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Performance Evaluation of Selected Animal and Vegetable Oil Based Cutting Fluids in Mild Steel Turning Operation

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Abstract

Mineral-based oils conventionally used as base oils in cutting fluids for mild steel turning operations are non-biodegradable and hazardous to human health. Alternative cutting fluids that will not present these difficulties needs to be developed. This study's goal was to assess how well cutting fluids made from vegetable and animal oils performed during mild steel turning operations. The sample fluids used were groundnut oil cutting fluid (GCF), palm kernel cutting fluid (PKCF), lard cutting fluid (LCF), tallow cutting fluid (TCF) and palm oil cutting fluid (POCF), while mineral oil-based cutting fluid (MCF) served as the control fluid. Different cutting speeds (34.88, 46.82, 62.84, 84.21) m/min; feed rates (0.20, 0.25, 0.30, 0.35) mm/rev and depths of cut (0.50, 1.00, 1.50, 2.00) mm were used in the turning operation. The parameters investigated were tool flank wear (T_w), spindle power (P), machine vibration (V_m), noise (N_m), work piece surface roughness (R_a), and tool temperatures (T). From the results, MCF recorded average values of 0.21mm, 613.75W, 0.52 m/s^2, 69.38dB, 1.14µm and 48.70^{o}C for T_w, P , V_m, N_m, R_a and T respectively, while the best performed sample fluid, LCF, recorded average values of 0.22mm, 602.50W, 0.52 m/s^2, 69.40dB, 0.45µm and 48.90^{o}C respectively. POCF was the least performed sample fluid, with average values of 0.28mm, 905.00W, 0.72 m/s^2, 71.58dB, 1.62µm and 53.55^{o}C for the above parameters, respectively. LCF recorded the closest values to MCF and this was followed by GCF, TCF, PKCF and POCF in that order respectively. The study showed that the investigated fluids offered competitive performance to that of MCF, hence, can serve as possible replacement for them.

Key words: Machining, animal fats, vegetable oils, cutting fluids, work piece.

1.0 INTRODUCTION

Studies have shown that neither pure mineral oil nor pure vegetable oil possess all the qualities needed by modern machining processes; as a result, some sort of mixture is required. This prompted the creation of numerous cutting fluids that made use of numerous soluble mineral oils (Adegbuyi *et al.* 2010; Anyanwu *et al*. 2020). Cutting fluids can be made up of pure oil, a blend of two or more oils, or an oil and water mixture (Adejuyigbe and Ayodeji, 2000). Mineral oils are derived from crude petroleum products and have a fossil fuel base. The most typical kind is soluble oil, which when combined with water yields the "slurry"—a white solution. This has effective lubricating and cooling properties. It typically has a mineral oil-soap solution mixture for the oily portion (Akpobi and Enabulele, 2002). Heat is produced during machining operations, and this has negative effects on the surface finish of the work piece, tool life, dimensional accuracy, and production rate. In order to achieve cooling, cooling and lubrication, lubrication alone, or to reduce chip adhesion to the work piece or tool, cutting fluids are therefore applied during machining operations. Any machining operation's purpose for using a lubricant depends on which of the listed functions is selected (Avila and Abrao, 2001).

Due to their suitable lubricating properties on both the work piece and the cutting tools, mineral oils have traditionally been used as the traditional source of cutting fluids in the machining of a variety of metals and alloys (DeGarmo, Black and Kosher, 1984). However, using such oils as lubricants or coolants in recent machining operations comes with a number of difficulties. These difficulties include, but are not limited to, the rising environmental worries about biodegradability and renewability (Khan, Mithu and Dhar, 2009). It is also of note that, prolonged exposure to or contact with mineral-based cutting fluids can lead to health problems like skin irritation (Anyanwu *et al.* 2020). Animal and vegetable oil-based cutting fluids are environmentally friendly, and there is no health risks associated with exposure to them. Additionally, recent studies have demonstrated that they have better lubricities than fluids based on mineral oil (Lawal, Choudhury and Nukman, 2011).

