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PERFORMANCE EVALUATION OF CASTOR OIL AND NEEM OIL AS CUTTING FLUIDS APPLIED IN DRILLING OPERATION OF MILD STEEL

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ABSTRACT

This study was based on the performance evaluation of oil extracts from castor seed and neem seed as cutting fluids in drilling operation of mild steel using high speed Steel (HSS) cutting tool at varying spindle speeds, feed rate and constant dept of cut. The growing demand for biodegradable materials has opened an avenue for using vegetable oils such as castor seed and neem seed as an alternative to conventional cutting fluids (soluble oils). The oil was extracted mechanically and also by the application of solvent extraction method. The oil obtained was investigated for physiochemical parameters and fatty acids. A commercially available convectional mineral oil was used as standard for comparative analysis. Cutting fluid was introduced to the machining zone using Minimum Quantity Lubrication method (MQLS) following the experimental design. The experimental procedure was designed using Minitab software 21.1. The independent factors considered were: spindle speed, feed rate and type of cutting fluid. Surface roughness/ finish was used as the response variable in evaluating the performance of the cutting fluids. The response was optimized using response surface methodology tool in quest of getting a cutting fluid with minimized surface roughness value. The thickness of the chips produced during the drilling operation for each cutting fluid applied was measured with micrometer screw gauge. The optimization result obtained showed that castor oil at a spindle speed of 290 rpm and feed rate of 0.0985 mm/rev. was the best cutting fluid compared to neem oil, soluble oil and dry drilling operation with a composite desirability value of 95.6%. The predicted value of surface roughness using the developed mathematical model at the stated optimal condition was 1.57186μm which was the minimum compared to other drilling conditions. The mathematical models developed for each cutting fluid had a high correlation coefficient, thus attesting to the models' suitability for response prediction at any considered factor level.

KEYWORDS: Drilling; castor oil; neem oil; soluble oil; spindle speed; feed rate; optimization.

1. INTRODUCTION

Machining processes involve the production of heat due to the friction between the contacting surfaces of the materials employed that will consequently lead the damage of the cutting tool, poor surface quality or even geometrical irregularity of the workpiece material being machined. Machining according to Thomas et al[1] encompasses a broad range of technologies and techniques that entails the process of removing materials from a workpiece using power driven machines to shape it into the required design configuration. The material removal process occurs due to the shearing effect impressed upon the workpiece by the applied cutting tool.

As explained by Alessandro[2] that the challenge of modern machining industries is focused mainly on the achievement of high quality, in terms of the dimensional accuracy of the work piece, high proportion rate, surface finish, less wear on the cutting tools, economy of machining in terms of cost saving and increase in the performance of the product with reduced environmental impact.

The gradual removal of materials from a workpiece during machining operations is done using either a single point tool or multi-cutting tool. Single point tools have only one cutting edge while multi-point tools have a minimum of two cutting edges. A rigid, hard, wedge-like shaped tool that is employed in compressing the work material and thereby shearing the excess layer of material is called the cutting tool. During machining, part of the cutting tool remains in physical contact with the workpiece and thus experiences severe cutting temperature and insistent rubbing. The material of the cutting tool must have the capability to sustain such high cutting temperature as well as cutting force. Every tool material must possess certain properties such as: high hardness, high hot hardness, high strength, higher melting point and chemically inert even at high cutting temperature. Jain and Suhane[3] explained that the physical and chemical properties of the base oil-cutting fluid also affects the tool life, surface finish, force and power requirements, disposability into the environment, toxicity of the fluid etc.

The wear rate of cutting tools during machining operations and the resulting poor surface quality and geometrical deformities are mitigated through the application of suitable cutting fluids. Cutting fluids perform the functions of dissipating the generated heat due to friction action, provides lubrication at the point where the chip sticks onto the tool face, flush off swarf and keep the cutting zone clear and equally protect the newly machined surface from rusting. A lot of research efforts have been exerted by people in quest of obtaining good cutting fluids for diverse process applications that would mitigate the wear rate of cutting tools and other accompanying effects.

Kathanore and Bachchha[4] employed the multi-attribute decision making (MADM) model to evaluate a complex problem of bio-based oil selection, considering qualitative and quantitative attributes. They used fourteen alternatives and their relevant nine attributes on the MADM and (AHP) to determine their subjective weights and its performance index through all alternatives. It was found that palm oil showed the height weight followed by coconut oil, jatropha oil, castor oil and rapeseed oil. Ozcelik[5-6] studied the formulation and evaluation of the tribo-mechanical properties of vegetable based cutting fluids of sunflower oil, Deshmukh and Hiremath[7] studied that of coconut oil, Srivyas and Charoo[8] did the same for cotton seed oil, Agrawal[9] worked on that of castor oil, Babalola[10] investigated for mustard seeds oil, Hassan[11] formulated and evaluated palm oil all employed various metal cutting operations like: drilling, lathe turning, milling etc. The studied oils exhibited good anti-wear properties and produced no hazardous gases to the environment. Also, Agrawal et al[9] studied the wear behavior of steel using cotton seed oil as cutting fluid for drilling operation. The oil performed well in terms of reduced tool wear rate and good surface finish of the workpiece. In addition, Srivyas and Charoo[8] performed a comparative study of various bio-based lubricants and mineral based oils in regard to their performance characteristics, lubrication mechanism, test methodology and tribological effects. Gajrani and Sanker[12] reviewed the physiochemical properties, composition and applications of individual vegetable oil as a metal cutting lubricant. Bachchhav[14], and Jane and Suhane[3] evaluated and reviewed the applicability of vegetable oil-based cutting fluid on various ferrous metals.

