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Original Article

Investigating Core Sustainability Components of Eco-Friendly Cutting Fluids Employing Hybrid Nano-Conglomerates

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Abstract - *This paper aims to discuss the biodegradability aspects of conglomerated nano-cutting fluids. Nano molybdenum di sulfide (nM) and nano titanium dioxide (nT) particles are mixed with green base fluids (gBf), and cutting fluids are formulated. Coconut oil (CC) and Canola (Can) are used as base oils to prepare the hybrid nanofluid (hnf) blends. Absorbance, biodegradability index, and microbial contamination of the blends are examined. The properties are measured using respective measurement devices. It was found that the biodegradability index for the formulations was between 0.3 and 0.4. at 0.5% hnf with nM and nT in Cc base fluid, the extent of biodegradation is 0.3525%, compared to other cases. The range within which the biodegradability index lies indicates that through seeding, the disposed fluids can be biologically treated and do not incur harm to the environment. Moreover, being supplied at a minimum quantity of 15ml/min in machining, the quantity of cutting fluids is very less. Microbial contamination (Mbc) is observed to be significant with Cc-based conglomerates compared to the other cases. Mbc for synthetic cutting fluid is more than pure oil blends. Among all the cases considered, hnf blends with CC resulted in less Mbc, followed by Can-based blends.*

Keywords - *Absorbance, Biodegradability aspects, Hybrid nanofluids, MQL, Microbial contamination.*

1. Introduction

Environmentally supportive and endurable cutting fluids are given eminence compared to traditional metal cutting fluids (tMcF). The reason is the non-impeccable outcomes of using tMcF [1,2]. They result in issues related to the wellness of the people/operators/machinists exposed to this machining condition. According to research reports, exposure of workers to machining conditions using synthetic McF effected the epidermis and/or alveolus, eventuating in dermatitis and chronic bronchitis [3,4]. Therewithal, the routine fluids or tMcF lead to disposal related problems in terms of their extensive use in bulk through flood mode of application as cutting fluids during machining operations and hinder the environment since they are not bio-decomposable [5,6]. The cost of machining is also high and contributive through tMcF usage. As reported by Astakov [7,8], tooling costs are approximately two-fold that of other costs. To obtain unmatched machining quality, optimum surface symmetry and minimum tool wear-out are prime factors [9,10]. Enabling this aspect, fluids are supplied incessantly to the exteriors from 1 liter/minute to even 63.4 liters/minute [11,12]. Hence, the probe for surrogates to these fluids has been immense. Near dry machining or minimal supply-assisted machining resulted in promising results, as Ali et al. reported [13]. They investigated machining performance using uncoated carbide tool tips while turning carbide steel (medium). It was noted that, under varying turning conditions, using cutting fluid at 150ml/hour reduced wear (tool) and roughness (workpiece surface). Tawakoli et al. [14] studied the effectiveness of minimal supply cutting fluids while grinding 100Cr6 grade steel using varying machining environments. Thermal defacement using Minimum Quantity Lubrication (MQL) abet grinding was minimal, and material edge flow was also low in correlation with other grinding environments. The viscosity of the coolant must be lower for effective results using MQL, as noted by Tosun and Mesut [15]. They worked with milling and reported that, at higher milling speeds, surface roughness was low through the MQL technique compared to flood mode. MQL is a preferred surrogate to conventional coolant supply methods in milling operations. Lubes extracted from natural eco-safe components like Cocus-nucifera, Helianthus annuus, Glycine max, Brassicaceae and Ricinus Communis oils, etc., are used in place of tMcF in machining operations. Kalowole and Odusote [16] evaluated the role of peanut and palm oils on mild steel during machining. They boosted the oxidative properties of the oils by dispersing citrus extracts.

Viscosity of 28.0 (poise) was the least recorded with peanut oil. The comparison of micrographs with peanut oil resulted in fine, smooth outputs compared to traditional oils. Thus, the surface finish imparted was better using peanut oil compared to other cases. Cutting temperatures recorded were also minimal with this oil. Hence, they proposed that the oil can be used as industrial cutting fluid due to its machining performance improvement characteristics. Given eco-safe machining processes, materials, and systems, researchers have worked on the sustainability aspects of cutting fluids [17].

Researchers [18] analyzed machining performance by taking tool runout and surface texture in mql-machining of Inconel (718) grade material. They considered power consumption, user health, and environmental impact while using dispersions of nAl_2O_3 and mW-CnT. They inferred that nanoparticle concentration contributes to machining outcome and sustainability aspects. Luka Sterle et al. [19] investigated the effect of MoS_2 ($2*10^{-6}$ m particle size) on the coefficient of friction using a tribometer for machining applications. They concluded that the friction coefficient ranged from 0.11 to 0.13, otherwise double conventional fluids' use. From this, they inferred that this solid lubricant can be used in cutting fluid formulations to reduce cutting temperatures during machining. Machining performance improved by a reduction in temperatures and an improvement in the surface quality of the workpiece.

Ricardo et al. [20] examined the comparative performance of graphene and molybdenum di sulfide micro solid lubricants while turning Ti-6Al-4V. Application of the latter resulted in improved tool life, reduced surface roughness, and minimum cutting temperatures compared to the former. Hence, they proposed that solid lubricant-based machining has the potential to improve productivity by enhancing the machining performance. Improvement in machining performance, putting the performance parameters on average, was observed to be up to 43% in the works reported, compared to TMF-assisted machining operations. Due to the high surface area to volume ratio and enhanced thermal conductivity, nanoparticles have the potential to be used in machining as dispersions in base fluids. Philip and Shima [21] reported that suspensions of nanoparticles as colloids in a base-fluid enhance the heat transfer ability of the fluid.

This is a favorable property of using these colloidal formulations in machining. Sharmin [22], with his co-researchers, worked with carbon nanotube dispersions in water-based MF and reported affirmative results regarding machining performance. Interfacial temperatures, machined surface texture, force, and tool runout were reduced by 29%, 34%, 33%, and 39%, respectively. This was at a 0.3% concentration of nano colloids. Nano-cutting fluids through the MQL technique were applied in machining operations by Hegab et al. [23]. MWCNT-based fluids were applied while cutting titanium-based alloy. They compared surface roughness using nanofluid-based and conventional environments. At 2% by weight of nano-dispersions, a 50% reduction was traced in surface roughness. A thirty-eight percent reduction in surface roughness was found at 4% weight of dispersions. They reported that applying MQL nanocutting fluids is affirmative in improving machining performance. Duc TM et al. applied Soyabean oil-based Al2O3 nano formulations during hard milling hardened steel-Si2Mn [24]. They concluded that pure oil based nanofluids with MQL reduced machining forces and improved surface quality.

The sustainability aspects of using nanocutting fluids dispersed in palm oil at varying weight percentages were experimented with by Ibrahim with co-researchers [25]. They worked with titanium alloys in grinding. Grinding energy (specific) was reported to be 91.7 % less than dry conditions at 0.1 % by weight of palm oil-based nano cutting fluids. They inferred that these formulations are energy efficient and contribute to sustainable cutting fluids. Optimum performance and resource utilization in terms of energy, economic viability and society friendly machining processes result in sustainable processes [26]. Hence, it is observed that researchers have conducted experiments related to applications of nanocutting fluids in various machining operations using different supply methods, materials and conditions.

