Experimental investigation of heat conduction and cooling properties of vegetable oil blends in machining

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Abstract

Metal cutting processes involve the generation of high temperatures which is due to the resistance of the work piece to shear force leading to high frictional forces arising from the sliding action at the point of contact between the tool and the work piece. Conventional soluble oils are used to provide lubrication and cooling between cutting tool and work piece during machining with excellent lubricity and chemical stability, but their uses have been questioned as regards to cost and environmental problems. Vegetable oils from non-edible sources have been used recently as bio-lubricant in machining owing to their remarkable and improve lubricity properties. In this study seven samples of cutting fluids were formulated from blends of Neem (N) and Castor (C) oils at varied proportion, each sample was investigated for physico-chemical properties and fatty acid profile for their suitability as lubricant. The results obtained when applied each of the sample on machining were recorded and compared with the results obtained with conventional soluble oil. From the results obtained 60N+40C blend proved to be the best as tool temperature was recorded as 57^0C and specimen temperature was recorded as 59.3^0C as against 79.5^0C for tool temperature and 68.9^0C for specimen respectively when machining with the conventional soluble oil. The indication that 60N+40C (300^0C) showed faster cooling rate than other formulated oil samples and conventional soluble oil is an evident that it will give better lubricating properties and surface finish and hence, replace the existing soluble oils.

Key words: *Cooling, Cutting fluid, Lubrication, Temperature, Vegetable oil.*

1.0 Introduction

Metal cutting processes involve the generation of high temperatures which is partly due from the sliding action at the point of contact between the tool and the work piece [1]. Nonetheless, for efficient cutting to take place, it is important that the friction at the interface between the chip and the cutting tool be kept as low as possible [2]. An increase in the coefficient of friction facilitates the formation of a built-up-edge on the cutting tool edge. The larger the built-up-edge, the more friction is created, which may result in poor surface finish, tool edge breakage with the attendant tool replacement or regrinding, eventually result in decrease in production rate [3,4]. The use of cutting fluids in metal cutting was first reported in 1894 by F. Taylor who noticed that cutting speed could be increased by 33% without reducing tool life by applying large amounts of water in the cutting zone [8]. Cutting fluids are used to reduce the negative effects of heat and friction on both tool and work piece, there by cooling and lubricating the chip tool interface and helps in chip removal rate.

2.0 Review of previous work

[9] used vegetable oil as Minimum Quantity Lubricant (MQL) during drilling of cast aluminum silicon alloys. The effect of various methods of cutting fluids applications (flood lubrication, MQL-mist, compressed air and dry) on cutting temperatures and torque. Cutting force and surfaces, torques, roughnesses were investigated.MQL using vegetable oil have lower feed forces, torques and surface roughness at the high cutting speeds and feed rates, flooding with mineral oil showed lowest cutting temperature. [10] studies the height of the chip under dry machining.MQL at the flow rate of 30ml/h and conventional way (flooding) in the drilling .Vegetable oil in MQL mineral oil in MQL and flooding and semi synthetic oil in flooding were used as cutting fluid. The smallest burr height was obtained for the dry drilling and the largest for the MQL systems. The MQL with vegetable oil generally produced smaller chip height than that of the MQL with mineral oil. Similarly, [10] studied MQL palm oil (MQLPO) as a lubricant in the high speed drilling of Ti-6Al-4V and for the comparison purpose MQL synthetic ester (MQL),air blow and flood conditions were used. MQLPO gave lower tool wear rate than MQLSE and flood condition also showed low flank and corner wear rate. For flood condition, both wear rates laid between MQLPO and MQLSE however, the tool life was the same. MQLPO exhibited lower tool rate than MQLSE and air blow condition and comparable with flood condition .Significant improvement of the friction and wear in palm oil was due to the fatty acid content of palm oil. The carbon chain length of the acids in palm oil is longer than the synthetic ester and this increment enhances durability of the contact. Reaction between metal oxide layer and the fatty acids leads to smooth sliding and low friction. Metal soap has been formed on the contact surface owing to this reaction. Longer carbon chain can resist high cutting temperature to protect the surface. The molecular thin film present during the drilling under MQLPO reduced the friction and heat generation thus improved tool wear. Besides, the high viscosity of palm oil has a tendency to resist the flow, providing effective lubricating at the tool-chip interface, which reduces the friction, thus prevent the cutting tool from rapid wear. They found that MQL and flooding condition have similar effects on the tool wear rate and tool life. The lowest thrust force and torque were obtained with flood condition. MQLPO exhibited comparable performance to the flood with respect to maximum work piece temperature. Hence, the use of vegetable oils may make possible the development of a new generation of cutting fluids of high performance in machining combined with good environmental friendliness. Vegetable oils are by their chemical structure, long chain fatty acids tri-esters of glycerol and are capable of providing the desired lubricant properties, such as: good boundary lubrication, high viscosity index, high flash point and low volatility [11]. Therefore, the present study is an attempt to investigate the heat conduction and cooling properties of some locally made vegetable oil blends (Neem and Castor oil) as a lubricant in machining. On the other hand thermal conductivity and diffusivity of vegetable oils are important factors in understanding the transport phenomenon and behavior of the oils with respect to cooling, heating and drying. In determine the thermal conductivity of vegetable oils the method employed and condition of measurement is important. [12,13] reported that thermal conductivity of vegetable oils found in literature showed some variation which may be due to composition and structure for the same materials, hence, thermal conductivity of vegetable oils depend strongly on moisture content, temperature, structure and orientation of the material under consideration.

