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Evaluation of Ecological Minimum Quantity Lubrication Turning of AISI 4340 Alloy for Parametric Choices Using the Distance from Average Solution (EDAS) Method

Chukwuka Prosper Ozule [1], Adeyinka Oluwo[2], Manasseh Olusegun Oyekeye[3], John Rajan[4], Swaminathan Jose[5], Sunday Ayoola Oke[6]*
[1,2,3,6] Department of Mechanical Engineering, University of Lagos, Lagos 101017 Nigeria
[4] Department of Manufacturing Engineering, School of Mechanical Engineering, Vellore Institute of Technology, Vellore 600127 India
[5]School of Mechanical Engineering, Vellore Institute of Technology, Vellore 600127 India

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ABSTRACT

Flood-cutting fluids and minimum quantity lubrication (MQL) schemes are associated with high cutting fluid costs and health effects, which should be regulated through the selection and optimization of parameters. This paper applies the distance from average solution (EDAS) method to assess the criteria value regarding three alternatives (cutting depth, cutting speed and feed) using CuO nano lubricants discharged in minimum quantity lubrication. Three responses, including beneficial (cutting speed, feed and cutting depth) and non-beneficial (cutting force) responses were used. A novel weight determination scheme based on the beneficial and non-beneficial criteria was established for the first time as inputs to the EDAS method. The weights established 0.1504, 0.2832, 0.2832 and 0.2832 for cutting force, cutting speed, feed and cutting depth, respectively. The results show a multi-modal best performance of 0.8438, which occurs in multiple experimental trials of 2, 4, 5, and 8. The optimization implemented in this study uses all inputs and the CuO nano lubricant was considered in each case using a spreadsheet for the evaluation. Case study data illustrating the uniqueness of the method using the literature data shows that EDAS is robust enough to be applied in machining activities.

***Corresponding Author**
Sunday Ayoola Oke
E-mail: sa_oke@yahoo.com

1. INTRODUCTION

Flood-cutting fluids and minimum quantity lubrication (MQL) fluids are alternative fluids used in machining and their use has been for several years now. For instance, flood-cutting fluids, also known as flood-cooling fluids, have recorded tremendous success for the past eight years according to a literature search. This is confirmed by the notable application by Sankar and Choudhury (2015) concerning the effect of flood cooling on three major responses of machining systems, notably tool flank wear, average surface roughness and the thickness of chips. Others are Gajrani et al

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(2017) with the application of flood cooling to the machining of hardened AISI H-13 steel. Gajrani et al (2019) conducted experiments on AISI H-13 steel with a bias for green cutting fluid under the flooding cooling system Gueli et al (2021) used the flood cooling scheme on Inconel 718 during a slot milling operation. Kumar et al (2022) analyzed the thermal scheme while drilling titanium under the flood cooling system. Das and Ghosh (2023) studied the effectiveness of using coats made of TiAlSiN under flood cooling conditions.

Besides this wide array of studies on flood cooling, the papers that have utilized minimum quantity lubrication are the following: Filho et al (2017) used the minimum quantity of lubrication fluid on cast aluminium alloy. Syed and Paliwal (2018) applied the minimum quantity lubrication fluid in modelling the lubrication problem from the finite element-based model for Liet al (2019) focused on the TC4 alloy while milling but using the minimum quantity lubrication scheme. Sharm and Kumar (2021) provided an overview of the minimum quantity lubrication fluid usage. Kumar and Prasad (2021) turned the DSS-2205 material under the minimum quantity lubrication scheme. Sonawane et al (2022) focused on minimum quantity lubrication but concentrated on vegetable oil. Maruda et al. (2023a) examined the minimum quantity of lubrication fluid and its impact when processing 316L steel.