Researchers have experimented with:

i. Vegetable oils, nanoparticles dispersed vegetable oils, surfactants, and emulsifier mixed: cutting fluids in machining operations.
ii. Dry machining, flood supply-based machining, MQL assisted machining, and MQL mist/aerosol-based machining using the above cutting fluids.
iii. Machining performance for different process parameters was investigated.

In addition to the above, it is also paramount that machining performance can be adjudged using hybrid conglomerates by taking advantage of dual nanoparticle combinations dispersed in a base oil. Hence, this work addresses the discussed aspect, which differs from the existing broad literature, emphasizing sustainability studies using experimental and basic software-focused analysis. Machining performance improved using the formulations. The performance of hybrid nano-conglomerates was not/rarely experimented more specifically from the perspective of biodegradability and microbial contamination-related aspects. Conducting research in these dimensions is vital to comprehend the performance of the formulations from machining and sustainability dimensions. Because of these research gaps, the present work also addresses the dimensions.

Fig. 1 (a) Bath type Sonicator for formulation of conglomerates: i) nTio$_2$ with base oil ii) nMoS$_2$ with base oil

Table 1. Properties of base fluids

Base fluid	Saturated	Unsaturated (Mono)	Unsaturated (Poly)
CC	91	6	3
CAN	15	41	42
ii) Carbon chain length			
Base fluid	**Carbon chain type**	**Length of Chain (carbons)**	
CC	M*	8 to 12	
CAN	L**	14 to22	

*M: Medium ; **L: Long

2. Materials and Methods

2.1. Preparation of Hybrid Nanoformulations

The formulations for examination are prepared by manual stirring of base fluids and nanoparticles followed by sonication in a bath-type sonicator for 1 hour [27] reference. Sonication results in a uniform composition of the resultant formulation, avoiding settling hybrid nanoparticles, as shown in Figure 1(a).

The sonication conditions are set at room temperature and slow vibration for one hour, enabling the formulation of the uniform conglomerate to be used for testing properties and machining operations. Coconut and canola oils are taken as base oils owing to their fatty acid composition and carbon chain lengths, as shown in Table 1.

2.2. Absorbance

The absorbance of the formulations reflects the extent of mixing of the conglomerates in the prime fluid. This property helps to interpret the performance of the fluids when applied to machining and aids in understanding their thermo-physical properties [28]. The hybrid conglomerates' absorbance is obtained using a double-beam UV visible spectrophotometer (wavelength:190 nm to 1100nm; accuracy:± 0.002 abs; range:± 4.0 abs; source: deuterium lamp (UV zone);). The samples after sonication are collected in cuvettes at the quantity of 2 ml. The resultant values are recorded thrice, and average values are considered final outputs.

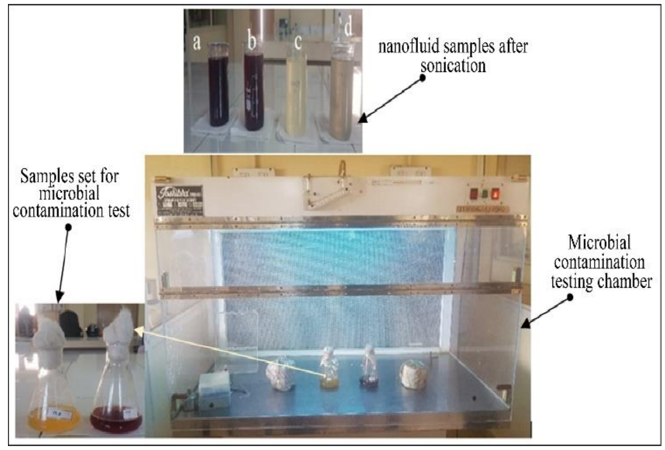

Fig. 1 (b) Samples prepared for contamination test (a,b : Cc+nM @ 0.25%; c,d : Cc+nT@ 0.25%)

2.3. Biodegradability Index

The potential of any matter/medium/substance to disintegrate into innocuous elements is termed biodegradability (Bio-di). This disintegration of the matter is encouraged by introducing pathogens into it. Thus, the extent of Bio-d signifies whether the substance under test is blending with the elements of nature without causing harm to the ecosystem. In this work, the Bio-d of the conglomerates is obtained by evaluating the Bio-d Index (Bio-di). Bio-chemical Oxygen Demand (BoCd) for 5 days (BoCd5) is one indicator of this index, in addition to chemical oxygen demand (ChoDp). The ratio of BoCd5 and ChoDp results in the Biodegradability index for five days. 0.25% and 0.5% of hnp suspensions in Coconut and Canola oils are considered for evaluation of Bio-di. The tests were conducted at Vimta Labs, Visakhapatnam.

2.4. Microbial Contamination

It is the contamination of the cutting fluids by contaminators like fungi, yeast, protozoa, etc. Microbial contamination of cutting fluids makes them lose their cooling and lubricative effectiveness if they are to be reused or left unused for longer. The assessment of this aspect enables understanding the possible extent of microbes' growth in different formulations. 0.25 l of hnf formulation is taken with the base fluids individually. Mbc is observed for 0.25% of hnp suspensions. Nutrient agar (Na) and Potato Dextrose Agar (Pda) are used to initiate Mbc, as shown in Figure 1(b). In the case of Pda, 3.9 g of agar is blended in 100 ml of water (distilled), while 2.8 g of Na was mixed in 100 ml. The resultants are pressurized to 15 lbs and maintained here for 15 minutes. After this, the resultant blends were allowed to cool for 30 minutes. Cutting fluids, when disposed of in the environment (especially water estuaries), poses a critical threat to the surroundings. This happens when the used cutting fluids are discarded without proper treatment [29]. The quantifying parameter measures the impact of cutting fluid discard on the environment's biodegradability. Besides this parameter, contamination in terms of the growth of microbes is also a compounding aspect of comprehending the biodegradability of the formulations. Microbial contamination is also examined for nano cutting fluids. Biodegradability tests were conducted at Vimta Laboratory in Visakhapatnam, and microbial contamination was examined at the Department of Bio-Technology, GITAM, Visakhapatnam.

3. Results and Discussion

The results obtained as a part of the work are reflected and discussed in this section under the following heads:

3.1. Absorbance

Figure 2 (a to c) presents the levels of absorbance of coconut and canola oil based dispersions. The absorbance of the fluids with individual nanoparticles (nM /nT) and hybrid nanoparticles (nM+nT) at varying particle concentrations ranging from 0.25% to 1% are presented and discussed.

