1 - INTRODUCTION

1.1. Crude Oil Components:

Crude oils are mixtures of many different substances, often difficult to separate, from which various petroleum products are derived, such as: gasoline, kerosene propane, fuel oil, lubricating oil, wax, and asphalt. These substances are mainly compounds of only two elements: carbon (C) and hydrogen (H) [1,2]. They are called, therefore: hydrocarbons.Refining crude oil involves two kinds of processes to produce the products so essential to modern society. First, there are physical processes which simply refine the crude oil (without altering its molecular structure) into useful products such as lubricating oil or fuel oil. Second, there are chemical or other processes which alter the molecular structure and produce a wide range of products, some of them known by the general term petrochemicals [3].

1.1.1 .Hydrocarbons: [4, 5, 6, 7]

Hydrocarbons may be gaseous, liquid, or solid at normal temperature and pressure, depending on the number and arrangement of the carbon atoms in their molecules. Those with up to 4 carbon atoms are gaseous; those with 20 or more are solid; those in between are liquid. Crude oils are liquid but may contain gaseous or solid compounds (or both) in solution. The heavier a crude oil (i.e. the more carbon atoms its molecules contain) the closer it is to being a solid and this may be especially noticeable as its temperature cools. Light oils will remain liquid even at very low temperatures.The simplest hydrocarbon is methane, a gas consisting of one carbon atom and four hydrogen atoms:

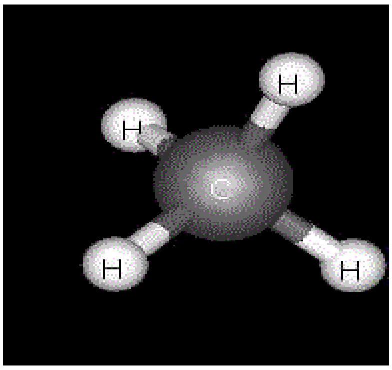


Fig (1): Structure of methane

. A carbon atom has four bonds that can unite with either one or more other carbon atoms (a property almost unique to carbon) or with atoms of other elements.

A hydrogen atom has only one bond and can never unite with more than one other atom. The larger hydrocarbon molecules have two or more carbon atoms joined to one another as well as to hydrogen atoms. The carbon atoms may link together in a straight chain, a branched chain, or a ring. Examples includes: Propane (C_3H_8), a straight chain molecule, shown below.

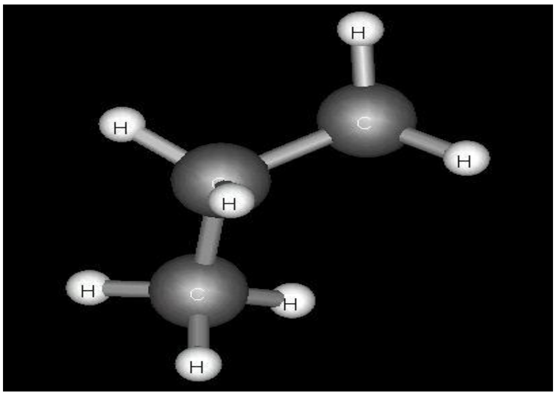


Fig (2): Structure of Propane.

An example of a branched chain, Isobutane (C_4H_{10}), is shown below:

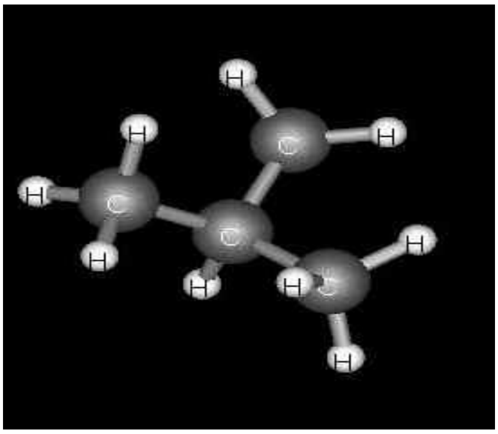


Fig (3): Structure of Isobutane

The hydrocarbon rings can become quite complex. As well, more complex molecules occur when one or more hydrogen atoms are replaced by hydrocarbon groups or by the condensing or "stacking" of one or more rings. A simple example of this occurs in naphthalene ($C_{10}H_8$). It is at this point that we are seeing molecules found in crude oil. As the molecular structure becomes characterized by denser carbon atoms and even further stacking, we enter the realm of "heavy oil". One of the most complex examples of "stacking" occurs in **asphaltenes**, a structure so important in the challenge of producing and refining heavy oil that separately. Thus, we see that the number of hydrogen atoms associated with a given skeleton of carbon atoms may vary. When the chain or ring carries the full complement of hydrogen atoms, the hydrocarbon is said to be "saturated".

When less than the full compliment of hydrogen atoms is present in a hydrocarbon chain or ring, the hydrocarbon is said to be "unsaturated".

Another molecular complexity is caused by introducing elements such as sulphur, nitrogen, and oxygen. With these, the number of different molecules based on the carbon skeleton increases tremendously.

1.1.2. Non-Hydrocarbons: [6, 8, 9]

Non-hydrocarbons that occur in crude oils and petroleum products may be small in quantity but some of them have considerable influence on product quality. In many cases they have noxious or harmful effects and must be removed or converted to less harmful compounds during the refining process. The most common occurring non-hydrocarbons are sulphur, nitrogen, and oxygen. There may also be small amounts of vanadium, nickel, sodium, and potassium.

Sulphur Compounds:

Sulphur is common in crude oils but it varies from 0.2% by weight to 6% by weight in crude oils. There are corrosive and non-corrosive sulphur compounds. One corrosive compound is Hydrogen Sulphide, the deadly H_2S which can kill an operator in 10 seconds. Extensive training and safety precautions are taken in the oil patch to reduce the risk from H_2S, whose molecule appears below:

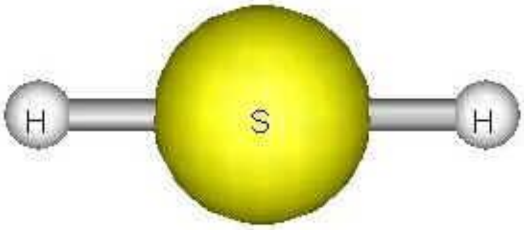


Fig (4): Structure of (H_2S).

Fortunately sulphides have a highly obnoxious smell which gives some warning of their danger. H_2S is often produced in Canadian natural gas wells, the so called "sour gas" wells. Production of H_2S may be as high as 30% by volume of the well flow. If one of the hydrogen atoms is replaced by a hydrocarbon group, the compound is called a mercaptan or thiol. Such compounds are formed during the distillation of crude oils. They can cause severe corrosion of the processing units and the addition of chemicals; proper temperature control and the use of special alloys in refinery equipment are required to control them.

If both of the two hydrogen atoms are replaced by hydrocarbon groups, the compound is called a sulfide or thioether. An example, thiophene (C_4H_4S) is shown below.

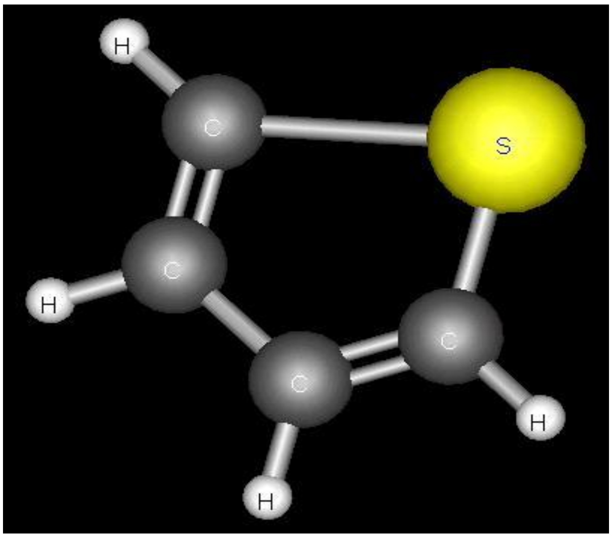


Fig (5): Structure of thiophenes.

Thiophenes, shown above, have a relatively pleasant odour, comparable to benzene, are relatively stable, and may even be beneficial. Other sulphur compounds are decidedly not. They cause serious corrosion of engines and furnaces, reduce the effect of anti-knock additives in gasoline, cause charring and deposits when burned, for example in a kerosene lamp, give a bad odour to dry cleaning solvents and may dis-colour paints.

Nitrogen Compounds:

Nitrogen compounds in crude oils are complex and distillation may give rise to nitrogen compounds. These may cause discoloration in gasoline and kerosene, or may produce a "lacquer" quality, reducing the effectiveness of lubricating oils.

Oxygen Compounds:

Some crude oils contain oxygen compounds. Their structure has not yet been established but on distillation of the crudes, the oxygen compounds decompose to form ring compounds with a carboxylic acid group in the side chain. These compounds are known as "naphthenic acids" having first been found in large quantities in the distillation of Russian naphthenic crudes.

