients and TCRs. Incorporating thermal-structure interaction is crucial for accurately modelling the characteristics of thermal-structure interaction due to dynamic shifts in boundary conditions. Previous transient thermal analysis methods have overlooked dynamic changes in heat sources and boundary conditions, highlighting the importance of including thermal-structure interaction when modelling high-speed spindle systems. The modelling process is divided into several sub-steps. The results of each sub-step influence the modification of heat sources and thermal boundary conditions. The adjusted heat sources and thermal boundary conditions are then applied to the finite element model to predict temperature and thermal deformation until convergence is achieved.

Bearings are older than thought. The invention of the bearing may be even older than the invention of the wheel. People discovered that it was the easier to move heavy objects along a way by placing rolling trunks underneath. Bas reliefs discovered that he was said to represent bearings by some, including layard, at Nineveh (Layard, 1849). First recorded use of cylinder to move building block and stone carvings emerged with this discovery. However, the evidence it is not clear whether Assyrians, who moved a human-headed bull about to 2700 years ago, used bearings due to the orientation of the rollers under the sled. Aristotle referred to frictional force and observed that it is lowest for round objects. Rolling elements in libraries in Alexandria were used with mechanical precision, and probably plain bearings have been developed. However, there is no evidence that rolling bearings have been used or studied. Engineers for Alexander the Great many important military machines were developed. One of them is a movable tower made by Diades from 330. Different fluids were also used for the lubricants used to make the reduce friction of bearing between those balls. An excellent example of bearing can be seen in the construction of the pyramids, where the Ancient Egyptians used roller bearings to support in the transfer of large stone bricks. Around 1500’s, about the next known mention of a ball bearing usage was a sketch by Leonardo Da Vinci. He added the ball bearings to the design of helicopter who was designed. After

100 years Galileo will describe another type of ball bearing relevant to Da Vinci’s sentence. The first modern patent for ball bearings was received by English inventor and blacksmith Philip Vaughan, who developed ball bearing design in Carmarthen in 1794. Bearing was played a crucial role in the Industrial revolution and enabled new industrial machinery to run efficiently. For example, they saw the use of holding the wheel and axle to drastically to reduce friction, where the friction created as the wheel turns is absorbed by the balls. The first roller bearings were the made with wooden, follow by bronze. Bearings have been made of many materials throughout history, including ceramic sapphire, glass, steel, bronze, other metals and plastic (polyethylene, nylon etc.). Simple bearings that reduce friction in rotating parts, such as the axles of cars, have been used for thousands of years. In the late 1800s, improvements in machining industry and manufacturing expanded the use of bearings in all types of machinery, highly increasing its precision. Bearings are reducing friction between rotating surfaces and ensure correct operation. Bearings become various shapes and sizes (including ball, roller, tapered and simple friction). Modern bearings are usually designed in an inner and outer ring. Variations in size, shape, alignment and cage allow bearings to be used in almost every industry, from industrial turbines, centrifugal machines and automobiles to household mixers. The rolling element options have been diversified and multiplied in according to using area. Bearings can now also carry greater forces and combined (axial and radial) loads. One of the most known bearings are classify and describe in below.

As a result of the decrease in the gaps between the balls in the bearing due to the temperature increase, a negative situation is observed in the function of the bearing. This leads to problems of bearing failure, vibration and reduced life. Therefore, it is desired that the temperature increase should be at a certain level. Since plastic cages cannot be used in high temperature applications, only brass cages become mandatory. In this case, it leads to difficulty in purchasing and not being able to find alternative parts.

3. MATERIAL AND METHOD

This chapter describes the devices used during the field testing of the thesis, the standard heat transfer equations, the heat transfer equations used for extended surfaces, the equations required to calculate the heat transfer in the oil chamber without fin and with fin, and the computer analysis inputs of the oil chambers.

Disc stack centrifugal separators function by continuously segregating solid particles present in fluids and/or fluid phases through the application of centrifugal force. There are various types of disc stack centrifugal separators, but one notable design distinction is the approach to solids removal. Manual cleaning separators require a dedicated cleaning operation, involving the disassembly of the entire machine, as they do not automatically eliminate solids from the bowl. In contrast, automatic cleaning separators include a discharge system that removes solid accumulations from the bowl.

The discharge system typically consists of a vertically movable piston that opens discharge ports during operation to expel solids. The hydraulic trigger for these discharge systems is water, and the frequency of solid discharge depends on the number of solid particles in the fluid. The centrifugal separator can employ a nozzle discharge system, which consists of a series of nozzles along the periphery of the bowl to ensure a continuous discharge of solids.

Centrifugal separators are classified as clarifiers, purifiers, and concentrators, depending on their intended applications. Clarifiers are used to remove solids from fluids or fluid mixtures, while purifiers and concentrators are used to separate fluid mixtures into phases. During phase separation, centrifugal separators effectively remove solid accumulations inside the bowl by discharging solids at specified intervals. The design of the chamber group within each centrifugal separator configuration varies significantly.

For a more comprehensive understanding of disc stack centrifugal separators, please refer to Figure 3.1, which displays a cross-sectional of the bowl group in a HAUS Maxcream 30T centrifugal separator. The Maxcream 30T model, referred to as the 'testing separator,' is used for calculations and experiments in this study.

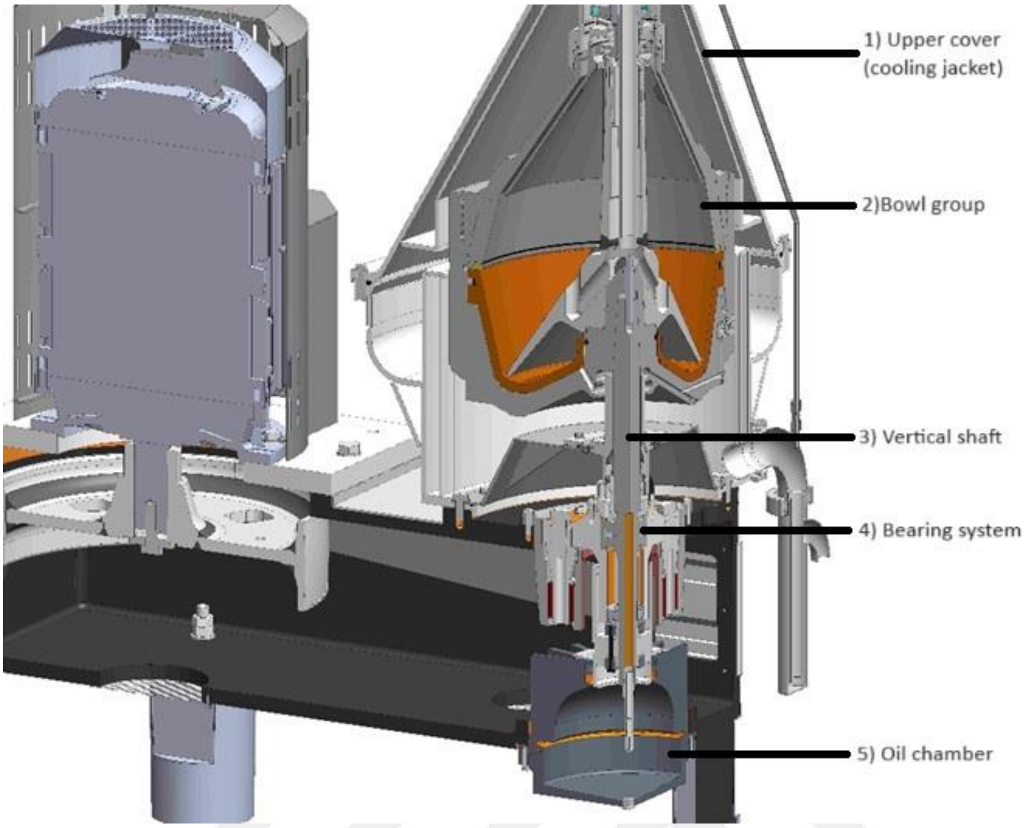

Figure 3.1. Cross section of the Maxcream 30T centrifugal separator. (HAUS Centrifuge Technologies).