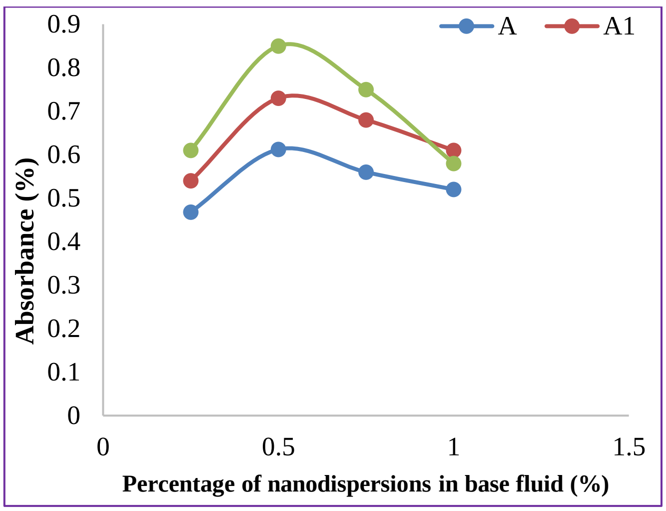

Fig. 2(a) Absorbance for CC based dispersions (A: CC + nM ; A1: CC+nT; A2: CC+nM+nT)

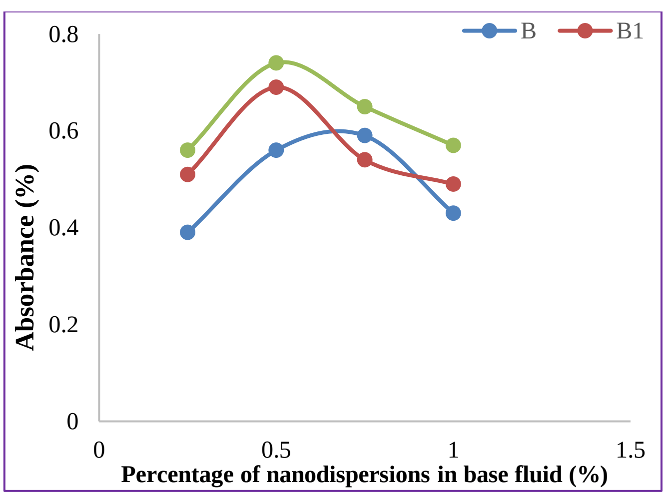

Fig. 2(b) Absorbance for CAN based dispersions (B : Can + nM,B1: Can+nT,B2: Can+nM+nT)

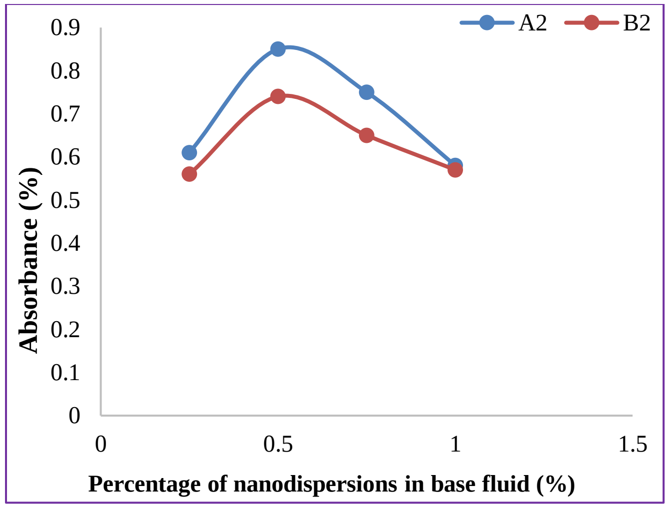

Fig. 2(c) Absorbance for hybrid dispersions (A2 : CC+nM+nT; B2 : Can+nM+nT)

It is observed that the absorbance of nT-based fluids in CC is more compared to nM-based fluids in both the base fluids. At the outset, combining hybrids in CC gave out better dispersion than hybrids in Can. From the viewpoint of particle percentage, absorbance is found to increase with an increase in nanoparticle concentration up to 0.5%, which reflects a decrease in the same after this percentage.

The reason may be aggregation n of np after a certain percent of dispersions. Depending on these results, machining experiments can be more affluently conducted up to a certain particle concentration (0.5% in this case), and more calculative experimentation beyond this percentage is required.

3.2. Biodegradability Index (Bio-di5)

Bio-di5 is reflected with BoCD and ChoDp in %, as shown in Table 2. The Bio-di5 for all the cutting fluid combinations with vegetable oils is greater than 0.3, from which it can be inferred that before being disposed to the environment, these conglomerates do not require any specific treatment for Bio-di5 of these samples compared to synthetic cutting fluids used in machining is less than 0.3 [30]. Thus, it is important to note that using natural vegetable oils with blends of np in milligrams does not hinder the environmental balance [31]. Moreover, titanium dioxide in the nanoform is a non-toxic material, and hence, researchers are finding ways to explore the applications of nT in the medical field [32]. Among all the cases tested in this work, within a fraction of a second decimal greater than 0.3, CC+0%nM+0.25%nT has a higher value of Bio-Di5. CC and Can, with 0.5% of nM and nT, each reflected the next level of biodegradability index compared to other cases. This is due to the non-toxic properties of nT compared to nM in the former case, while in the latter case, an increase in the percentage of nT from 0.25 to 0.5 has imparted a good extent of biodegradability. Bio-di5 value of 0.3525 is reflective of the following aspects:

1) The composition is subjected to slow degradation and is invulnerable to microbes.
2) Subject to additional processing/ treatment, it does not harm the environment.
3) The extent of biological disintegration activity aided by bacterial/fungi.

In total, with slight variation, all the samples / hybrid conglomerates resulted in a comparable and safe range of biodegradability index, which is less than 0.3. This variation in the index for all the samples is reflected in Figures 3 to 5, showing BoCD and ChoDp with respect to the sample on the x-axis.

Table 2. BoCd, ChoDp for nano-conglomerates (value set2) with Biodegradability index (BoDi)

Conglomerate description	BoCD (%)	ChoDp (%)	Bio-di = BoCD5/ChoDp (Index)
CC+0.25%nM+0% nT	24.6	69.8	0.3524
Can+0.25%nM+0%nT	33.3	97.1	0.3429
Can+0%nM+0.25%nT	45.8	105.6	0.3496
CC+0%nM+ 0.25%nT	72.6	208.2	0.3487
CC+0.25%nM+0.25%nT	23.4	69.8	0.3352
Can+0.25%nM+0.25%nT	44.4	127.0	0.3496
CC+0.5%nM+0.5%nT	60.6	171.4	0.3535
Can+0.5%nM+0.5%nT	70.5	200	0.3525
CC+0.75%nM+0.75%nT	62.4	179.0	0.3486
Can+0.75%nM+0.75%nT	59.7	170.1	0.3509

