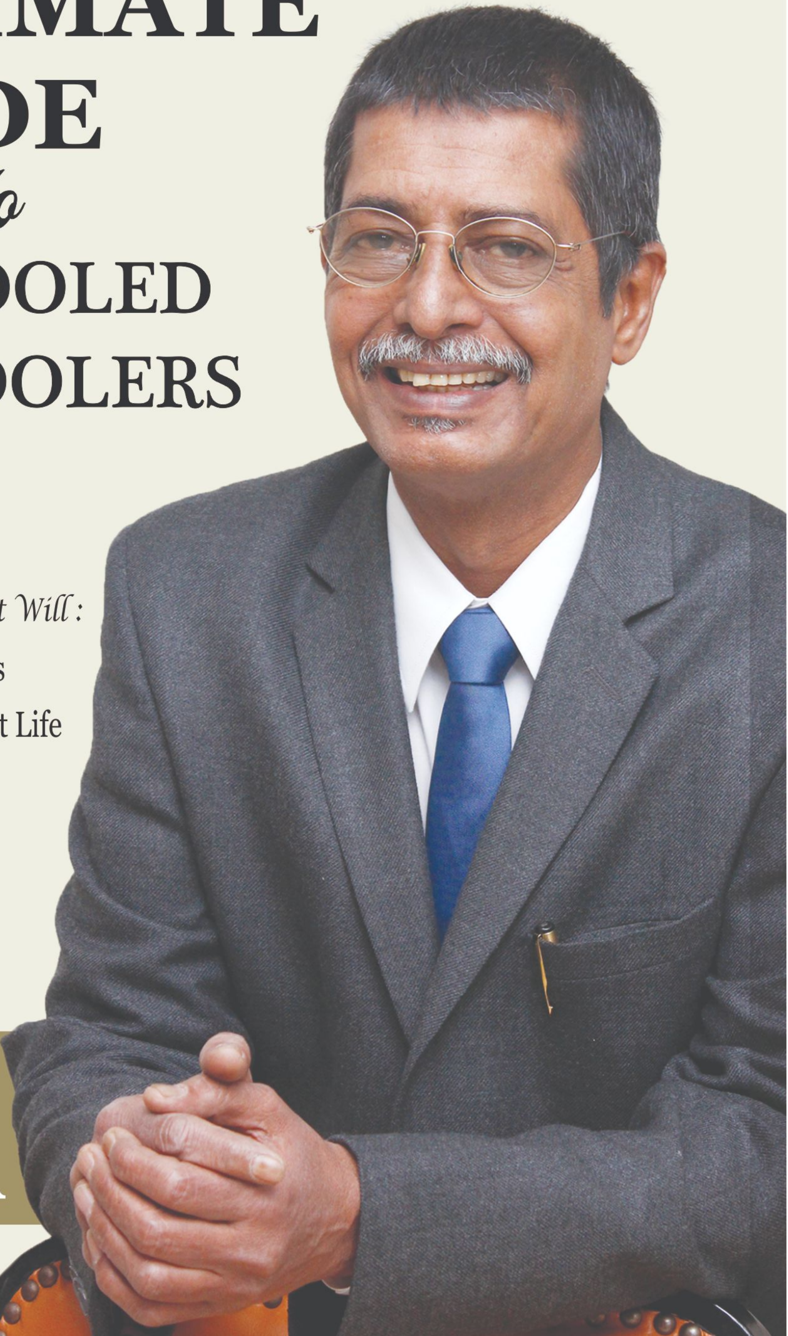
The ULTIMATE GUIDE *to* AIR COOLED OIL COOLERS



1. Little Change That Will :

- Reduce Energy Bills
- Increase Equipment Life
- Improve Efficiency

VINEET TANEJA

THE ULTIMATE GUIDE
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VINEET TANEJA

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Dedicated To

I dedicate this book to my parents Smt. Kamla and Sh. Dev Raj Taneja.

Without their understanding, patience, support and most of all love, the completion of this work would not have been possible.

Acknowledgements

I would like to express my gratitude to the many people who saw me through this book; to all those who provided support, talked things over, read, wrote, made drawings, edited pictures, offered comments, allowed me to quote their remarks and assisted in the editing, proofreading and design.

Nobody has been more important to me in the pursuit of this project than the members of my family. I would like to thank my parents, whose love and guidance are with me in whatever I pursue. They are the ultimate role models.

Most importantly, I wish to thank my loving and supportive wife, Priya and my son Ambar, who provide unending inspiration. I cannot thank my team at Ace Automation Engineers enough for the contribution they have made in my life & business.

Last but not least: I beg forgiveness of all those who have been with me over the course of years and whose names I have failed to mention.

Foreword

Having spent some time in the hydraulics equipment business as an R & D engineer you come across a mixed bag of practitioners and practices. Mr. Vineet Taneja belongs firmly in the good bag. My earliest experience goes back a good 10 - 12 years when we met at our Delhi Office. He was looking for some write-up on proportional valves, specifically Yuken's valves - their functioning, construction, etc. It was only much later that I figured out that he was actually trying to trouble-shoot/come up with his unique solution to a problem that he had noticed with a customer's hydraulic power unit. Fast forward a few years, a couple of meetings and many phone conversations, I had in Mr. Taneja a sounding board for new ideas on products, modifications and most importantly a source for feedback and a clear definition issues with hydraulic valves and pumps. It was during one such conversation that I learned of his other pet project - oil coolers and to be specific air-cooled oil cooler.

Oil coolers are an important element of any hydraulic equipment, unfortunately often amongst the last things to be thought of/added to units. Like with most machinery, the prime movers (electric motor or IC engines) are selected for peak loads while the load in working conditions fluctuates based on the processing cycle. As a result, the energy generated during portions of the cycle when the system does not require the energy is typically expended as heat. This 'waste heat', in hydraulic equipment is transferred into the hydraulic oil. While there are a number of ways in which hydraulic systems are optimized to reduce this heat, the benefits provided by a good heat exchanger or an oil cooler is irreplaceable. Selection, Operation and Maintenance of Oil Coolers are key piece of the technology that is neither well understood nor is due attention given in general engineering circles. 'Dumb' rules and guesstimates based on hearsay are the typical basis for using oil coolers without an understanding of the duty/load cycles, operating conditions, or the type of hydraulic system that heat exchanger is to be paired with. A comprehensive guide for machine builders, designer and users focused on this part of the technology is missing.

I am sure Mr. Taneja's attempt at bringing up some of these issues with regard to oil coolers and discussing them in a clear and forthright manner will resonate with engineers and practitioners in the industry. He has been very strategic in focusing on this area of oil coolers giving insights into practical expertise he has gained through his relentless pursuit and entrepreneurial spirit. We hope that this effort of his might encourage the next crop of industrial equipment designers to go back to the basics to look for new and innovative solutions to oil cooling.

Hemanth Gopal
Chief Technology Officer
Yuken India Ltd.

Foreword

The author - Vineet Taneja, as I know him is an avid technocrat who firmly believes that without a solution there cannot be a problem. A down to earth person with no personal ego and a golden heart, always ready to walk the extra mile for the betterment of the society, fellow beings and... Totally committed, dependable and reliable personality, leading a very simple life (no fanfare).

A born technocrat whose mind focuses on solutions rather than problems. He is very much talented in his field of Hydraulics management and has solution for all your problems / requirements. A delightful personality having enormous wealth of knowledge of the various facets of life. My association with him is almost over two decades and his knowledge and dedication makes me think as if it's not blood but hydraulic oils flow in his veins and engineering is the only thought in his mind. It's always a pleasure and privilege for me to have him as one of my close friend / business associate whom I can trust blindly for solutions to all my technical problems.

This book I am sure is going to be an eye opener for a whole lot of people looking for technical solutions for their day-to-day problems. Very simple yet effective solutions genuinely coming from the vast practical experience of his is going to be a boon for the readers.

I was not at all aware of this very facet of his personality until I saw the book. It's a very pleasant surprise for me and I personally wish him every success in this endeavor. Keep working, thinking, writing and publishing all the practical aspects of your knowledge on the subject for the betterment of the future generation of our Great Nation.

All the Very best Vineet Taneja for all your future endeavor's

May God bless you with all the success in life.

Cheers!!!!

A N Shukla
Chief General Manager Production
Knorr-Bremse India Private Ltd.

About the book

This book talks about the heat produced during operation of machine & machine elements - gearboxes, bearings, hydraulic power units, lubrication units, spindles, electrical transformers, welding equipment and the like. The causes, consequences, their treatment and the resulting benefits. It's designed in a simple question - answer format and need not be read cover to cover. After familiarizing themselves with the basics, the readers can choose and read specific chapters based on equipment(s) of interest. It gives not only the scientific way but also rules of thumb to resolve the problem associated with the specific type of equipment that interests the reader. The rule of thumb should work in most commonly faced situations in the industry, barring exceptions. The reader is also advised to read the nuances described in the relevant chapter / topic.

Must read for business owners, CEOs, CFOs, mechanical / instrumentation managers & engineers. It provides useful insights to those involved with equipment selection, procurement & maintenance.

About the author

Meet Vineet Taneja

Vineet Taneja is an expert and a trainer in **Industrial Hydraulics & Oil Cooling** whose accomplishments include:

Education:

- Hons. Degree in Mechanical Engineering from Birla Institute of Technology & Science, Pilani (BITS Pilani).

- Masters with Hons. in Mathematics from Birla Institute of Technology & Science, Pilani (BITS Pilani).

Work History:

- Worked for 5 years with corporations including Chicago Pneumatics Ltd.

- 28+ years of running his enterprise designing, manufacturing & installation of Hydraulic, Oil Cooling & Lubrication equipment

- Expanded his business to ten countries

Certifications:

- Business Mastery Certification from Business Coaching India
- Certified Digital Marketing Certification from Business Coaching India
- Financial Control Certification
- DISC Profiling Certification
- SPIN Sales Certification

Personal Info:

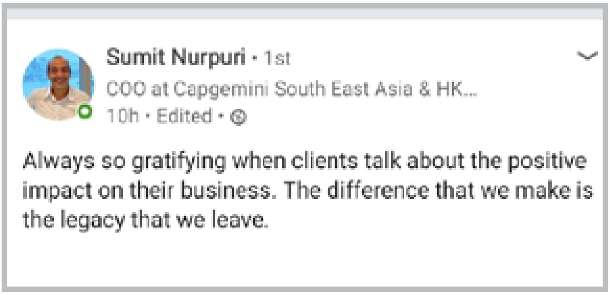
- Happily married for 30 years to Priya & blessed with a lovely son Ambar.
- Worked with over 1050 businesses and helped increase production anywhere from 7% to 73% and save energy costs up to 19.3%.

