Effect of Static Magnetic and Pulsated Electromagnetic Fields On the Dynamic and Kinematic Viscosity of Metal Cutting Fluids

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Abstract: In this paper, authors investigated the difference between the influence of static magnetic field and pulsating electromagnetic field on metal cutting fluids. Two essential physical parameters of the cutting fluids, dynamic and kinematic viscosity coefficients were analyzed during the experiment in the same laboratory condition. The results obtained from the experimental research show that the influence of the static magnetic field on sample metal cutting fluids is greater than the influence of the pulsating electromagnetic field. Such as, after magnetizing cutting fluids under the effect of three various static magnetic field strengths, the kinematic and dynamic viscosity have decreased about 17% and 6% respectively, while they declined about 7% and 4% after magnetizing the fluids under the effect of the same electromagnetic magnetic field strengths. Moreover, special magnetizing devices have been designed to magnetize different types of fluids in their flowing condition.

Keywords: Cutting fluid, electromagnetic field, magnetic field, machining, viscosity

1. Introduction

It is known that the molecular structure of fluids is changed by the Magnetic field. Chang and Weng said that after magnetic water treatment, in molecule clusters of water, the volume of hydrogen bonds increased [1]. The another study shows that water surface tension was degraded and viscosity coefficient escalated after the effect of magnetized water treatment. Cho and Lee studied the influence of magnetic field on water surface tension [2]. They investigated that the surface tension of magnetized water did not significantly related to the water hardness. They also found that because of the increased number of colloidal particles under the influence of the magnetic field, the surface tension of magnetized water decreased. The experiment they conducted in dye-injection, they noticed that in not magnetized water, dye drops extend along the radial direction fast; or more clearly, not magnetized water wasn't penetrated by dye, however it was always on the water surface. However, when they magnetized the water, a lot of dye drops left the surface of the magnetized water. Famous scientists Amiri and Dadkhah [3] were obtained some controversial results, they studied the difference between the surface tension of magnetized and not magnetized water. They conducted about 200 tests in six-month, and they found that there was noticeable decrease on the surface tension of magnetized water it was because of magnetic field treatment. Zhian Liu [4] investigated that the low-frequency magnetic field made by permanent magnets is an oscillating magnetic field and it emerges a strong shock wave. As a result of that low-frequency oscillating magnetic field, metabolism was delayed and microbial were died. Christian Baresel et al. found that the magnetic particles produced in their experiment worked perfectly for magnetic separation, even if extra optimizations were possible. They said that the probability to recuperate a main part of the particles scaled-up system could be good in the future [5]. Mardovov Umidjon et al. studied the influence of the stationary magnetic field on the mechanical properties of three different cutting fluids. They investigated that impact of the static magnetic field with various magnetic field strengths on boiling temperature, density and kinematic viscosity coefficient of metal cutting

fluids related to magnetic field strengths (MFS). Moreover, they found that after magnetic field effect boiling point and kinematic viscosity coefficient of fluids decreased and the density increased [6-7, 18].

On the other hand, the impact of magnetic field on fluids remains one of the controversial topics in the world. The thorough recognition of the magnetic field impact on cutting fluids has a great advantage on production, manufacturing, science, biotechnology and other various fields [8-10]. Many researchers have worked on the problem of magnetic field effect on water, however, researches on this topic is not many in the world, specially, the magnetic field influence on various cutting fluids.

2. Methods

2.1 Measuring The Dynamic Viscosity

There are a lot of types of viscometers which measures the dynamic viscosity coefficient. The Stokes viscometer's theory is based on the study of the free fall of the ball in experimented fluid.

The Stokes viscometer is usually a crystal clear cylinder filled with the studied fluid. The time Δt of the falling ball between two lines at a distance $X=\Delta l$ is measured by special timer. The material of the ball can be chosen according to laboratory condition; it can be iron or any type of steel. Taking into account a simple formula for the final velocity $v = \Delta l/\Delta t$ and paying attention to the equation [1] we finally reached an equation to find the dynamic viscosity coefficient,

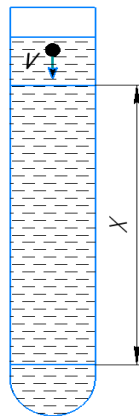$$\mu = \frac{2}{9}gr^2(\rho_{ball} - \rho)\frac{\Delta t}{\Delta l} \qquad (1)$$

Where,
g - the free fall acceleration (gravity),
r - the ball radius,
ρ_{ball} - the ball material density,
ρ - the studied fluid density,
Δt - the time of the free fall of the ball between the two marks placed at the distance Δl.