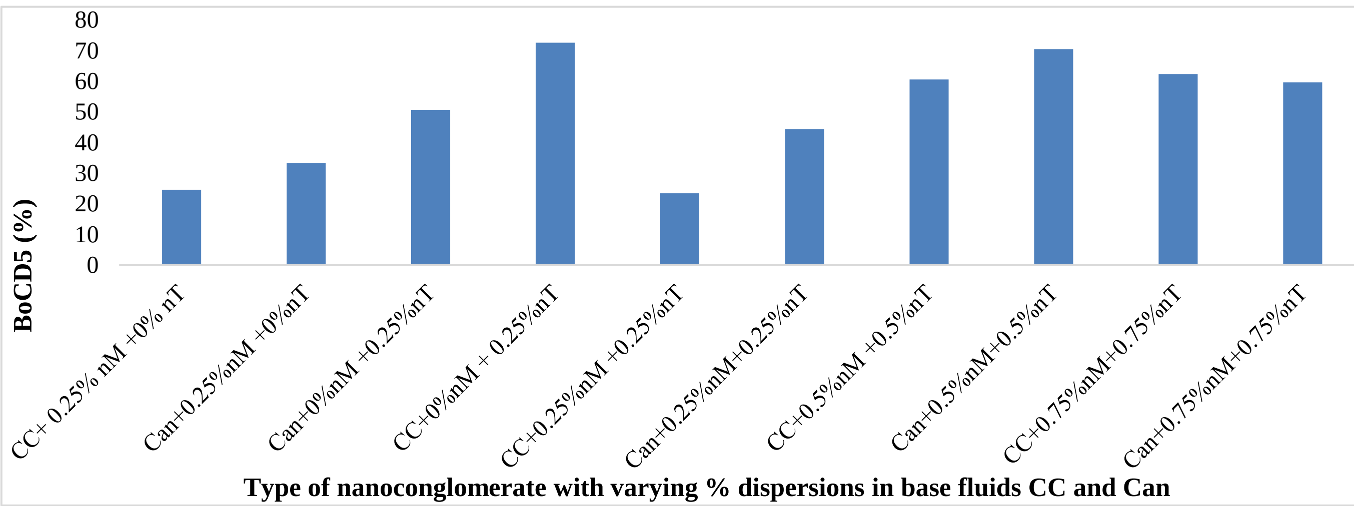

Fig. 3 Biochemical oxygen demand @ 5 days for different types of conglomerates

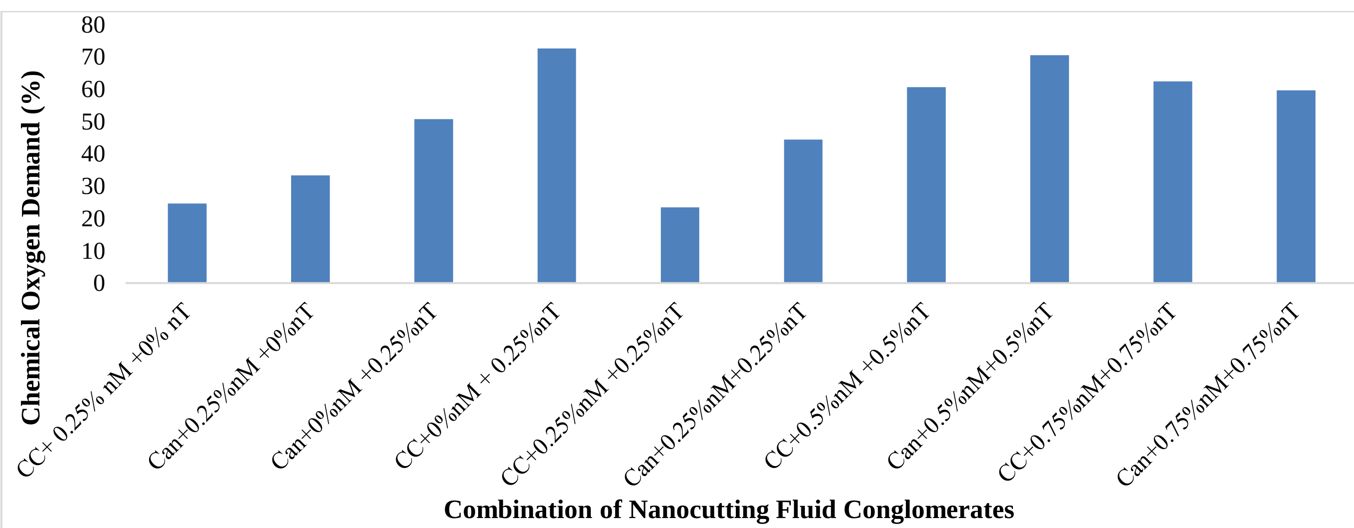

Fig. 4 Chemical oxygen demand for different types of conglomerates

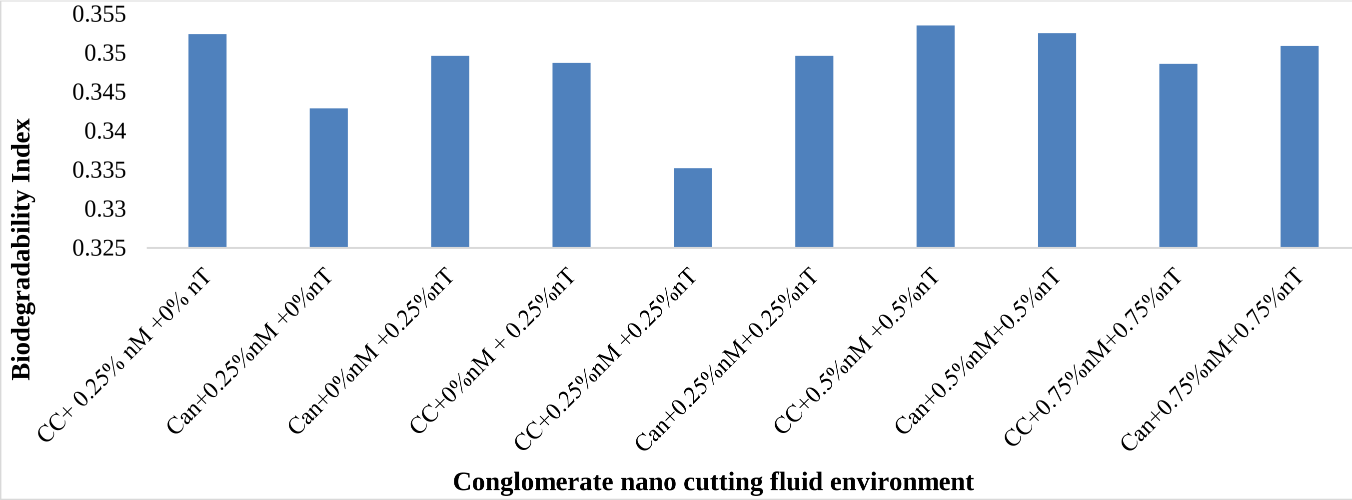

Fig. 5 Biodegradability index for varying cutting fluid conglomerates

The cutting fluids with a biodegradability index (0.3 to 0.4) are partially biodegradable. These values are affirmative compared to the biodegradability index of conventional fluids used in machining. Hence, their usage deems it advantageous compared to their conventional counterparts. In real-time environments, post-usage, these formulations can be reused/ treated and disposed of to minimize the environmental impact. Moreover, the supply method for these conglomerates is minimal lubrication, 10ml/min to 15 ml/min. Hence, the fluids' quantity is minimal during disposal compared to flood-based conventional cutting fluids. Through MQL, the huge quantity of fluid usage is reduced, and by adding hybrid dispersions, the aim is also to improve machining performance.

