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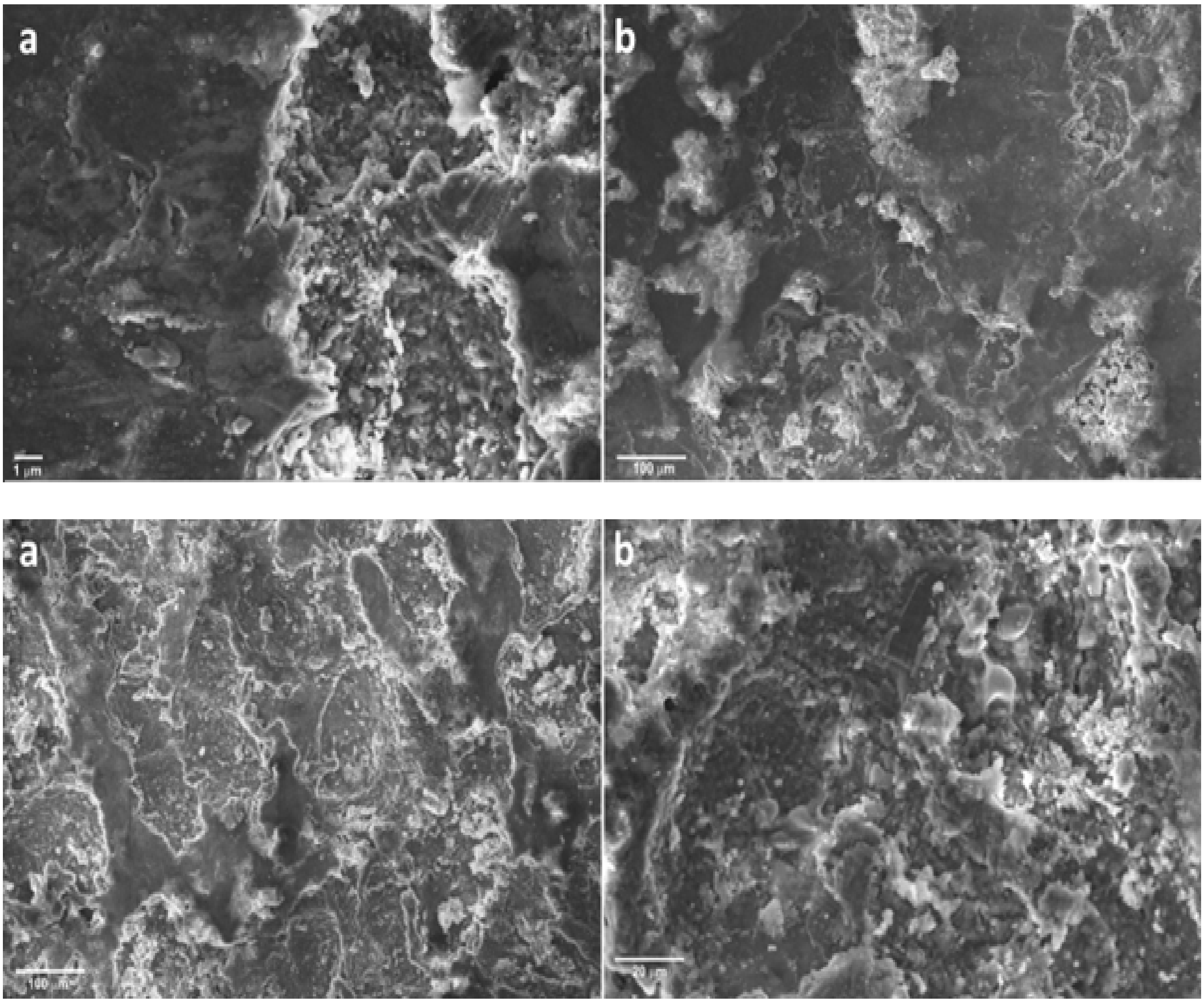

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SADRŽAJ/CONTENTS

A systematic approach for design of distributed wastewater treatment systems

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Abstract

Due to increasingly strict environmental regulations, the cost of handling various waste streams is gradually rising. Therefore, it is crucial to minimize unnecessary stream merging when designing distributed wastewater treatment systems, to reduce the overall treatment flow rate whenever possible. In a distributed wastewater treatment system, the wastewater streams are separated for treatment and only combined when necessary. This results in a significant reduction in the total treatment flow rate compared to traditional centralized treatment systems where all the streams are merged before treatment. Design of a distributed wastewater treatment system can be accomplished using pinch analysis and mathematical programming approaches. This paper suggests a straightforward approach for designing such networks, with the following steps in the design process: First, the primary function of each treatment unit is determined. Next, using the pinch method, the lowest treatment quantity is determined for the primary pollutant for each unit. Finally, a three-unit group is selected, with the pinch stream partially treated, the streams above the pinch completely treated, and the stream below the pinch completely bypassed. Two literature case studies demonstrate the viability and effectiveness of this strategy.

Keywords: Multiple pollutants; process synthesis; pinch analysis; water networks.

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1. INTRODUCTION

One important area of study in process synthesis is water network synthesis. The integration of a wastewater treatment system, which is the most important aspects of managing water resources, has drawn increasing attention due to rising wastewater discharge and stricter environmental regulations. The development of a water distribution system using water pinch method and mathematical optimization has been the focus of a significant number of research studies. Pinch analysis techniques and mathematical programming techniques can be used to integrate distributed wastewater treatment systems.

The pinch analysis approach was first presented [1] for the purpose of designing distributed wastewater treatment facilities. After using a graphical method to determine the objective minimum treatment flow rate, many principles based on pinch location were put forth to create a design that would achieve the goal. Thereafter, numerous initiatives were made to advance and enhance those strategies [2].

A targeting strategy was described for the entire water system, which includes wastewater treatment, regeneration, and reuse of water. Using graphical and algebraic approaches, the relationships between the various components of the system were examined [3]. Targeting the lowest treatment flow rate for systems with flow loss required an extension of the algebraic and graphical methods [4].

In order to address the issue of unnecessary stream mixing in distributed wastewater treatment systems, pinch stream identification was utilized as an analytical approach for systems dealing with a single contaminant [5]. The design of such systems often involves a process that reduces pollutant concentrations and increases treatment flow rates downstream, leading to undesired stream mixing. Therefore, minimizing unnecessary stream mixing is of utmost

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importance. To achieve this, accurate and statistically sound measurements of stream mixing are crucial. In this context, the concept of total treatment flowrate potential (TTFP) was introduced as an indicator to determine the optimal operating order of treatment processes [6]. A method for establishing heuristic rules to ascertain the treatment processes' operating order was proposed [7]. Since rule-based approaches lack quantitative indicators, they are not well suited for more complicated systems. Total mixing influence potential (TMIP), a numerical indicator, was introduced to try and minimize needless stream mixing. It was intended to identify the optimal sequence of treatment procedures for a wastewater treatment network containing several contaminants [8].

For sophisticated wastewater treatment system integration, mathematical programming techniques are the primary instruments. The design of multi-contaminant wastewater treatment networks (WTNs) was given a subsequent relaxed solution to a nonconvex nonlinear problem [9]. The optimization of wastewater treatment systems was demonstrated using a two-step approach. Completing the non-linear programming model is the second phase, while creating a linear programming model to generate initials is the first [10].

A straightforward yet reliable optimization approach was provided, by constructing a superstructure using pinch analysis and the wastewater degradation concept [11].

Based on genetic algorithms, an integrated water network (IWN) that combines water-using units (WUs) and treatment units (TUs) is optimized by aiming for maximum treated water reuse and, thus, minimal freshwater use. The related water network (WN) topologies are generated using various scenarios and examined, and broad conclusions are given for each example [12].

A staged wastewater treatment (WWT) strategy was put out, consisting of three to four consecutive phases: preliminary, primary, secondary, and tertiary. In the early stages of design, a comprehensive list of all potential networks of technologies and their connections was generated using mathematical modelling and optimization methods to build this methodical approach to designing wastewater treatment networks [13].

It was suggested that the formulation and resolution of an optimization problem using nonlinear programming and a mono-objective function that takes sustainability's environmental component into account would solve the sustainable wastewater treatment network design dilemma [14].

A decision support method was outlined for the planning of regional wastewater systems. To determine the best arrangements for the position, kind, and scale of the system's wastewater treatment facilities and infrastructure, optimization models are employed. It was demonstrated that the benefits of using optimization models may be extended to wastewater system regional planning [15].

For the entire water network with several contaminants, an iterative design process was suggested, in which wastewater treatment, regeneration, reuse/recycling, and reuse are all considered at the same time. Suggested design process is detailed step-by-step, and it is evident how important engineering is. Both the total annual cost and the freshwater use are competitive [16].

A combined conceptual and mathematical programming approach-based integrated methodology has been presented for the design of sustainable wastewater treatment plants (WWTPs). The objective was to provide and test a unique integrated strategy using multiobjective optimization to design sustainable WWTPs for a multipollutant scenario [17,18].

The focus should not be solely on the role of wastewater treatment plants in reducing freshwater consumption or removing pollutants before they are discharged into the environment. Instead, it is essential to consider the potential benefits that can be derived from the pollutants generated during the treatment process. Specifically, these pollutants can be repurposed as fertilizers in agriculture, thereby contributing to sustainability and enhancing the overall efficiency of the treatment plants [19].

In another study, the total wastewater treatment network system's economic and environmental viability was assessed by utilizing the life cycle assessment and life cycle assessment techniques. While the conventional wastewater treatment system (CWTS) was less ecologically friendly, the total wastewater treatment network system (TWTNS)was more fiscally favourable. From the perspective of eco-design, which aims to comprehensively enhance environmental, life cycle assessment (LCA) and life cycle costing (LCC) methods, it was shown that the TWTNS was not eco-efficient when the ratios of the total environmental effect scores and economic costs throughout the life cycle in the TWTNS to those in the CWTS were equally compared [20].

The present paper aims to design wastewater treatment networks with the lowest flow rate while simultaneously adhering to environmental standards and regulations regarding the concentration of pollutants discharged into the environment.

2. EXPERIMENTAL

2. 1. Problems statement

A collection of wastewater streams with known concentrations of multiple of contaminants is provided. Furthermore, a collection of treatment units is provided, each of which can eliminate one or more impurities. Designing a treatment system to efficiently remove a specific contaminant is necessary to adhere to environmental regulations.

2. 2. Design procedures

Step 1

The primary pollutant for each treatment unit should be identified as the one that has the highest removal ratio. This is because the principal pollutant in a treatment plant with multiple pollutants is the one that corresponds to the highest removal ratio.

Step 2

By using equation (1), calculate the lowest flow rate required to remove a specific contamination from a single stream. Then, add up all these flow rates to calculate the overall lowest flow rate necessary for a particular treatment plant to remove a certain contaminant from all streams.

$$F_{i,j}^{k} = F_{i}\frac{C_{i,j}^{in}-C_{env,j}^{lim}}{C_{i,j}^{in}RR_{j}} \tag{1}$$

Step 3

The total minimum flow rates for each treatment plant are established, and the smaller the total treatment flow rate value of a process, the higher its priority in implementation.

Step 4

Arrange the streams in each treatment plant from the highest to the lowest of pollutant *j* concentration. Then, use equation (2) to determine the lowest removal mass load needed as:

$$M_{j}^{rem} = \sum m_{i,j} - C_{env,j}^{lim}\sum f_{i} \tag{2}$$

where

$m_{i,j}=F_iC_{i,j}$

Step 5

Determine the stream that flows through the pinch point, equation (3).

$$\sum_{i=1}^{p-1} m_{i,j} \prec M_{TP_{i,j}} \leq \sum_{i=1}^{p} m_{i,j} \tag{3}$$

where:

$$M_{TP_{i,j}} = \frac{M_{j}^{rem}}{RR_{j}}$$

Step 6

Calculate the pinch stream S_p by the TP_k treatment flow rate and the pinch stream S_p by the TP_k bypass flow rate using equations (4) and (5), respectively.

$$F_{TP_{k,pt}} = \frac{M_{TP_{k,j}} - \sum_{i=1}^{p} m_{i,j}}{C_{p,j}} \tag{4}$$

$$F_{TP_{k,pb}} = F_{p} - F_{TP_{k,pt}} \tag{5}$$

Step 7

Determine the treatment unit's minimum treatment flow rate by equation (6):

$$F_{TP_k} = F_{TP_{k,pt}} + \sum_{i=1}^{p-1} F_i \tag{6}$$

where: ΣF_i is the flow rate for all streams above the pinch point.

3. CASE STUDIES

3. 1. Case one

Tables 1 and 2 displays the figures for Case one, sourced from literature [6]. The maximum allowable concentration for the pollutant A, B and C in the environment is adopted as 100 ppm.

Table 1. Streams data for Case one [6]

Stream	Flow rate, t h^{-1}	Concentration, ppm		
		A	B	C
S_1	20.00	600.00	500.00	500.00
S_2	15.00	400.00	200.00	100.00
S_3	5.00	200.00	1000.00	200.00

Table 2. Treatment process data for Case one [6]

Treatment plant	Removal ratio, %		
	A	B	C
TP_1	90.00	0.00	0.00
TP_2	0.00	99.00	0.00
TP_3	0.00	0.00	80.00

Step 1

Determine the major pollutant for each treatment plant: the main pollutant for TP_1 is A, for TP_2 is B, and for TP_3 is C.

Step 2

Calculate the flow rate required to treat a given pollutant j in a given stream *i*: total minimum flow rates required by a given treatment plant to remove a given pollutant from all streams are shown in Table 3, calculated by using equation (1)

Table 3. Flow rate values for TP_1, TP_2, and TP_3.