Numerous studies have been done to find out how cutting fluids made from vegetable oil affect the machining process. Kuram *et al.* (2010) investigated the effectiveness of cutting fluids made from four vegetable oils (olive oil, groundnut oil, palm oil, and palm kernel oil) in turning mild steel under various cutting conditions and contrasted it with dry cutting. They claimed that when assessing the effectiveness of the cutting fluid made from each of the vegetable oils, temperature was taken into account. Furthermore, Krishna *et al.* (2010) used three different vegetable-based cutting fluids made from raw and refined sunflower oil to study the impact of cutting fluid types and cutting parameters on surface roughness and thrust force. Similarly, Khan, Mithu and Dhar (2009) investigated the impact of minimal lubrication with cutting fluids based on vegetable oil when using uncoated carbide tools to turn AISI 9310 low alloy steel. Both studies reported success stories on the potency of vegetable oils when employed as cutting fluids. Again, Sreejith and Ngoi (2000) investigated the effectiveness of groundnut and palm oil-based cutting fluids in mild steel machining under various machining conditions. The performance parameters that were examined in their study included chip formation rates as well as work piece temperature. The study reported increased tool life as a result of the cutting fluids employed. Although, these studies investigated the performance of some vegetable oils as cutting fluids, none of them studied the possibility of using animal oils as cutting fluids. Also, the performance characteristics (parameters) investigated in terms of machining trials in each study was also limited.

The current study investigates the potentials of some of the commercially available vegetable and animal oils, locally formulated into cutting fluids, as possible replacement for conventional soluble mineral oils. While mild steel was being turned, the oils' performance was assessed. Machine noise, vibration, spindle power consumption, tool temperatures, as well as chip formation, were the performance characteristics (parameters) that were taken into consideration. This was done under various cutting circumstances. Mild steel was chosen as the work piece due to its low cost, availability, and extensive use in the Nigerian economy's manufacturing and production sectors.

2.0 METHODOLOGY

2.1 Cutting Fluid Formulation

The lard (from pigs) and tallow (from cows) were cleaned, cut into pieces, and then steam-cooked in a pot without water for about 20 minutes. Through this procedure, the oil was taken out of both animals' fatty tissues. The oily content was then sieved out and given about 4 minutes to cool. The vegetable and animal oils were subsequently formulated into cutting fluids (see Table 1) in accordance with the recommendations by Anyanwu *et al.* (2020) and Bartz (2001).

Table 1: Cutting Fluid Emulsion Formulation

S/N	Material	Function	Content: %vol / vol of fixed oil
1	Fixed Oil (Sample fluids)	Base Oil	80
2	Emulsifying agents	Emulsification	10
3	Phenolphthalein solution (phenol)	Disinfectant, also removes odor.	5
4	Sulphur	Extreme pressure agent improves oxidative stability during usage at high temperature.	5

2.2 Work-piece Composition

This was determined via an Energy Dispersive Spectroscopy coupled on a TESCAN Scanning Electron Microscope.

2.3 Performance Evaluation of the Formulated Cutting Fluids (Machining Trials)

The machining operation involved was turning (Figure 1 shows the experimental setup). The operation was done on a Lathe machine (Colchester 1800, rated 3HP, 415V, driven by a 3-phase motor). The cutting tool employed was carbide cutting tool held on a tool holder designated DIN 4980R 20X20 and the mode of cutting fluid application was by direct flood method. The cutting conditions were varied increasingly at every level of cut. The values used are cutting speeds, v = 34.88, 46.82, 62.84 and 84.21 m/mins respectively; feed rates, $\dot{f}$ = 0.20, 0.25, 0.30, and 0.35 mm/rev respectively; depth of cuts, d = 0.50, 1.00, 1.50 and 2.00 mm respectively.

Following the different cutting parameters employed, the performance characteristics investigated include:

i. Flank Tool Wear, T_w: This was measured using a 20X magnifying lens after each cutting conditions.
ii. Spindle power consumption, *P*: This was determined via a logit voltage-current data logger, connected to the machine. For every cutting condition, a mean value of voltage, V and current, I, was taken. The power, *P*, was then computed using equation 1 (Kuram *etal.* 2010) which is the power drawn by a machine tool using 3-phase motor.

$$P = IV\sqrt{3} \tag{1}$$

iii. Machine Noise, N_m: This was determined by a noise recording and analysis software application (cool edit pro). The application was first loaded in a laptop computer and configured to a sample rate of 96000; stereo channeled and a 32 bit (float) resolution. The laptop was placed about 1.2 meters away from the machine.
iv. Machine Vibration, V_m: This was determined by a vibration meter (lutron vibration meter VB8206SD). The vibration meter probe was placed beside the machine’s headstock, very close to the spindle. The reading was taken in terms of acceleration.

v. Work piece surface roughness, *Ra*: The workpiece average surface roughness at a particular cutting condition (84.21 m/mins. 0.35 mm/rev, 2.00 mm) was determined using a Veeco 150 surface profile meter.

vi. Tool Temperatures (T): These were measured directly with a PeakTech Infra-red thermometer. It was achieved by pointing the thermometer's probe at the surface of the tool, as the machining time elapses.