Further on the studies conducted by researchers in quest of an optimal cutting fluid with good operating characteristics, Eziwhuo and Alibi[15] carried out the evaluation of Apricot kernel, avocado and African pear seed oil as vegetable based cutting fluids in turning operation of AISI 1020. They concluded that in all the formulations, apricot kernel oil cutting fluid showed the best tribological pairs surface: cooling characteristics and lower surface roughness at high speed and lower chip thickness formation. Babuje and Bature[16] Investigated the properties of mahogany oil for use as a cutting fluid. They concluded that the eco-friendly vegetable oil could successfully replace petroleum-based ones in the formulation of cutting fluids used in machining operations. Eziwhuo and Joseph[17] worked on the performance evaluation of non-edible seed oil as cutting fluid in metal turning operation. They concluded by saying that non-edible vegetable-based fluids make a good lubricant by reducing the temperature and improving the tool life, producing good surface finish and performed more than the commercial cutting fluids.

This study was focused on determining the optimal cutting fluid among the selected base-oils (castor oil, neem oil, soluble oil) in drilling operation of mild steel specimens using the variations of the spindle and feed rate as the independent variables and surface roughness as response variable. A vertical drilling machine with high speed steel (HSS) cutting tool was used. Minimum Quantity Lubrication system (MQL) was adopted for the purpose of lubrication instead of the conventional method of flooding. The Physio-chemical properties of these oils which include: relative density, acid value, saponification value, fatty acids and viscosity were evaluated and the nature of the chips produced by the oils were also investigated. Drilling operation was equally performed under dry condition- no cutting fluid application to help understand the effects of the cutting fluids during machining operations.

2 MATERIALS AND METHOD

2.1 Materials

The materials employed in this study are: mild steel specimen, cutting fluids: castor seed oil, neem oil and soluble oil and various machines needed for the experimentation process. These materials are vividly elucidated below.

2.1.1 Mild steel specimen

The workpiece used was mild steel and it was source from the market in Warri, Delta state, Nigeria.

2.1.2 Cutting fluids

The castor seed was obtained from the market in Onitsha, Nigeria. Neem seed was sourced from the National Research Institute for Chemical Technology (NARICT) Zaria, Nigeria. The analyses of the two seed oils was carried out at springboard Research laboratory, Awka, Nigeria. The conventional mineral oil with the trade name Geiger soluble cutting oil was equally employed. Geiger soluble cutting fluid is designed to be mixed with water at a concentration ratio of 1:10.

2.1.3 Equipment/machines/tools

The tools, equipment and machines and their specifications used in achieving the research aim are shown in table 1.

Table 1: Equipment/machines and tools used in the study.

S/N	Equipment/machines/tools	Specifications
1	Vertical Drilling machine	Brand/Model: Chofum Column drilling Machine No.5226
2	Surface Roughness Tester	Model:TR200
3	Digital Rotational Viscometer	Model: NDJ-5S
4	Micrometer screw gauge	Brand/ Model: More and Wright NO 712 Range: 0.6 to 1.0 pitch
5	High Speed Steel (HSS) drill tool bit	20 mm diameter and 120 mm in length
6	Hammer, mallet, Center punch and Knockout punch kit	
7	THTK-803 Digital 20:1 Professional Infrared Thermometer	
8	Compressor	
9	Lubricating Oil Reservoir	
10	Mixing Chamber	
11	Nozzle	

2.2 METHOD

The research method entails the procedural extraction of the cutting fluids from their respective seeds, property determination of the extracted oils, development of the minimum lubricating system (MQL) for cutting fluid application while drilling, methodical description of the experimental process, design of experiment and variable measurement such as: temperature and surface roughness.

2.2.1 Extraction of the cutting fluids from their seeds

2.2.1a Castor oil and neem oil

The castor seeds for this research was source from the market at Onitsha, Anambra state, Nigeria. Castor oil seed contains about 30%–50% oil. Castor oil can be extracted from castor beans by either mechanical pressing, solvent extraction, or a combination of pressing and extraction. The combination of pressing and extraction and solvent extraction methods were used. The seeds were allowed to dry so that the seed hull would split open thus, releasing the seeds inside. The extraction process started with the removal of the hull from the seeds using castor beans dehuller equipment. After the removal of the hull from the seed, the seeds were cleaned to remove any foreign materials such as: sticks, stems, leaves, sand, or dirt. A continuous screw or hydraulic press was used to crush the castor oil seeds to facilitate removal of the oil. The first phase of this extraction is called pre-pressing. Prepressing phase involves the use of a screw press called oil expeller to discharge the seed oil. The oil expeller is a high-pressure continuous screw press to extract the oil. Although this process could be done at a low temperature using mechanical pressing machine but it yields only 45% of the castor oil. Higher operating temperatures increase the efficiency of oil extraction giving about 80% oil. The extraction temperature is controlled by circulating cold water through a pressing machine responsible for cold pressing of the seeds. Cold-pressed castor oil has lower acid and iodine content and is lighter in color than solvent-extracted castor oil. The extracted oil was collected and filtered. The filtered material was combined with new, fresh seeds for repeat extraction process. In this way, the bulk filtered material keeps getting collected and runs through several extraction cycles combining with new bulk material as the process gets repeated. This material was finally ejected from the press and is known as castor cake. The castor cake from the press contains up to approximately 10% castor oil content. After crushing and extracting oil from the bulk of the castor oil seeds, further extraction of oil from the leftover castor cake material was accomplished by crushing the castor cake followed by the application solvent extraction method. The same process was followed to extract neem oil from the procured neem seed. Figure 1 shows the extracted oils.

