Modification of coolant fluid controller for minimum quantity lubrication (mql) methods with use of arduino uno-based control system

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Abstract. Coolant is important in the machining process. Excessive and uncontrolled use of coolant can cause high production costs, affect the human health and the waste of coolant polluting the environment. One method that has been used to reduce the amount of coolant is the limiting coolant distribution method or commonly called MQL (Minimum Quantity Lubrication). The MQL equipment which is available in the market has a relatively expensive, so a prototype of a coolant control system of MQL method has been designed and made. However, the prototype made not meet the desired specifications then a modified control system is added to the prototype. Prototype performance is compared before and after the control system being added. The duration of fluid drop and the output capacity of the fluid sprayed are measured to test the function of the device. It is found that with the addition of modified control systems, the performance of MQL cooling regulator is improved, but it is applied mostly for fluids which have viscosity ranging about viscosity of oil and cooking oil. For cooking oil fluid, the MQL tool performance increase as the capacity of the fluid decreases due to the control system being applied at all case of air valve openings for the diameter orifice of 2 mm. It is also found that at the aperture of the air valve of ¼, with a 10 second delay time and an orifice diameter of 2 mm, the capacity coolant sprayed is reduced from 107.348 ml/hr to 89.609 ml/hr when the modified control system is added. For the Bromus fluid, the capacity of the fluid decreases as the control system being applied. The MQL tool performance increase only occur in the smallest valve opening of ¼ that is about 9 to 26%. However, the capacity of Bromus types of fluid increase as the air valve openings increase.

1. Introduction
The use of coolant in the machining process by using a machine tool is an important part. The coolant has a role in reducing friction so that the tool will last longer and be able to maintain the quality of the machining product. During this time many people argue that the more liquid given, the better. Excessive use of coolant in the machining process has a negative impact on the environment as revealed by the coolant supplier company, Blaser. Economically, the use of coolant had already exceeded the costs for procurement of tools [1]. Excessive use of coolant will cause high production costs and affect the health and waste of polluting the environment [2,3].
One method that has been used to reduce the effects of coolant is the method of limiting the coolant distribution or commonly called (Minimum Quantity Lubrication). Various studies have proven that this method is able to exceed the ability of excessive use of coolant in extending tool life \[4,5\]. Some large companies have successfully used it, such as the Ford Motor Co., America and General Motor Co., USA production lines \[6,7\]. This tool is commercially available in the market, but in terms of investment cost, this tool is still expensive, especially for small manufacturing companies.

In a previous work, it has been designed and made a prototype of a coolant regulator using a simple MQL method \[8\]. The prototype was functionally worked, but the prototype has not been able to produce the desired coolant flow rate range of 1 to 500 ml/hour at a pressure of 30 MPa. Then a control system is created and applied to the MQL tool. Modification of the tool by adding the control system is expected to be able to eliminate deficiencies that exist in the previous MQL tool.

MQL tools are usually used in the machining process to reduce the working temperature in the cutting process. The cutting process is carried out using a cutting tool that is mounted on a machine tool. Cutting the workpiece by utilizing the relative motion between the cutting tool with the workpiece so as to produce a product in accordance with the desired product geometry. This process has the waste part from machining on a product commonly referred to as chip \[9\].

Reducing the temperature in the machining process can use several methods, one of which is by flowing the cutting fluid. In general, coolant is a cooling medium used to cool workpieces and cutting tools during the machining process. The coolant is also used to lubricate the cutting tool so that it has a longer service life. Coolant is a liquid resulting from a mixture of ethylene or propylene glycol and water. Usually the ratio of mineral substances is about 50/50 \[10\].

Minimum Quantity Lubrication (MQL) is a cooling system in the machining process that allows the use of a limited amount of coolant. In the MQL method the distribution of coolant is by combining liquid fluid and air so as to form aerosols or fogging in other words the use of coolant can be minimized. MQL system consists of two types, namely external and internal systems.