Phenolic compounds occur in some crude and are formed during cracking. Derived from aromatic hydrocarbons, the simplest member is the phenol, shown below:

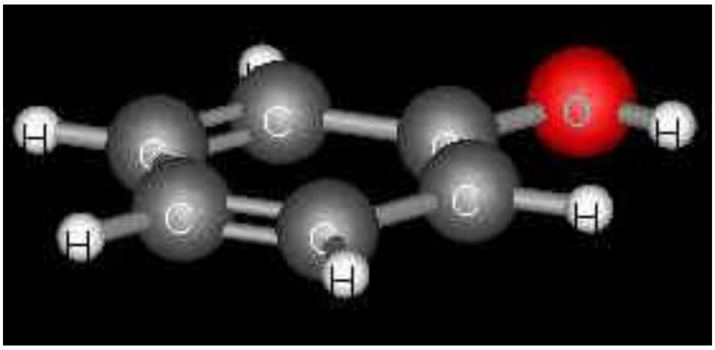


Fig (6): Structure of phenol**.**

1.1.3 Other Compounds:

Several other organic and inorganic compounds occur in crude oils. One example is the metal vanadium which is sometimes present. Vanadium is an important component in the manufacture of specialty steels and can be recovered from the residue of the refining process.

1.2. Base oils categories

1.2.1 Paraffinic base oils:

Consist mainly of fully saturated straight- and branched-chain hydrocarbons with the general formula C_nH_{2n+2}.Their advantages as lubricants are that they are stable and have good viscosity temperature characteristics, i.e. a high viscosity index, meaning a slow reduction in viscosity with increase in temperature. Their disadvantages are relatively low polarity and correspondingly poorer solvency characteristics. This is not desirable for certain categories of lubricants, e.g. soluble metalworking fluids, greases etc. where base oil with higher polarities are preferable. Poor low temperature properties are due to the separation of wax crystals and consequent solidification at relatively high temperatures which results in high 'pour-points' and 'cloud points', necessitating the incorporation of pour-point depressants [10].

1.2.2 Naphthenic base oils:

Are saturated polycyclic hydrocarbons with or without aliphatic side chains. They have better low temperature properties than the paraffinic oils, i.e. separation of wax crystals occur at a lower temperature. However they are less stable than paraffinic oils and therefore more susceptible to oxidative degradation. This is due to the strain inherent in a ring formation as opposed to a linear molecule. They also have poor viscosity/temperature characteristics [11].

Differences in the properties of the different compounds determine the end-use of that basestock, e.g. paraffinic basestocks with their high viscosity indices are more suitable for the production of automotive crankcase oils, naphthenic basestocks with their higher polarity are more useful for the manufacture of greases and soluble oils.

1.2.3 Aromatic base oils:

Are basically compounds containing aromatic rings with or without saturated side chains. They have high polarity and solvency power and for this reason they find use mainly as process oils, for example as printing ink oils or as rubber extenders. Their main disadvantage is that their general stability is poor. Indeed, part of the refining process in base oil manufacture consists of the removal of aromatics from both paraffinic and naphthenic base oils. For this reason the aromatics are often referred to as 'aromatic extracts', the refined residue being termed the 'raffinate'. They are little used in lubricants [12].

1.3. Additives in Lubricating Oils:

The function of an additive is to modify the inherent properties of the base fluid (low- temperature properties, VT characteristics, etc.), or confer new properties (emulsion- forming tendency, anti-corrosion properties, extreme pressure lubrication properties, etc.). The properties required depend on the application of the lubricant. It is likely that a high degree of stability, i.e. resistance to oxidative degradation break down is universally desirable, but other characteristics may be more specific to the end-use.

Some additives affect the physical properties of the base fluid, others have a chemical effect. Additives can assist each other, resulting in a synergistic effect, or they can lead to antagonistic effects. Many modern additives are supplied as a pre-mixed package having several functions and thus the possibility of antagonism is reduced. [13]

1.3.1 -Friction modifiers :

Friction modifiers and mild antiwear agents are polar molecules added to lubricants for the purpose of minimizing light surface contacts (sliding and rolling) that may occur in a given machine design. These are also called boundary lubrication additives. Esters , natural synthetic fatty acids and some solid materials such as graphite and molybdenum disulfide are used for these purposes. [14]

These molecules have a polar end (head) and an oil-soluble end (tail). Once placed into service, the polar end of the molecule finds a metal surface and attaches itself. If one could 'see' the orientation of the molecules on the surface, it would appear something like the fibers of a carpet, with each molecule stacked vertically beside the others.

As long at the frictional contact is light, these molecules provide a cushioning effect when one of the coated surfaces connects with another coated surface. If the contact is heavy, then the molecules are brushed off, eliminating any potential benefit of the additive.

When the machine designer anticipates more than light surface contact (from shock loading for instance) then the designer would select a stronger type of friction modifier characterized as an antiwear additive.

Zinc dialkyldithiophosphate is a common antiwear agent. This type of additive literally reacts with the metal surface when the reaction energy (temperature) is high enough. The reaction layer provides sacrificial surface protection. As the loading and metallic contact increase, the strength of additive and the strength of the reaction process increases. This leads to the use of sulphur-phosphorus based EP chemicals. The EP additives form organo-metallic salts on the loaded surfaces that serve as sacrificial films to protect against aggressive surface damage [15].

1.3.2 -Anti-wear additives:

Anti-wear additives prevent direct metal-to-metal contact between the machine parts when the oil film is broken down. Use of anti-wear additives results in longer machine life due to higher wear and score resistance of the components. The mechanism of anti-wear additives: the additive reacts with the metal on the part surface and forms a film, which may slide over the friction surface.The following materials are used as anti-wear additives:

(Zincdithiophosphate(ZDP);Zincdialkyldithiophosphate(ZDDP);Tricresylphosphate (TCP).) [16].

1.3.3 - Extreme pressure (EP) additives:

Extreme pressure (EP) additives prevent seizure conditions caused by direct metal-to-metal contact between the parts under high loads. The mechanism of EP additives is similar to that of anti-wear additive: the additive substance form a coating on the part surface. This coating protects the part surface from a direct contact with other part, decreasing wear and scoring.The following materials are used as extra pressure (EP) additives:

(Chlorinatedparaffins; Esters; Zincdialkyldithiophosphate (ZDDP); Molybdenum disulfide (MoS_2) ;) [17].

1.3.11- Anti-oxidants [25&27]:

Mineral oils react with oxygen of air forming organic acids. The oxidation reaction products cause increase of the oil viscosity, formation of sludge and varnish, corrosion of metallic parts and foaming.Anti-oxidants inhibit the oxidation process of oils.Most of lubricants contain anti-oxidants.The following materials are used as anti-oxidants:

(Zincdithiophosphate (ZDP); Alkylsulfides; Aromaticsulfides; Aromaticamines; Hindered phenols.).

1.3.5 – Detergents:

Detergents neutralize strong acids present in the lubricant (for example sulfuric and nitric acid produced in internal combustion engines as a result of combustion process) and remove the neutralization products from the metal surface. Detergents also form a film on the part surface preventing high temperature deposition of sludge and varnish. Detergents are commonly added to Engine oils.

Phenolates, sulphonates and phosphonates of alkaline and alkaline-earth elements, such as calcium (Ca), magnesium (Mg), sodium (Na) or Ba (barium), are used as detergents in lubricants[20&21].

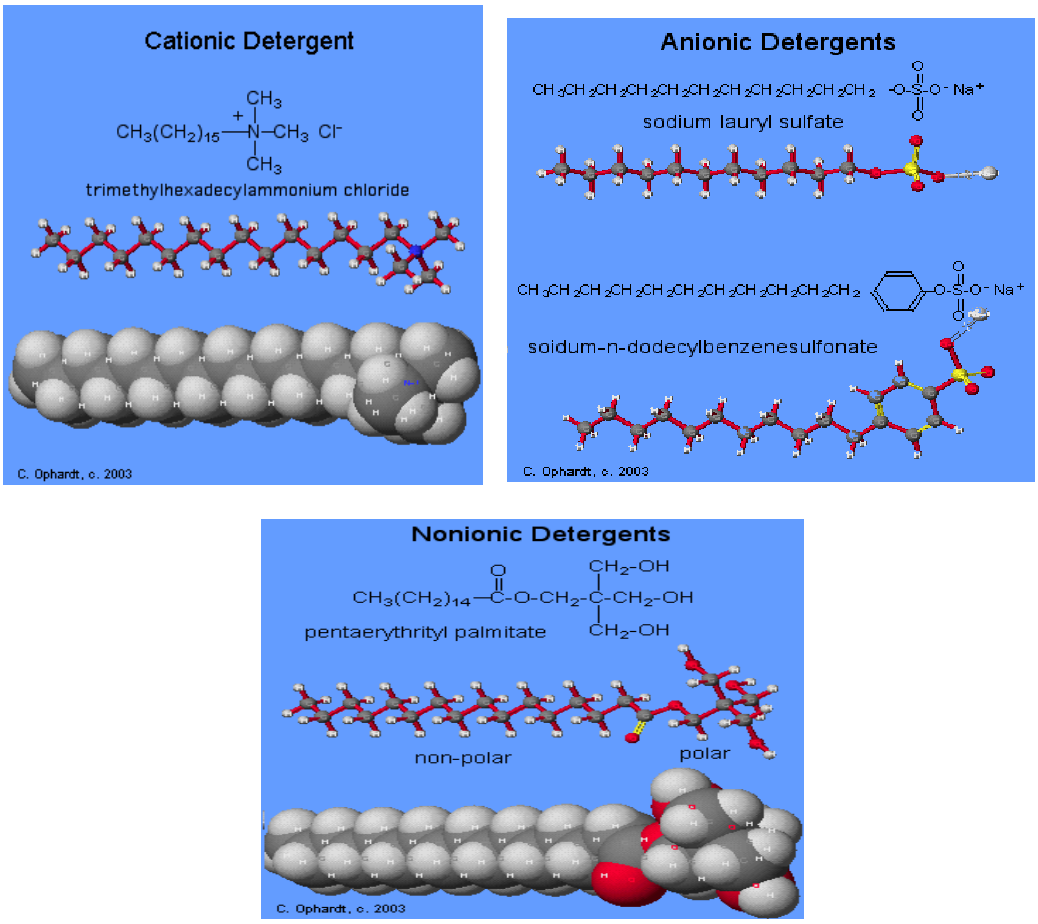


Fig (7): Structures of detergents.

