A study of energy consumption in turning process using lubrication of nanoparticles enhanced coconut oil (NECO)

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Abstract. Cutting fluids play very important role in machining application in order to increase tool life, surface finish and reduce energy consumption. Instead of using petrochemical and synthetic based cutting fluids, vegetable oil based lubricants is safety for operators, environmental friendly and become more popular in the industrial applications. This research paper aims to find the advantage of using vegetable oils (coconut oil) with additional of nano particles (CuO) as lubricant to the energy consumption during machining process. The energy was measured for each run from 2 level factorial experimental layout. Obtained results illustrate that lubricant with enhancement of nanoparticles has capability to improve the energy consumption during the machining process.

1. Introduction
Nowadays, sustainability becomes a major consideration aspect during fulfilling the requirements of humans. One of the most important requirement especially during industrial revolutionary is energy. Over the last decades, energy consumption is drastically increased due to the excessive used and improper management of the resource. In manufacturing sectors, energy is crucial especially involving heavy machineries for production activities. The initiative to establish advanced methods for higher quality of products and productivity are common target for continuous improvement activities in the factories. However, it might affect the energy consumption if no proper monitoring for excessive used. Sarhan et al. claimed that correct application of lubricants has been proven to greatly reduce friction and hence, reduced power consumption [1]. Related with the issue, this study was implemented that focusing on the efficiency of energy consumption during turning process by using Nanoparticles Enhanced Coconut Oil (NECO) as the lubricant. In general, lubricant or cutting fluid is well-known plays an important role in lubricating and removing heat, gives cooling effect instead of overheating the machine, tool and workpiece during cutting process and removed chips from the cutting zone of flushing effect [2]. NECO lubricant is seen can enhance the efficiency of energy due to the significant impact on the machinability. The previous experimental researches also indicated that lubricant with nano particles can increase the machinability rather than using general lubrication. Moreover, as a way of addressing this issue towards the environmentally friendly manufacturing, minimal quantity lubrication (MQL) is introduced due to its contribution of benefits for health and environment. MQL is based on the residue-free cutting oil usage principle and low flow of cutting fluid as it is
mixed with compressed air and it is been used in high pressure. Usually, a small quantity of lubricant is used for less than 100mL/h to reduce the friction at the cutting area [3].

This development of sustainability technology can overcome negative impact of abusing the lubrications or cutting fluids especially when applying mineral oils that can cause environmental pollution, water pollution, soil contamination, and to machining operators. While machine operators are exposed to cutting fluids, they are in high-risk to the diseases of lung cancer, respiratory problem, dermatological and genetic diseases. The initiative to replace the mineral oil based with vegetable oils is important and good practice during the production. Thus, in this research, vegetable oil-based was employed and enhanced with the mixing of nanoparticles in order to achieve higher machinability and better efficiency of energy consumption.

2. Methodology

The method of the experiment was carried out by turning operation on carbon steel S45C, diameter 50mm using CNMG120408 HSS tool insert. Two levels of full factorial experiment with three replications of centre points runs was selected to design the experimental layout with total number of 11 runs, see Table 1 for the range of the parameters. Three numeric parameters were used in the experiment; cutting speed (Vc), feed rate (f), and proportion of nanoparticles to analyse the specific cutting energy. The nanoparticles was copper oxide (CuO) with average size of 100nm. The results were analyzed statistically using Design Expert 7.0.0. The data of the energy consumption was obtained using Picolog current data logger, see Figure 1. CNC turning machine was employed to carry on the experimental using MQL system, brand UNiST.

| Parameters         | Low level (-) | Centre level (0) | High level (+) |
|--------------------|---------------|-----------------|----------------|
| Cutting speed (m/min) | 100           | 130             | 160            |
| Feed rate (mm/rev)       | 0.20          | 0.25            | 0.30           |
| Proportion of CuO (wt%)        | 0.00          | 0.25            | 0.50           |