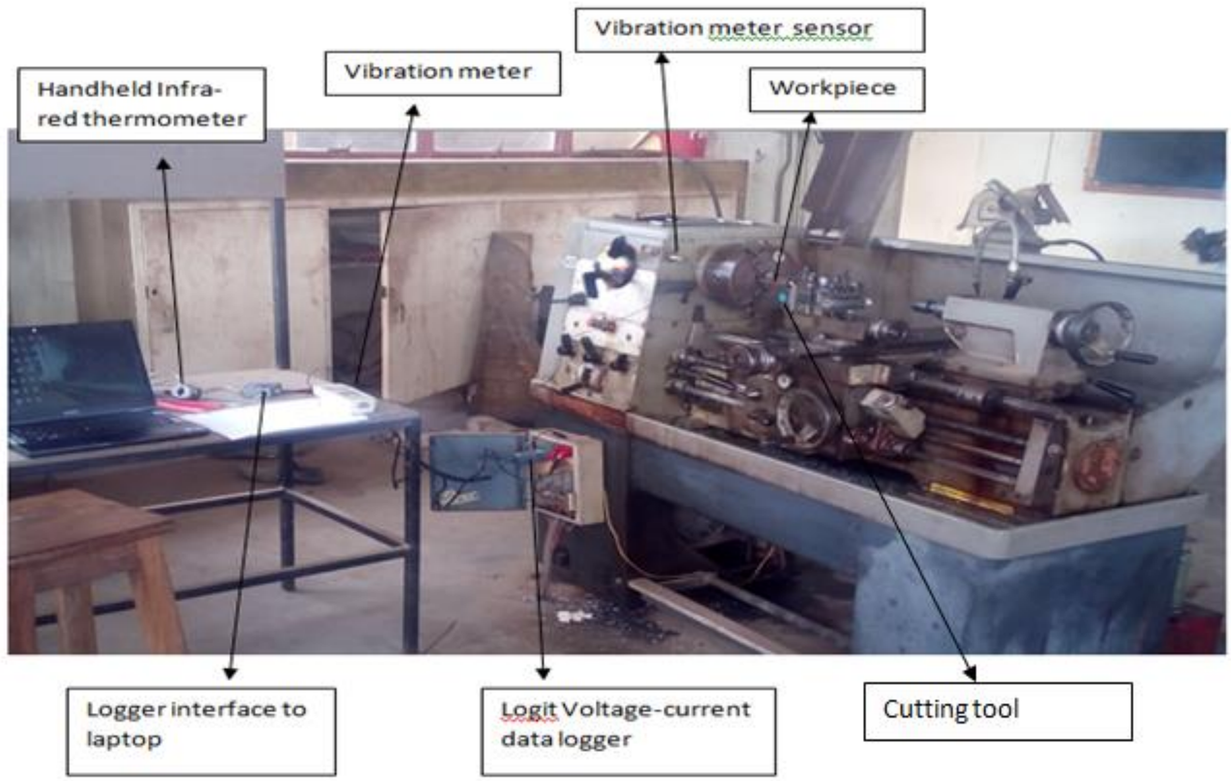

Figure 1: Experimental Setup

3.0 RESULTS AND DISCUSSIONS

Figure 2 shows the SEM/EDS spectra of the as received mild steel sample. It is seen that the carbon content (0.26%) falls within the acceptable values for low carbon steel steels.