1.3.6– Dispersants:

Dispersants keep the foreign particles present in a lubricant in a dispersed form (finely divided and uniformly dispersed throughout the oil). The foreign particles are sludge and varnish, dirt, products of oxidation, water etc.Long chain hydrocarbons succinimides, such as polyisobutylene succinimides are used as dispersants in lubricants[16&18].

1.3.7 - Pour point depressants:

Pour point is the lowest temperature, at which the oil may flow. Wax crystals formed in mineral oils at low temperatures reduce their fluidity.Pour point depressant inhibit formation and agglomeration of wax particles keeping the lubricant fluid at low temperatures[20].Co-polymers of polyalkyl methacrylates are used as pour point depressant in lubricants[22].

1.3.8 - Viscosity index improvers:

Viscosity of oils sharply decreases at high temperatures. Low viscosity causes decrease of the oil lubrication ability. Viscosity index improvers keep the viscosity at acceptable levels, which provide stable oil film even at increased temperatures. Viscosity improvers are widely used in multigrade oils, viscosity of which is specified at both high and low temperature.Acrylate polymers are used as viscosity index improvers in lubricants [23&24].

1.3.9- Anti-foaming agents:

Agitation and aeration of lubricating oil occurring at certain applications (Engine oils, Gear oils, and Compressor oils) may result in formation of air bubbles in the oil - foaming. Foaming not only enhances oil oxidation but also decreases lubrication effect causing oil starvation. Dimethylsilicones (dimethylsiloxanes) is commonly used as anti-foaming agent in lubricants [24].

1.3.10 -Emulsifiers and emulsifying aids: [25&26]

Emulsifiers and emulsifying aids are included in the formulations of soluble oils used in metalworking applications, fire-resistant hydraulic oils, quenching oils, etc. They have a structure containing both hydrophobic and hydrophilic groups, and act by reducing the interfacial surface tension, thereby assisting in the formation and stabilisation of oil-in-water and water-in-oil emulsions depending on the requirement. The hydrophobic part of the molecule consists of a hydrocarbon radical; the hydrophilic part depends on whether the emulsifier is anionic, cationic or non-ionic. The activity of the emulsifiers depends upon the pH and hardness of the water.

* Anion-active emulsifiers normally consist of alkaline salts of long-chain, usually unsaturated carboxylic acids such as mixtures of oleic acid, tallow-oil fatty acids, naphthenic acids etc., and of synthetic carboxylic acids and sulphonamides.

* Cation-active emulsifiers all belong either to the long-chain alkylated ammonium salts, such as dimethyl-dodecyl-benzylammonium chloride, or to the imidazolinium salts.

* Non-ionic emulsifiers almost entirely contain polythene oxide radicals such as the alkyl-, alkylaryl-, acyl-, alkylamino- and acylaminopolyglycols as well as long-chain acylated mono- and diethanolamines. (Note that the use of diethanolamine has virtually ceased in Germany due to restrictions on the use of secondary amines.)

1.3.4 -Rust and corrosion inhibitors:

Rust and Corrosion inhibitors, which form a barrier film on the substrate surface reducing the corrosion rate. The inhibitors also absorb on the metal surface forming a film protecting the part from the attack of oxygen, water and other chemically active substances [18].

Rust inhibitors are used to prevent metals from rusting under various conditions, and a variety of surfactants are utilized as rust inhibitors.

Rust inhibitors are divided into products of various types such as oil-soluble rust inhibitors, water soluble rust inhibitors; and vapor phase rust inhibitors.

Oil soluble rust inhibitors are dissolved in mineral oil and like to prepare rust- inhibiting oil (rust – preventing oil). They are adsorbed on the surface of metal to form a film, and protect the surface from corrosion by water and oxygen. Fig (8) is an illustrative model to show adsorption of anti corrosion oil on the surface of metal.

Water soluble rust inhibitors : are generally used for temporary rust prevention during the processing of metal goods for instance , they are used for temporary rust prevention of machine processed metal goods until the goods are subsequently plated .another example of their application is rust prevention during hydraulic testing of newly constructed tanks . Surfactants are the main components of water soluble rust inhibitors, and inorganic salts such as sodium silicate and sodium phosphate are used together in some products.

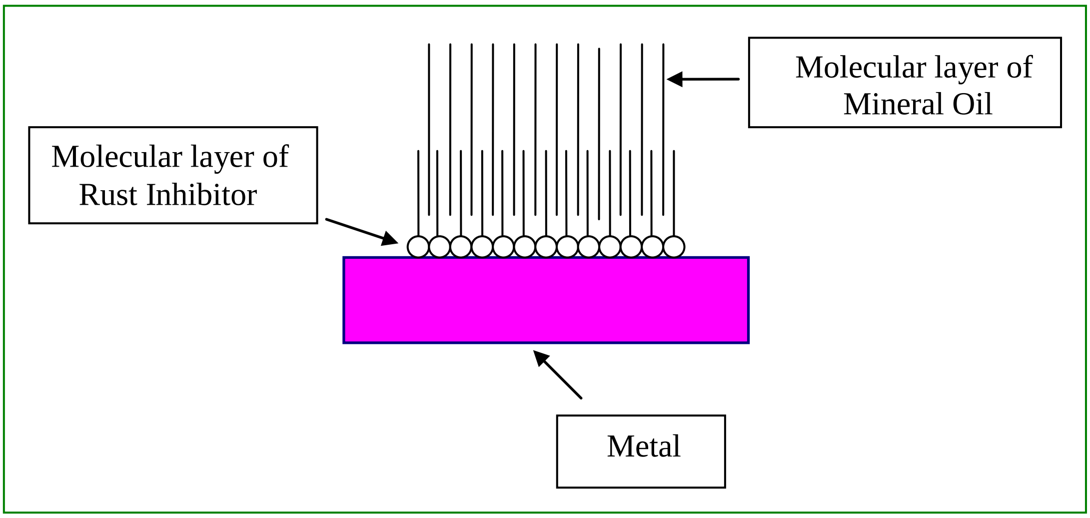


Fig (8): Illustrative model of adsorption of anti corrosion oil on the surface of metal.

The following materials are used as rust and corrosion inhibitors: (Alkalinecompounds; Organicacids; Esters; Amino-acid derivatives; Fatty acid alkanolamide) [19].

1.4 .Lubricating oils classification

1.4. 1-Engine oils [28،29&30]:

Engine oil (motor oil) provides lubrication of moving and sliding parts of the engine. The following base stocks are used for manufacturing engine oils: Mineral oil, Highly refined mineral oil, Ultra refined mineral oil, Synthetic oil (Polyalphaolefins).

Functions of engine oil:

1 - Provision of stable oil film between sliding surfaces.

Direct contact between a rotating crankshaft and the engine bearings occurs only for short periods of engine start and shutdown. In normally operating engine there is a continuous oil film between the two surfaces. This friction regime is called hydrodynamic. Oil film provides low coefficient of friction, distributes load applied to the bearing over its surface, cools down the sliding parts, takes foreign particles away from the friction region.

2 - Provision of reliable engine operation in a wide temperature range:

Viscosity of an oil strongly depends on its temperature.When an engine starts at low temperature the oil is viscous (thick). If the viscosity is too high the oil will not be able to flow to the sliding parts and the non-lubricated engine will not operate.On the other hand oil viscosity in a heated engine is low. The oil flows easily, however oil film thickness of the hot oil is low, and it may become less than roughness of the sliding surfaces. In this case hydrodynamic regime is broken and direct metal-to-metal contact between the surfaces occurs. Metal-to-metal contact causes excessive wear, overheating and even Fatigue of the sliding materials.

3 - Rust/corrosion protection of the engine parts:

Combustion gases containing water vapors and other chemically active gases partially penetrate to the crankcase and may cause corrosion. In addition to this some constituents of the combustion gases dissolve in the oil and increase its acidity. Such oil may become aggressive to the metal parts contacting with it.Corrosion inhibitors are added to engine oils in order to provide protection of metallic (both ferrous and non-ferrous) parts.

4 - Cleaning the engine parts from sludge:

Combustion gases past through the piston rings to the crankcase contain some amount of not burnt carbon, which may deposit on the rings, valves and cylinders, forming a sludge. The sludge clogs oil passages and clearances decreasing lubrication of the engine parts.In order to remove the sludge from the surface detergents are added to the engine oils. Dispersants, which are also added to the engine oils, help to maintain the removed sludge and other contaminants (non-metallic and metallic) in form of fine suspension permitting engine functioning between the oil changes.

5 - Sealing piston ring - cylinder gap:

Imperfection on the surfaces of the piston rings and cylinders walls result in penetration of combustion gases into the crankcase, which decreases the engine efficiency and causes contamination of the oil. Engine oil fills these microscopic passages and seal the combustion gases.

6 - Prevention of foaming.

Engine oil circulating in an engine may entrap air and form foams (foam is a mixture of a liquid with gas bubbles). Foamed oils are less effective in their important functions (oil film formation, heat removal, cleaning). In order to diminish foam formation special additives (anti-foaming agents) are added to engine oils.

7 - Cooling the engine parts.