Flow rate, t h^{-1}					
TP_1		TP_2		TP_3	
A		B		C	
$F^1_{1,A}$	18.52	$F^2_{1,B}$	16.16	$F^3_{1,C}$	20.00
$F^1_{2,A}$	12.50	$F^2_{2,B}$	7.58	$F^3_{2,C}$	0.00
$F^1_{3,A}$	2.78	$F^2_{3,B}$	4.55	$F^3_{3,C}$	3.13
$\sum F^1_{T,A}$	33.80	$\sum F^2_{T,B}$	28.28	$\sum F^3_{T,C}$	23.13

For example, the flow rate $F^1_{1,A}$ is calculated as presented by equation (7):

$$F^1_{1,A} \frac{20(600\text{-}100)}{600 \times 0.9} = 18.52 \text{ t h}^{-1} \tag{7}$$

Step 3

In this step, the performing order for implementing the treatment unit is determined based on the results in step 2 as TP_3, then TP_2, and finally TP_1.

Step 4

The lowest removal mass load for all pollutants is calculated according to equation (2) based on the data presented in Tables 4, 5, and 6.

Table 4. Stream data for the pollutant C before TP_3 (Case one)

Stream	f_i / t h^{-1}	$C_{i,C}$ / ppm	$m_{i,C}$ / g h^{-1}	$\Sigma m_{i,C}$ / g h^{-1}
S_1	20	500	10000	10000
S_3	5	200	1000	11000
S_2	15	100	1500	12500
Sum	40		12500	

Table 5. Stream data for the pollutant B before TP_2 (Case one)

Stream	f_i / t h^{-1}	$C_{i,B}$ / ppm	$m_{i,B}$ / g h^{-1}	$\Sigma m_{i,B}$ / g h^{-1}
S'_3	1.87.00	1000.00	1870.00	1870.00
S'_1	23.13	567.66	13129.97	14999.98
S_2	15.00	200.00	3000.00	17999.98
Sum	40.00		17999.98	

Table 6. Stream data for the pollutant A before TP_1(Case one)

Stream	f_i / t h^{-1}	$C_{i,A}$ / ppm	$m_{i,A}$ / g h^{-1}	$\Sigma m_{i,A}$ / g h^{-1}
S''_1	1.51	545.87	824.26	824.26
S''_3	23.49	518.34	12175.81	13000.07
S_2	15.00	400.00	6000.00	19000.07
Sum	40.00		19000.07	

Taking into account the limiting pollutant concentration of 100 ppm, the lowest mass loads that have to be removed can be calculated by equation (1) and the values presented in Tables 6, 5, and 4, yielding the values:

M_A^{rem}=15000.07 g h^{-1}, M_B^{rem}= 13999.98 g h^{-1}, and M_C^{rem}=8500 g h^{-1}, respectively.

Step 5

Streams that correspond to the pinch point can be determined as follows. Considering removal rates presented in Table 2 and the calculated values of the lowest mass loads by using equation (3a). The mass load of pollutant C at the entrance of TP_3 is:

$$M_{TP_{3,C}} = 8500 / 0.8 = 10625 \text{ g h}^{-1}$$

The obtained value is between the mass loads in S_1 and S_2 for TP_3 and by using equation (3), *i.e.* 10000 < 10625 < < 11000 g h^{-1}. Therefore, S_3 will be the pinch stream, which requires partial treatment and partial bypass. By carrying out the same procedure for TP_2 and TP_1, the pinch streams will be S'_1 and S_2, respectively.

Step 6

Portions needed to be treated and bypassed from the pinch stream are calculated by equations (4) and (5) resulting in values:

$F_{TP_{3,pt}}$ = 3.13 t h^{-1}, $F_{TP_{3,pb}}$ = 1.87 t h^{-1}, $F_{TP_{2,pt}}$ = 21.62 t h^{-1}, $F_{TP_{2,pb}}$ = 1.51 t h^{-1}, $F_{TP_{1,pt}}$ = 9.17 t h^{-1} and $F_{TP_{1,pb}}$ = 5.83 t h^{-1}

Step 7

Minimum treatment flow rates per treatment unit are calculated by using equation (6) resulting in values:

F_{TP_1} = 23.13 t h^{-1}, F_{TP_2} = 23.49 t h^{-1} and F_{TP_3} = 34.17 t h^{-1}

Figure 1 displays the completed design that was produced throughout this work.

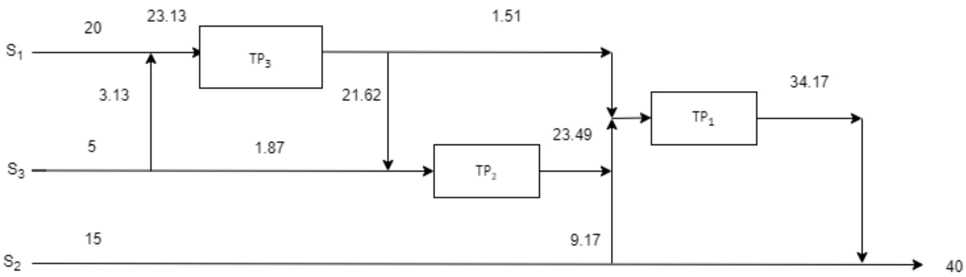

Figure 1. Optimal design network (Case one)

3. 2. Case two

Table 7displays the figures for Case two, sourced from a study reported in literature [7]. The maximum allowable concentration for the pollutant A, B, C, D, E and F in the environment is taken as 100 ppm. Tables 7, and 8 present figures in the stream and treatment processes for the Case two.

Table 7. Streams data for the Case two [7]

Stream	Concentration, ppm						Flow rate, t h^{-1}
	A	B	C	D	E	F	
S_1	1100.00	500	500	200.00	800.00	100.00	19.00
S_2	40.00	0.00	100.00	300.00	910.00	200.00	7.00
S_3	200.00	220.00	200.00	500.00	150.00	0.00	8.00
S_4	60.00	510.00	500.00	200.00	780.00	100.00	6.00
S_5	400.00	170.00	100.00	300.00	900.00	0.00	17.00

Table 8. Treatment process data [7]

Treatment plant	Removal ratio, %					
	A	B	C	D	E	F
TP_1	99.00	0.00	0.00	0.00	0.00	0.00
TP_2	0.00	99.00	0.00	0.00	0.00	0.00
TP_3	0.00	0.00	99.00	0.00	0.00	0.00
TP_4	0.00	0.00	0.00	99.00	90.00	0.00
TP_5	0.00	0.00	0.00	0.00	99.00	99.00

Step 1

Determine the major pollutant and compute the lowest treatment flow rate for each treatment plant. Table 8 shows that TP_1, TP_2, and TP_3 can only remove pollutants A, B, and C, respectively. Process TP_4 can eliminate two pollutants, E and D, with removal ratios of 90 and 99 %, respectively. Therefore, the major pollutant in TP_4 is D. Since pollutant F has mass loads in all streams that are below the maximum allowable environmental limit, as shown in Table 7, it is unnecessary to consider this contaminant. Hence, the major pollutant of TP_5 is E.

Step 2

Tables 9 and 10 show the minimum total flow rates required for the treatment plant k to remove the pollutant j from all streams.

Table 9. Flow rate values for TP_1, TP_2, and TP_3

Flow rate, t h^{-1}					
TP_1		TP_2		TP_3	
A		B		C	
$F^1_{1,A}$	17.45	$F^2_{1,B}$	15.35	$F^3_{1,C}$	15.35
$F^1_{2,A}$	-10.61	$F^2_{2,B}$	0.00	$F^3_{2,C}$	0.00
$F^1_{3,A}$	4.04	$F^2_{3,B}$	4.41	$F^3_{3,C}$	4.04
$F^1_{4,A}$	-4.04	$F^2_{4,B}$	4.87	$F^3_{4,C}$	4.85
$F^1_{5,A}$	12.88	$F^2_{5,B}$	7.07	$F^3_{5,C}$	0.00
$\sum F^1_{T,A}$	19.72	$\sum F^2_{T,B}$	31.70	$\sum F^3_{T,C}$	24.24

Table 10. Flow rate values for TP_4 and TP_5

Flow rate, t h^{-1}							
TP_4				TP_5			
D		E		E		F	
$F^4_{1,D}$	9.60	$F^4_{1,E}$	18.47	$F^5_{1,E}$	16.79	$F^5_{1,F}$	0.00
$F^4_{2,D}$	4.71	$F^4_{2,E}$	6.92	$F^5_{2.E}$	6.29	$F^5_{2,F}$	3.54
$F^4_{3,D}$	6.46	$F^4_{3,E}$	2.96	$F^5_{3,E}$	2.69	$F^5_{3,F}$	0.00

Flow rate, t h^{-1}							
TP$_4$				TP$_5$			
D		E		E		F	
$F^4_{4,D}$	3.03	$F^4_{4,E}$	5.81	$F^5_{4,E}$	5.28	$F^5_{4,F}$	0.00
$F^4_{5,D}$	11.45	$F^4_{5,E}$	16.79	$F^5_{5,E}$	15.26	$F^5_{5,F}$	0.00
$\sum F^4_{T,D}$	35.25	$\sum F^4_{T,E}$	50.95	$\sum F^5_{T,E}$	46.31	$\sum F^5_{T,F}$	3.54

Step 3

In this step, the performing order for implementing the treatment unit is determined based on the results in step 2 and we can say that the performing orders will be TP$_1$, TP$_3$, TP$_2$, TP$_5$, and TP$_4$.

In Tables 11 to 15, the streams are arranged based on the concentration of the pollutant that needs to be removed in each treatment process. The arrangement begins with the highest concentration and proceeds to the lowest concentration. This ordering is essential to identify the pinch point, which helps determine the streams that will undergo treatment in each treatment process. Additionally, it aids in calculating the mass load that is removed by each treatment unit.

Table 11. Streams data for the pollutant A before TP$_1$ (Case two)

Streams	$C_{i,A}$ / ppm	f_i / t h^{-1}	$m_{i,A}$ / g h^{-1}	$\Sigma m_{i,A}$ / g h^{-1}
S$_1$	1100	19	20900	20900
S$_5$	400	17	6800	27700
S$_3$	200	8	1600	29300
S$_4$	60	6	360	29660
S$_2$	40	7	280	29940
Sum		57	29940	

Table 12. Stream data for the pollutant C before TP$_3$ (Case two)

Streams	$C_{i,C}$ / ppm	f_i / t h^{-1}	$m_{i,A}$ / g h^{-1}	$\Sigma m_{i,A}$ / g h^{-1}
S$_4$	500.00	6.00	3000.00	3000.00
S'$_1$	400.57	27.96	11199.94	14199.94
S$_3$	200.00	8.00	1600.00	15799.94
S$_2$	100.00	7.00	700.00	16499.94
S$_5$	100.00	8.04	804.00	17303.94
Sum		57.00	17303.94	17303.94

Table 13. Streams data for the pollutant B before TP$_2$ (Case two)

Stream	$C_{i,B}$ / ppm	f_i / t h^{-1}	$m_{i,B}$ / g h^{-1}	$\Sigma m_{i,B}$ / g h^{-1}
S$_2$	457.58	7.00	3203.06	3203.06
S'$_4$	443.13	27.77	12305.72	15508.78
S$_3$	220.00	8.00	1760.00	17268.78
S''$_1$	170.00	6.19	1052.30	18321.08
S'$_5$	0.00	8.04	0.00	18321.08
Sum		57.00	18321.08	

Table 14. Streams data for the pollutant E before TP$_5$ (Case two)

Stream	$C_{i,E}$ / ppm	f_i / t h^{-1}	$m_{i,E}$ / g h^{-1}	$\Sigma m_{i,E}$ / g h^{-1}
S'$_2$	1077.32	34.77	37458.42	37458.42
S'$_5$	910.00	8.04	7316.40	44774.82
S''$_1$	900.00	6.19	5571.00	50345.82
S$_3$	150.00	8.00	1200.00	51545.82
Sum		57.00	51545.82	

Table 15. Streams data for the pollutant D before TP_4 (Case two)

Stream	$C_{i,D}$ / ppm	f_i / t h^{-1}	$m_{i,D}$ / g h^{-1}	$\Sigma m_{i,D}$ / g h^{-1}
S_3	500.00	8.00	4000.00	4000.00
S''_1	318.31	4.49	1429.21	5429.21
S''_2	310.98	44.51	13841.72	19270.93
Sum		57.00	19270.93	

Step 4

The lowest mass load required for each pollutant to be removed is calculated according to equation (2) and the data presented in Tables 11-15 as:

M_A^{rem} = 24240 g h^{-1} (Table 11), M_C^{rem} = 11603.94g h^{-1} (Table 12), M_B^{rem} = 12621.08 g h^{-1} (Table 13), M_E^{rem} = 45845.82 g h^{-1} (Table 14), M_D^{rem} = 13570.93 g h^{-1} (Table 15).

Step 5

By using equation (3), the mass load at the inlet of TP_k and the corresponding pinch streams are calculated and summarized in Table 16.

Table 16. Determining the pinch stream

Pollutant	TP_k	M_{TP_k} / g h^{-1}	Pinch stream
A	1	24484.85	S_5
B	2	12748.57	S'_4
C	3	11721.15	S'_1
D	4	13708.01	S''_2
E	5	46308.91	S''_1

Step 6

Portions needed to be treated and bypassed from the pinch stream are calculated by equations (4) and (5) yielding the values:

$F_{TP_{1,pt}}$ = 8.96 t h^{-1}, $F_{TP_{1,pb}}$ = 8.04 t h^{-1}, $F_{TP_{2,pt}}$ = 27.77 t h^{-1}, $F_{TP_{2,pb}}$ = 0.00 t h^{-1}, $F_{TP_{3,pt}}$ = 21.77 t h^{-1}, $F_{TP_{3,pb}}$ = 6.19 t h^{-1}, $F_{TP_{4,pt}}$ = 26.62 t h^{-1}, $F_{TP_{4,pb}}$ = 17.89 t h^{-1}and $F_{TP_{5,pt}}$ = 1.70 t h^{-1}, $F_{TP_{5,pb}}$ = 4.49 t h^{-1}

Step 7

Minimum treatment flow rates per treatment unit are calculated by using equation (6) yielding values:

F_{TP_1} = 27.96 t h^{-1}, F_{TP_2} = 34.77 t h^{-1}, F_{TP_3} = 27.77 t h^{-1}, F_{TP_4} = 39.11 t h^{-1} and F_{TP_5} = 44.51 t h^{-1}

Figure 2 displays the completed design that was produced throughout this work.