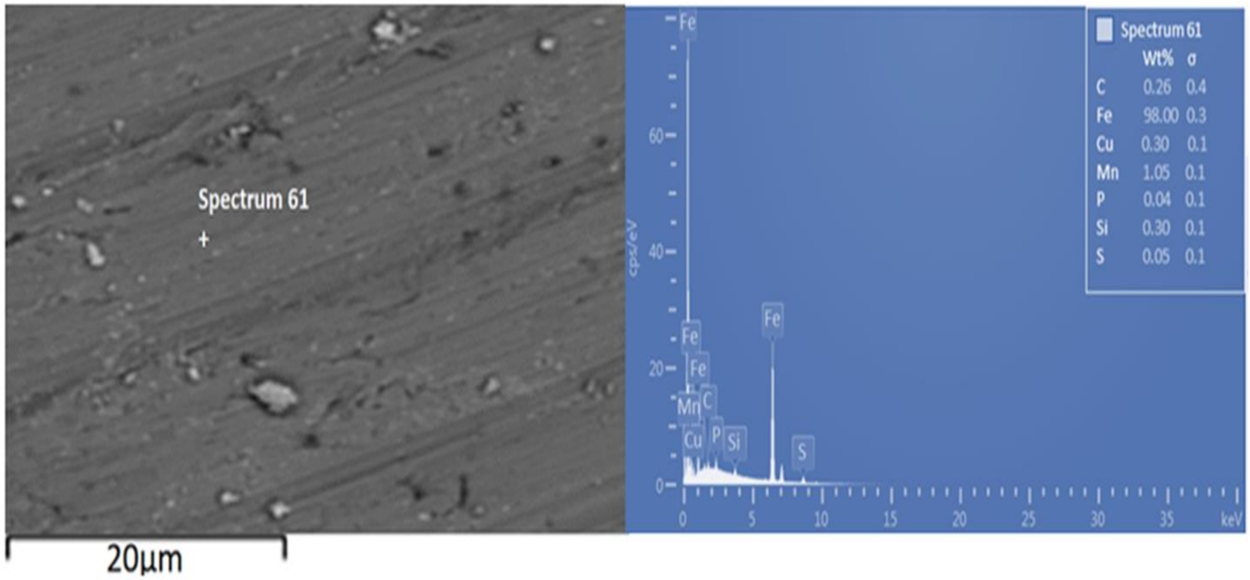

Figure 2: SEM / EDS Spectra of the as received mild steel sample

The results for the performance evaluation are presented side by side the control fluid (MCF) in order to know which sample fluid best compares well with it.
The results for variation of tool wear (flank) for all sample and control fluids at different cutting conditions are presented on Figure 3. It is seen that as the cutting conditions increases for every level of cut, the tool flank wear also increases. This may be as a result of increase in cutting stress on the tool surface and the trend is in agreement with what Sharif *et al*. (2009) reported. The entire sample fluids recorded flank wear values close to that of the control fluid (MCF) with an average tool flank wear value of 0.21mm. LCF recorded an average tool flank wear value of 0.22mm making it the closest among the sample fluids in terms of tool wear performance, when compared to the control cutting fluid (MCF). This was followed by GCF (0.24mm) and TCF (0.26mm) respectively. POCF and PKCF recorded equivalent average tool flank wear values of 0.28mm each, making them the least performed with respect to the stated performance parameter.

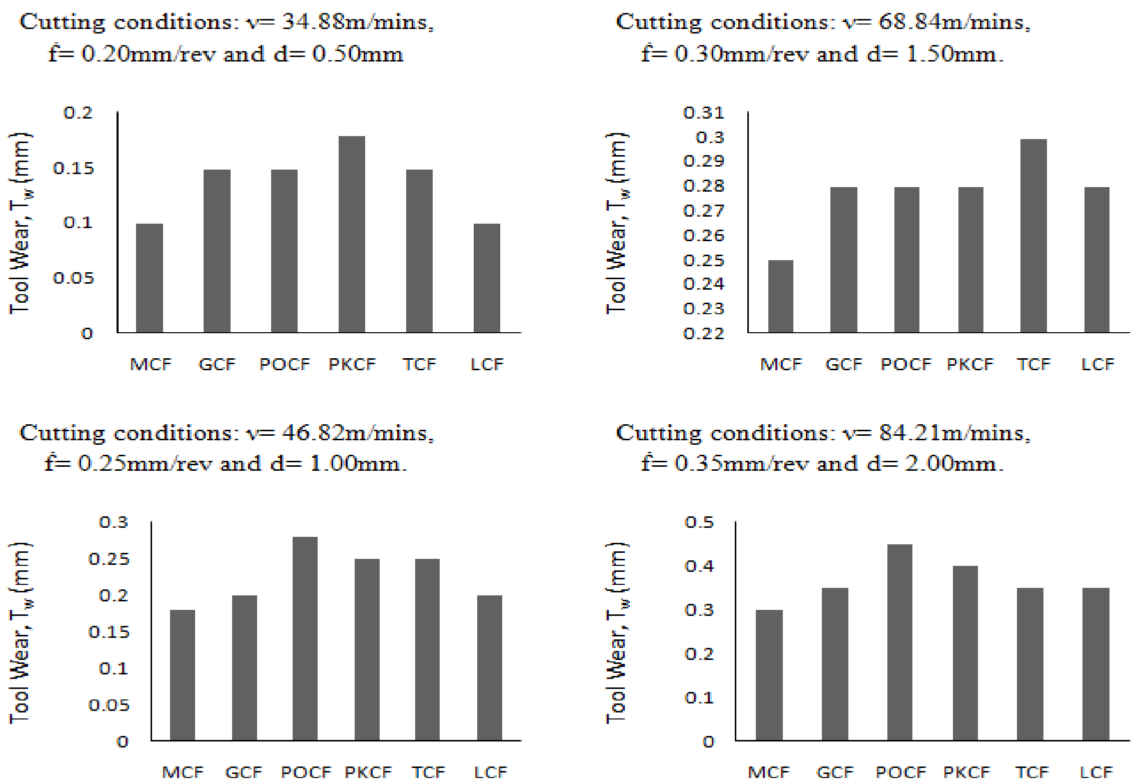

Figure 3: Variation of tool wear (flank) for all sample fluids at different cutting conditions