Figure 1: Extracted neem oil and castor oil.

2.2.1b Preparation of soluble oil: Geiger soluble oil

The soluble oil was prepared by mixing Geiger soluble oil in water at a ratio of 1:10 as directed by the manufacturer. The desired mixing ratio was achieved with the aid of a measuring cylinder. Table 2 shows the properties of soluble oil as specified by the manufacturer.

Table 2: Properties of Geiger soluble oil.

S/N	Property	Value
1	Density	0.86kg/l
2	Pour point	-5°C
3	Viscosity @ 40°C	32
4	Emulsion stability	Excellent

2.2.2 Physiochemical analysis of the prepared oils: castor, neem and Geiger soluble oils.

The physicochemical properties of the extracted/prepared oils include: relative density, refractive index, saponification value, peroxide value, acid value, iodine value and viscosity. These properties were analyzed by employing the methods developed by the Association of official Analytical Chemists (AOAC,2002) and American oil Chemists Society (AOCS, 1992). Also, the standard methods were used in determining the properties of the oils at Springboard Research laboratories, Awka.

a. Determination of the fatty acid content

i. Mix 25ml of diethyl ether with 25ml alcohol and 1ml phenolphthalein (1%) and carefully neutralize it with 0.1M of NaOH.

ii. Dissolve 1-10g of the oil or melted fat in the mixed neutral solvent and titrate with aqueous 0.1M NaOH shaking it constantly until a pink color which persists for 15 seconds is obtained.

$$\text{Acid value} = \frac{\text{titre (ml) x 5.61}}{\text{weightof sample used}} \qquad (1)$$

The FFA figure is usually calculated as oleic acid (1ml 0.1M sodium hydroxide = 0.0282g oleic acid), in which case the acid value = 2x FFA.

For most oils acidity begins to be noticeable to the palate when the FFA calculated as oleic acid is about 0.5- 1.5 % using a smaller amount of the sample. It should be noted also that the less unsaturated fats with low iodine values are solid at room temperature, and conversely, oils that are more highly unsaturated are liquid showing that there is a relationship between melting points and the iodine value.

b. Specific gravity

i. Thoroughly wash a 50ml pycnometer bottle with detergent water and petroleum ether, then dry and weigh it.

ii. Fill the bottle with water and weigh it.

iii. After drying the bottle, fill it with the oil sample and weigh.

The value of specific gravity is computed using the formula:

$$\text{Specific gravity} = \frac{\text{weight of Xml of oil}}{\text{weightofXml of water}} \qquad (2)$$

c. Density

i. Thoroughly wash a 50ml pycnometer bottle with detergent water and petroleum ether, then dry and weigh it.

ii. Fill the bottle with water and weigh it.

iii. After drying the bottle, fill it with the oil sample and weigh

$$\text{Density of oil} = \frac{\text{weight of oil}}{\text{volume of oil}} \qquad (3)$$

d. Percentage Yield

The percentage (%) yield of each of the oil sample is the ratio of the weight of extracted oil to the weight of the cake after extraction. The mathematical expression is given in equation 4

$$\text{percenatge yield of oil} = \frac{\text{weight of the oil}}{\text{weight of the sample}} \times 100\% = \frac{W_1}{W_2} \times 100\% \qquad (4)$$

Where:

W_1 = Weight of sample before extraction and

W_2 = Weight of cake after extraction.

e. Refractive Index

Abbey refractometer was used in determining the refractive index of each of the oil sample. The measuring prism surface was cleaned with solvent and distilled water, and then wiped with a clean towel after which the mode selector was regulated to the desired mode position. A drop of oil was dropped on the prism surface using a glass dropper and covered. The illumination arm was then positioned so that the exposed face of the upper prism will be fully illuminated. The refractometer was used through the eyepiece, the dark position view was adjusted to be in line with the cross line. At no parallax error, the pointer to the scale pointed at the refractive index, the reading was then noted. This measurement represents the refractive index of the oil sample.

f. Relative Density

A clean and dry relative density bottle was weighed (M_1). The bottle was filled with distilled water and gently covered with the lid, the outside walls of the bottle was cleaned and weighed (M_2). The same procedure was repeated for each of the oil and the relative density was calculated using equation 5.