Combustion heat and friction energy must be removed from the engine in order to prevent its overheating. Most of heat energy is taken by the engine oil.Clean oil passages, proper viscosity and low contamination provide sufficient flow rate of the engine oil and effective cooling.

SAE viscosity grading system

The Society of Automotive Engineers (SAE) established a viscosity grading system for engine oils.According to the SAE viscosity grading system all engine oils are divided into two classes: monograde and multigrade.

1.4.2 – Industrial Oils:

1.4.2.1-Transformer oils (insulating oils) [30] :

Transformer oils (insulating oils) are dielectric oils used in oil-filled transformers, some high voltage capacitors and circuit breakers, fluorescent lamp ballasts.Oil-filled transformers are more efficient, more reliable more compact, more quiet and with longer lifespan than dry transformers.

Transformer oils have the following functions:

1 - Prevention of electrical discharges between the transformer coils: corona and arc (insulating).

2 - Removal of heat generated by the transformer (cooling). Transformer oil forced by natural convection circulates through a radiator carrying the heat out of the transformer.Transformer oils (insulating oils) have replaced toxic PCB (polychlorinated biphenyl).Mineral oils, vegetable lubricants (soybean oil, vegetable based esters) or synthetic lubricants (polydimethylsiloxane) are used as basics for transformer oils.

1.4.2.2-Quenching oils [29&31]:

Quenching oils: are oils formulated to serve as a fluid media in quenching operation.Different quenching media provide a variety of cooling rates. When the fastest cooling rate is required water or brine solutions are used as quenching media. Air quenching produces the lowest cooling rate.Oils are intermediate quenching media and they are ideal for quenching steels (oil-hardened steels, Tool and die steels).

Cooling rates obtained in oil quenching and the final hardness of the parts are determined by the specific heat of the oil: the higher specific heat of the oil, the greater hardness value may be obtained.

Oils providing relatively high cooling rates are called accelerated oils and used for parts having low susceptibility to cracks caused by internal stresses. Slow cooling rates obtained by non-accelerated oils are important in heat treatment of heavy parts, in which the surface hardening should be achieved when the core remains ductile. Oils are not used for quenching non-ferrous alloys (Aluminum alloys, Copper alloys).

Mineral paraffinic oils, vegetable lubricants (soy oil, cottonseed oil) or animal lubricants (fish oil, lard) are used as quenching oils.

1.4.2.3-Heat transfer oils [28&29]:

Heat transfer oils are oils formulated to serve as a fluid media in closed and open liquid phase heat transfer systems.Oil used in closed systems may be used at temperatures up to 550°F (288°C). The hot oil must not come into a contact with air because of the possible oxidation and ignition.Maximum temperature of heat transfer oils used in open systems is limited by the value 374°F (190°C).

Heat transfer oils are used in the following applications:

1- Oil heaters for asphalt processing;
2- Polymers fabrication: cooling of molds in injection molding machine and extrusion equipment.
3- Organic synthesis hot oil systems;
4- Plastic coating equipment.
5- Heat transfer oils have low volatility (prevents vapor locks in circulating pumps) and minimum change of viscosity over wide temperature range.
6- Other characteristics of heat transfer oils are similar to those of quenching oils
7 - Some of heat transfer oils may be used as quenching oils.

1.4.2.4- Rust protection oils [31]:

Rust protection (prevention) oils are lubricants providing temporary protection of metal parts from oxidation caused by moisture, oil contaminants and chemically active atmosphere. Rust (Galvanic corrosion|) protection oils contain Corrosion inhibitors, which form a barrier film on the substrate surface. The inhibitors consist of polar molecules possessing water-repellent properties. The inhibitor molecules absorb on the metal surface forming a film protecting the part from the attack of oxygen, water and other chemically active substances. Rust inhibiting additives contain also surfactants (wetting agents), which form strong bond with the metal part surface and provide efficient spreading the inhibitor molecules over the surface. Sodium sulphonate is commonly used as wetting agent.

The following materials are used as rust and corrosion inhibitors:

* Alkaline compounds;
* Organic acids;
* Esters;
* Amino-acid derivatives.

Rust and corrosion inhibitors are added to various lubricants: Engine oils, Gear oils, Hydraulic oils, Cutting fluids (coolants), Way lubricants, Compressor oils etc.

Rust protection oils are used for protection finished and packed metal parts and also parts temporary stored between the fabrication stages.

Rust protection oils are commonly based on mineral oils (either paraffinic or naphtenic).

Suppliers of rust protection oils determine the oils performance in the Product Data: protection film thickness, storage period varying from short-term (two weeks) to long-term (12 months or even longer), indoor or outdoor storage, type of metal to be protected, finger prints protection etc.Rust prevention oils are applied by dip, spray or brush-on. The protection film may be easily removed by either a detergent (alkaline cleaner) or a solvent.

1.4.2.5-Compressor oils [33]:

Compressor oils are fluids used for lubrication of moving metal parts of gas (air) compressors. The following factors are taken into account in selection of compressor oil:

- Type of compressor
- Gas to be compressed.

Chemically active gases (Oxygen, hydrogen chloride) are not compressed in compressors lubricated by hydrocarbon oils (not mineral norsynthetic), which are flammable. Mineral oils are not used for compressing breathing air. Hydrocarbon gases (natural gas) may dissolve in the compressor lubricant changing its properties. The lubricant for this application should resist to gas absorption.

Compressed gas pressure.

Maximum compressed gas pressure is determined by the compressor type. Discharge temperature. Lubricants of low viscosity grades are used in refrigeration compressors and other low temperature applications. High viscosity grade oils are used at increased temperatures. 150°C–200°C For the discharge temperature above 300°F (150°C) synthetic lubricants (polyglycol, diester, polyolester, phosphate ester) are used.

Compressors types:

1- Reciprocating compressor.
2- Sliding vane compressor.
3- Centrifugal compressor.
4- Screw (helical lobe) compressor.
5- Rotary lobe compressor.

1.4.2.6-Gear oils[29&34]:

Gear oil is a fluid lubricant used in gears (gearboxes) for reduction of friction and wear of the gear tooth surfaces, removal of the heat generated by the operating gear and corrosion protection of the gear parts. The following properties of gear oils are important for their operation:

1 - Proper viscosity;
2 - Ability to withstand extreme pressures (EP);
3 - Thermal and oxidation stability;
4 - Corrosion and rust protection;
5 - Compatibility with seal materials.

Gear oils should provide reliable, efficient (low friction), low maintenance operation of gears at different speeds, temperatures, oil contaminations.

Types of gear oils:

Combinations of additives impart special functions to gear oils:

1 - Rust and oxidation preventive gear oils:

Rust and oxidation preventive (R&O) oils are mainly mineral base. They contain rust and oxidation inhibitors. The viscosity of R&O oilsaccording to the ISO grading system is between 32 to 320.

2 - Compounded gear oils:

Compounded oils are mineral base. They contain rust and oxidation inhibitors, demulsifiers and up to 10% of fatty oils for better lubricity. Compounded oils are used mainly in worm gears. The viscosity of compounded oils according to the ISO grading system is between 460 to 1000.

3 - Extreme Pressure (EP) gear oils:

EP oils may be either mineral or synthetic base. They contain EP additives, rust and oxidation inhibitors, anti-foaming agents and demulsifiers. The viscosity of EP oils according to the ISO grading system is between 68 to 1500.

4 - Synthetic gear oils :

Synthetic gear oils may be based on polyalphaolefins (PAO), esters oils or polyglycols. They may contain EP additives, rust and oxidation inhibitors, anti-foaming agents and demulsifiers. The viscosity of synthetic oils according to the ISO grading system is between 32 to 6800.

Synthetic gear oils are used for gears operating under extreme conditions: very low or very high temperatures, high pressures.

Viscosity of gear oils:

Viscosity of gear oils (lubricants) is a compromise between the gear parameters requiring low viscosity and those requiring high viscosity. Low viscosity is favorable for: high speed, low loaded gears with a good tooth surface finish. Low viscosity provides thin oil film, low friction (high mechanical efficiency), good cooling (heat removal) conditions. High viscosity is favorable for: low speed, highly loaded gears with a rough tooth surface. High viscosity provides thick oil film, high wear resistance and low galling even at high pressure (EP).Viscosity of a gear oil depends on the temperature, therefore an oil selected for a particular gear should provide its reliable operation within the expected temperature range.The low temperature limit of a gear oil is 9°F (5°C) higher than its pour point (the lowest temperature, at which the oil may flow).

Mineral oils possess relatively high pour point - about 20°F (-7°C). Pour point of syntethic oils may reach -50°F (-46°C).The highest operation temperature in spur gears is about 130°F (54°C). In the worm gears the temperature may reach 200°F (93°C).

I.4.2.7- Refrigerator Oils [29]:

Generally, refrigerator lubricants are highly refined petroleum oils. To provide them with low pour temperatures, naphthenic base crude oils are used. Oils from paraffinic crude oils have to be deeply dewaxed otherwise hydrocarbon solids may precipitate in the cold halogenated hydrocarbons. This may occur when the lubricant is diluted with the refrigerant at a temperature, which exceeds the cloud point of the lubricant. This phenomenon may cause plugging of control devices and lines of the refrigerating plant, and effect the heat exchange.

1.4.2.8Cutting fluid [34]:

(Metalworking fluid, coolant) is a liquid used in metalworking operations for reducing friction between the work piece and the tool and for removal of the heat generated by the friction.