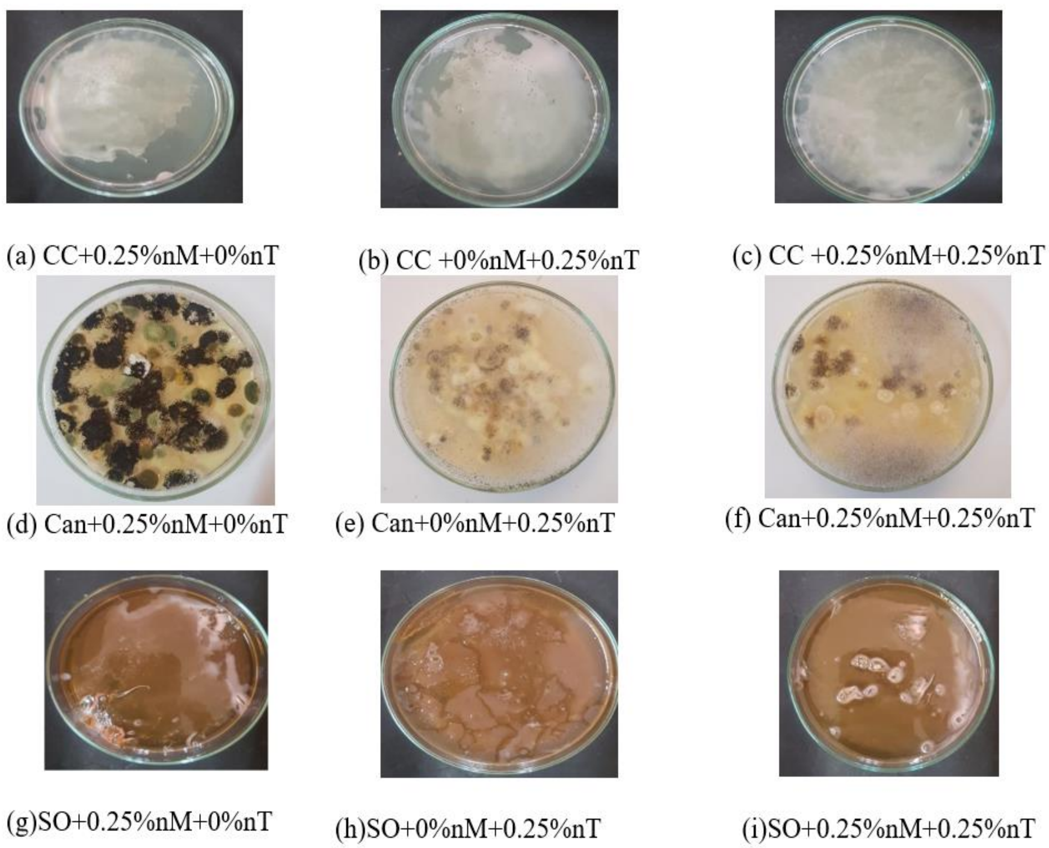

Fig.6 Images of microbial contamination for various conglomerates (a-c) : CC with nanoformulations ; (d-f) Canola with nanoformulations ; (g-i) Soluble oil with nanoformulations

3.3. Microbial Contamination

Microbial contamination for nanocutting fluid and hybrid nanocutting fluid conglomerates is presented with images and inferences in Figure 6 (a to i). The results for SAE oil with nano and hybrid nano dispersions are also shown. Mbc for CC based blends is shown in Figure 6(a-c), similarly for CAN based ones from Figure 6(d-f), and the last three images reflect Mbc for SAE nano and hybrid nano blends, respectively. The extent of contamination is more significant in the case of SAE-based blends than in the case of Can and CC counterparts. Meanwhile, for CC-based nano and hybrid blends, Mbc is the least compared to Can-based cutting fluids. Mbc for all the samples is observed for 3 days at 0.25% of nano dispersions. The comparison is made with 0.25% nM and 0.25% nT individually in all three oils and with a hybrid blend. The hybrid blend of nM and nT at 0.25% exhibited less Mbc than nT and nM. nT being is less toxic than nM, resulting in less Mbc in individual blends.

The very nature of Cc being antibacterial because it is used for skin-related problems has resulted in low Mbc compared to Can. The combination of Cc with nM and nT reflected the least microbial contamination, as seen in the images. Besides visual observations of Mbc, the formation of bacteria and fungi in the nanocutting fluids is reflected through the number of colony formation units or colony-forming units (CoFu) [33]. Figure 7 (a to i) shows the nanofluid type and the number of CoFu for the samples considered in this work. In equivalence to the visual observation of images, the extent of microbial contamination is more significant in the case of SO and CAN-based fluids compared to CC-based counterparts.