Similarly, results for the variation of spindle power consumption for all sample and control fluids at different cutting conditions are presented on Figure 4. It is seen that, as the cutting conditions increases, the spindle power consumption also increases. This may be as a result of increased cutting stress exerted on the machine during the turning operation. The trend however is in agreement with what Bartz (2001) reported. The average spindle power values obtained by some of the sample fluids are close to that recorded by the control fluid (MCF). The control fluid recorded an average spindle power of 613.75W for all cutting conditions stated. However, LCF recorded the minimum average spindle power of 602.50W for the conditions stated, making it the best performed with respect to the given performance parameter. GCF, TCF and PKCF recorded average spindle power values of 727.50W, 772.5W and 925.00W respectively for the stated cutting conditions. The maximum average spindle power value of 1030.00W was recorded by POCF making it the least performed sample fluids with regards to the performance parameter stated.

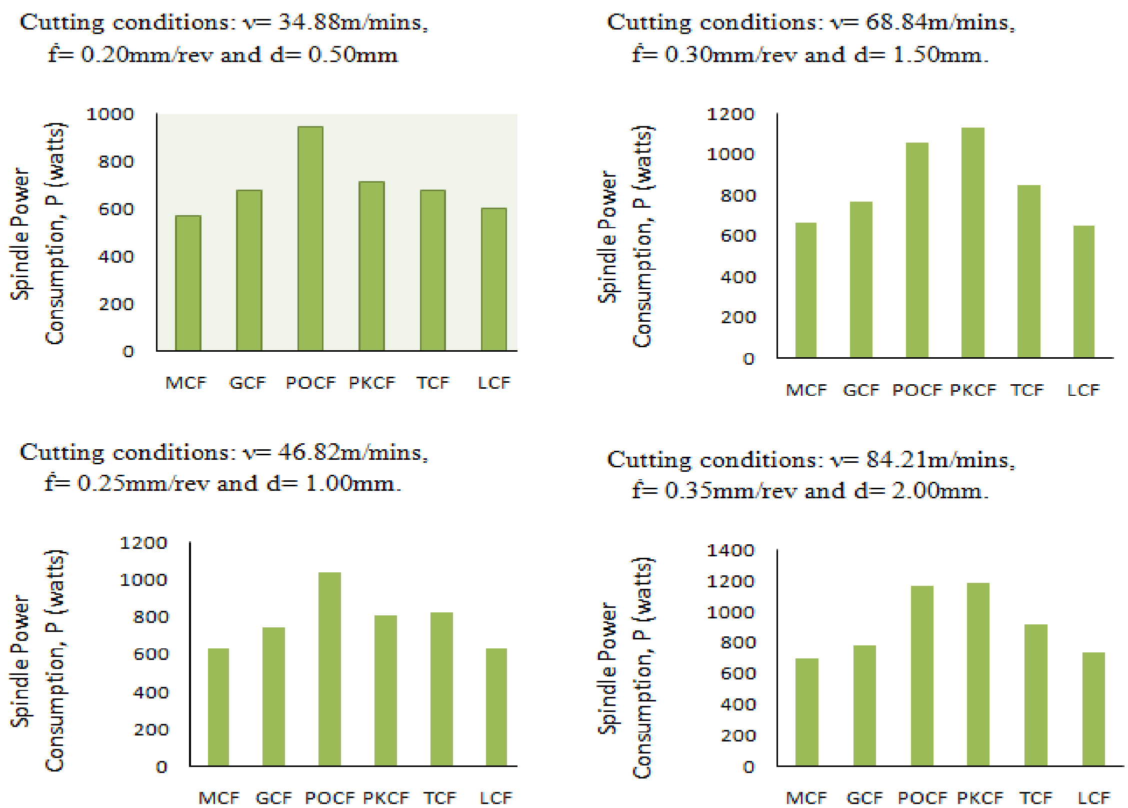

Figure 4: Variation of spindle power consumption for all sample fluids at different cutting

The variation of machine vibration for all sample and control cutting fluids at different cutting conditions is shown on Figure 5. A look at it shows that as the cutting conditions increases for every level of cut, the machine vibration also increases. This may not be unconnected to the increase in spindle power consumed during the turning operation process (Kuram *et al.* 2010). Again, the average values recorded by the sample fluids are close to those obtained by the control fluid at all cutting conditions stated. The minimum average machine vibration values with respect to the stated cutting conditions was 0.52 m/s^2 obtained by MCF. When compared to the sample fluids, LCF gave an equivalent value of 0.52 m/s^2, making it the best performed with respect to the given parameter. This was followed by GCF maintaining a value of 0.58 m/s^2. POCF, however, gave the maximum average value of 0.72 m/s^2 with making it the least performed in this regard.