I.4.2.9. Textile Oils [35]:

These oils are used in the fiber and textile industries either to lubricate the textile machinery, or as components of process oils used for the working of natural fibers, the production and processing of synthetic fibers, or the finishing of intermediate or final products. Textile oils are often made from technical white oils and oxidation inhibitors, plus agents ensuring removal of the oils by washing, even after a long period of use.

1.5- Cutting oils

1.5.1-Introduction:

Cutting fluid or coolant is a liquid added to reduce the friction coefficient between the grain and workpiece by way of cooling and lubricating the cutting site of machine tools by flooding orspraying during broaching, boring, grinding, milling, sawing, shaping or tapping. The coolant containing EP additives is added to the sump of equipment with lathes, milling machines, shapers, bandsaws. Liquid (water or petroleum oil) cooled water tables are used with the plasma arc cutting (PAC) process.Metal cutting operations involve generation of heat due to friction between the tool and the pieces and due to energy lost deforming the material. This heat needs to be carried away otherwise it creates "white spots".There are generally 3 types of liquids: mineral, semi-synthetic and synthetic [36].

Mineral coolants, which are (petroleum based) began in the late 1800s.Semi-synthetic coolants are an emulsion ormicroemulsion of water with mineral oil beginning in the 1930s. Synthetic coolants originated in the late 1950s and are usually water-based [37].

A hand-held refractometer is used to determine the mix ratio (also called strength) of water soluble coolants to verify effectiveness. Numerous other test equipment are used to determine such things as acidity, and amount of conductivity.Cutting fluids have been associated with skin rashes, dermatitis, lung disease and cancer. Safer environmental formulations for workers and the environment provide a natural resistance to tramp oils allowing improved filtration separation without removing the base additive package.

Bacterial growth is predominant in semi-syntheic and synthetic fluids. Tramp oil along with human hair, skin oil are some of the debris during cutting which accumulates and forms a layer on the top of the liquid, anaerobic bacterials proliferate due to a number of factors. Early signs of replacement usually is noticed by the "Monday Morning" smell (due to lack of usage from Friday to Monday) and is a sensory sign of the breakdown of the Coolant [38].

1.5.2. Historyof cutting oils:

No one knows with any certainty where or when metalworking began. The earliest technologies were impermanent to say the least and were unlikely to leave any evidence for long. The advance that brought metal into focus was the connection of fire and metals. Who accomplished this is as unknown as the when and where.

Not all metal required fire to obtain it or work it. Isaac Asimov speculated that gold was the "first metal [39]. His reasoning is that gold by its chemistry is found in nature as nuggets of pure gold. In other words, only gold, as rare as it is, is found in nature as the metal that it is. There are a few exceptions as a result of meteors. All other metals are found in ores, a mineral bearing rock, that requires heat or some other process to liberate the metal. Another feature of gold is that it is workable as it is found, meaning that no technology beyond eyes to find a nugget and a hammer and an anvil to work the metal is needed. Stone hammer and stone anvil will suffice for technology. This is the result of gold's properties of malleability and ductility.

The earliest tools were stone, bone, wood, and sinew. They sufficed to work gold.At some unknown point the connection between heat and the liberation of metals from rock became clear, rocks rich in copper, tin, and lead came into demand. These ores were mined where ever they were recognized. Remnants of such ancient mines have been found all over what is today the Middle East [40].

The end of the beginning of metalworking occurs sometime around 6000 BCE when copper smelting became common in the Middle East.

The ancients knew of seven metals. Here they are arranging in order of their oxidation potential:

- Iron +0.44,
- Tin +0.14
- Lead +0.13
- Copper -0.34
- Mercury -0.79
- Silver -0.80
- Gold -1.50

The oxidation potential is important because it is one indicator of how tightly bound to the ore the metal is likely to be. As can be seen, iron is significantly higher than the other six metals while gold is dramatically lower than the six above it. Gold's low oxidation is one of the main reasons that gold is found in nuggets. These nuggets are relatively pure gold and are workable as they are found.Copper ore, being relatively abundant, and tin ore became the next important players in the story of metalworking. Using heat to smelt copper from ore, a great deal of copper was produced. It was used for both jewelry and simple tools. However, copper by itself was too soft for tools requiring edges and stiffness. At some point tin was added into the molten copper and bronze was born. Bronze is an alloy of copper and tin. Bronze was an important advance because it had the edge-durability and stiffness that pure copper lacked. Until the advent of iron, bronze was the most advanced metal for tools and weapons in common use[41].

Looking beyond the Middle East, these same advances and materials were being discovered and used the world around. China and Britain jumped into the use of bronze with little time being devoted to copper. Japan began the use of bronze and iron almost simultaneously. In the new world things were different. Although the peoples of the New World knew of metals, it wasn't until the arrival of Europeans that metal for tools and weapons took off. Jewelry and art were the principal uses of metals in the New World prior to European influence.Around the date 2700 BCE, production of bronze was common in locales where the necessary materials could be assembled for smelting, heating, and working the metal. Iron was beginning to be smelted. Iron began its emergence as an important metal for tools and weapons. The Iron Age was dawning[42].

By the historical periods of the Pharaohs in Egypt, the Vedic Kings in India, the Tribes of Israel, and the Mayan Civilization in North America, among other ancient populations, precious metals began to have value attached to them. In some cases rules for ownership, distribution, and trade were created, enforced, and agreed upon by the respective peoples. By the above periods metalworkers were very skilled at creating objects ofadornment, religious artifacts, and trade instruments of precious metals (non-ferrous), as well as weaponry usually of ferrous metals and/or alloys. These skills were finely honed and well executed. The techniques were practiced by artisans, blacksmiths, atharvavedic practitioners, alchemists, and other categories of metalworkers around the globe. For example, the ancient technique of granulation is found around the world in numerous ancient cultures before the historic record shows people traveled seas or overland to far regions of the earth to share this process that still being used by metalsmiths today.

As time progressed metal objects became more common, and ever more complex. The need to further acquire and wor metals grew in importance. Skills related to extracting metal ores from the earth began to evolve, and metalsmiths became more knowledgeable. Metalsmiths became important members of society. Fates and economies of entire civilizations were greatly affected by the availability of metals and metal smiths. Today modern mining practices are more efficient, but more damaging to the earth and to the workers that are engaged in the industry. Those that finance the operations are driven by profits per ounce of extracted precious metals [43].

1.5.3. Mechanisms of action [44 & 45]

A – Cooling:

Metal cutting operations involve generation of heat due to friction between the tool and the pieces and due to energy lost deforming the material. The surrounding air alone is a rather poor coolant for the cutting tool, because the rate of heat transfer is low. Ambient-air cooling is adequate for light cuts with of rest in between, such as are typical in maintenance, repair and operations (MRO) work or hobbyist contexts. However, for heavy cuts and constant use, such as in production work, more heat is produced per time period than ambient-air cooling can remove. It is not acceptable to introduce long idle periods into the cycle time to allow the air-cooling of the tool to "catch up" when the heat-removal can instead be accomplished with a flood of liquid, which can "keep up" with the heat generation.

B - Lubrication at the tool-chip interface:

Besides cooling, the other way that cutting fluids aid the cutting process is by lubricating the interface between the tool's cutting edge and the chip. By preventing friction at this interface, some of the heat generation is prevented. This lubrication also helps prevent the chip from being welded onto the tool, which interferes with subsequent cutting.

1.5.4. The Use of Cutting Fluids in Drill Press Operations [46]:

The coolant should be aimed at the area where the tool contacts the work. It should be flooded so that as much fluid as possible reaches the cutting edges. The operator should withdraw the tool occasionally to remove the chips. The best method is the use of tools that have integral oil holes. This means that various tools are available that feed the coolant through the tool and directly to the cutting edge (see Figure 9). This also helps wash the chips out of the hole.

Figure (9): Oil hole drills will supply cutting fluid directly to the cutting edges of the drill.

1.5.5. The Use of Cutting Fluids in Milling Operations [47]

Two nozzles should be used whenever possible in milling operations. One nozzle should be in front of the cutter and one behind. Together they cool the tool and the work piece and wash the chips away.

1.5.6 The Use of Cutting Fluids in Turning Operations [48]

In a turning operation, the coolant must be supplied to the area where the chip is being produced. For turning and facing operations, the nozzle should be directed so that the coolant is supplied directly over the tool. In heavy-duty cutting, two nozzles would be advisable, one above and one below the tool (see Figure 10).

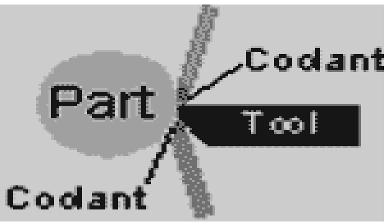
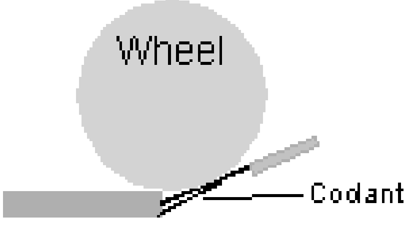
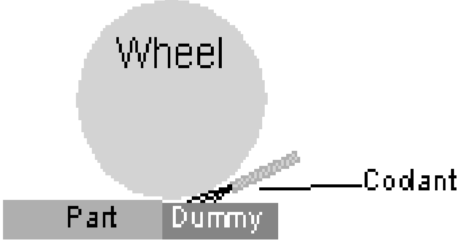


Figure (10): For heavy cutting, it is advisable to have cutting fluid directed at the top and bottom of the cutting area

1.5.7. The Use of Cutting Fluids in Grinding Operations [49]

Grinding produces a great deal of heat because the wheel contains thousands of small cutting edges, each producing heat as it cuts. Flood coolant is most appropriate when grinding. When possible, use two nozzles for flood coolant, one on the left and one on the right of the wheel. Keep the nozzles as close to the work as possible. It is recommended that you use a dummy block on the side of the workpiece. This helps get an adequate supply of coolant to the work at the start of the cut.In cylindrical grinding, a fan-shaper nozzle that is slightly wider than the wheel should be used. This assures that the entire grinding surface is flooded. When internal grinding, the wheel should be as large as possible. The wheel should be approximately 75% of the diameter of the hole in the workpiece. This does not allow much room to get coolant into the bore. Make sure that an adequate amount of coolant flows into the bore.