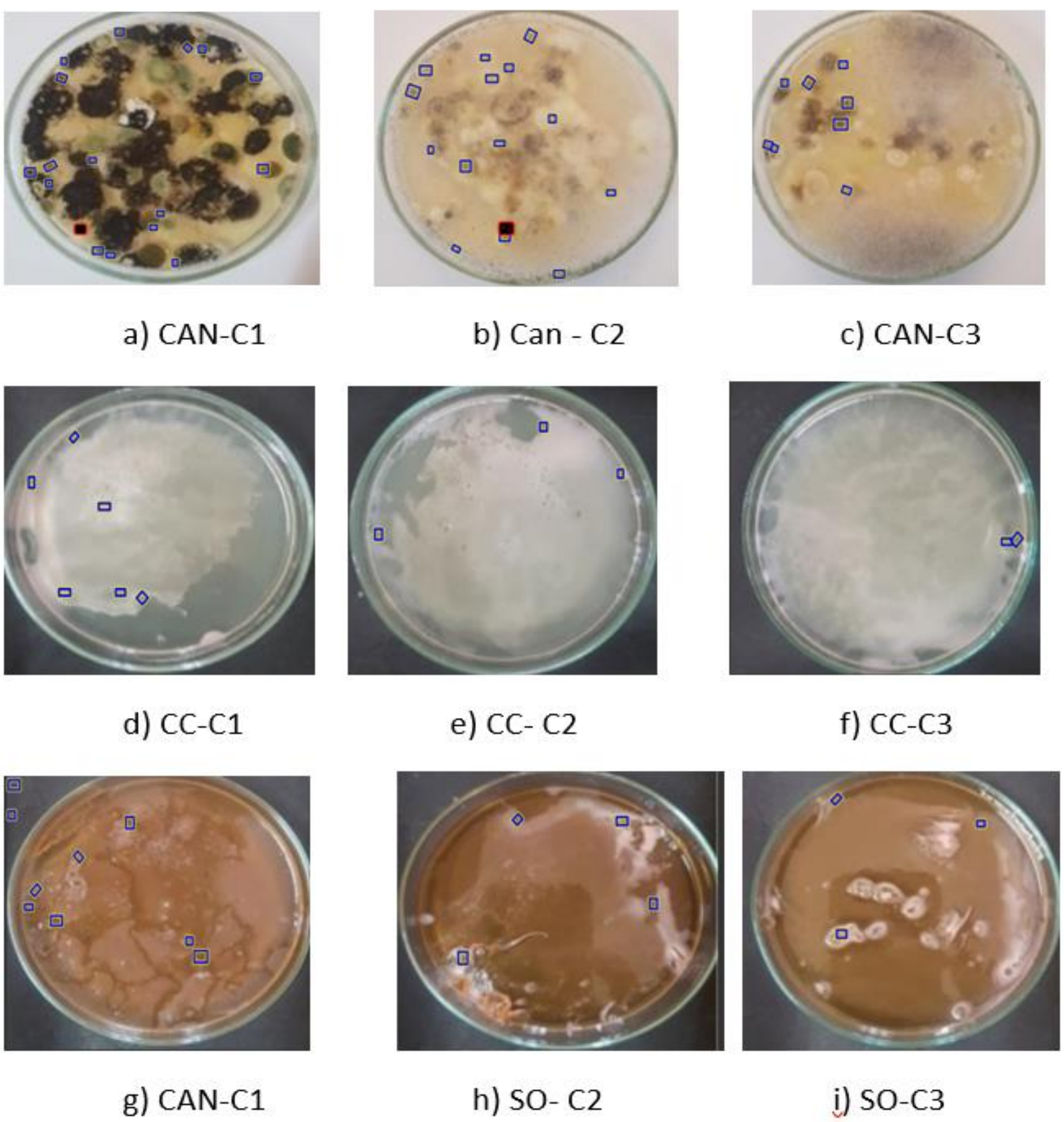

Fig. 7 Representation of CoFu in each type of nanofluid sample (a-i)

Individually, hybrid conglomerates gave out minimum CoFu in each base fluid. The formation of colonies is identified and marked in blue, as shown in Figure 8.

The datasheet extracted from OpenCFU application software is presented in Figure 9, representing the characteristics of the images processed for identifying CoFu in each petri plate of a specific nanofluid type. It is observed that nanohybrid conglomerates in all three base oils gave out low values of CoFu. Within the three oils, a deviation is observed in Canola oil with 0.25% nM, resulting in a maximum CoFu of 16 compared to other cases, including soluble oil. The reason can be attributed to the agglomeration of nanoparticles, and the base fluid might contain previously existing colony formation, which accelerates during the Mbc examination process. Except for this deviation, the Mbc for pure oils is less than the mineral oil counterpart in all the other cases. Hence, it can be inferred that, compared to this case (Canola's Mbc), CC with nanohybrids Mbc is less by 87.5% and 77.7% compared to SO (CoFu = 7 with nM).

In total, the results obtained as an outcome of this experimental work are better/comparable to those available in literature because of the ensuing aspects:

- Testing procedures implemented are in industrial / research labs and are as per standards.
- Hence, the results are more accurate than those obtained in academic testing environments.
- Bio-Di5 and Mbc are examined for hybrid nano-conglomerates with nT and nM dispersions, which is different in this work compared to other existing literatures.
- The purpose of the formulations is to be used in machining as machining fluids subject to verification of properties and sustainability facets. Hence, the purpose is not limited to analysis of the aspects but also to inspect the applicability of the fluids in the aforesaid operations.
- Mbc for various cases reported here is tested using the OpenCFU software application, where the results also agree with those obtained for Bio-Di5.

