Optimization of Energy Consumption Process in Bearing Industry

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Major Project Report

Submitted in partial fulfillment of the requirements

for the Degree of

Master of Technology in Mechanical Engineering

(Thermal Engineering)

By

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Declaration

This is to certify that

1. The thesis comprises my original work towards the degree of Master of Technology in Mechanical Engineering (Thermal Engineering) at Institute of Technology, Nirma University and has not been submitted elsewhere for a degree.

2. Due acknowledgment has been made in the text to all other material used.

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Undertaking for Originality of Work

I, **Thakkar Jay Piyushbhai**, Roll No. **12MMET**27, give undertaking that the Major Project entitled **"Optimization of Energy Consumption Process in Bearing Industry"** submitted by me, towards the partial fulfilment of the requirements for the degree of **Master of Technology in Mechanical Engineering (Thermal Engineering)** of Nirma University, Ahmedabad, is the original work carried out by me and I give assurance that no attempt of plagiarism has been made. I understand that in the event of any similarity found subsequently with any published work or any dissertation work elsewhere; it will result in severe disciplinary action.

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Thakkar Jay Piyushbhai

Abstract

The energy issue is becoming a determining factor in the living standards of individuals as well as societies. The increasing demand for productivity, improved quality of products/services, reduced environmental emissions, and reduced energy costs are all incentives for organizations to invest in and implement new energy efficiency technologies with management approaches. This necessitates a collective effort towards the efficient and careful utilization of all energy resources.

Present study, introduces the concept of ISO 50001:2011 Energy Management System (EnMS). This approach would require the involvement of all members of a facility to take part in energy conservation activities. This approach will help to implant the awareness and commitment to energy conservation on all levels, therefore saving money and protecting the environment.

In present scenario, bearing industry has major energy consumption areas heat treatment process, air handling unit, air compressor and chiller for cooling. Here focus on chiller is given to reduce energy consumption. To fulfill the requirement of chiller tank in heat treatment area where temperature required is around 7^oC can be retrofit with Li-Br system and can increase evaporator temperature of main chiller up to 15^oC where normally it is around $7-10^oC$. This action will help to increase COP of main chiller and hence saving energy.

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Nomenclatures

Q	=	Heat Load(kW)
T	=	Temperature(^oC)
P	=	Pressure(kPa)
L	=	Length(ft)
H	=	Enthalpy(kJ/kg)
W	=	Mass Flow Rate(kg/s)
C_P	=	Specific Heat(kJ/kgK)
ρ	=	Densitykg/m^3
X	=	Concentration of LiBr in Solution(%)
ΔT	=	Temperature Difference^oC
U	=	Overall Heat Transfer CoefficientW/m^2K
σ	=	Stefan-Boltzman constant(W/m^2K^4)
ε	=	Emissivity of the surface
R	=	Thermal Resistance of Furnace Wall$(^oC/W)$
F_{fa}	=	View factor between the inside of Furnace and Surroundings
V	=	Volume Flow Rate(m^3/hrs)
V	=	Volts
R	=	Ohm

Abbreviation

MDG_s	=	Millennium Development Goals
$OECD$	=	Organization for Economic Co-operation and Development
$OPEC$	=	Organization of the Petroleum Exporting Countries
$MTOE$	=	Million tonnes of Oil Equivalent
$EnMS$	=	Energy management System
$LEED$	=	Leadership in Energy and Environmental Design
$IGBC$	=	India Green Building Council
VAR	=	Vapour Absorption Refrigeration
COP	=	Co-efficient Of Performance
$24HSVAR$	=	24 Hour Solar Vapour Absorption Refrigeration
TR	=	Ton of Refrigeration
SDB	=	Switch distribution board
PCM	=	Phase change material
$GSHP$	=	Ground source heat pump

Chapter 1

Introduction

1.1 General

Energy is critical, directly or indirectly, in the entire process of evolution, growth and survival of all living beings and it plays a vital role in the social-economic development and human welfare of a country. Energy has come to be known as a 'strategic commodity' and any uncertainty about its supply can threaten the functioning of the economy, particularly in developing economies. Achieving energy security in this strategic sense is of fundamental importance not only to India's economic growth but also for the human development objectives that aim at alleviation of poverty, unemployment and meeting the Millennium Development Goals (MDGs). Holistic planning for achieving these objectives requires quality energy statistics that is able to address the issues related to energy demand, energy poverty and environmental effects of energy growth.[1]

1.2 World Energy Review-2012

Once again, all of the net growth took place in emerging economies, with China and India alone accounting for nearly 90% of the net increase in global energy consumption. OECD (Organization for Economic Co-operation and Development) consumption declined for the fourth time in the past five years, led by a large decline in the US. Despite the slowdown, consumption and production reached record levels for all fuels except nuclear power and bio-fuels. The data suggests that growth in global CO_2 emissions from energy use continued in 2012, but at a slower rate than in 2011.[2]

Oil prices are influenced by number of factors. Crude oil prices peaked in March 2012 following a decline in Iranian exports, but eased thereafter in the face of rising output in the US, Libya, and other OPEC producers. Oil production growth in the US was the largest in the world in 2012, and the largest in the country's history. In response, the differential between Brent and West Texas Intermediate (WTI) reached another record premium, although the gap began to narrow later in the year as infrastructure bottlenecks in the US eased.

Natural gas prices rose in Europe and Asia, but fell in North America, where rising US natural gas output pushed gas prices to record discounts against both crude oil and international gas prices. Coal prices declined in all regions.

1.3 Energy developments:

World primary energy consumption grew by 1.8% in 2012, well below the 10-year average of 2.6%. Consumption in OECD (Organization for Economic Co-operation and Development) countries fell by 1.2%, led by a decline of 2.8% in the US (the world's largest decline in volumetric terms). Non-OECD consumption grew by 4.2%, below the 10-year average of 5.3%. Global consumption growth was below average for each fossil fuel and for nuclear power; regionally growth was below average everywhere except Africa. Oil remains the world's leading fuel, at 33.1% of global energy consumption, but it also continued to lose market share for the 13th consecutive year and its current market share is the lowest in our data set, which begins in 1965.[2]

1.3.1 Oil

Global oil consumption grew by 890,000 barrels per day (b/d), or 0.9%, below the historical average. Oil had the weakest global growth rate among fossil fuels for the third consecutive year. OECD consumption declined by 1.3% (530,000 b/d), the sixth decrease in the past seven years; the OECD now accounts for just 50.2% of global consumption, the smallest share on record. Outside the OECD, consumption grew by 1.4 million b/d, or 3.3%. China again recorded the largest increment to global consumption (+470,000 b/d, +5%) although the growth rate was below the 10-year average. Japanese consumption grew by 250,000 b/d (+6.3%), the strongest growth increment since 1994. Light distillates were the fastest-growing refined product category by volume for the first time since 2009.

Global oil production, in contrast, increased by 1.9 million b/d, or 2.2%. OPEC accounted for about three-quarters of the global increase despite a decline in Iranian output (-680,000 b/d) due to international sanctions. Libyan output (+1 million b/d) nearly regained all of the ground lost in 2011. For a second consecutive year, output reached record levels in Saudi Arabia, the UAE and Qatar. Iraq and Kuwait also registered significant increases. Non-OPEC output grew by 490,000 b/d, with increases in the US (+1 million b/d), Canada, Russia and China offsetting unexpected outages in Sudan/South Sudan (-340,000 b/d) and Syria (-160,000 b/d), as well as declines in mature provinces such as the United Kingdom and Norway.

Global refinery crude runs increased by a below-average 480,000 b/d, or 0.6%. Non-OECD countries accounted for two-thirds of the net increase, rising by 320,000 b/d. OECD throughputs grew by 160,000 b/d, with continued throughput declines in Europe more than offset by throughput increases in North America, where the US consolidated its position as a net product exporter. Global refinery capacity utilization improved to 82.4%; global refining capacity increased by a modest 360,000 b/d overall, but large capacity additions East of Suez were largely offset by substantial capacity reductions in and around the Atlantic Basin.

Global oil trade in 2012 grew by 1.3%, or 0.7 million b/d. At 55.3 million b/d, trade accounted for 62% of global consumption, up from 57% a decade ago. The relatively small global increase hides large regional changes. US net imports fell by 930,000 b/d and are now 36% below their 2005 peak. Conversely, China's net oil imports grew by 610,000 b/d, 86% of the global increase. Growth in net exports from Canada and North Africa, together with reduced US oil import dependence, offset declining exports from several regions.

1.3.2 Natural Gas

World natural gas consumption grew up to 2.2%, below the historical average of 2.7%. Consumption growth was above average in South & Central America, Africa, and North America, where the US (+4.1%) recorded the largest increment in the world. In Asia, China (+9.9%) and Japan (+10.3%) were responsible for the next-largest growth increments. These increases were partly offset by declines in the EU (-2.3%) and the Former Soviet Union (FSU) (-2.6%). Globally, natural gas accounted for 23.9% of primary energy consumption. OECD consumption grew more rapidly than non-OECD consumption for the first time since 2000.

Global natural gas production grew by 1.9%. The US (+4.7%) once again recorded the largest volumetric increase and remained the world's largest producer. Norway (+12.6%), Qatar (+7.8%), and Saudi Arabia (+11.1%) also saw significant production increases, while Russia (-2.7%) had the world's largest decline in volumetric terms.

Global natural gas trade was very weak, growing by just 0.1% in 2012. Pipeline shipments grew by 0.5%, with declines in net Russian exports (-12%) partly offset by growth in Norwegian exports (+12%). US net pipeline imports dropped by 18.8%. Global LNG trade fell for the first time on record (-0.9%): a decline in net European LNG imports (-28.2%) was offset by net increases in Asia (+22.8%). Among exporters, an increase in Qatari (+4.7%) shipments was nearly offset by a decline in Indonesia (-14.7%). LNG's share of global gas trade declined slightly to 31.7%.

1.3.3 Other Fuels

Coal consumption grew up to 2.5% in 2012, well below the 10-year average of 4.4% but still the fastest-growing fossil fuel. Consumption outside the OECD rose by a below-average 5.4%; Chinese consumption growth was a below-average 6.1%, but China still accounted for all of the net growth in global coal consumption, and China accounted for more than half of global coal consumption for the first time. OECD consumption declined by 4.2% with losses in the US (-11.9%) offsetting increases in Europe and Japan. Global coal production grew by 2%, with growth in China (+3.5%) and Indonesia (+9%) offsetting a decline in the US (-7.5%). Coal reached the highest share of global primary energy consumption (29.9%) since 1970.

Global nuclear output fell by 6.9%, the largest decline on record for a second consecutive year; Japanese output fell by 89%, accounting for 82% of the global decline. Nuclear output accounted for 4.5% of global energy consumption, the smallest share since 1984. Global hydroelectric output grew by an above-average 4.3%, with China accounting for all of the net increase. Hydroelectric output reached 6.7% of global energy consumption, the highest share on record.