Fig. 1 - Liquid's dynamic viscosity coefficient measuring scheme, Stock's method

Ball diameter is measured with ultra-accurate electronic micrometer marked DM025. The ball fell into cylinder through the liquid (it should be focused on that the ball have to fall into close to the cylinder axis and the surface of the liquid). The timer measures the time that the ball passes through the distance X shown in the fig. 1.

Measurement of the distance *X* is defined by utilizing the typical ruler. To reach the accurate results, experiment was done using 10 balls for each cutting fluid. According to the values of g, x, ρ, ρ_{ball} and Δt, the dynamic viscosity of the experimented cutting fluids is calculated by using the equation (1).

2.2 Measuring The Kinematic Viscosity

The viscometer chosen for the experimental measurement of the kinematic viscosity is VPJ-4 and it is made of capillary glass. Nowadays, the VPJ-4 viscometer is quite popular measuring tool for fluid science. The viscometer is standardized in accordance with GOST 33-66 (Fig. 2). It can measure minimum of 0.6 mm^2/s, maximum of 10*10^3 mm^2/s kinematic viscosity. Moreover, it is portable and feasible to use. The shape of the capillary viscometer is a U-formed tube. The joint (1) is fastened with the capillary (5). A certain volume of an experimented fluid flows through the capillary and the flowing time determination is basics measuring kinematic viscosity with the viscometer.
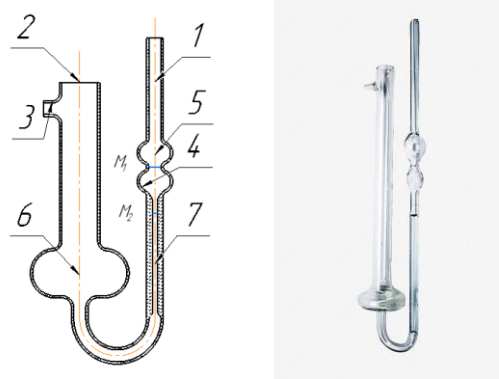
Fig. 2 - The VPJ-4 capillary viscometer. 1, 2 - the viscometer bends; 3- release pipe; 4- a lower storage; 5 - an upper storage; 6 - bottom storage; 7- capillary; M_1 and M_2 - label marks

To define the liquid flowing time to the release pipe (3), put on a rubber tube related to a rubber bulb is inserted. Then, keeping the viscometer bend (2), the viscometer is growing to become over and the second bend (1) is immersed into a container with experimented fluid. The fluid is pressured to the M_1 mark (through the release pipe), at the same time there should not be as air bubbles in the liquid. When the liquid reaches the M_1 mark, the tool is eliminated from the reservoir and grew to become over fast to its authentic position. After that, the fluid is extracted from the bend (1), the rubber tube is disposes from the bend (2). Following this, the rubber tube is put on the bend (1). Then, the liquid is absorbed into the bend to the level of 1/3 of an upper storage (5). After all, the rubber tube is taken off and the time is measured with a timer for the meniscus degree to flow from the M_1 mark to the M_2 mark.

The capillary diameter is 3.55 mm and the following equation [GOST 33-66] is used to calculate the kinematic viscosity of the experimented fluid,

$$V = \frac{g}{9.807} \times T \times K \qquad (2)$$

Where,
K -The viscometer constant (9.224 mm^2/s^2, GOST 33-66);
V - Fluid Kinematic viscosity in mm^2/s;
T - Measured flowing time of the fluid in second.