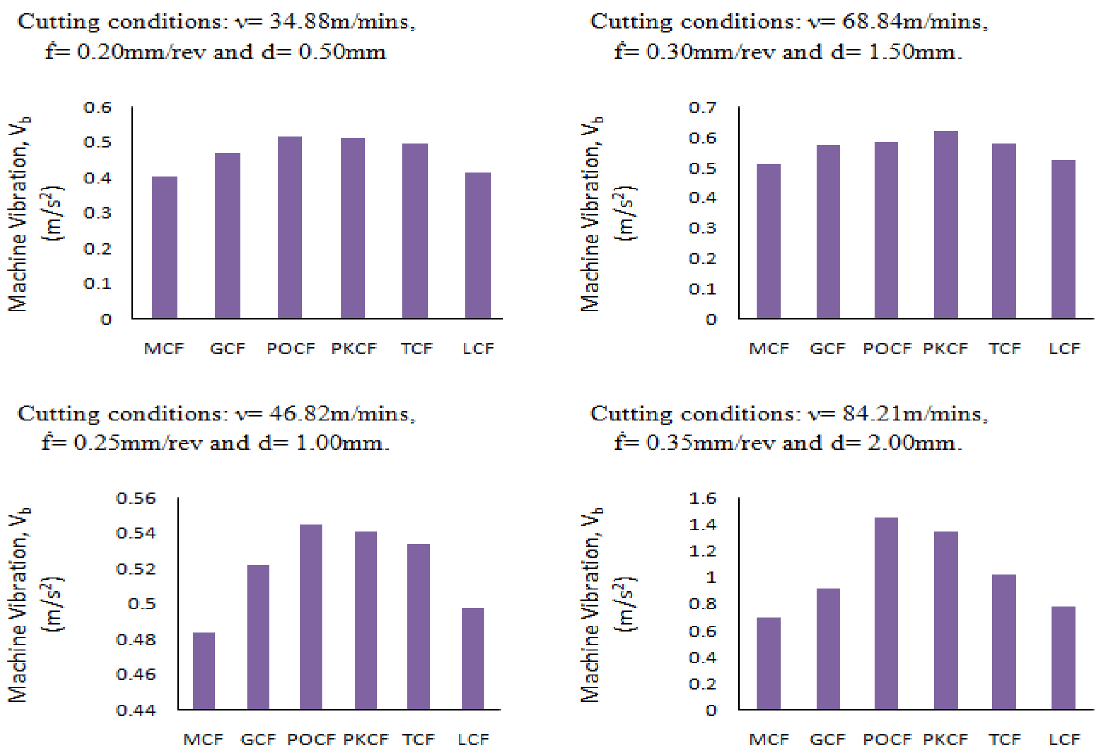

Figure 5: Variation of machine vibration for all sample fluids at different cutting

Figure 6 presents the variation of machine noise for all sample and control fluids at different cutting conditions. it is seen that as the cutting conditions increases for every level of cut, the machine noise also increases. The values obtained by all the sample fluids were close to those recorded by the control fluid (MCF). The values also fall within the recommended machine noise value of 85dB, prescribed for 8 hours per day work for unprotected ear, by the National Institute for Occupational Safety and Health (NIOSH), USA. The least average machine noise value of 69.30 dB was recorded by MCF. Among the sample fluids, LCF recorded the least average value of 69.40 dB. GCF, TCF and PKCF recorded average noise values of 70.60 dB, 71.22 dB and 71.58 dB respectively. POCF, however, gave the maximum value of 71.60 dB with respect to the stated cutting conditions.