Renewable energy sources saw mixed results in 2012. Global bio-fuels production recorded the first decline since 2000 (-0.4%, or -0.1 mtoe), due to a decline in the US (-4.3% or -1.2 mtoe). In contrast, renewable energy used in power generation grew by 15.2%, slower year-on-year growth for the first time since 2008 but still slightly above the historical average. Wind energy (+18.1%), accounted for more than half of renewable power generation growth, with China (+34.6%) accounting for the largest increment in wind generation. Solar power generation grew even more rapidly (+58%), but from a smaller base. Renewable forms of energy accounted for 2.4% of global energy consumption, up from 0.8% in 2002; renewable in power generation accounted for a record 4.7% of global power generation.

1.4 Introduction of energy management

Energy management is a term has its own importance as the one which is relating to energy saving in businesses, public/government organizations, and residential apartments.

Energy-saving

“ In context to energy saving, energy management is the procedure of monitoring, controlling, and sustaining energy in a building or organization”.

Normally ,this consists of the following steps:

• Gathering the data and scaling energy consumption .

• Searching for chances to save energy, and calculating amount of energy each chance provides to save. Data examination of energy meter to find and measuring daily energy wastage. Inspect the energy saving done by changing equipment (e.g. lighting) or by upgrading building’s insulation.

• Starting to work on techniques to save energy (i.e. acting on the routine waste and upgradation of the inefficient equipment). Normally, start with the best method initially.

• Monitoring of progress is done by analyzing meter data to have a look on the efforts of energy-saving that has been taken.

The above four-step process applies either by energy saving measures that involve buying new equipment or upgrading building fabric.

1.4.1 Importance of energy management

Energy management is the key to saving energy in organization. Much of the importance of energy saving stems from the global need to save energy - this global need affects energy prices, emissions targets, and legislation, all of which lead to several compelling reasons why should save energy at organization specifically.[3]

1.4.1.1 The global demand to save energy:

Global demand to conserve energy in order to:

• Minimize the damage that society does to Earth.

• Minimize the usage of fossil fuels which are limited in supply.

1.4.1.2 Restricting and minimizing energy consumption:

Energy management is the technique for restricting and minimizing energy consumption of organization. Controlling and reducing organization's energy consumption is important because of following reasons:

• **Minimize costs:** This is one of the important point as energy costs increases.

• **Minimize carbon emissions and the environmental damage:** Cost-related consideration of carbon taxes and other organization may be interested to minimize its carbon footprint to promote a green campaign .

• **Minimize risk:** More the energy is consumed, bigger the risk of energy price increment or shortages of supply could seriously have its effects on the profit to be gained or even make it difficult for business/organization to continue. Energy management can minimize this risk by minimizing the demand of energy and by restricting it.

Apart from these reasons, it's quite evident that some techniques used for reduction of energy consumption that are thought to be reaching at some troublesome end in the near future. The understanding of effective energy management will be effective to meet requirements.

1.4.2 Major steps required for energy management process

There are four steps required to the energy-management process. Introduction of all major steps is maintained below:

1.4.2.1 Scaling energy consumption and data collection:

The former methodology to deduce the energy data collection is to study meter's reading, weekly or monthly. But it lags to the mark of performance that modern methods gives.

The modern method of energy data collection is installation of digital meters which itself measures and read energy consumption at decided intervals such as every 30 minutes or hour.

Detailed interval of energy consumption data makes it easy to examine energy waste that it would be difficult to examine otherwise. For example, there is no way that weekly or monthly meter readings can indicate the amount of energy is used at different times. And examining these patterns makes it much easier to find the routine waste in organization.

1.4.2.2 Searching and measuring chances to save energy:

The detailed meter data collection will be costly for searching and measuring energy-saving chances. The comfortable and most economical energy-saving chances normally needs lesser or no bigger investment.

Observing the detailed interval energy data is the perfect method to search daily energy wastage. Check whether staff and timers are switching things off without keeping watch for 24 hrs, and some investigation to find out the reasons responsible for energy wastage.

If it is identified that a lot of energy is being wasted by equipment left on over the weekends, following steps are to be taken:

A. Use interval reading to evaluate amount of energy in kWh that is used each weekend.

B. Decide the ratio of that energy which is wasted (by equipment that should be turned off).

C. Using the values from A and B, calculate the total kWh that is wasted each weekend.

In other hand, if there is no consideration of the ratio of energy that is being wasted by equipment left on , then:

A. Check the building to ensure that everything has been switched off

B. Recheck the data for that evening which shows the kW, being used after switching off everything.

C. Minus the target kW of B from the general kW value for weekends to calculate the potential savings in kW.

D. Multiply the kW savings by hours taken during weekend to get the total potential kWh energy savings.

Even though the detailed meter data will not be helpful to find out these equipment- or building-fabric-related opportunities (e.g. it won't tell that a more efficient type of lighting equipment exists), it will be useful having help by measuring the potential savings that each opportunity could bring.

1.4.2.3 Targeting the opportunities to save energy

Just finding the opportunities to save energy won't help to save energy - take action to target them.

For those energy-saving opportunities that are required to motivating the people in any organization, it can be hard work, but, if people are on right side for energy management, some serious big energy savings without investing anything other than time.

1.4.2.4 Tracking your progress at saving energy

Once the action is been taken to save energy, effectiveness of the action are to be found out:

• Energy savings that come from behavioral changes (e.g. getting people to switch off their computers before going home) need ongoing attention to ensure that they remain effective and achieve their maximum potential.

• If money is invested into new equipment, probably want to prove that the energy savings achieved which predicted.

• If faulty timers or control-equipment settings are correct, then also required to keep checking again to ensure that . Simple things like a power cut can easily cause timers to jump back to factory settings.

• If targets have been decided for energy saving, gives proof for moving forward to that aim.

• Sometimes, it is required to show that progress isn't achieved (e.g. try to convince the investors to have some money into energy management program).

1.4.3 Controlling energy consumption effectively is a continuous process

To analyze the energy data in a regular way to make sure that the conditions didn't get adverse. Normally when the buildings are not in use it is having a possibility to lose their efficiency and forget about the labor of work been proposed to establish. So, energy management is basically exploring the new methods to achieve the target and designing the new techniques in saving the energy.

1.5 Introduction of standard

A standard is a document that provides requirements, specifications, guidelines or characteristics that can be used consistently to ensure that materials, products, processes and services are fit for their purpose.[4]

1.5.1 Introduction of ISO

ISO (International Organization for Standardization) is the world's largest developer of voluntary International Standards. International Standards give state of the art specifications for products, services and good practice, helping to make industry more efficient and effective. Developed through global consensus, they help to break down barriers to international trade.

1.5.2 Benefits of International Standards

International Standards bring technological, economic and societal benefits. They help to harmonize technical specifications of products and services making industry more efficient and breaking down barriers to international trade. Conformity to International Standards helps reassure consumers that products are safe, efficient and good for the environment.

The existence of different national or regional standards can create technical barriers to trade and increase the cost of doing business. International Standards provide the technical basis on which political trade agreements can be put into practice, whether they are at the regional or international level.

1.5.3 ISO 50001 - Energy management

Using energy efficiently helps organizations save money as well as helping to conserve resources and tackle climate change. ISO 50001 supports organizations in all sectors to use energy more efficiently, through the development of an energy management system (EnMS).

The purpose of this International Standard is to enable organizations to establish the systems and processes necessary to improve energy performance, including energy efficiency, use and consumption. Implementation of this International Standard is intended to lead to reductions in greenhouse gas emissions and other related environmental impacts and energy cost through systematic management of energy.

This International Standard specifies energy management system (EnMS) requirements, upon which an organization can develop and implement an energy policy, and establish objectives, targets, and action plans which take into account legal requirements and information related to significant energy use.

An EnMS enables an organization to achieve its policy commitments, take action as needed to improve its energy performance and demonstrate the conformity of the system to the requirements of this International Standard.

1.6 Motivation

Energy management is one of the most constructive and cost–effective ways to address the challenges of high energy prices, energy security and independence, air pollution, and global climate change. Improving energy efficiency will decrease greenhouse emission, reduce water consumption and decrease electricity cost. Energy efficiency integrated into energy resource plans, energy efficiency provide long term benefits by lowering base load and peak demand and reduce cost for additional generation.

1.7 Objectives

The objective of the work is described below:

- Make energy review of the industry. Collect old data of energy consumption and take daily consumption data.

- Based on energy review find out the major consumption area of the industry.

- To optimize energy consumption, find out opportunities for save energy from available sources and save energy in major consumption area by small amount of changes in existing system.
- Design of $Libr - H_2O$ vapour absorption refrigeration system.

Chapter 2

Literature Review

2.1 Introduction of heat treatment process

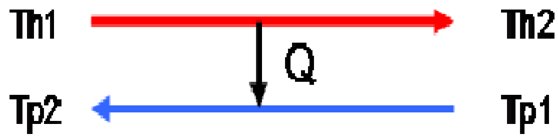
Heat Treatment is the controlled heating and cooling of metals to alter their physical and mechanical properties without changing the product shape. Heat treatment is sometimes done inadvertently due to manufacturing processes that either heat or cool the metal such as welding or forming. Heat treatment is often associated with increasing the strength of material, but it can also be used to alter certain manufacturability objectives such as improve machining, improve formability, restore ductility after a cold working operation. Thus it is a very enabling manufacturing process that can not only help other manufacturing process, but can also improve product performance by increasing strength or other desirable characteristics.

2.1.1 Heat Exchanger Effectiveness Approach

In many process heating applications, the primary energy conversion process is either the conversion of chemical energy in fuel to sensible energy via combustion or the conversion of electrical power to heat through electrical resistance, induction or arching. In both cases, the temperature of the heat is determined by the conversion process and is typically very high. Heat not transferred to the end product (or lost in other ways) is typically carried away in exhaust gasses. Thus, increasing the quantity of heat transferred to the process typically decreases the quantity of heat lost in exhaust gasses and improves the efficiency of the process.[5]

Conceptually, this can be understood by considering heat transfer from a hot medium, h, to a process, p.

Figure 2.1: Heat exchanger effectiveness approach



The rate of heating, Q, is:

$$Q = U \times A \times (T_h - T_P) \tag{2.1}$$

U represent the overall heat transfer coefficient, A is area, $T_h$is average temperature of the heating medium; $T_P$is average temperature of process.

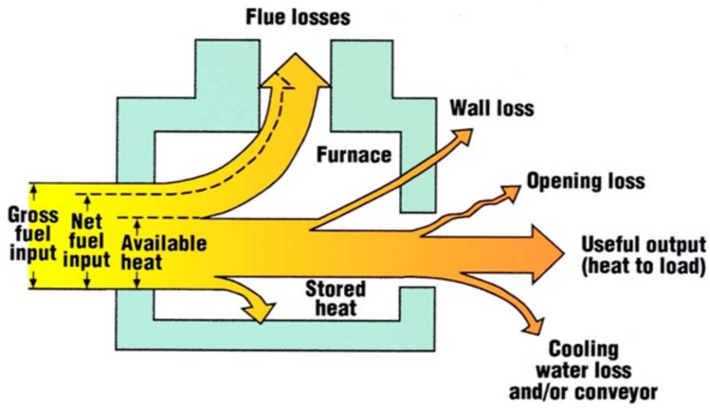
Increasing heat transfer effectiveness, represented by U, increases the rate of heating and decreases the temperature of energy carried away in the heating medium, T_{h2}. This increases the efficiency of the heating process. Thus, increasing heat transfer effectiveness is a key mechanism for improving process heating efficiency. Heat transfer effectiveness can be increased by increasing the heat transfer surface area, increasing the turbulence or density of the heat carrying medium, increasing radiation exchange between the heat source and the product or employing counter-flow heat exchange.