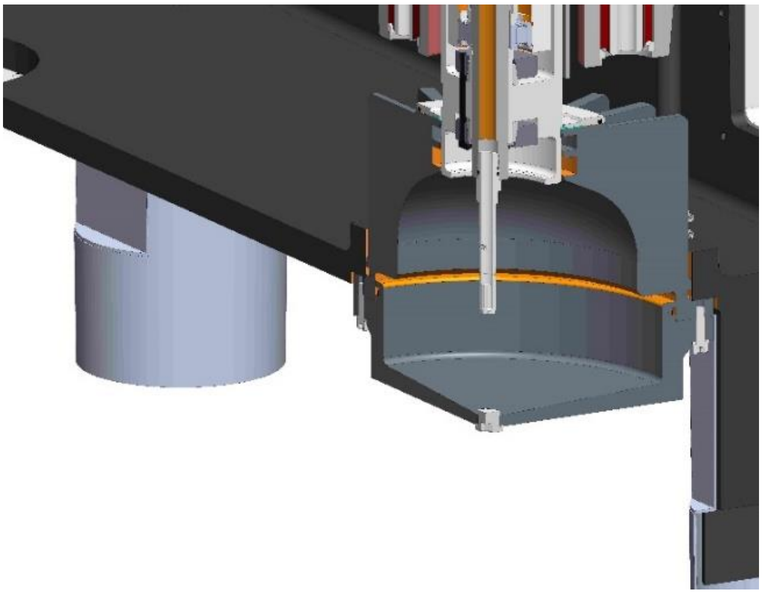

Figure 3.2. The distributor with oil chamber. (HAUS Centrifuge Technologies).

Oil chamber (Figure 3.2), a vertical shaft-connected distributor to effectively distribute the oil to the bearing elements, lubrication starts when the separator reaches approximately 3000 rpm. The lubricating oil which is goes up under the effect of centrifugal force from hole in the shaft, first reaches the deep groove ball bearings. The 7000 series was chosen for this ball bearing to take up vertical incoming loads. From here, the lubricating oil, which is goes through the lubricating parts comes to the N series bearing which is the study of this thesis. The most important issue in lubricating oils is the absence of a polluting element. For this reason, it is recommended to renew the oil approximately 250 hours after first operation. In this way, the oil will collect the contaminants that may be present in the materials after the first operation and will ensure the cleaning of the materials.

The lubricating system plays an important role in the effective operation of the bearings. With the deterioration of this situation, vibration and bearing deterioration that may occur in the machine are inevitable. For this reason, it is important that the oil temperature remains at a certain level. The choice of lubricant used is also considered as another important factor. The viscosity of the lubricant forms a parabolic curve depending on the temperature. As the temperature increases, the viscosity tends to decrease logarithmically and this decrease occurs dramatically. In order not to be affected by this situation, it is one of the first targets that the oil temperature does not increase. If the temperature continues to increase, the viscosity of the oil will decrease and the oil film between the balls will become thinner. This will reduce the residence time of the oil on the bearing and cause the lubrication principle to not work properly. The deformations that will be experienced as a result of this cause the machine to not work and thus the financial losses of the enterprise. At the same time, temperature rise is an undesirable situation in bearings. It both reduces the variety of bearings that can be used and reduces the gaps between the bearing balls, resulting in a decrease in the vertical loads that the bearing can bear. Due to this situation, it is a fact that the working life of the bearing will increase and therefore the working life of the machine will increase as a result of every effort to keep the oil temperature under control.

3.1. Field Test Unit

The test separator was placed in the HAUS Centrifuge Technologies R&D test area. The test setup equipment can be seen in Figure 3.3 – Figure 3.4. First, the without fin oil chamber is mounted on the separator to be tested. After all values were taken, the test was continued by attaching the oil chamber with fins.

Figure 3.3. First testing setup in R&D testing field.

The first test was performed with the HAUS disc type centrifuge machine produced as a standard, and the test duration was determined as 7 hours. During this period, values will be taken every 1 hour and the rate and amount of increase in oil temperature will be measured.

Figure 3.4. Second testing setup in R&D testing field.

The separator oil chamber contains 9.5 liters of oil. All other parts of the separator are assembled. Sight glass is placed in front of the separator so that lubrication can be observed. Lubrication will reach all bearing elements under centrifugal force. The product inlet line is connected to the feed pump. 1 number is oil chamber, 2 number is product inlet.

The separator speed can be adjusted with the VFD installed inside the electrical panel (Figure 3.5). Lubrication starts after 3000 rpm. The maximum speed of the separator is 5800 rpm at 50 Hz. It is important not to operate below 3000 rpm to prevent deformation of the bearings. Thanks to the motor VFD, the separator bowl speed can be adjusted. The separator bowl speed can be read from the electrical panel screen.

Table 3.1. Electrical panel features.

Properties	Device	Brand
Speed Control	VFD	DANFOSS
Vibration control	Vibration sensor	IFM-VKV021
Value control	Screen	SIEMENS KTP-700

Figure 3.5. Electrical panel.

A flow meter (Figure 3.6) is connected to the feeding line to ensure the stability of the product to be fed to the separator. After making sure that both tests were at the same flow rate, the values were taken. The product inlet capacity is 30 m3/h. Heavy phase outlet pressure is set as 3 bar.

The table shown provides the specifications of the flow meter used in the field test.

Table 3.2. Flow meter features.

Properties	Value	Unit
Measuring range	1 - 50	m^3/h
Max. process pressure	PN 10 – PN40	bar
Ambient temp. range	-20 --- +60	°C
Protection class	IP 67	-
Inputs	Status	-
Outputs	4-20	mA

Figure 3.6. Flow meter

Figure 3.7. A screen of showing flow rate

In order to keep the temperature of the bowl group constant, a solenoid valve has been added on the line so that cold water can be supplied to the outer body. 1500 ms cold water was given every 10 seconds. In this way, the outer body temperature was kept constant at approximately 40-45ºC.

The test was carried out with the without fin oil chamber and the oil chamber with fins added for 7 hours at an ambient temperature of 21-22º. Oil temperatures were measured from 2 different points (Figure 3.8) every 1 hour.

The finned oil chamber is designed to have 360º fins as shown in Figure 3.9. The fins are optimized so that they do not protrude from the part. The surface area that will transfer heat has been increased by 15%.

Figure 3.8. Heat measurement points

Table 3.3. Temperature measurement device features.

Properties	Value	Unit
Accuracy	0 < x < 100, ±2°C	°C
Reaction time	%95 in 500 ms	-
Repeatability	%1 for each measure	-
Environment condition	0 - 60	°C

Figure 3.9. With fin oil chamber before assembling the separator

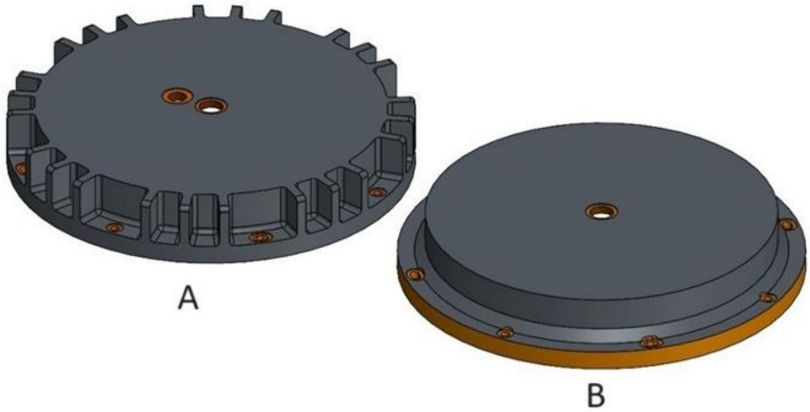

Figure 3.10. 3D models of oil chambers (A is with fin oil chamber, B is without fin oil chamber).

This configuration was specifically designed to study the effects of extended surfaces on heat transfer. It will be compared with the design with no surface augmentation. All test conditions are the same for both parts.

3.2. Identifying of the Main Factors Affecting Heat Increasing

Disc type centrifugal separators are systems consisting of a drum group with an outer body, driven by an electric motor, where the product is exposed to centrifugal force. The drum is mounted with a vertical shaft and transmits the drive it receives from the electric motor to the drum group. Electric motors can be directly connected or controlled via an inverter. Drivers are now preferred in new technologies. Since the bearing elements of centrifugal separators are not self-lubricating, they must be lubricated with liquid oil. This lubrication system is carried out by the flow of oil from the channel in the vertical shaft to the bearing elements together with the vortex created by the centrifugal force based on the same principle through the vertical shaft. This lubrication starts at approximately 3000 rpm.