The lubrications were prepared based on 3 different of weight proportions of nanoparticles in 150ml of pure coconut oils, which are 0 wt%, 0.25 wt% and 0.5 wt%. The particles were mixed in coconut oils using ultrasonic mixer for 1 hour, see Figure 2. Then, the nanolubricant was poured into MQL system’s beaker, attached on machine and located the flexible nozzle on the cutting tips. During the experimental runs, average currents consumption data were determined from the picolog graphs. Then, the average data were converted into cutting energy. The following equations were used to obtain the required cutting energy for each run, see equation 1 and 2.

\[ P = \sqrt{3} \times I \times V \]  \hspace{1cm} (1)

\[ E = P \times t \]  \hspace{1cm} (2)
3. Experimental results

The energy data that collected from the experimental work was shown in Table 2. Results show that the highest energy consumption that recorded was 156 kJ. It can be obtained from the lowest setting of cutting speed and feed rate, and without nanoparticles in the lubricant. Meanwhile, the lowest energy consumption value was 56 kJ when setting the lowest cutting speed, highest feed rate and 0.50 wt % of nanoparticles in the lubricant. The presence of nanoparticles in this experimental work can impact the energy consumption of the process. Using Analysis of Variance (ANOVA), the characteristic of main effects and interactions were determined as shown in Table 3. All main effects with interaction between cutting speed and feed rate, and interaction between cutting speed and percentage of nanoparticles significantly influenced the energy consumption. The highest contribution factor was feed rate and proportion of nano particles only contributed 1.98%. However, the nanoparticles impact 12.69% while interacted with cutting speed. The reason was the nanoparticles in the lubricant can reduce wear and friction between cutting tool and the workpiece surface [4]. Thus, the cutting energy was also reduced because the less loading capacity on the spindle during the cutting process.

Figure 3 indicated the behaviour of the energy consumption against the different ranges of parameters setting. The parameters show negative effects for the energy when increasing the setting values. It shows that the cutting energy was getting better by increasing the setting values of cutting speed and feed rate, see Figure 3 (a) and (b). It happened because the instability of cutting occurred when too slow rotation of workpiece and movement of cutting tool. The instability cutting can increase the spindle’s load that consumes larger energy in order to keep the performance of the cutting. Meanwhile, proportion of nanoparticles also exhibited the same trend, see Figure 3 (c). The energy can be reduced by adding greater amount of nanoparticles. The reason is the nanoparticles serve as spacer between cutting tool and workpiece [5]. They tend to roll while having movement between the surfaces. In general, lubricant itself has capability to reduce the friction between cutting tool and workpiece. However, nanoparticles can reduce the friction two times greater than pure oil that can significantly improve the lubrication performance [6].

Cutting speed exhibited different pattern when interacted with both of feed fate and %wt of nanoparticles in lubricant as shown in Figure 4 (a). The energy consumption graph tends to go down although at low range of feed rate while increasing the cutting speed. This condition means that the lowest setting of feed rate which giving the highest reading by itself can be compromised with the cutting speed in order to reduce the energy consumption. Meanwhile, %wt of nanoparticles also indicated the same situation when interacted with cutting speed, see Figure 4 (b). However, there was a stagnant effect when applying larger amount of nanoparticles in the lubricant. Too much amount of nanoparticles at an area of contact surface can disturb the movement of the grains and avoiding the rolling effect, hence no more advantage to have the particles in the lubricant. Only the optimized proportion of nanoparticles can be used to significantly decreasing the energy consumption when increasing the speed of the cutting.

| Standard order | Cutting speed | Feed rate | wt% of CuO | Energy (J) |
|---------------|--------------|-----------|-------------|------------|
| 1             | -            | -         | -           | 156,036    |
| 2             | +            | -         | -           | 80,704     |
| 3             | -            | +         | -           | 81,566     |
| 4             | +            | +         | -           | 57,974     |
| 5             | -            | -         | +           | 117,225    |
| 6             | +            | -         | +           | 91,145     |
| 7             | -            | +         | +           | 56,471     |
| 8             | +            | +         | +           | 75,237     |
| 9             | 0            | 0         | 0           | 76,347     |
| 10            | 0            | 0         | 0           | 70,376     |
| 11            | 0            | 0         | 0           | 71,450     |
### Table 3: Result of ANOVA (Reduced model)