 Figure (11): No dummy block was used in this case, so at the start of the cut there is very little coolant when the cut begins.	 Figure (12) In this figure a dummy block was used. This assures adequate coolant at the start of the cut.

1.5.8. Prolongation the Life of Metal Working Fluids:

a-The Importance of Coolants:

The metal working process creates much heat and friction. If the heat and friction are not reduced, the tools used in the process are quickly damaged and/or destroyed. Also, the quality of the products made is diminished because of inefficient tools and damage to the product while it is being manufactured. Coolants reduce friction at the tool/substrate interface and transfer heat away from the tools and the material being processed, reducing the time to process the metal, increasing the quality of the workmanship, and increasing tool life. The ability to transfer the heat away from the metal working process is why metal working fluids are often called coolants [50&51].

B-Coolants Work:

Oils are natural lubricants and provide this quality to coolants that are petroleum-base. Other coolants' ability to reduce friction comes from lubricating additives. During the metal working process, heat diffuses into the coolant [52]. The "heated" coolant flows off the work area into a collection container or sump, where it cools off and then enters the cycle again. Water has excellent cooling characteristics and many coolants contain water or are primarily water to cool the machining process. Soluble oils and semi-synthetic oils have both water and oil components. Coolants containing both oil and water require surfactants to form and maintain emulsions, a mixture of the oil and water, so that both properties can work together [53].

C- Considerations for Choosing a Coolant [54&55]

Different metal working processes have varying cooling and lubrication needs. Coolants have many properties that increase their efficiency, extend their life, and minimize the potential to damage tools and products. Therefore, when choosing a coolant, many factors need to be considered. These considerations include:

- Tramp oil rejection
- Ability to settle out solids
- Bacterial resistance
- Corrosion and rust resistance
- Emulsification capability

- Foaming nature and resistance
- Optimal coolant life
- Longevity of coolant as measured against current industrial standards
- Cost of coolant
- Chemical restrictions and reactivity of coolant
- Lubricating quality
- Biodegradability
- Recyclability of coolant
- Capacity of recycled coolant to prevent galvanic attack
- Water compatibility and requirements: pH, deionized water requirements, mineral content and hardness
- History of dermatitis

D- Coolant Effectiveness:

The effectiveness of a coolant for heat transfer and as a lubricant decreases for a number of reasons. Coolants break down in process. They accumulate foreign substances including tramp oil, swarf, dissolved minerals, and/or dirt from the process. These substances prevent the coolant from working. Selective depletion of a fluid component could also reduce coolant effectiveness. For example, swarf is particulate metal created during the grinding or cutting of metals. The presence of swarf creates friction, defeating both the lubricating ability and cooling capabilities of the coolant. The increased concentration of tramp oil similarly interferes [56].

E- Water Requirements:

Some coolant manufacturers state that their coolant can use any type of water while others specify deionized water or mineral free water. Deionized water does not contain minerals that in time may interfere with. The coolant's efficiency. Tap water has minerals and ions in it as well as bacteria [55]. Water based coolants will evaporate while sitting in the sump and vaporize while the coolant is being applied to the metal working process. The minerals present are not evaporated and accumulate in the sump increasing the concentration of minerals in the coolant. If tap water is continually used, the mineral content of the coolant continues to increase. Concentrated minerals can form deposits and soaps, gumming up the metal working process. Tap water may be acceptable for the initial preparation of the coolant but any additional water should be mineral free (deionized or reverse osmosis processed) [57].

F- Coolant Deterioration [58&59]:

During the metal working process, the heat of operation and the chemical reactivity of swarf fines initiate degradation of the metal working fluid. The particles chemically interact with the oils in the emulsions, weakening the emulsion and breaking the fluid down to its separate constituents. Swarf also facilitates the growth of the bacteria and fungi that feed on the coolant by providing a substrate for them to grow on. Bacteria use the emulsions, additives and oil for food and similarly contribute to coolant degradation. This is called coolant spoilage. Coolant degradation results in a reduction of the ability of the coolant to lubricate and transfer heat away from the metal working process.

G- Microbial Activity:

Bacteria and other microbial organisms thrive in the environment created by the impurities in the coolant. They feed upon mineral oils, fatty acids, emulsifiers, corrosion inhibitors, other additives and waxes in oil based and synthetic coolants. The corrosion inhibitors of synthetic coolants, for example, are consumed. Aerobic bacteria require oxygen for metabolism and efficiently destroy the coolant. Anaerobic bacteria grow in environments lacking oxygen. They feed upon the coolant and produce noxious byproducts such as hydrogen sulfide. This is commonly referred to as the Monday morning odor [60].

H- Problems Associated With Microbial Spoilage

Microbial action directly affects the coolant resulting in the splitting of emulsions, decreased pH, increased corrosion, degradation of the ingredients in the coolant and a loss of lubricating ability within the coolant itself. Odors may develop including hydrogen sulfide as a product of the bacteria's metabolism [48]. Bacteria may also expose workers to pathogens and contribute to respiratory irritation and skin irritation, like dermatitis [61]. Work piece quality decreases, resulting in increased surface blemishes, decreased tool life, and increased down time to treat for bacteria and repair the equipment. The bacteria may also cause increased foaming and oil separation in the system and cause clogged lines, filters, and valves [52].

I- Extending the Life of Coolants: [51, 54&59]

Swarf and tramp oil should be removed in process. Chemicals are available that can be added to the coolant to protect emulsions from reactive metal fines and extend the life of the coolant. The presences of swarf and tramp oil create a habitat that promotes the growth of bacteria. Aerobic and anaerobic bacteria and fungi eat the organic components of the oil and/or emulsions reducing the effectiveness of the coolant. Therefore bacteria and fungi should be removed from the coolant or prevented from growing in the coolant. A coolant management system can be incorporated by a business to increase the effectiveness of the coolant by extending its life. In summary:

1. Remove chemically reactive compounds;
2. Remove substances that physically interfere with the coolant;
3. Remove organisms that degrade the coolant;
4. Remove substances that create habitats for destructive organisms;
5. Initiate a coolant management system for the long term.

J- Swarf and Tramp Oil Removal

A variety of filter media, filtering devices and oil skimmers exist to remove impurities including swarf and tramp oil from the coolant. Filtering devices include gravity filters or settling tanks, centrifuges, coalescers, reverse osmosis filtration units, and hydrocyclones. Drum, disc, belt, and rope oil skimmers and oil absorbing pillows are commonly used to remove tramp oil from coolant in the sump. A sump and coolant cleaning process are also necessary for long coolant life [56].

K-Microbial Control:

There are many ways of controlling bacteria. The best method is to not create a habitat conducive to microbial growth. This includes keeping the coolant and the sump free from impurities that create habitats conducive to microbial growth. Microbes can find shelter in crevices, corners, and porous materials that may be hard to clean. The corners of the sump can be rounded to make cleaning easier [53]. A coolant and sump cleaning program helps extend the life of the coolant. Cement sumps and coolant system components should be avoided because bacteria can establish themselves in the pores of the cement and continually infect the coolant. In such a situation, it is impossible to maintain uninfected coolant without replacing the cement sump or blocking it off with a nonporous (and nonreactive) material such as stainless steel. Epoxy coatings may also create a barrier to the bacteria.

One common method to control microbes is by adding biocides to the coolants. Biocides are toxic and kill the bacteria. Many biocides are consumed while killing the bacteria. Therefore, biocides may need to be periodically added to the coolant [57]. If coolants are treated with biocides, additional requirements may exist to govern the coolant's eventual disposal. Coolants with biostatic properties also may be purchased. They are coolants that are not affected or eaten by bacteria. Many coolants that are labeled biostatic by producers require biocides and therefore are not truly biostatic. Some coolants may be pasteurized to kill bacteria. Another method is adjusting the pH to neutralize the effects of the bacteria. The effects of anaerobic bacteria can be reduced by maintaining an amount of oxygen in the coolant. Anaerobic bacteria are most active over the weekend when no processes are running [61]. It is possible to prevent the growth of anaerobic bacteria by agitating or aerating the sump over periods of time when the process is not in operation, including weekends. Such aeration may cause problems in the coolant however and increase the foaming of some coolants.

1.5.9. Cutting Fluids Types and Uses:

The two types of cutting fluids most commonly used are:
* Oil-based fluids, including straight oils and soluble oils
*Water-based fluids, including synthetics and semi-synthetics

OIL-BASED CUTTING FLUIDS

1 - STRAIGHT OILS (100% petroleum oil):

Straight oils, so called because they do not contain water, are basically petroleum, mineral, or ag-basedoils. They may have additives designed to improve specific properties [62, 63]. Generally additives are not required for the easiest tasks such as light-duty machining of ferrous and nonferrous metals [64, 65]. For more severe applications, straight oils may contain wetting agents (typically up to 20% fatty oils) and extreme pressure (EP) additives such as sulfur, chlorine, or phosphorus compounds. These additives improve the oil's wettability; that is, the ability of the oil to coat the cutting tool, workpiece and metal fines [66]. They also enhance lubrication, improve the oil's ability to handle large amounts of metal fines, and help guard against microscopic welding in heavy duty machining. For extreme conditions, additives (primarily with chlorine and sulfurized fatty oils) may exceed 20%. These additives strongly enhance theantiwelding properties of the product [65].