The temperature of the lubricating liquid of centrifugal separators is directly proportional to the efficiency and life of the bearing system. For this reason, keeping the temperature at certain levels and not increasing excessively are important for centrifugal separators. Many factors can be written as the main reason for the increase in temperature. Among these factors, the most suitable one should be determined and temperature increase should be prevented by making appropriate revisions. Theoretically, the following parameters can be listed to increase the lubricating oil temperature.

- Wind: Air friction caused by high-speed rotation of the vertical shaft.
- Mechanical Parts: Mechanical parts in contact with each other.
- Product Temperature: Which temperature product the processed.

$$E_i - E_0 = 0\# \tag{3.1}$$

Even though energy is produced in the environment, it does not affect the energy balance on the control surface. If we write the energy balance for 3 heat transfer terms;

$$q''_{conduction} - q''_{convection} - q''_{convection} = 0\# \tag{3.2}$$

Before moving on to heat transfer calculations, it will be useful to know the temperature increase depending on the operating hours of a lubricant.

Table 3.4. Lubricant oil features (Shell General Catalogue, (2016)).

Features	Method	Omala 220 (Oil)	Unit
ISO viscosity level	ISO 3448	220	-
Kinematic viscosity (40°C)	ISO 3104	220	mm^2/s
Kinematic viscosity (100°C)	ISO 3104	19.4	mm^2/s
Density (15°C)	ISO 12185	899	kg/m^3

As you can see, the oil temperature is fixed at approximately 50ºC after one hour. This study will be based on an oil temperature of 50ºC and validated in field testing. You can find the heat transfer equation (Cengel and Cimbala, 2018) of a system simply below.

$$Q = kA\frac{dT}{dx} \tag{3.3}$$

One reason of the temperature increases of the lubricant in separators is the air friction known as the windage effect. The high-speed rotation of the vertical shaft stirs the air in and around the oil chamber, causing a wind effect. To understand the wind effect, a simplified drawing of the test separator is shared and the air turbulence is shown in this Figure 3.4, inside the oil chamber and the frame body.

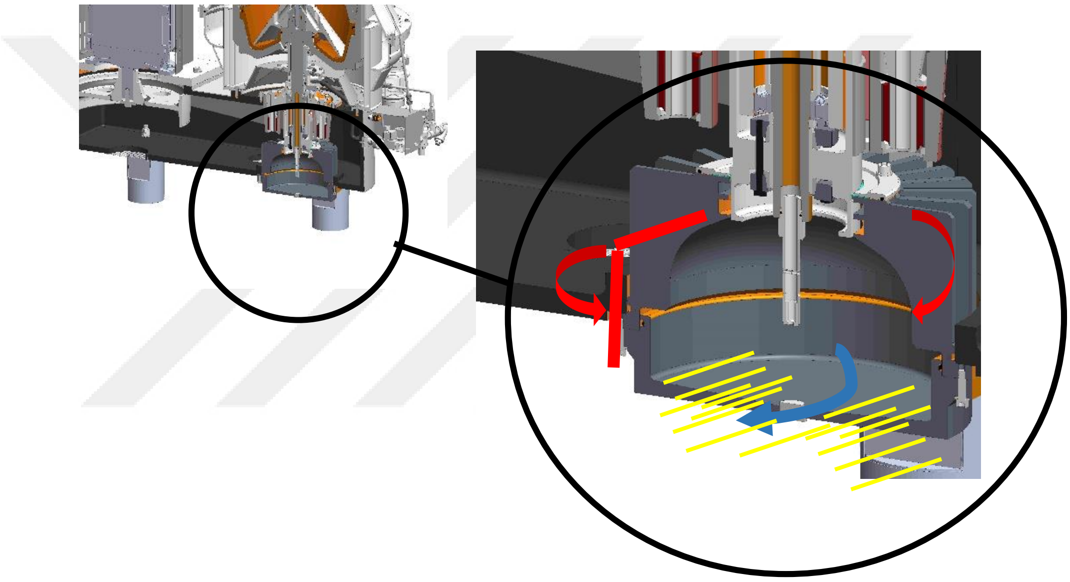

Figure 3.11. Without fin oil chamber of the testing separator centrifugal separator (HAUS Centrifuge technologies).

Since the oil is constantly exposed to this wind effect, the temperature increase will increase depending on the ambient temperature. Reducing the contact of the lubricant with the external environment and increasing the heat transfer with the ambient temperature will minimize and control the temperature increase. The ribs on the upper part of the oil reservoir are the right choice for this, but not on the lower part. This section will focus on this piece. For calculation, there is a heat transfer by conduction and convection. The following equation can be written to calculate the heat transfer by conduction(Incropera and DeWitt, (2010));

$$q''_x = -k\frac{dT}{dx}\ (Fourier\ rule)\#\qquad(3.4)$$

and,

$$\frac{dT}{dx} = \frac{T_2 - T_1}{\mathrm{L}}\#\qquad(3.5)$$

And heat flux;

$$q''_x = -\mathrm{k}\ \frac{T_2 - T_1}{\mathrm{L}}\#\qquad(3.6)$$

Thus equation is heat transfer with conduction and convection equation is below;

$$\mathrm{q}'' = \mathrm{h}\ (T_s - T_\infty)\#\qquad(3.7)$$

There is only one wall here and the heat conduction to the lubricant will be from the environment. The equation for this heat through conduction is found by Fourier's law.;

$$q_x = -kA\frac{dT}{dx}\#\qquad(3.8)$$

and the equation for oil chamber can be expressed as;

$$q''_x = \frac{q_x}{A} = \frac{kA}{L}\ (T_{s,1} - T_{s,2})\#\qquad(3.9)$$

As it is known, the equation in 3.10 shows the similarity between heat dissipation and electric current. If we write the heat conduction formula using this similarity;

$$R_{t,con} = \frac{T_{s,1} - T_{s,2}}{q_x} = \frac{L}{kA} \# \tag{3.10}$$

Likewise, the thermal resistance may be related to the transfer of heat by convection at the surface, from which the air lubricant heating formula can be written as follows;

$$R_{t,conv} = \frac{T_{s,1} - T_{\infty}}{q_x} = \frac{1}{hA} \# \tag{3.11}$$

This temperature changes with time. The oil temperature rises as the machine continues to run, but at some point it no longer remains constant. The reason for this is that there is an internal and external balance. Here we can write the time dependent heat transfer equation as follows.

$$L_c = \frac{V}{A_s} \tag{3.12}$$

After the characteristic length is found, the Biot number must be less than 0.1 in order to use the total mass law in the calculation.

$$Bi = \frac{hL_c}{k} \tag{3.13}$$

From here, the following equation is used to calculate the time taken for heating.

$$b = \frac{hA_s}{\rho c_p V} = \frac{h}{\rho c_p L_c} \tag{3.14}$$

When the equation here is written in its place below(Cengel and Cimbala, 2018);

$$\frac{T(t) - T_\infty}{T_i - T_\infty} = e^{-bt} \tag{3.15}$$

3.2.1. Increase the Heat Transfer between Oil and Outside

Centrifugal separators need roller bearing (angular contact ball bearing and cylindrical bearings and etc.) system due to its high loading capacity and high speeds. This system is lubricated with liquid lubrication. In this way, liquid lubrication allows to reach higher speed than grease lubrication. The life and quality of the oil used play and important role. As the lubricating oil heat increasing and its viscosity decreases. This may cause the lubrication layer not to be fully formed between the balls in the bearing and cause the balls to rub against each other. In this way, the temperature due to friction increases and the mechanical parts mix into the oil. So, shelf life of the oil reduce and maybe after cannot be used. Bearing damage and inability to use the lubricant can cause the centrifugal separator to stop and caused of operating costs. For this reason, it is important that the temperature of the lubricating oil is as low as possible and that it is within the temperature limit determined by the bearing manufacturer. In this way, the lower temperature increases the bearing life. There are a number of ways to keep temperature of the lubricating oil low. Running cold water in the oil, operating the centrifugal separator in a cold environment, etc. The subject we will examine is extended surfaces. With fins oil chamber in order to increase heat transfer with the environment, further heating of the oil will be prevented and it will be desired temperature level. The upper chamber of the oil chamber, this issue we will study is the lower chamber of the oil.