Most of what you need is instruction and encouragement from someone who has "been there and done that!" with **how to Reduce Energy Bills, Increase Equipment Life, Improve efficiency & Increase Profits.**

And as you can see, Oil Cooling & Industrial Hydraulics expert Vineet Taneja is uniquely qualified to help you understand everything you need to know about **Air Cooled Oil Cooling!**

Preface

In the past 33 years I have visited 1583 factories and analyzed 509 machine failures across industries paper, cement, sugar, steel, power and more. I realized that thousand and millions of dollars of **profit is being lost.** What is surprising is that most of the times the **business owners,** the **CEOs** and the **CFOs** aren't even **aware** of this. A lot many of these are easily preventable. I shared my insights with a few business owners and they achieved amazing results in terms of **reduced energy bills, increased equipment life, improved efficiency & increased profits.** It was so gratifying to hear of positive results that were produced. I decided to look for books on the subject and I couldn't find any. It was this that prompted me to write a book so that other companies too could use the information and **increase** their **profits, reduce** premature, unplanned & unscheduled **maintenance shut downs & increased productivity.** My dear friend Sumit Nurpuri's post on LinkedIn expresses the emotion behind this book beautifully.



It is estimated that there are over 7.7 billion people living on the earth today. The total human production of goods & services is estimated to be over $66 trillion. To achieve this we consume an estimated 13 trillion calories per day of energy. As this energy is consumed to run machines they heat up and need to be cooled. Even though newer and better material technologies & smarter processes are increasing machine efficiency. The need to produce more & more goods and services, are increasing energy consumption at an unprecedented pace. So is the heat generated in machines, an estimated 1400 trillion calories per annum of it. **This wasted heat energy** needs to be **checked, dissipated** or removed to prevent **machines** from **overheating**. Unchecked or **not dealt** with **properly** they cause havoc, result in **unscheduled failure, losses** in terms of **increased power bills & reduced production.**

Traditionally water has been used for centuries as a cooling medium. However annual water consumption in the world has reached to around 4 million cubic meters. The increasing scarcity of fresh water resulted in the need of its recirculation. In order for it to be recirculated for cooling, the water needs to be cooled. Which is done by cooling it with air. Newer technologies therefore evolved to increasingly use air directly as a cooling medium. Air-cooled systems dissipate heat with flowing air. These have the advantage of easy availability, higher reliability, lower running cost and are simpler to maintain. They also eliminate the problem of water-contamination and minimize corrosion.

Contents

1 WHY DO MACHINES HEAT UP?

No energy consuming machine or system is 100% efficient. Though most of the energy consumed by a machine is used to do useful work, a part of the energy gets converted into heat. If this heat is not managed properly, the temperature of the equipment keeps increasing till it overheats. This causes irreparable damage, which in turn reduces the efficiency further. The end result is **increased power consumption, reduced equipment life, break downs** & increased **maintenance cost.**

To help in managing the heat generated most equipment - hydraulic systems, gearboxes, spindles, large electrical transformers, engines, compressors, turbines, vacuum pumps, generators, blowers – use industrial oils & coolants to **lubricate, cool** & keep the temperatures in check.

2 WHY IS THIS HEAT OF CONCERN?

The **heat production** due to inefficiencies in machines if not managed properly, results in **heavy** consequential cost. As we move forward we discuss ways of managing the heat that gets generated. Industrial oils are used to lubricate, remove wasteful energy and clear away the debris produced by wear & tear, they in turn get heated & need to be cooled. Not treated properly this has a cascading affect as the machines over heat, causing increased wear & tear, which in turn leads **to higher energy consumption, increased maintenance & reduced equipment life.**

Oil coolers are heat exchangers that are used to cool these fluids by passing them over a cooler fluid, separated by a barrier to prevent intermixing. They remove excess heat generated by energy losses in a system. In fact, **oil coolers** are **essential** for designing **temperature-**

optimized machines or systems that keep oil temperatures within a limited range. They are basic prerequisites for **cost-efficient operation,** as they provide a number of **performance enhancing, economic, and environmental benefits.**

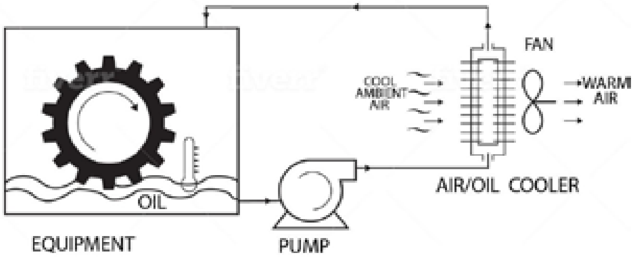
3 DOES THE HEAT PRODUCED NEED TO BE MANAGED?

All equipment in which the rate of heat buildup is larger than the heat dissipation capacity to the ambient air by natural radiation, need a mechanism for heat removal built into them. By and large equipment that is sparingly used with large time gaps between usage cycles are able to naturally radiate the heat built up, to the environment during periods of inactivity. However continuous duty equipment especially in energy intensive manufacturing processes need efficient & reliable systems for heat dissipation. This is done using heat exchangers or oil coolers.

4 WHAT ARE THE DIFFERENT METHODS FOR MANAGING HEAT?

In the industry various types of cooling media are used to transfer heat from cooling oils & lubricants e.g. water, air, refrigerants, hydrogen. Of these we discuss primarily the two cooling media that are most commonly used & readily available, with a relatively low cost viz. Air and water.

Air Cooled Oil / Fluid Coolers: In air cooled oil coolers the hot oil or fluid is passed in close proximity to a blast of ambient air. The heat exchange takes place across a barrier between the hot oil and cool ambient air (refer Fig. 4-1).



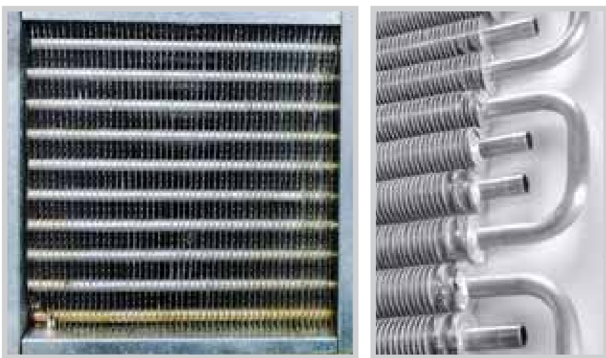
Air Based Oil Cooling System - (Fig.4-1)

There are primarily three types of air cooled oil coolers or heat exchangers, based on construction design & the manufacturing process used. Each type has a similar working mechanism & performs similar function.

A. Tube Fin Type - Fig. 4-2

B. Plate Fin Type - Fig. 4-3

C. Stacked Layer or D Cup Type - Fig. 4-4



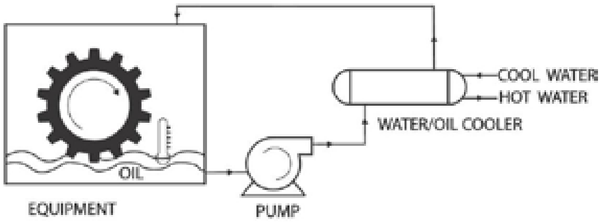
Tube Fin Type Air Cooled Oil Coolers - (Fig.4-2)

Plate Fin Type Air Cooled Oil Coolers - (Fig.4-3)

Stacked Layer or D Cup Type Air Cooled Oil Cooler (Fig.4-4)

These are explained in greater detail in Chapter 6.

Water Cooled Oil Coolers: The hot oil is passed in close proximity to water and the heat exchange takes place across a barrier between the hot oil and cool cooling water (refer Fig. 4-5).



Water Based Oil Cooling System - (Fig.4-5)

These are mainly of three types.

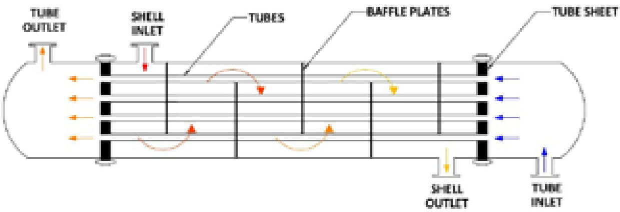
A. Shell & Tube Type – Fig. 4-6

B. Gasket Plate Type – Fig. 4-7

C. Brazed Plate Type – Fig. 4-8

The hot & cool fluids enter the heat exchanger through respective inlet ports. After the heat exchange takes place across a barrier separating the two fluids, the fluids exit the heat exchanger through the outlet ports. The shell & tube heat exchangers comprises of a tube bundle encased in an outer housing or shell. The cool fluid usually travels through the tubes & the hot fluid moves in the shell. The heat exchange taking place across the tube surface as shown in Fig. 4-6A.

Shell & Tube Type Water Cooled Oil Cooler (Fig.4-6)



Working principle of A Shell & Tube Type Water Cooled Oil Cooler - (Fig. 4-6A)

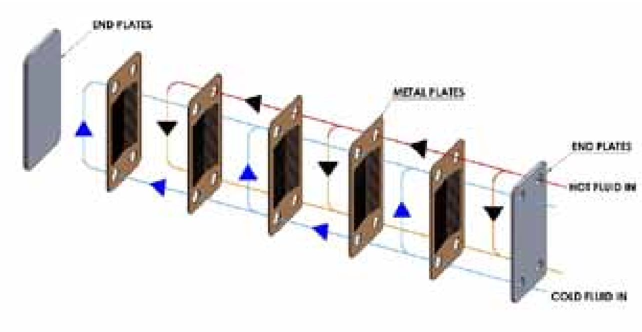
The **gasket plate** & the **brazed plate** type heat exchangers consist of parallel plates. The hot and cool fluids flow in between alternating plates, as shown in Fig. 4-9.

Gasket Plate Type Water Cooled Oil Cooler - (Fig. 4-7)

As the name suggest, in the gasket plate type alternating layers of gaskets & plates are bolted together (Fig. 4-7).

Brazed Plate Type Water Cooled Oil Cooler - (Fig.4-8)

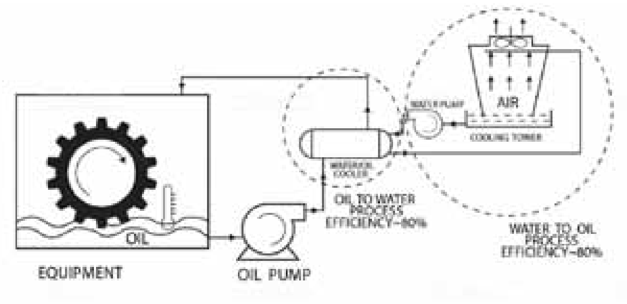
The **Brazed plate type is** similar in construction except that the plates are brazed together in a vacuum furnace. The primary advantages of brazed plate type over gasket plate ones is that the chance of intermixing of the fluids due to a damaged gasket is minimized and they can handle higher working pressures.



Working principle of Plate Type Water Cooled Oil Cooler Fig. 4-9

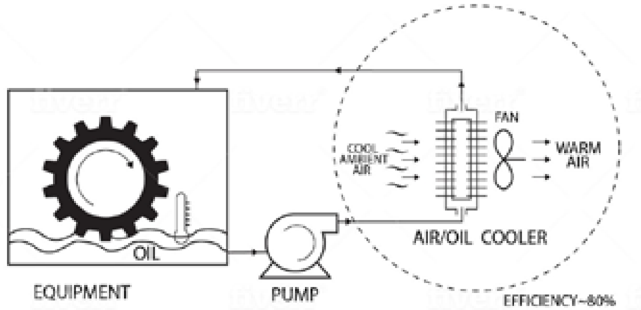
5 WATER COOLED OR AIR COOLED OIL COOLING?