$$\text{Relative density (R.D.)} = \frac{(M1 - M2)\ \text{oil}}{(M2 - M1)\ \text{water}} \qquad (5)$$

g. Acid Value

A 50ml (1:1) solvent minute of diethyl ether and ethanol was measured into an Erlenmeyer flask and 2g of oil was added and shacked. To the solution, 1% phenolphthalein solution was added and titrated with 0.1m potassium hydroxide solution. The acid value was then computed using equation 6.

$$\text{Acid Value} = \frac{\text{weight of sample}}{(\text{Titration (ml)}) \text{X} 5.61} \qquad (6)$$

h. Saponification value

i. Weigh 2g of the oil or fat into a conical flask and add exactly 25ml of the alcoholic potassium hydroxide solution.

ii. Attach a reflux condenser and heat the flask in boiling water for 1hr, shaking frequently.

iii. Add 1ml of phenolphthalein (1%) solution and titrate hot the excess alkali with 0.5m hydrochloric acid.

The saponification value is computed thus.

Saponification value $= \frac{\text{weight of sample}}{\text{weight (g) of sample}}$ (7)

I. Iodine value

i. Pour the oil into a small beaker, add a small rod and weigh out a suitable quantity of the sample by difference into a dry glass -stoppered bottle of about 250ml capacity. The approximate weight in grams of the oil to be taken can be calculated by dividing 20 by the highest expected iodine value.

ii. Add 10ml of carbon tetrachloride to the oil or melted fat and dissolve.

iii. Add 20ml of wijis' solution, insert the stopper (previously moistened with potassium iodine solution) and allow to stand in the dark for 30 minutes.

iv. Add 15ml of potassium iodine solution (10%) and 100ml water, mix and titrate with 0.1M thiosulphate solution using starch as indicator just before the end-point (titration = aml).

v. Carry out a blank at the same time commencing with 10ml of carbon tetrachloride (titration = bml).

vi. Preparation of wijis' solution: dissolve 8g iodine trichloride in 200ml glacial acetic acid; dissolve 9g iodine in 300ml carbon tetrachloride; mix the two solutions and dilute to 1000ml with glacial acetic acid.

J. Peroxide value

i. Weigh out 1g of oil or fat into a clean dry boiling tube and while still liquid add 1g powdered potassium iodide and 20ml of solvent mixture (2 vol glacial acetic acid + 1 vol. chloroform).

ii. Place the tube in boiling water so that the liquid boils within 30 seconds and allow to boil vigorously for not more than 30 seconds.

iii. Pour the contents quickly into a flask containing 20ml of potassium iodide solution (5%), wash out the tube twice with 25ml water and titrate with 0.002M sodium thiosulphate solution using starch.

iv. Perform a blank at the same time.

K. Viscosity

i. Suspend 10% flour in distilled water and mechanically stir for 2hours at room temperature.

ii. Using Oswald type viscometer measure the viscosity.

2.2.3 Minimum quantity lubrication delivery system set-up (MQL system)

A minimum lubrication delivery system was set-up for the purpose of applying the extracted cutting fluids on the mild steel workpiece during the drilling operation. The MQL system consisted of four major components: compressor, lubricating oil reservoir, mixing chamber and nozzle. In this study, lubricant (cutting fluids) and air were mixed using the MQL setup that is based on spray gun concept. The two separate hollow pipes carry lubricant and air which are mixed in a mixing chamber just before the tip of the nozzle. The lubricant flow is controlled by a knob. In order to have a contentious mist, constant pressure is ensured through the use of pressure gauge. This is essential because a change in the pressure may vary the quantity of the lubricant issuing out of the nozzle. Figure 2 shows the MQL system set-up.

Figure 2: MQL system set-up.

2.2.4 Surface roughness measurement

The surface finish of all the drilled holes was measured using the TR200 roughness tester. The work piece was set on a fixture before taking measurements. During the measuring process, the sensor moved linearly along the measured length. The probe in-turn moved according to the profile on the surface. These movements are converted into electrical signals which are amplified, filtered and converted into digital signals by an A/D converter. These signals are then refined in the main processor and displayed on the screen. This exercise was repeated thrice for each sample size on three different spots. The average was taken as the surface roughness value.

2.2.5 Methodical description of the experimental process

The oil (cutting fluid) was applied using Minimum Quantity Lubrication method which involves the application of small amount of cutting fluid in the form of mist to the cutting zone rather than flooding the workpiece. The lubricant (cutting fluid) was applied by the means of spray nozzles around the circumference of the tool. In contrast to flood lubrication, minimum quantity lubrication uses only a few drops of lubricant (approximately 5ml to 50ml per hour) in machining. However, the process used more than 150ml/h based on short intervals and also because the cutting tools have a bigger diameter of 40mm. The application of a targeted supply of lubricant directly at the point of use lubricates the contact surface between the tool, workpiece and chip or the contact point of the tool (cutting edge). The lubricant was applied as an aerosol using compressed air. The lubricant was applied until the end of the drilling operation. The flow rates of the three selected plant oils were approximately the same because their viscosities were very close. The chips produced under specified drilling parameters of varying spindle speed, feed rates and constant depth of cut for various cutting fluids and dry drilling environment were measured with micrometer screw gauge. Three chips per each sample of drilled piece were measured and the average was taken as the required chip thickness for a particular sample piece. The time taken for the workpiece to be drilled through was measured with digital clock. The entire processes were repeated for various oils under investigation and dry drilling environment, while observing basic machining operational principle at every moment of drilling. The experimental design was followed while performing the experiment.