However, of interest to many researchers nowadays is the MQL scheme because of the immense benefits that it showcases. These include reducing the machining work cycle times, which is generally claimed in literature to be roughly between 25% and 80%. Other advantages include superior finish and tolerance and, total life increase, which improves time to change a tool. It also yields the benefit of increased productivity. Moreover, the MQL scheme describes an arrangement where volumetric quantities of fluids (i.e. plant oils, petroleum distillates and animal fats with or without water) are pumped to the surface of the steel alloy removal surface (Sankar and Choudhury 2015; Gajrani et al., 2017; Gajrani et al., 2019). In the MQL, however, the cost of cutting fluids is high and the health effect of non-ecological cutting fluids is undesirable (Sankar and Choudhury, 2015).

Moreover, some related studies on minimum quantity lubrication are reviewed as follows: The idea of machining metals under the minimum quantity lubrication (MQL) scheme has greatly influenced discussions in the machining domain among researchers for many years. Previous studies have included the MQL scheme where the temperature prediction of the milling process is of interest (Cai et al., 2022). In this context, the generation of a temperature profile is of interest where the workpiece surface is examined within 1 minute (Cai et al., 2022). Besides, in the context of MQL, the performance of the AISI 1522H steel grade was evaluated with the aid of a multicriteria tool, analysis of variance and definitive screening design (Abas et al., 2022). In a study, using the MQL scheme, the effect of introducing graphene-based nanofluid on the machining performance of M42 steel was examined (Anandan et al., 2021). It was revealed that through the development of an integrated method of AHP-MOORA, the influence of the graphene-based nanofluid on the surface roughness reduction was up to 91%, reduction of temperature during cutting was 82% and tool wear decreased by 95% (Anandan et al., 2021), in a dry condition. However, the performance declined considerably to 66% for surface roughness, 57% for temperature reduction and 86% decrease by tool wear when an oil environment was used to turn M42 steel. In furtherance of investigations on MQL, a study focused on the turning of Inconel 825 (Babu et al., 2021). In the attempt the following tools were deployed for analysis: Taguchi's L27 orthogonal matrix, combined technique for order preference through similarity to ideal solution and analytical hierarchy process (Babu et al., 2021). It was concluded that ionic liquids in the perception of MQL exhibited great potential to reduce tool wear, surface roughness, chip thickness and cutting temperature for the Inconel 825 materials. Moreover, with an increasing shift of work centers from the long-established traditional cutting fluid application scheme to an advancement in the control application of cutting fluids through the MQL scheme, multicriteria methods have proved themselves useful.

Notwithstanding, the literature reviewed so far has demonstrated the sparseness of information on multicriteria methods applied to the minimum quantity lubrication. However, it is interesting to note two articles, which are associated with the subject of interest. The first article by Attri et al. (2024) approached the multicriteria analysis of the machining process by introducing the complex proportional assessment approach. However, the limitation is that it was conducted under the flood cooling scheme and not the minimum quantity lubrication technique as advocated in the present study. Moreover, Babu et al. (2021) considered the optimization and selection of parameters in the turning of Inconel 825, using ionic liquids and deploying a combination of Taguchi method and multicriteria approaches (i.e. technique for order preference by similarity to ideal solution, TOPSIS, and analytic hierarchy process, AHP. While the study is associated with the present study in the contexts of applying multicriteria methods and experimenting within the minimum quantity lubrication domain, the advantages of simplicity and effectiveness of the evaluation of distance from average solution (EDAS) in the context of minimum quantity lubrication remains a disadvantage of the study.

Furthermore, in the research domain on minimum quantity lubrication, the primary focus has been the effects of certain measures or issues on the lubrication performance of minimum quantity lubrication. Such concerns have included nano-particle variables such as their concentration and sizes as they are introduced into the minimum quantity lubrication scheme (Maruda et al., 2023a). Others include the interactions between these nanofluids and the cutting parameters (Kumar and Prasad, 2021). Still, others may be the introduction of enhancements such as graphene to improve the performance of the minimum quantity lubrication (Li et al., 2019). Notwithstanding, despite significant advancements in studies associated with minimum quantity lubrication, the choice of the best parameters to be used as inputs in machining decision-making cannot still be accurately established and the consideration of efficient multicriteria methods under the action of the minimum quantity lubrication and using the AISI 4340 alloy still need to be unearthed. This aspect of machining is significant to clarify and advance decision-making on machining.