Let's take a closer look at a **water based oil cooling system** (Fig. 4-5). The hot oil from the equipment is pumped through the shell of a water cooled heat exchanger & the cooling water is passed through the tubes. There is exchange of heat between the **hot oil** & the **cooling water.** The cooled oil is returned back to the oil sump or reservoir. The water after it has performed its function of removing the heat from the oil, is itself now warm and has lost the ability to further extract heat efficiently. What do we do with this water? In the olden days it was simply flushed away and more fresh water was used for cooling. With growing **environmental concerns** coupled with the scarcity and cost of fresh water, it needs to be recirculated. In order for it to be effectively re-used as a cooling media, the water needs to lose the heat that it has picked up and be cool enough to be able to remove heat efficiently from the oil. For this the warm water is then pumped to a cooling tower where an air draft is used to cool it. There are two processes involved here - the cooling of oil using water, which in turn gets heated & the cooling of hot water with ambient air. As we know that no process is 100% efficient. Assuming we have two well-designed processes, each having an overall efficiency of say 80%, we have **20% loss of efficiency** in each process. From Fig. 5-1 of a **water cooled oil cooling system** it is evident that we have a total loss of efficiency of 20% + 20%.



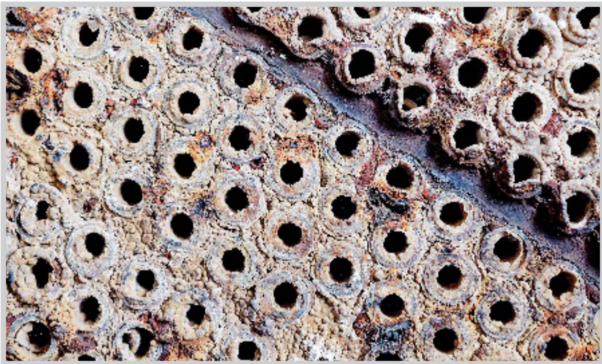
Efficiency Of Water Based Oil Cooling System - (Fig. 5-1)

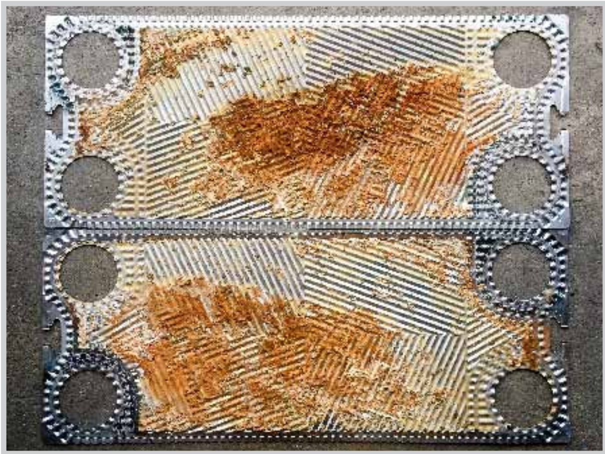
In comparison if we look at an **air cooled oil cooling system,** we have only one process. Again assuming we have a well-designed process with an overall efficiency of 80%, there is a direct benefit of **20%** in **improved efficiency** (refer Fig. 5-2) while using an **air cooled oil cooling system** in comparison to a water based one.



Efficiency Of Air Based Oil Cooling System - (Fig. 5-2)

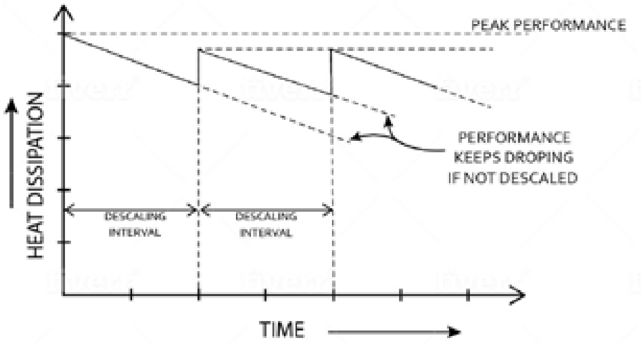
There are other **important nuances** that need to be considered. For instance the **cost of energy required to pump cooling water** for the **entire** usable life of the **equipment**. There is also the cost of plumbing in the initial setup, coupled with the hidden cost of maintenance of the **water pump** & the **plumbing**. It is also noteworthy that the water needs to be treated to **remove salts** and **minerals**, in order to achieve consistent heat exchange. Untreated cooling water is more often than not, laden with salts and minerals. These too add their bit to a maintenance engineer's woes. The salts & minerals present in the water deposit on the barrier between the two fluids, commonly known as **scaling**. Fig. 5-3 shows scaling in shell - tube & gasket plate type heat exchangers. Water **scale** is a **bad conductor of heat.** Therefore the ability of the oil cooler to transfer heat reduces considerably over time, due to scaling.





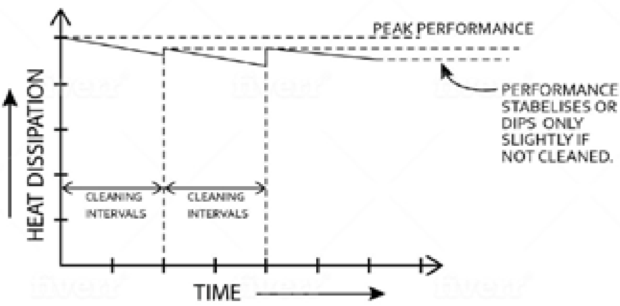
Scale Formation Inside a Water Cooled Oil Cooler
(Fig. 5-3)

Water based oil coolers therefore need to be **descaled**. Fig. 5-4 depicts the typical heat dissipation performance cycle of a water based oil cooler. As the water flows through the oil cooler, salts start depositing on the surface of the tube or plate barrier between the two fluids, through which the heat is being transferred. These salt or chemical deposits called **scale** (usually white or off white in color) build up over time. As a result heat exchange reduces considerably. Water cooled heat exchangers therefore need to be serviced or descaled from time to time. From the graph in Fig. 5-4, it is evident that the performance reduces with respect to usage time. The extent of loss in **efficiency** is dependent on the quality of water available at the site of usage. The amount and type of dissolved salts & minerals in the water determines the frequency of descaling (or servicing in case of gasket plate heat exchangers).



Heat Dissipation Performance Of A Water Cooled Oil Cooler With Respect To Time & Intervals Between Descaling - (Fig. 5-4)

These cost **heavily**, not only in terms of **maintenance cost, cost of gaskets / descaling chemicals time, money & production loss** due to repeated maintenance shutdowns.



Heat Dissipation Performance Of An Air Cooled Oil Cooler With Respect To Time & Intervals Between Cleaning - (Fig. 5-5)

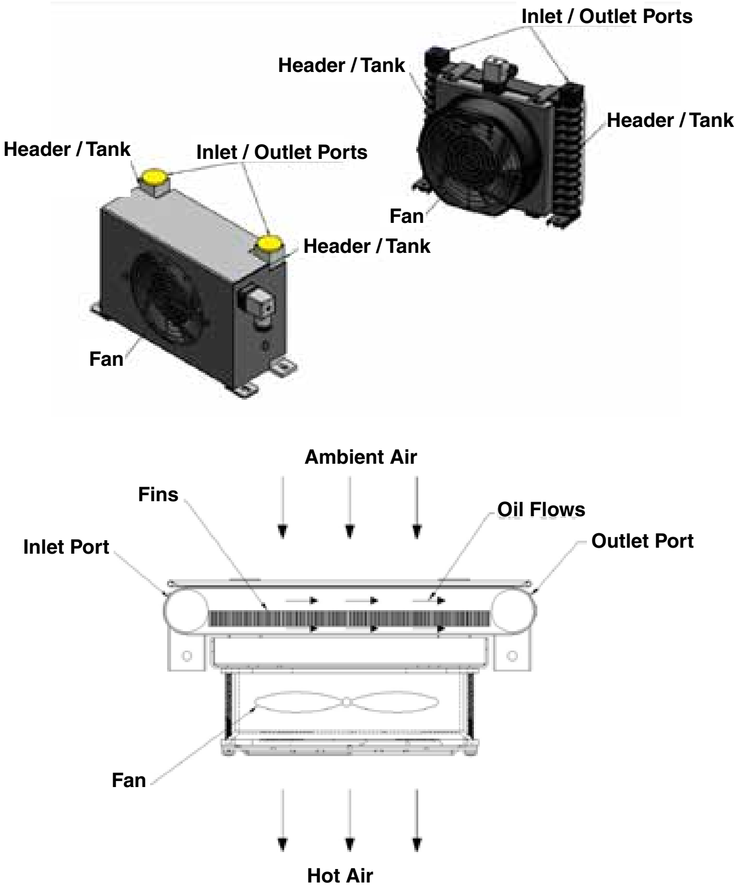
On the other hand let's look at an air based oil cooling system. Here too there is a drop in efficiency with time, as dust and pollutants from the atmosphere deposit on the fin surface (refer Fig. 5-5). The fins too need to be cleaned. But the **cleaning process** is **simple** and **effective**. A compressed air blast cleaning done regularly is enough to remove the dust build up. This cleaning can be carried out while the system is still operative & **does not require a shut down**. Besides the above, an obvious **advantage** of an **air cooled oil cooler** is that as it **does not require water.** Which in turns means that the equipment requiring cooling need not be near a cooling water connection or source. The machine can therefore be **stand alone.** Just plug in the electrical power and we are good to go. On the contrary every time a machine with a water based oil cooling needs to be shifted or relocated, the water supply **plumbing needs to be redone.** Further, the problems associated with treatment and disposal of water have become more costly with **government regulations and environmental concerns.** Air-cooled or air blast or fan cooled oil coolers as they are commonly called provide means of transferring the heat from the fluid directly into ambient air, **without environmental concerns** and at a nominal running cost.

6 HOW DO AIR COOLED OIL COOLERS WORK?

As discussed in chapter 4 there are predominantly three types of air cooled oil coolers based on design & the process used in manufacturing them.

A. Tube Fin Type – Fig. 4-2
B. Plate Fin Type – Fig. 4-3
C. Stacked Layer or D Cup Type – Fig. 4-4

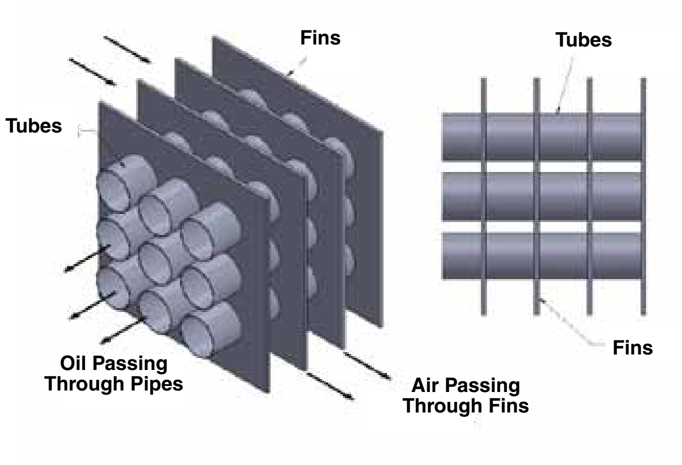
Hot fluid enters the heat exchanger through an **inlet header or tank** via the **inlet port.** From the inlet header it is distributed through round or rectangular tubes, where the heat dissipation takes place. The cooled fluid is then collected in an outlet manifold called the **outlet header or tank.** Finally exiting through the **outlet port** (Fig. 6-1).



