

Optimization of Vegetable Oil Properties in Machining Environment Through CFD

Suresh Babu Valeru, P. Nageswara Rao, K.N.S Suman

Abstract: Various vegetable oils were widely used as a lubricant in machining since 1990's. However during machining of various materials, various vegetable oils gave superior performance related to other oils which is due to their individual thermo physical properties. So that the prediction of influencing properties of various vegetable oils novel technique. Therefore in the present work turning of AISI 304 steel with carbide tool is taken as a case study for ascertaining the influence of vegetable oil properties in the machining environment. Among the fluid properties, properties such as viscosity, thermal conductivity, density and specific heat are taken for optimization. For optimization of fluid properties initially DOE Technique has been adopted, using which L16 orthogonal array has been formed for carrying out the simulations. CFD analysis with proper boundary conditions has been adopted for predictions the generated temperature at a constant distance from tool tip. From the obtained results, it is perceived that thermal conductivity is performed a major role to reducing of generated temperature within the tool followed by viscosity and specific heat whereas effect of density on generated temperature is found to be least significant. Therefore the present work highlights the combinations of DOE approach and CFD analysis in predicting the influence of vegetable oil properties and their values in the machining environment

Key words: Vegetable oil fluid properties, CFD, Optimization, Temperature generation.

I. INTRODUCTION

Vegetable oils are widely used as lubricants in machining applications from last two decades because their high lubrication performance and less toxic, eco-friendly and non hazardous. Based on those characteristics, many researchers has been used bear vegetable oils in machining as a lubricant. The used vegetable oils performance was evaluated in machining response such as chip formation, tool wear, surface roughness, thrust force and generated temperatures [1-3]. However from those output responses in machining compared to commercial oils, vegetable oils gave better but within which some vegetable oil gave better machining performance compared to other vegetable oils. But long term usage of bear vegetable oils few challenges associated with as cutting fluids. Generally these oils having low temperature viscosities and also during long term usage oxidative and hydrolytic instabilities associated with the triglycerides naturally within the oils [4-6].

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To reduce these poor performance characteristics it has been acknowledged that existence of alkylated phenols, pour point depressants and poly alpha olefins within the bear oil have made a remarkable impact on improving the various poor performance characteristics of vegetable oils [7-9]. However the good lubricant not only for long term usage it must be improving the machining performance. The machining performance is indirectly influenced by the various properties of vegetable oils. Therefore various vegetable oils thermo physical properties modified by the addition of various nanoparticles [11, 13] from the obtained results they were concluded that higher thermal conductivity of oil and lower viscosity of oil by the MQL application, higher viscosity of oil in flood machining was gave better resulted and also those properties are influencing indirectly influencing the other properties. Therefore from the above literature it was observed that the machining performance indirectly influenced by the various properties of lubricant for better machining.

II. PROBLEM STATEMENT

Vegetable oils are significantly improving the machining performance compared to other cutting fluids. Anyhow within the wide variety of various vegetable oils available, their extensive utilization in machining environment is limited to few oils due to the wide variation of fluid properties among the various oils. Ascertaining the influence of vegetable oil properties and their interactions therefore an optimum combination among the various influential fluid properties such as thermal conductivity, viscosity, density and specific heat for the vegetable oil is essential for making it viable as a commercial lubricant. The advance in nano technology is already proved the way for designing of nanofluids according to the needs of the customer and also for the application under concern. Therefore the present work deals with the on the generated temperature during machining is carried out through numerical investigation using CFD.

III. METHODOLOGY

To investigate the effect of fluid properties on the temperature generated during machining generally four influential properties are influenced [15-17] such as viscosity, density, thermal conductivity and specific heat are considered for optimization using taguchi DOE technique. Based on the data of properties available in the literature [18-21] for various vegetable oils, four levels for each properties were considered accordingly taguchi L16 array was designed which were shown through table I and table II.