3.2.2. Theory of Increasing Heat Transfer Due to Fins

The aim of the improvement works carried out to increase the heat transfer is to is to increase amount of heat transfer, to reduce temperature between the environment and the fluid. Thus, to improve the total heat transfer efficiency. The methods used to increase heat transfer can be briefly listed as increasing the heat transfer surface, improving the surface and making the flow with turbulent. In today's technology, it is generally used to increase the surface area to increase the amount of heat transfer. Finned surfaces (with extended surfaces) increase heat transfer by increasing the surface and making turbulent flow with the liquid or gas that will increase the heat transfer. General usage areas can be counted as gas turbine engines, electrical motor frames, aircraft industry and chemical production facilities.

Fins are chosen and designed for a specific purpose. Fins can be designed in many different geometries. For example, rectangular fins are generally used in computer operating systems and circular fins are used in heat exchangers.

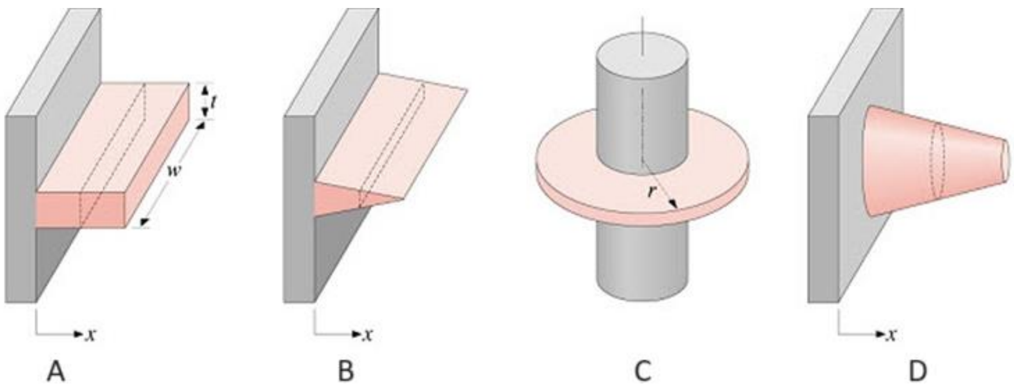

Figure 3.12. Specific fins designed (Cengel and Cimbala, 2018).

In our thesis, we will consider the rectangular fin (A image in Figure 3.12) design. By placing this fin design on the outer diameter of the oil chamber at the bottom of the centrifugal separator. It will increase the amount of heat transfer between environment and the oil chamber. In this way it is aimed of the prevent further heating of the lubricating oil. Before moving on to the design, let's find out how we can increase the efficiency of the cooling capacity.

1. Increase the temperature of between surface and ambient temperature. $(T_y - T_\infty)$

2. Increase the convection efficiency.

$$q_x = -hA\frac{dT}{dx}\ (FourierLaw) \tag{3.16}$$

As can see upper equation, if increase the convection efficiency than heat transfer amount will increase. There are 2 ways to improve the convection (h)

- Change the fluid
- İncrease the velocity of ambient cooling gas

3. Increase the surface area (A).

$$\varepsilon_{fin} = \frac{A_{fin}}{A_b}\,\eta_{fin} \tag{3.17}$$

A_{fin} = Total heat transfer square for the fin

A_b = Total heat transfer square without the fin

Where η_{fin} can be defined as the ratio the actual heat transfer from the fin (Ó) , to the ideal heat transfer ($Ó_{max}$);

$$\eta_{fin} = \frac{Ó}{Ó_{max}} \tag{3.18}$$

Ó : Actual heat transfer rate from fin

$Ó_{max}$: Maximum heat transfer rate

Heat transfer amount of finned surface can be written to below;

$$m = \sqrt{\frac{2h}{kt}} \tag{3.19}$$

t = thickness of fin,

$$A_{fin} = 2wL_c \tag{3.20}$$

w = wideness of fin, L_c = corrected fin length;

$$\eta_{fin} = \frac{tanh\,(mL_c)}{mL_c} \tag{3.21}$$

$$\dot{Q}_{fin} = \eta_{fin}\, A_{fin}\, (T_b - T_\infty) \tag{3.22}$$

Wing efficiency on finned surfaces, fin thrown the maximum amount of heat that can be removed from the fin under those conditions is defined as the ratio of heat transfer.

The longer the fin, the larger the heat transfer area and therefore the higher the amount of heat transfer from the fin.

The larger the fin, the greater its mass. As a result, the price goes up. Heat transfer will also increase with convection. Due to the decrease in temperature at the tip of the wing depending on the fin length, the fin efficiency decreases as the fin lengthens.

3.2.3. Fin Effectiveness

The performance of the fins is evaluated according to the increase in heat transfer compared to the finless condition. This increase is called fin efficiency.

$$\varepsilon_{fin} = \frac{A_{fin}}{A_b}\, \eta_{fin} = \frac{\dot{Q}_{fin}}{\dot{Q}_{no\ fin}}, \dot{Q}_{no\ fin} \tag{3.23}$$

$$= h\, A_{no\ fin}\, (T_b - T_\infty)$$

$$\varepsilon_{fin} = \begin{cases} < 1 & \text{Fin acts as insulation} \\ = 1 & \text{Fin doesn't affect heat transfer} \\ > 1 & \text{Fin useful heat transfer} \end{cases}$$

In order to increase the heat transfer enhancing efficiency of the fins, they must have the following features:

- The thermal conductivity of the fin material should be as high as possible
- The ratio of the circumference of the part taken over the fin to the cross-sectional area of the fin p/Ac should be as high as possible.
- Fins increase the amount of heat transfer in the most effective way in the region where natural convection heat transfer will occur.

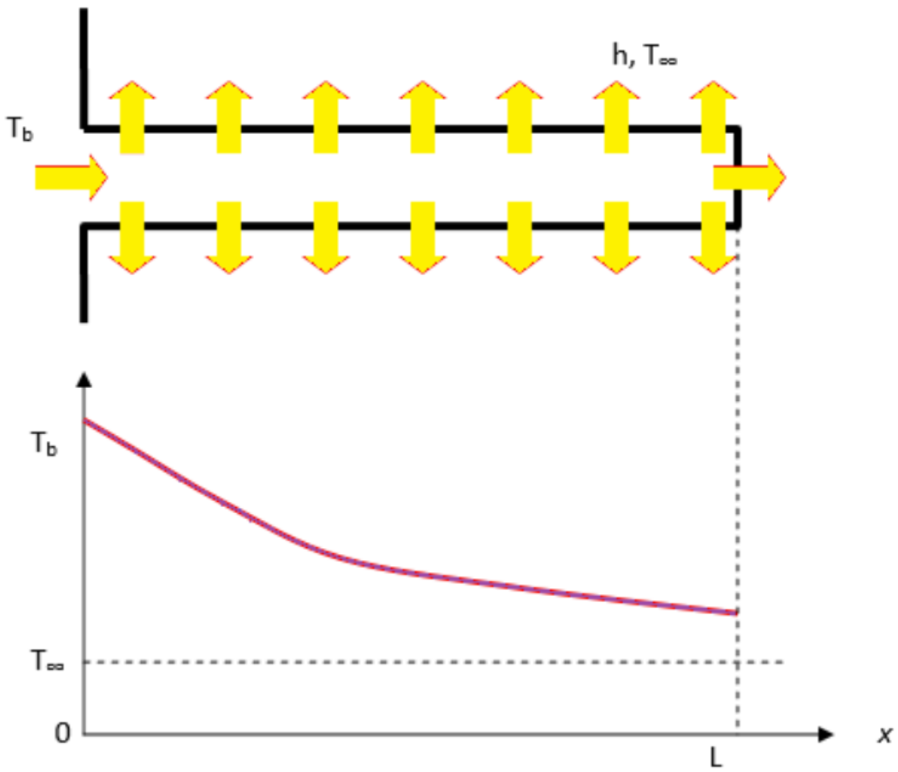

Figure 3.13. Heat transfer on the extended surface (Cengel and Cimbala, (2018)).