ADVANTAGES:

The major advantage of straight oils is the excellent lubricity or "cushioning" effect they provide between the work piece and cutting tool [63]. This is particularly useful for low speed, low clearanceoperations requiring high quality surface finishes [64, 65]. Although their cost is high, they provide the longest tool life for a number of applications. Highly compounded straight oils are still preferred for severe cutting operations such as crush grinding, severe broaching and tapping, deep-hole drilling, and for the more difficult-to-cut metals such as certain stainless steels and superalloys. They are also the fluid of choice for most honing operations due to their high lubricating qualities [66].Straight oils offer good rust protection, extended sump life, easy maintenance, and are less likely to cause problems if misused. They also resist rancidity, since bacteria cannot thrive unless water contaminates the oil [64].

DISADVANTAGES:

Disadvantages of straight oils include poor heat dissipating properties and increased fire risk [64, 65]. They may also create a mist or smoke that results in an unsafe work environment for the machine operator, particularly when machines have inadequate shielding or when shops have poor ventilation systems. Straight oils are usually limited to low temperature, low-speed operations [62]. The oily film left on the workpiece makes cleaning more difficult, often requiring the use of cleaning solvents.

Straight oil products of different viscosities are available for each duty class. Viscosity can be thought of as a lubricant factor--the higher the oil's viscosity, the greater its lubricity. Highly viscous fluids tend to cling to the workpiece and tool. This causes increased cutting fluid loss by dragout and necessitates lengthier,more costly cleanup procedures. It can be more efficient to choose a low-viscosity oil that has been compoundedto provide the same lubricity as a highly viscous one.

Table (1)
Composition of non-water miscible cooling Lubricants

Component	Content
Basic oil	87-95%
Sulphur	~0.5%
Sulphurised ester or sulphurised olefin	3-6%
Organophosphorus compounds and calcium sulphonate	0-3%
Carbon acid ester (friction modifier)	0-3%
Mist inhibiting agent	0.5-1%
Antioxidant	~0.2%

2 - SOLUBLE OILS (60-90% petroleum oil)

Soluble oils (also referred to as emulsions, emulsifiable oils or water-soluble oils) are generally comprised of 60-90 percent petroleum or mineral oil, emulsifiers and other additives [62, 64, 67]. A concentrate is mixed with water to form the metalworking fluid. When mixed, emulsifiers (a soap-like material) cause the oil to disperse in water forming a stable "oil-in-water" emulsion [68,66]. They also cause the oilsto cling to the workpiece during machining. Emulsifier particles refract light, giving the fluid a milky, opaque appearance.

ADVANTAGES:

Soluble oils offer improved cooling capabilities and good lubrication due to the blending of oil and water [66]. They also tend to leave a protective oil film on moving components of machine tools and resist emulsification of greases and slide way oils [68].

Soluble oils are a general purpose product suitable for light and medium duty operations involving a variety of ferrous and nonferrous applications. Although they do not match the lubricity offered by straight oils, wetting agents and EP additives (such as chlorine, phosphorus or sulfur compounds) can extend their machining application range to include heavy-duty operations. Most cutting operations handled by straight oils (such as broaching, trepanning, and tapping) may be accomplished using heavy-duty soluble oils.

DISADVANTAGES:

The presence of water makes soluble oils more susceptible to rust control problems, bacterial growth and rancidity, tramp oil contamination, and evaporation losses. Soluble oils are usually formulated with additives to provide additional corrosion protection and resistances to microbial degradation. Maintenance costs to retain the desired characteristics of soluble oil are relatively high.

Other disadvantages of soluble oils include the following:

When mixed with hard water, soluble oils tend to form precipitates on parts, machines and filters [64, 65]; Due to their high oil content, they may be the most difficult of the water-miscible fluids to clean from the workpiece. As a result of these disadvantages, soluble oils have been replaced in most operations with chemical cutting fluids. Misting of soluble oils may produce a dirty and unsafe work environment, through slippery surfaces and inhalation hazards.

Table (2)
Composition of traditional emulsifiable
Cooling lubricants

Component	Content
Basic oil	~60%
Emulsifier (anionic)	15-20%
Solubiliser	~5%
Friction modifier	0-5%
Aliphatic acids	~5%
Corrosion protection agent	~5%
Neutralization agent	0-3%
Bactericide	~4%
Fungicide	0-1%

Note: content refers to that of the concentrate, not of the lubricant as use

3 - SYNTHETICS (0% petroleum oil):

Synthetic fluids contain no petroleum or mineral oil [68, 65]. They were introduced in the late 1950's and generally consist of chemical lubricants and rust inhibitors dissolved in water. Like soluble oils, synthetics are provided as a concentrate which is mixed with water to form the metalworking fluid. These fluids are designed for high cooling capacity, lubricity, corrosion prevention, and easy maintenance. Due to their higher cooling capacity, synthetics tend to be preferred for high-heat, high-velocity turning operations such as surface grinding. They are also desirable when clarity or low foam characteristics are required. Heavy-duty synthetics, introduced during the last few years, are now capable of handling most machining operations. Synthetic fluids can be further classified as simple, complex or emulsifiable synthetics based on their composition [64, 65]. Simple synthetic concentrates (also referred to as true solutions) are primarily used for light duty grinding operations [68]. Complex synthetics contain synthetic lubricants and may be used for moderate to heavy duty machining operations. Machining may also be performed at higher speeds and feeds when using complex synthetics. Both simple and complex synthetics form transparent solutions when mixed in a coolant sump, allowing machine operators to see the workpiece.Emulsifiable synthetics contain additional compounds to create lubrication properties similar to soluble oils, allowing these fluids to double as a lubricant and coolant during heavy-duty machining applications. Due to their wettability, good cooling and lubricity, emulsifiable synthetics are capable of handling heavy-duty grinding and cutting operations on tough, difficult-to-machine and high temperature alloys [68]. The appearance of emulsifiable synthetic fluids ranges from translucent to opaque. Chemical agents found in most synthetic fluids include:

& Amines and nitrites for rust prevention
& Nitrates for nitrite stabilization
& Phosphates and borates for water softening
& Soaps and wetting agents for lubrication
& Phosphorus, chlorine, and sulfur compounds for chemical lubrication
& Glycols to act as blending agents
& Biocides to control bacterial growth

ADVANTAGES:

Synthetic fluids have the following qualities which contribute to superior service life [64, 69]:

& Excellent microbial control and resistance to rancidity for long periods of time.
& Nonflammable, nonsmoking and relatively nontoxic.
& Good corrosion control;
& Superior cooling qualities;
& Greater stability when mixed with hard water;
& Reduced misting problems; and
& Reduced foaming problems.

DISADVANTAGES:

Although synthetics are less susceptible to problems associated with oil-based fluids, moderate to high agitation conditions may still cause them to foam or generate fine mists [62]. A number of health and safety concerns, such as misting and dermatitis, also exist with the use of synthetics in the shop [64]. Ingredients added to enhance the lubricity and wettability of emulsifiable synthetics may increase the tendency of these fluids to emulsify tramp oil, foam and leave semi-crystalline to gummy residues on machine systems (particularly when mixed with hard water) [68]. Synthetic fluids are easily contaminated by other machine fluids such as lubricating oils and need to be monitored and maintained to be used effectively [62,66].

Table (3)
Composition of aqueous cooling lubricants
(Mineral oil free)

Component	Content
Corrosion protection	20-40%
Neutralization agent (soaping)	15-25%
Solubiliser	10-20%
Friction modifier	5-10%
Water	5-30%
Biocide	3-4%
Fungicide	0-1%

Note: contents refers to that of the concentrate, not of the lubricant as used.

4 - SEMISYNTHETICS (20-50% petroleum oil):

As the name implies, semi synthetics (also referred to as semi-chemical fluids) are essentially a hybrid of soluble oils and synthetics. They contain small dispersions of mineral oil, typically 2 to 30 percent, in awater-dilutable concentrate [62, 64, 70]. The remaining portion of a semi-synthetic concentrate consists mainly of emulsifiers and water. Wetting agents, corrosion inhibitors and biocide additives are also present.

Semi synthetics are often referred to as chemical emulsions or preformed chemical emulsions since the concentrate already contains water and the emulsification of oil and water occurs during its production. The high emulsifier content of semi synthetics tends to keep suspended oil globules small in size, decreasing the amount of light refracted by the fluid. Semi synthetics are normally translucent but can vary from almost transparent (having only a slight haze) to opaque [64, 65]. Most semi synthetics are also heat sensitive. Oil molecules in semisynthetics tend to gather around the cutting tool and provide more lubricity. As the solution cools, the molecules redisperse.

ADVANTAGES:

Like synthetics, semisynthetics are suitable for use in a wide range of machining applications and are substantially easier to maintain than soluble oils. They provide good lubricity for moderate to heavy duty applications. They also have better cooling and wetting properties than soluble oils, allowing users to cut at higher speeds and faster feed rates [8]. Their viscosity is also less than that of a soluble oil, providing better settling and cleaning properties. Semisynthetics provide better control over rancidity and bacterial growth, generate less smoke and oil mist (because they contain less oil than straight or soluble oils), have greater longevity, and good corrosion protection.