Reducing the process temperature $T_P$increases the temperature difference $(T_h - T_P)$. As $(T_h - T_P)$ increases, more heat is transferred to the process. As in the case of increased U, this decreases the temperature of energy carried away by the heating medium and increases the efficiency of the heating process.

2.1.2 Energy Balance Approach

Minimizing energy losses also improves process heating system efficiency. For example, energy flows into and out of a fuel-fired furnace are shown below. Part of the energy in the fuel input is exchanged as useful heat to the load. The rest is lost as heat in gasses, through the walls, through openings, absorbed by cooling, absorbed by conveyer devices, or stored in the furnace walls. Reducing these losses reduced the gross fuel input, and improves the energy efficiency of the process.

Figure 2.2: Energy balance approach



2.1.3 Reducing heat loss from walls

Hot surfaces free heat to the surroundings via convection and radiation. Insulation decrease the rate of heat flow, and as a reaction always results in energy savings. The heat loss equation to the surroundings at T_a, from a hot surface at T_s, with area A can be expressed here as

$$Q = U \times A \times (T_s - T_a) + \sigma \times A \times \varepsilon \times (T_s^4 - T_a^4) \tag{2.2}$$

Where U is the convection coefficient,$\sigma$is the Stefan-Boltzman constant ($0.1714 \times 10^{-8} W/m^2K^4$), $\varepsilon$is the emissivity of the surface (about 0.9 for dark surfaces).

Assuming steady state conditions, surroundings walls heat loss must equal the furnace walls heat loss:

$$Q = h \times A \times (T_s - T_a) + \sigma \times A \times \varepsilon \times (T_s^4 - T_a^4) = A \times (T_f - T_s)/R \tag{2.3}$$

Where T_f is the interior temperature of the furnace and R is the thermal resistance of the furnace wall including the interior convection coefficient.

Exterior convection over a hot surface is caused when air is warmed, becomes less dense than the surrounding air, and rises. Thus, natural convection is a function of the temperature difference between the hot surface and outside air. In these relations, L is vertical length (ft), ΔT is temperature difference between the surface and the surrounding air (F), and U is the coefficient of convection.

2.1.4 Reducing heat loss due to infiltration

Most extreme temperature furnaces and ovens operate at a negative air pressure in context to ambient air pressure. Thus, openings in the furnace wall allow air to enter into the furnace. Entering air is heated to the operating temperature of the furnace before exhausted.

Table 2.1: Natural convection value for horizontal and vertical surface

	$Laminar - L^3 \triangle T < 63$	$Turbulent - L^3 \triangle T > 63$
Surface in horizontal	$U = (\triangle T/L)^{0.25} \times 0.27$	$U = (\triangle T)^{0.33} \times 0.22$
Surfaces in vertical	$U = (\triangle T/L)^{0.25} \times 0.29$	$U = (\triangle T)^{0.33} \times 0.22$

The excluded heat by entering air, Q, at volume flow rate, V, with increase temperature from ambient temperature T_a, to the furnace exhaust temperature T_{ex} is:

$$Q = V_P \times C_P \times (T_{ex} - T_a) \tag{2.4}$$

Where $(V_P \times C_P)$ shows density and air specific heat $(0.018kJ/m^3K)$

Lost in energy due to infiltration can also be acknowledged by recognizing the fact that quantity of excess air in the exhaust is the sum of the excess combustion air, ventilation air and infiltrating air. By taking the steps to deduct infiltration and ventilation of air to minimize the amount of air in exhaust and increases its overall combustion efficiency

2.1.5 Reducing radiation loss through openings

Openings in furnace walls allow heat to radiate outward. Radiation heat loss can be reduced by covering openings. The figures below show openings in a heat treat furnace. The first opening shows "room for improvement". The second opening is covered with flaps to reduce radiation loss to the surroundings.

Figure 2.3: furnace door for improvement

(a) furnace door covered with flap

Heat is radiated from the hot surface temperature of a furnace through openings to the surroundings. Due their geometries, both the interior and the surroundings can be approximated as black bodies with emissivity equal to 1.0. Thus, loss in heat, Q, through an opening of area, A, from the interior surface of a furnace at temperature T_f, to the surroundings at temperature T_a, is

$$Q = \sigma \times A \times F_{fa} \times (T_f^4 - T_a^4) \tag{2.5}$$

Where $\sigma$is the Stefan-Boltzman constant ($0.1714 \times 10^{-8} W/m^2 K^4$) and $F_{fa}$is the view factor between the inside of the furnace and the surroundings. If the opening is approximated as a circle with radius r through a wall of thickness L, the view factor can be calculated from the following two equations.

$$S = 2 + (L/r)^2 \tag{2.6}$$

$$F_{fa} = 0.5 \times [S - (S^2 - 4)^{0.5}] \tag{2.7}$$

If the entrance were blocked by a radiation shield with emissivity ε_{sheild}shield the heat transfer reduced by following eqution:

$$Q = \sigma \times A \times F_{fa} \times (T|_f^4 - T_a^4) \times [\varepsilon_{sheild}/2] \tag{2.8}$$

2.1.6 Reducing heat loss to cooling

Cooling of doors and other equipments is done in high temperature furnaces to prevent failures and warping. The heat removed by cooling water, Q, at volume flow rate, V, with temperature rise from T_{W1} to T_{W2} is:

$$Q = V_P \times C_P \times (T_{W2} - T_{W1}) \tag{2.9}$$

Where V_P is the density of water ($1000 kg/m^3$) and $C_P$is the specific heat of water ($4.186 kJ/kgK$). The heat removed by the cooling water is also equal to the heat loss from the furnace.

The heat loss from the furnace can be evaluated as:

$$Q = U \times A \times [T_f - (T_{W2} + T_{W1})/2] \tag{2.10}$$

Where U is the overall heat transfer coefficient, A is area; T_f is the temperature of the furnace.

2.1.7 Reducing Heat Loss Due to Excess Combustion Air

The process in which, to complete the combustion the minimal necessary amount of air added is known as "stoichiometric" air and when supplied maximum gives maximum combustion efficiency. more addition of such gases will dilute the gases of combustion, causes lowering in combustion temperature and their efficiency. To avoid the non burned fuel addition in the concentration of oxygen than the stoichiometric air and increases its efficiency preventing excessive combustion.

Lee and Jou[6] gives information on saving fuel consumption and decreasing emission from the heat treatment furnace. The furnace efficiency can be maintained and improve by reduce the excess air ratio and preheat the combustion air. The results obtained with a plant-size industrial furnace show that when the excess air oxygen concentration is reduced from 4% to 3%, the furnace efficiency is raised by 0.6%. Raising the temperature of the per-heated air will cause a higher furnace temperature and a faster flowing speed of the air in the furnace. Thus, the heat in the radiation zone of the furnace can be evenly transmitted to shorten the time for the fuel to reach the igniting point, and reduce the heat loss from the hot air stream. This will reduce the emission of CO_2 and NO_X. Such operational adjustments of the furnace using the recovered fuel gas will save energy reduce CO_2 emission and alleviate the adverse impact to environment.

2.2 LiBr vapour absorption system

Vapour absorption refrigeration methods are usually used to take care of bigger cooling loads ranging from 10TR to 3500TR according to which their size and construction changes. Another convention about such systems is that they use waste heat or in some cases directly fuel to satisfy the requirement of heat supply in generator.[7]

Vapour absorption cooling has some very attractive features such as it can work with the help of heat instead of electricity, has no moving part except one pump, easy to maintain, noise free operation, environment friendly, sturdy construction and durability and most attractive of all in which we are interested is it can use solar energy directly to operate.

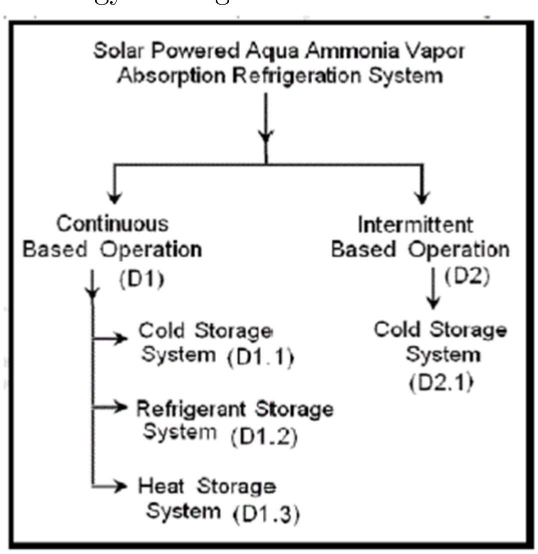
V.K. Bajpai[8] gives the information on design and study an environmental friendly vapour absorption refrigeration system of unit capacity using NH_3 and water as working fluid. The basic idea of this paper is derived from the solar heating panel which is used for the heat source of making water hot for generator source. In this paper flat plate solar collector is used for making water hot for generator source. Solar energy is very large, inexhaustible source of energy. The power from the sun intercepted by the earth is approximately 1.8×1011 MW which is much larger than the present consumption rate on the earth of all commercial sources. In this paper basic step is given for the design of vapour absorption cycle. First decide operating pressure (condenser pressure & evaporator pressure) at which the system function properly. The point of operating pressure plotted on the enthalpy-concentration diagram. Based on this enthalpy of the NH_3 at various point can be calculated. By use of enthalpy value the flow rate of the refrigerant is evaluted. Based on enthalpy and flow rate value, find the amount of heat required in generator, condenser, evaporator and absorber.

S. B. Riffat[9] gives information on the use of solar energy in absorption refrigeration to get the desalinated water. It is an open cycle system. The evaporator is supplied with brine or impure water which is to be purified, at low pressure. Now because of the low pressure in evaporator this water evaporates and goes to the absorber, leaving behind concentrated waste water. From absorber to condenser the circuit is same. Water vapour is absorbed by Li-Br or any other absorber that can be used in place of Li-Br. Solar heat is used in generator to separate water from absorbent. When this water vapour is condensed in condenser ,pure desalinated water is made. Which can further be used in various applications such as working fluid in power plant, feed water in boilers, in food industries, pharmaceutical purposes etc.

Said et al.[10] gives various methods by which solar energy can be used for 24 hour working absorption system. These authors have suggested mainly four methods to make the system work for 24 hours. According to them the methods have been classified in two different types. Continuous based operation and intermittent based operation. According to the description given in the paper for these two systems continuous based systems are those in which vapour production in the generator and the cooling produced in the evaporator take place simultaneously and intermittent operation means vapour production and the cooling effect does not take place simultaneously. In intermittent systems vapour generation take place in the day time and the cooling take place in the night time.