Table I. Factors and levels

Factors	Levels			
	1	2	3	4
Viscosity (kg/m.s)	0.025	0.03	0.035	0.04
density (kg/m ³)	910	920	930	940
Thermal conductivity (w/mk)	0.15	0.16	0.17	0.18
Specific heat (J/kg-k)	1700	1800	1900	2000

Table II. L16 orthogonal array

S.No.	VISCOSITY	DENSITY	THERMAL CONDUCTIVITY	SPECIFIC HEAT
1	0.025	910	0.15	1700
2	0.025	920	0.16	1800
3	0.025	930	0.17	1900
4	0.025	940	0.18	2000
5	0.030	910	0.16	1900
6	0.030	920	0.15	2000
7	0.030	930	0.18	1700
8	0.030	940	0.17	1800
9	0.035	910	0.17	2000
10	0.035	920	0.18	1900
11	0.035	930	0.15	1800
12	0.035	940	0.16	1700
13	0.040	910	0.18	1800
14	0.040	920	0.17	1700
15	0.040	930	0.16	2000
16	0.040	940	0.15	1900

For performing simulations solid domain for a cutting tool (having a constant temperature at its tip) and fluid domain at different levels of fluid properties were generated for all the 16 combinations, and their interactions were studied on the tool by the measurement of temperature distribution along the rake face at constant distance. In the present work, a constant heat source at its tip i.e 803° C was selected as input for each trial [22]. In this study carbide insert was used as tool its properties are shown in table III. The energy equation in the solid domain and numerical equations governing thermal fields and flow in the fluid domain were concurrently solved by retaining heat flux and temperature continuity at solid-fluid interface.

Table III. Properties of carbide cutting insert

Density	kg/m ³	14,950
Thermal conductivity	W/mK	80
Specific heat	J/kg K	480

IV. MODELING AND SIMULATION

Within the present work cutting insert with rectangular domain was created in the CATIA package. The designed geometry was imported in ANSYS FLUENT as IGS file, and cutting insert was selected solid domain with a constant temperature at its tip and rectangular domain was selected as fluid which is shown in figure 1.

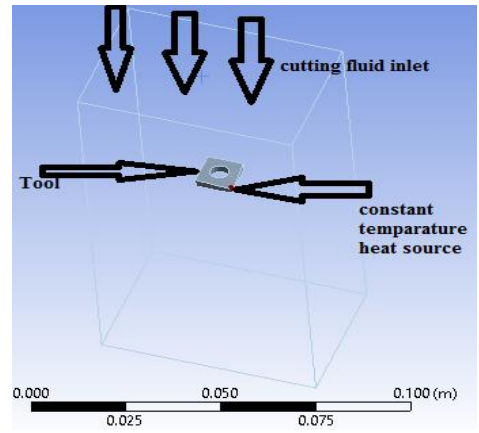


Fig 1: Generated computational domain

A. Assumptions involved in analysis

For the analysis purpose following assumptions have been considered

- i. The cutting tool inserts works under the steady-state condition.
- ii. No fouling occurs on heat transfer surface (cutting tool insert).
- iii. Thermo physical properties of the fluids are temperature dependent.

B. Turbulence model

Selection of proper turbulence model is of a primary importance to predict the results accurate manner therefore for the present work shear stress transport (SST) model is selected due to its superior accuracy in capturing flow behavior in the near-wall regions. This model is combination of k-omega and K-epsilon turbulence model such that the K-omega is used in the inner region of the boundary layer and its switches to the k-epsilon in the free shear flow. A good agreement between mass-transfer simulations with experimental data were attained for turbulent flow by many researchers using the SST turbulence model [23]

C. Computational domain, mesh generation and input conditions

The computational domain in this work consists of solid (cutting tool) and fluid domains. After selection of fluid and solid domains. Before generation of mesh, the mesh independence study was performed to make the result independent of cell size. The results were plotted in Fig. 2 from the plot it was observed that there is no variation of temperature at 1.01 million cells. Therefore the mesh was generated with 1.01 million cells in the current problem. The generated meshed model was shown in separately solid and fluid domain in figure 3(a)-(b). After generation of mesh for performing simulations input conditions were taken which was tabulated in table.IV and also it was assumed that velocity is unvaryingly distributed and the direction of the inlet velocity is perpendicular to the rake face of cutting tool. Velocity inlet is taken as inlet and outlet it is kept as pressure outlet took a gauge pressure zero (ambient pressure). For the tool interface no slip boundary condition was executed while each of four side walls of the computational domain symmetric boundary condition was implemented.