2.2.6 Design of experiment

Minitab software 20.1.3 package was employed in this study for the use of its specialized two goals - Design of Experiments (DOE) and constructing Response Surface Methodology (RSM). Response surface methodology (RSM) is a collection of mathematical and statistical techniques for empirical model building. By careful design of experiments, the objective is to optimize a response (output variable) which is influenced by several independent variables (input variables). The response can be represented graphically, either in the three-dimensional space or as contour plots that help visualize the shape of the response surface. The most extensive applications of RSM are in the particular situations where several input variables potentially influence some performance measure or quality characteristic of the process. Thus, performance measure or quality characteristic is called the response. The input variables are sometimes called independent variables, and they are subject to the control of the scientist or engineer. The field of response surface methodology consists of the experimental strategy for exploring the space of the process or independent variables, empirical statistical modeling to develop an appropriate approximating relationship between the yield and the process variables, and optimization methods for finding the values of the process variables that produce desirable values of the response. In quest of finding the optimum factor combination that would minimize the response variable-surface roughness response surface methodology tool was applied. The input and response variables employed in the experimental design are shown in table 3. A total of 16 runs/simulations were obtained from the experimental design and was meticulously followed while performing the experiment.

Table 3: Input factors and response variable employed in the optimization process

S/N	Factors		
1	Input factors	Numerical	Spindle speed Feed rate
		Categorical	Oil type
2	Response variable	Surface roughness	

The mathematical inequalities which governed the experimental design are.

$0.05 \leq \text{feed rate (mm/rev)} \leq 0.25$

$75 \leq \text{spindle speed (rpm)} \leq 290$

3 RESULTS AND DISCUSSIONS

3.1 Result of the physio-chemical characteristics of different oil samples under investigation.

Table 4 Shows the result of the physio-chemical properties of the oil samples used as cutting fluids during the drilling operations.

Table 4: Physiochemical characteristics of different oil samples-castor oil, neem oil and soluble/conventional oil.

Parameters	Castor oil	Neem oil	Soluble oil
Saponification value (mg/kg)	169.70	206.17	136.04
Acid value (mgKOOH/g)	9.554	4.215	12.643
FFA (mgKOH/g)	4.777	2.107	6.323
Peroxide value (mleq/kg)	12.2	23.0	20
Specific gravity	0.9784	0.9449	0.8687
Density (g/ml)	0.9955	0.9614	0.8687
Iodine value (g/100g)	121.82	100.25	116.33

Refractive index	1.4641	1.4571	1.4117
Viscosity (Pa.s) @32^{o}	1.9449	0.7562	0.4691

From table 4, the soluble oil has higher acidic value compared to castor and neem oils. This thus implies that the risk of burn effect is greater than that of the other oils- castor oil and neem oil.

3.2 Result of the percentage yield of the vegetable oils: castor oil and neem oil

The percentage yield of castor oil and neem oil is shown in table 5.

Table 5: Percentage yield of castor oil and neem oil.

Oil samples	weight of seed before extraction (g)	weight of cake after extraction (g)	Weight of extracted oil (g)	Percentage yield (%)
Castor seed oil	2155	1440	1225	56.85
Neem seed oil	2016	1774	709	35.17

Table 5 shows that castor oil was extracted more from its seeds compared to neem oil. This was because the supplied castor seeds were more in number than the neem seeds. Also, the experimental procedures and methodical sequence could equally contribute to the variation in the percentage yield of the extracted oils.

3.3 Result of the chip thicknesses produced during drilling operation while varying the spindle speed and feed rate

The effect of the application of various cutting fluids (castor oil, neem oil and soluble oil) and dry drilling operations under the condition of varying spindle speeds during drilling operation is shown in figure 3.

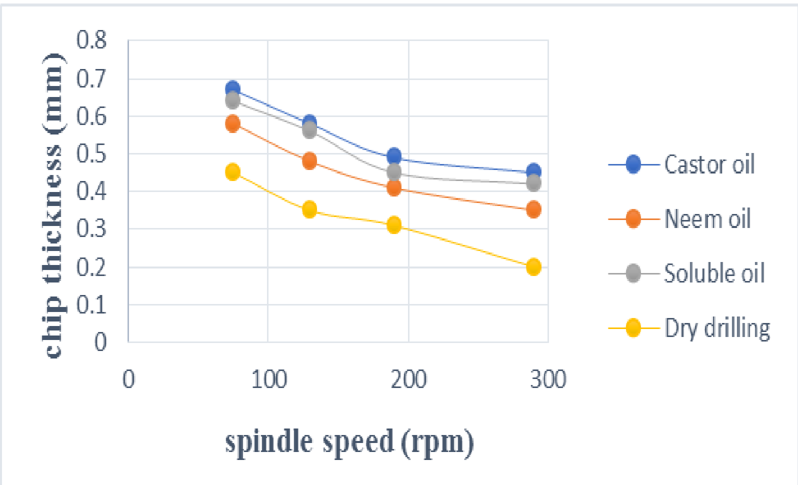

Figure 3: Effect of cutting fluids on chip thickness at various spindle speeds.