In this external system has 2 air channels, the first functions to create an air casing as a mixing chamber, while the second provides atomization (fogging) of the air supply, and the misted oil is supplied through the middle section. This external system with ejector nozzle is the cheapest and simplest method \[11\]. Whereas in the internal system, aerosols are prepared in sprayers and then supplied through shafts or internal channels on the device. When this system is used in machining centers or manufacturing cells, the aerosol supply unit must react to the frequency of changes in the tool which only takes 1 or 2 seconds. The proper aerosol parameter settings for each tool are given.

This principle is applied to MQL tools and can be controlled as required. The control system itself is the process of regulating or controlling one or several quantities (variables or parameters) so that they are at a certain value or range.

Open loop control system (Open Loop) is a control system in which the amount of output does not have an effect on the amount of input, so the controlled variable output cannot be compared to the desired value of the initial setting variable as figure 1.

![Figure 1. Open loop control system [12]](image)

Closed loop control system (closed loop) is a control system where the amount of output has an effect on the amount of input, so that the amount of output can be compared to the desired input \[12\]. Furthermore, the value difference between the value output and the initial setting input is used as a correction which is the control target as seen in figure 2.
2. Methodology

2.1. Tool Design Specifications

In this study, it is planned that a cooling fluid regulating system will be created using the Minimum Quantity Lubrication (MQL) method. Based on the analysis results obtained by looking at products that are already on the market, it can be concluded that the existing equipment is still expensive and they have a complicated system and limitations in fluid distribution. In order to fulfill these requirements, it is planned that the tools can meet the needs as listed in table 1.

| Specification              | Description                                      |
|----------------------------|--------------------------------------------------|
| Flowrate                   | 1 - 500 ml / hour                                |
| Air pressure               | 30 Pa                                            |
| Capacity                   | 1 L.                                             |
| Fluid Down System          | Gravity                                          |
| Mixing Type                | Internal mixing                                  |
| Valve Open Range           | Aperture, ¼, ½, ¾, full                          |
| Viscosity Range            | SAE 40 or SAE 20                                 |

The desired flowrate is from 1 to 500 ml/hour. The range of flowrate chosen is very wide because each type of material from the workpiece has a different level of hardness, so the greater the range of flowrate the more types of material can be tested. The MQL tool uses air to drive the desired fluid and air pressure which ranges from 1 to 10 Pa, depending also on the flowrate to be used. If the flowrate is high, then the air pressure is set to be high accordingly.

2.2. System Design

In this study an internal system is used, the form of system design that will be made as shown in figure 3.
The working principle of the MQL tool is that the fluid in reservoir $A$ passes through valve $B$ which is open as specified. Fluid valves can be open $\frac{1}{4}$, $\frac{1}{2}$, $\frac{3}{4}$, or fully open. Fluid valves will be able to open and close based on a set amount of time. Then after the fluid passes through the valve, then the air will blow to push the fluid out the nozzle. The air that comes out of the compressor will pass through valve $C$, just like valve $B$, the air valve can also be adjusted to aperture of $\frac{1}{4}$, $\frac{1}{2}$, $\frac{3}{4}$, or even a full aperture.

The mixture of air and fluid will pass through the nozzle $D$. On the nozzle $D$ there is a flow sensor (flowensor) to read the flow rate of the discharge fluid. This measurement signal is sent to Arduino. If the measured flow rate is not the same as what has been set in the program, then the Arduino will make an adjustment.

Arduino UNO is an Arduino product that is used as a controller of an electronic or mechatronic system. Arduino UNO consists of an electronic board containing an ATmega 328 microcontroller [13]. Arduino consists of two main parts namely a physical circuit board (often also called a microcontroller) and a software or IDE (Integrated Development Environment) that runs on a computer. This software is often called Arduino IDE which is used to write and upload code from a computer to the Arduino hardware board as shown in figure 4.

Flow sensors consist of plastic valve bodies, water rotors, and hall effect sensors. When water flows through, the rotors wind up [14]. The speed is converted from the difference in the rotation of the timer on the sensor rotor, changes will be seen at different rates of flow. The advantage of this sensor is that it only requires 1 signal (GIS) in addition to the 5V dc and ground lines as shown in figure 5.