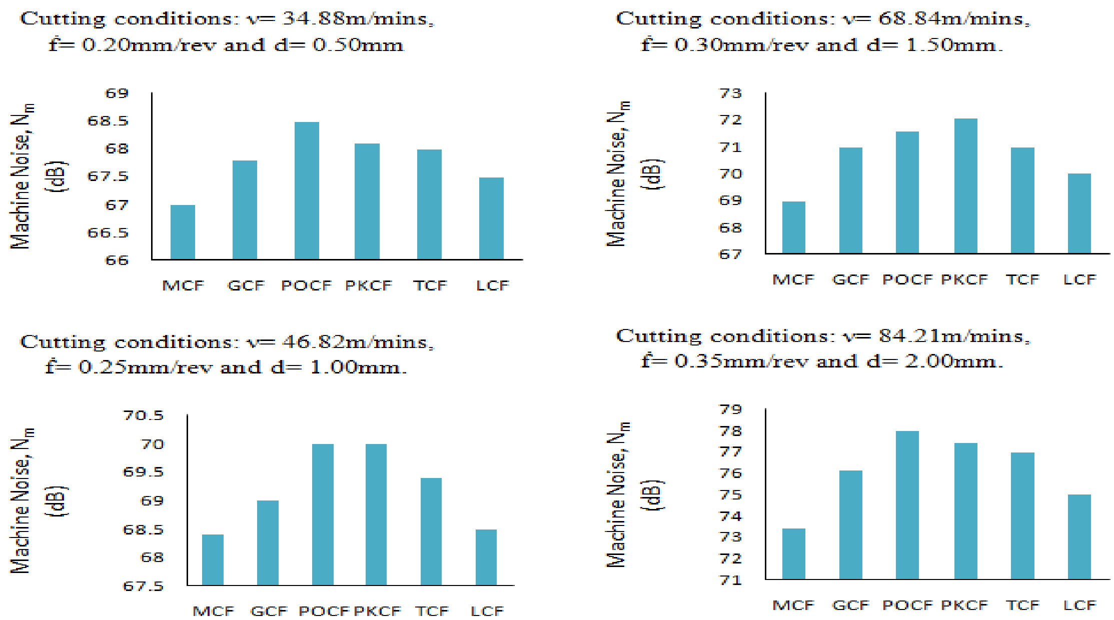

Figure 6: Variation of machine noise for all sample fluids at different cutting conditions

Figure 7 presents the variation of surface roughness values for all sample and control cutting fluids. The results show that the average surface roughness values obtained for the cutting conditions employed were close to those recorded by the control fluid (MCF). The values also compare well with those reported by Kuram *et al.* (2010). LCF recorded the least average roughness value of 0.450µm among the sample fluids and MCF. This is as result of the LCF fluidity value at higher temperature. Hence, LCF performed better in terms of workpiece surface roughness than the control fluid (MCF) which had a roughness value of 1.139µm. GCF, however, was the next in line with a workpiece surface roughness value of 1.140µm, followed by TCF (1.190µm) and PKCF (1.402µm) respectively, leaving POCF as the fluid with the highest work piece surface roughness value of 1.623µm.

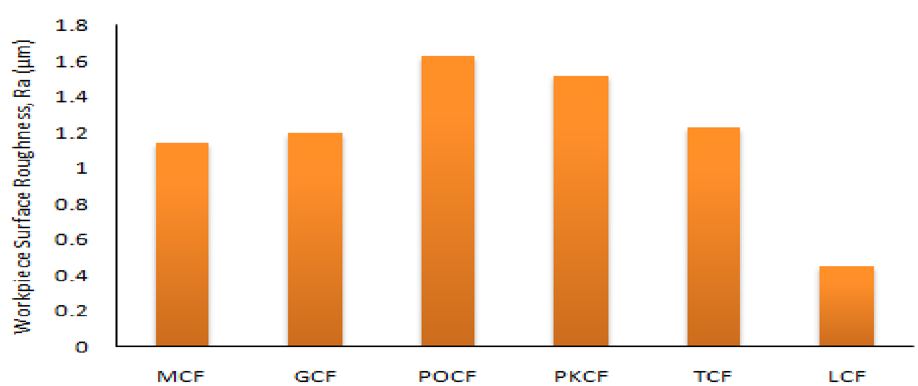

Figure 7: Variation of surface roughness values for all sample fluids at v= 84.21m/mins, f̂= 0.35mm/rev and d= 2.00mm

Figure 8 presents the variation of tool temperatures for all sample fluids at different cutting conditions. It shows that as the cutting conditions increases for every level of cut, the tool temperature also increases progressively. It is not unconnected to the increase in work / energy required to turn the sample. Tool temperatures recorded by the sample fluids were close to those obtained by the control fluid. The average minimum tool temperature of 48.70°C was achieved with MCF. When compared to the sample fluids, LCF gave the closest average value of 48.90°C. This was followed by GCF with an average value of 50.85°C. Maximum average temperature value of 50°C was recorded by POCF with respect to the stated cutting conditions.