3. Experimental Design

In the experiments three various type of cutting fluids has been used and the first of them is typical water (liquid-1) used in Tashkent city (Uzbekistan) and it is provided from the local water supply company in Uzbekistan (JSC SuvSoz). Other two cutting fluids (liquid-2 and liquid-3) were provided by a manufacturing enterprise (Meridian-A, Tashkent). The fluids chosen for the experiment have been utilized as a cutting fluids in the weighted parts manufacturing factory "Meridian-A". The second liquid (liquid-2) is 2 % concentration of $K_2Cr_2O_7$ in typical tap water. To conduct the experiment m=50 gram of $K_2Cr_2O_7$ powder has been dissolved in m_0=25 kg of tap water. This type of cutting fluid (the same concentration) is popular in mechanical processing of not hard alloys in turning and boring machines in the enterprise. The third cutting fluid (liquid-3) is also the one of the widely used cooler in Uzbekistan and it is mainly used in machining carbon steels and hard alloy part. This cutting fluids (liquid-3) is a 5% concentration of BM-76M on typical tap water.

UMD-1 magnetizing device was developed to provide a permanent magnetic field for magnetizing flowing liquids, there are eight ceramic magnets with the size of 120 mm in length, 80 mm in width, and 16 mm in height. Maximum MFS of the magnets that have those characteristics are 100 mT. By the help of UMD-1 magnetizing device, we can take up to 40 mT of MFS. The construction of the magnetizing setup UMD-1 is given in Fig. 3.
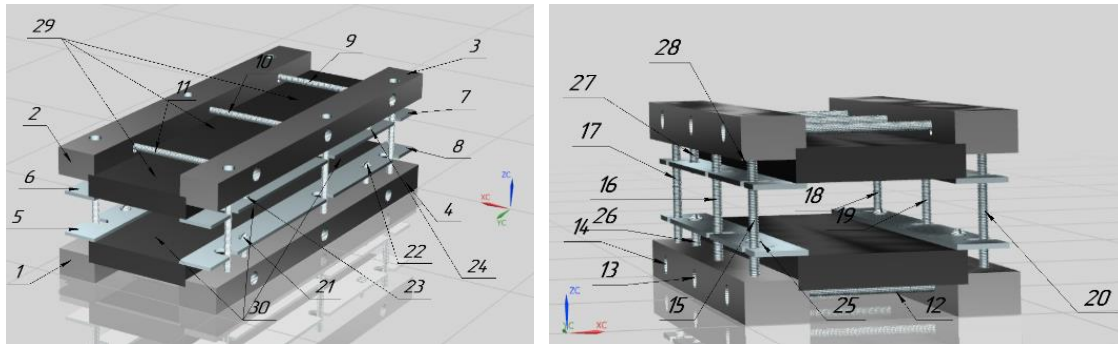
Fig. 3 - UMD-1 magnetizing setup details. 1, 2, 3, 4 - Supports, 5, 6, 7, 8 - holders, 9-20 - Vertical hexagon bolts, 21-28 - Screws, 29-30 - Static magnets

It can be seen from the Fig. 3 that, ceramic magnets (29, 30) are stand on base (1, 4) and top (2, 3) supports by opposite poles. Paying attention to width of the ceramic magnets long horizontal hexagon bolts (9-14) are settled, and holders (5-8) are fixed to attach the ceramic magnets tough with the aid of screw (21-28). In the experiment, it is very important to adjust the length between ceramic magnets. To provide that adjustment, holders and supports are developed on the UMD-1 setup construction. Base and top supports have the equal shape and sizes, and the space among them can be modified without problems with the aid of vertical hexagon bolts (15-20). Converting the space among the base and top supports is designed to alternate the space among the ceramic magnets located on base and top supports. Because of this design, it is very easy to alternate the static magnetic field strength through adjusting the space among lower and higher magnets. Furthermore, the magnetizing setup design is developed to hold the magnets with different length, that is the space among the supports can be adjusted horizontally in line taking into account the length of the magnets. The construction of the the magnetizing tool is generic due to the fact it is feasible to hold magnets with various sizes. The tool is designed to fix the magnets that have size from 20x10x5 (mm) to 300x80x30 mm. The gap between the upper and lower magnets can be modified from zero to 50 mm and it is also related to the sizes of the magnets located on the supports. Moreover, the the magnetizing tool could be very transportable and it is very feasible to exchange its function on metal cutting process.