DC servo motors are widely used in the design of mechatronics because the torque characteristics and speed of DC motors in accordance with the configuration of the electronic circuit in this case is a servo motor [15]. The physical form of a DC servo motor can be seen as figure 6.
2.3. Tools and Materials

To test the capabilities of the MQL tool, a measuring media and device are required. To find out the ability of the tool (in this case how much volume of fluid is coming out) then a sponge is used as shown in figure 7. Sponge is used to capture the fluid that comes out so that it can be weighed. This media is used to ease measuring the amount of fluid released. The fluid mass measured is the fluid mass used for 10 minutes of operating time of the tool. 10 minutes will be converted into units of hours so that the measured flowrate becomes ml/hour. To measure how much fluid is trapped inside the sponge, a digital scale that has a precision of up to 1/100 gram will be used. The scales used are BL 4100s type Setra with the specifications of being able to read weights to the lowest of 0.01 grams as shown in figure 8. This scales will be used to measure dry and wet sponge (weight after trapped fluid).

\[ \text{Fluid mass} = \text{Weight of sponge after} - \text{weight of initial sponge} \]

After the fluid mass is obtained, it will be converted to ml using Equation (2):

\[ \text{Density (}\rho\text{)} = \text{mass} / \text{volume} = \text{gr} / \text{cm}^3 \]

2.4. Measurement Method

After the tool is finished, several tests will be conducted to determine the lowest and highest capabilities of the tool. For this reason, the parameters set are the aperture of the valves for fluid flow and for air flow. The apertures are \(\frac{1}{4}\), \(\frac{1}{2}\), \(\frac{3}{4}\) and full aperture for both fluid flow and air flow valves. While the desired output is the amount of fluid trapped in the sponge.

2.5. Testing the MQL Tools

To ensure that the equipment planned and manufactured meets the initial criteria, the MQL tool is tested. The procedure for testing the MQL tool is as follows. First, the MQL tool is prepared; determined the initial sponge's weight, then place the sponge at the nozzle's mouth and fill fluid into the reservoir. Next, the control system is turned on. After that, activate the MQL tool, then adjust the fluid valve opening as desired. Operate the machine for 10 minutes. Weigh the weight of the sponge.
after the process. Repeat the procedure for next valve opening variation. After getting the data, then it is processed and analyzed.

3. **Result and Discussion**

3.1. **Modification of the MQL Tool**

In this research, the cooling fluid regulator has been successfully modified in the machining process using the MQL (Minimum Quantity Lubrication) method by utilizing an Arduino Uno-based control system. The modified tool can be seen in figure 9.

![Figure 9. Modified MQL equipment](image)

In figure 9, the modified part is marked by a dashed red line. The emphasis on modifying the MQL tool is done on the part to adjust the droplet when the fluid enter the orifice to the fitting T and on the air valve control.

3.2. **Functional Test of the Modified MQL Tool**

3.2.1. **Test of the duration of the fluid droplet.** This test aims to find out how long the fluid drops from the bottle to the fitting T. The test is done by putting oil paper into the fitting T, then calculated with a stopwatch the time required by the fluid dropping from the reservoir into the oil paper. The test is done by varying the number of different volumes in the bottle which are 100 ml and 300 ml with 2 repetitions each. The tests are carried out before and after applying of the control system on the tool. The time span obtained is useful to know whether the amount of fluid volume in the bottle affects the flow rate of fluid down to the fitting T. The data in table 2 are the data obtained after testing. Applying the control system resulted in a longer fall of the fluid from the reservoir.
**Table 2. Duration of the fluid droplet**

| Fluid Types | Fluid Amount | Data 1 (without a control system) | Data 2 (with a control system) |
|-------------|--------------|-----------------------------------|-------------------------------|
|             | Time (s)     | Time (s)                          |                               |
| Oil         | 100 ml       | 12.87                             | 13.82                         |
|             | 12.35        | 13.35                             |                               |
|             | 300 ml       | 11.19                             | 10.35                         |
|             | 10.52        | 9.25                              |                               |
| Cooking oil | 100 ml       | 5.17                              | 4.95                          |
|             | 5.55         | 4.75                              |                               |
|             | 300 ml       | 4.29                              | 3.35                          |
|             | 4.57         | 4.17                              |                               |
| Bromus      | 100 ml       | 2.26                              | 2.46                          |
|             | 2.28         | 2.56                              |                               |
|             | 300 ml       | 1.29                              | 2.03                          |
|             | 1.93         | 2.18                              |                               |