Three methods for the continuous system and one for the intermittent systems are introduce here. These three methods are (1) cold storage method, (2) refrigerant storage method, and (3) heat storage method. (1) In cold storage method the continuous cold storage system operates at the daytime and produces the required refrigeration effect for the daytime as well as store the additional cooling effect in a cold storage unit. The cold storage unit then fulfills the cooling requirement at the night time when the solar energy is not available. This absorption system remains in operation at the day time and cease to operate during the night time. (2) In refrigerant storage method mass flow in condenser is kept higher than the mass flow in the evaporator. During the day time when the cycle is operational condenser condenses additional amount of refrigerant to store in the refrigerant storage tank. This tank stores the refrigerant that is to be used for the operation of the night time. With the refrigerant tank there is also need for a tank for the storage of the absorbent and refrigerant solution because during night time the generator and condenser won't work. (3) In the heat storage system solar heat is stored in different tank with the help of heat solution. It is also mentioned about this system that this need the solar panels which can work at higher temperatures. The storage tank has to be highly insulated. So this is rather expensive option. On the other hand for the intermittent system there is only one method of cold storage system is given.

Figure 2.4: Solar energy storing methods for 24 hour working system



D. I. Tchernev[11] gives the application of zeolites in the adsorption processes. It is mentioned that the zeolites can adsorb gases or vapour of the refrigerants up to its 30% weight. Zeolites-water combination gives most efficient system and requires small quantity of zeolites for the process. Detail explanation is given in the paper about working of system. Zeolites during the day time absorb the solar heat and desorb the water vapour. Once the pressure of water vapour has reached to the condenser pressure it is cooled in the condenser and then it is stored in the storage tank. And now during night time the zeolite gets cooled and so the pressure in the vessel reduces and the liquid in the storage tank begins to evaporate and produces the cooling effect. During the whole night the zeolites adsorbs the vapour and by the morning it is ready start the new cycle.

Zhai et al.[12] gives information on new design option for solar absorption cooling systems. In this paper some new design introduce regarding solar collectors, auxiliary energy systems and cooling modes and also 3 types of solar absorption chiller were summarized. (1) Double effect absorption chiller (2) Half effect absorption chiller and (3) Two stage absorption chiller. For buildings with high amounts of cooling load and limited installation area, solar-powered double effect absorption cooling systems may be considered on condition that the direct irradiation is high enough. Half-effect absorption chiller and two-stage absorption chiller seem to be more suitable for air-cooled solar absorption cooling systems in hot and dry regions which are short of water.

Table 2.2: Conventional and new design option for solar powered absorption cooling system

Sub system	Conventional method	New design option
Solar collectors	Flat-plate or evacuated tubular solar collector	Parabolic through collector
Auxiliary energy systems	Electric heater, oil/gas boiler and conventional air/water cooled cooling system	LPG-fired heating unit, biomass gasifier boiler, free cooling system and GSHP
Cooling modes	Water-cooled mode using a cooling tower	Air-cooled, ground cooling and Phase change material together with an air cooler
Heat storage modes	Heat storage water tank	Phase change material

Chapter 3

Energy Review of Bearing Industry

3.1 Energy review

Review of organization's energy performance based on data and other information, which lead to identification of opportunities for improvement.

Table 3.1: Energy consumption review during 1-January 2013 to 31-January 2014

Sr no.	Energy usage activity	Energy consumption (MWh)
1	Channel-1 & 2 SDB-1	489.2642
2	Channel-4 SDB-2	499.0592
3	Channel-6A SDB-3	132.3078
4	Channel-6B SDB-4	118.9127
5	Channel-6C SDB-5	132.6963
6	Aichelin Furnace SDB-6	1484.7076
7	Bainite Tank SDB-7	2575.7962
8	Melting Tank SDB-8	2018.1349
9	Chiller SDB-9	1832.217
10	Air Compressor SDB-10	2185.9585
11	Basement SDB-12	582.287
12	Light SDB-13	596.5798
13	Air Handling Unit SDB-14	407.3713
14	Pump house	373.69171
Total electricity consumption: 14785.954 MWh		

Major energy consumption areas observed as per table 3.1

1. Heat Treatment Department (SDB- 6, 7, 8)
2. Chiller (SDB-9)
3. Air Compressor (SDB-10)

4. Air Handling Unit (SDB-14)

All area or equipment which mention above are working 24×7 in industry. Heat treatment is used to harden bearing and also electric heaters are used for heating the bearing rings, salt melting and tempering process. Chiller and air handling units are used for cooling purpose. Air compressor is use for pneumatic system of machine.

3.2 Heat treatment department (SDB-6, 7, 8)

When steel is heated it undergoes thermal expansion and carbon atoms changes their arrangement due to thermal expansion. After that cooling is done and carbon atoms are then wedged into new arrangement their by lock material which then become hardened.Before heat treatment rings are soft and easy to machine. Rotating ring around its axis will give its shape but it remains soft to be used as bearing. Heat treatment hardens the bearing ring and it will last longer and take heavy loads.

The Specification of furnace are as follows:

Make: AICHELIN Heat treatment system, Beijing

Type: Bainite and Marten site heat treatment roller hearth furnace

Installed Capacity: 1600 Kg/hr

Maximum Weight: 1000 Kg

Dimensional Range: Outer Diameter-70-1400 mm

Inner Diameter- 500 mm

3.2.1 Major Steps required for decreasing energy consumption in heat generation system:

In bearing industry heat treatment process is to harden bearing. For this purpose batch type heat treatment furnace is used. This type of furnace heating system is divided in mainly three zones. 1^{st} zone is pre heating zone, 2^{nd} is gas heating zone and 3^{rd} is soaking zone. 1^{st} and 3^{rd} zone is electric heating zone. Temperature is high and for achieving this temperature gas and electric heaters are used so consumption of gas and electricity is more in furnace. To decrease consumption in heating zone following method is suggest :

1. **Fuel fired furnace:**

- Check possible air leakages downstream the combustion fans or blowers.
- Check the Air/Fuel ratio: to have the (theoretically) best combustion one should be at the stoichiometry ratio but normally, to ensure a complete combustion, one should add 15 to 20% excess air into the burner.

- Check the color of the flame: it should be bluish.
- All burners (flames) in the same zone (controlled by the same valve) should burn similarly (have similar colour).
- Regularly rotate and clean radiant tubes to avoid varying counter pressure for fuel and air.
- Preheat the air, use recuperative burner.

2. **Electrically heated furnace:**

   - Check condition of heating elements by measuring the resistance using a Wheatstone bridge or by measuring voltage and current and use the Ohm law, $V = I \times R$, to get the resistance.
   - Compare resistance/current/voltage between elements in series or parallel, they should be the same.
   - Repeated element breakage in the same position indicates fault.

3. **Heat transfer:**

   - Ensure a good radiation in the furnace: size correctly the furnaces for the piece of metal to be heated, not too long distance between goods and roof/walls.
   - Ensure a good convection in the furnace: improve the air circulation.

4. **Heat containment:**

   - Reduce Air leaks into the furnace.
   - Close the entrances of the furnace as much as possible.
   - Control the pressure into the furnace: $\approx$100 – 200 Pa.
   - To high the heat is pushed through the insulation.
   - To low the hot air leaks from the entrance.

5. **Reduce heat losses:**

   - The temperature outside the wall should be less than 60 Degrees, check the thickness, the type and the condition of the insulation. Hot spots indicate potentially weak insulation.
   - Reduce the piping system to the minimum feasible, check its insulation.

6. **Sensors and Controls:**

- Improve process measurements, controls and process management by developing procedures for regular operation, calibration and maintenance of process sensors (i.e. pressure, temperature and flow) and controllers.

7. Heat recovery:

- In most industrial heating processes, a large proportion of the heat supplied is wasted in the hot flue gases. Recuperative burners are designed to recover some of this waste heat and use it to preheat the incoming combustion air, resulting in improved fuel efficiency and heat transfer rates.
- This is achieved by a simple compact system in which the burner, flue and recuperator are integrated into a single burner unit, making this type of burner very attractive for smaller furnaces and kilns.

3.2.2 Some other possibilities to save energy in heat treatment department

1. Improving the Effectiveness of Production Planning:

- Minimizing the Furnace run time by accumulating the product.
- Planning based on Furnace capacity.
- Minimizing the change overs (Martensite to Bainite visa-varsa).
- Mandatory Shutdown for once six months

2. Reducing Temperature Losses in Heat Treatment Furnace:

- Check the Furnace Insulation effectiveness.
- Control the Bainite Bath temp loss by covering open surface.
- Arrest the Leakages if any
- Reduce the supply Air in Winter season

3. Optimization of Process Parameters in Heat Treatment Furnace:

- Optimization of Gas Flow rates.
- Optimizing the Salt Bath Temperature.
- Optimize utilization of Pre & Post wash Heaters.
- Reducing the Speed of motor by VFD.

- Effective Preventive Maintenance of All Motors.

4. Reduce Electric & Gas Consumption in Heat Treatment Furnace:

- Reduce Gas supply when furnace in ideal condition.
- Reduce Furnace temperature if it is long time waiting.
- Minimize the exhaust burner flow.
- Switch off the heaters when it is not required.
- Switch off the agitators of $27m^3$and $37m^3$ tanks.
- Check the possibility of heater quantity.
- Providing the thyristor based heating control.
- Reduced the speed of motor by VFD

Based on the above study for energy saving opportunities in bearing industry, the final schedule indicate the expected annual energy saving in KSEK(Thousand Swedish Krona), expected time for implementation, expected payback, expected environment,health and safety (EHS) impact and expected production efficiency impact was suggested. Information for the same is presented in table 3.2

Table 3.2: Prioritizing of energy performance improvement opportunities

Opportunity number	Opportunity description	Criteria					Opportunity score
		Expected annual energy saving	Expected time for implementation	Expected payback	Expected EHS impact	Expected production efficiency impact	
		1: 0-25 KSEK	1: More then 1 year	1: More then 3 years	1: Clear negative impact	1: Clear negative impact	
		2: 25-100 KSEK	2: 6-12 months	2: 1-3 years	2: Minimal negative impact	2: Minimal negative impact	
		3: 100-500 KSEK	3: Less then 6 months	3: 6-12 months	3: No change	3: No change	
		4: 500- KSEK	4: Immediately	4: Less then 6 months	4: Positive impact	4: Positive impact	
1	Proposal to install Solar Electricity Generation system (1MW) catering to supply the power to Bainite Bath electrical heaters of Aichelin	4	2	1	4	3	96
2	Proposal to install Waste Heat recovery system on Compressors catering to hot water requirement for Pre Washer in Aichelin furnace	1	2	2	4	3	48

3	Proposal to use PNG instead of Propane gas for Aichelin furnace	3	2	2	4	3	144
4	Proposal to install in house N2 Generator instead of hiring tankers & storing liquid N2 in plant.	3	3	3	3	2	162
5	Proposal to install Solar Water heating system catering to hot water requirement for new phosphating plant.	2	2	2	4	3	96
6	Proposal to cover bainite bath tanks from top to avoid heat loss	1	2	2	3	2	24
7	Install SMARTLINK to monitor compressor performance	1	3	3	4	2	72
8	Perform Energy and Air audits annually.	1	3	3	4	2	72
9	Proposal to replace existing HT ventilation blower system with efficient systems	1	1	1	3	3	9
10	Install Lighting Energy Savers for reducing lighting system energy consumption	1	2	2	3	3	36

Chapter 4

Design of vapour absorption refrigeration system

4.1 Introduction

An absorption refrigeration system is a heat operated device based on two factors which produce a refrigeration effect; these are

A. Primary fluid will boil at low temperatures.

B. A secondary fluid will absorb the primary fluid which has been vaporized in the evaporator.

When the system utilizes a mechanical pump to circulate the absorbent refrigerant solution, a small amount of work input will be required.