Based on the reports of earlier findings, it may be safely inferred that the method of minimum quantity lubrication shows the capacity to apply a valuable parametric selection method in the decision-making domain for diverse metal working materials. Many of the studies have adopted the Taguchi optimization approach where a selection of the best parameter is obtained through the ranks given from the magnitude of the delta values of the parameters. Nonetheless, very few studies have scrutinized the multicriteria method for the parametric selection of the minimum quantity lubrication system for the turning process in machining. However, adopting an efficient and straightforward multicriteria approach in the perspective of turning AISI 4340 alloy using CuO nano coolants of CuO dissolved nanoparticles in fluid may represent an innovative way to establish the parametric value of the minimum quantity lubrication system. Furthermore, the concern for sustainable energy expenditure necessitates studies and incorporation of cutting forces, cutting speed, feed and cutting depth as crucial factors for energy control studies. Moreover, despite the overwhelming studies on these parameters, their linkages with the best parametric choices in multiple and conflicting situations have not been largely established. Thus, this investigation conducted a parametric analysis of the minimum quantity lubrication system using the AISI 4340 alloy under lubrication tests of CuO-based nanolurbicant while using cutting force, cutting speed, cutting depth and feed as parameters.

Furthermore, from a comprehensive literature review, there is a comparative dearth of systematic studies that examine the best parameter in minimum quantity lubrication turning. In addition, studies that efficiently explore the mentioned goal in AISI 4340 alloy are sparsely noticed in the literature. To address this shortcoming, experimental data from the literature (Elsheikh et al., 2021) based on the AISI 4340 alloy under the minimum quantity lubrication was used in the present study. Interestingly, the distance from average solution (EDAS) method with its unique ability to handle conflicting criteria and the requirement for fewer computations has not been exploited within the MQL scheme domain. But there is a need for a powerful assisting tool, which can handle conflicting criteria with minimum computations for easy assimilation by the practicing engineer. Besides, previous research has not also focused on simplification of the optimization and selection process for the convenience of the machinist and the engineer in interpreting and implementing optimization and selection procedures. But while considering the multicriteria attributes of the turning process for the AISI 4340 alloy and the straightforwardness of the method, the EDAS method comes into the limelight. Thus, the MQL turning of AISI 4340 alloy is a fertile opportunity to apply the EDAS method.

Consequently, this paper uses the EDAS method to assess the criteria value regarding three alternatives namely the cutting depth, cutting speed and feed). The responses used are the cutting force, surface roughness and the tool wear. To our knowledge, earlier studies have disregarded the multiple attribute criteria in the MQL turning of AISI 4340 alloy. The key parameters representing the turning process are first defined and their average solution is established. Then the positive and negative distances from the average from the beneficial and non-beneficial perspective are conceived. Then their weighted sums and their normalized formats are established.

2. METHODOLOGY

2.1 Pre-EDAS implementation procedure

Before applying the EDAS method turning problem, a pre-processing procedure to determine the weights of the cutting force and inputs should be initiated as follows:

1. Determine the nature of criteria for the inputs or entities whose weights are to be determined. The two categories are beneficial and non-beneficial (cost) criteria. While maximum value is desired for the beneficial criterion, minimum value is sought for the non-beneficial criterion.
2. Normalise the entries in the matrix.
3. For each column of entries, pick the maximum for the beneficial criterion and the minimum for the non-beneficial criterion.
4. Consider the marked values in a row; sum them up and obtain fractions of the sum for each column.
5. The obtained proportions are called the weights of the criterion.

2.2 EDAS method

The EDAS method was deployed to the experimental data of El-Shiekh et al. (2021) which is the outcome of a turning process involving the AISI 4340 alloy using the minimum lubrication scheme. The findings of this application exercise, which will be shown in the next section on results and discussion", reveal the feasibility of applying the EDAS method to the turning operation of AISI 4340 alloy. Thus, the different steps that would yield feasible results are shown as follows:

Step 1: *Problem formulation and definition of solution space.*

From an extensive literature review, it was found that the EDAS method is potentially useful for solving the parametric selection problem, hence, a thorough analysis of the requirements of the approach is made. Moreover, the perceptions of the decision maker on the outputs of the system need to be defined. Here cutting force surface roughness and tool wear are the major outputs of the turning process. When these outputs increase, they are non-beneficial to the system since such increases are not desired beyond a particular threshold in the turning operation. Furthermore, the inputs of the turning operation are the cutting speed, feed rate and cutting depth. These could be adjusted to obtain favourable responses from the turning process.