In table 2 it can be seen that the amount of fluid volume in the bottle affects the drop time of the fluid. The more volume in the bottle, the faster the fluid dripping down. Apart from the amount of volume, the thing that also influences the fluid drop time is the viscosity of the fluid. In theory, the fluid sequence from the thick to the thin one is oil, cooking oil, and the most watery bromus. Tests are carried out before and after the existence of a control system, the difference can be seen in figure 10.

![Figure 10](image_url)  
**Figure 10.** Graph of data of the droplet lag time of the fluid without using and using a control system

There is a difference, that is, the droplet lag time of the fluid will be longer if using a control system, it is influenced by the addition of a droplet regulator before the fluid enters the orifice and the
fitting T. The graph shows that not all the droplet lag time of the fluid increase but there are decrease of the droplet lag time. The droplet lag time of the fluid increase namely the droplet lag time of the oil fluid for 100 ml volume and the the droplet lag time for bromus fluid. From these data, the discrepancy occurs because it should be that with the addition of a control system causes a slowdown in the time the fluid falls. The difference in data is suspected to occur because when data collection with variations in the type of fluid, the tool is not first cleaned from the remaining of the previous fluid, then the mixing of the fluid occurs so that the oil fluid will be thin and runny and the time of the fluid fall becomes faster. However, in general the MQL tool with the addition of a control system slowing down the fluid drop. This is because the falling fluid will be regulated by a droplet scheme before enter the Orifice and fitting T.

3.3. Tool Performance Test

This test is carried out to get how much volume (capacity) of each fluid within 1 hour. It is expected that the addition of the control system will cause an increase in the performance of the MQL tool that has been made in achieving the desired specifications.

The graph of the results of testing the tool performance before and after adding the control system for cooking oil fluid can be seen in figure 11. The graph show that at all cases for the diameter orifice of 2 mm, the capacity of the fluid decreases as the control system being applied, so the tool performance increase. Meanwhile for the diameter orifice of 5 mm, the capacity of the fluid decreases only for ¾ and full air valve openings.

![Graphs showing tool performance test results](image)

*Figure 11. Capacity of cooking oil fluid without using and using a control system, a) For air valve openings ¼, b) For air valve openings ½, c) For air valve openings ¾, dan d) For full air valve openings*
The capacity of cooking oil types of fluid has increased only in the cases of air valve openings in a range of about 0 to 45% and for the diameter orifice of 5 mm. The decrease in performance for cooking oil fluids after using a control system tends to occur in small air valve openings and long delay times, this is due to the long delay making droplets and orifice too long so that the fluid will flow in large amounts. This large amount of fluid flowing causes an increase in the fluid capacity of the MQL tool.

The graph of the results of testing the performance of the MQL tool before and after adding the control system for oil fluid can be seen in figure 12. In this Figure, all the data that has been obtained as expected. There is an increase in the performance of the MQL tool after the implementation of the control system. Improved performance on this oil fluid is the best, with a range of about 1 to 67% in all air valve openings. This is suspected because of the role of the control system applied to the MQL tool. Performance of oil type fluids is improved because oil has a high viscosity compared to bromus and cooking oil fluids. The fluid flow down to the fitting T drop by drop. The fall of the oil droplet is set to coincide with an air push. This arrangement makes the capacity of the fluid decreases and the MQL tool performance will increase.