7	Reservoir	Fluid
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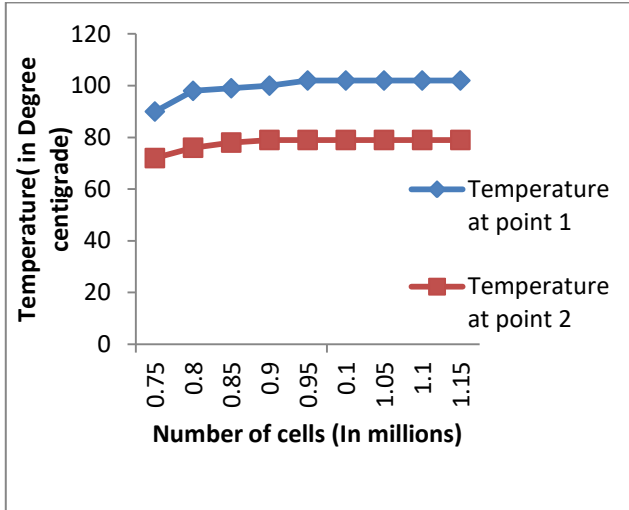


Fig. 2: Mesh independence test result

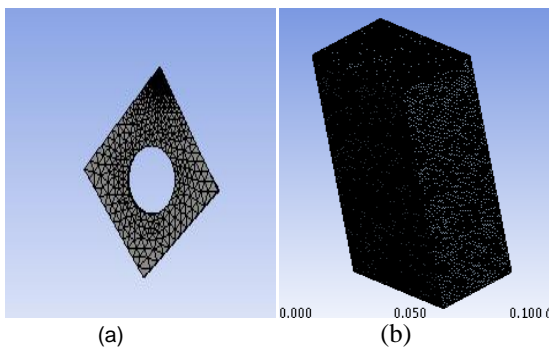


Fig.3 Meshed domain a) solid b) fluid

Table IV. Input conditions

S. No.	Input condition	Value/zone
1	Inlet velocity	26m/s
2	Outlet pressure	0 Pascal
3	Tool tip temperature	803 ⁰ C
5	4 Side walls	Symmetry
6	Tool	Solid

V. RESULTS AND DISCUSSION

The simulations were carried out to optimize the fluid properties by the considering temperature distribution along the rake face as the output response. Full factorial orthogonal array was used for designing different level of fluid properties to conducting the simulations. Contours of temperature distribution along rake face of tool for trail number 4 and 16 randomly shown in figure 4(a)-(b). and also temperature were plotted separately with respect to distance then the tool tip for trial no.4 and 16 as shown in figure 5(a)-(b). Based on simulations at different levels and factors the obtained temperature at 4 mm away of the tool tip is taken as reference and tabulated through table V.

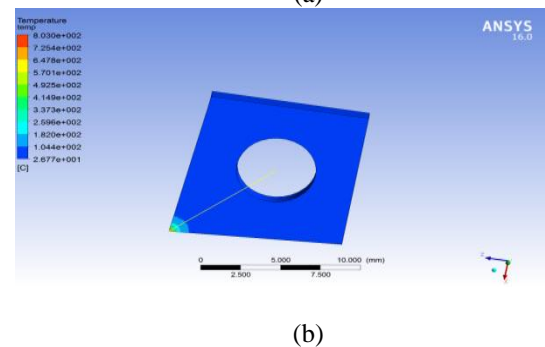
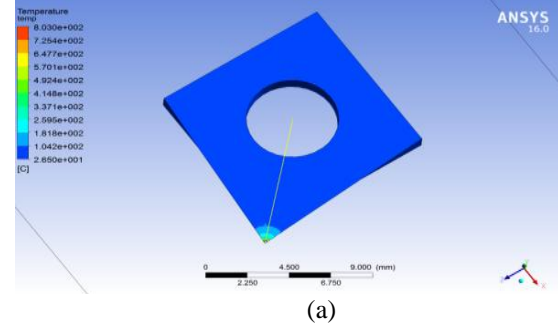