Step 2: *Data collection*
The data used in the present article was obtained from El-Shiekh et al. (2021). The data assisted in calculating the objective values for the different outputs.

Step 3: *Determine the average solution for the cutting force while using the CuO as the nanofluid.* Equation (1) shows how to calculate the average solution, shortened as AV;

$$AV_j = \frac{\sum_{i=1}^{n} X_{ij}}{n} \quad (1)$$

Where *n* is the total of each process parameter at a time.
X_{ij} is the value of each particular process parameter in its column.
However, for simplicity, a spreadsheet package (i.e. Microsoft Excel) can be used to evaluate the average solution and other essential computations in this work.

Step 4: *Calculate the positive distance from the average solution.*
Here, the calculation of the positive distance from the average solution is made from two aspects. This depends on the classification of the parameter as either beneficial or non-beneficial as defined in Equations (2) and (3) respectively.
If beneficial,

$$PDA_{ij} = \frac{\max(0, X_{ij} - AV_j)}{AV_j} \quad (2)$$

But if non-beneficial,

$$PDA_{ij} = \frac{\max(0, AV_j - X_{ij})}{AV_j} \quad (3)$$

Step 5: *Determine the weighted sum of the positive distance from the average solution.*
In this case, each parameter is obtained by multiplying its assigned weighted values. The representation here is SP_i, which is calculated by carrying out the summation of the values of the process parameters along the rows (horizontally), shown in Equation (4)

$$SP_i = \sum_{j=1}^{m} W_j PDA_{ij} \quad (4)$$

Step 6: *Calculate the negative distance from the average.*
This step is similar to the preceding step, which describes the positive distance from the average. However, the concept is treated in two parts, according to the beneficial and non-beneficial aspects. While the beneficial aspect is shown in Equation (5), the non-beneficial concern is shown in Equation (6)
If beneficial,

$$NDA_{ij} = \frac{\max(0, AV_{ij} - X_{ij})}{AV_j} \quad (5)$$

While for the non-beneficial variable,

$$NDA_{ij} = \frac{\max(0, X_j - AV_j)}{AV_j} \quad (6)$$

Step 7: Determine the weighted sum of the negative distance from the average. Here, the weighed sum of NDA for the cutting force using CuO is obtained by multiplying the assigned weighted values with each column of each process parameter. SN_i is calculated by assignment weighted values with each column of each process parameter horizontally. SN_i is shown in Equation (7)

$$SN_i = W_j NDA_{ij} \quad (7)$$

Step 8: Calculate normalize values for SP, SN, NSP, NSN and SN_i values as showing in Equations (8) and (9), respectively.

$$NSP_i = \frac{SP_i}{\max_i(SP_i)} \quad (8)$$

Where max (SP_i) is the sum of the SP_i values.
NSP_i (Normalised sum of SP_i): This column represents the normalized sum of the SP_I values for each observation

$$NSN_i = \frac{SN_i}{\max_i(SN_i)} \tag{9}$$

NSN_i (Normalised sum of SN_i)

This column represents the normalized sum of the SN_i values for each observation where max (SN_i) is the sum of the whole SN_i

AS_i (Average of SP_i and SN_i) for each observation.

$$AS_i = 0.5\,(NSP_i + NSN_i) \tag{10}$$

After using Equations (8), (9) and (10), the making of the value stakes place, which forms the completion of the whole process and therefore producing the final table where the ranks are stated. For normalization, the 0-1 interval normalization is used with the max-min scheme where Equations (11) and (12) represents the beneficial and non-beneficial criteria, respectively. The normalized value of the beneficial criterion is as follows:

$$n_{ij} = \frac{x_{ij}}{\max x_{ij}} \tag{11}$$

Also, the normalized value of the non-beneficial criterion is as follows:

$$n_{ij} = \frac{\min x_{ij}}{x_{ij}} \tag{12}$$

3. RESULTS AND DISCUSSION

Table 1 shows the process parameters with their assigned weighted values coupled with the input parameters being termed beneficial and the output non-beneficial. The equations are sourced from Keshavarz-Ghorabaee (2015). The average value was calculated hereafter.