Working principle of an air cooled Oil Cooler
(Fig. 6-1)

Tube Fin Oil Coolers

These are usually made of tubes with fins on the outer surface, Fig. 6-2. The hot fluid flows through the round tube transferring heat to the tube wall which in-turn transfers heat to the fins attached to the outer surface of the tube. The fins are cooled by a draft of forced air. This type



Tube Fin Design - (Fig. 6-2)

of oil coolers generally have low heat dissipation per unit volume of the heat exchanger. The primary reasons for this is due to low fin density, lack of turbulence inside the tube & through the fins.

Plate-Fin & Stacked Layer Oil Coolers

Plate-fin & stacked layer oil coolers though different in terms of their manufacturing processes they have a similar working philosophy. **Plate-fin** heat exchanger are, **structurally stronger** and find usage in a wider range of applications. **Stacked layer** or **'D cup'** as they are commonly called have the advantage of ease of manufacturing, higher production volumes & **lower cost.**

Plate fin & stacked layer, both use a number of

rectangular tubes Fig. 6-4. These rectangular tubes are fabricated by brazing together Aluminum alloy plates (also known as separator plates), sidebars & inside bars. The oil to be cooled flows in through an inlet header and is then distributed through these rectangular tubes, Fig. 6-3.

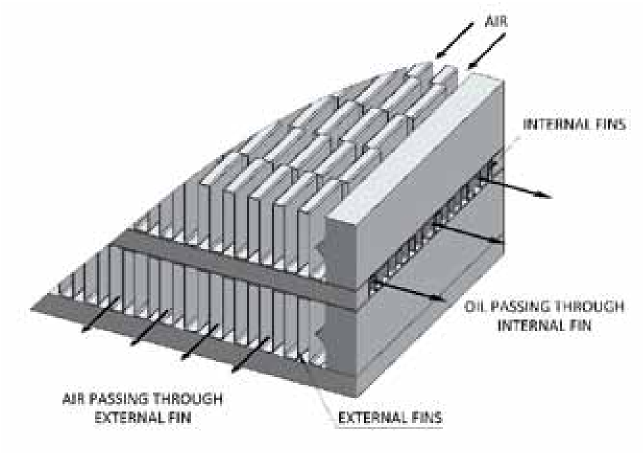


Plate Fin Design – working principle - (Fig. 6-3)

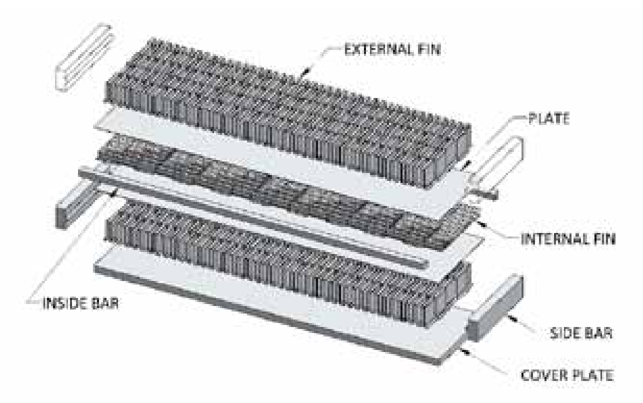


Plate Fin Design - construction - (Fig. 6-4)

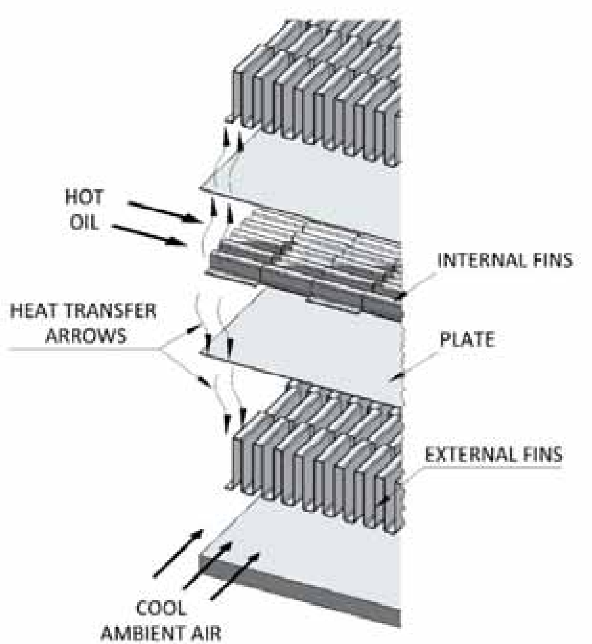
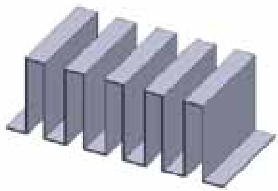


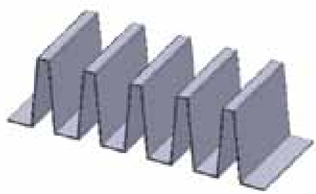
Plate Fin Design – heat flow - (Fig. 6-5)

Enclosed inside these rectangular tubes are fins called **internal fins or internal turbulators.** The heat is transferred from the oil to the internal fins. These fins play a very important role in the heat dissipation process. For one there is **larger surface area** available for heat transfer and secondly the fins cause **turbulence** in the oil thereby resulting in greater transfer of heat from the oil to the internal fins. The heat is then conducted from the internal fins to the plates. Between each pair of plates are **external fins** or **external turbulators** and the heat is in turn transferred from the plates to the external fins by conduction. A draft of cool ambient air is forced through the external fins carrying away the heat, Fig. 6-5. The oil cooled in the rectangular tubes then collects in the outlet header and exits the heat exchanger through the **outlet port.**

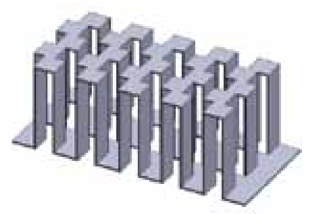
The **external fins** also serve a **dual purpose** of creating **turbulence** in the air flow and providing a larger surface area, thereby resulting in greater heat transfer. This type of heat exchangers are often categorized as compact heat exchanger to emphasize their relatively high heat transfer surface area to volume ratio. This and their light weight properties make plate-fin heat exchangers an obvious choice and are widely used in many industries. They have the ability to facilitate heat transfer even when the temperature difference between the hot fluid and the cool fluid is small. The internal & external fins besides providing an extended surface area for heat transfer also serve to increase the structural integrity of the heat exchanger and allow it to withstand higher pressures & pressure fluctuations.



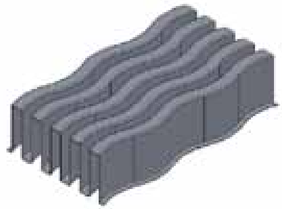
Plain Rectangular Fins
(Fig. 6-6)



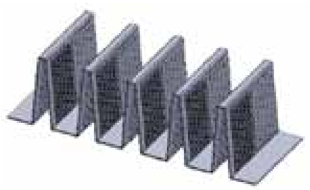
Plain Trapezoidal Fins
(Fig. 6-7)



Staggered Or Offset Fins
(Fig. 6-8)



Wavy Fins
(Fig. 6-9)



Louvered Fins
(Fig. 6-10)

Perforated Fins
(Fig. 6-11)

Whereas each type may show some characteristic advantage over the other in terms of **effective surface area available, heat exchange capacity, turbulence, resistance to clogging with dirt or grease & ease of cleaning.** There are advantages & disadvantages of each type over the others & maybe be best suited for particular application & environment. However, staggered or offset fins have universal appeal & their design is well suited for most applications & environments. Louvered fins have been found to be more effective in small, compact coolers, however they are not well suited for dusty environments as dust tends to get trapped in the louvers reducing heat dissipation efficiency over time.

7 WHAT ARE THE CONSEQUENCES OF NOT INSTALLING AIR COOLED OIL COOLER?

For most medium to large continuous duty machines fitment of adequately sized oil coolers becomes mandatory for achieving temperature optimized systems that keep oil temperatures within an acceptable range. Doing so is a basic prerequisite for **cost-efficient operation,** as they provide a number of **performance, economic and environmental benefits**. These include:

1. Maintaining the correct temperature keeps oil at its recommended viscosity and ensures that mechanical components are properly lubricated and fluid power devices run at peak performance & efficiency, thereby **reducing energy bills.** Letting oil temperature rise beyond recommended limits can **reduce the life of the equipment** due to **poor lubrication,**

higher **internal & external leakages,** and a higher risk of component damage.

2. Operation **within recommended temperature** range increases equipment's **availability and efficiency** thereby **improving productivity.**

3. Keeping temperatures down also helps ensure that the **oil lasts longer.** Excess heat can **degrade oils,** form **harmful varnish / sludge** on component surfaces and accelerate the **deterioration of rubber and elastomeric seals,** leading to **leakages & loss** of expensive oils. The sludge formed also results in sticking of internal moving parts of valves & other components.

4. With less machine downtime it **reduces service and repair costs.**

5. Accurate sizing of oil coolers is an extremely important task of a design engineer, considering the resulting benefits coolers offer. Under sizing results in higher than recommended oil temperatures yet over sizing is an increased expense due to a larger-than-necessary purchase. However when in doubt a larger sized oil cooler is definitely a better option in comparison to an under sized one.

8 ARE AIR COOLED OIL COOLERS AVAILABLE FOR ALL TYPES OF EQUIPMENT?

In the industry various types of fans are used to create the air draft for cooling the oil. Different types of fans need to be selected based on the application of the equipment. The options are air cooled oil cooler with:

A. AC Fan

B. DC Fan

C. Hydraulic Motor driven Fan

D. Flameproof Motor driven Fan

E. Fan & Built in Pump

Oil Coolers with AC Fan Fig. 8-1. Air cooled oil coolers with a fan driven by a **single or three phase** alternating current **(AC)** motor. These are typically used to cool oil in the **industrial environment.**

Air Cooled Oil Cooler with AC Fan - (Fig. 8-1)

Oil Coolers with DC Fan Fig. 8-2. Air cooled oil coolers with **12V & 24V** direct current **(DC)** power operated fans. These usually find application in mobile or vehicle mounted equipment.

Air Cooled Oil Cooler with DC Fan - (Fig. 8-2)

Oil Coolers with Hydraulic Motor Driven Fans Fig. 8-3. Air cooled oil coolers having fans operated by **hydraulic motors.** These are used in:

a. Aggressive environments where an electrical spark could be a fire hazard

b. Where we wish to use the residual power of return line pump flow to rotate the impeller of the fan.

Air Cooled Oil Cooler with Hydraulic Motor Driven Fan - (Fig. 8-3)

Oil Coolers with Flameproof Motor driven Fan Fig. 8-4. Air cooled oil cooler with a fan driven by a **Flame Proof motor.** These are again used in aggressive environments, where an electrical spark could have potential to cause damage. The impeller for these applications should ideally be made of anti-static material, to prevent or minimize the chance of a spark due to the built-up static electricity.