Fig.4.Contours of temperature a) trail4 b) trail 16

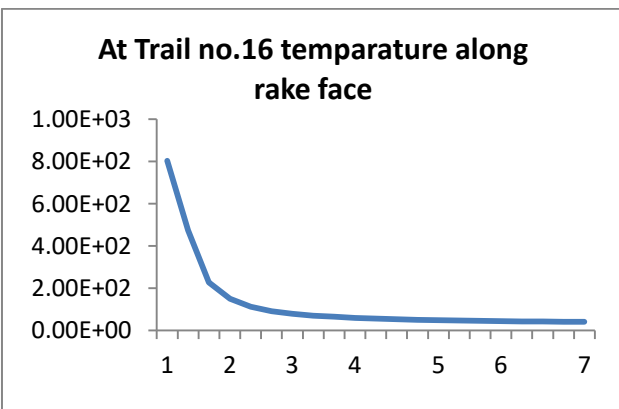
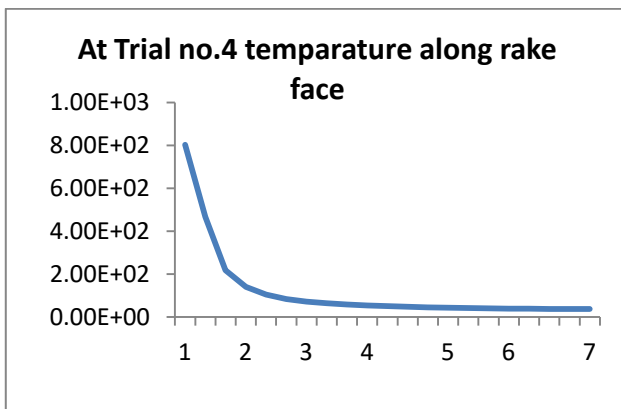


Fig.5: Temperature distrubution along diagnol line on the rake face a)trail no.4 b) trail no.16.

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Table V: Generated temperatures at different levels

Trial no.	VISCOSITY	DENSITY	THERMAL CONDUCTIVITY	SPECIFIC HEAT	TEMPERATURE At 4 mm away of tool tip
1	0.025	910	0.15	1700	51.5
2	0.025	920	0.16	1800	49.1
3	0.025	930	0.17	1900	51.1
4	0.025	940	0.18	2000	47.9
5	0.030	910	0.16	1900	51.1
6	0.030	920	0.15	2000	51.7
7	0.030	930	0.18	1700	49.8
8	0.030	940	0.17	1800	52.1
9	0.035	910	0.17	2000	51.5
10	0.035	920	0.18	1900	50.9
11	0.035	930	0.15	1800	53.0
12	0.035	940	0.16	1700	52.1
13	0.040	910	0.18	1800	51.2
14	0.040	920	0.17	1700	52.1
15	0.040	930	0.16	2000	52.4
16	0.040	940	0.15	1900	53.2

A. Taguchi analysis

To obtain optimum properties, the smaller is the better performance characteristic for temperature distribution along the rake face at a constant distance from the tool tip was considered. Analysis was carried out to identify significant fluid properties on temperature distribution along the rake face is generated and S/N ratio was calculated for

all the simulations which is taken as a measure to identify the influence of fluid properties by using Minitab software. The generated results of temperature distribution and S/N ratios were tabulated in table VI.

Table VI: Numerical results at various levels and their S/N ratios

Trial no.	VISCOSITY	DENSITY	THERMAL CONDUCTIVITY	SPECIFIC HEAT	TEMPERATURE At 4 mm away of tool tip	SNRA 15	MEAN 15
1	0.025	910	0.15	1700	51.5	-34.2361	51.5
2	0.025	920	0.16	1800	49.1	-33.8216	49.1
3	0.025	930	0.17	1900	51.1	-34.1684	51.1
4	0.025	940	0.18	2000	47.9	-33.6067	47.9
5	0.030	910	0.16	1900	51.1	-34.1684	51.1
6	0.030	920	0.15	2000	51.7	-34.2698	51.7
7	0.030	930	0.18	1700	49.8	-33.9446	49.8
8	0.030	940	0.17	1800	52.1	-34.3368	52.1
9	0.035	910	0.17	2000	51.5	-34.2361	51.5
10	0.035	920	0.18	1900	50.9	-34.1344	50.9
11	0.035	930	0.15	1800	53.0	-34.4855	53.0
12	0.035	940	0.16	1700	52.1	-34.3368	52.1
13	0.040	910	0.18	1800	51.2	-34.1854	51.2
14	0.040	920	0.17	1700	52.1	-34.3368	52.1
15	0.040	930	0.16	2000	52.4	-34.3866	52.4
16	0.040	940	0.15	1900	53.2	-34.5182	53.2