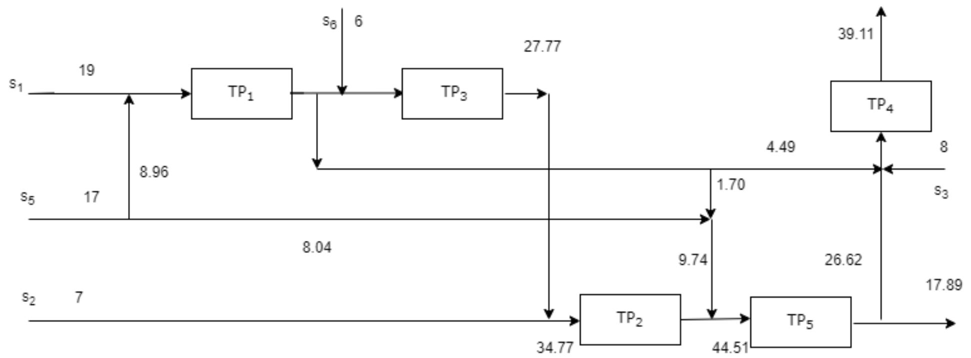

Figure 2. Optimal design network (Case two)

4. RESULTS AND DISCUSSION

The main objective of this work is to reduce the concentration of pollutants discharged into the environment while simultaneously decreasing the flow rates in the treatment units.

This approach yields results that are comparable to those reported in the literature, both in terms of reducing pollutant concentration and flow rate, particularly when the number of treatment units or streams is low. This is evident from the comparison of results for Case one in Table 17.

However in Case two, we observe that this objective was not fully achieved due to an increase in the number of treatment units and the number of streams. This leads to a higher occurrence of stream mixing, resulting in an increase in the flow rate. This is clearly evident in the increased flow rate in Case two as shown Table 18.

Thus, Therefore, the proposed approach delivers satisfactory results when the number of streams or treatment units is low. However, when number of streams or treatment units is high, it still provides satisfactory results, making it suitable as an initial model in mathematical optimization.

Table 17. Comparison of results for the Case one obtained in the present work and reported in the source study [6]

	Discharging concentration, ppm			Total flow rate, t h^{-1}
	A	B	C	
This work	99.97	99.99	100	80.79
Shi and Liu [6]	99.97	99.99	100	80.79

Table 18. Comparison of results for the Case two obtained in the present work and reported in the source study [7]

	Discharging concentration, ppm					Total flow rate, t h^{-1}
	A	B	C	D	E	
This work	100	52	100	100	100	174.12
Liu *et al.* [7]	100	100	100	89.69	100	134.75

The presented approach aims to sequence treatment units based on flow rates. Treatment units with the lowest total flow rate are prioritized, followed by those with higher flow rates. The initial total flow rate for each treatment unit is determined by summing the required flow rates for treating each stream individually. If the required flow rate is zero, it indicates that the stream does not require treatment (when the stream's inlet concentration of the pollutant is equal to the environmentally permissible limit concentration of the pollutant). Conversely, if the flow rate value is negative, it means that the stream not only does not require treatment but also allows for reducing the flow rate in other streams necessary for treatment in the unit.

5. CONCLUSION

In this study, a straightforward strategy for designing a distributed treatment system is presented. One of the main aspects emphasized in this strategy is the reduction of stream mixing, which is considered crucial in minimizing the overall treatment requirement of the system. The streams in the treatment system that are above the pinch are totally treated, while the streams in the pinch are only partially treated. The pinch technique is applied to compute the lowest treatment quantity for every unit for its primary pollutant. Two case studies are provided to demonstrate the effectiveness of the proposed strategy. Moreover, the approach is characterized by its simplicity and technical nature. The computational effort required is not significantly affected by the quantity of streams, pollutants, or treatment facilities.

6. NOMENCLATURE

$F_{i,j}^{k}$	- The flow rate of process k to remove pollutant j in stream i
$F_{T,j}^{k}$	- The minimum total flow rate of process k to remove pollutant j in all streams
F_i	- Flow rate of stream i
$C_{i,j}^{in}$ / ppm	- Stream i's inlet concentration of pollutant j
$C_{env,j}^{lim}$ / ppm	- Environmentally permissible limit of pollutant j in S_i
$C_{i,j}$ / ppm	- Concentration of pollutant j in S_i
RR / %	- Removal ratio
M_j^{rem}	- The lowest mass load of pollutant j needed to be removed

$F_{TP_{k,pt}}$	- Flow rate of S_p needed to be treated by TP_k
$F_{TP_{k,pb}}$	- Flow rate of S_p not needed to be treated by TP_k
F_{TP_k}	- The minimum treatment flow rate of treatment unit k
S_p	- Stream point
$C_{p,j}$	- Concentration of pollutant j at stream point
$M_{TP_{k,j}}$	- Mass load of pollutant j at the entrance of TP_k
$m_{i,j}$	- Mass load of pollutant j in S_i
TP_k	- Treatment plant k
S_i	- Stream i
P	- Process

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Sistematski pristup projektovanju distribuiranih sistema za prečišćavanje otpadnih voda

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(Stručni rad)

Izvod

Zbog sve strožije regulative u zaštiti životne sredine, troškovi rukovanja različitim tokovima otpada postepeno rastu. Zbog toga je ključno minimizirati nepotrebno spajanje tokova prilikom projektovanja distribuiranih sistema za prečišćavanje otpadnih voda, kako bi se smanjio ukupni protok tretiranih voda kad god je to moguće. U distribuiranom sistemu za prečišćavanje otpadnih voda, tokovi otpadnih voda se odvajaju za tretman i kombinuju samo kada je to potrebno. Ovo rezultira značajnim smanjenjem ukupnog protoka u poređenju sa tradicionalnim centralizovanim sistemima za tretman gde se svi tokovi spajaju pre tretmana. Dizajn distribuiranog sistema za prečišćavanje otpadnih voda može se postići korišćenjem pinč (engleski *pinch*) analize i pristupa matematičkog programiranja. Ovaj rad predlaže jednostavan pristup za projektovanje takvih mreža, sa više koraka u procesu projektovanja: Prvo se određuje primarna funkcija svake jedinice za tretman. Zatim, primenom pinč (*eng*. pinch) metode se za svaku jedinicu utvrđuje najmanja količina za tretman za primarni zagađivač. Konačno, bira se grupa od tri jedinice, pri čemu se pinč tok delimično tretira, tokovi iznad pinč toka potpuno obrađuju, a tokovi ispod pinča se potpuno zaobilaze. Dve studije slučaja iz literature pokazuju održivost i efikasnost ovog pristupa.

Ključne reči: višekomponentni zagađivači; sinteza procesa; pinč analiza; mreže tokova vode

Mechanical properties of surface-modified magnesium alloy AZ61 with nanoparticles of aluminum oxide and titanium dioxide by friction stir processing

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Abstract

The present work investigates the mechanical properties of surface-modified magnesium alloy AZ61 reinforced with Al_2O_3 and TiO_2 nanoparticles by using the friction stir processing (FSP) technique. Surface-modified AZ61 alloys were fabricated by the addition of dufferent amount of Al_2O_3 and TiO_2 nanoparticles (5, 10, and 15 vol.%). The developed surface composites were studied regarding microstructure, revealing a uniform dispersion of the added nanoparticles, which resulted in improved mechanical properties of the obtained composites by FSP. The ultimate tensile strength, impact strength, and microhardness improved by 20, 45, and 67 % by reinforcing the alloy with nanoTiO_2 particles when compared to the as-cast alloy. The results of this study indicate that the reinforced AZ61 Mg alloy can be a potential material for applications in automobile sectors due to its high strength and lightweight components.

Keywords: Characterization; metallography; high-speed tool; nano-fillers.

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TECHNICAL PAPER

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1. INTRODUCTION

Magnesium and its alloys exhibit a promising potential for usage in automobile, aerospace, and marine applications, attributed to their high strength-to-weight ratio and lightweight nature. Researchers have demonstrated that reinforcing by the addition of secondary particles to magnesium in the fabrication of Mg matrix composites significantly improves both grain refinement and mechanical properties. Currently, various techniques such as stir casting, spray deposition, in-situ fabrication, and powder metallurgy are utilized for composite fabrication. Mechanical stir casting was used to fabricate hybrid composites of AZ61 magnesium alloys reinforced with alumina (Al_2O_3: 2 wt.%) and silicon carbide (SiC) nanoparticles at various proportions showing that compressive, microhardness and tensile properties are directly related to SiC concentration so that maximal values were obtained for composites with 1 wt.% SiC [1]. Physical vapor deposition and chemical vapor deposition are used to generate thin films and coatings from 50 nm to a few microns to protect the materials and improve their properties. Still, these coatings cannot withstand significant mechanical loadings. [2]. Thermal spraying is an efficient technique to produce thick ceramic layers so it is the most preferred method. However, these coatings could be microporous with microcracks and show poor substrate adherence. Therefore, these methods often result in defects leading to increased costs and longer processing times. Therefore, to overcome these drawbacks, it is essential to develop an effecient technique for preparing defect-free high-quality surface composites. friction stir processing (FSP) is a solid-state processing method that employs principles of friction stir welding (FSW) to produce improved magnesium matrix composites, potentially resolving the limitations mentioned above [3]. By FSP, simultaneous homogenization, densification, and grain refinement of the microstructure can be achieved [4], resulting in improved mechanical properties of the materials. It has been widely reported that the

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FSP technique can be used to significantly refine the grain size and enhance the mechanical properties of magnesium alloys [5-7]. FSP was utilized to add various reinforcement particles like ZrC [8], B_4C [9], Si_3N_4 [10], TiC [11], 304 stainless steel powders, fly ash, Ti-6Al-4V, palm kernel shell ash [12], TiAlC [13] and $NiTi_p$ [14] to Mg alloys to improve alloy mechanical properties. The present research aimed to attempt the addition of nano-particles of Al_2O_3 and TiO_2 in the AZ61 Mg alloy by using this technique.

2. EXPERIMENTAL SETUP

The magnesium alloy AZ61 (Venuka Engineering Private Limited, India) with a chemical composition of 5.98 wt.% Al, 0.95 wt.% Zn, 0.001 wt.% Fe, and Mg in balance was chosen for this study with the dimensions of 150×50×10 mm and nanoparticles of Al_2O_3 (Nano Labs, India) and TiO_2 (Nano Labs, India) were employed as reinforcements. The powders were analyzed by scanning electron microscopy, (SEM) so that the average particle size was determined to be between 10 and 20 nm. In this application, the area of interest is a semicylindrical groove about 3 mm in diameter, which was drilled into the workpiece and filled with nanoparticles. The semicylindrical groove of was drilled in a zigzag manner along the length of the plate. FSP was performed by using a specially designed, non-consumable tool made of H13 (K.R. Engineering, Chennai, India) and an FSP machine (Fig. 1, Annamalai University, India) with binary elements namely a pin and a shoulder. The tool is made to revolve at the required speed, and by applying downward force to the tool, the pin penetrates the base material, and the shoulder just touches the surface of the material.

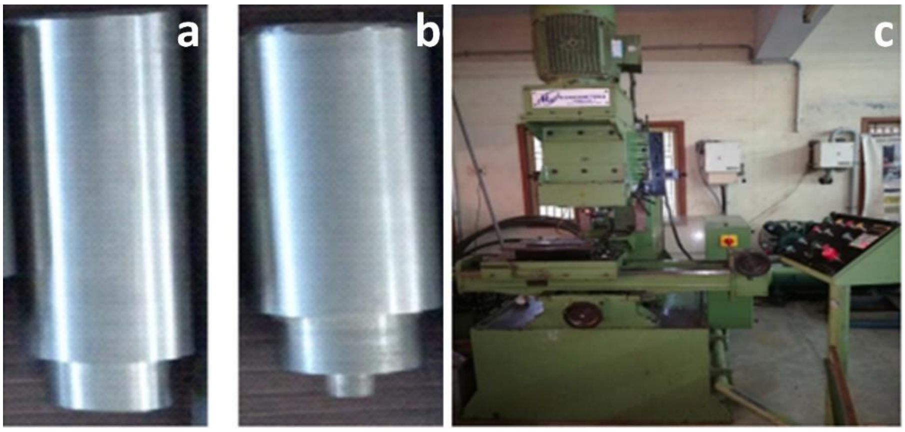

Figure 1. Photographs of the experimental friction stir processing (FSP) set-up: FSP tool (a) without the pin for specimen preparation, (b) with a cylindrical pin profile for processing, and (c) FSP machine

FSP was performed with the following parameters: tool rotation speed of 1000 rpm, travel speed of the tool of 10 mm/min, axial force of 4.5 kN, and the tilt angle of the tool of 2°. Surface-modified specimens at various powder contents (*i.e.* 5, 10 and 15 vol.%) are displayed in Figure 2.

Figure 2. FSPed specimens with a) nano-Al_2O_3, b) nano-TiO_2

SEM micrographs were taken by a scanning electron microscope (Evo 18, Carel Zeiss, India) above the surface of the coated and intersection region to study the microstructure of the friction stir processed samples. FSP samples were cut into needed dimensions 1×1 cm via wire electrical discharge machining (Chmer CNC wire cut, Taiwan) to carry out the microscopy analysis. Samples were refined *via*SiC emery sheets, followed by polishing of the sample surfaces using diamond paste. Chromic acid was used as an etchant after polishing.