Air Cooled Oil Cooler with Flameproof Motor Driven Fan - (Fig. 8-4)

Oil Cooling System with Pump (and or filter) Fig. 8-5. These type of oil coolers have a built in **pump** (and optionally a **filter**). Mostly used for industrial applications, these cool oil independent of the hydraulic or lubrication system of the equipment in a separate **kidney loop** fashion. Typical applications are a **retrofitting job** on an old machine, without changing the existing hydraulic setup. These are also good for hydraulic systems with large fluctuations in flow rate and or a pulsating flow.

Air Cooled Oil Cooler with a Built in Fan & Filter
(Fig. 8-5)

Oil cooling systems with a built in pump are also used for **bearing, gear box** & oil cooling in equipments that do not have a pump installed in them.

9 WHAT ARE THE REQUIRED OIL PROPERTIES & COMMON TERMS?

In order to understand oil cooling and select the right oil cooler one needs to understand the common terms used and the properties of industrial oils. The table Fig. 9-1 describes the commonly used terms & the associated units required to understand heat dissipation. It also gives the conversions between the commonly used units.

Common Terms, Parameters & Units		
Term	Description	Units
Oil Inlet temp.	The temperature of oil entering the oil cooler	°C
Oil outlet temp.	The temperature of oil exiting the oil cooler	°C
Ambient air temp.	The temperature of the atmospheric air	°C
Specific heat of a fluid	The heat required to heat (or cool) 1Kg of fluid by 1°C	Kcal/Kg°C
Oil density	The density of the oil	Kg/liter
Tank capacity	Reservoir capacity (upto max level)	Liters
Heat generation / dissipation	The heat generated or dissipated	KW or Kcal/hr
ΔT	The temperature difference between the oil and the ambient air	°C
Kr	Specific heat dissipation capacity of an oil cooler - The heat dissipated per degree temperature difference between the oil and air	KW/ °C or Kcal/ hr, °C
1 KW = 860 Kcal/hr		
1 Cal = 4.18 Joule		
1 KJ = 0.0002775 KW-hr		
1 KJ = 0.23869 Kcal		

Common Terms & Parameters - Fig. 9-1

The table at Fig. 9-2 gives the two essential oil properties required for heat dissipation calculation.

1. **Density:** The weight per kilogram of different grades of oil at 40°C.
2. **Specific Heat:** The amount of energy required to be added (or removed) to increase (or decrease) the temperature of 1 Kg of oil by 1°C.

Properties of Different Oil Grades at 40 °C			
ISO VG Grade	Density (Kg/Litre)	Specific Heat Capacity	Specific heat Capacity (KW-hr/Kg°C
32	0.837	2.142	0.000594
46	0.837	2.142	0.000594
68	0.847	2.13	0.000591
100	0.847	2.13	0.000591
150	0.847	2.13	0.000591
220	0.857	2.118	0.000588
320	0.857	2.118	0.000588
460	0.857	2.118	0.000588
680	0.857	2.118	0.000588

Properties of Different Oil Grades at 40 °C - Fig. 9-2

10 AIR COOLED OIL COOLING OF HYDRAULIC SYSTEMS

As discussed earlier **heating** is caused by the **inefficiencies** of the system. These inefficiencies result in conversion of a part of the **input power** into **heat**. It is imperative that the heat generated is effectively dissipated, either naturally or using an oil cooler. In any reliable system we have to ensure that the heat dissipation capacity is higher than or equal to the heat generated. The commonly used or required parameters are as follows:

i. Motor (KW)
ii. Pump (LPM)
iii. Working Pressure (BAR)
iv. Tank Capacity (LITRES)
v. Max. Ambient temperature at site (°C)
vi. Required Oil Temperature (°C)
vii. Pump used is Variable or Fixed displacement type ?

viii. Duty cycle.

ix. Application / Industry.

In practice all of these may or may not be available. The user is advised to collect as much of the above information as possible.

Hydraulic System with an Air Cooled Oil Cooler
(Fig. 10-0)

10A: Q - Do all hydraulic systems need oil cooling?

For deciding whether a hydraulic system needs oil cooling or not, we need to consider if it's a **continuous duty** system or an **intermittent duty** system. In intermittent duty systems the heat produced during the work cycle gets **radiated naturally** from the surface of **oil tanks,** during the gaps between the work cycles. If the heat produced during the work cycle is less than or equal to the heat dissipated from the tank surface during periods of inactivity i.e. the gaps between work cycles, a heat exchanger is not required. In continuous duty systems which are working round the clock or for long durations of time, if the wasteful energy that is converted to heat can be dissipated effectively by radiation naturally from the surface of the tank we do not need an external oil cooler. The amount of heat that a tank can dissipate with respect to the temperature difference between the oil temperature & the temperature of the ambient air can be estimated with the help of the table Fig. 10-1. If the heat generation is more than what can be dissipated from the tank surface, an oil cooler should be installed. Most continuous duty systems with relatively large motors (greater than 2.2kW Or 3HP) do need an oil cooler to dissipate the heat.

Heat Radiating Capacity of Reservoirs									
Tank Cap.	Tank Area	Temperature Difference (Oil Temp. - Ambient Air Temp.)							
		10°C	15°C	20°C	25°C	30°C	35°C	40°C	45°C
Litre	Metre sq.	KW	KW	KW	KW	KW	KW	KW	KW
40	1	0.14	0.22	0.29	0.36	0.43	0.51	0.58	0.65
55	1.2	0.17	0.26	0.35	0.43	0.52	0.61	0.69	0.78
75	1.3	0.19	0.28	0.38	0.47	0.56	0.66	0.75	0.85
110	1.5	0.22	0.33	0.43	0.54	0.65	0.76	0.87	0.98
150	2.3	0.33	0.50	0.66	0.83	1.00	1.16	1.33	1.50
200	2.7	0.39	0.59	0.78	0.98	1.17	1.37	1.56	1.76
225	2.9	0.42	0.63	0.84	1.05	1.26	1.47	1.68	1.89
300	3.7	0.53	0.80	1.07	1.34	1.60	1.87	2.14	2.41
380	4.4	0.64	0.95	1.27	1.59	1.91	2.23	2.54	2.86
450	4.9	0.71	1.06	1.42	1.77	2.12	2.48	2.83	3.19
570	5.2	0.75	1.13	1.50	1.88	2.25	2.63	3.01	3.38
750	6.5	0.94	1.41	1.88	2.35	2.82	3.29	3.76	4.23

Heat Radiating Capacity of Reservoirs - (Fig. 10-1)

10B: Q - What happens if we don't install an oil cooler?

We can see from Fig. 10-1, the heat dissipation from the tank surface increases as the temperature difference between the oil & ambient air increases. If the heat generated in the hydraulic system is more than the heat dissipation capacity of the tank and there is no oil cooler installed, the temperature of the oil in the tank will keep rising till it equals the amount of heat that can be radiated from the tank surface. For instance, if we look at the hydraulic system with a 450 liter oil tank working in an environment with ambient temperature of 40°C.

Let us say we want to restrict the oil temperature to 55°C.

- Oil tank capacity = 450 liters
- Ambient air temp. = 40 °C
- Max allowed oil temp. = 55 °C
- $\Delta T = 55 - 40 = 15$ °C
- From fig. 10-1 Heat dissipation capacity = 1.06 KW
- If efficiency of hydraulic system = 70% (i.e.) Heat Generation = 30% X Motor Power (KW)

The rule of thumb: Efficiency of hydraulic systems with fixed displacement pumps is considered 70% & for systems with variable displacement pumps is considered 80%.

In this example let us consider that the installed motor power is 10 KW. Our equation now becomes:

- If efficiency = 70%,

Heat generation = 30% X 10KW = 3 KW (That's equivalent to having a 3KW electrical heater inside the tank)

- Heat dissipation capacity = 1.06 KW
- Access heat production = 3 -1.06 = 1.94 KW.

As the equipment operates, the temperature will keep rising till the heat dissipation from the tank surface equals 3KW. As we can see from the table, this will happen when the oil temp. reaches approximately 42.4 °C above the ambient temperature (i.e.) oil temperature of 82.4 °C. At that point there will be a state of equilibrium and oil temperature will stabilize. However at a temperature of 82.4 °C the viscosity of the oil would have reduced drastically, making it susceptible to internal & external leakages. Furthermore the additives added to the oil will irreversibly lose their properties. Therefore we have two options. Either to increase the size of the tank or install an oil cooler. Even if we did manage to **increase the oil tank size**, the **economics** will rarely justify this. Not only on account of the added expense of building a larger tank, as also the **increased oil fill cost,** each time we replace the oil. We also have to consider the cost of space occupied by such a large tank. Increasing the oil tank capacity therefore becomes unviable. We would need to install an oil cooler with a heat dissipation capacity of 1.94 or say 2 KW.

High hydraulic oil temperatures will progressively start **damaging seals, internal moving parts** and directly affect the **power consumed, life & reliability** of the equipment. For most continuous duty equipment we do need to have an external mechanism installed for dissipating that heat.

10C: Q - What is the right oil temperature?

For answering this question scientifically, we would have to study the manufacturer's datasheet for all the components that are present in the hydraulic system and check for the maximum allowed temperature. For example, a vane pump would have a different maximum allowed temperature in comparison to a solenoid valve or a proportional relief valve. One thing we will find in common by studying components of most of the hydraulic part manufacturers is that practically all components are designed to be tolerant for a temperature range of 0 to 60 °C. So if we are able to ensure that the oil temperature never crosses 60 °C, we are good to go. To be on the safer side, **we shall try to restrict the max design oil temperature between 50 - 55°C,** during oil cooler sizing calculations.

10D: Q - How do we select an oil cooler size?

For selecting or sizing an oil cooler, we have the following methodologies:

i. Tank oil temperature change method.

ii. Dissipated heat method.

iii. Cycle time analysis

i. Tank oil temperature change method.