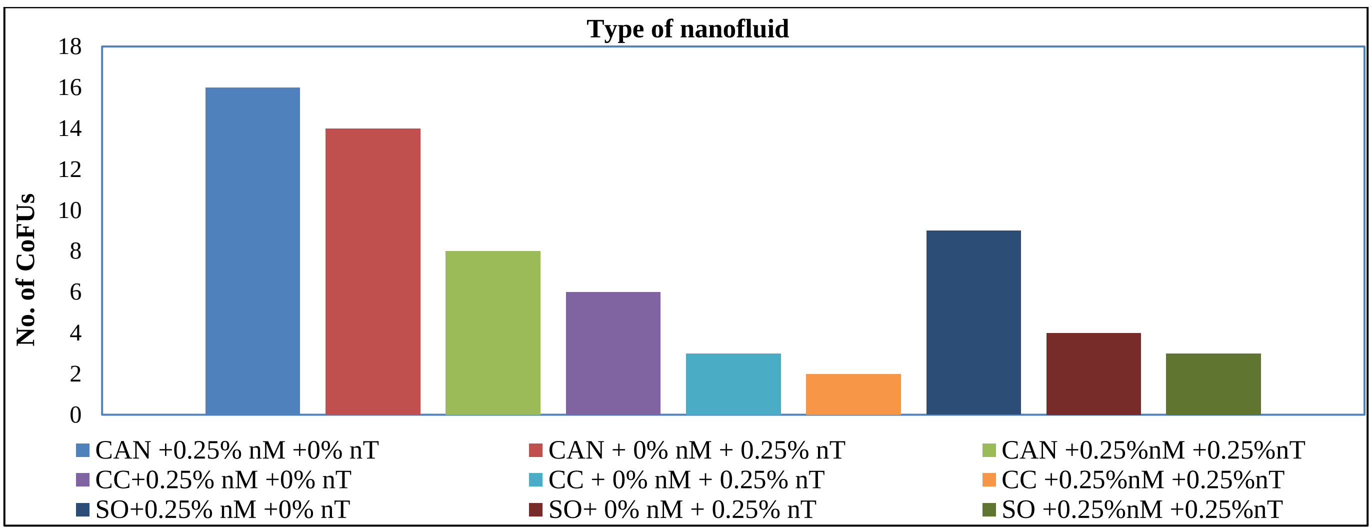

Fig. 8 Representation of CoFu for different nanofluid samples

Full_Path	X	Y	ROI	N_in_clust	Area	Radius	Hue	Saturatior	Rmean	Gmean	Bmean	Rsd	Gsd
C:\Users\91837\Desktop\running\Manuscripts\IMGS\CAN CASE 1	100.5	152	1	2	17	3	42	44	96.4118	88.4118	67.5294	33.867	33.6191
C:\Users\91837\Desktop\running\Manuscripts\IMGS\CAN CASE 1	28	106	1	4	18	3	18	49	58.9444	46	40	10.9637	8.83156
C:\Users\91837\Desktop\running\Manuscripts\IMGS\CAN CASE 1	17	99.5	1	4	35	4	36	10	68.7429	67.2571	63.8286	29.623	27.9161
C:\Users\91837\Desktop\running\Manuscripts\IMGS\CAN CASE 1	151	97.5	1	2	36	4	38	101	130.333	102.278	55.75	25.9678	22.231
C:\Users\91837\Desktop\running\Manuscripts\IMGS\CAN CASE 1	35.25	44.75	1	2	20	3	34	83	100.05	78.15	51.15	22.3693	20.739
C:\Users\91837\Desktop\running\Manuscripts\IMGS\CAN CASE 1	63.5	147.5	1	1	16	3	52	33	68.8125	66.6875	52.5625	21.7853	20.7918
C:\Users\91837\Desktop\running\Manuscripts\IMGS\CAN CASE 1	56	145	1	1	26	4	44	36	88.5385	82.7308	67.1923	37.3828	38.0297
C:\Users\91837\Desktop\running\Manuscripts\IMGS\CAN CASE 1	88	131.5	1	1	16	3	42	93	102.75	86.9375	48.1875	19.478	16.0726
C:\Users\91837\Desktop\running\Manuscripts\IMGS\CAN CASE 1	46	132.5	1	1	15	3	36	77	170.333	140.867	96.0667	11.2155	12.7693
C:\Users\91837\Desktop\running\Manuscripts\IMGS\CAN CASE 1	92	123.5	1	1	15	3	36	96	84.0667	65.4	38.2667	15.8659	14.8072
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C:\Users\91837\Desktop\running\Manuscripts\IMGS\CAN CASE 1	107.75	27.25	1	1	17	3	36	82	80.3529	63.7647	41.4118	21.9788	19.1385
C:\Users\91837\Desktop\running\Manuscripts\IMGS\CAN CASE 1	116	28	1	1	18	3	32	50	63.6111	53.9444	42.9444	10.604	9.80323
C:\Users\91837\Desktop\running\Manuscripts\IMGS\CAN CASE 1	68.5	18	1	1	25	3	46	21	86.28	83.44	72.6	29.9213	29.5154
C:\Users\91837\Desktop\running\Manuscripts\IMGS\CAN CASE 2	82	131	1	2	24	4	32	68	146.875	118.417	85.2083	11.887	12.2691
C:\Users\91837\Desktop\running\Manuscripts\IMGS\CAN CASE 2	83	126	1	2	27	4	32	79	145.741	113.444	76.6296	16.8922	16.3992
C:\Users\91837\Desktop\running\Manuscripts\IMGS\CAN CASE 2	38.5	83	1	3	16	3	32	67	177	150.75	121.375	9.71063	10.0588
C:\Users\91837\Desktop\running\Manuscripts\IMGS\CAN CASE 2	114	151	1	1	30	4	50	26	144.433	140	119	18.4159	17.7432
C:\Users\91837\Desktop\running\Manuscripts\IMGS\CAN CASE 2	53.4	137.2	1	1	13	3	34	44	174.923	161.154	142.385	6.13602	5.40011
C:\Users\91837\Desktop\running\Manuscripts\IMGS\CAN CASE 2	144.5	106.5	1	1	21	3	34	61	173	150.238	121.19	9.95491	10.1386
C:\Users\91837\Desktop\running\Manuscripts\IMGS\CAN CASE 2	59	92	1	1	43	4	34	66	164.302	135.581	100.628	15.207	15.5158

my_results | Sheet1

Fig. 9 Representation of OpenCFU data sheet for the nanofluid images processed

4. Conclusion

The absorbance of CC-based fluids is higher by approximately 10 to 15 % than its pure oil counterpart. The biodegradability index for all the samples is greater than 0.3. CC+0%nM+0.25%nT has a higher value. With 0.5% of nM and nT, CC and Can report the next value. Microbial contamination is high for mineral oil-based formulations, followed by canola counterparts. CC-based formulations are seen to be subjected to the least contamination. Among all the cases, contamination for hybrid conglomerates of nT and nM in CC is the least obtained from OpenCFU software-based image processing and analysis.

Limitations

- This work primarily focuses on sustainability aspects at large. Machining performance regarding temperature effects is not discussed, but it can be addressed from the application point of view.
- The conglomerates are in the 0.25 to 0.75% percentile range, as considered in this work. The variation in the percentage of hybrid nanoparticles can be further extended beyond 0.75% to comprehend the sustainability facets at a broader.
- The duration of microbial conta mination considered in this work is two months. An extended period of contamination studies would reveal more interesting results for interpreting the exact combinations of oil and nanoparticle percentages that trigger contamination in addition to environmental conditions. This aspect is vital and must be analyzed in view of industrial cutting fluids.The results obtained in this world can ensure the applicability of eco-safe fluids for industrial needs. Hence, it needs further exploration.

Future Work

This work can be further enhanced in the long run for extended investigations of the following aspects:

i. To conduct the biodegradability and microbial contamination tests for more than 3 months for in-depth analysis and inferences.
ii. Optimization in terms of hybrid nanoparticle percentage and type of oil can be done to obtain the best results in terms of sustainability aspects and machining performance, as well as with minimal utilization of resources.
iii. Economic evaluation can be done to interpret the cost-benefit analysis of testing and using the conglomerates.

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References

[1] Mirko Soković, and Krsto Mijanović, "Ecological Aspects of the Cutting Fluids and its Influence on Quantifiable Parameters of the Cutting Processes," *Journal of Materials Processing Technology*, vol. 109, no. 1-2, pp. 181-189, 2001. [CrossRef] [Google Scholar] [Publisher Link]

[2] Agustín Alomar, "Occupational Skin Disease from Cutting Fluids," *Dermatologic Clinics*, vol. 12, no. 3, pp. 537-546, 1994. [CrossRef] [Google Scholar] [Publisher Link]

[3] Kun Li et al., "Health Risks from Exposure to Metal-Working Fluids in Machining and Grinding Operations," *International Journal of Occupational Safety and Ergonomics*, vol. 9, no. 1, pp. 75-95, 2003. [CrossRef] [Google Scholar] [Publisher Link]

[4] Meciarova Julia, and Miroslav Stanovsky, "Cutting Fluids Evaluation Based on Occupational Health and Environmental Hazards," *Contents of Proceedings of 10th International Scientific Conference, Engineering for Rural Development*, Jelgava, Latvia, 2011. [Google Scholar] [Publisher Link]

[5] Ratul Saha, and Robert S. Donofrio, "The Microbiology of Metalworking Fluids," *Applied Microbiology and Biotechnology*, vol. 94, pp. 1119-1130, 2012. [CrossRef] [Google Scholar] [Publisher Link]

[6] Christina Cheng, David Phipps, and Rafid M. Alkhaddar, "Treatment of Spent Metalworking Fluids," *Water Research*, vol. 39, no. 17, pp. 4051-4063, 2005. [CrossRef] [Google Scholar] [Publisher Link]

[7] Viktor P. Astakhov, *Ecological Machining: Near-Dry Machining*, Machining, Springer, pp. 195-223, 2008. [CrossRef] [Google Scholar] [Publisher Link]

[8] Viktor P. Astakhov, *Environmentally Friendly Near-Dry Machining of Metals*, Metalworking Fluids (MWFs) for Cutting and Grinding, pp. 135-200, 2012. [CrossRef] [Google Scholar] [Publisher Link]

[9] Ben-Kai Li et al., "An Investigation on Machined Surface Quality and Tool Wear during Creep Feed Grinding of Powder Metallurgy Nickel-Based Superalloy FGH96 with Alumina Abrasive Wheels," *Advances in Manufacturing*, vol. 8, pp. 160-176, 2020. [CrossRef] [Google Scholar] [Publisher Link]

[10] Mohd Naqib Derani, and Mani Maran Ratnam, "The Use of Tool Flank Wear and Average Roughness in Assessing Effectiveness of Vegetable Oils as Cutting Fluids During Turning-A Critical Review," *The International Journal of Advanced Manufacturing Technology*, vol. 112, pp. 1841-1871, 2021. [CrossRef] [Google Scholar] [Publisher Link]