Table 1. Average solution for cutting force using CuO

Item	Non-beneficial	Beneficial	Beneficial	Beneficial
S/N	Cutting force (N)	Cutting speed (m/mm)	Feed (mm/rev)	Cutting depth (mm)
1	129	80	0.05	0.3
2	137	80	0.1	0.4
3	144	80	0.15	0.1
4	149	80	0.2	0.2
5	156	100	0.05	0.4
6	161	100	0.1	0.3
7	163	100	0.15	0.2
8	171	100	0.2	0.1
9	180	120	0.05	0.3
10	184	120	0.1	0.4
11	192	120	0.15	0.1
12	198	120	0.2	0.2
13	209	140	0.05	0.4
14	221	140	0.1	0.3
15	232	140	0.15	0.2
16	243	140	0.2	0.1
AV_j	179.31	110	0.125	0.25
Total	**2869**	**1760**	**2**	**4**

The commencement of further analysis is at normalizing all the entries in the matrix. Normalization is conducted along the columns. This is aided by adding all the values for serial nos. 1 to 16, which gives 2869 cutting force, 1760 for cutting speed, 2 for feed and 4 for cutting depth. Then, normalization is done for the cutting force using Equation (12), which gives 0.9416 for the cell under cutting force for experimental trial 1. For experimental trial 2 and the cell undercutting force, the value obtained is 0.89583. Similarly, other values for cutting force from experimental trials 3 to 16 are calculated as shown in Table 2. Furthermore, the cutting speed is normalized with Equation (11) since it is viewed as a beneficial criterion. Here, for experimental trial 1, the obtained calculation is 80/140, which is 0.571429. Still, for cutting speed and experimental trial 2, the normalized value is 0.571429. a normalized value of 1 is obtained for experimental trials 13,14,15 and 16. Also, feed is beneficial and the computation follows Equation (11), which is also used for cutting depth. In total, the normalized values are shown in Table 2. Then, the pre-EDAS implementation procedure is used starting with the cutting force. This is a non-beneficial criterion whose minimum normalized value is 0.5390, which is picked as the first element of a forthcoming analysis. Next is the cutting speed, a beneficial criterion whose maximum normalized value of 1 is desired. This is the second pick in a future analysis. For the feed parameter, which is beneficial, a maximum normalized value of 1 is expected. Also for the cutting depth parameter, a maximum normalized value of 1 is desired from this beneficial criterion. Thus, there are four values picked in a row 0.5309, 1, 1, and 1, which sums up to 3.5309. Since the sum is greater than 1, the individual values of 0.5309, 1, 1 and 1 are normalized such that the sum is 1. This is done as each of these values is divided by 3.5309. Thus, the normalized values, which serves as weights for the cutting force, cutting speed, feed, and cutting depth are 0.1504, 0.2832, 0.2832 and 0.2832, respectively, which sums up to 1. Next, the average of each entity along the column is obtained. These are 0.7441, 0.7857, 0.6250 and 0.6250, for the cutting force, cutting speed, feed and cutting depth, respectively. This information is used to produce values in Table 3. Table 3 has 16 experimental counts. The computation starts with the first experimental count. Here, the second column and the second row show the intersection of experimental trial 1 and the cutting force. Here, the cutting force is a non-beneficial element. Thus, the PDAij of this cell is calculated where the numerator is first computed. The difference between 0.7441 and 1 is -0.2559. The maximum value between 0 and -0.2559 is 0. If the value of 0 is divided by 0.7441, then 0 is obtained. This value becomes the PDAij for experimental trial 1 for cutting rate. For the beneficial parameter, cutting speed, the PDAij is calculated slightly differently from the non-beneficial parameter. In this case, from Table 2, experimental trial 1 and cutting speed, Xij is 0.5714 while AVj is 0.7857. However, when 0.7857 is subtracted from 0.5714, the result is -0.2143. The maximum value between 0 and -0.2143 is 0. If the value of 0 is divided by 0.7857, the value is still 0, which is the PDAij. By following this procedure for all the entries of Table 2, a new table called Table 3 emerges.