From figure 3, it is evident that the thickness of the chips produced during the drilling operation decreases in value as the spindle speed drops. For all the considered cutting fluids-castor oil, neem oil, soluble or conventional oil and drill drilling condition, it could be vividly seen that the highest chip thickness was obtained at the lowest spindle speed of 75rpm and the smallest chip thickness was gotten at the highest spindle speed of 290rpm. Higher chip thickness was gotten with castor oil used as cutting fluid. This was followed by neem oil application, soluble oil and dry drilling condition. At a condition of dry drilling operation (no cutting fluid application), lowest chip thickness was obtained. This, thus endorses the usefulness of cutting fluid application during drilling/machining operations. Krahenbuhl[18] explained that high value of chip thickness yields an optimal material removal phenomenon because of lesser time consumed during the process. These observations could be attributed to the culminated effect of the viscosity and density values of the applied cutting fluids. Castor oil has the highest viscosity of 1. 9449Pa.s and density of 0.9955g/ml. While the other considered cutting fluids, neem oil and soluble oil have viscosity and density values of 0. 7562Pa.s, 0.9614g/ml and 0. 4691Pa.s, 0.8667g/ml respectively as shown in table 4. As a result of the high values of viscosity and density of castor oil, the lubrication potential of the fluid and its heat absorption capacity will be high, thereby, enhancing the ease of material removal process which is accompanied by larger chip thickness production.

The variation of chip thicknesses produced at various feed rates for all the cutting fluids considered is shown in figure 4. From figure 4, castor oil was observed to produce the highest chip thickness at a greater feed rate application during the drilling operation.

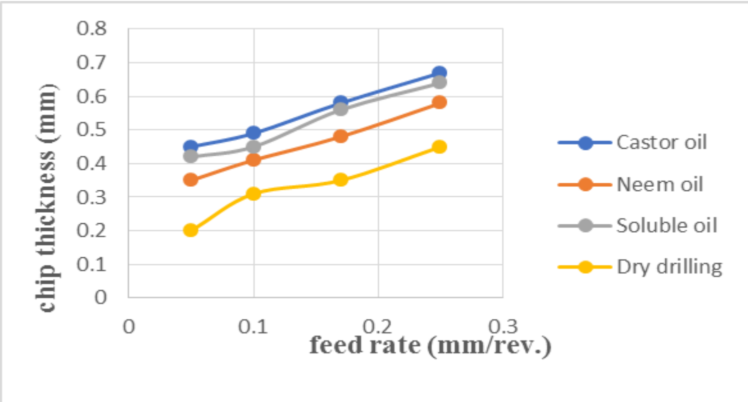

Figure 4: Effect of cutting fluids on chip thickness at various feed rates.

This was followed by soluble oil, neem oil and lastly dry drilling operation. Also, the thickness of the produced chips increases as the feed rate expands in value. Castor oil produced chips of higher thickness because of its viscosity value. Its value of viscosity as shown in table 4 was greater than that of the other cutting fluids and as such it was able to withstand the thermal shear stress induced on it by the dissipated heat accompanying drilling or machining operations. The lubricating effect of cutting fluids is adversely affected by the heat released during machining operations. Fluids of good viscosity, density etc. values absorb machining heat well before its shear strength is reached and consequently loss of these potentials would ensue. The thickness of chips produced at dry drilling condition was observed to be the smallest compared to that produced when cutting fluid was applied. This observation relates to the production of heat as a result of the friction between the cutting tool and the work piece that was not absorbed due to no application of cutting fluid. This caused the chips to cut off from the metal within a short time, thereby producing chips of smaller thicknesses.

The surface roughness or surface finish of the work piece at varying spindles was also noted to be affected by cutting fluids application as shown in figure 5. From figure 5, the surface roughness of the material dropped in value at increasing values of spindle speeds from 75-290rpm. It was deduced that all the applied cutting fluids had good surface finish at low spindle speed of 75rpm. Castor oil had the best surface finish, followed by neem oil and then soluble oil. The good surface finish of castor oil application was still because of its excellent lubricating effect, heat absorption and shear strength value compared to that of the other cutting fluids-neem and soluble oils.

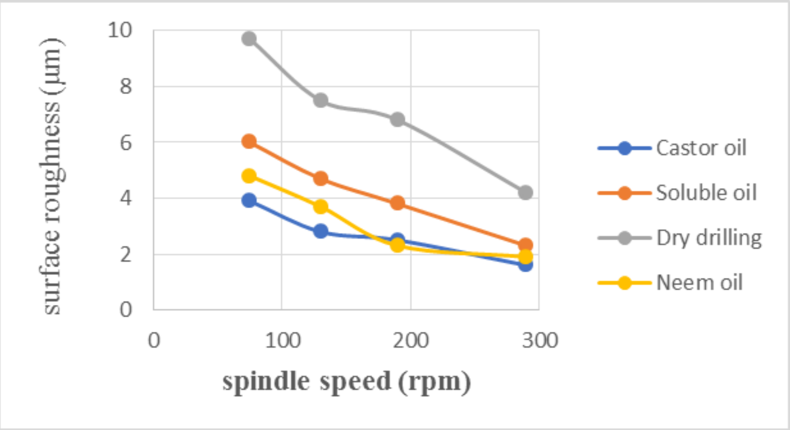

Figure 5: Effect of cutting fluids on surface roughness at varying spindle speeds.