We calculate the tank oil fill volume and measure the temperature of the oil over a period of time. That is, we note the oil temperature and time. Taking readings every hour for a few hours, under actual working conditions. With this we can exactly calculate the rate of heat buildup. Once the rate of heat buildup is known, we select an oil cooler with a heat dissipation 10-20 % higher. Let us consider an example of a system with following specifications:

- Oil tank volume: 200 liters of ISO VG 68 oil
- Pump flow: 20 LPM
- Ambient air temp.: 40°C
- Max. allowed oil temp = 53 °C
- Motor : 2.2 KW = 3 HP

We take temperature readings every hour and suppose we have the following observations:

Tank Oil Temperature Change Data				
OIL TANK CAPACITY L(cm) X W(cm) x H(cm)/1000 Litres : 200 Litres				
DATA CAPTURE DURATIONS : 1 Hr				
S NO.	AMBIENT AIR TEMP. °C	TIME Hr	TANK OIL TEMP. °C	TEMP CHANGE °C/Hr
T0	40	0	40	0
T1	40	1	46	6
T2	40	2	53	7
T3	40	3	59	6
T4	40	4	58	-1
T5	40	5	57	-1
T6	40	6	59	2
T7	40	7	58	-1

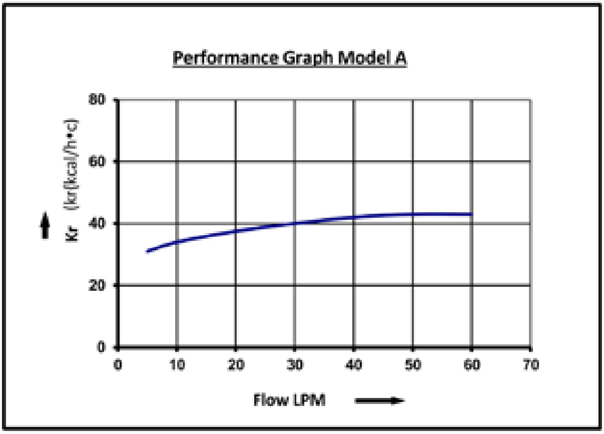
Tank Oil Temperature Change - (Fig. 10-2)

The max increase in oil temperature is T2-T1 = 7°C over a period of 1 hour. For ISO VG 68 we have from Fig. 9-2

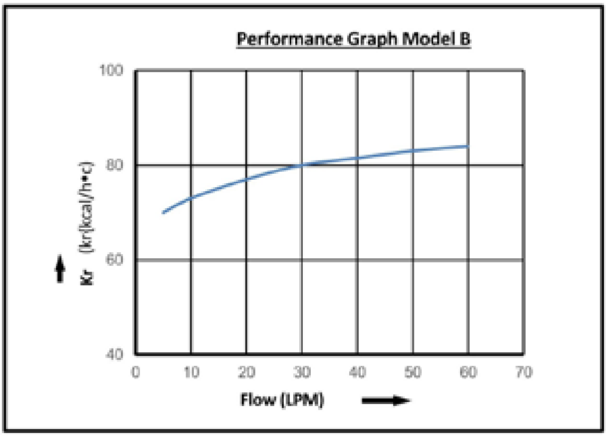
- Specific heat = 0.000591 KW hr./Kg°C
- Density = 0.847 Kg/liter
- Heat buildup = Tank capacity x Specific heat x Density x Max. Temp. change
  - Heat buildup = 200x0.000591x0.847x7 = 0.7KW
- Factor of safety = 10%
- Required heat dissipation = 1.1x0.7KW = 0.77KW
- Ambient air temp.: 40°C
- Max allowed oil temp = 53 °C
- ΔT = 13°C
- Specific cooling required = 0.77/13 KW/°C at an oil flow of 20 LPM = 0.0592 KW/°C

  From Fig. 9-1 we get 1 KW = 860 Kcal /hr
- We need an **Oil Cooler with specific heat Kr ≥ 50.94 Kcal/hr °C at a flow of 20 LPM.**

We now refer to specific cooling curves in the oil cooler manufacturer's catalogue or datasheet (refer Fig. 10-3 & Fig 10-4). We see that for an oil flow rate of 20 LPM **Model A** has **Kr** of **38 Kcal/hr °C** whereas **Model B** has **Kr** of **76 Kcal/hr °C** which is more than our requirement of **50.94**. Therefore Model B is a suitable choice for this application.



Performance Graph of Model A - (Fig. 10-3)



Performance Graph of Model B - (Fig. 10-4)

ii. Dissipated Heat method. This technique can be very effectively used for **replicating an**

existing cooler. That is if we have an existing operating system with an efficient oil cooler installed & we wish to replicate it. We note the heat exchanger oil inlet temp., oil outlet temp. & measure the oil flow rate. The readings are to be taken when the equipment has been **running** under its **normal operating conditions** for a few hours and has reached a steady temperature state. This will give us a fairly accurate estimation of the cooling capacity of the existing oil cooler. Note that we have to take these readings under actual working conditions. A **safety margin of 10 to 20%** should be taken.

Let us take the example of a hydraulic system with an existing oil cooler installed, with following specifications:

- Oil tank volume: 200 liters of ISO VG 68 oil
- Pump flow: 20 LPM
- Ambient air temp.: 40°C
- Motor: 2.2KW
- Oil inlet temp. to oil cooler = 53°C (Tin)
- Oil outlet temp. from oil cooler = 50°C(Tout)
- Heat dissipation/hr. = Oil flow per hour x specific heat x density x (Tin-Tout)
- Specific heat = 0.000591 KW-hr/Kg°C
- Density = 0.847 Kg/liter
- Heat dissipation = 2020x60x0.000591x0.847x3
  = 1.8 KW = 1548 Kcal/hr.

- Factor of safety = 10%

We need to select an oil cooler from the oil cooler manufacturer's specific cooling curve that dissipates 1.1*1548 = 1703 Kcal/hr. at a flow of 20LPM.

- Oil temperature = 53°C
- Ambient air temp = 40°C
- ΔT = 13°C
- **Specific cooling Kr ≥ 1703/13=131 Kcal/hr. °C**

We need an **Oil Cooler with Kr ≥ 131 Kcal/hr.°C at a flow of 20 LPM.**

As shown in section 10D (i) above we use the manufacturers specific heat dissipation graph similar to Fig. 10-3 & Fig. 10-4 to select an oil cooler with Kr ≥ 131 Kcal/hr.°C at a flow of 20 LPM.

iii. Cycle time analysis. Both the above options are tedious tasks but would produce accurate results. However many a times these may not be possible. We have to understand that the maximum heat generation happens when the hydraulic system is not doing productive mechanical work. If the motor is powering the pump and the oil flow is actually doing some mechanical work like moving the actuator (hydraulic cylinders or motors), the heat production is low. Whereas, if for instance, the cylinders are constantly pressurized and there is no work being done, most or all of the energy being consumed by the electrical motor is getting converted into heat. Therefore we have to calculate how many percent of the cycle time the system is pressurized or on full load. So, if the system is pressurized for 50% of the time, we know that we need an oil cooler with a heat dissipating capacity equal to or more than 50% of the power consumed. As recommended for the above two options a safety margin of 10 – 20% should be considered. If we have a hydraulic system that is constantly pressurized, that means the cylinders or motors are not doing any work and all the energy consumed by the electrical motor is getting converted into heat. In such a situation we have to size the cooler to 100% of the capacity of the motor. Consider the example:

- Oil tank volume: 200 liters of ISO VG 68 oil
- Pump flow: 20 LPM
- Ambient air temp.: 40°C
- Motor power load: 2.2KW

Let us say in this case we have a total cycle time of 5 minutes and the cylinders or actuators are pressurized for 1.6 minutes during the cycle.

- Total cycle time = 5 minutes
- System pressurized for = 1.6 minutes
- The energy getting converted to heat = 1.6/5 % of the time
- Estimated heat production = 2.2 x 1.6/5 = 0.704 KW
- Safety margin: 10%,

We select an oil cooler that dissipates over 0.774 KW or 666Kcal/hr.°C at a flow of 20LPM.

- Oil temperature = 53°C
- Ambient air temp = 40°C
- ΔT = 13°C.

Required specific oil cooling Kr ≥ 666/13 = 51.23 Kcal/hr. We need an Oil Cooler with Kr ≥ 51.23 Kcal/hr.°C at a flow of 20 LPM. Refer 10D(i) for selection of the right model.

The Rule of Thumb

In the event that none of the above three options are available or viable, a rule of thumb can be applied. For most general applications the following rule of thumb can be applied. If the pump used is a:

i. **Fixed displacement pump** type, we can estimate the heat production to be **30%** of the power drawn by the electrical motor.

ii. **Variable displacement pump** type, we can estimate the heat production to be **20%** of the power drawn by the electrical motor.

As in earlier examples it is advisable to take a margin of **safety** of about **10% - 20%.**

In our example of a system with the specifications:

- Oil tank volume: 200 liters of ISO VG 68 oil
- Pump flow: 20 LPM
- Ambient air temp.: 40°C
- Motor power load : 2.2 KW
- Oil temperature = 53°C
- Ambient air temp = 40°C
- ΔT = 13°C
- For a fixed displacement pump system expected heat dissipation = (30% X 2.2 KW) X 1.1 = 0.726 KW.

We select an oil cooler that dissipates over 0.726 KW = 624 Kcal/hr. at a flow of 20LPM (i.e.) Kr ≥624/13 = 48 Kcal/hr.°C

- For a variable displacement pump system expected heat dissipation = (20% X 2.2 KW) X 1.1 = 0.484 KW.

We select an oil cooler that dissipates over 0.484 KW = 416 Kcal/hr. at a flow of 20LPM.Kr ≥416/13 = 32 Kcal/hr.°C

To sum up it would serve us well if we select an oil cooler with specific heat Kr as below:

Kr≥48 Kcal/hr °C for a fixed displacement pump & Kr≥32 Kcal/hr °C for a variable displacement pump at an oil flow of 20LPM. Refer 10D(i) for selection of the right model.

NOTE: An important factor that one needs to consider is the kind of components that are used. For example, if the components used are proportional or servo valves which are sensitive to temperature changes. They may withstand the oil temperature but since they are sensitive, one may not get accurate repeatability of speed or force if the oil temperature fluctuates too much. In such cases sizing a cooler at **80%** of installed power for **proportional valves & 100%** in case of **servo valves** is recommended.

11 AIR COOLED OIL COOLING OF GEAR BOXES

Heating of the oil in **gear boxes** is primarily caused by the frictional losses and mechanical inefficiencies of the equipment. It is the loss of a part of the input power that is transformed into heat energy. This **loss of power** is the sum of losses due to many factors (viz.) **gear mesh, bearing, oil seal, internal windage & oil churning.** Out of these gear mesh losses & bearing losses are load dependent & a direct function of the power being transmitted through the gear box. The oil cooler sizing should be such that it is able to dissipate the heat generated and the three primary objectives are met (i.e.) **lubricate, remove heat & flush the debris generated due to wear & tear.**

Air Cooled Oil Cooling System for Gear Box Cooling

(Fig. 11-1)

11A: Q - Do gearboxes need oil cooling?

Most **large gearboxes** which are of **continuous duty** need an **external oil cooling** mechanism. In some lighter duty applications, attaching a fan to the drive motor to enhance the natural heat dissipation may suffice. However in most large continuous duty applications we do need to have an external oil cooling mechanism in place. The oil is sucked in from the sump of the gearbox, passed through an air-cooled oil cooler and delivered back to the top of the gearbox. The primary purpose of the lubricating oil in a gear box is:

- To Lubricate
- To Remove Heat
- To Remove the Debris that has been generated due to wear and transport it to the sump.

As the oil in the sump lubricates the mechanical moving parts it also serves to remove heat & debris generated due to wear & tear of the meshing parts. In larger pieces of equipment the natural heat dissipation is less than the heat generated. Therefore the **temperature** begins to **rise**. As a result the **viscosity** of the oil **drops** and it's ability to **lubricate** is **compromised**. This in turn has a cascading affect & the **heat generation increases.** Resulting in further reduction in lubricating properties of the oil and consequential oil temperature rise.

11B: Q - What happens when we don't cool the oil?

When we don't cool the oil, the **lubrication** of the mechanical moving parts, gears, bearings, & bushes is **compromised**. As a result the temperature keeps rising. Resulting in **reduced lubrication** & **further heat generation.** Eventually leading to **increased wear** & **tear and reduced equipment life.** A gear, bearing or a bush may not fail suddenly. There is going to be **progressive wear and tear** that takes place. As a result, the efficiency or the power required to drive the gearbox will start increasing. This is a **silent killer** because we don't even come to know that it's drawing **more power** and **adding to** our **electricity bills**. So, it is imperative that we have a good cooling system in place. Secondly, it would also add value to have a filter in place. This will help **contain the debris** and prevent its recirculation. This ensures that all the mechanical moving parts are getting cooled, filtered oil delivered to them for lubrication and removing the heat.