| Source     | Sum of Square | df | Mean Square | F-Value | P-value | Percentage contribution |
|------------|---------------|----|-------------|---------|---------|-------------------------|
| Model      | 7.568E+009    | 5  | 1.514E+009  | 76.71   | 0.0005  |                         |
| A-CS       | 1.411E+009    | 1  | 1.411E+009  | 71.50   | 0.0011  | 17.07                   |
| B-FR       | 3.778E+009    | 1  | 3.778E+009  | 191.49  | 0.0002  | 45.72                   |
| C-CuO      | 1.638E+008    | 1  | 1.638E+008  | 8.30    | 0.0450  |                         |
| AB         | 1.166E+009    | 1  | 1.166E+009  | 59.10   | 0.0015  | 14.11                   |
| AC         | 1.049E+009    | 1  | 1.049E+009  | 53.16   | 0.0019  | 12.69                   |
| Curvature  | 6.173E+008    | 1  | 6.173E+008  | 31.28   | 0.0050  |                         |
| Residual   | 7.893E+007    | 4  | 1.973E+007  |         |         |                         |
| Lack of Fit| 5.867E+007    | 2  | 2.933E+007  | 2.90    | 0.2567  |                         |
| Pure Error | 2.026E+007    | 2  | 1.013E+007  |         |         |                         |
| Cor Total  | 8.265E+009    | 10 |             |         |         |                         |

**Figure 3 (a):** Cutting Speed vs. Energy Consumption
Figure 3 (b): Feed Rate vs. Energy Consumption

Figure 3 (c): Cutting Speed vs. Energy Consumption

Figure 3: Main effects of the model, (a) A: Cutting speed, (b) B: Feed rate and (c) C: Proportion of Nanoparticles.
Figure 4(a): Interaction of Feed Rate and Cutting Speed

Figure 4(b): Interaction of Proportion of Nanoparticles and Cutting Speed

Figure 4: Significant interactions of the model (a) Interaction of Feed Rate and Cutting Speed, (b) Interaction of Proportion of Nanoparticles and Cutting Speed
4. Conclusion
In conclusion, it was found that cutting speed, feed rate and proportion of nanoparticles (CuO) significantly affect the energy consumption. The interaction between cutting speed and proportion of nanoparticles also indicated the same impact. The nanoparticles are able to enhance the lubrication of cutting fluid between the cutting tool and workpiece surfaces by reducing the friction. This condition can decrease the cutting load and able to make an efficient process in term of energy consumption. Overall, NECO lubricant can be used significantly in machining process for sustainability and better environmentally.

5. References
[1] Sarhan, A.A.D., Sayuti, M., Hamdi, M., 2012. Reduction of power and lubricant oil consumption in milling process using a new SiO2 nanolubrication system. Int. J. Adv. Manuf. Technol, vol. 63, pp. 505-512.
[2] G.E Totten, 2006, Handbook of Lubrication and Tribology volume 1: Application and Maintenance, Second edi. Boca Raton, FL: Taylor & Francis Group.
[3] L. R. Silva, E. C. S. Corrêa, J. R. Brandão, and R. F. De Ávila, 2013, Environmentally friendly manufacturing: Behavior analysis of minimum quantity of lubricant - MQL in grinding process, J. Clean. Prod. https://doi.org/10.1016/j.jclepro.2013.01.033.
[4] J. Padgurskas, R. Rukuiza, I. Prosyčevas, and R. Kreivaitis, 2013, Tribological properties of lubricant additives of Fe, Cu and Co nanoparticles, Tribol. Int., vol. 60, pp. 224–232.
[5] Mohd Sayuti, Ooi Ming Erh, Ahmed E.D. Sarhan, Mohd Hamdi, 2014, Investigation on the morphology of the machined surface in end milling of aerospace AL6061-T6 for novel uses of SiO2 nanolubrication system, J. Clean. Prod., vol. 66, pp. 655-663.
[6] C. Nagelreiter, H. Kotisch, T. Heuser, and C. Valenta, 2015, Size analysis of nanoparticles extracted from W / O emulsions, vol. 488, pp. 29–32.