Along with morphological features, the modified alloy surfaces were tested and characterized for their improved mechanical properties. Tensile strength was determined by a computerized micro-tensile machine (Model FIE5000PF, Fuel Instruments and Engineers, India) as per the ASTM standard E-8. Sample dimensions 55×10×10 mm with a 45° notch used to carry out impact test (XJJU-5.5, Kystal Equipments, India) as per ASTM standard E-24 and the hardness of the surface modified specimen was measured by the Vicker's hardness tester (HDNS-Kelly Instruments, China) as per E-94 standard.

3. RESULTS AND DISCUSSION

3.1. Metallographic characterization

The surface morphology of AZ61 magnesium alloy samples reinforced with nano Al_2O_3powders at different contents produced by FSP was examined by using SEM (Figure 3). FSP is a suitable technique to distribute the reinforcement particulates uniformly in the stir region, in contrast to the stir casting process which results in non-uniform distribution of reinforcements because of density variation of matrix and reinforcing phases and solidification connected factors. Nevertheless, the FSP process parameters have to be adjusted to attain appropriate dispersal of particles. In this study, the traverse speed and number of passes, in addition to the percentage of nanoTiO_2 particulates, were varied in pursuit of uniform dispersal, *i.e.* the aim was to achieve the microstructure of the whole stir region with distributed particles.

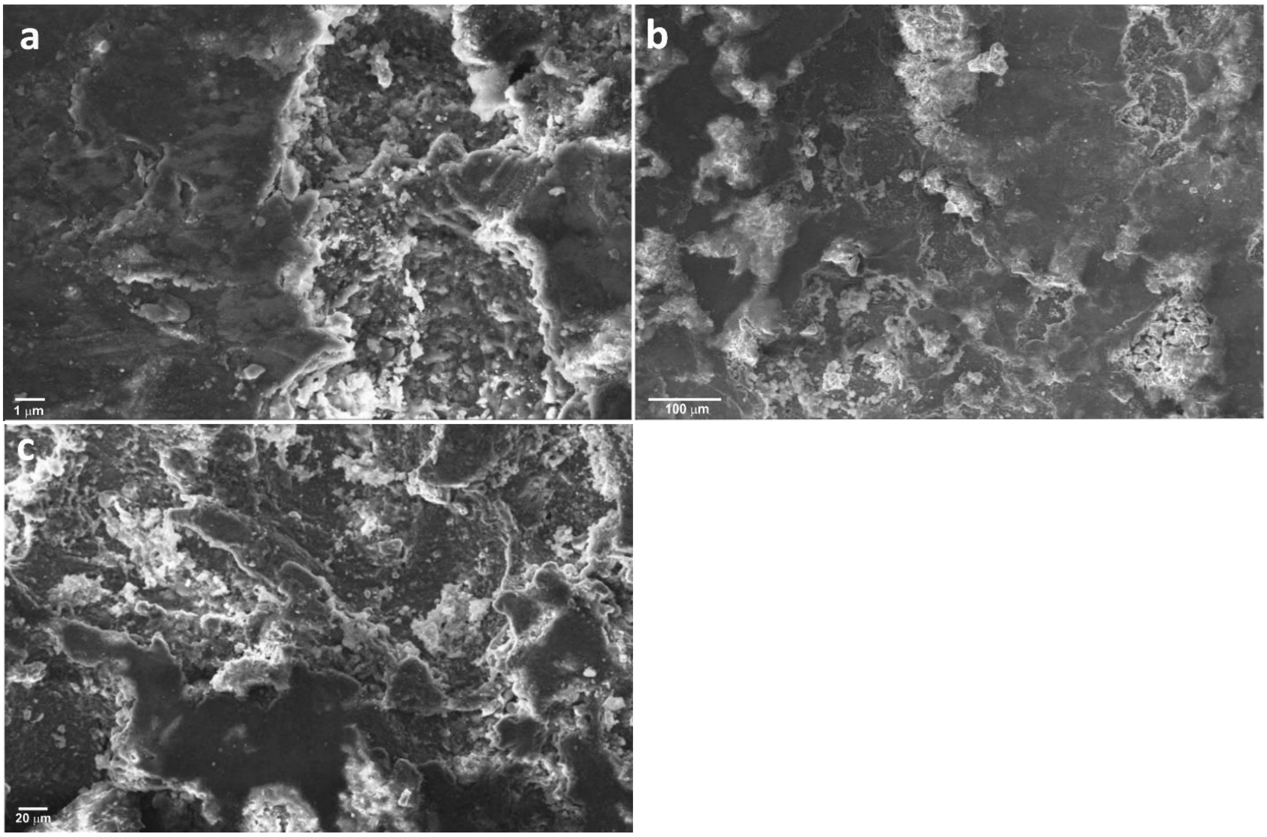

Figure 3. Microstructure of AZ61 Mg alloys reinforced with (a) 5 vol.% nanoAl_2O_3, (c) 10 vol.% nanoAl_2O_3 and (c) 15 vol.% nanoAl_2O_3

The microstructure is notably affected by two FSP factors: frictional heat and mechanical stirring. Frictional heat alters the grain size, thus enhancing the ease of plasticization. Nonetheless, it does not have a straight effect on the drive of particulates. Mechanical stirring distorts the heated materials and directly disturbs the drive of particulates. Traverse speed determines instantaneouslyboth thefrictional heat and mechanical stirring. The increase in traverse speed induces a decrease in both factors. Consequently, the dispersal became worse as the traverse speed increased despite the reduction in stirring and lower frictional heat, which lessened the grade of plasticization. It was observed that circulation improved at a traverse speed of 30 mm min^{-1}. The particulates couldn't touch altogether the areas of the stir region [15]. Figure 4 displays the friction stir processed nanoTiO_2 reinforced AZ 61 magnesium alloy.

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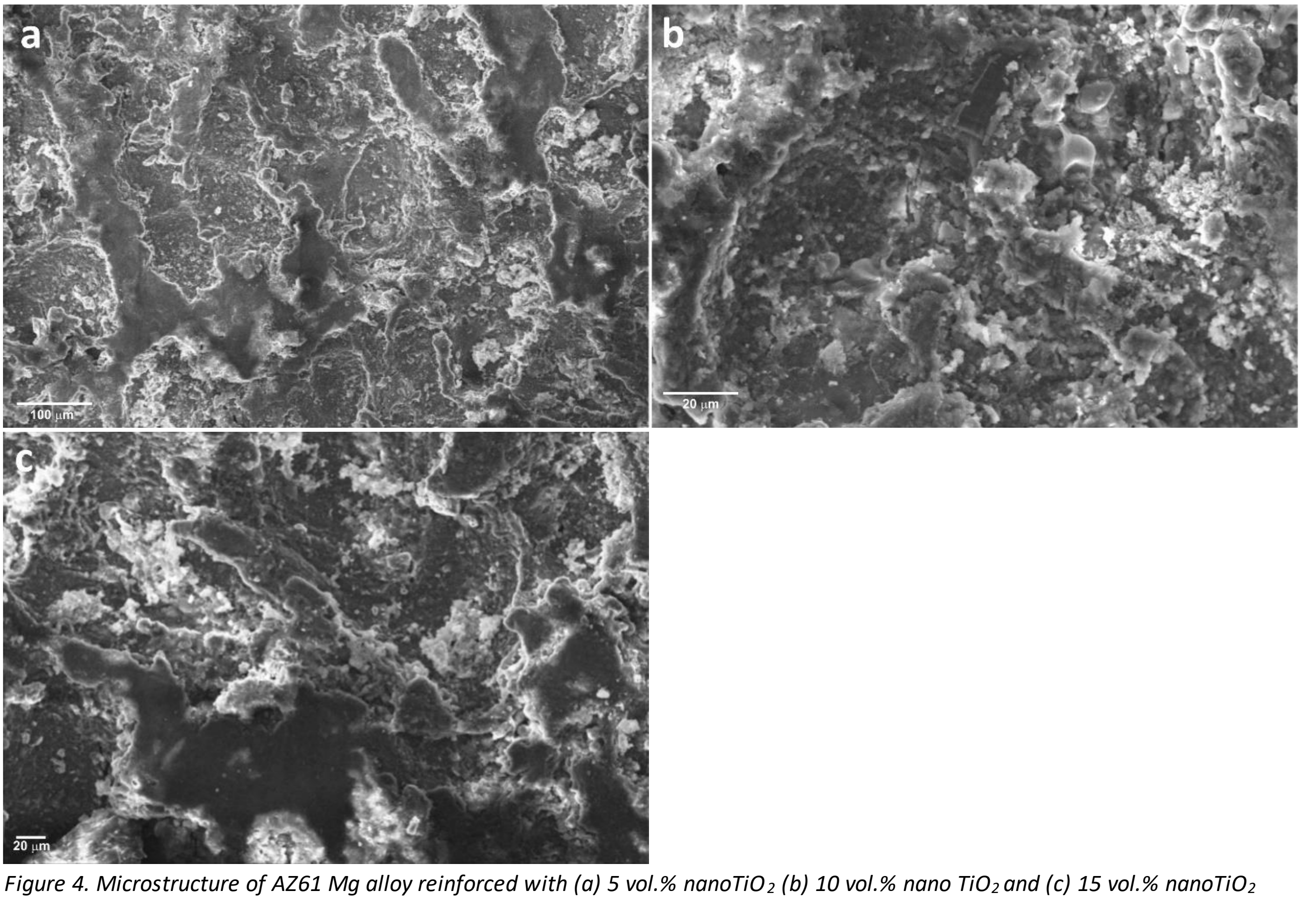

Figure 4. Microstructure of AZ61 Mg alloy reinforced with (a) 5 vol.% nanoTiO_2 (b) 10 vol.% nano TiO_2 and (c) 15 vol.% nanoTiO_2

3.2. Tensile strength of the surface-modified specimens

Ensuring the quality of the metal specifications' tensile properties is the most influential factor in selecting the material for engineering applications. Tensile tests were carried out on the friction stir processed AZ61 magnesium alloy strength-henedwith different proportions of nanoAl_2O_3 and nanoTiO_2 powders as well as the unmodified AZ61 magnesium alloy for comparison. It was found that nano-TiO_2 reinforced alloy possesses higher tensile strength (203 MPa) than unreinforced and nano-Al_2O_3 reinforced alloy, as shown in Figure 5.

The improvement in tensile strength was achieved with recrystallization and modification of grains, homogeneous distribution, and definite boundary. The tensile load is effectively moved to the particle to the matrix material, without any interfaces. Nano-TiO_2 reinforcement enhanced the plastic flow of the AZ61 Mg alloy. The crack surface of the alloy shows a system of modest pores, and nano-TiO_2 particles are seen on the crack surface. Fine voids appear on the fractured surface of the AZ61 with nano-TiO_2 particles being pulled out from the surface by debonding/fracture during the test. The results indicate that nanoAl_2O_3-reinforced AZ61 Mg alloys exhibit slightly lower tensile strength than that of nano-TiO_2-reinforced alloys. The major reason for this result could be that nano-TiO_2 particles are distributed more evenly in the alloy in addition to the higher strength of these particles.

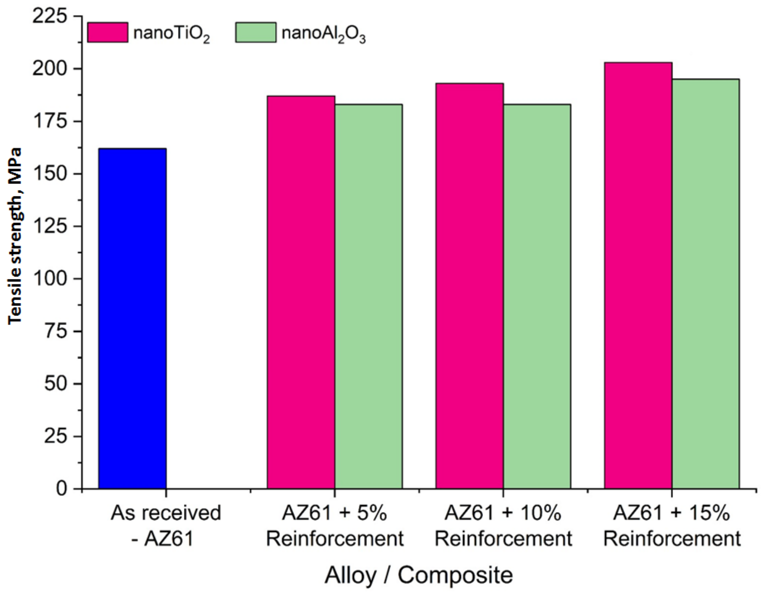

Figure 5. Tensile strengths of the non-modified AZ61 Mg alloy and reinforced with Al_2O_3 or TiO_2 nanoparticles at different concentrations

3.3. Impact test

Impact tests were performed to determine the toughness of the unreinforced AZ61 Mg alloy and those reinforced by nano-Al_2O_3/nano-TiO_2. The impact strength comparison is shown in Figure 6.