These observations were based on the viscosity and density values of the cutting fluids. The surface finishing produced at dry drilling conditions could be seen to be poor. This was because no cutting fluids was applied to aid the drilling operation and also absorb the generated heat due to friction.

In addition, the application of cutting fluids on a workpiece-cutting tool interface during drilling or machining operations equally affects the surface roughness/finish of the material at varying feed rates conditions. This is vividly shown in figure 6.

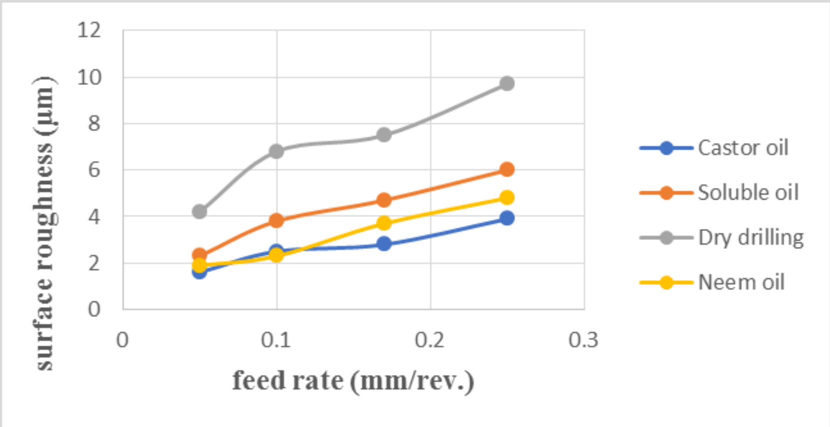

Figure 6: Effect of cutting fluids on surface roughness at varying feed rates.

From figure 6, surface roughness/finish of the material could be seen to increase in value as the feed rate expands proportionally. Also, castor oil showed to give a better surface finish compared to neem oil and soluble oil. The frictional effect that led to the generation of heat under dry drilling operation contributed to the poor surface finish produced on the material in addition to no cutting fluid application. Cutting fluid application helped greatly during drilling or machining operations by absorbing the heat generated during the process, reduction of the machining time and production of quality surface finish of the material.

3.4 Optimization of the response-surface roughness/finish

The level of effect which the independent variables: spindle speed, feed rate and oil type (castor, neem and soluble oils) and at dry drilling operations had on the response variable - surface roughness was studied using the Pareto chart of standardized effects shown in figure 7.

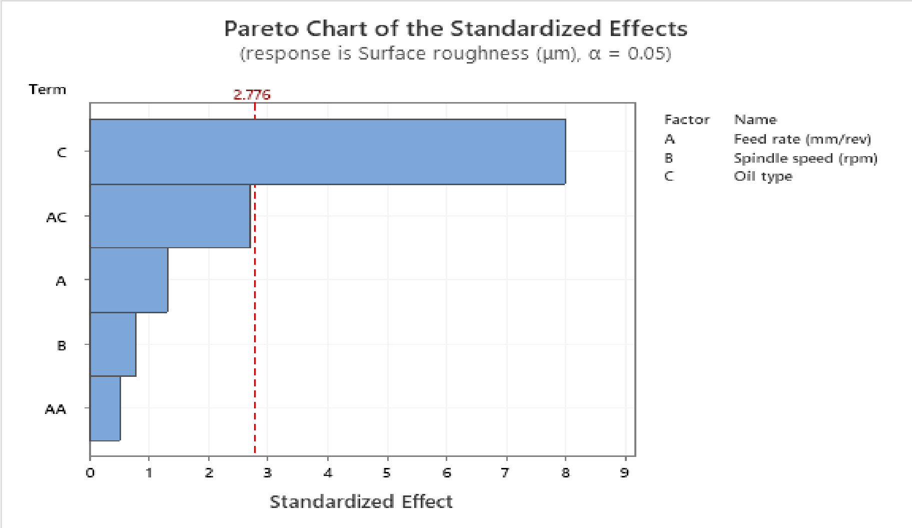

Figure 7: Pareto chart of the standardized effects of the independent variable on the response variable-surface roughness.

From figure 7, using a confidence interval of 95% and a corresponding significance level of 5%, the individual and combined/interactive effects of the independent variables on surface roughness of the material could be seen to vary and based on the considered factors. The oil type used as cutting fluid could be seen to have the greatest effect on the surface finish of the material. The feed rates applied had more effect on the response variable- surface roughness than spindle speed. Also, the interactive/combined effect of the feed rate and oil type was seen to be more the individual effect of feed rate and spindle speed. The quadratic model 'AA' had the least effect on the response variable. This thus implies that during drilling and machining operations, absolute attention should be paid to the choice of cutting fluid, feed rate and spindle speed with greater focus on cutting fluid to be applied.

In quest of getting the optimum factor combination that would yield a good characteristic value of the response.