Table 2. Normalized matrix

Item	Non-beneficial	Beneficial	Beneficial	Beneficial
S/N	Cutting force (N)	Cutting speed (m/mm)	Feed (mm/rev)	Cutting depth (mm)
1	1.0000	0.5714	0.2500	0.7500
2	0.9416	0.5714	0.5000	1.0000
3	0.8958	0.5714	0.7500	0.2500
4	0.8658	0.5714	1.0000	0.5000
5	0.8269	0.7143	0.2500	1.0000
6	0.8012	0.7143	0.5000	0.7500
7	0.7914	0.7143	0.7500	0.5000
8	0.7544	0.7143	1.0000	0.2500
9	0.7167	0.8571	0.2500	0.7500
10	0.7011	0.8571	0.5000	1.0000
11	0.6719	0.8571	0.7500	0.2500
12	0.6515	0.8571	1.0000	0.5000
13	0.6172	1.0000	0.2500	1.0000
14	0.5837	1.0000	0.5000	0.7500
15	0.5560	1.0000	0.7500	0.5000
16	0.5309	1.0000	1.0000	0.2500
AV_j	**0.7441**	**0.7857**	**0.6250**	**0.6250**

The next task is to compute the weighted sum PDA for the cutting force using CuO. This will be shown in Table 4. Notice that Equation (4) is applied in this case. Recall that at the start of the computation, the weight of the elements of the process was calculated as 0.1504, 0.2832, 0.2832 and 0.2832 for cutting force, cutting speed, feed and cutting depth, respectively. Consider the entry at the intersection of experimental trial 1 and cutting force. If the value at this cell is observed in Table 3, it is 0.0000. However, the weight for the cutting force is 0.1504. With the multiplication of 0.0000 and 0.1504, a value of 0.0000 is obtained. The same procedure is used to compute all the values in Table 4, which are the weight PDA_{ij} for the criteria using the CuO nanofluid. A close observation of Table 4, which has both non-beneficial and beneficial sides indicates that indices related to SN_i are associated with the non-beneficial side and only one column of item is involved. This is the cutting force. However, the beneficial side, which has cutting speed, feed and cutting depth as its parameters are associated with SP_i. To proceed with the computation, all the values of the SP_i are added as shown in Table 4. Next is the computation of the NSN_i, which uses Equation (9).

Table 3. PDAij for the criteria using CuO as nanofluid

	Non-beneficial	Beneficial	Beneficial	Beneficial
Weights	0.1504	0.2832	0.2832	0.2832
S/N	Cutting force (N)	Cutting speed (m/mm)	Feed (mm/rev)	Cutting depth (mm)
1	0.0000	0.0000	0.0000	0.2000
2	0.0000	0.0000	0.0000	0.6000
3	0.0000	0.0000	0.2000	0.0000
4	0.0000	0.0000	0.6000	0.0000
5	0.0000	0.0000	0.0000	0.6000
6	0.0000	0.0000	0.0000	0.2000
7	0.0000	0.0000	0.2000	0.0000
8	0.0000	0.0000	0.6000	0.0000
9	0.0369	0.0909	0.0000	0.0000
10	0.0579	0.0909	0.0000	0.6000
11	0.0971	0.0909	0.2000	0.0000
12	0.1245	0.0909	0.6000	0.0000
13	0.1706	0.2727	0.0000	0.6000
14	0.2156	0.2727	0.0000	0.2000
15	0.2528	0.2727	0.2000	0.0000
16	0.2866	0.2727	0.6000	0000