11C: Q - What is the right oil temperature in a gearbox?

A gearbox is able to tolerate higher temperatures in comparison to a hydraulic system. For most general applications, the seals and the rubber parts installed in a gearbox are made of neoprene and can withstand a temperature of about 80 degree centigrade. The bearings and the other mechanical moving parts can withstand higher temperatures. As a thumb rule, **limiting temperatures of 80°C** should not be exceeded in a normal gearbox (unless it is designed for working under special temperature conditions). It would be wise to try & restrict the oil temperature to 75 °C.

11D: Q - How do we select the right size of air cooled oil cooler?

For selecting or sizing an oil cooler, we have the following options:

i. Heat load calculations.

ii. Sump / reservoir oil temperature change method.

iii. Dissipated heat method.

i. Heat load calculations. Gear box heat load calculations can be done based on **AGMA 2001-C95 & AGMA ISO 14179-1.** These are complex & beyond the scope of this book. **Manufacturer's guidelines must be taken** at the time of **purchase**.

ii. Sump / reservoir oil temperature change method. The heat produced in a gear box can be calculated from the **oil sump volume, viscosity, specific heat** of the oil and the rate of **increase of temperature** of the oil over a period of time, under actual working conditions. The rate of **increase in temperature** of the oil spread over a few hours is an accurate method for calculating the heat buildup. It's best to take these readings at the hottest time of the day. With these temperature readings spread over a few hours we can exactly calculate the rate of heat buildup. Oil Cooler selection & pump size can then easily be deduced, based on the ambient air temp at the site.To be on the safer side we select an oil cooler with a heat dissipation 10-20 % higher. Some gear boxes may have a **built in pump** attached to the output or input shaft. In others an **external pump** is to be used. Let us consider an example of a system with following specifications:

- Sump volume: 80 liters of ISO VG 220 gear oil
- Pump flow: 10 LPM
- Ambient air temp.: 40°C
- Max. allowed oil temp = 70 °C
- Gear box: 220 KW

We take temperature readings every hour and suppose we have the following observations:

Gear Box Sump Oil Temperature Change Data				
SUMP CAPACITY L(cm) X W(cm) x H(cm)/1000 Litres : 80 Litres				
DATA CAPTURE DURATIONS : 1 Hr				
S NO.	AMBIENT AIR TEMP. °C	TIME Hr	TANK OIL TEMP. °C	TEMP CHANGE °C/Hr
T0	30	0	30	0
T1	30	1	53	23
T2	30	2	54	1
T3	30	3	86	32
T4	30	4	80	-6
T5	30	5	79	-1
T6	30	6	78	-1
T7	30	7	78	0

Gear Box Sump Oil Temperature Change - (Fig. 11-2)

The max increase in oil temperature is T3-T2 = 32°C over a period of 1 hour. For ISO VG 220 we have from Fig. 9-2

- Specific heat = 0.000588 KW hr./Kg°C
- Density = 0.857 Kg/liter
- Heat buildup = Sump capacity x Specific heat x Density x Max. Temp. change
- Heat buildup = 80x0.000588x0.857x32 = 1.29KW
- Factor of safety = 10%
- Required heat dissipation = 1.1x1.29KW = 1.42KW
- Ambient air temp.: 40°C
- Max. allowed oil temp = 70°C
- ΔT = 30°C
- Specific cooling required = 1.42/30 KW/°C at an oil flow of 10 LPM = 0.047 KW/°C

From Fig. 9-1 we get 1 KW = 860 Kcal /hr

- We need an **Oil Cooler with specific heat Kr ≥ 40.42 Kcal/hr °C at a flow of 10 LPM.**

As shown in section 10D (i) If we use the manufacturers specific heat dissipation graph in Fig. 10-3 & Fig. 10-4, we select **Model B** having a **Kr=73 Kcal/hr.°C** at an oil flow of 10 LPM.

iii. Dissipated Heat method. This method can be very effectively used for **replicating an existing gear box with an oil cooler.** We note the heat exchanger oil inlet temp., oil outlet temp. & the oil flow rate. The readings are to be taken when the equipment has been running under its normal operating conditions for a few hours and has reached a steady temperature state. This will give us a fairly accurate estimation of the cooling capacity of the existing oil cooler. Note that we have to take these readings under actual working conditions. A safety margin of 10 to 20% should be added.

Let us take the same example with following specifications:

- Sump volume: 80 liters of ISO VG 220 gear oil
- Pump flow: 10 LPM
- Ambient air temp.: 40°C
- Max. allowed oil temp = 70 °C
- Gear box: 220 KW
- Oil inlet temp. to oil cooler = 86°C (Tin)
- Oil outlet temp. from oil cooler = 50°C (Tout)
- Heat dissipation/hr. = Oil flow per hour x specific heat x density x (Tin-Tout)
- Specific heat = 0.000588KW-hr/Kg°C
- Density = 0.857 Kg/liter

- Heat Dissipation = 10x60x0.000588x0.857x36

  = 10.88 KW = 9357 Kcal/hr.

Considering a safety mark up of 10%, we need to select an oil cooler from the oil cooler manufacturer's catalogue that dissipates over 10,293 Kcal/hr. at a flow of 10 LPM.

- Oil temperature = 70°C
- Ambient air temp = 40°C
- ΔT = 30°C
- Oil Cooler with Kr ≥ 10,293/30 = 343 Kcal/hr. °C

We need an Oil Cooler with Kr ≥ 343 Kcal/hr.°C at an oil flow rate of 10 LPM. Selection methodology similar to 10D(i) is to be used for selecting the right oil cooler model.

The Rule of Thumb

For this we need to know the overall efficiency of the gearbox from the manufacturer. For example, if we have a 100KW gearbox with an efficiency of 95%, then it would be apt to select an oil pump and oil cooler capable of removing 5KW of heat. As a thumb rule, for a gearbox in relatively good working condition, we can use the table in Fig. 11-2. For example for a 50 KW Bevel Gear Box we can take an efficiency of 95% (i.e.) a 5% inefficiency for every reduction step. If we have two reduction steps, we can assume inefficiency of 10%, requiring an oil cooling arrangement having heat dissipation capability of 5 KW. So, it would suffice if we select a pump & oil cooler combination suitable to remove heat equivalent to 4300 Kcal/hr.

Guidelines in section 10D(i) may be used for selection of the right oil cooler model.

Type of Gear Box	Estimated Efficiency (per gear pair)
Helical / Spur Gears	96 % to 99 %.
Bevel / Spiral Bevel	92 to 95 %
Worm Gears	90 % (can reduce to 70% with increased backlash)

Estimated Efficiency of Different Types of Gearboxes (Fig. 11-2)

12 AIR COOLED OIL COOLING OF CENTRALIZED LUBRICATION SYSTEMS, BEARINGS & BUSHES

In contrast to applications like hydraulic systems & gearboxes discussed so far, heating of the oil of centralized lubrication systems, bearings & bushes depends not only on its own design and efficiency but also on

- The **inefficiencies** of the **equipment** that is being **lubricated**.
- The **heat picked up** by the oil from other **heat sources** in the equipment being lubricated, steam or flue gas heated rollers for example. Typical examples are the dryer section of a paper mill or hot metal rolling in a steel rolling mill or the bearings of a gas based generating set. In a paper mill for instance, the steam flowing through hollow rolls is used to dry paper. The heat from the roller is transmitted to the bearings, thereby heating the bearing oil.

Bearing Oil Cooling System - (Fig. 12-1)

In these type of oil cooling systems the lubricating oil is stored in a reservoir. It is picked up from the reservoir by a pump, cooled, filtered and dispensed to the various bearings, bushes, gears and other mechanical rotating elements that it is supposed to lubricate. As in the case of gearboxes there are three primary objectives lubricate, remove heat & to remove the debris that have got generated due to the wear & tear of the mechanical moving parts.

A part of the **input power** of the **equipment** or system that is **being lubricated** is converted into heat. The amount of **heat generated** is a **function** of the **power being transmitted** through the gearbox / bearing / bush and the system efficiency. Also adding to the heat load is the **heat picked up** by the oil through **conduction**. The oil cooler sizing should be such that it is able to dissipate the total heat load (i.e.) the heat generated plus the heat picked up by conduction.

12A: Q - Do centralized oil lubrication systems need oil cooling?

It is imperative that centralized oil lubrication systems supply cooled, filtered oil because their primary purpose is to lubricate & cool various bearings, bushes, gears & other rotating parts in the plant. If we are going to send out hot oil from the centralized oil lubrication system, the oil will not be able to perform its function effectively. This will result in **premature failures** which means incurring **replacement & down time costs**. An inefficient centralized lubrication system is a **silent killer**, in the sense that if the lubrication is not adequate, the equipment will start drawing more power. Resulting in **inflated power bills,** causing losses to the organization **day on day**, week on week, month on month. Installing a good, adequately sized oil lubrication system with an efficient oil cooler will pay many times over in the future by cutting down costs.

12B: Q - What is the size of an oil cooler that we need in a lubrication system?

For this we have to look at the primary source of energy that is driving the system being lubricated. We have to look at each one of the individual components that are part of the equipment or system, calculate the inefficiencies of each component and add them up so that we can know what is the amount of heat that the oil is expected to carry back into the tank. The **two methods** described in chapter 11 on gearbox section **11D (ii) & (iii)** can very effectively used (viz.) **Sump / reservoir oil temperature measurement method & Temperature difference method.**

The Rule of Thumb

We can take 0.3 – 0.4KW per liter of oil that is being pumped. For example, if we have a 100 liter per minute pump, then a 30 to 40 KW heat exchanger should suffice. This is of course a very crude & generic estimation, however it should cover most common industrial applications.

13 AIR COOLED OIL COOLING OF ELECTRICAL TRANSFORMERS

Like all equipment no electrical transformer is 100% efficient and hence part of the energy being transmitted gets converted to heat. If this heat is not dissipated, the temperature in the transformer rises and could result in failure or reduced life of the insulation. Therefore a cooling mechanism is required. There are two types of transformers:

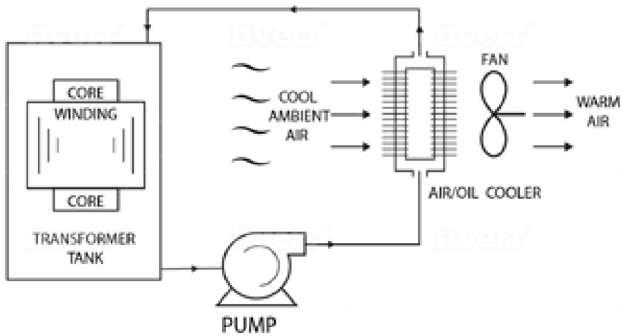
- Dry transformers
- Wet or oil immersed transformers.

13A: Q -Do all electrical transformers need oil cooling?

The outer casing of most dry transformers and wet transformers (up to 60 MVA) have fins. They are cooled by natural air or by employing a fan to direct an air blast on the fins of the transformer. However larger transformers of capacities more than 60 MVA do need an external heat dissipation arrangement.