B. Effect of properties on temperature distribution

The S/N ratios of obtained temperature from the plots at a 4 mm distance of tool tip, it was observed that compared all four properties density and specific heat are less significant compared to remaining properties such as thermal conductivity and viscosity. It is due to that higher thermal conductivity of fluid is absorbing the high amount of heat in machining zone and lower viscosity of oil is properly settled

down between tool and work piece and provides the cushioning effect, hence decreases the temperature in machining zone. The affect of each control factor can be more clearly conferred with response graphs. Response graphs for all control factors are shown in fig.6 and response for Signal to Noise Ratios Smaller is better is tabulate in table VII.

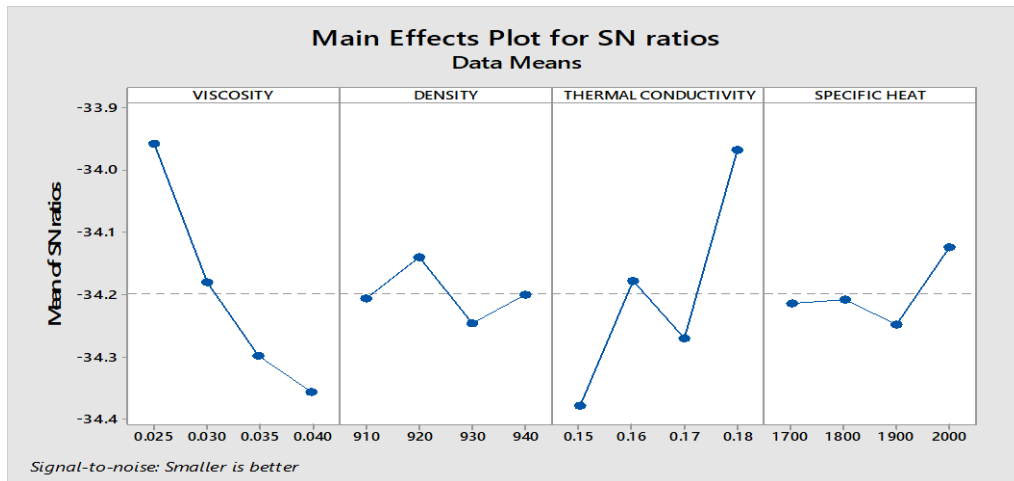


Fig.6. Main effect Plot for temperature versus Viscosity, Density, Thermal conductivity and Specific heat

Table VII: Response Table for S/N Ratios Smaller is better

Level	VISCOSITY	DENSITY	THERMAL CONDUCTIVITY	SPECIFIC HEAT
1	-33.96	-34.21	-34.37	-34.21
2	-34.18	-34.14	-34.18	-34.21
3	-34.30	-34.25	-34.27	-34.24
4	-34.35	-34.19	-33.97	-34.12
Delta	0.39	0.11	0.40	0.11
Rank	2	4	1	3

C. Confirmation test

From the L16 orthogonal array At optimal level of fluid properties from different level of fluid properties are Viscosity (kg/m.s)- 0.025, Density (kg/m³)- 920, Thermal conductivity(w/mk)-0.18, Specific heat(J/kg-k)-2000. With the obtained optimum fluid properties confirmation test was conducted and the S/N ratio was much lower compared to all set of experiments. The temperature generated 4mm away from the tool tip is found to be 46.8⁰c which is the lowest compared to all.

VI. CONCLUSIONS

The present work clearly highlights the influence of fluid properties in reducing the generated temperatures in cutting zone which indirectly enhances the tool life by reduction of tool wear. By means of optimization analysis it is found that out of the major fluid properties. Thermal conductivity and viscosity are pre dominant compared to remaining. At the optimized fluid properties i.e viscosity (kg/m.s) 0.025, Density (kg/m³) 920, Thermal conductivity (w/mk) 0.18 and Specific heat (J/kg-k) 2000.

From optimized fluid properties from the confirmation test, generated temperature 4 mm away of the tool tip from the rake face was observed i.e 46.8⁰. It is 12.03% is decreased

from highest generated temperature at trail no.16 among all the levels of fluid properties.

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