Table 4. Weighted PDAij for the criteria using CuO as nanofluid

	Non-beneficial SN_i	Beneficial	Beneficial	Beneficial	SP_i
S/No	Cutting force (N)	Cutting speed (m/mm)	Feed (mm/rev)	Cutting depth (mm)	
1	0.0000	0.0000	0.0000	0.0566	0.0566
2	0.0000	0.0000	0.0000	0.1699	0.1699
3	0.0000	0.0000	0.0566	0.0000	0.0566
4	0.0000	0.0000	0.1699	0.0000	0.1699
5	0.0000	0.0000	0.0000	0.1699	0.1699
6	0.0000	0.0000	0.0000	0.0566	0.0566
7	0.0000	0.0000	0.0566	0.0000	0.0566
8	0.0000	0.0000	0.1699	0.0000	0.1699
9	0.0055	0.0257	0.0000	0.0000	0.0257
10	0.0087	0.0257	0.0000	0.1699	0.1956
11	0.0146	0.0257	0.0566	0.0000	0.0823
12	0.0187	0.0257	0.1699	0.0000	0.1956
13	0.0257	0.0772	0.0000	0.1699	0.2471
14	0.0324	0.0772	0.0000	0.0566	0.1338
15	0.0380	0.0772	0.0566	0.0000	0.1338
16	0.0431	0.0772	0.1699	0.0000	0.2471

To analyse this, consider the second column of Table 4 with the label SN_i. Along this column, for experimental trial 1, SN_i is 0.0000. However, along the column, the maximum value is 0.0431, which is for experimental trial 16. Then 0.0000 divided by 0.043 yields 0.0000. When this value is subtracted from 1, a value of 1.0000 is obtained as the NSN_i where *i* ranges from 1 to 16 will be achieved. Next is the application of Equation (8), which is used in the last column of Table 4. Consider experimental trial 1 with SP_1 of 0.0566. The maximum for the SN_i , where *i* ranges from 1 to 16 is 0.2471. Then, 0.0566 divided by 0.2471 yields 0.2291. computations are made along the same logic while the results of both NSN_i and NSP_i are summarized in Table 5. In Table 5, a column containing AS_i, which is the 50% content of each of NSN_i and NSP_i. Considering experimental trial 1 where NSN_i is 1.0000 and NSP_I is 0.2291, the sum of these two numbers is 1.2291 while the average result is 0.6145. Now, from the values in the AS_i column, the highest value is 0.8438, which occurs at experimental trials 2, 4, 5 and 8. These are the best-performing values of the criteria.

Table 5. Computation of ASi for the criteria using CuO as nanofluid

S/N	NSN_i	NSP_i	$AS_i = 0.5(NSN_i + NSP_i)$	Rank
1	1.0000	0.2291	0.6145	5
2	1.0000	0.6876	0.8438	1
3	1.0000	0.2291	0.6145	5
4	1.0000	0.6876	0.8438	1
5	1.0000	0.6876	0.8438	1
6	1.0000	0.2291	0.6145	5
7	1.0000	0.2291	0.6145	5
8	1.0000	0.6876	0.8438	1
9	0.8724	0.1040	0.4882	8
10	0.7981	0.7916	0.7949	2
11	0.6613	0.3331	0.4972	7
12	0.5661	0.7916	0.6789	4
13	0.4037	1.0000	0.7019	3
14	0.2483	0.5415	0.3949	9
15	0.1183	0.5415	0.3299	10
16	0.0000	1.0000	0.5000	6

4. CONCLUSIONS

The selection of appropriate and the best parameters in an industrial environment is placed as a top priority item in the context of sustaining the manufacturing system. Moreover, failure to choose appropriate parameters has been linked to its negative influences on safety, health and the environment in the context of keeping to government regulations concerning industrial operations. In the present research, the EDAS method was applied to the literature data in the experiments performed by Elsheikh et al. (2021). The optimal conditions situations where the response was determined based on CuO were independently established. It was found that the EDAS method is flexible in all the four scenes examined. Furthermore, the F test under the 5% level of significance shows that there are no significant differences in the results obtained. Further work is expected in other multilateral methods such as VIKOR and WASPAS for a deeper understanding of the problems and its solution.

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