3.0 Materials and methods

Materials

The materials used in this research are as follows: Castor (C) and Neem (N) seeds oil (obtained from a market in Bichi local government area of Kano state, Nigeria) and low carbon content mild steel as work piece.

Table 1: Equipment and the parameters measured

Equipment	Parameters measured
Lathe machine (model XL400)	Machining operation
HSS cutting tool (19mmx 19mm)	Turning

Digital venier caliper	Measuring tool
Conical flask	Measuring tool
PH Meter (Jenway3510)	PH
Viscometer(model TT-J)	Viscosity
Optical Electron Spectrometer(MS6500K)	Chemical composition
Mechanical Extractor	Oil Extraction
Micrometer screw gauge	Measuring tool
Thermocouple	Temperature
Pensky-martens flash tester	Flash point tester

4.0 Method

The formulation of the cutting fluid was conducted in a 250ml seven necked round bottom flask connected to a overhead motor stirrer, a thermometer and an open separating funnel, Castor oil in various proportions was blend with Neem oil. The formulated oils in their various proportions were charged into the round bottom flask. The mixture was allowed to stir for 30 minutes at 40^{0}C. The blending ratios of the formulated cutting fluids are presented in Table 2.

Table 2: **Method of formulating Cutting fluid**

% Oil sample	Oil quantity ml	Blend ratio	Additives	% Formulation	Remark
100Neem	250	100:1	-	100Neem oil	Cutting fluid
100Castor	250	100;1	-	100Castor oil	Cutting fluid
90Neem+10castor	250	90:10	-	90Neem+10castor	Cutting fluid
80Neem+20castor	250	80:20	-	80Neem+20castor	Cutting fluid
70Neem+30Castor	250	70: 30	-	70Neem+30Castor	Cutting fluid
60Neem+40Castor	250	60: 40	-	60Neem+40Castor	Cutting fluid
50Neem+50Castor	250	50: 50	-	50Neem+50Castor	Cutting fluid

Figure 1: formulated cutting fluids

Table 3: **Determination of Physico-Chemical properties of the formulated Cutting fluids**

Oil sample (%)	Density at 26.3 °C ASTM D97	Refractive index ASTM D97	Saponification no. ASTM D 93	Iodine value ASTM D482	Specific gravity ASTM D93	Viscosity at 23.6°C ASTM 189	Flash point °C ASTM D92	Pour point °C ASTM D97	Emulsion stability	Acid value Mg KOH/g ASTM D95	Viscosity index
100 neeem	4.83	1.466	194.69	88.83	0.917	12.00	329	-38	Good	8.415	50
100 Castor	0.945	1.465	179.23	83.50	0.961	65.33	368	-39	Excellent	17.952	53
90neem+10 Castor	0.934	1.467	39.55	86.29	0.961	21.33	367	-37	Excellent	15.708	56
80neem+20 Castor	0.923	1.468	9.817	30.46	0.927	10.00	368	-37.5	Excellent	7.854	55
70neem+30 Castor	0.892	1.468	5.049	63.45	0.929	20.67	370	-35.1	Excellent	21.879	54.5
60neem+40 Castor	0.835	1.469	39.83	81.23	0.933	27.33	375	-33	Excellent	24.123	56
50neem+50 Castor	0.795	1.470	31.416	116.75	0.937	25.33	354	-42	Excellent	22.40	50