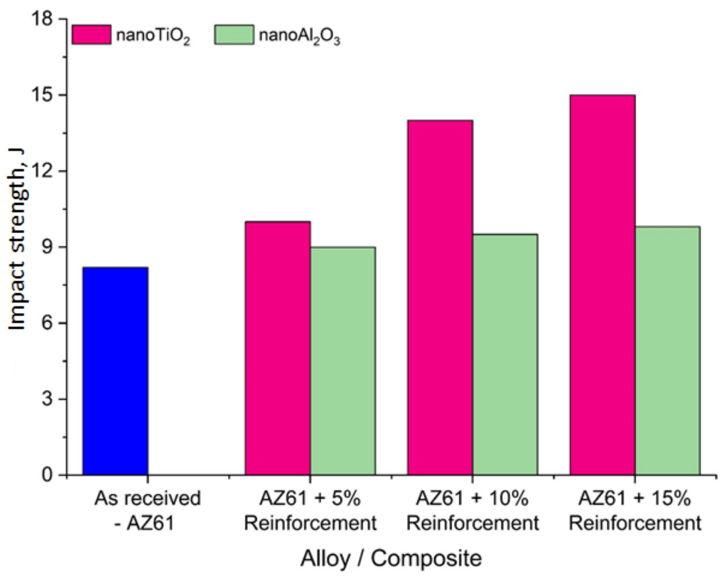

Figure 6. Impact strength of the non-modified AZ61 Mg alloy reinforced with nano-Al_2O_3 or nano-TiO_2 nanoparticles at different concentrations

The maximal impact strength was determined for the alloy reinforced with 15 vol.% nano-TiO_2 amounting to 15 J. In contrast, the alloys reinforced with nano Al_2O_3 showed negligible difference as compared to the received alloy amounting to 9 J. This is due to the influence of reinforced nanoparticles that resist fracture and can withstand higher energy generated during the impact loads. With the increase in the percentage of nano-TiO_2 from 5 to 15 vol.% the impact strength is increased. However, the increase in the content of nano-Al_2O_3 did not improve the impact strength of the alloy. This result might be because of the grain alteration in the friction stir region despite the maximum heat production [16].

3.4. Microhardness

Comparison of measured microhardness values for the as-received AZ61 Mg alloy and those reinforced by nano-Al_2O_3/nano-TiO_2 is shown in Figure 7. All reinforced specimens show higher microhardness in the nugget zone than that of the unmodified specimen. Nano-TiO_2 reinforced AZ61 Mg alloys generally exhibited higher microhardness than those of nano-Al_2O_3 reinforced alloys except for the alloy with 10 vol.% nano-Al_2O_3.

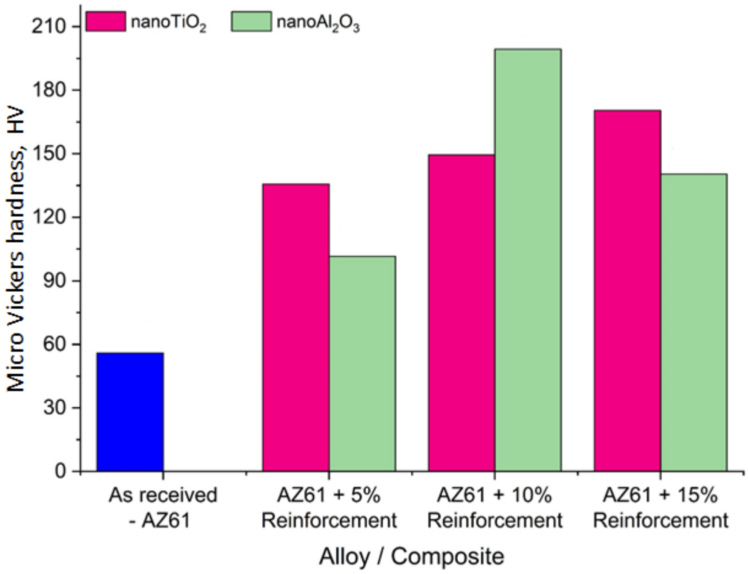

Figure 7. Microhardness of the non-modified AZ61 reinforced with Al_2O_3 or TiO_2 nanoparticles at different concentrations

Orowan strengthening, grain refinement, and substructure strengthening are the major mechanisms identified that improve the strength of the nano-ceramic strengthened surface-modified composite that is obtained with the uniform dispersal of nano-TiO_2 particles and better bonding with the AZ61 matrix. The material drifts in a multifaceted fashion from the receding to the progressing side amid FSP, offering an increase in the inclines in temperature, strain, and strain rate through the stir region. Furthermore, since a groove was created in the middle of the specimen to receive nano-particles, the specimen must drift into the drilled groove to seal it to provide a defect-free continuous stir region. A lower microhardness of nano-Al_2O_3 reinforced AZ61 Mg alloys could be due to grain modification in the FSP region because of higher heat generation [17].

4. CONCLUSION

1. The new magnesium surface composite created in this work revealed improved mechanical properties as compared to the neat Mg alloy, proving that reinforcementby the surface modification method used in the present study is a viable way for qualities such an improvement also result in desirable surface properties.
2. The best mechanical properties were achieved with 15 vol.% of nano-TiO_2 although microhardness was lower as compared to 10 vol.% due to lower homogeneity of nanoparticles and weaker bonding under loads.

3. Mg alloy strengthened with nano-TiO_2 powder has the potential for utilization in the automotive industry due to its high mechanical strength. This will lead to even wider applications of already broadly used magnesium alloys, significantly increasing their use.

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Mehanička svojstva površinski modifikovane legure magnezijuma AZ61 sa nanočesticama aluminijum oksida i titanijum dioksida obradom putem tehnike trenja sa mešanjem

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(Stručni rad)

Izvod

U ovom radu su prikazani rezultati istraživanja mehaničkih osobina površinski modifikovane legure magnezijuma AZ61, ojačane nanočesticama Al_2O_3 i TiO_2 primenom tehnike trenja sa mešanjem (engl. *friction stir processing* - FSP). Površinski modifikovane legure AZ61 su proizvedene dodavanjem različitih količina nanočestica Al_2O_3 i TiO_2 (5, 10 i 15 vol.%). Mikrostruktura dobijenih površinskih kompozita pokazuje ujednačenu disperziju dodatih nanočestica, što je rezultiralo poboljšanjem njihovih mehaničkih svojstava primenom FSP. Ojačavanjem legure nanočesticama TiO_2 krajnja zatezna, udarna i mikro-tvrdoća su poboljšane za 20, 45 i 67 %, redom, u poređenju sa livenom legurom. Rezultati ove studije ukazuju da ojačana legura AZ61 Mg može biti potencijalni materijal za primenu u automobilskoj industriji, jer poseduje veliku čvrstoću i malu specifičnu težinu.

Ključne reči: Karakterizacija; metalografija; oruđa velike brzine; nanoispunioci

Assessment of the size of the danger zone caused by an accident during transportation of a dangerous chemical substance

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Abstract
Air pollution is the central topic of all discussions related to environmental protection. Modelling the spread of pollution is one of the methods used to predict the spread paths and levels of pollution and to act in order to combat this problem. The paper presents modelling of dispersion of ammonia through the air using a software tool ALOHA (Areal Locations of Hazardous Atmospheres) based on the Gaussian model of particle dispersion. Modelling in the work is based on data related to the accident that occurred in December 2022 in the vicinity of the city of Pirot, Serbia, as well as on real meteorological data that were collected during the time of the accident and the spread of pollution. As a result of modelling, zones with increased ammonia concentration are obtained. The zone areas will depend on the ammonia concentration at the source and meteorological conditions during the period of the leakage. The aim of the paper is to point out the need to introduce modelling into the operational centres of the local police or military units in charge of emergency situations, as well as additional safety protocols when transporting dangerous goods.

Keywords: Gaussian model; areal locations of hazardous atmospheres; dispersal; ammonia; Pirot.

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TECHNICAL PAPER

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1. INTRODUCTION

The great technological progress of civilization and growth of both the smaller and the leading economies of the world led to the fact that exploitation of chemically hazardous substances experienced a huge expansion, and thus there was a significant increase in the number of chemical accidents. In this case, China could be a very good example [1]. The number of chemical accidents with injured persons in this country in the period between 2006 and 2017 amounted to a total of 3,974 [2]. A significant number of those chemical accidents (in China) occurred during the transport of dangerous chemical substances, amounting to 2,657 [3]. That is not a surprise since from more than a 6,000 existing dangerous goods that are transported, 2,000 of them is transported by public roads in China [4]. A large number of accidents were also recorded in maritime transport amounting to 650 for European ports alone for the period from 1919 to 2019 [5]. Data accessible at the global level show a large number of accidents during the transport, roughly 35 %, while 40 % happen during production and the rest present accidents occurring while in storage [6]. In Serbia on the state level the figures are about the same [6]. All countries in the world have to fight with these problems, Serbia not being an exception [7], given the fact that dangerous chemical substances, such as ammonia, cause serious health consequences in the living organisms [8].

Modelling the spread of pollution is one of the methods used to predict the movement path and level of pollutants in a certain zone [9]. There are many mathematical models used as a base for various software tools, programming codes or entire systems utilized to predict propagation of particles [10,11]. The basic division of mathematical models lies in the area of their application [11], but also software tools and modelling systems (such as AERMOD View, Lakes Software, Canada) are divided according to the field of application. Modelling of particles caused by road traffic [12], is not the same as that for particles originating from industrial zones [13], primarily because the shapes and surfaces of

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the pollution sources themselves are different, as well as dimensions and movement frequency of the particles. Also, different modelling approaches are applied for pollution originating from continuous sources [14] and for that arising due to accidents having a certain "shorter" duration [9,15].

2. MATERIALS AND METHODS

The most commonly used mathematical models for predicting the movement path of pollutant particles are the Gaussian dispersion model and the Euler-Lagrange model. Both models are also used with some modifications [16]. The most commonly used Gaussian dispersion models are the Gaussian Plume Model [17] and the Gaussian "Puff" Model [18].

The Gaussian plume model is a basic model, very simple to implement. Let's assume that the source is continuous with the power *Q* (usually expressed in μg s^{-1} representing the rate at which pollutants are emitted). If the source is located at an effective height (*h*), and the wind speed is constant (*u*) then the concentration of pollutants (usually expressed in μg m^{-3}) can be determined by the Equation (1) [19]:

$$C = \frac{Q}{2\pi\sigma_y\sigma_z u} e^{-\frac{y^2}{2\sigma_y^2}} \left[e^{-\frac{(z-h)^2}{2\sigma_z^2}} + e^{-\frac{(z+h)^2}{2\sigma_z^2}} \right] \quad (1)$$

where the coordinate *y* determines the width of the plume, while the position on *z* axis determines the height of the plume, and the position on *x* axis determines the reach of the plume (Fig. 1). Also, the wind direction is in the direction of the x axis. Parameters σ_y and σ_z represent the standard deviation of pollutant dispersion on the given axis, which are obtained by using models combining experimental data and theoretical considerations. The level of turbulence and, correspondingly, σ_y i σ_z, depend on atmosphere stability and orographic structure. Those parameters are divided into classes according to the levels of atmosphere stability defined as: A (extremely unstable), B (unstable) i C (mildly unstable), neutral class D, and stable E (stable) i F (very stable) [20].

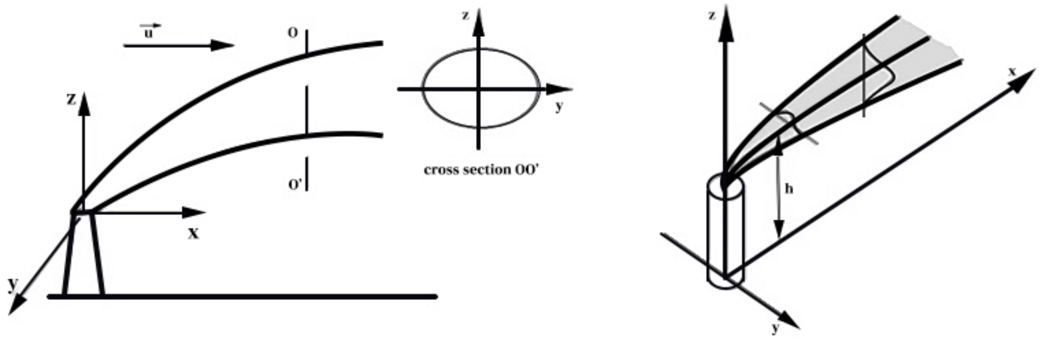

Figure 1. Orientation of the coordinate axes when modelling the smoke plume

There are several models to determine σ_y and σ_z, among which the most common are the Pasquill-Gifford model and Briggs model [20]. Horizontal and vertical dispersions are calculated by this simple Equations (2) and (3) [21]:

$\sigma_y = ax^b$ (2); $\sigma_z = cx^d$ (3)

The parameters a, b, c, and d from these equations are available in tabular form in many references, including [21].

Areal Locations of Hazardous Atmospheres (ALOHA®) is a software tool introduced by the US Environmental Protection Agency (EPA) and its primary use is for modelling chemical accidents [22] and determination of the pollution level and distribution after an accident. It is very convenient for use in the cases of accidents that are related to transport of dangerous goods primarily of chemical nature [23]. In specific, sizes and shapes of the tank as well as of damage could be chosen with specifying a distance from the bottom. It is possible to model accidents from ground fixed reservoirs [24,25], as the one arising from a chemical puddle that evaporates, and even if the source of pollution is a damaged pipe or a puddle. ALOHA is based on the Gaussian model of dispersion and in the menu “calculation options” it offers to use the Gaussian model or the Heavy Gas Dispersion model or alternatively the option “Let ALOHA to decide (select this if unsure)", and the method will be determined based on the substance involved. This application could be used for damage control and respond, risk assessment and management, or as a quick response in the case of an accident [26]. ALOHA offers even more diversity, so that the accident could be a toxic cloud, area in a blaze, an accident involving explosion and through forming an area of dissipation [27].

3. RESULTS AND DISCUSSION

The accident for which the modelling was done happened on December 25, 2022. between 16:30 and 17:30, near the town of Pirot, Serbia, on the bend of the railway line between Staničenje and Sopot, at coordinates 43°13' N, 22°32'21'' E. According to the reports of some media, the accident happened exactly at 16:36, while others state that it took place at 17:30. The accident occurred when four out of a total of 20 tank wagons derailed. The tankers were transporting ammonia from Bulgaria to the town of Šabac. According to the media and officials from the Department for emergency situations, they were overloaded and carried 45 t each. Figure 2 shows technical characteristics of the tanks with the length of 16.1 m, volume of 95.3 m^3, corresponding to the diameter of 2.75 m. These data are very important presenting input parameters regarding the source of pollution.