The heat source may be steam or another hot fluid. There are two main types of absorption systems: the aqueous lithium bromide system and the aqua ammonia system. Other absorbent-refrigerant combinations have recently been considered.

The majority of modern absorption refrigeration units currently in use are operated by solar energy. A large number of successful and reliable cycles have been produced commercially.

Improvements in cooling by absorption and changes in operation have been reported in the literature. Investigators have examined many aspects of research such as the thermodynamic analysis of the basic cycle, the effect of variations in cooling water temperature, the improvement of mechanical design, the evaluation of performance under conditions of reduced capacity or transient start-up, and the full scale testing.

However, in recent years the increasing interest in energy conservation and the efficient use of energy has led to a new methodology and a powerful approach to analyze all processes and installations.

4.2 Thermal Design

The design of vapour absorption refrigeration system is presented here.

Industry uses chilled water deep cooling tank with the capacity of 16,000 Litre in the heat treatment process for getting martensite structure in bearing ring. For getting martensite structure this deep cooling tank is maintained at 10^oC. For maintaining10^oC, the inlet temperature of chiller water is at 7^oC. In the heat treatment department, atmospheric temperature is nearer to 48^oC. With this high atmospheric temperature convection and conduction losses are high in the deep cooling tank. Due to these high losses the electricity consumed by chiller is very high.

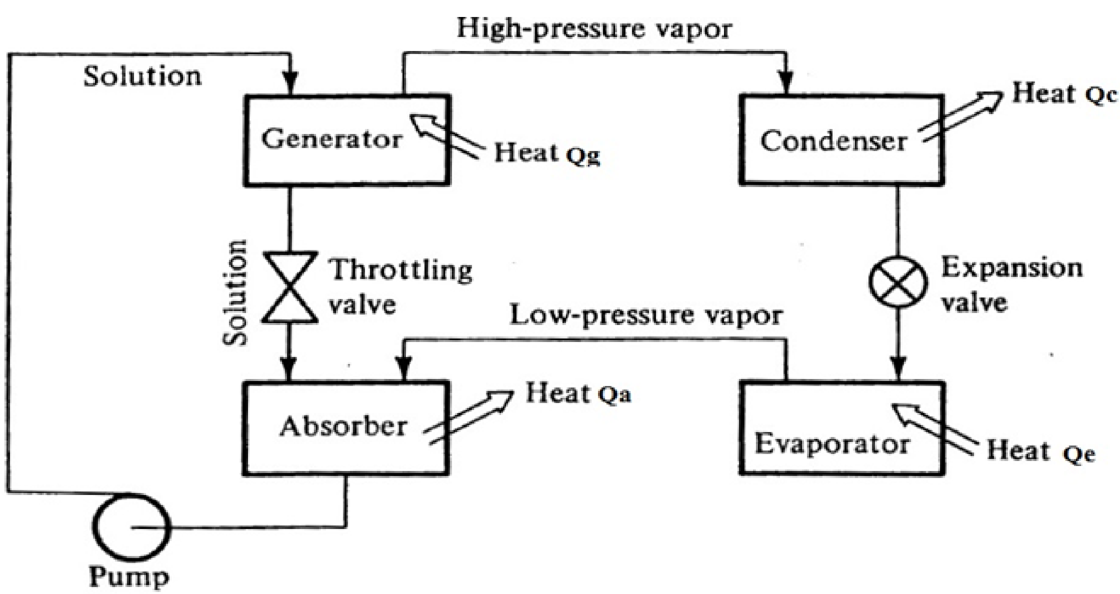
Heat loss in deep cooling tank:

Time require to increase temperature of deep cooling tank from 10^oC to 12^oC is 15 min so the heat loss from the deep cooling tank is

$$Q_e = \frac{m \times C_p \times \triangle T}{Time} = \frac{16000 \times 4.186 \times (12 - 10)}{15 \times 60} = 148.83kW \tag{4.1}$$

Heat loss in the deep cooling tank is 148.83 kW. Based on value of Qe, $Libr - H_2O$ vapour absorption refrigeration system will be design

Figure 4.1: Simple vapour absorption cycle



Based on ASHRAE concentration chart minimum evaporator temperature is 5^oC. To avoid crystallization of Libr-H2O solution, 55 % concentration is used in industry. Considering atmospheric temperature as 30^oC. so condenser temperature is taking 40^oC. Based on this generator concentration is 61% from ASHRAE concentration chart.

System has to be maintained at 10^oC, therefore evaporator temperature is set up to 5^oC, condenser temperature is taking 40^oC. Based on ASHRAE $Libr-H_2O$ concentration chart absorber temperature is 34^oC and generator temperature is 88^oC.

X_1= Leaving absorber at a solution temperature of $34^oC$and a pressure of 0.87 kPa is 0.55

X_2= Leaving generator at a solution temperature of 88^oC and a pressure of 7.38 kPa is 0.61

Now enthalpy of the solution can be

H_1= H at 34^oC and $X_1$of 55% = 83 kJ/kg

H_2= H at 88^oC and $X_2$of 61% = 220 kJ/kg

H_3= H of saturated vapour at88^oC = 2656.9 kJ/kg

H_4= H of saturated liquid at40^oC= 167.57 kJ/kg

H_5= H of saturated vapour at5^oC = 2510.60 kJ/kg

Now find out flow rate from evaporator to absorber (W_5)

$$Q_e = W_5H_5 - W_4H_4 = W_5(H_5 - H_4) \tag{4.2}$$

$$W_5 = \frac{Q_e}{(H_5 - H_4)} = \frac{148.83}{2510.6 - 167.57} = 0.063kg/s \tag{4.3}$$

$W_5 = 0.063kg/s$

Based on the above value of W_5, find out heat load of condenser. Here assume that the flow rate from generator to condenser, condenser to evaporator and evaporator are same means the value of W_3,W_4,$W_5$are same.

$$Q_c = W_3H_3 - W_4H_4 = W_3(H_3 - H_4) = 0.063 \times (2656.9 - 167.57) = 156.82kW \tag{4.4}$$

$Q_c = 156.82kW$

Libr Balance:

$$W_1X_1 = W_2X_2 \tag{4.5}$$

$$W_2 = W_1 \times \frac{X_1}{X_2} = 0.90 \times W_1 \tag{4.6}$$

Total mass flow balance:

$$W_1 = W_2 + W_3 = (0.90 \times W_1) + 0.063 \tag{4.7}$$

$$W_1 = 0.63kg/s \tag{4.8}$$

$$W_2 = 0.90 \times 0.63 = 0.567 kg/sec \tag{4.9}$$

W_1= Mass flow rate from absorber to generator is 0.63 kg/s.

W_2= Mass flow rate from generator to absorber is 0.567 kg/s.

Based on the value of W_2, find out heat load of absorber

$$Q_a = W_2H_2 + W_5H_5 - W_1H_1 \tag{4.10}$$

$$Q_a = (0.567 \times 220) + (0.063 \times 2510.6) - (0.63 \times 83) = 230.61 kW \tag{4.11}$$

$Q_a = 230.61kW$

Based on the value of W_1, find out heat load of generator

$$Q_a = W_3H_3 + W_2H_2 - W_1H_1 \tag{4.12}$$

$$Q_a = (0.063 \times 2656.9) + (0.567 \times 220) - (0.63 \times 83) = 239.83 kW \tag{4.13}$$

$Q_a = 239.83kW$

The total heat load required of the $Libr - H_2O$ vapour absorption refrigeration system should be maintained at below:

1. Generator Heat Load Qg = 239.83 kW
2. Condenser Heat Load Qc =156.82 kW
3. Evaporator Heat Load Qe =148.83 kW
4. Absorber Heat Load Qa = 230.61 kW

4.2.1 Coefficient of performance of system

$$COP = \frac{Q_e}{Q_g} = \frac{148.83}{239.83} = 0.63 \tag{4.14}$$

$COP = 0.63$

4.2.2 Pump work calculation

Generator pressure= 7.38 kPa

Absorber pressure= 0.87 kPa

Pressure difference= 7.38-0.87= 6.51 kPa=6510 N/m^2

Pressure head

$$H_{head} = \frac{\triangle P}{\rho g} = \frac{6510}{9.81 \times 1620} = 0.4096m \tag{4.15}$$

$H_{head} = 0.4096m$

Pumping power required will be

$$p = \frac{mgh}{1000} = \frac{0.63 \times 9.81 \times 0.4096}{1000} = 2.53 \times 10^{-3} kW \tag{4.16}$$

$P = 2.53 \times 10^{-3} kW$

4.3 VAR component design

4.3.1 Copper pipe data

Table 4.1: Copper pipe detail [23]

Property	Nomenclature	Value	Unit
Material of pipe		Cooper (B640)	
Tensile strength	σ_t	30000	psi
Yield strength	σ_y	9000	psi
Thermal conductivity of pipe	k	401	W/mK
Outer diameter of pipe	d_o	0.0222	m
Inner diameter of pipe	d_i	0.0199	m

4.3.2 Evaporator design

Evaporator works at 5^oC temperature and refrigerant is being water its property as follows

Table 4.2: Thermophysical properties of refrigerant in evaporator [15]

Property	Nomenclature	Value	Unit
Evaporator inlet temperature (sat. liquid)	T_4	5	^oC
Evaporator outlet temperature (sat. vapour)	T_5	5	^oC
Density of liquid	$\rho_{l,4}$	1000	kg/m^3
Dynamic viscosity of liquid	$\mu_{l,4}$	0.0015025	Pa s
Specific heat of liquid	$C_{Pl,4}$	4.202	kJ/kgK
Thermal conductivity of liquid	$k_{l,4}$	0.573	W/mK
Density of vapour	$\rho_{v,5}$	0.006903	kg/m^3
Dynamic viscosity of vapour	$\mu_{v,5}$	0.000008225	Pa s
Thermal conductivity of vapour	$k_{v,5}$	0.0185	W/mK
Surface tension	σ	0.0749	N/m
Thermal diffusivity	α_l	1.3555×10^{-7}	m^2/s
Atomic weight of water	M	18	gm/mol

System has to be maintained at 10^oC, so for achive temperature of system, assume 12^oC as inlet hot water temperature and 7^oC as outlet hot water temperature.