[11] E.C. Bianchi et al., "Optimization of Minimum Quantity Lubrication in Grinding with CBN Wheels," *Machining and Machine-Tools*, pp. 113-133, 2013. [CrossRef] [Google Scholar] [Publisher Link]

[12] Junaid Haider, and Mohammed Saleem J. Hashmi, "8.02-Health and Environmental Impacts in Metal Machining Processes," *Comprehensive Materials Processing*, vol. 8, pp. 7-33, 2014. [CrossRef] [Google Scholar] [Publisher Link]

[13] S. M. Ali, N. R. Dhar, and S. K. Dey, "Effect of Minimum Quantity Lubrication (MQL) on Cutting Performance in Turning Medium Carbon Steel by Uncoated Carbide Insert at Different Speed-Feed Combinations," *Advances in Production Engineering and Management*, vol. 6, no. 3, pp. 185-196, 2011. [Google Scholar] [Publisher Link]

[14] Taghi Tawakoli, Mohammad Jafar Hadad, and Mohammad Hossein Sadeghi, "Investigation on Minimum Quantity Lubricant-MQL Grinding of 100Cr6 Hardened Steel Using Different Abrasive and Coolant-Lubricant Types," *International Journal of Machine Tools and Manufacture*, vol. 50, no. 8, pp. 698-708, 2010. [CrossRef] [Google Scholar] [Publisher Link]

[15] Nihat Tosun, and Mesut Huseyinoglu, "Effect of MQL on Surface Roughness in Milling of AA7075-T6," *Materials and Manufacturing Processes*, vol. 25, no. 8, pp. 793-798, 2010. [CrossRef] [Google Scholar] [Publisher Link]

[16] Sharafadeen Kunle Kolawole, and Jamiu Kolawole Odusote, "Performance Evaluation of Vegetable Oil-Based Cutting Fluids in Mild Steel Machining," *Chemistry and Materials Research*, vol. 3, no. 9, pp. 35-45, 2013. [Google Scholar] [Publisher Link]

[17] Hussien Hegab, Basil M. Darras, and Hossam A. Kishawy, "Sustainability Assessment of Machining with Nano-Cutting Fluids," *Procedia Manufacturing*, vol. 26, pp. 245-254, 2018. [CrossRef] [Google Scholar] [Publisher Link]

[18] V. Sharan, N. Rajesh Jesudoss Hynes, and R. Sankaranarayanan, "Biodegradable Cutting Fluids for Manufacturing Processes," *3rd International Conference on Condensed Matter and Applied Physics*, *AIP Conference Proceedings*, Bikaner, India, vol. 2220, no. 1, 2020. [CrossRef] [Google Scholar] [Publisher Link]

[19] Luka Sterle, Mitjan Kalin, and Franci Pušavec, "Performance Evaluation of Solid Lubricants under Machining-Like Conditions," *Procedia CIRP*, vol. 77, pp. 401-404, 2018. [CrossRef] [Google Scholar] [Publisher Link]

[20] Ricardo R et al., "The Effect of Application of Cutting Fluid with Solid Lubricant in Suspension during Cutting of Ti-6Al-4V Alloy," *Wear*, vol. 332-333, pp. 762-771, 2015. [CrossRef] [Google Scholar] [Publisher Link]

[21] John Philip, and P.D. Shima, "Thermal Properties of Nanofluids," *Advances in Colloid and Interface Science*, vol. 183-184, pp. 30-45, 2012. [CrossRef] [Google Scholar] [Publisher Link]

[22] Israt Sharmin, Abdul Gafur, and Nikhil Ranjan Dhar, "Preparation and Evaluation of a Stable CNT-Water Based Nano Cutting Fluid for Machining Hard-to-Cut Material," *SN Applied Sciences*, vol. 2, no. 4, 2020. [CrossRef] [Google Scholar] [Publisher Link]

[23] H. Hegab et al., "On Machining of Ti-6Al-4V Using Multi-Walled Carbon Nanotubes-Based Nano-Fluid Under Minimum Quantity Lubrication," *The International Journal of Advanced Manufacturing Technology*, vol. 97, pp. 1593-1603, 2018. [CrossRef] [Google Scholar] [Publisher Link]

[24] Tran Minh Duc, Tran the Long, and Ngo Minh Tuan, "Performance Investigation of MQL Parameters Using Nano Cutting Fluids in Hard Milling," *Fluids*, vol. 6, no. 7, pp. 1-15, 2021. [CrossRef] [Google Scholar] [Publisher Link]

[25] Ahmed Mohamed Mahmoud Ibrahim et al., "Energy Conservation and Environmental Sustainability during Grinding Operation of Ti-6Al-4V Alloys via Eco-Friendly Oil/Graphene Nano Additive and Minimum Quantity Lubrication," *Tribology International*, vol. 150, 2020. [CrossRef] [Google Scholar] [Publisher Link]

[26] Peter Krajnik et al., "Transitioning to Sustainable Production-Part III: Developments and Possibilities for Integration of Nanotechnology into Material Processing Technologies," *Journal of Cleaner Production*, vol. 112, pp. 1156-1164, 2016. [CrossRef] [Google Scholar] [Publisher Link]

[27] Franci Pusavec et al., "Sustainable Machining of High Temperature Nickel Alloy-Inconel 718: Part 1-Predictive Performance Models," *Journal of Cleaner Production*, vol. 81, pp. 255-269, 2014. [CrossRef] [Google Scholar] [Publisher Link]

[28] Dayanand Ananda Ghatge et al., "Improvement of Machinability Using Eco-Friendly Cutting Oil in Turning Duplex Stainless steel," *Materials Today: Proceedings*, vol. 5, no. 5, pp. 12303-12310, 2018. [CrossRef] [Google Scholar] [Publisher Link]

[29] Jiju Guan et al., "Lubrication Mechanisms of a Nanocutting Fluid with Carbon Nanotubes and Sulfurized Isobutylene (CNTs@ T321) Composites as Additives," *Lubricants*, vol. 10, no. 8, pp. 1-15, 2022. [CrossRef] [Google Scholar] [Publisher Link]

[30] Ramanujam Saravanathamizhan, and V.T. Perarasu, "Improvement of Biodegradability Index of Industrial Wastewater Using Different Pretreatment Techniques," *Wastewater Treatment*, pp. 103-136, 2021. [CrossRef] [Google Scholar] [Publisher Link]

[31] Evangelos G. Giakoumis, "Analysis of 22 Vegetable Oils' Physico-Chemical Properties and Fatty Acid Composition on a Statistical Basis, and Correlation with the Degree of Unsaturation," *Renewable Energy*, vol. 126, pp. 403-419. [CrossRef] [Google Scholar] [Publisher Link]

[32] Daniel Ziental et al., "Titanium Dioxide Nanoparticles: Prospects and Applications in Medicine," *Nanomaterials*, vol. 10, no. 2, pp. 1-31, 2020. [CrossRef] [Google Scholar] [Publisher Link]

[33] Lizhi Tang et al., "Biological Stability of Water-Based Cutting Fluids: Progress and Application," *Chinese Journal of Mechanical Engineering*, vol. 35, no. 1, pp. 1-24, 2022. [CrossRef] [Google Scholar] [Publisher Link]