Figure 2. Specifications on tanks transporting ammonia

Although there is uncertainty about the initial size and shape of the hole through which ammonia leaked, the hole location and size can still be inferred from published leak data. According to publicly available data, the tankers were returned to the track on January 14, 2023, with the remaining 20 t of ammonia, from the initial 45 t. Based on that fact, it can be assumed that the hole was rectangular, 5 cm long and about 3 cm wide or round shaped equivalent, and it had to be about 90 cm from the bottom, approximately one third of the tank height.

Modelling was performed for three scenarios. The first scenario includes meteorological data that were reported on that day (December 25, 2022). It is also the most likely scenario for the given event. The other two scenarios are given for meteorological data that were reported on the coldest and the hottest day of the year. These are practically the limit values for the year 2022. Since the range of variables is determined in this manner, it can be presumed that particle dispersion for the studies case falls between those limits.

Scenario 1 (the most probable one)

Meteorological data is adopted from two sources [28,29], which verify that at the given time from 17 till 18 h, temperature was in the interval from 9.3 and 7.7 °C. Thus, the value of 8.5 °C was accepted for the calculation as the arithmetic mean. The substance in the tank was assumed to be at the same temperature, which is ambient temperature. The summary of meteorological data is presented in Table 1. Under these conditions, 45 t of liquid ammonia occupies 68.2 % of the entire tank volume.

Table 1. *Meteorological data (at the moment of incident)*

Parameters	Actual conditions
Temperature	8.5 °C
Wind direction	West
Wind speed	2 m/s
Humidity	70 %
Cloudiness	5/10
Atmospheric stability level	F

The option of ALOHA choosing the appropriate model, Gaussian or Heavy Gas Dispersion model, was used resulting in selection of the second model. The predicted leakage results are as follows – two streams of ammonia as a mixture of liquid and aerosol, leaked initially at the average flow rate of 1,350 kg min^{-1} followed by a sudden drop about 20 min later (Figure 3); the total amount of ammonia that escaped in the environment is 25,718 kg.

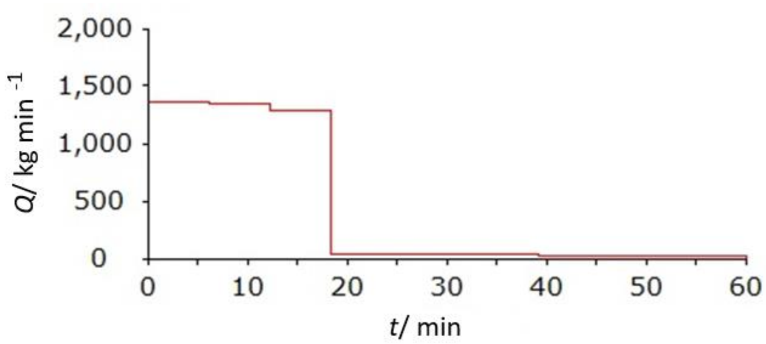

Figure 3. Predicted source strength – flow rate, Q, over time, t, after the start of the accident in Scenario 1

The potential danger zone was about 200 km^2 in size (Fig. 4). The zone of the highest pollution (more than 1,100 ppm, which corresponds to the value of 1.1 kg m^{-3}) extended 2.1 km from the source (red zone in Fig. 4), the zone of significant pollution (more than 160 ppm, *i.e.* 0.16 kg m^{-3}) extended at a distance of 6 km from the source, while the zone of relatively low pollution (more than 30 ppm, *i.e.* 0.03 kg m^{-3}) extended at a distance of 10 km from the source. All concentrations are given for a period of 60 min, although considering the source power diagram (Figure 3), it is clear that the released amounts from the source after 20 min from the initial moment are negligible.

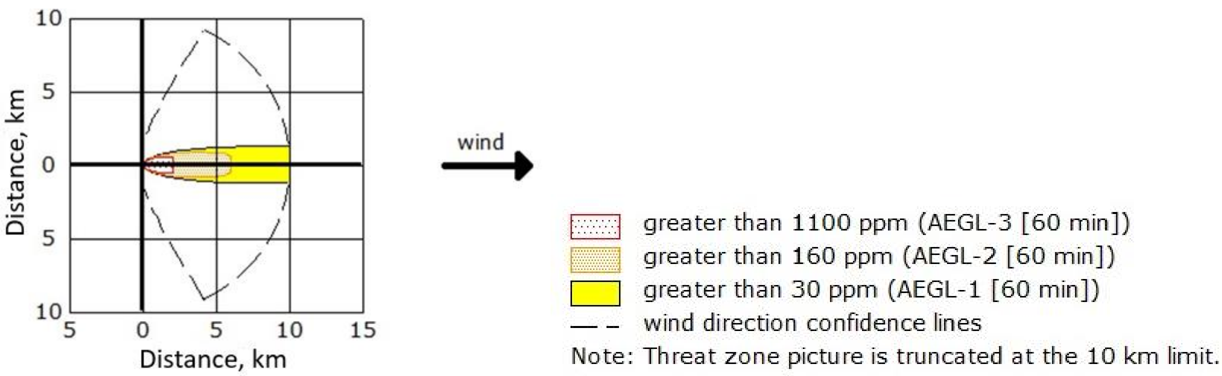

Figure 4. Toxic threat zone - area affected by a certain concentration of ammonia predicted in Scenario 1

Geographical representation of the threat for the city of Pirot and the zones obtained by modelling in ALOHA can be seen in Figure 5. The highest concentration of pollution was at the highway intersection A4, which is why the traffic on this part of the road was stopped. Only due to the favourable meteorological conditions (primarily the wind direction) concentrations in the populated places of Sopot, Staničenje and Pirot were not the highest possible, that is, the red and orange zones bypassed these densely populated places. In this accident, 50 people had injuries to their respiratory organs due to ammonia inhalation, and two people lost their lives.

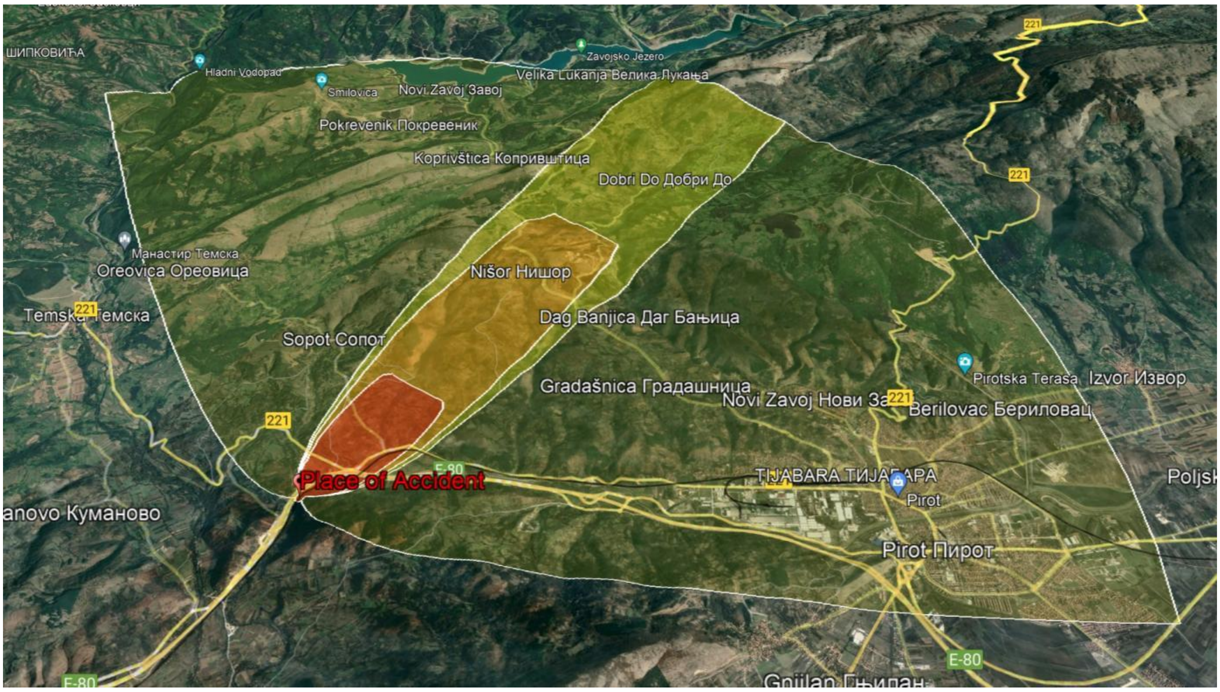

Figure 5. Geographical view of threat zones in Scenario 1

Scenario 2 (extreme winter condition)

Day with the lowest temperature in 2022 was January 25. The complete meteorological data are shown in Table 2 [28,29]. Under these conditions, 45 t of liquid ammonia occupies 64.8 % of the entire tank volume.

Table 2. Meteorological data (under extreme winter conditions reported for January 25, 2022)

Parameters	Winter conditions
Temperature	-16.5 °C
Wind direction	South/South East
Wind speed	1 m/s
Humidity	60 %
Cloudiness	0/10
Atmospheric stability level	F

The predicted leakage results are as follows – two streams of ammonia as a mixture of liquid and aerosol, leaked at the average flow rate of 713 kg min^{-1} initially followed by a sudden drop 35 min later (Fig. 6); the total amount of ammonia that escaped in the environment is 23,935 kg.

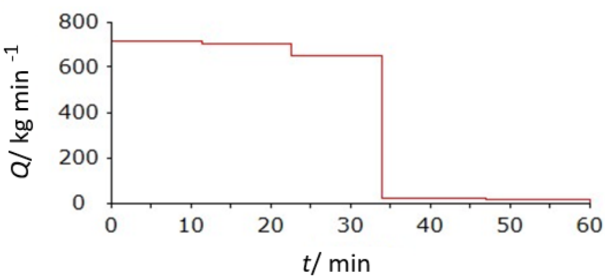

Figure 6. Source strength – flow rate depending of duration from start point

The potential danger zone was a circle about 314 km^2 in size (Fig. 7). The zone of the highest pollution extended 2.2 km from the source (red), the zone of significant pollution extended at a distance of 5.8 km from the source (orange), while the zone of relatively low pollution extended at a distance of more than 10 km from the source (yellow). All concentrations are given for a period of 60 min.

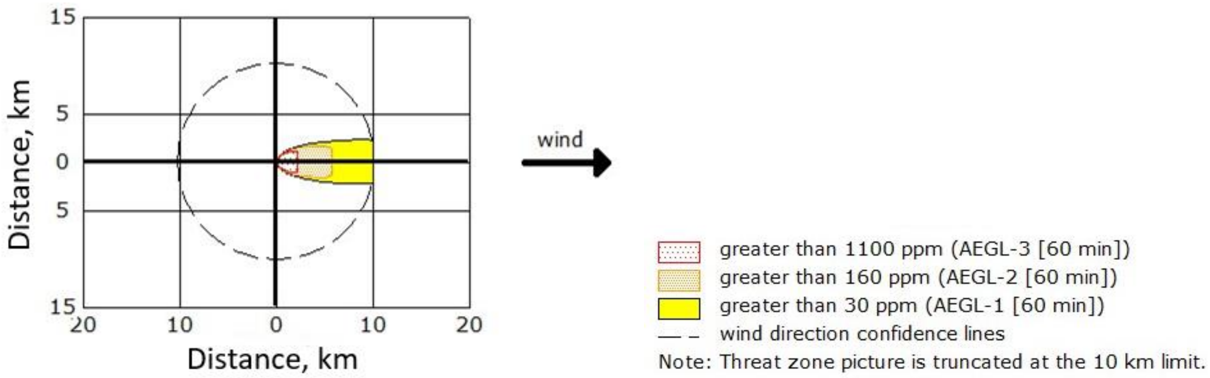

Figure 7. Toxic threat zone - area affected by a certain amount of hazard

Geographical representation of the threat for the city of Pirot and the zones obtained by modelling in ALOHA can be seen in Figure 8.

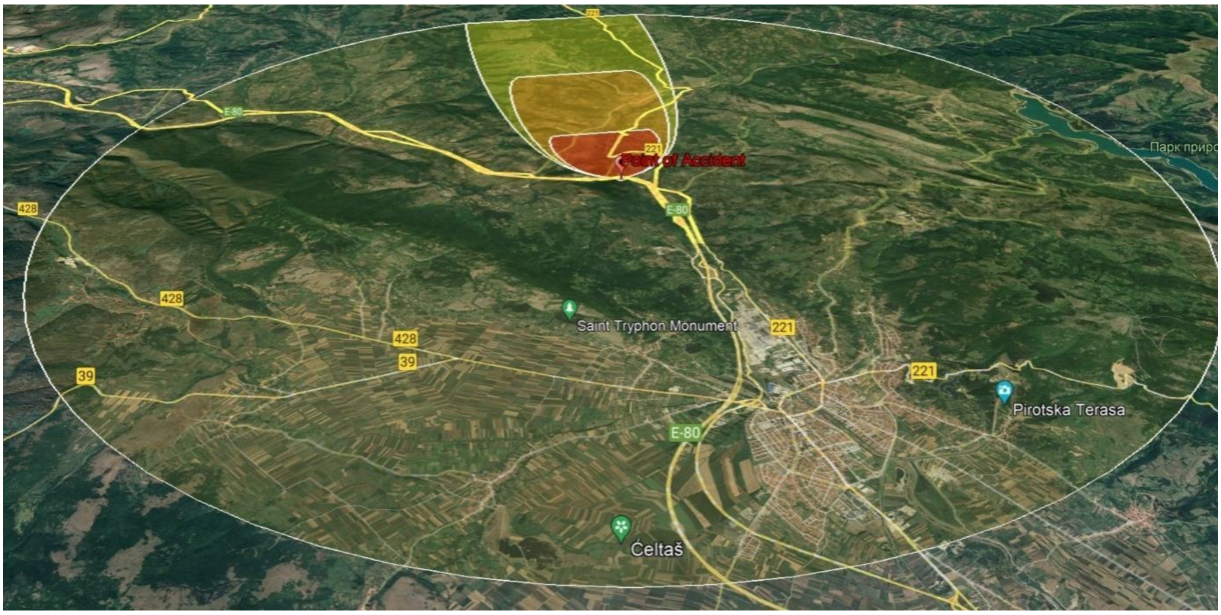

Figure 8. Geographical view of threat zones in Scenario 2

In this scenario the outcome is almost the same as in Scenario 1, but since the wind was blowing from a different direction, dangerous zones are completely away from the populated areas.