The Polyvinyl chloride pipe is places between the top and bottom magnets, and the diameter of the pipe is 10 mm. In the experiment, the magnetic field with the length of 480 mm has been made and the pipe passed through the magnetic fields. A fluid flow through the pipe (Polyvinyl chloride) turned into magnetized fluid. All of the fluids flowed at 0.4 m/s of flowing speed for 60 minutes through the magnetizing setup UMD-1. Fig. 4 shows the setup details of the fluid magnetizing process.
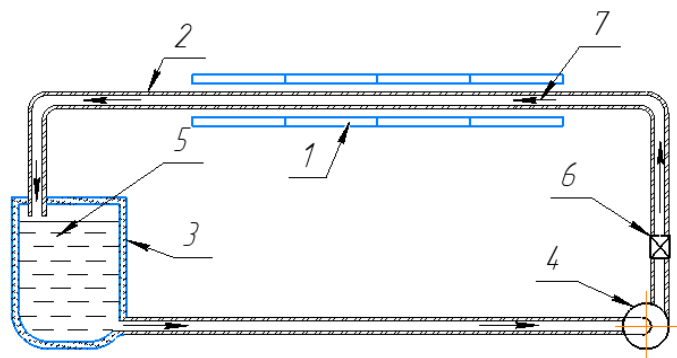
Fig. 4 - 1 - Magnetizing setup with static magnetic field (UMD-1), 2 - Polyvinyl chloride pipe, 3 - Storage, 4 - Pump, 5 - Cutting fluid, 6 - Speed controller, 7 - Fluid movement direction

In the experiment, to provide the pulsating electromagnetic field to magnetize the sample cutting fluids, the special SMD-2 magnetizing laboratory setup tool designed and developed (Fig. 5).
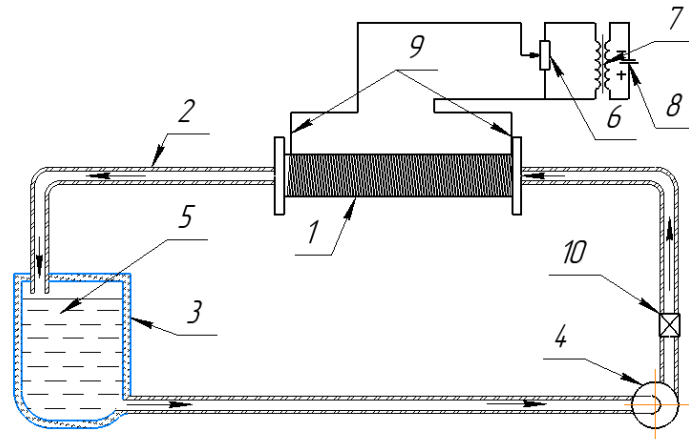
Fig. 5 - Magnetizing setup with electromagnetic field. 1-Solenoid (SMD-2), 2- Polyvinyl chloride pipe, 3- Storage, 4-Pump, 5-Cutting fluid, 6-Rheostat, 7-Transformer, 8-Electric power, 9- Pulsated signal, 10- Speed controller

The experimented cutting fluid (5) is stored in the container (3), eight liters of cutting fluid samples have been used in each experiments. Then, the cutting fluid in the storage can flow through polyvinyl chloride pipe the form the storage, and the pump (4) is used to provide flowing cycle to the cutting fluids that is experimented. The cutting fluid flowing through the polyvinyl chloride tube is follows the course (shown in fig. 5) flows through the middle of solenoid (1) that has the diameter of 18.5 mm and is poured again into the storage. The cutting fluid flowing through the polyvinyl chloride passes from the middle of the solenoid, that is creating a pulsating electromagnetic field. After passing through the electromagnetic field, it becomes a magnetized cutting fluid and is poured again into the storage.