Table 4: **Fatty acid profile of Castor and Neem seed oil**

Fatty acid	**%composition(Neem oil)**	**%composition(Castor)**
Oleic acid (C18:1)	42.20	2.8
Linoleic acid (C18:2)	19.50	4.4
Linolenic acid (C18:3)	0.09	0.2
Erucic acid (C22:1)	0.28	-
Palmitoleic acid (C16:1)	1.88	-
Palmitic acid (C16:1)	15.55	0.69
Stearic acid (C18:0)	18.32	0.72
Arachidic acid (C20:0)	0.18	-
Behenic acid(C22:0)	0.11	-
Lignoceric acid(C24:0)	0.71	-
Dihydroxy stearic acid	-	0.43
Ricinoleic acid(C18:1)	-	90.58
Total	100	99.82

The fatty acid composition of Neem oil (refer to Table 4) shows the present of nine fatty acids, including four major ones. These are oleic acid (42.20%), followed by linoleic acid 19.50%, stearic acid 18.68%, and palmitic acid 15.56%. These fatty acid profiles are within the ranges reported in the literature [14]. Similarly, Table 4 shows the results of fatty acid composition of Castor seed oil. The saturated fatty acids detected in the samples were palmitic, stearic, linoleic, linolineic and dihydroxyl stearic acids. The values were 0.69%, 0.72%, 4.4%, 0.2% and 0.43% respectively. The unsaturated fatty acids detected were ricinoleic acid (90.58%), which may be due to the crude form of the oil, and oleic acid (2.8%). The total fatty acid detected was 99.82%, the reason mighty be as a result of impurities that are present in the crude Castor seed oil [15]. In lubricants industries, knowledge of the fatty acid content could guide the product formulator as to the type of oil and what ingredients to include in the formulation [16].

4.1 Heat conduction and cooling properties test.

Heat removal test was conducted on each of the formulated cutting fluids and the cooling curves were obtained in the non- agitated condition at 32.3^{0}C according to ASTMD6200 which utilizes a 10.5mm diax55mm INCONEL600 cylindrical with a type K thermocouple. Temperatures were recorded at selected time intervals to establish cooling temperature versus time curve. The formulated oils were heated below their various flash point temperatures to prevent the oil from burning and then cooled. Temperatures (^{0}C) were recorded at interval of 60 seconds for each of the blend ratio until the temperature fall to the room temperature.

4.2 Determination of specific heat capacity of the formulated oil samples

Seven samples of formulated oils from the blends of Castor and Neem seed oil were analyzed to determine their specific heat capacities. The samples were labeled as 100% Neem oil, 100% Castor oil, 90% N + 10% C, 80% N + 20% C, 70% N + 30% C, 60% N + 40% C and 50% N + 50% C. 250cm^3 of each of the blended samples were measured. The masses and their volume first noted and recorded. The initial temperature of the samples were also noted and recorded. The sample was put inside a bomb copper calorimeter with the electrode inside the sample oil and a stirrer to distribute the energy supplied. The current and voltage in the experimental circuit was set at1.3A and 3.2V respectively. The energy supplied through the calorimeter is given as Q = Ivt, where I is the current supplied in ampere, v the voltage and t is the heating time. In this experiment, the specific heat capacities of the samples were calculated using heater. The temperature changes were observed every 30seconds till when the temperature gets to 60^{0}C

5.0 Result and discussion

Table 6: Determination of heat conduction and cooling properties of vegetable oils blends

TIME(S)	TEMPERATURE (^{0}C)							
	Neem oil	Castor oil	90N + 10C	80N + 20C	70N +30C	60N + 40C	50N +50C	100SOL
60	265.83	297.34	293.6	297.7	297.85	301	284.97	205.9
120	264.52	294.77	278.33	295.14	295.14	282	280.7	193.5
180	264.18	258.7	264.56	279.44	281.9	262.16	275.13	185.23
240	232.93	223.74	256.23	266.56	271.56	235.35	268.34	174.74
300	199.37	220.74	245.56	253.23	262.66	217.78	259.16	163.22
360	166.80	185.84	234.98	242.45	251.77	202.66	247.44	155.23
420	153.82	164.36	221.34	231.66	238.66	188.67	231.55	146.72
480	145.12	153.37	207.66	219.44	219.78	162.98	222.43	132.66
540	132.53	138.29	197.56	206.98	206.78	132.66	201.88	125.13
600	126.83	129.83	183.56	195.42	195.55	115.56	188.89	112.22