DISADVANTAGES:

Water hardness affects the stability of semisynthetics and may result in the formation of hard water deposits. Semisynthetics also foam easily because of their cleaning additives and generally offer less lubrication than soluble oils.

Purpose of the Semi Synthetic Additives

Table (4):

Additive	**Purpose**	**Example**
oilness agent	increases film strength	polyol ester
emulsifier (more complex)	to improve wetting of part, disperse oil in water	fatty amides, salts of fatty acids, nonionic surfactants
Alkanolamine	to provide reserve alkalinity	monethanolamine, triethanolamine
extreme pressure agent	to lubricate under high pressure	sulfurized fatty materials, chlorinated paraffins, phosphorus derivatives
Biocide	to reduce microorganisms	triazine, oxazolidine
coupling agent	to improve the solubility of the various additives in the MWF	fatty alcohol
Defoamer	to reduce foam production	long chain fatty alcohol
corrosion inhibitor	to prevent part or tool corrosion	amine salt or boric acid
Chelator	to reduce hard water effects	EDTA
metal passivator	to protect newly exposed metal from corrosion	triazole
dye	aesthetic, identification	***

Table (5)
Average composition of semi-synthetic cutting oils

Component	**%**
Emulsifiers	35-50
Oiliness agents	5-20
Corrosion inhibitors	1-3
Coupling agents	2-3
Extreme pressure additives	0-10
Water	25-50
Biocides	1-2
Mineral oil	Balance

Table (6)

The advantages, disadvantages and applications of each fluid are summarized below.

	Advantages	**Disadvantages**
Straight Oils	rust protection; good sump life; easy Excellent lubricity; good maintenance; rancid resistant.	Poor heat dissipation; Limited to increased risk of fire low-speed cutting operation.
Soluble Oils	Good lubrication; improved cooling capability; suitable for light and medium-duty operations involving avariety of ferrous and nonferrous applications	More susceptible to rust problems,bacterial growth, tramp oil contamination and evaporation losses.
Synthetics	Excellent microbial control and rancid resistant; relatively nontoxic; superior cooling qualities; easy maintenance; relatively long service life; capable of handling heavy-day cutting operations	Reduced lubricity; may cause misting, foaming and dermatitis; may emulsify tramp oil; easily contaminated by other machine fluids.
Semi synthetics	Good microbial control and rancid resistant; relatively nontoxic; superior cooling qualities; easy maintenance; relatively long service life.	Water hardness affects stability; may emulsify tramp oil; easily contaminated by other machine fluids.

Table (7)
Mixing ratios for cooling lubricant emulsions for different processes

Cutting process	**Concentration**	**Concentrate: water**
Broaching	10 - 20	1:10 - 1:5
Thread cutting	5 - 10	1:20 - 1:10
Deep hole drilling	10 - 20	1:10 - 1:5
Parting off	5 - 10	1:20 - 1:10
Milling, cylindrical Milling	5 - 10	1:20 - 1:10
Turning, drilling, automation work	3 - 10	1:33 - 1:10
Sawing	5 - 20	1:20 - 1:5
Tool grinding	3 - 6	1:33 - 1:17
Cylindrical grinding	2 - 5	1:50 - 1:20
Centreless grinding	3 - 6	1:33 - 1:17
Surface grinding	2 - 5	1:50 - 1:20

1.5.10. HEAITH EFFECTS: [71, 72, 73, 74]

General:

Metalworking fluids (MWFs) can cause adverse health effects through skin contact with contaminated materials, spray, or mist and through inhalation from breathing MWF mist or aerosol. Skin and airborne exposures to MWFs have been implicated in health problems including irritation of the skin, lungs, eyes, nose and throat. Conditions such as dermatitis, acne, asthma, hypersensitivity pneumonitis, irritation of the upper respiratory tract, and a variety of cancers have been associated with exposure to MWFs (NIOSH 1998a). The severity of health problems is dependent on a variety of factors such as the kind of fluid, the degree and type of contamination, and the level and duration of the exposure.

Skin Disorders

Skin contact occurs when the worker dips his/her hands into the fluid or handles parts, tools, and equipment covered with fluid without the use of personal protective equipment, such as gloves and aprons. Skin contact may also result from fluid splashing onto the employee from the machine if guarding is absent or inadequate.

Two types of skin disease associated with MWF exposure are contact dermatitis and acne.

Contact dermatitis is the most commonly reported skin disease associated with MWFs. People with contact dermatitis have itchy skin and a rash, often with cracks, redness, blisters, or raised bumps. The two kinds of contact dermatitis are irritant contact dermatitis and allergic contact dermatitis. In irritant contact dermatitis the rash is confined to the area in contact with the irritating substance. In allergic contact dermatitis the rash can spread beyond the area directly in contact with the irritant. Fourteen to 67 percent of workers exposed to MWFs are at risk for developing dermatitis (NIOSH 1998a). This high rate of dermatitis indicates susceptibility of many employees to the irritating or sensitizing nature of MWFs and their contaminants or additives. Once the skin is compromised, very small exposures, which previously did not have any effect, can cause an episode of dermatitis. It is important to try to prevent skin disease from developing and to treat it early because untreated dermatitis can lead to more serious complications (NIOSH 1998a).

In metalworking operations contact dermatitis may be caused by any of the following factors: clothing contaminated with MWF; poor personal hygiene (e.g., allowing MWF to remain in contact with skin by not washing after exposure); poor housekeeping practices; higher than recommended metalworking fluid concentrations; high alkalinity of in-use fluid which can remove natural skin oils; metal processing aids such as degreasers, cleaners, or rust inhibitors; metal shavings contained in the fluid which may abrade the skin; prolonged contact with the MWF; tramp oils (e.g., hydraulic fluids, gear or spindle oils, way lubes, grease); hand washing with abrasive soaps or with water that is excessively hot or cold; seasonal conditions (e.g., winter dryness); other contaminants (e.g., water in an oil based system).

People working with water based, synthetic, and semi synthetic MWFs are most at risk for developing contact dermatitis.

Straight oils are often associated with acne-like disorders characterized by pimples in areas of contact with the MWFs. Red bumps with yellow pustules may develop on the face, forearms, thighs, legs, and other body parts contacting oil-soaked clothing.

Respiratory Diseases

Inhalation of MWF mist or aerosol may cause irritation of the lungs, throat, and nose. In general, respiratory irritation involves some type of chemical interaction between the MWF and the human respiratory system. Irritation may affect one or more the following areas: nose, throat (pharynx, larynx), the various conducting airways or tubes of the lungs (trachea, bronchi, bronchioles), and the lung air sacks (alveoli) where the air passes from the lungs into the body. Exposure to MWF mist or aerosol may also aggravate the effects of existing lung disease.

Some of the symptoms reported include sore throat, red, watery, itchy eyes, runny nose, nosebleeds, cough, wheezing, increased phlegm production, shortness of breath, and other cold like symptoms. These symptoms may indicate a variety of respiratory conditions, including acute airway irritation, asthma (reversible airway obstruction), chronic bronchitis, chronically impaired lung function, and hypersensitivity pneumonitis (HP). When symptoms of respiratory irritation occur, in many cases it is unclear whether the disease was caused by specific fluid components, contamination of the in-use fluid, products of microbial growth or degradation, or a combination of factors.

Exposure to MWFs has been associated with asthma. In asthma, airways of the lung become inflamed, causing a reduction of the flow of air into and out of the lungs. During an asthmatic attack, the airways become swollen, go into spasms and fill with mucous, reducing airflow and producing shortness of breath and a wheezing sound. A variety of components, additives, and contaminants of MWFs can induce new-onset asthma, aggravate pre-existing asthma, and irritate the airways of non-asthmatic employees.

Chronic bronchitis is a condition involving inflammation of the main airways of the lungs that occurs over a long period of time. Chronic bronchitis is characterized by a chronic cough and by coughing up phlegm. The phlegm can interfere with air passage into and out of the lungs. This condition may also cause accelerated decline in lung function, which can ultimately result in heart and lung function damage.

Hypersensitivity pneumonitis (HP) is a serious lung disease. Recent outbreaks of HP have been associated with exposure to aerosols of synthetic, semi synthetic and soluble oil MWFs. In particular, contaminants and additives in MWFs have been associated with outbreaks of HP (NIOSH 1998a). In the short term, HP is characterized by coughing, shortness of breath, and flu-like symptoms (fevers, chills, muscle aches, and fatigue). The chronic phase (following repeated exposures) is characterized by lung scarring associated with permanent lung disease.

Other factors, such as smoking, increase the possibility of respiratory diseases. Cigarette smoke may worsen the respiratory effects of MWF aerosols for all employees.

Cancer:

A number of studies have found an association between working with MWF and a variety of cancers, including cancer of the rectum, pancreas, larynx, skin, scrotum, and bladder (NIOSH 1998a). Studies of MWF and cancer have relied on the health experiences of workers exposed decades earlier. This is because the effects of cancers associated with MWF may not become evident until many years after the exposure. Airborne concentrations of MWF were known to be much higher in the 1970s - 80s than those today. The composition of MWFs has also changed dramatically over the years. The fluids in use prior to 1985 may have contained nitrite, mildly refined petroleum oils, and other chemicals that were removed after 1985 for health concerns. Based on the substantial changes that have been made in the metalworking industry over the last decades, the cancer risks have likely been reduced, but there is not enough data to prove this.