In Figure 13 the following will show the difference in the capacity of the bromus type fluid. The graph of the results of testing the tool performance before and after adding the control system for bromus type of cutting fluid can be seen in figure 13. The graph a show that it is only for air valve openings ¼, the capacity of the fluid decreases as the control system being applied, so the tool performance increase. Meanwhile, the capacity of bromus types of fluid has increased as the air valve openings increase.
Broadly speaking, the bromus type fluid capacity has decreased performance, but in the smallest valve opening ¼ there was an increase of about 9 to 26% and in the air valve opening ¾ and full air valve openings also increased, but only at 5mm orifice with delay 3s and 5s. From the data it can be seen that the tool performance increases only at small air valve openings because at small air valve openings air pressure will be large and bursts occur in the form of aerosols (a mixture of liquid and gas fluid), while for large valve openings air pressure drops so that the fluid will continue flows in the nozzle interval and cannot be controlled by droplet and orifice schematics. That is caused by the viscosity of the bromus which is smaller than the oil fluid and cooking oil, so that the flowing fluid cannot be controlled and the capacity becomes high.

In the following table 3 we can see the difference between the performance of MQL tools before and after using a control system for one type of air and orifice valve openings.

**Table 3. Performance of MQL tool**

| Fluid Types     | Time (s) | Orifice Diameter (mm) | Capacity (ml/hour) |
|-----------------|----------|-----------------------|--------------------|
| Oli             | 10       | 2                     | Before: 21.273     | After: 13.500       |
| Bromus          | 10       | 2                     | Before: 796.576    | After: 723.061      |
| Cooking Oil     | 10       | 2                     | Before: 107.348    | After: 89.609       |
From table 3, it can be seen a decrease in fluid capacity, in other words an increase in performance from the previous condition. The increase is quite significant, ranging between 65% to 67%, but from this data, the performance of this MQL tool is still not in accordance with the design plan in table 1.

The improved performance does not meet the desired specifications. This is due to the inappropriate selection of material and mechanical systems of the MQL tool components. For example, the fluid valve material is made of acrylic. This material cannot withstand the falling fluid and causes the fluid still leaking down to the fitting T. The channel used is made of PVC pipe with a fairly large size, with a diameter of ¼ inches. The PVC material is larger than the channel on the MQL tool that is available on the market, so the air sprayed is not optimal to push the fluid that falls from the reservoir.

4. Conclusions and suggestions

4.1. Conclusions

After obtaining data from several tests that have been carried out, it can be concluded that:

1. It is found that with the addition of modified control systems, the performance of MQL cooling regulator is improved, but it is applied mostly for fluids which have viscosity ranging about viscosity of oil and cooking oil.
2. The tool performance increase as the capacity of the fluid decreases due to the control system being applied for oil fluid. Improved performance on this oil fluid is the best, with a range of about 1 to 67% in all air valve openings. Improved performance in oil type fluids because oil has a high viscosity compared to bromus and cooking oil fluids.
3. For cooking oil fluid, the MQL tool performance increase as the capacity of the fluid decreases due to the control system being applied at all case of air valve openings for the diameter orifice of 2 mm. It is also found that at the aperture of the air valve of ¼, with a 10 second delay time and an orifice diameter of 2 mm, the capacity coolant sprayed is reduced from 107.348 ml/hr to 89.609 ml/hr when the modified control system is added.
4. For the Bromus fluid, the capacity of the fluid decreases as the control system being applied. The MQL tool performance increase only occur in the smallest valve opening of ¼ that is about 9 to 26%. However, the capacity of Bromus types of fluid increase as the air valve openings increase. That is caused by the viscosity of the bromus which is smaller than the oil fluid and cooking oil, so that the flowing fluid cannot be controlled and the capacity becomes high.

4.2. Suggestions

The results of this research still has some shortcomings. For further research in order to minimize these deficiencies, the authors provide the following suggestions:

1. It is recommended that the mechanical system of MQL distribution can be improved so that the performance of the MQL tool can be maximized.
2. It is recommended that the size of the fluid channel pipe is smaller so that the channel is more maximum and the pressure used is also maximum.
3. It is recommended that the air pressure used in this MQL tool be adjusted so that it is constant according to the desired specifications.

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