Desired in the heat transfer improvement studies in heat exchangers; decrease in weight and size, heat transfer to increase the amount. Average temperature difference between fluids is to improve overall efficiency. heat transfer

The methods used to increase are usually enlarged surfaces.

It includes some changes to be made on the surface and the turbulence desired to be created in the flow area.

Expanded heat transfer surfaces are one of the most commonly used methods to increase the amount of heat transfer. Finned surfaces increase the surface area and turbulence of the flow by convective heat and mass increase their transmission. The application area of finned surfaces is very diverse. Gas turbines as the main areas of use cooling of turbine blades in engines, aviation, aircraft with cooling of electronic devices and various heat exchangers in chemical production facilities. However, the fins improper use may increase heat transfer can reduce instead. Fin material, type, layout, mounting type and considering each of the environmental conditions separately.

It should be examined and designed to increase heat transfer.

As a result of the decrease in the amount of heat supplied, it causes a decrease in the performance of the heat exchanger. This means capacity loss in the system using a heat exchanger.

Two-dimensional flat model by Lee and Abdel-Moneim using the CFD model.

Heat transfer and flow from the surface numerically investigated. Experimentally and numerically investigated the flow and heat transfer in the fins for the periodically developing flow field. Liou, Chang and Hwang [5] and Liou, Hwang [6] different fin height and conducted their research for two pairs of turbulent generators arranged in tandem at different inclination angles at flow rates (Chang vd.)

(1.2 x 104 < Re < 12 x 104). The effects of three different enlarged surface geometries placed in a two-dimensional rectangular channel on heat transfer effects. Minimum inlet temperature using air as working fluid the thermal design of a counter-flow heat exchanger is done according to the difference and minimum entropy generation unit conditions. Smooth and serrated analyzed the flow and heat transfer characteristics for finned plate heat exchangers.

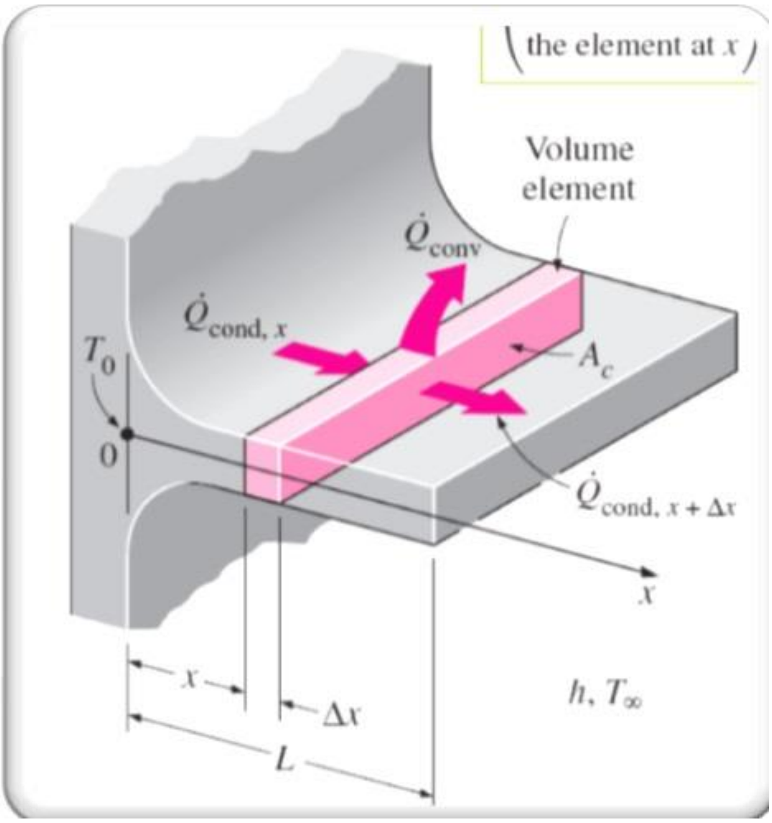

Figure 3.14. Theory of fins to heat transfer (Cengel and Cimbala, 2018).

Finned surfaces are used to increase heat transfer in areas where effective cooling is required. By increasing the heat transfer surface area. The heat transferred from the environment per unit time are heat exchangers that contribute to the recovery of the rectangular fin amount.

3.3. Oil Chamber Simulation in Comsol Multiphysics

3.3.1. Problem Definition

In this study, a CFD model related to oil temperature rise and bearing life improvement with alternative oil chamber designs placed at the outlet of an industrial disk pile separator was created.

A test setup was created assuming that the outdoor temperature and all conditions were constant throughout the test period. With this approach, the analysis made under defined boundary conditions of CFD converges with the real application.

The only design differences in the oil chambers are the extended heat transfer surface areas and are visible on the model.

Ambient temperature and heat transfer conditions and parameters apply to input conditions for all 3D models that have secondary and tertiary processes applied in SolidWorks. The heat transfer and the change of oil temperature are collected via CFD. With this data, it becomes the result of the rest of the heat transfer calculation.

3D models of the parts are shared to better understand the heat transfer surface areas. (Figure 3.15)

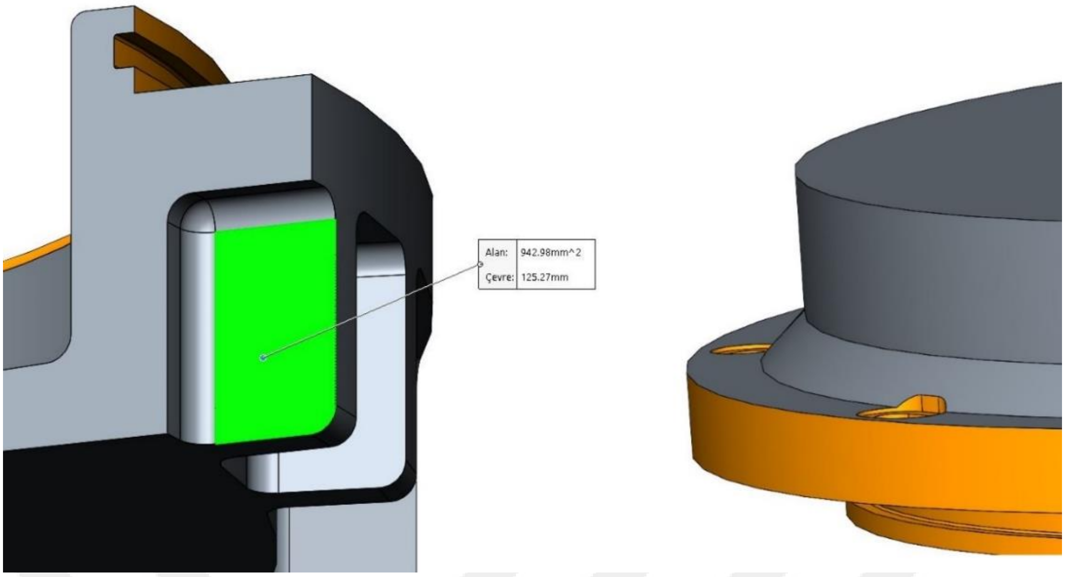

Figure 3.15. The 3D models of oil chambers designs.

Total surface area of the heat transfer has been shared in the Table 3.5

Table 3.5. That squares from SolidWorks 3D models and calculation.

Type	Value	Unit
Without fin oil chamber	0.153	m^2
Extended surface oil chamber	0.175	m^2

The 3D model is created in CAD-CAE (Computer Associated Design-Computer Associated Engineering) systems. In order to create the heat transfer zone realistically, the data from the test setup was entered into Comsol Multiphysics. By taking values in this way, it was desired to control how much the deviation value between reality and theory would be. This model preparation process is given below step by step.

- CAD data is imported and edited into Comsol Multiphysics Design Modeler,
- Environmental conditions and system requirements are transferred into Comsol Multiphysics and environmental conditions are ignored,
- Design excess is trimmed for final design and accurate result,
- The final 3D model is imported back into Design Modeler, then meshing and solver setup begins.