660	121.74	118.26	174.23	183.38	183.38	98.56	172.22	99.79
720	195.33	103.43	158.88	172.66	172.66	88.56	164.8	89.13
780	186.82	92.63	146.43	164.77	164.77	75.95	149.45	72.45
840	178.03	84.15	138.45	155.77	155.77	63.79	132.55	63.67
900	167.33	76.23	126.34	147.83	147.83	51.28	121.13	56.34
960	158.04	63.26	116.52	134.9	134.9	43.86	98.46	48.67
1020	152.03	58.24	103.89	123.67	123.67	32.3	83.77	40.64
1080	147.36	46.27	93.57	119.78	119.78		72.18	35.55
1140	132.73	40.86	84.25	102.33	102.33		63.13	32.3
1200	128.43	36.21	73.79	88.77	88.77		51.88	
1260	122.63	32.3	65.72	73.87	73.87		40.16	
1320	118.4		52.18	64.56	64.56		32.3	
1380	106.12		45.67	55.67	55.67			
1440	98.63		38.61	43.68	43.68			
1500	92.14		32.3	32.3	32.3			
1560	87.32							
1620	83.11							
1680	78.86							
1740	72.63							
1800	67.25							
1860	61.43							
1920	58.77							
1980	53.26							
2040	48.37							
2100	42.13							
2160	38.73							
2220	36.46							
2280	32.3							

From data of heat conduction and cooling of formulated oils (Table 5), and their corresponding cooling curves in figure 1, the thermal gradient for the first cooling duration of 960 seconds was calculated to evaluate the steepness of the gradient of the tested oil samples. It was observed that the thermal gradient of 60N+40C (i.e 3.57) is steeper than 100C (4.15), 50N+50C (4.77), 90N+10C (5.06), 80N+20C (5.51), 70N+30C (5.51) 100 soluble oil (5.809) and 100N (8.43) respectively. Hence, the steeper the thermal gradient of the cooling curves the shorter and faster the cooling rate and better thermal behavior of the oil formulation in terms of heat removal. To this effect, it could be established that 60N+40C oil samples exhibited the best heat removal propensity than 100C, and 50N+50C oil samples. While, 100N and 100% soluble oil demonstrated longer cooling rate and the worst heat removal behavior, this means faster heat removal rate of cutting fluids at the cutting zone results in good surface finish, accurate dimensions, extension of tool life and continuous chip formation during machining. Therefore, It is evident from the foregoings to suggest that 60N+40C, 100C, and 50N+50C oil samples with their superior heat removal behavior than other tested oil samples in the group, would fittingly perform better as cutting oil for machining operations than soluble oil currently in wide applications