The flowing speed of the cutting fluid is managed through speed controller (10) and the specified flowing speed of the experimented fluid is obtained. Providing the cycle for about one hours (it is calculated for experimented eight liters of fluid in the container) the cutting fluid within the storage will become a completely magnetized and the viscosity coefficient of the sample cutting fluid can be measured. The solenoid created for the experiment was made by way of wrapping an insulated copper wire on in a plasma coil with a radius of 25 mm, and the diameter of the wire is d=1.06 mm. The quantity of turns of wires on it was n=2100. The voltage (U=220 V) from the source (8) is passes through the transformer (7) and managed through a rheostat (6) that allows you to flip to a regulated pulsating voltage (9). The pulsating voltage from the diode bridge is transmitted to the solenoid and an electromagnetic field is generated. The volume of the electric power is managed the use of a rheostat and it can be settled to the favored voltage.

3.1 Laboratory Condition in The Experiments

In order to provide the reliability of the experimental results, all experiments were carried out under the same laboratory conditions. While conducting the experiment, the MFS, magnetic field type, and cutting fluid speed were regarded as the most affecting aspects that affect the changes caused by the magnetic and electromagnetic fields [11, 12]. Hence, the experiments on the effect of two types of magnetic fields is conducted in the similar laboratory situation. The laboratory was 440 meters high above sea level and atmospheric pressure was P= 770 mmHg when all of the experiments were conducted. The PVC pipe which diameter was d= 10 mm was used for passing fluids through an electromagnetic and static magnetic fields. The flowing velocity of the liquids was v= 0.4 m/s while the experiment was conducting. The specification of the laboratory situation is given in table 1.

Table 1 - Details of the laboratory condition during the experimentation time

|	
Atmospheric pressure	770 mmHg
Humidity	16%
Diameter of the pipe	10 mm
Height above sea level	440 m
Magnetization duration	60 min
Flowing speed of the fluid	0.4 m/s
Room temperature	27 ^{0}C

4. Results and Discussions

For studying the impact of the static magnetic and pulsated electromagnetic fields on the dynamic and kinematic viscosity coefficient of fluid, we magnetized three various cutting fluids in flowing conditions in 60 minutes. We used 8 ceramic magnets (magnetic field strength is 100 mT) for making a stationary magnetic field. In the experiment, it is

studied the effect of three different magnetic/electromagnetic field strengths such as 40 mT, 60 mT and 80 mT. The electromagnetic treatment equipment is prototype equipment of 12-layer solenoid coils. Each of the layer contains 175 turns-off wires with, and the wire thickness is 1.06 mm. The internal diameter of the pipe of the equipment is d=18.5 mm and the external diameter is D=25 mm with 6.5 mm of wall thickness. The length of the solenoid coil is 200 mm (Fig. 5). The core of the device is made of ceramic material. The device was fixed to produce maximum 80 mT 50 V/8A with a power consumption of 400 watts/h.
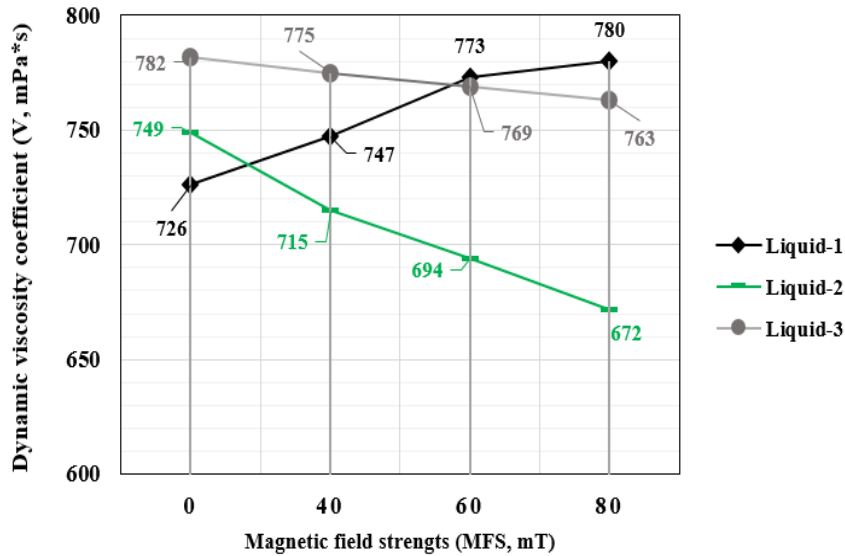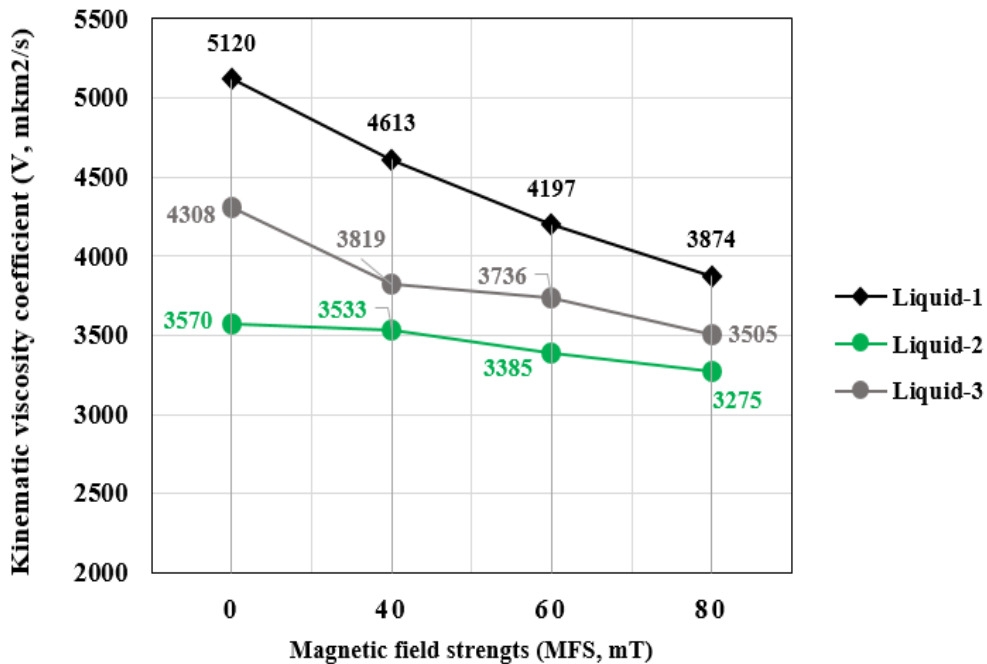