Table 4.3: Thermophysical properties of water inside tube [14, 15]

Property	Nomenclature	Value	Unit
Inlet temperature of hot water	T_{c1}	12	^oC
Inlet enthalpy of hot water	H_{c1}	50.41	kJ/kg
Outlet temperature of hot water	T_{c2}	7	^oC
Outlet enthalpy of hot water	H_{c2}	29.39	kJ/kg
The bulk mean temperature	T_b	9.5	^oC
Density	ρ_b	1000	kg/m^3
Dynamic viscosity	μ_b	0.0009485	Pa s
Specific heat	C_{Pb}	4.1902	kJ/kgK
Thermal conductivity	k_b	0.5862	W/mK

4.3.2.1 Evaporator inside pipe calculation

For cooper tube velocity of fluid is not more than 2 m/s. So velocity of fluid is assumed to be 2 m/s.Based on value of velocity required mass flow rate is

$$m = \rho AV = \rho \times \frac{\pi}{4} d_i^2 \times V = 1000 \times 3.108 \times 10^{-4} \times 2 = 0.621 kg/s \tag{4.17}$$

Renold number for inside pipe

$$Re = \frac{\rho V d_i}{\mu} = \frac{1000 \times 2 \times 0.0199}{0.0009485} = 41960.99 \tag{4.18}$$

Prandlt number for inside pipe

$$Pr = \frac{\mu C_P}{k} = \frac{0.0009485 \times 4.1902 \times 1000}{0.5862} = 6.77 \tag{4.19}$$

The Renold number is greater than 2300. So to find Nusselt number (Nu) Petukhov co-relationas as given in sadik Kakac 2nd edition book is used as follows

$$Nu = \frac{(f/2)RePr}{1.07 + 12.7(f/2)^{0.5}(Pr^{2/3} - 1)} \tag{4.20}$$

$$f = (1.58lnRe - 3.28)^{-2} = (1.58ln(41960.99) - 3.28)^{-2} = 5.45 \times 10^{-3} \tag{4.21}$$

$$Nu = \frac{(5.45 \times 10^{-3}/2) \times 41960.99 \times 6.77}{1.07 + 12.7 \times (5.45 \times 10^{-3}/2)^{0.5} \times (6.77^{2/3} - 1)} = 279.45 \tag{4.22}$$

$$h_i = \frac{Nu \times k}{d_i} = \frac{279.45 \times 0.5862}{0.0199} = 8231.83W/m^2K \tag{4.23}$$

4.3.2.2 Evaporator outside pipe calculation

Outside of cooper pipe is refrigerant pool. So to find heat transfer co-efficient two types of cases have been considered. (1) Natural convection (2) Nucleate boiling

1. Natural convection

For natural convection Nusselt number is function of Grashoff number and Prandlt number.

Grashoff number

$$Gr = \frac{L_C^3 g\beta\Delta T}{\nu^2} = \frac{(0.0222^3) \times 9.81 \times (1/280.25) \times 4.5}{(0.0015025/1000)^2} = 763424.0932 \tag{4.24}$$

L_C = Effective length (For horizontal cylinder is taken diameter of cylinder).

β = Average of both bulk mean temperature.

ΔT = Temperature difference b/w both bulk mean temperature.

ν = Kinematic viscosity.

Prandlt number

$$Pr = \frac{\mu C_P}{k} = \frac{0.0015025 \times 4.202 \times 1000}{0.573} = 11.01 \tag{4.25}$$

To calculate Nusselt number for heat transfer co-efficient, ASHRAE fundamental gives equation for horizontal cylinder as follows.

$$Nu = \left[0.6 + \frac{0.387(GrPr)^{1/6}}{[1+(0.559/Pr)^{9/16}]^{8/27}}\right]^2 \tag{4.26}$$

$$Nu = \left[0.6 + \frac{0.387 \times (763424.0932 \times 11.01)^{1/6}}{[1+(0.559/11.01)^{9/16}]^{8/27}}\right]^2 = 34.16 \tag{4.27}$$

$$h_{o1} = \frac{Nu \times k}{d_o} = \frac{34.16 \times 0.573}{0.0222} = 888.61 W/m^2K \tag{4.28}$$

2. Nucleate Boiling

(A) Stephen and Abdelsalam Equation

$$\frac{h_o D_d}{k_l} = 0.0546 \times \left[\left(\frac{\rho_v}{\rho_l}\right)^{0.5}\left(\frac{q}{A} \times \frac{D_d}{k_l T_{sat}}\right)\right]^{0.67} \times \left(\frac{h_{fg} D_d^2}{\alpha_l^2}\right)^{0.248} \times \left(\frac{\rho_l - \rho_v}{\rho_l}\right)^{-4.33} \tag{4.29}$$

Where σ= surface tension andα_l= Thermal Diffusivity

$$D_d = 0.0208\theta \left[\frac{\sigma}{g(\rho_l - \rho_v)}\right]^{0.5} \tag{4.30}$$

In this equation θ is always take as 35^o , which in radians comes to be 0.6105 rad.

$$D_d = 0.0208 \times 0.6105 \times \left[\frac{0.0749}{9.81 \times (1000 - 0.006930)}\right]^{0.5} = 3.5087 \times 10^{-5} \tag{4.31}$$

$$\frac{q}{A} = h \times \Delta T = 881.69 \times 4.5 = 3967.605 \tag{4.32}$$

Value of h taken from the natural convection

$$\frac{h_o D_d}{k_l} = 0.0546 \times \left[\left(\frac{0.006930}{1000}\right)^{0.5}\left(3967.605 \times \frac{3.5087 \times 10^{-5}}{0.578 \times 278}\right)\right]^{0.67} \times \left(\frac{(2489.6 \times 10^3)(3.508 \times 10^{-5})^2}{(1.3555 \times 10^{-7})^2}\right)^{0.248} \times (0.99)^{-4.33} = 5.76 \times 10^{-3} \tag{4.33}$$

$$h_{o2} = \frac{5.76 \times 10^{-3} \times 0.573}{3.5087 \times 10^{-5}} = 94.065 W/m^2K \tag{4.34}$$

(B) Cooper co-relation

Cooper gives co relation as follows

$$h = 55(Pr^{(0.12-0.4343lnRp)}) \times (-0.4343lnPr)^{-0.55} \times M^{-0.5} \times \left(\frac{q}{A}\right)^{0.67} \tag{4.35}$$

Pr = It is ratio of saturation pressure and critical pressure.

Rp = Surface roughness which is to be taken as 1 if it is unknown.

M = Atomic weight of water

$$Pr = \frac{P_{sat}}{P_{crit}} = \frac{0.0087}{220.6} = 3.95512 \times 10^{-5} \tag{4.36}$$

$$h = 55 \times (3.95512 \times 10^{-5})^{0.12} \times (-0.4343 ln(3.95512 \times 10^{-5})^{-0.55} \times 18^{-0.5} \times (3967.605)^{0.67} = 437.868 W/m^2K \tag{4.37}$$

It also said in reference, multiply 1.7 with 'h' in case of cooper surface.

$$h_{o3} = 744.3760 W/m^2K \tag{4.38}$$

(C) Gorenflo Equation

Gorenflo gave following equation.

$$h = h_o F_{pf} \left(\frac{(q/A)}{(q/A)_o}\right)^{\eta f} \left(\frac{Rp}{Rp_o}\right) \tag{4.39}$$

$F_{pf} = 1.2(Pr)^{0.27} + 2.5(Pr) + \frac{Pr}{1-Pr} = 0.07773$

$\eta f = 0.9 - 0.3(Pr)^{0.15} = 0.8344$

Here same as before Pr is a ratio of saturation pressure and critical pressure. According to reference value of $(q/A)_o$ is taken as 20000 and Rp_0 is 0.4.According to reference value of $h_o$is taken as 5600.

$$h = 5600 \times 0.07773 \times \left(\frac{3967.605}{20000}\right)^{0.8344} \left(\frac{1}{4}\right)^{0.133} = 127.50 W/m^2K \tag{4.40}$$

4.3.2.3 Evaporator over all heat transfer co efficient

Table 4.4: Heat transfer coefficient for evaporator design

	coefficient	Value	Unit
Inside Pipe	h_i	8231.83	W/m^2K
Outside pipe			
Natural convection	h_{01}	881.69	W/m^2K
Nucleate Boiling	h_{02}	94.065	W/m^2K
	h_{03}	744.3760	W/m^2K
	h_{04}	127.50	W/m^2K

In evaporator outside pipe natural convection and nucleate boiling takes place. So for calculation, value of outside heat transfer coefficient h_o is taken addition of natural convection and avg. value all 3 of nucleate boiling. Value of h_o is 1203.67 W/m^2K and value of h_i is 8231.83 W/m^2K. Values of fouling factor for both inside and outside pipe are same and value is 0.000088 W/m^2K.

$$U_{eva} = \frac{1}{\left(\frac{r_o}{r_i} \times \frac{1}{h_i}\right) + \left(\frac{r_o}{r_i} \times R_{fi}\right) + \frac{r_o ln(r_o/r_i)}{k} + R_{fo} + \frac{1}{h_o}} \tag{4.41}$$

$$U_{eva} = \frac{1}{(\frac{0.0222}{0.0199} \times \frac{1}{8231.83}) + (\frac{0.0222}{0.0199} \times 0.000088) + \frac{0.0222 ln(0.0222/0.0199)}{2 \times 401} + 0.000088 + \frac{1}{1203.67}} = 865.86 W/m^2K \tag{4.42}$$

4.3.2.4 Evaporator required heat transfer area

$T_{h1} = 12^oC, T_{h2} = 7^oC$

$T_{c1} = 5^oC, T_{c2} = 5^oC$

$$LMTD = \frac{(T_{h1} - T_{c2}) - (T_{h2} - T_{c1})}{ln\frac{T_{h1} - T_{c2}}{T_{h2} - T_{c1}}} = 3.99 \tag{4.43}$$

Required heat transfer area

$$A_{HT} = \frac{Q}{U_{eva} \times LMTD} = \frac{148.83 \times 1000}{865.86 \times 3.99} = 43.07 m^2 \tag{4.44}$$

4.3.2.5 Evaporator required shell diameter

$$D_s = 0.637 \times \sqrt{\frac{CL}{CTP}} \times \left[\frac{A_{HT}(PR)^2 d_o}{L}\right]^{1/2} \tag{4.45}$$

CTP = 0.9 (for 2 tube pass)

CL = 0.87 (tube layout constant for $30^o$and 60^o)

PR = 1.25 (assume)

L = 3 m (assume)

$$D_s = 0.637 \times \sqrt{\frac{0.87}{0.9}} \times \left[\frac{43.07 \times 1.25^2 \times 0.0222}{3}\right]^{1/2} = 0.44 m \tag{4.46}$$

4.3.2.6 Evaporator required number of tubes

$$N_t = 0.785 \times \left(\frac{CTP}{CL}\right) \times \frac{D_s^2}{PR^2 \times d_o^2} \tag{4.47}$$

$$N_t = 0.785 \times \left(\frac{0.9}{0.87}\right) \times \frac{0.44^2}{1.25^2 \times 0.0222^2} = 204.16 tubes \tag{4.48}$$

In evaporator 204 tubes required with shell diameter of 0.44 m.