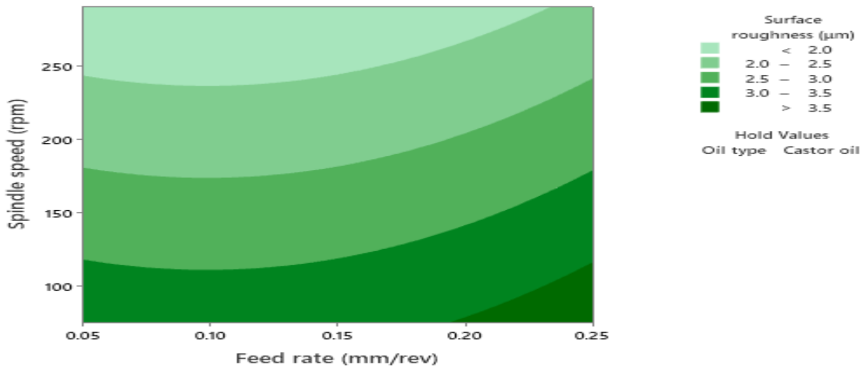

Figure 8: Contour plot of spindle speed against feed rate.

variable- surface finish, response surface methodology was applied and the contour and 3D surface plots of the response surface are shown in figure 8 and 9 respectively.

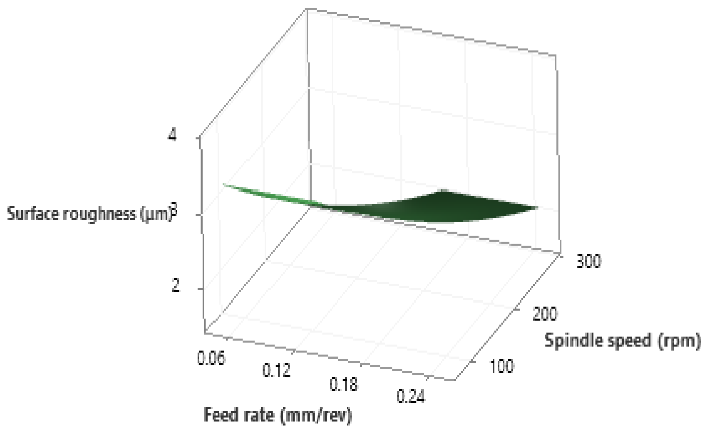

Figure 9: 3D surface plot of the response variable-surface roughness/finish.

From these figures, the optimum factor interaction that would yield the best surface finish of a mild steel material during a drilling or general machining operation was obtained at a spindle speed of 290rpm, feed rate of 0.0985 and usage of castor oil as cutting fluid. Table 6 shows the summary of the optimal solution obtained and the multiple response prediction at the optimal point.

Table 6: Optimal factor combination for yield of best surface finish and the corresponding response prediction.

Sol.	Feed rate (mm/rev.)	Spindle speed (rpm)	Oil type	Surface roughness fit (µm)	Composite desirability
1	0.0984848	290	Castor oil	1.57186	0.956252
Multiple Response Prediction					
	Response	**Fit**	**S.E Fit**	**95% CI**	**95% PI**
	Surface roughness	1.57186	0.899	(-0.925, 4.069)	(-1.050, 4.193)

From table 6, at the gotten optimum factor combination, a surface roughness/finish value of 1.57186 was predicted using the developed mathematical model stated in table 7 for all the cutting fluids/dry drilling applied. The highest desirability value of 96% approx which formed the basis of the selected optimal factors was gotten.

Table 7: Regression equations in un-coded Units.

Castor oil	Surface roughness (μm)	=	4.12 - 4.7 Feed rate (mm/rev) - 0.0080 Spindle speed (rpm) + 23.7 Feed rate (mm/rev) * Feed rate (mm/rev)
Dry drilling	Surface roughness (μm)	=	4.83 + 32.5 Feed rate (mm/rev) - 0.0080 Spindle speed (rpm) + 23.7 Feed rate (mm/rev) *Feed rate (mm/rev)
Neem oil	Surface roughness (μm)	=	3.95 - 0.2 Feed rate (mm/rev) - 0.0080 Spindle speed (rpm) + 23.7 Feed rate (mm/rev) *Feed rate (mm/rev)
Soluble oil	Surface roughness (μm)	=	4.63 + 2.3 Feed rate (mm/rev) - 0.0080 Spindle speed (rpm) + 23.7 Feed rate (mm/rev) *Feed rate (mm/rev)

From table 7, the mathematical models for computing surface roughness values at any considered factor combination of spindle speed and feed rate for a specific cutting fluid type proved to efficient as the Pearson coefficient of correlation confirmed. Correlation values of 0.991, 0.982, 0.994 and 1.0 were gotten for each of the cutting fluids: castor oil, neem oil, soluble oil and dry drilling operation respectively. These values of Pearson correlation attest to the suitability of the model for response prediction at any factor level/cutting fluid considered.

4 CONCLUSION

Machining operations leads to the generation of heat due to the rubbing friction between the material-cutting fluid interface. This study proved that the application of cutting fluids during drilling or general machining operations helps greatly in giving a good surface finish to the material and reduces the machining time. The optimization performed, further attested that castor oil gives the best surface finish than the other cutting fluids- neem oil and soluble oil. In addition, dry drilling operation, that is a condition of no fluid application, produced a small chip thickness and poor surface finish.

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