(a)
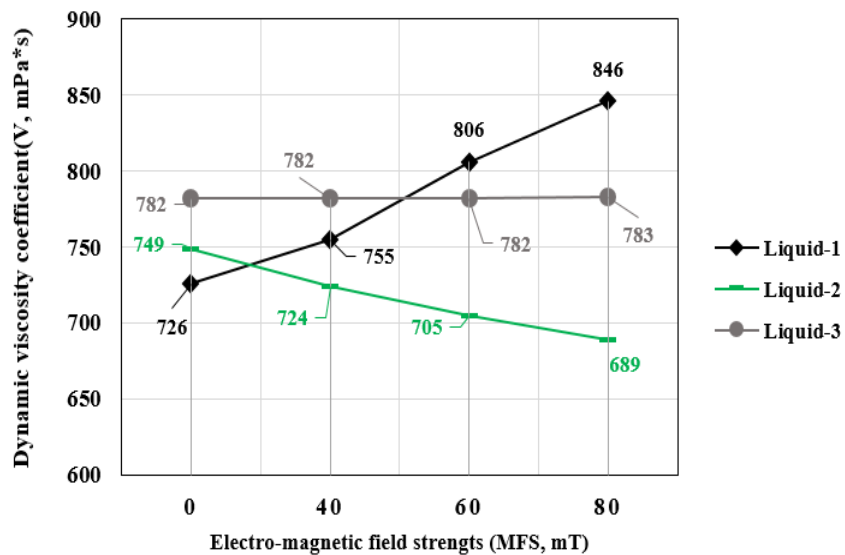
(b)

Fig. 6 - Influence of the stationary magnetic field (a) and electromagnetic field; (b) on the dynamic viscosity of fluids in different magnetic field strengths

Line graphs given on the Fig. 6 (a) and (b) show the diversity among the influence of the magnetic and pulsed electromagnetic fields on the dynamic viscosity coefficient of experimented cutting fluids. The experiment, which was conducted in liquid-1 shows that a pulsed electromagnetic field affects it more than a stationary magnetic field.