13B: Q - How do we cool electrical transformer oil?

A pump is connected to the bottom of the tank. The oil sucked out by the pump is then passed through an air cooled oil cooler, cooled and sent back to the top of the tank.



Air Cooled Transformer Oil System - (Fig. 13-1)

13C: Q - What is the size of an oil cooler that we need for an electrical transformer?

The heat produced by an electrical transformer can accurately be calculated from the oil holding capacity, volume, viscosity, specific heat of the oil and the rate of increase of temperature over a period of time, under actual load conditions. The peak increase in temperature spread over a 24 hour cycle, can be used to calculate the rate of heat buildup. Cooler & pump size can easily be deduced, based on the ambient air temp at the site. Refer to Tank / Sump Oil Temp Change Method & Dissipated Heat Method described in chapter 10 & 11. The oil cooler model selection can be done as described in section 10D(i).

The Rule of Thumb

The overall efficiency of a transformer is estimated to be between 95 - 98.5% of its full load capacity. An oil cooler with heat dissipation capacity of between 5 to 2% (depending on the efficiency) of peak load capacity coupled to a suitably selected pump should be sufficient to maintain optimum temperature. A safety margin of 10-15% should also be considered.

14 AIR COOLED OIL

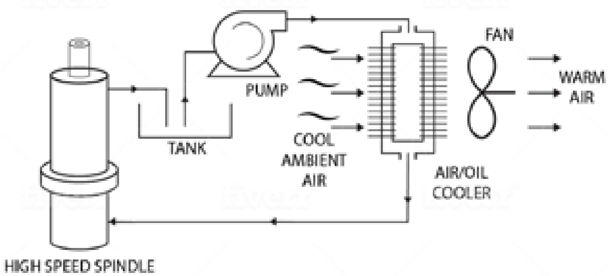
COOLING OF OTHER EQUIPMENT– SPINDLES, VACUUM PUMPS, X-RAY MACHINES, QUENCH OIL, TIG TORCHES

Air cooled fluid coolers can be used to make an offline cooling circuit to cool a **large variety** of **equipments, increase** their **efficiency & optimize** their **energy consumption**. An offline oil cooling circuit has been regarded as an effective technique to cool fluids. **Offline systems** also called **kidney loops**, work by using a **pump** to **draw** fluid from the **equipment's reservoir**, circulate the fluid through an **air cooled oil cooler**, and **returning** the cool fluid **back to a reservoir**. High temperatures can quickly degrade fluids and at times even produce by products that become particulate contamination in the fluid. Incorporating a filter in the circuit may also reduce the contaminants in the fluid.

A brief description and the generalized schematic of a few equipments are given below.

Offline Oil Cooling System Complete with Pump
(Fig. 14-1)

1. Spindles



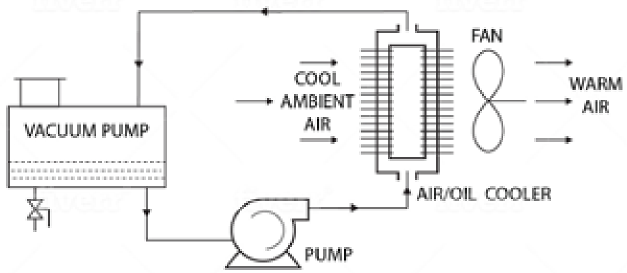
Air Cooled Spindle Oil Cooling System - (Fig. 14-2)

Maintaining **optimum temperatures** in machine tool spindles **prevents deviation** in spindle **center line & heat deformation** of the equipment, **prolongs life time, improves** working **precision, reduces noise & vibration.**

Conventionally refrigerated cooling solutions are used to cool high speed spindles. These are expensive to buy & also have a high running cost. Air cooled oil coolers help in maintaining temperatures at relatively steady temperatures and can effectively replace refrigerated coolers in a lot many situations.

2. Vacuum pumps

In lubricated vacuum pumps if the temperature rises beyond the acceptable limit, the capacity of the vacuum pump to suck air reduces. An oil cooler will **improve** the **performance** of the vacuum pump, minimize sludge generation & **extend** the life of the **oil seals**.



Air Cooled Vacuum Oil Cooling System

(Fig. 14-3A)

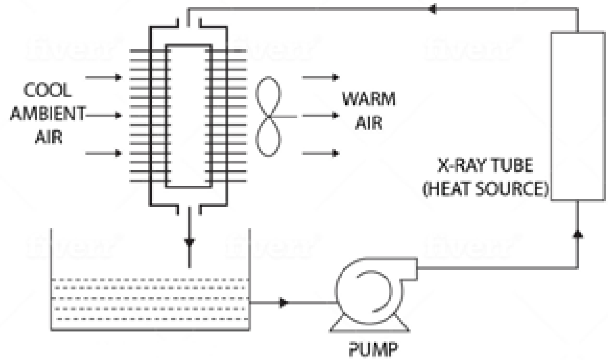
Air Cooled Vacuum Oil Cooling System

(Fig. 14-3B)

Using an external oil cooling mechanism can also help in **simplifying** the **design** of the body of the vacuum pump, by reducing or eliminating fins provided on the body of the vacuum pump. These fins increase the surface area required for higher natural heat dissipation to the surrounding ambient air. Fig. 14-3 shows an air cooled vacuum pump & also the schematic of an air cooled oil cooling system. An external pump as shown may not always be required.

3. Industrial X-ray machines

Industrial X-ray machines are increasingly being used for a wide variety of applications. Only a small portion of the energy consumed is used to emit as X-ray.

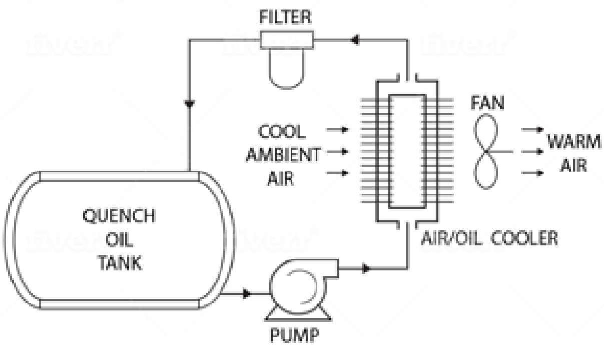


Air Cooled X-Ray Heat Source Oil Cooling System
(Fig. 14-4)

The rest being converted to heat. Industrial X-ray machines can generate several kilowatts of heat during operation and require cooling of the anode to dissipate this heat for **optimized performance, longer operation life and reduced overall cost.** Fig. 14.4 shows a schematic of an air cooled oil cooling system for the cooling of an X-ray tube.

4. Quench Oil Cooling Systems

Quenching is a heat treatment process of **rapid cooling of metal work pieces** in liquids, usually **oil** to achieve certain material properties. Quenching requires the hot metal parts to be dropped into quench oil reservoirs. The basic purpose is to bring about a sudden drop in temperature of the metal part. As a result the heat energy is transferred from the hot metal part to the quench oil, thereby increasing the temperature of the quench oil. If this heat is not removed from the quench oil, the next lot of hot metal parts that is dropped into the oil will not cool down as rapidly to the desired temperature. This in turn will result in:



Air Cooled Quench Oil Cooling System

(Fig. 14-5)

- Non uniformity of properties of the part
- Distortion
- Cracking and
- Rejection of the part.

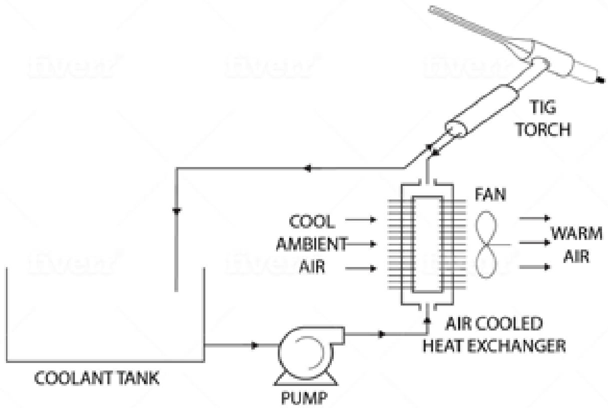
To **prevent these losses**, it is very important to cool the oil and maintain it within a stable temperature range for **effective** and **reliable quenching**. Air cooled quench oil systems also eliminate the danger of **water leaking** and mixing with the quench oil.

Air Cooled Quench Oil Cooler
(Fig. 14-6)

In most cases the amount of heat to be rejected is fairly large & requires large cooling units. Fig.14-5 & 14-6 show the schematic of a quench oil cooling system & a typical air cooled quench oil cooler respectively. **It is imperative that a filter is installed between the pump & the oil cooler to restrict the carbon, mill scale & other contaminants reaching and getting trapped in the oil cooler.**

5. TIG torch cooling

Tungsten Inert Gas welding (TIG welding) creates a lot of heat. These temperature can create thermal stress that is harmful. This is especially true when the TIG torch runs continuously for long hours. Cooling the torch using air cooled heat exchangers will improve life of the equipment, reduce stress on the welding machine operator, and result in good quality welds.



Air Cooled TIG Torch Oil Cooling System

(Fig. 14-7)

In the industry the list of applications is endless and includes compressors, generators, blowers, stone crushers, varnish dryers. Even though the efficiencies may vary from equipment to equipment, the science behind calculating the heat load remains primarily the same as discussed in the previous chapters. **Keeping** the **temperatures in check** will go miles in **optimizing** the **energy consumption, life** & **overall efficiency** of the **equipment**.

15 CONCLUSION

Effective management & dissipation of the wasteful energy in continuous duty equipment is the key to **Reduce Energy Bills, Increase Equipment Life, Improve efficiency& Increase Profits.**

Action points

- **List** down all the **energy consuming equipment** in your manufacturing process, their rated power & if possible their present energy consumption.

- Sort these in decreasing order of rated power / power consumed. Identify the top **20% energy consuming equipment.**

- Start **following the basic principles** discussed in this **book** & the results will automatically follow.

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THE ULTIMATE GUIDE
TO AIR COOLED OIL COOLERS

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Vineet Taneja an expert and a trainer in Oil Cooling & Industrial Hydraulics is an engineer from Birla Institute of Technology & Science, Pilani (BITS Pilani). Out of his total industrial experience of 34 years, for 28+ years he has successfully been running his enterprise designing, manufacturing & installing Hydraulic, Oil Cooling & Lubrication equipment. He has worked with over 1050 businesses and helped increase production anywhere from 7% to 73% and save energy costs up to 19%. Industrial Hydraulics & Oil Cooling expert Vineet Taneja is uniquely qualified to help you understand everything you need to know about Oil Cooling!

I have known Vineet for over 10 years. I have worked on few projects with him, and every single time, he has exceeded my expectations. His background in thermodynamics, thermal, mechanical and hydraulics combined has made him a valuable asset in this industry. No wonder his "Air cooled Heat exchangers" are so popular, because he delivers what he says.

Ajay Sharma
CEO Hydra Power Inc, USA

We have worked with Vineet for over 11 years now, he has thorough knowledge of Oil Cooling & Hydraulics. He has always been instrumental in providing a technically competent solution each time, even when time at hand was a challenge.

Vijay Phalke
Ask Hydraulics, Pune

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