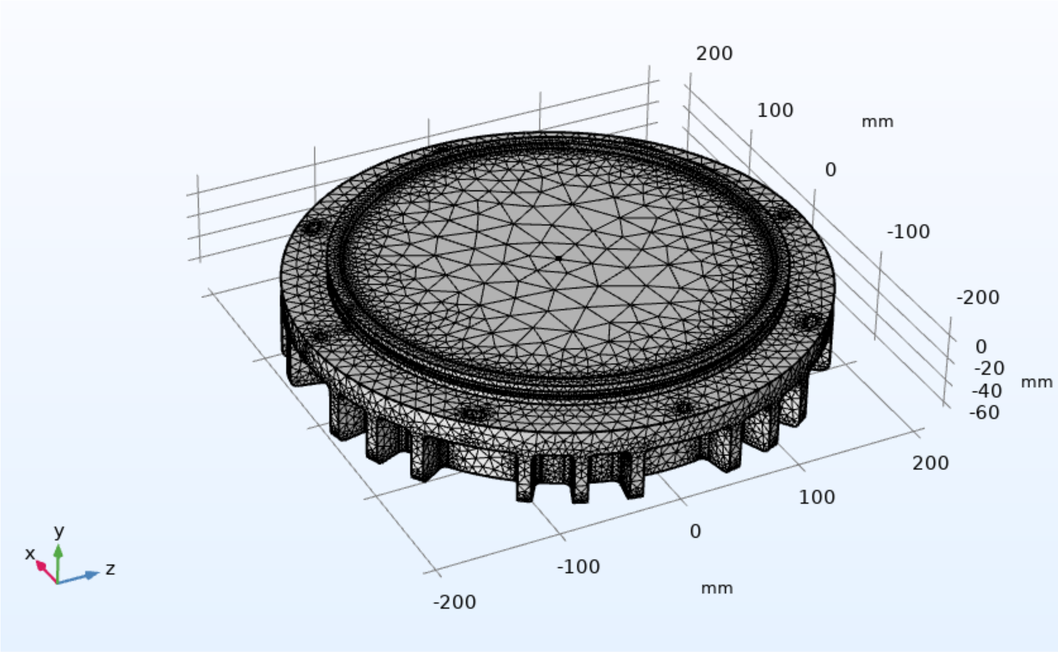

Figure 3.16. Meshing model.

Mesh was applied to the system in order to analyze the heat transfer connection between the air flow and the lubricant more precisely. The analysis was processed on the model in accordance with the field test results and the simulation was applied in parallel.

Comsol Multiphysics was used as the analysis program. At the first moment, the temperature of the entire part is assumed to be ambient temperature. The assumptions made for analysis are listed below; (Both extended surface oil chamber and without fin oil chamber)

- Both solid domain and fluid domain has initial temperature of 20ºC.
- Heat transfer in solid and fluid module is applied.
- Surface to radiation boundary condition is applied on both solid and fluid domain
- Surface emissivity of fluid domain is 0.4
- Surface emissivity of solid domain is 0.8
- Time dependent analysis is run for 7 hours.

Table 3.6. Mesh properties applied to each model.

Property	Value
Element size	Fine
Elements	174686
Minimum element quality	0.1225
Average element quality	0.6377
Element volume ratio	$1.28E^{-6}$
Mesh volume	9049000 mm^3
Mesh vertices	37738
Triangles	40304
Edge elements	7770

4. RESULTS AND DISCUSSIONS

A two-step field test was carried out in the assembly test area of the HAUS R&D Department. First, tests were made with the without fin oil chamber, then the part with added fins was tested by assembly. Ambient temperature was checked before testing began to ensure that ambient temperature or other factors did not affect the results. During both tests, it was observed that the ambient temperatures were at the level of approximately 20ºC. Before both tests, the equipment of the test site such as the flow meter and the feed pump were checked. The same test procedures were applied for both parts.

Temperatures were collected carefully during testing. Temperatures were taken every 1 hour for a total of 7 hours for one part. A total of 14 temperatures were taken and the maximum temperature reached by the oil was revealed. At what moment the temperature reached its peak point, in which interval the temperature exhibited a linear increase, all the parameters were collected, and the graphs below were created.

You can see the pictures of the measurements taken during the test in Figure 4.1 to Figure 4.5.

Figure 4.1. Environment temperature from ground.

Figure 4.2. First temperature without fins part before machine start.

Figure 4.3. Without fin oil chamber temperature at last sample.

Figure 4.4. First temperature part with extended fin oil chamber before machine start.

Figure 4.5. With fin oil chamber temperature at last sample.

4.1. Heat Transfer Calculation (Without fin oil chamber)

The heat transfer calculation was calculated by taking the ambient temperature constant. The following steps will be followed for calculation.

Table 4.1. Without fin oil chamber heat transfer solution properties.

Parameter	Value
T_a	20 °C
T_c	61.5 °C
T_o	40.3 °C
T_{oil}	78 °C
k	237.25 W/mK
A	0.153 m^2
L	0.019 m

We can find the heat transfer wires on the wall of the oil chamber using Equation 3.8,

$$Q_x = 31.5\, W$$

As it can be understood from the magnitude of the heat transfer rate, with the increase in the oil temperature, the temperature in the external environment increases rapidly and a hot environment emerges accordingly. This reduces the viscosity of the oil, thins the oil layer that will form between the bearing balls, and causes an ineffective lubrication. Due to the fact that the oil chamber is a flat diameter, it causes inefficient heat transfer with the external environment and causes the oil temperature to increase more.

Table 4.2. Without fin oil chamber time solution properties (Cengel and Ghajar, 1998)

Parameter	Value
h	17 W/m^2K
ρ	2700 kg/m^3
c_p	896 kJ/kgK

Thus, time can be calculated from Equation 3.15,

$$t = 24871\, s \cong 7\, hours$$

The result of the field test with the without fin oil chamber coincides with the calculation. When the calculation is made, the result is approximately 7 hours, and in the field test, this temperature was reached after 7 hours. In the images below, the temperature increase is also seen on the analysis.

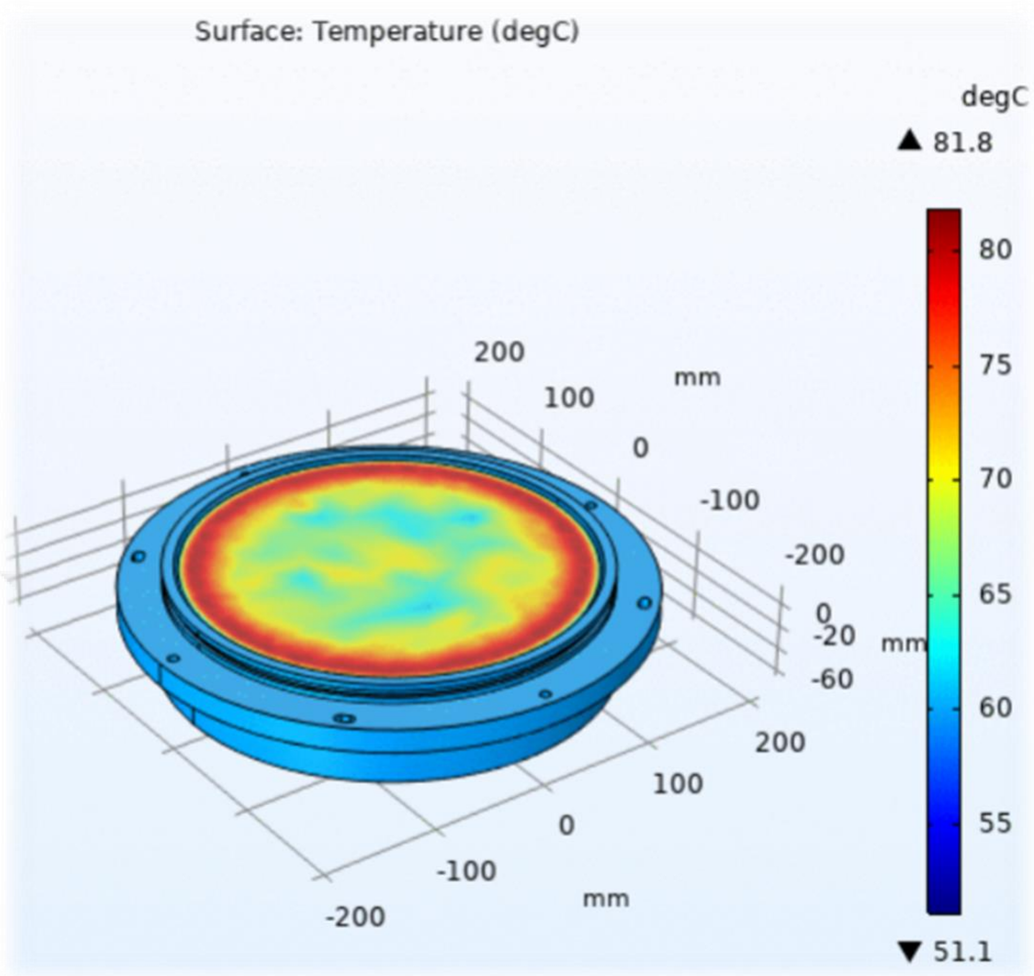

Figure 4.6. Oil chamber without fin temperature change by time.