Table 2 - Dynamic viscosity coefficient of the experimented liquids under the effect of static and electromagnetic fields

Liquid type	Magnetic field type	Magnetic/electromagnetic field strength, mT			
		0	40	60	80
Liquid-1 (Tap water)	Effected by static magnetic field	726	747	773	780
	Effected by electromagnetic field	726	755	806	846
Liquid-2 (2% concentration of $K_2Cr_2O_7$ powder in water)	Effected by static magnetic field	749	715	769	763
	Effected by electromagnetic field	749	724	705	689
Liquid-3 (5% concentration of BM-76M synthetic oil in water)	Effected by static magnetic field	782	775	769	763
	Effected by electromagnetic field	782	782	782	783

It is clear from the results given in the table 2, when the liquid-1 (tap water) was affected by the same magnetic and electromagnetic field strengths (80 mT) the dynamic viscosity coefficient was 780 mPa*s and 846 mPa*s respectively. The viscosity coefficient of not magnetized liquid-1 was 726 mPa*s and after the impact of the electromagnetic field, it was increased by 14% while the stationary magnetic field caused 7% of increase on the viscosity coefficient of liquid-1. The interesting results was observed when magnetic and electromagnetic fields caused a decline on the dynamic viscosity of other two sample cutting fluids. While the natural dynamic viscosity coefficient of liquid-2 was 749 mPa*s, it dropped at 672 mPa*s after the effect of the permanent magnetic field (80mT) and dropped at 689 mPa*s under the effect of the pulsed electromagnetic field (80mT). The experiment conducted on liquid-3 also showed the almost same percentage of decrease on the dynamic viscosity coefficient under the impact of various MFS. Such as, the dynamic viscosity of liquid-3 was declined from 782 mPa*s to 763 mPa*s as a result of the static magnetic field effect. However, the electromagnetic field which had the same strength with static magnetic field caused a nearly change on the viscosity coefficient of liquid-3.

(a)

(b)
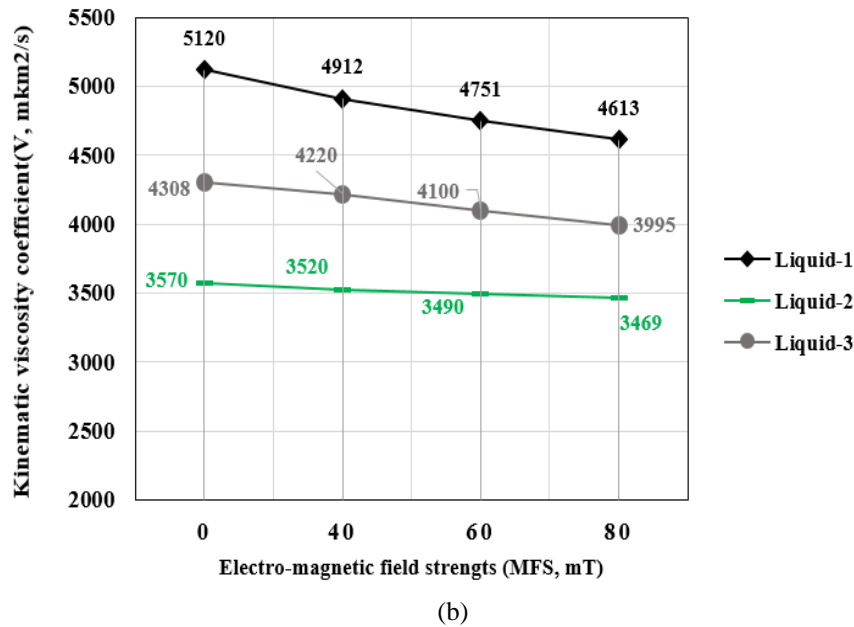
Fig. 7 - Influence of the stationary magnetic field (a) and electromagnetic field; (b) on the kinematic viscosity coefficient of fluids in different magnetic field strengths