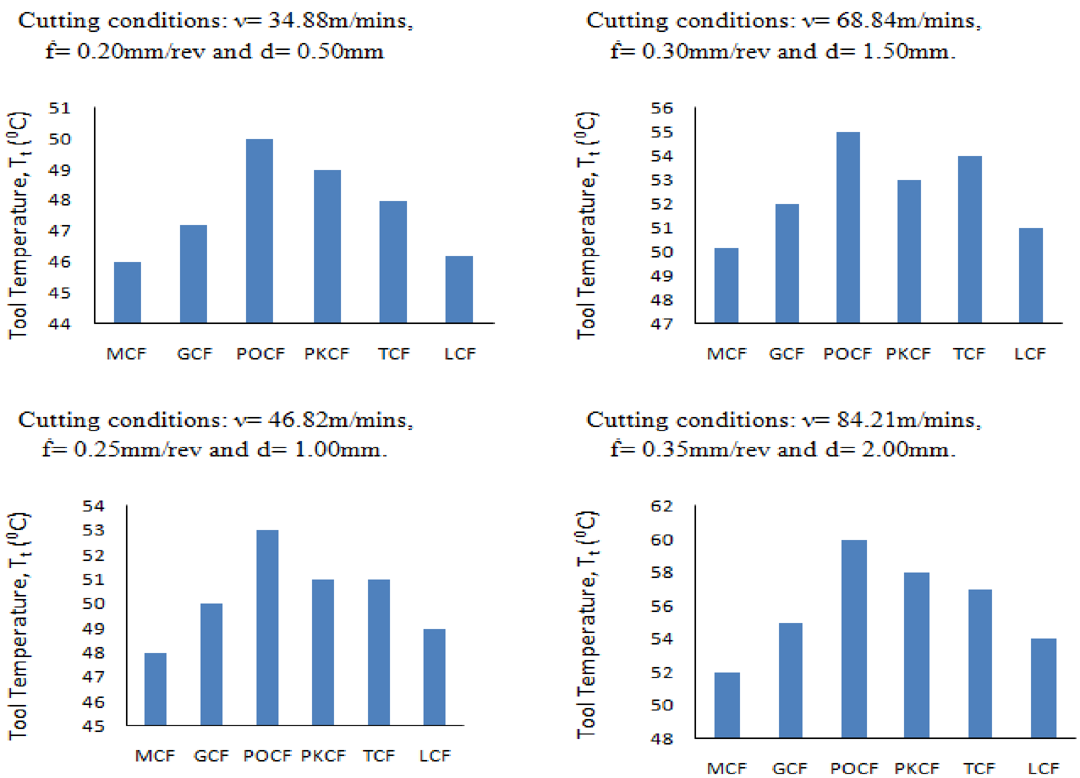

Figure 8: Variation of Tool Temperatures for all sample fluids at different cutting

4.0 CONCLUSION

The study has shown the performance evaluation of some animal (lard and tallow) oils and vegetable (groundnut oil, palm oil, palm kernel) oils as potential cutting fluids in mild steel machining (turning) operations. The following conclusions are drawn from the study:

i. The flank tool wear and spindle power consumption obtained by all sample fluids at different cutting conditions were close to those recorded by the control cutting fluid (MCF). LCF, however, recorded the minimum spindle power consumption of 602.75W compared to that of MCF (613.75W). MCF had the minimum tool wear of 0.21mm. The closest value to this was 0.22mm recorded by LCF.

ii. The results obtained for machine vibration and noise by all sample fluids at different cutting conditions were also encouraging. That of noise fell within the NIOSH recommended value (85dB) for an 8 hours' work with unprotected ear. The values obtained for both parameters were also close to those recorded by the control cutting fluid. LCF, however, recorded the closest values, followed by GCF, TCF, PKCF and POCF respectively.

iii. The formulated fluids also recorded low work piece surface roughness values when compared with the control cutting fluid. LCF provided the least surface roughness value of 0.45µm. This value was less than the surface roughness recorded by the control cutting fluid (1.14µm) for the same cutting condition.

iv. The cooling properties of the formulated fluids also offered competitive performance with that of the control cutting fluid as shown by the narrow tool temperature differences between them. MCF had the minimum tool temperature value of 48.70^{o}C and the closest to this was 48.9^{o}C recorded by LCF.

v. The lubricating properties of the formulated fluids offered competitive performance with the control fluid despite the fact that the control cutting fluid had standard additives included in its formulation. The best performed sample fluid with respect to all the parameters investigated and compared with the control fluid (MCF) was LCF. This was followed by GCF, TCF, PKCF and POCF, respectively.

The study showed that the investigated cutting fluids offered competitive performance to that of mineral oil based cutting fluids, hence, can serve as possible replacement for them.

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