4.2. Heat Transfer Calculation (Extended Surface Applied Oil Chamber)

With the results obtained from the field tests, it can be found how long it will take to reach the maximum temperature by calculating as follows in the oil chamber with an extended surface depending on time.

Table 4.3. Extended surface oil chamber heat transfer solution properties.

Parameter	Value
T_a	20 °C
T_c	53.2 °C
T_o	41.3 °C
T_{oil}	70.5 °C
k	237.25 W / mK
A	0.175 m^2
t	10 mm
w	45 mm
L	40 mm

We can calculate to heat transfer amount a fin with using Equation 3.22,

$$\acute{O} = 40\,W\ (for\ a\ fin)$$

Around of the oil chamber has 24 extended surfaces,

$$\acute{O} = 40\ x\ 24 \cong 960\,W\ (all\ extended\ surface)$$

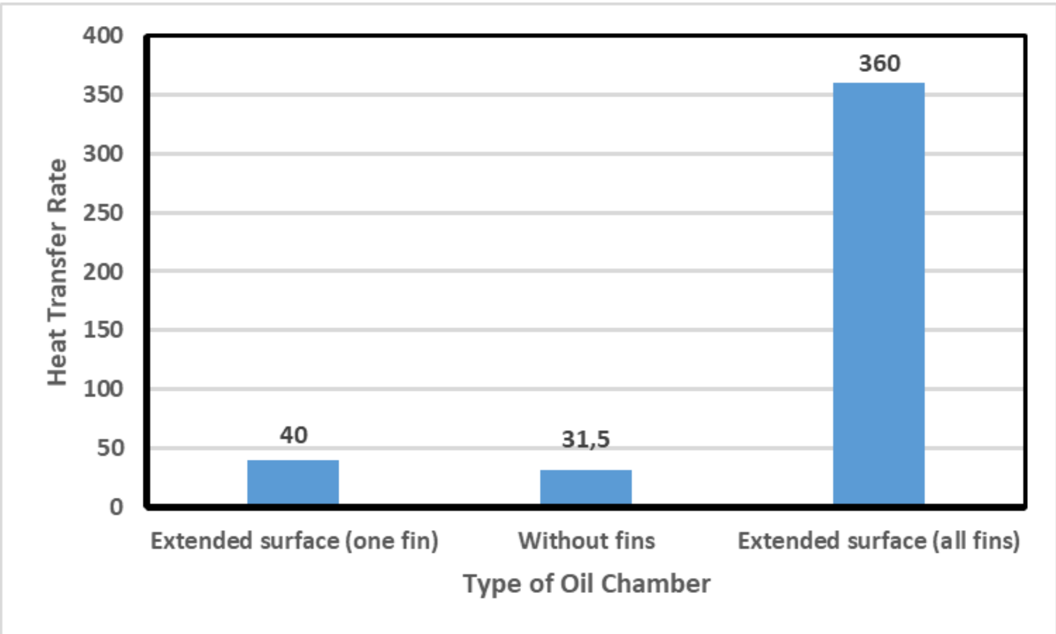

Figure 4.7. Heat transfer amount between oil chambers.

We can calculate to efficiency of a fin with using Equation 3.23,

$\varepsilon_{fin} \cong 6.8 > 1$, value bigger than 1, it has effect on the heat transfer rate.

The positive effect of extended surfaces made in this way on the amount of heat transfer is also supported by calculations. The results obtained along with field tests have been verified by calculation and analysis. What will be done from here on is to ensure that controls are made to extend the period of major maintenance that has a positive effect on the machine working in the field under real working conditions.

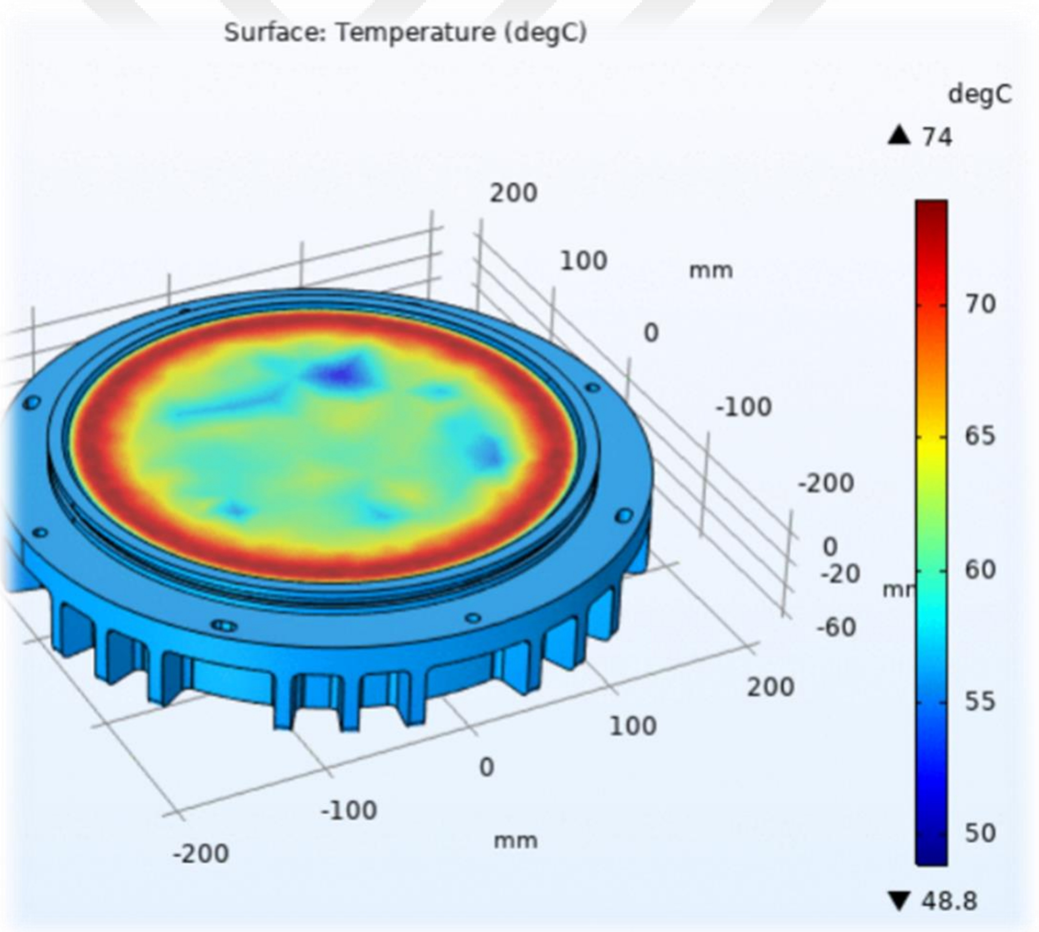

Figure 4.8. With fin oil chamber temperature change by time.

The test results showed that the extended surfaces (fin) have an effect on the heat transfer rate and the heat transfer flow rate.

When the calculation was checked, it was understood that the without fin oil chamber was insufficient in heat transfer and accordingly the temperature increased more. It has been shown by the field and calculation method that the extended surfaces increase the heat transfer and, accordingly, cool the lubricant in the environment more effectively. In this way, the prolongation of the lubrication time of the bearings can be observed with the increase of the decreasing trend in the viscosity of the lubricant.

