

## Introduction to Industrial Cutting Fluid – A Review

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### ABSTRACT

Cutting fluids play a crucial role in metalworking and machining processes by extending tool life, enhancing surface finish, and dissipating the heat generated during cutting operations. Their primary function is to manage heat dissipation and prevent overheating during machining, which in turn improves tool longevity and machining efficiency. Choosing the right cutting fluid is essential in these processes, as various types provide unique benefits and properties. Cutting fluids are widely utilized in machining and metalworking to lubricate, cool, and remove metal chips. These fluids enhance tool longevity, workpiece quality, and overall machining efficiency. Different types, such as oils, emulsions, and synthetics, are selected based on the specific requirements of the application. Effective selection and management of cutting fluids are vital for optimizing processes.

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### Introduction

A cutting fluid, used in metalworking tasks like cutting, drilling, milling, and turning, plays a diverse role in reducing heat produced during deformation and machining while also providing lubrication to lessen friction and wear on the workpiece. While often informally called a coolant or lubricant, these terms do not fully encompass its extensive functions. Cutting fluids are applied during machinery operations to lubricate, cool, and minimize friction at the interface between the cutting tool and workpiece, thereby extending tool life, enhancing surface finish, and dissipating heat generated throughout the machining process [1].

In addition to cooling and lubrication, cutting fluids aid in achieving excellent surface finishes and precise dimensional accuracy. These functions are achieved through a formulation that combines water and oil, supported by an emulsifier that helps blend the two [2]. The effectiveness of cutting fluids can be further improved by adding specific chemicals to develop synthetic fluids. Cutting fluids are essential in the metal-cutting process as they help to minimize heat generation and decrease friction. They are available in several types, such as soluble cutting oils, neat cutting oils, synthetic coolants, and solid lubricants. Choosing the appropriate cutting fluid is vital and is influenced by the material being cut, the tool utilized, and the specific operation being conducted [3,4].

In terms of high-quality cutting fluids, Castrol provides a variety of options that serve different industries and applications. Ranging from soluble cutting oils to synthetic coolants, Castrol's cutting fluids are engineered to deliver exceptional performance and safeguard machinery, offering high flash points, non-corrosive characteristics, and effective lubrication [5].

### Functions of Cutting Fluids

The various roles of Cutting Fluids include:

- The primary role of cutting fluid is to dissipate heat, which reduces friction and prevents overheating during machining processes, thereby improving tool longevity and preserving workpiece quality.
- Another key function of cutting fluid is to cool both the workpiece and the cutting tool.
- It also serves to minimize friction between the tool and the workpiece.
- Cutting fluid aids in the removal of chips from the cutting area.
- It contributes to the durability of cutting tools.
- The use of cutting fluid results in smoother surfaces on workpieces.
- It helps to prevent corrosion of both the workpiece and the machine tool.
- Cutting fluid minimizes material buildup on the tool.
- It plays a role in managing dust and fumes for safety purposes.
- Cutting fluid allows for a broader range of cutting parameters.
- It enhances the machining capabilities for various materials.

### Cutting Fluids in CNC Machining Processes

Discover the essential function of cutting fluids in CNC machining, emphasizing their ability to extend tool lifespan, enhance surface quality, and facilitate effective chip removal, in line with precision-focused CNC machining technologies [6].

A cutting fluid is a specially formulated substance for metalworking and machining tasks, acting as both a lubricant and a coolant throughout these operations. This fluid is typically introduced during the machining process itself, and can be applied through methods such as flooding, fluid jets, or mist spraying [7].

## Types of Cutting Fluids

There are several categories of cutting fluids that can be distinguished based on their phase, composition, source, and application method. However, they can generally be grouped as follows.

### Soluble Oils (Emulsions)

Soluble oils are stable emulsions created by mixing mineral oil with water in specific ratios (typically 1-20% oil to water) [8]. The components that constitute soluble oils include:

- Emulsifiers like sodium sulfonate, which facilitate the mixing of oil droplets with water by reducing the water's surface tension;
- Additives that serve as coupling agents or enhance corrosion resistance;
- Biocides that inhibit bacterial growth;
- Anti-wear additives that enhance lubrication.

Soluble oils are the most affordable and widely used cutting fluids in machining processes [9]. They offer effective cooling and moderate lubrication properties, making them ideal for light cutting tasks.

### Straight Oils

Straight oils are mineral oils that do not mix with water and are utilized without any water addition. Initially, pure animal and vegetable oils served as lubricants in metal cutting [5]. Despite their environmentally friendly biodegradability, they are costly and break down quickly. Consequently, they are now primarily used as additives to enhance the lubrication properties of petroleum and mineral oils. Mineral oils are derived from petroleum-based hydrocarbons obtained through the refining process of crude oil [4]. These oils may include extreme pressure additives like chlorine, phosphorus, and sulphur to minimize tool wear.

### Synthetic Fluids

These fluids, which are water-based, compete with mineral and petroleum-based oils. They are created by dissolving organic and inorganic chemical compounds in water, along with various additives [8]. These additives consist of lubricant enhancers, rust inhibitors, and corrosion preventatives. All these components enhance properties such as lubrication, which could otherwise be negatively affected by the water content in the fluids.