The distinction among the influence of magnetic and pulsed electromagnetic fields on the kinematic viscosity coefficient of experimented metal cutting fluids was also found in the experiment. Fig. 7(a) and Fig. 7(b) show that the magnetic field can cause to the decrease (15%) on the kinematic viscosity coefficient of liquid-1 from $5120*10^{-3}$ mm^2/s to $3840*10^{-3}$ mm^2/s when the magnetic field strength was changed from 0mT to 80mT. However, under 60 minutes of the effect of the electromagnetic field (80mT), it was dropped (10%) until $4613*10^{-3}$ mm^2/s. Kinematic viscosity coefficient was also decreased in liquid-2 in the same order as it was in liquid-1. The kinematic viscosity coefficient of liquid-2 was $3570*10^{-3}$ mm^2/s, but it decreased until $3275*10^{-3}$ mm^2/s after 80mT of magnetic treatment. However, the influence of the electromagnetic field (80mT) causes three percent of decrease (until $3469*10^{-3}$ mm^2/s) in kinematic viscosity coefficient. While the results reached from the liquid-3 have different numbers but the order is the same as other differences. Clearly, the kinematic viscosity of liquid-3 was decreased from $4308*10^{-3}$ mm^2/s to $3505*10^{-3}$ mm^2/s after magnetic treatment (80mT), while it dropped until $3995*10^{-3}$ mm^2/s under the effect of a pulsed electromagnetic field with the same strength (Table 3).

Table 3 - Kinematic viscosity coefficient of the experimented liquids under the effect of static and electromagnetic fields

Liquid type	Magnetic field type	Magnetic/electromagnetic field strength, mT			
		0	40	60	80
Liquid-1 (Tap water)	Affected by static magnetic field	5120	4613	4197	3874
	Affected by electromagnetic field	5120	4912	4751	4613
Liquid-2 (2% concentration of K$_2$Cr$_2$O$_7$ powder in water)	Affected by static magnetic field	3570	3533	3385	3275
	Affected by electromagnetic field	3570	3520	3490	3469
Liquid-3 (5% concentration of BM-76M synthetic oil in water)	Affected by static magnetic field	4308	3819	3736	3505
	Affected by electromagnetic field	4308	4220	4100	3995

Our experimental results show that there is a diversity between the effect of magnetic and pulsed electromagnetic fields on the dynamic and kinematic viscosity coefficient of cutting fluids including water. Moreover, it was investigated that the impact of magnetic and electromagnetic fields on the dynamic viscosity coefficient of fluids depends on the content of fluids. Because of the results obtained from the experiment, liquids with a various content were influenced differently by the same magnetic and electromagnetic field strength. The results obtained from the

experiment show that the pulsed electromagnetic field affects the dynamic viscosity coefficient more than a stationary magnetic field. However, the magnetization effect on dissolved liquids (liquid-2 and liquid-3) is more in the stationary magnetic field than a pulsed electromagnetic field. Measurement of the kinematic viscosity coefficient of fluids also proves that a stationary magnetic field causes more changes in the physical characteristics of the experimented cutting fluids than a pulsed electromagnetic field. Furthermore, one noticeable point is that the MFS, magnetizing situation, and fluid flowing speed were the most affecting characteristics in the experiment that affected the changes caused by the magnetic and electromagnetic field [11, 12].

However, the method of magnetic field treatment is unclear, some researchers have done it to understand and clarify it. The theory was suggested by the authors wat that the hydrogen bonds among water molecules were likely affected by the magnetic field [13-18]. But still, there is not comprehensive information about the influence of magnetic field treatment of fluids.

5. Conclusion

According on the results obtained from the experiment in this manuscript, the following conclusions can be drawn.

A stationary magnetic field by the ceramic magnets affects the dynamic and kinematic viscosity of experimented cutting fluids more than a pulsed electromagnetic field. Nonetheless, the effect of a pulsed electromagnetic field on the viscosity coefficient of sample cutting fluids is higher than the impact of a static magnetic field when the cutting fluid has fewer dissolved solids.

The effect of the magnetic/electromagnetic fields on cutting fluids depends on dissolved elements in the fluids. In the experiment, dissolved cutting fluids such as second and third fluids have less change on the dynamic and kinematic viscosity than typical tap water (liquid-1) after static magnetic and pulsed electromagnetic field treatment.

Acknowledgement

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