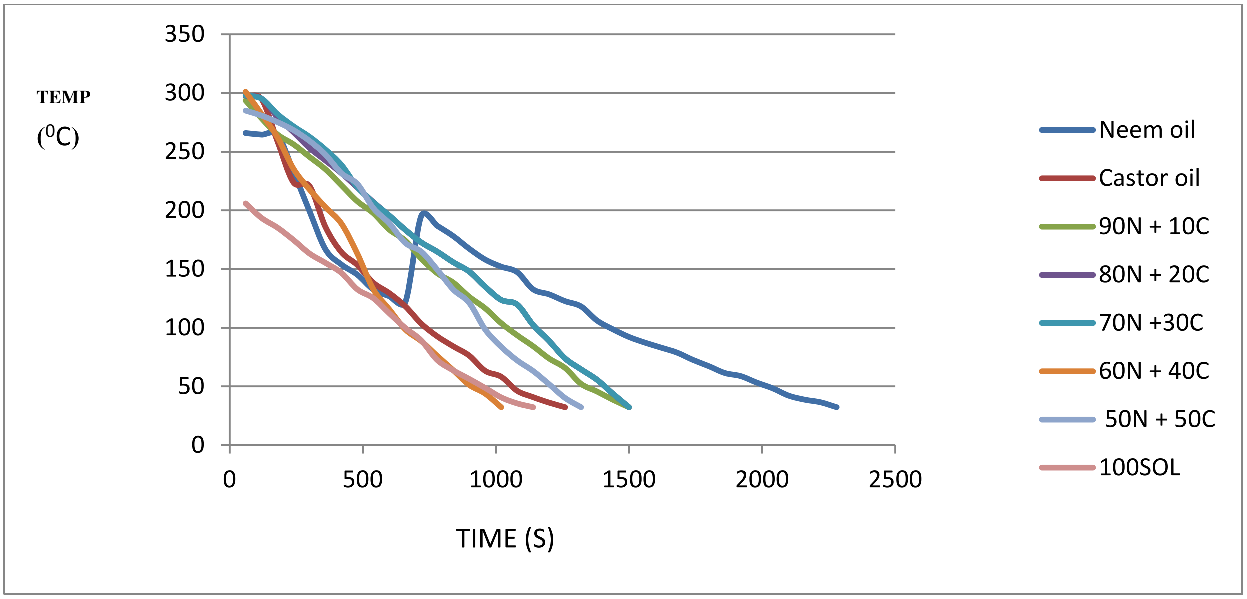

Figure1: Cooling curves for various blends ratios during heating and cooling

Table 6 shows the heat conduction and cooling rate of formulated oils samples namely, 100N, 100C, 90N+10C, 80N+20C, 70N+30C, 60N+40C and 50N+50C from temperature range of 285 ^{0}C to 32.3^{0}C. The table shows that at 300^{0}C, the 60N +40C reach its elevated temperature at 60s while 100N, 100C, 90N+10C; 80N+20C, 70N+30C and 50N+50C reach their elevated temperature at 265.83^{0}C, 297.34^{0}C, 296.6^{0}C, 297.7^{0}C, 297.850C, 284.970C and 205.9^{0}C respectively. This indicates that 60N+40C (300^{0}C) offered a faster cooling behavior than the others oil blends at this heating temperature, while the least temperature was obtained by50N+50C blend ratio. This result reveals that 60N+40C have the best cooling capacity as compared to other oil formulated samples. Cooling capacity is an indication of ability of fluid to remove heat from the heated material during cooling [17]. Neem oil has been reported as having low Linolenic acid (18:2) value which is indication of high heat removal rate.

Table 5: Specific heat capacity of formulated oil samples

% Oil Samples	Specific Heat Capacity (KJ/KgK)
100 Neem (N)	1.5827
100 Castor (C)	1.6953
90 Neem + 10 Castor	1.6503
80 Neem + 20 Castor	1.6412
70 Neem + 30 Castor	1.6211
60 Neem + 40 Castor	1.6991
50 Neem + 50 Castor	1.6779