### Semi-Synthetic Fluids

Semi-synthetic fluids are a blend of synthetic fluids, water-based fluids, and emulsions of soluble oils. They comprise a mixture of 5-50% mineral oil, additives, and chemical compounds that dissolve in water to create microemulsions with particle sizes ranging from 0.1 to 0.01mm. Semi-synthetic fluids integrate the characteristics of both soluble oils and synthetic fluids [8].

## Functions of Cutting Fluids in CNC Machining Processes

### Cooling

In metal cutting machining operations, heat is produced in the workpiece, chips, and cutting tool due to friction between the cutting tool and the workpiece surface. Additionally, heat arises from the plastic deformation of the metal in the shear zone [2]. This heat can lead to several negative consequences, including thermal expansion, chemical reactions like oxidation, surface welding, and more. A cutting fluid helps to cool both the tool and the workpiece, thus mitigating these effects.

### Lubrication

Friction is the primary source of heat during machining. The combination of heat and friction can cause surfaces to weld together. Cutting fluids minimize friction by establishing a thin layer between the chip and the tool, which effectively reduces their contact [9]. Lubrication also lessens the wear on the cutting tool and decreases the energy required for the machining process.

### Prevention of Corrosion

Cutting fluids contain rust and corrosion inhibitors that protect machine parts and the machined surface from corrosion. Mineral oil-based cutting fluids prevent oxidation by creating a very thin protective film over exposed surfaces [5].

### Improvement of Tool-Life

By dissipating heat, minimizing friction and wear, and preventing corrosion and rust, cutting fluids significantly reduce tool wear, thereby enhancing tool life.

### Removal of Chips

In certain machining processes like milling and drilling, chips can accumulate around the cutting area. This accumulation can obstruct cutting. Cutting fluids also help to wash away chips from the cutting zone.

### Enhancement of Surface Finish

By preventing thermal expansion and changes in the properties of a workpiece, cutting fluids play a vital role in achieving a high-quality surface finish on machined components.

### Characteristics of a Cutting Fluid

The following outlines the essential properties that an effective cutting fluid should possess [5,8].

- **High Thermal Conductivity:** This property indicates how efficiently a substance can transfer heat. For cutting fluids, it refers to their ability to dissipate heat from both the workpiece and the tool.
- **High Heat Capacity:** A cutting fluid with a high heat capacity can absorb more heat before reaching elevated temperatures or boiling.
- **Low Viscosity:** The low viscosity of cutting fluid facilitates smooth flow and helps prevent sludge formation caused by the mixing of chips with the fluid.
- **Non-Corrosive:** An effective cutting fluid should not corrode the workpiece or the tool.
- **Corrosion and Oxidation-Resistant:** Beyond being non-corrosive, a quality cutting fluid must also inhibit corrosion and oxidation of components.
- **Non-Toxic:** Given its potential contact with humans or the environment, a good cutting fluid must be non-toxic to both.
- **Chemically Nonreactive:** Cutting fluids should not engage in chemical reactions with the surfaces they contact, as this can damage those surfaces and compromise the fluid's integrity.
- **Odourless:** To prevent any unpleasant odors on the machine or the machined component, a good cutting fluid should be free of odor.
- **Sufficiently Clear (Transparent):** A quality cutting fluid should be clear enough to allow visibility of the workpiece.
- **Stability:** An effective cutting fluid should maintain its properties without rapid degradation during use or storage.

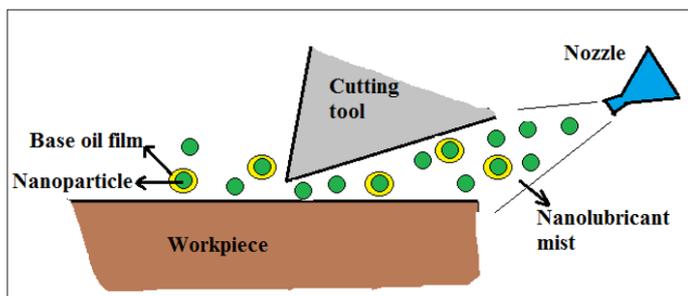


Figure 1: Nanofluid-SQL Mechanism Schematic

### Methods Of Application and Usage of Cutting Fluids in CNC Machining

The roles of cutting fluids discussed earlier are relevant to CNC machining processes. Nonetheless, there are different machining processes that utilize various application methods.

- **CNC Milling:** In CNC milling operations, the workpiece remains stationary while the cutting tool is in motion. For this operation, the most effective way to apply cutting fluid is through flooding.
- **CNC Drilling:** The primary function of cutting fluids in CNC drilling is to facilitate chip removal and provide cooling. Lubrication is generally unnecessary since the likelihood of built-up edges is minimal. It is advisable to use jet application for the cutting fluid [4].
- **CNC Turning:** This process operates at extremely high speeds, making cooling essential. Given that the workpiece rotates, jet application of the cutting fluid is appropriate.