4.3.3 Absorber design

Table 4.5: Thermophysical properties of cooling water in Absorber [14, 15]

Property	Nomenclature	Value	Unit
Inlet temperature of cooling water	T_{c1}	25	^oC
Inlet enthalpy of cooling water	H_{c1}	104.89	kJ/kg
Outlet temperature of cooling water	T_{c2}	27	^oC
Outlet enthalpy of cooling water	H_{c2}	113.25	kJ/kg
The bulk mean temperature	T_b	26	^oC
Density	ρ_b	997.008	kg/m^3
Dynamic viscosity	μ_b	0.000802	Pa s
Specific heat	C_{Pb}	4.1789	kJ/kgK
Thermal conductivity	k_b	0.6079	W/mK

Table 4.6: Thermophysical properties of $Libr - H_2O$ solution in Absorber [16, 20]

Property	Nomenclature	Value	Unit
Inlet temperature of solution	T_2	47	^oC
Outlet temperature of solution	T_1	34	^oC
The bulk mean temperature	T_b	40.5	^oC
Concentration of solution	X_1	55	%
Density	ρ_{X1}	1600	kg/m^3
Dynamic viscosity	μ_{X1}	0.0037	Pa s
Specific heat	$C_{P,X1}$	2.07	kJ/kgK
Thermal conductivity	k_{X1}	0.47	W/mK

4.3.3.1 Absorber inside pipe calculation

Same as in evaporator here also copper tube is used. For cooper tube velocity of fluid is not more than 2 m/s. so velocity of fluid is assumed to be 2 m/s.Based on value of velocity required mass flow rate is

$$m = \rho AV = \rho \times \frac{\pi}{4} d_i^2 \times V = 997.008 \times 3.108 \times 10^{-4} \times 2 = 0.619 kg/s \tag{4.49}$$

Renold number for inside pipe

$$Re = \frac{\rho V d_i}{\mu} = \frac{997.008 \times 2 \times 0.0199}{0.000802} = 49477.45 \tag{4.50}$$

Prandlt number for inside pipe

$$Pr = \frac{\mu C_P}{k} = \frac{0.000802 \times 4.1789 \times 1000}{0.6079} = 5.51 \tag{4.51}$$

The Renold number is greater than 2300. So to find Nusselt number (Nu) Petukhov corelationas as given in sadik Kakac 2nd edition book is used as follows

$$Nu = \frac{(f/2) Re Pr}{1.07 + 12.7 (f/2)^{0.5} (Pr^{2/3} - 1)} \tag{4.52}$$

$$f = (1.58 ln Re - 3.28)^{-2} = (1.58 ln(49477.45) - 3.28)^{-2} = 5.25 \times 10^{-3} \tag{4.53}$$

$$Nu = \frac{(5.25 \times 10^{-3}/2) \times 49477.45 \times 5.51}{1.07 + 12.7 \times (5.25 \times 10^{-3}/2)^{0.5} \times (5.51^{2/3} - 1)} = 292.34 \tag{4.54}$$

$$h_i = \frac{Nu \times k}{d_i} = \frac{292.34 \times 0.6079}{0.0199} = 8930.325 W/m^2 K \tag{4.55}$$

4.3.3.2 Absorber outside pipe calculation

Outside of pipe is a pool of weak solution. Here natural convection considered to be take place.

Grashoff number

$$Gr = \frac{L_C^3 g \beta \Delta T}{\nu^2} = \frac{(0.0222^3) \times 9.81 \times (1/306.5) \times 14.5}{(0.0037/1600)^2} = 949515.3091 \tag{4.56}$$

L_C = Effective length (For horizontal cylinder is taken diameter of cylinder).

β = Average of both bulk mean temperature.

ΔT = Temperature difference b/w both bulk mean temperature.

ν = Kinematic viscosity.

Prandlt number

$$Pr = \frac{\mu C_P}{k} = \frac{0.0037 \times 2.07 \times 1000}{0.47} = 16.29 \tag{4.57}$$

To calculate Nusselt number for heat transfer co-efficient, ASHRAE fundamental gives equation for horizontal cylinder as follows.

$$Nu = \left[0.6 + \frac{0.387(GrPr)^{1/6}}{[1 + (0.559/Pr)^{9/16}]^{8/27}}\right]^2 \tag{4.58}$$

$$Nu = \left[0.6 + \frac{0.387 \times (949515.3091 \times 16.29)^{1/6}}{[1 + (0.559/16.29)^{9/16}]^{8/27}}\right]^2 = 41.75 \tag{4.59}$$

$$h_o = \frac{Nu \times k}{d_o} = \frac{34.16 \times 0.573}{0.0222} = 884.0576 W/m^2K \tag{4.60}$$

4.3.3.3 Absorber over all heat transfer co efficient

Table 4.7: Heat transfer coefficient for Absorber design

	coefficient	Value	Unit
Inside Pipe	h_i	8930.325	W/m^2K
Outside pipe	h_0	884.0576	W/m^2K

$$U_{abs} = \frac{1}{\left(\frac{r_o}{r_i} \times \frac{1}{h_i}\right) + \left(\frac{r_o}{r_i} \times R_{fi}\right) + \frac{r_o ln(r_o/r_i)}{k} + R_{fo} + \frac{1}{h_o}} \tag{4.61}$$

$$U_{abs} = \frac{1}{(\frac{0.0222}{0.0199} \times \frac{1}{8930.325}) + (\frac{0.0222}{0.0199} \times 0.000176) + \frac{0.0222 ln(0.0222/0.0199)}{2 \times 401} + 0.0006 + \frac{1}{884.0576}} = 487.08 W/m^2K \tag{4.62}$$

4.3.3.4 Absorber required heat transfer area

$T_{h1} = 47^oC, T_{h2} = 34^oC$

$T_{c1} = 25^oC, T_{c2} = 27^oC$

$$LMTD = \frac{(T_{h1} - T_{c2}) - (T_{h2} - T_{c1})}{ln\frac{T_{h1} - T_{c2}}{T_{h2} - T_{c1}}} = 13.77 \tag{4.63}$$

Required heat transfer area

$$A_{HT} = \frac{Q}{U_{eva} \times LMTD} = \frac{230.61 \times 1000}{487.08 \times 13.77} = 34.38 m^2 \tag{4.64}$$

4.3.3.5 Absorber required shell diameter

$$D_s = 0.637 \times \sqrt{\frac{CL}{CTP}} \times \left[\frac{A_{HT}(PR)^2 d_o}{L}\right]^{1/2} \tag{4.65}$$

CTP = 0.9 (for 2 tube pass)

CL = 0.87 (tube layout constant for $30^o$and 60^o)

PR = 1.25 (assume)

L = 3 m (assume)

$$D_s = 0.637 \times \sqrt{\frac{0.87}{0.9}} \times \left[\frac{34.38 \times 1.25^2 \times 0.0222}{3}\right]^{1/2} = 0.39m \tag{4.66}$$

4.3.3.6 Absorber required number of tubes

$$N_t = 0.785 \times \left(\frac{CTP}{CL}\right) \times \frac{D_s^2}{PR^2 \times d_o^2} \tag{4.67}$$

$$N_t = 0.785 \times \left(\frac{0.9}{0.87}\right) \times \frac{0.39^2}{1.25^2 \times 0.0222^2} = 160.39 tubes \tag{4.68}$$

In absorber 160 tubes required with shell diameter of 0.39 m.

4.3.4 Condenser Design

Table 4.8: Thermophysical properties of cooling water in condenser [14, 15]

Property	Nomenclature	Value	Unit
Inlet temperature of cooling water	T_{c1}	25	^oC
Inlet enthalpy of cooling water	H_{c1}	104.89	kJ/kg
Outlet temperature of cooling water	T_{c2}	27	^oC
Outlet enthalpy of cooling water	H_{c2}	113.25	kJ/kg
The bulk mean temperature	T_b	26	^oC
Density	ρ_b	997.008	kg/m^3
Dynamic viscosity	μ_b	0.000802	Pa s
Specific heat	C_{Pb}	4.1789	kJ/kgK
Thermal conductivity	k_b	0.6079	W/mK

Table 4.9: Thermophysical properties of cooling water in condenser [14, 15]

Property	Nomenclature	Value	Unit
Vapour inlet temperature	T_3	88	^oC
Vapour inlet enthalpy	H_3	2656.9	kJ/kg
Condensate outlet temperature	T_4	88	^oC
Condensate outlet enthalpy	H_4	368.51	kJ/kg
Latent heat of evaporation	H_{fg}	2288.3	
Density (liquid)	$\rho_{l,4}$	966.18	kg/m^3
Density (vapour)	$\rho_{v,3}$	0.3942	kg/m^3
Dynamic viscosity (liquid)	$\mu_{l,4}$	0.0003163	Pa s
Dynamic viscosity (vapour)	$\mu_{v,3}$	0.000011615	Pa s
Specific heat (liquid)	$C_{Pl,4}$	4.203	kJ/kgK
Specific heat (vapour)	$C_{Pv,3}$	1.9965	kJ/kgK
Thermal conductivity (liquid)	$k_{l,3}$	0.675	W/mK
Thermal conductivity (vapour)	$k_{v,4}$	0.0239	W/mK

4.3.4.1 Condenser inside pipe calculation

Inside pipe cooling water is moving which cool refrigerant, this is same water which moving in inside pipe of absorber. So for inside pipe heat transfer coefficient is same which in absorber.

Inside heat transfer coefficient hi = 8930.325 W/m^2K.