Scenario 3 (extreme summer conditions)

The warmest day in 2022 was July 23 for which all meteorological data are provided in Table 3 [28,29]. Under these conditions, 45 t of liquid ammonia occupies 73 % of the entire tank volume.

Table 3. Meteorological data (under extreme summer conditions reported for July 23, 2022)

Parameters	Summer conditions
Temperature	37 °C
Wind direction	North/Northwest
Wind speed	2 m/s
Humidity	30 %
Cloudiness	0/10
Atmospheric stability level	B

The predicted leakage results are as follows – two streams of ammonia as a mixture of liquid and aerosol, leaked at the average flow rate of 2,150 kg min^{-1} initially followed by a sudden drop 12 min later (Fig. 9); the total amount of ammonia that escaped in the environment is 28,002 kg.

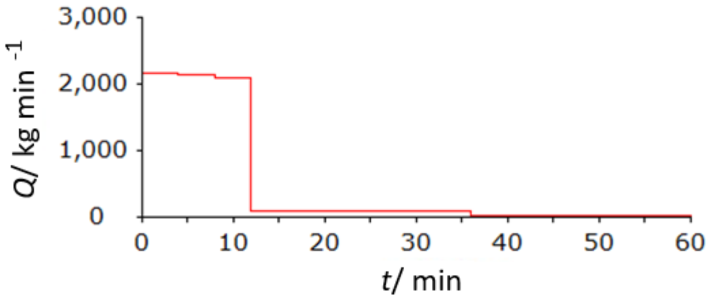

Figure 9. Source strength – flow rate depending of duration from start point

The potential danger zone was about 200 km^2 in size (Fig. 10). The zone of the highest pollution extended 1.6 km from the source (red), the zone of significant pollution extended at a distance of 4.7 km from the source (orange), while the zone of relatively low pollution extended at a distance of more than 10 km from the source (yellow).

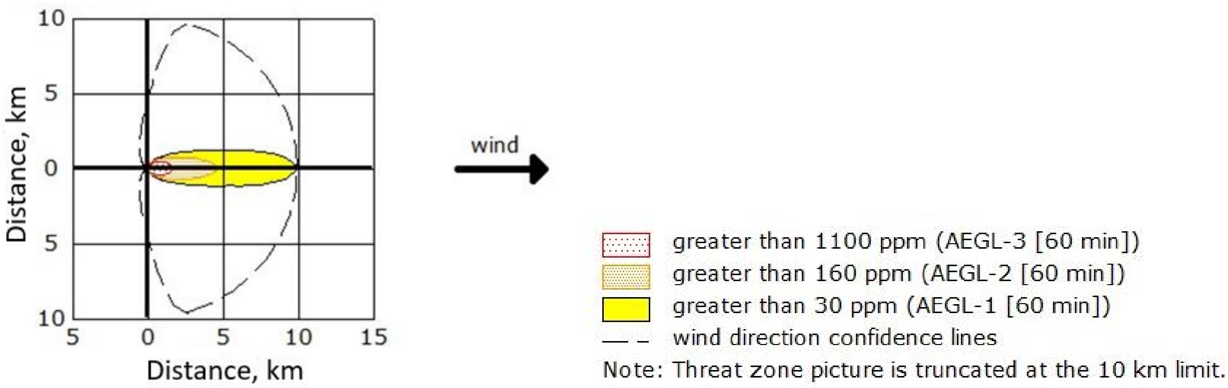

Figure 10. Toxic threat zone - area affected by a certain amount of hazard

Geographical representation of the threat for the city of Pirot and the zones obtained by modelling in ALOHA can be seen in Figure 11.

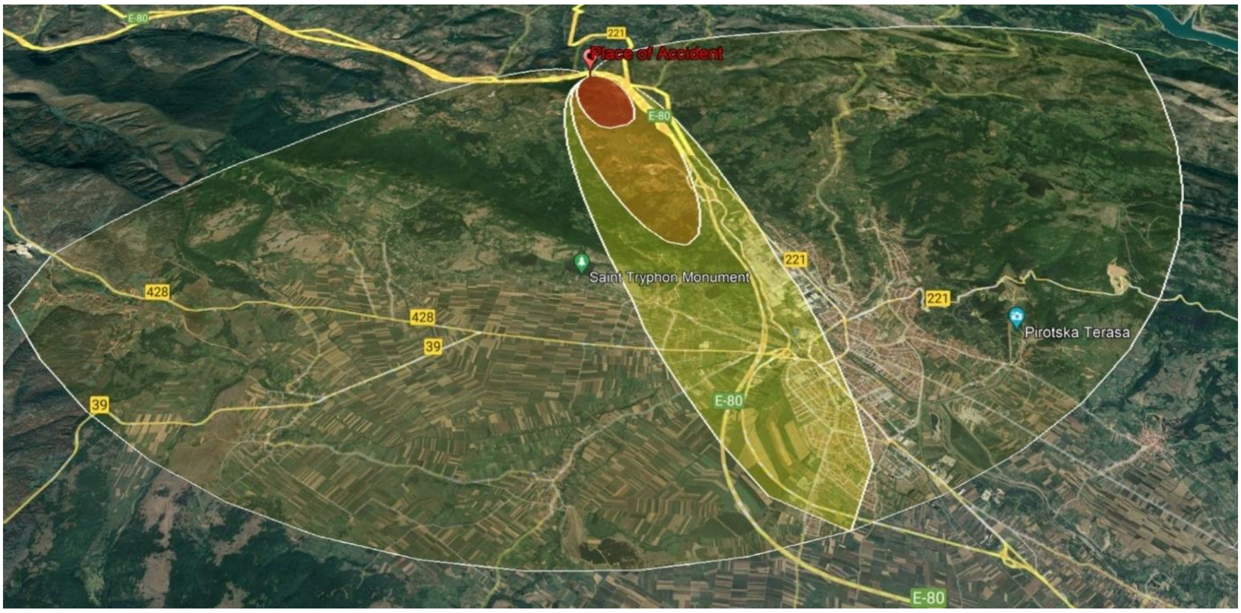

Figure 11. Geographical view of threat zones in Scenario 3

At first glance at the map, this scenario seems the worst of all three scenarios, but that is purely due to the wind direction. If the same wind direction was adopted in the previous two scenarios, it would show a far worse situation in terms of dangerous or lethal concentrations in populated areas. Depending on the conditions at the time of the accident, there is a large difference in the degree of danger. Thus, it could be clearly concluded that wind plays a key role. However, in the case of the city of Pirot, the orography also plays a certain role. In specific, the terrain is such that it would stop further dispersal, but it would also create pockets of higher concentrations.

The fact that it took 20 days to remove the tanks actually indicates how difficult and dangerous it would be to access the site of a more serious accident and how complicated it would be to carry out recovery in a potential severe case. Information circulated in the national media that this is not an isolated case and that there are about 80 of such accidents per year on average. It was announced that this particular place is marked as dangerous, due to derailments often happening there. The tendency to overload wagons is also dangerous. In the present case, the nominal weight was 20 t, but in reality, it was 45 t, which is more than 2-fold higher. By using the same modeling approach in ALOHA the same accident was modelled for a tank carrying 20 t and compared with the modeling results for the real case of 45 t (Table 4).

Table 4. Modelling results for 3 studied scenarios with tanks carrying 45 t and 20 t of ammonia

	45 t ammonia		20 t ammonia	
	Release rate, kg min^{-1}	Total released amount, kg	Release rate, kg min^{-1}	Totala released amount, kg
Scenario 1 (25.12.2022.)	1,350	25,718	1,180	3,293
Scenario 2 (25.01.2022.)	713	23,935	484	1,403
Scenario 3 (23.07.2022.)	2,150	28,002	1,990	5,571

As expected, by reducing the amount of ammonia in the tanks, the leaking rate and the total volume of the spill was reduced, so the danger to the environment is significantly smaller. That alone would have a greater impact than any variable being tested. Reducing the total mass of ammonia in the wagons would certainly lead to a more stable ride and lower tendency to derail.

4. CONCLUSION

In this research, modelling using the ALOHA software tool in real-time conditions was applied for the accident that occurred during the transport of ammonia near Pirot, Serbia. At that occasion a significant number of people were injured and two people lost their lives. The modelling results indicate that the situation could have been even much worse in the event of different meteorological conditions (wind direction and intensity, temperature, *etc.*). In the present case, the zones with the greatest pollution "missed" the densely populated places, that is the whole city of Pirot, while the highest concentration of ammonia as a semi-volatile substance (above 1.1 kg m^{-3}) was present exclusively at a distance of 2.1 km from the source, which affected the intersection at the A4 highway near Sopot.

Modelling using ALOHA and similar software tools should become a practice in risk assessment and risk management when dealing with hazardous chemicals and other hazardous substances. As weather conditions play a very important role in the spread of pollution particles, when planning every transport of dangerous goods, analysis and risk assessment in the event of an accident should be carried out with real-time data, read just before the vehicle passes through a certain inhabited zone. In the event that an accident has already occurred, it is necessary to react quickly in order to protect people's lives and health, by monitoring the situation, but also by modelling using the real data, in order to evacuate people from the zones with highest concentrations as soon as possible. This is particularly important since the dispersion is most intense during the first hour after the accident, which is precisely the reason that the ALOHA algorithm was designed to limit the modelling time to 1 h. After that time most sources do not emit hazardous substances any longer. Further spreading of pollutants is exclusively caused by meteorological conditions, primarily by the wind, which eventually lifts the particles and transports them to further places. Places on roads and railways that are marked with a black dot should be additionally secured, while modelling should be performed especially for these places when planning the transport of hazardous materials along these routes. Also, in the cases that those routes are predicted to be too risky, an alternative solution for the transport of the given shipment should be considered.

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Procena veličine zone ugroženosti nastale akcidentom prilikom transportovanja opasne hemijske supstancije

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(Stručni rad)

Izvod

Zagađenje vazduha je centralna tema svih diskusija koje su u vezi sa zaštitom životne sredine. Modelovanje širenja zagađenja je jedan od načina kako možemo da predvidimo putanje širenja i nivoe zagađenja, te da delujemo u cilju suzbijanja ovog problema. U radu je modelovana disperzija amonijaka u vazduhu korišćenjem softverskog alata "ALOHA" (engl. *Areal Locations of Hazardous Atmospheres*) koji se zasniva na Gausovom modelu disperzije čestica. Modelovanje u radu se zasniva na podacima vezanim za akcident koji se dogodio u decembru 2022. godine u okolini grada Pirota, Srbija, kao i na stvarnim meteorološkim podacima koji su bili aktuelni u vremenskom periodu u kom se odigrao akcident i širenje zagađenja. Kao rezultat modelovanja, dobijene su zone sa povećanom koncentracijom amonijaka. Njihova površina zavisi od koncentracije amonijaka na izvorištu i meteoroloških uslova u periodu otpuštanja opasne materije. Cilj rada je da ukaže na potrebu za uvođenjem modelovanja u operativne centre jedinica MUP-a zaduženih za vanredne situacije, kao za i uvođenjem dodatnih bezbednosnih protokola prilikom transporta opasnih materija.

Ključne reči: Gausov model; prostorne lokacije opasnih atmosfera; disperzija; amonijak; Pirot

Nanofluids: Why we love them?

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Abstract

The rising need for fluids with significantly improved heat transfer properties led to the development of nanofluids. The first experiments showed encouraging results reflected in increased thermal conductivity and heat transfer coefficient accompanied with better stability than colloid suspension. Many research laboratories and companies observed the potential of nanofluid technology for specific industrial applications. However, after publication of numerous papers with contradictory results for the same or similar nanofluids, many issues arose. Although in some branches of industry nanofluids have already found practical applications, at some point researchers went back to basics, conducting extended studies and benchmark tests in attempt to explain the nanoparticle influence on thermophysical properties of nanofluids. The final goal of the whole scientific community is to produce nanofluids at low cost, exhibiting long-term stability, and good fluidity as the three most significant preconditions toward practical applications in the heat transport field.

Keywords: Thermophysical properties; thermal conductivity; dispersion stability.

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1. INTRODUCTION

The term “nanofluid” was presented to the scientific community in the 90s, while the expansion of research involving nanofluids started a few years later and never stopped. According to the Web of Science, this topic followed the exponential growth in the number of publications per year: from only 4 in the 2020, to more than 1400 papers 15 years later and up to 5000 papers in 2022. It is estimated that more than 300 research groups in academic institutions and companies are involved in nanofluid research worldwide, covering all topics from basic research to high-tech applications.

What lies behind the popularity of nanofluids? Are they really that superior to conventional fluids? Or is it simply the fact that it pays to think "nano" regardless of whether you are applying for research funding or marketing a new product? Before answering these questions, let's briefly recall what nanofluids really are and what we can achieve with them.