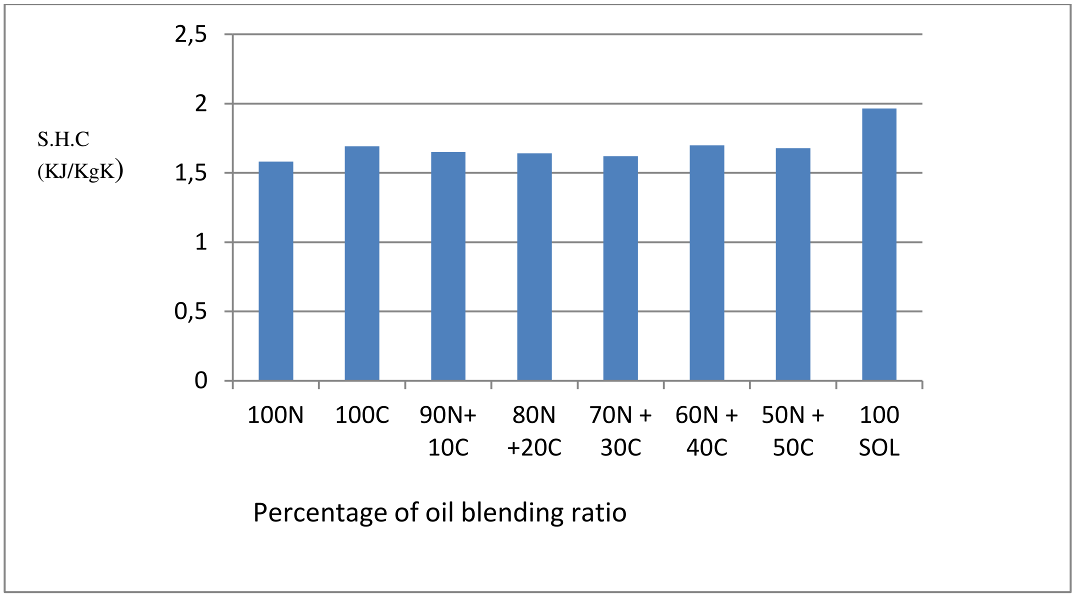

Figure: 2: *Formulated cutting fluids and their specific heat capacity)*

The specific heat capacity is the amount of heat per unit mass required to raise the temperature by one degree Celsius. A good cutting fluid should have high specific heat capacity, so that it can absorb maximum heat from the machining zone as well as cooling the cutting tool and the work piece. Refer to Table 5, it could be seen that blend of 60N+40C oil has highest value of 1.6991 KJ/KgK, followed by pure Castor with value of 1.6817 KJ/KgK. This shows that the blends are capable of absorbing higher heat from the machining zone or acts as a good coolant compared to others formulated cutting fluids. It could be observed that 100%soluble oil exhibited the highest specific heat capacity values than other oil formulated under this study.

5.2 Machining operation:

A mild steel work specimen with dimension 90mm x 75mm x15mm was machined on a lathe, using all samples of the formulated cutting fluid for performance evaluation. The work piece was mounted on a lathe face and centered. Turning operation was conducted at varying speed of 90, 120, 150,180,250,270, 300 and 320rpm respectively at constant feed of 0.5 mm/rev and depth of 2 mm.

Table 6: Effects of machining on some of the measured parameters

Cutting fluid	**Speed (rpm)**	**Chip thickness(mm**	**Chip ratio**	**Temp (^{0}C)**
100N	90	0.317	0.159	52.0
100C	120	0.473	0.237	55.0
90N+10C	150	0.520	0.260	60.1
80N+20C	180	0.660	0.330	69.2
70N+30C	250	0.540	0.270	53.2
60N+40C	270	0.213	0.107	57.3
50N+50C	300	0.325	0.120	59.1
Soluble oil	320	0.21	0.163	77.63

5.3 Effects of Cutting Speed and Feed Rate on Temperature

Table 6 shows the effects of measured parameters on temperature. It can be seen that temperature increases as speed increases and also as the depth of cut increases, and it can also be observed that increase in feed rate at constant speed and depth of cut cause decrease in temperature. This is because cutting forces decrease with speed and since quantity of heat produced is directly proportional to the product of force and velocity (FV) and inversely proportional to mechanical equivalent (E) [18]. It follows that more heat would be generated with an increase in cutting speed. The Neem and Castor oil and their blends sample shows better temperature control in both cutting speed and feed rate compared with conventional cutting fluid as shown in Table 6.Hence, the formulated cutting fluids is capable of temperature control at the cutting zone, through cooling and lubrication as well as improving the qualities of work piece and extend the tool life.

6.0 Conclusion

The cooling property of Castor and Neem oil and their blends offer a competitive performance with that of the convectional cutting fluid as shown by the average temperature difference of 77.6^0C using convectional cutting fluid and 62.3^0C when seven samples of vegetable oil base cutting fluids were applied in machining. The chip thickness formed using vegetable oil base cutting fluid at 90rpm was found to be 0.317 mm which is higher than that of the convectional cutting fluid of 0.213 mm at constant depth of cut of 2mm, the high chip thickness value is probably due to its better lubricating ability, and this allows for better metal removal rate. Hence, better cooling and lubricating properties of oil blends from Castor and Neem oil have found important industrial applications for abundant Neem and Castor oils in Nigeria.

7.0 Recommendation

Further research work on the analysis and the effects of antioxidant (lemon juice) as cutting fluid additive on foaming can be carried out as foam formed takes time to diminish after agitation, this was probably because formulation was carried out at room temperature it likely requires elevating the temperature above 40^0C because surface tension decreases significantly with temperature.

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