4.3.4.2 Condenser outside pipe calculation

Outside heat transfer coefficient

$$\frac{h_o d_o}{k_l} = 0.728 \times \left[\frac{\rho_l(\rho_l - \rho_g) g h_{fg} d_o^3}{\mu_l (T_{sat} - T_w) k_l} \right]^{1/4} \tag{4.69}$$

$$\frac{h_o d_o}{k_l} = 0.728 \times \left[\frac{969.46 \times (969.46 - 0.3350) \times 9.81 \times 2301.1 \times 1000 \times (0.0222)^3}{0.0003395 \times (88 - 26) \times 0.671} \right] = 260.63 \tag{4.70}$$

$$h_o = \frac{0.675 \times 260.63}{0.0222} = 7924.56 W/m^2K \tag{4.71}$$

4.3.4.3 Condenser over all heat transfer co efficient

Table 4.10: Heat transfer coefficient for Absorber design

	coefficient	Value
Inside Pipe	h_i	8930.325
Outside pipe	h_0	7924.56

$$U_{con} = \frac{1}{\left(\frac{r_o}{r_i} \times \frac{1}{h_i}\right) + \left(\frac{r_o}{r_i} \times R_{fi}\right) + \frac{r_o ln(r_o/r_i)}{k} + R_{fo} + \frac{1}{h_o}} \tag{4.72}$$

$$U_{con} = \frac{1}{(\frac{0.0222}{0.0199} \times \frac{1}{8930.325}) + (\frac{0.0222}{0.0199} \times 0.000176) + \frac{0.0222ln(0.0222/0.0199)}{2\times401} + 0.0006 + \frac{1}{7924.56}} = 953.27W/m^2K \tag{4.73}$$

4.3.4.4 Condenser required heat transfer area

$T_{h1} = 88^oC, T_{h2} = 88^oC$

$T_{c1} = 37^oC, T_{c2} = 35^oC$

$$LMTD = \frac{(T_{h1} - T_{c2}) - (T_{h2} - T_{c1})}{ln\frac{T_{h1}-T_{c2}}{T_{h2}-T_{c1}}} = 51.99 \tag{4.74}$$

Required heat transfer area

$$A_{HT} = \frac{Q}{U_{eva} \times LMTD} = \frac{156.82 \times 1000}{953.27 \times 51.99} = 3.16m^2 \tag{4.75}$$

4.3.4.5 Condenser required shell diameter

$$D_s = 0.637 \times \sqrt{\frac{CL}{CTP}} \times \left[\frac{A_{HT}(PR)^2 d_o}{L}\right]^{1/2} \tag{4.76}$$

CTP = 0.9 (for 2 tube pass)

CL = 0.87 (tube layout constant for $30^o$and 60^o)

PR = 1.25 (assume)

L = 1 m (assume)

$$D_s = 0.637 \times \sqrt{\frac{0.87}{0.9}} \times \left[\frac{3.16 \times 1.25^2 \times 0.0222}{1}\right]^{1/2} = 0.20m \tag{4.77}$$

4.3.4.6 Condenser required number of tubes

$$N_t = 0.785 \times \left(\frac{CTP}{CL}\right) \times \frac{D_s^2}{PR^2 \times d_o^2} \tag{4.78}$$

$$N_t = 0.785 \times \left(\frac{0.9}{0.87}\right) \times \frac{0.20^2}{1.25^2 \times 0.0222^2} = 42.18 tubes \tag{4.79}$$

In condenser 42 tubes required with shell diameter of 0.20 m.

4.3.5 Generator design

Based on generator inlet and outlet temperature

$Q = m \times C_P \times \Delta T$

$239.83 = m \times 2.07 \times (88 - 74)$

$m = 8.27 kg/s$

If inlet temperature of water is assumed 120^oC

$Q = m \times C_P \times \Delta T$

$239.83 = 8.27 \times 2.07 \times (120 - t)$

$t = 114.01 kg/s$

Table 4.11: Thermophysical properties of hot water in generator [14, 15]

Property	Nomenclature	Value	Unit
Inlet temperature of hot water	T_6	120	^oC
Inlet enthalpy of hot water	H_6	503.71	kJ/kg
Outlet temperature of hot water	T_7	114.01	^oC
Outlet enthalpy of hot water	H_7	478.24	kJ/kg
The bulk mean temperature	T_b	117.005	^oC
Density	ρ_b	945.17	kg/m^3
Dynamic viscosity	μ_b	0.00024025	Pa s
Specific heat	$C_{P,b}$	4.239	kJ/kgK
Thermal conductivity	k_b	0.6857	W/mK

Table 4.12: Thermophysical properties of $Libr - H_2O$ solution in generator [16, 20]

Property	Nomenclature	Value	Unit
Inlet temperature of solution	T_1	74	^oC
Outlet temperature of solution	T_2	88	^oC
The bulk mean temperature	T_b	81	^oC
Concentration of solution	X_2	61	%
Density	ρ_{X2}	1700	kg/m^3
Dynamic viscosity	μ_{X2}	0.0028	Pa s
Specific heat	$C_{P,X2}$	1.8	kJ/kgK
Thermal conductivity	k_{X2}	0.48	W/mK

4.3.5.1 Generator inside pipe calculation

Same as in evaporator here also copper tube is used. For cooper tube velocity of fluid is not more than 2 m/s. so velocity of fluid is assumed to be 2 m/s.Based on value of velocity required mass flow rate is

$$m = \rho AV = \rho \times \frac{\pi}{4} d_i^2 \times V = 945.17 \times 3.108 \times 10^{-4} \times 2 = 0.587 kg/s \tag{4.80}$$

Renold number for inside pipe

$$Re = \frac{\rho V d_i}{\mu} = \frac{945.17 \times 2 \times 0.0199}{0.00024025} = 156577.59 \tag{4.81}$$

Prandlt number for inside pipe

$$Pr = \frac{\mu C_P}{k} = \frac{0.00024025 \times 4.239 \times 1000}{0.6857} = 1.48 \tag{4.82}$$

The Renold number is greater than 2300. So to find Nusselt number (Nu) Petukhov corelationas as given in sadik Kakac 2nd edition book is used as follows

$$Nu = \frac{(f/2) Re Pr}{1.07 + 12.7 (f/2)^{0.5} (Pr^{2/3} - 1)} \tag{4.83}$$

$$f = (1.58 ln Re - 3.28)^{-2} = (1.58 ln(156577.59) - 3.28)^{-2} = 4.09 \times 10^{-3} \tag{4.84}$$

$$Nu = \frac{(4.09 \times 10^{-3}/2) \times 156577.59 \times 1.48}{1.07 + 12.7 \times (4.09 \times 10^{-3}/2)^{0.5} \times (1.48^{2/3} - 1)} = 383.3088 \tag{4.85}$$

$$h_i = \frac{Nu \times k}{d_i} = \frac{383.3088 \times 0.6857}{0.0199} = 13207.78 W/m^2 K \tag{4.86}$$

4.3.5.2 Generator outside pipe calculation

Outside of pipe is a pool of weak solution. Here natural convection considered to be take place.

Grashoff number

$$Gr = \frac{L_C^3 g\beta\Delta T}{\nu^2} = \frac{(0.0222^3)\times 9.81\times(1/372.0025)\times 36.005}{(0.0028/1700)^2} = 3829364.153 \tag{4.87}$$

L_C = Effective length (For horizontal cylinder is taken diameter of cylinder).

β = Average of both bulk mean temperature.

ΔT = Temperature difference b/w both bulk mean temperature.

ν = Kinematic viscosity.

Prandlt number

$$Pr = \frac{\mu C_P}{k} = \frac{0.0028\times 1.8\times 1000}{0.48} = 10.5 \tag{4.88}$$

To calculate Nusselt number for heat transfer co-efficient, ASHRAE fundamental gives equation for horizontal cylinder as follows.

$$Nu = \left[0.6 + \frac{0.387(GrPr)^{1/6}}{[1+(0.559/Pr)^{9/16}]^{8/27}}\right]^2 \tag{4.89}$$

$$Nu = \left[0.6 + \frac{0.387\times(3829364.153\times 10.5)^{1/6}}{[1+(0.559/10.5)^{9/16}]^{8/27}}\right]^2 = 54.75 \tag{4.90}$$

$$h_o = \frac{Nu\times k}{d_o} = \frac{54.75\times 0.48}{0.0222} = 1183.891 W/m^2K \tag{4.91}$$

4.3.5.3 Generator over all heat transfer co efficient

Table 4.13: Heat transfer coefficient for Absorber design

	coefficient	Value	Unit
Inside Pipe	h_i	13207.78	W/m^2K
Outside pipe	h_0	1183.891	W/m^2K

$$U_{gen} = \frac{1}{\left(\frac{r_o}{r_i}\times\frac{1}{h_i}\right)+\left(\frac{r_o}{r_i}\times R_{fi}\right)+\frac{r_o ln(r_o/r_i)}{k}+R_{fo}+\frac{1}{h_o}} \tag{4.92}$$

$$U_{gen} = \frac{1}{(\frac{0.0222}{0.0199}\times\frac{1}{13207.78})+(\frac{0.0222}{0.0199}\times 0.00079)+\frac{0.0222ln(0.0222/0.0199)}{2\times 401}+0.000176+\frac{1}{1183.891}} = 502.6464 W/m^2K \tag{4.93}$$

4.3.5.4 Generator required heat transfer area

$T_{h1} = 120^oC, T_{h2} = 114.01^oC$

$T_{c1} = 74^oC, T_{c2} = 88^oC$

$$LMTD = \frac{(T_{h1} - T_{c2}) - (T_{h2} - T_{c1})}{ln\frac{T_{h1}-T_{c2}}{T_{h2}-T_{c1}}} = 35.85 \tag{4.94}$$

Required heat transfer area

$$A_{HT} = \frac{Q}{U_{eva} \times LMTD} = \frac{239.83 \times 1000}{502.6464 \times 35.85} = 13.30m^2 \tag{4.95}$$

4.3.5.5 Generator required shell diameter

$$D_s = 0.637 \times \sqrt{\frac{CL}{CTP}} \times \left[\frac{A_{HT}(PR)^2 d_o}{L}\right]^{1/2} \tag{4.96}$$

CTP = 0.9 (for 2 tube pass)

CL = 0.87 (tube layout constant for $30^o$and 60^o)

PR = 1.25 (assume)

L = 3 m (assume)

$$D_s = 0.637 \times \sqrt{\frac{0.87}{0.9}} \times \left[\frac{13.30 \times 1.25^2 \times 0.0222}{3}\right]^{1/2} = 0.24m \tag{4.97}$$

4.3.5.6 Generator required number of tubes

$$N_t = 0.785 \times \left(\frac{CTP}{CL}\right) \times \frac{D_s^2}{PR^2 \times d_o^2} \tag{4.98}$$

$$N_t = 0.785 \times \left(\frac{0.9}{0.87}\right) \times \frac{0.24^2}{1.25^2 \times 0.0222^2} = 63.64tubes \tag{4.99}$$

In generator 64 tubes required with shell diameter of 0.24 m.

Chapter 5

Conclusions and Future Work

5.1 Conclusions

Following are the major conclusions of present work

1. Four major consumption area of bearing industry are (1) heat treatment process, (2) chiller, (3) air handling unit, (4) air compressor.
2. Among all chiller is a major consumption area in industry. To decrease energy consumption of chiller and increase COP of chiller, $Libr - H_2O$ vapour absorption refrigeration system is designed.Required heat load of generator (Qg), condenser (Qc), evaporator (Qe) and absorber (Qa) is 239.83 kW, 156.82 kW, 148.83 kW and 230.61 kW respectively.
3. Solar collector may be design for present vapour absorption refrigeration system.
4. To minimize energy loss the following proposal are been suggested:
   (a) To install Waste Heat recovery system on Compressors catering to hot water requirement for Pre Washer in Aichelin furnace
   (b) To install in house N_2Generator instead of hiring tankers & storing liquid N_2 in plant.
   (c) To install Solar Water heating system catering to hot water requirement for new phosphating plant.
   (d) To cover bainite bath tanks from top to avoid heat loss
   (e) To install SMARTLINK to monitor compressor performance

5.2 Future Work

There is a scope of using evacuated tube solar collector (ETC) or concentric parabolic collector (CPC) for better economic analysis. It is also good opportunity to use hybrid system like fuel and solar to provide heat in generator.

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