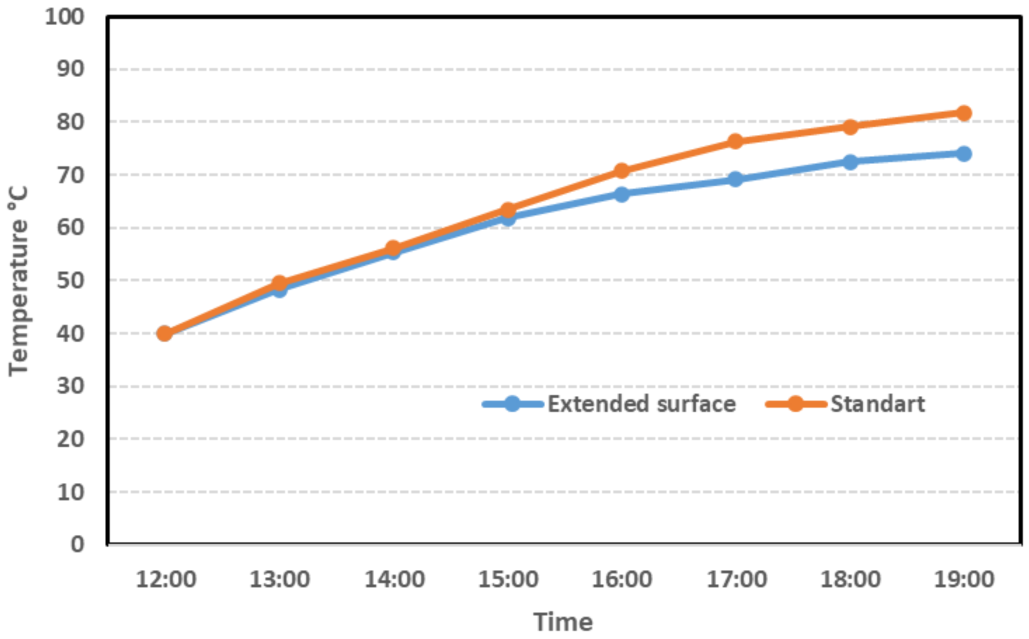

Figure 4.9. Temperature observes between oil chambers with analyse.

There is some deviation between the analysis and actual values. The reasons for this can be considered as wind effect, heat transfer coefficients of the materials being different in the real situation, friction and losses. Analysis shows us a way here, and when we look at the analysis result, it is seen that the without fin oil chamber has a higher temperature increase over time than the extended surface oil chamber.

As seen in the field tests, the maximum temperature reached by the oil within the test conditions showed a decrease of 17% with the extended surface. Therefore, the increase in bearing life can be found by observing the machine operation in line with the analysis and field test results.

For this reason, by increasing the heat transfer, the bearing life can be increased and more effective lubrication of the machine and longer life can be achieved.

The temperature comparison of without fin oil chamber design and the design with fins has been shared in Figure 4-8

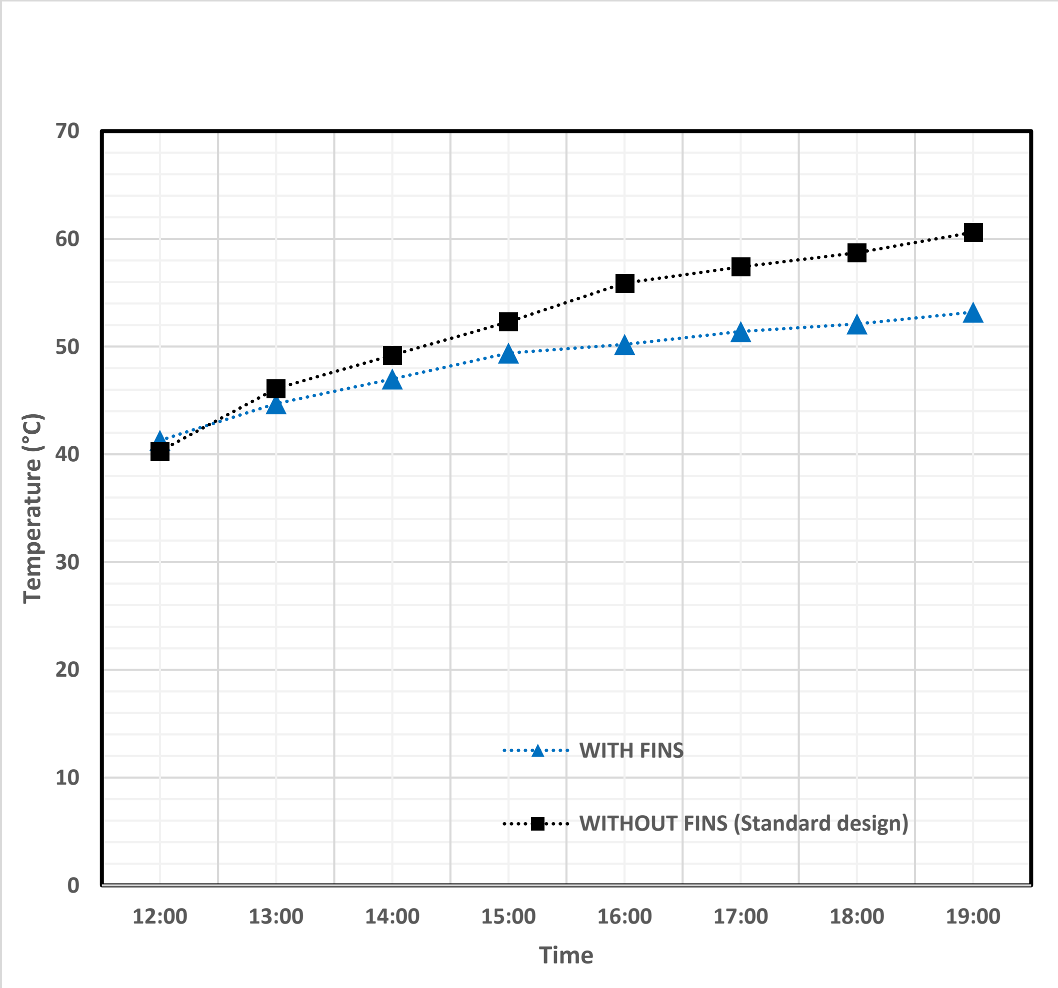

Figure 4.10. Temperature comparison between oil chambers according to experimental test.

5. CONCLUSION

Disc type centrifugal separators are useful but well-maintained equipment of the industry. It is essential to use bearings in the system, since they rotate at high speeds, the weight of the working equipment and a bearing system that carries this weight. The lubrication systems of these bearings are also of great importance in this regard. Operating temperatures of lubricants directly affect their viscosity. Viscosity can be stabilized by using a high-quality lubricant, but this will increase costs significantly. Considering the field observations, the optimum operating temperatures of the lubricant are between 50-55ºC. If the oil film is not formed at a sufficient level, adhesive wear begins. In systems that continue to operate in this way, bearing failure is inevitable.

In this study, how the temperature rise of the separator lubricant increased in 2 different parts was examined in detail. The temperature increases due to the increase in the amount of heat transfer that the oil reservoir with the extended surface can realize with the external environment decreased by 17%. While the viscosity values of the lubricant used at the temperatures reached are about 2.6 Pa. s for 52ºC, this value is 1.8 Pa. s for 61ºC (Temiz, 2015). There is a decrease in viscosity of approximately 45%. Due to the decrease in temperature, the bearing oil film layer can be preserved for a long time and lubrication can be done more effectively.

Determining the main factor in increasing the film layer is also important for future designs. It is theoretically possible for the lubricant to work steadily at 50ºC by designing a more effective extended surface on the part to be made or by designing automatic cooling systems. This will extend the bearing life as well as the period of periodic change of the lubricant. It is important to keep the temperature constant since the increase in temperature negatively affects the characteristic properties of the lubricant.

If the fin efficiency is above 1 on extended surfaces, the amount and speed of heat transfer increase. In this way, a 17% temperature was observed under the same conditions.

- The temperature can be kept at optimum values by increasing the number of ribs and the area on the oil reservoir. Since this situation depends on the ambient temperature, an external oil cooling mechanism can be recommended.
- With the extended surface added oil chamber, the machine has been working in the field and has reached 1500 hours. It was disassembled in 1000 hours and there was no problem in bearing and bedding. It will be checked again when 3000 hours.
- As the lubricant temperature rises, the film layer formed between the lubricant and the bearing becomes thinner. When the machine is disassembled, the amount of oil remaining on the bearings varies.

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