Selecting the Right Cutting Fluid for Your CNC Machining Process  
Choosing a cutting fluid is influenced by several factors, including the type of cutting tool, the material of the workpiece, and the specific machining operation [8].

### Cutting Tool Type

Carbide tools can reach very high temperatures, making them more vulnerable to thermal shock, which occurs when different sections of the cutting tool expand at varying rates. For this type of tool, a synthetic cutting fluid with exceptional cooling properties is recommended.

High-speed steels also heat up, but not to the extent of carbide tools. Soluble oils and semi-synthetic fluids are appropriate for these tools [9].

### Workpiece Material

Metals are the most frequently used materials for workpieces that necessitate cutting fluids [5]. Below are some of the commonly machined metals along with their appropriate cutting fluids.

- Steel – Mineral Oils with Lubricant Additives
- Alloy Steels – Sulphur brass oil or mineral oil
- Aluminium – Soluble oils or mineral oils that do not contain active sulphur (as active sulphur can stain aluminium)
- Copper – Soluble Oils
- Stainless Steels – Mineral oils with superior extreme pressure additives
- Cast Iron – None

### Machining Operation

Machining operations that are relatively straightforward, such as turning, milling, forming, and drilling, occur at higher speeds. At these speeds, a significant amount of cooling is necessary. Only basic lubrication and extreme pressure characteristics are needed.

Therefore, synthetic fluids are most appropriate for these tasks. While soluble oils can also be utilized.

Conversely, more challenging machining operations like broaching and thread cutting demand effective lubrication. These processes are conducted at lower speeds and under high pressures, thus requiring cutting fluids that offer excellent lubrication and extreme pressure properties. Mineral oils with extreme pressure additives are the optimal selection.

### Selection of Cutting Fluids

The selection of cutting fluids depends on the following factors:

- First and foremost, it is based on the composition of both the workpiece material and the tools used in the process.
- The nature of the machining operation being performed is another critical factor in choosing cutting fluids.
- Ultimately, the choice is affected by the required cooling effect essential for the machining task.

### Purpose of Cutting Fluid

The four main functions of cutting fluids are:

- **Temperature Control:** Cutting fluids are vital in reducing friction and heat generation between the tool and workpiece, thereby prolonging the tool's life by preventing excessive temperature increases.
- **Lubrication:** Cutting fluids serve as lubricants for both the tool and workpiece, minimizing friction and cutting forces. This lubrication not only enhances tool durability but also improves the surface finish.
- **Cleaning the Machine:** Cutting fluids assist in removing chips, particles, and debris, protecting the workpiece's surface finish from possible damage.
- **Prevention of Harmful Contamination:** By forming a protective layer on the workpiece, cutting fluids help prevent contamination from harmful atmospheric gases such as SO<sub>2</sub>, O<sub>2</sub>, and H<sub>2</sub>S<sub>2</sub>.

### Advantages of Cutting Fluids

The benefits of cutting fluids include:

- Heat Dissipation.
- Reduced Friction.
- Improved Chip Removal.
- Extended Tool Life.
- Enhanced Surface Finish.
- Corrosion Protection.
- Environmental Control.
- Increased Speed and Feed Range.
- Material Compatibility.

### Disadvantages of Cutting Fluids

The drawbacks are:

- Health and Safety Risks.
- Environmental Issues.
- Costs Associated with Purchase and Disposal.
- Maintenance and Monitoring Requirements.
- Potential for Skin Irritation.
- Odor and Discomfort in the Workplace.

### Application of Cutting Fluids

Cutting fluids serve several purposes, including:

- Machining Operations.
- Metalworking Processes.
- Minimizing Friction.
- Extending Tool Lifespan.

- Dissipating Heat.
- Improving Surface Finish.
- Preventing Corrosion.
- Cooling Both the Workpiece and the Tool.
- Facilitating Chip Removal.
- Controlling Environmental Conditions.

### Conclusion

Cutting fluids are extensively utilized in the manufacturing sector as they assist in cooling both the tool and workpiece, lubricating the chip-tool interface, and enhancing tool longevity. This article reviews various machining environments and types of cutting fluids. It aims to summarize significant published research regarding the impact of different machining environments on workpiece temperature and hardness post-machining, thrust force, average surface roughness, and flank wear. The latest technology, minimum quantity lubrication using nanofluids, seeks to mitigate the adverse environmental effects of cutting fluids while improving thermal and tribological properties [10-15].

No specific cutting fluid possesses cooling and lubrication properties that are universally suitable for all metalworking applications. The effects of various cutting fluids are examined.

### Key Findings Include

- Straight oil offers good lubrication but has limited cooling capabilities.
- Water serves as an effective cooling agent but provides poor lubrication and can lead to rusting.
- Soluble oil resulted in the least flank wear compared to mentholated spirit, paraffin, and dry machining conditions.

While cutting fluids enhance tool life, surface finish, and reduce costs, their environmental impact poses a challenge to their widespread use. Consequently, recent methods such as MQL and MQL with nanofluids, which utilize smaller quantities of traditional cutting fluids while offering improved cooling and lubrication effects, have garnered the interest of researchers.

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