This new class of fluids contains particles in the size range under 100 nm which are uniformly and stably suspended in a liquid. Adding the nanoparticles to the base fluid will lead to changed effective thermophysical properties. The term effective means that the base fluid is not affected itself, but a new type of fluid is created, consisting of the base fluid and nanoparticles dispersed in it. Dilute colloidal dispersions of nanosized particles in a fluid have exhibited some advantageous features compared to larger particles suspended in a liquid, such as improved heat transfer, longer shelf life, and control of suspension stability. Also, as a result of the small size of nanoparticles, channel clogging and erosion of walls are less pronounced as compared to the use of larger particles, which is a unique combination of features most highly desired for different engineering applications.

Nanofluids can significantly improve/change properties of the base fluid such as thermal conductivity, specific heat, heat transfer coefficient, absorption, refractive index, lubricity, electric conductivity, etc. The much larger surface area of nanoparticles relative to those of conventional particles should not only improve heat transfer capabilities, but also increase the stability of suspensions. Due to the large area of potential usage, the most investigated nanoparticles include metals and oxides, but also carbides, nitrides or carbon tubes, while base fluids are usually water, ethylene glycol, oils or ionic liquids.

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2. NANOFLUID PREPARATION AND STABILITY

Over the years the preparation methods of nanofluids also experienced some changes. Firstly, researchers generated nanoparticles directly in the base fluids without the need for a redispersion process, but nowadays as nanoparticles are widely commercially available, preparation of nanofluids follows the so-called two step method. In the first step, nanoparticles are produced or bought and then, in the second, dispersed in the base fluid at the desired concentration.

But, although the two-step method seems "easier", researchers report that stability is a significant issue in this method as nanopowders aggregate easily because of the strong van der Waals force among nanoparticles. The one-step method seems to produce more stable nanofluids [1]. Another advantage of the one-step method is that drying, storage, transportation, and nanoparticle dispersion are avoided. The main fault of this method is that residual reactants remain in the nanofluids because of incomplete reaction or stabilization. Also, synthesizing nanofluids on a large scale is difficult when employing the one-step method. Thus, the two-step method is the most economical method for large-scale production of nanofluids because nanopowder synthesis techniques have already been scaled up to industrial production levels. For dispersion of nanoparticles in the base fluid different dispersion methods can be used to gain the stability of nanofluids such as sonication, homogenization and ball milling.

Figure 1 presents a stable nanofluid with uniformly dispersed nanoparticles in the base fluid on the left side, and an unstable nanofluid with nanoparticles quickly settling down after preparation, on the right side.

Figure 1. Photographs of a stable (a) and an unstable (b) nanofluid

Stabilization depends upon the choice of nanoparticles and a proper dispersion method. Hence, preparation and stabilization of nanofluids sets an exciting challenge to a researcher since the main objective and goal in nanofluid research is to develop a nanofluid with adequate stability for industrial applications. Along with the visual test to monitor agglomeration and sedimentation over time, UV-Vis spectroscopy and zeta potential measurements were adopted to observe stability of nanofluids. Other techniques include dynamic light scattering and laser diffraction analysis for particle size investigations.

How much only sonication mode, continuous or discontinues pulses used in nanofluid preparation, can influence the particle distribution and stability of the prepared nanofluid can be seen in [2]. It is shown that discontinuous vibrations cannot break the clusters and provide good distribution of nanoparticles and achieve constant stability of a nanofluid over long period of time.

Another aspect regarding stability of nanofluids that has to be considered is the usage of surfactants or dispersants, which, on the other hand, may affect the properties of nanofluids [3]. This information is often either intentionally or inadvertently neglected, which leads to apparently different experimental results for nominally the same fluids. Few papers over the years were dealing with this issue and concluded that addition of a surfactant remarkably affects transport properties and heat transfer performance of nanofluids and may be responsible for the discrepancy among the experimental data obtained for nanofluids in different research groups. Although their usage can help to enhance nanoparticle stability in fluids, the functionality of surfactants for high-temperature applications of nanofluids is a major concern.

3. THERMOPHYSICAL PROPERTIES OF NANOFLUIDS

Basic research of nanofluids is usually focused on the effect that nanoparticles have on thermophysical properties of the base fluid. Despite the attention this field has received in recent years, uncertainties concerning the fundamental effects of nanoparticles on these properties of solvent media remain [4]. Four thermophysical properties, *i.e.* density, specific heat, thermal conductivity, and viscosity, are intensely discussed in the literature, among which thermal conductivity is the property that has catalysed attention of the nanofluids research community the most. Based on experimental measurements, it was determined that the increase in thermal conductivity is mostly influenced by the concentration and shape of particles, as well as temperature and pressure in the system. It is interesting that the increase is often greater than the value which could be predicted by conventional theories. Several attempts were made to incorporate these results into correlations.

Due to large discrepancies and inconsistencies regarding the degree of thermal conductivity enhancement of the “same” nanofluids, a comprehensive International Nanofluid Property Benchmark Exercise was conducted [5]. Thirty-four organizations worldwide received identical samples of nanofluids in order to measure thermal conductivity using different experimental methods (the transient hot wire method, steady-state and optical methods). Four sets of test samples were procured covering variety of base fluid and different nanoparticles material, shape and concentration.

Three main conclusions were established: (i) the thermal conductivity enhancement rises with increasing the particle concentration and decreasing the base fluid thermal conductivity, (ii) deviations between experimental data obtained by different labs for the same samples fall within 10 %, which is attributed to the different measurement methods, and (iii) any anomalous enhancement of thermal conductivity was not observed and the classic theory accurately described the behaviour of thermal conductivity of nanofluids. Although some deviations are noticeable for directly measured thermal conductivities, the calculated enhancement of this parameter showed much better agreement between different labs since the same measurement technique at the same temperature conditions was also used to measure the thermal conductivity of the base fluid.

Figure 2 presents one of the graphs for the experimental thermal conductivity data of Au + water nanofluid sample [5]. There are noticeable deviations in the graph between the values obtained by different measurement methods at different laboratories as well as somewhat higher reported uncertainties for some of the results.

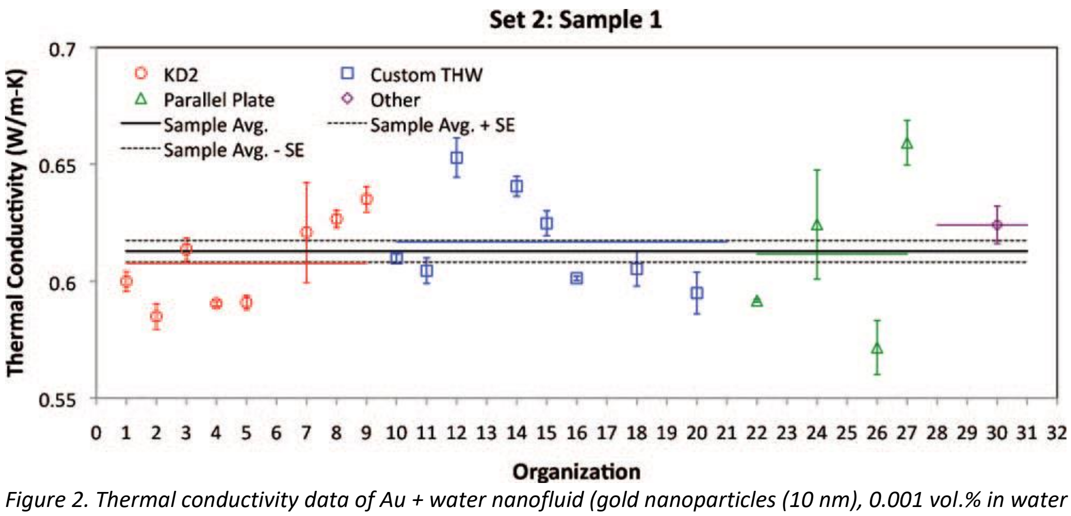

Figure 2. Thermal conductivity data of Au + water nanofluid (gold nanoparticles (10 nm), 0.001 vol.% in water + stabilizer) at room temperature, measured by different organizations and measurement methods: the KD2 Decagon thermal properties analyser, custom thermal hot wire (THW), steady state parallel plate and other techniques. The solid line represents the average of all data points, and the dotted lines are the standard error of the mean. Reprinted from Buongiorno et al. [5], with permission. Copyright [2009] by the AIP Publishing

From all mentioned above, it can be summarized that the complicated enhancement mechanism in nanofluids originate from several factors such as the physical properties of nanoparticles and base liquids, size and shape distribution of nanoparticles, volume fraction and agglomeration of suspended nanoparticles and the interaction between nanoparticles and the base fluid.

An interesting type of a nanosuspension should be mentioned which were obtained by suspending particles generated from biomass in a base fluid. The aim of these studies was to develop biofluids that would be an alternative to existing nanofluids. Queirós et al [6] investigated ionic biofluids as dispersions of ground lignocellulosic biomass in the mixture of 1-ethyl-3-methylimidazolium acetate [EMIM][OAc] with water as a base fluid. In this way, the researchers actually obtained a microfluid with a size of suspended particles smaller than 180 µm. With a small amount of suspended particles (1 wt.%), thermal conductivity of the base fluid did not increase. However, a significant increase in this parameter of 35 % was achieved at a mass concentration of particles of 3 wt.% at room conditions. Radojčin *et al.* [7] produced particles from sunflower stalks using hydrothermal carbonization and heat treatment in an inert atmosphere oven. The fraction of fine particles with mean peak diameter of 729.5 nm was about 20 %. The generated particles were suspended in the ionic liquid 1-hexyl-3-methylimidazolium bis (trifluoromethylsulfonyl)imide [HMIM][NTf_2] as a base fluid. The thermal conductivity of the dispersion increased by ~12 % relative to the ionic liquid in the case of 5 wt.% mass concentration of particles. The study was repeated with ethylene glycol as a base fluid and the thermal conductivity of the dispersion increased by 10 % relative to ethylene glycol in the case of 5 wt.% mass concentration of particles [8].

4. PRACTICAL APLICATIONS OF NANOFLUIDS

Applied research on nanofluids is focused on various fields: electronics, transportation, medicine, solar cells, sensors, cooling, micro-electromechanical systems (MEMS), tuneable optical fibres, optical switches, *etc*. Nanofluids are mentioned mainly as cooling agents in the automotive sector, fuel cells, electronics, in refrigeration or heat pump cycles and as a phase change material [4]. A great area of potential usage of nanofluids is for solar thermal absorbers where numerous publications can be found, but little experience exists regarding pilot scale or full-scale plants. Information about high temperature, high pressure and long-term behaviour of nanofluids in mentioned systems is lacking. Therefore, besides basic research it is of great importance to expand studies to specific applications, realized in a suitable environment. Figure 3 provides a scheme for practical applications of nanofluids.

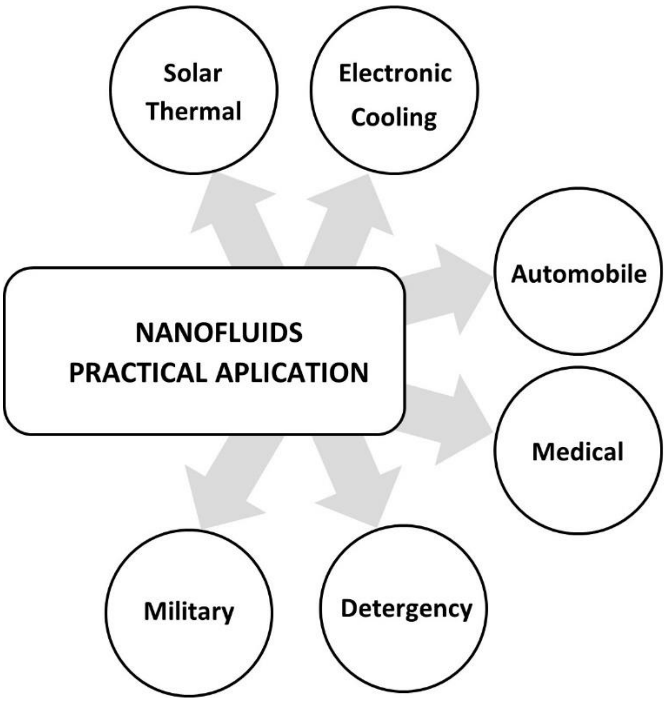

Figure 3. Schematic presentation of possibilities for practical applications of nanofluids

Given that the highest influence of nanoparticles is exerted on the thermal conductivity of the base fluid, it is inevitable that a large number of papers dealing with the practical application of nanofluids are focused on heat exchangers.

In order to validate a nanofluid as a heat transfer fluid, forced convection in nanofluids is often investigated. The concept of convective heat transfer of nanofluids through a straight pipe section is mostly studied by analysing the Nusselt number and convective heat transfer coefficient [9]. Yet, still high costs of nanofluids pose a problem in conducting such experimental research. As a result, small-volume facilities have to be used for testing the forced convection of nanofluids, which is a real challenge from the point of view of development and performance of such facilities [10,11]. This is the reason why computational fluid dynamics (CFD) is widely used for the purposes of research of forced convection of nanofluids [12-14].

The experimental data showed that, among other factors, the flow regime within this equipment is essential for the effectiveness of a nananofluid. Under laminar flow conditions the heat exchanger operates at high costs and the nanofluid stability cannot be guaranteed. On the other hand, using nanofluids when a heat exchanger operates under turbulent flow conditions is beneficial only if the increase in thermal conductivity is accompanied by a marginal increase in viscosity, which is very difficult to achieve [4].

A class of nanofluids that is singled out due to the influence of its magnetic effect on heat transfer is also tested for usage in heat exchangers as a heat transfer fluid. These magnetic nanofluids, also called the ferrofluids, contain the single-domain superparamagnetic materials (ferro or ferromagnetic) in the size range of 3-15 nm coated with a surfactant or polymer, and dispersed in the base fluid [15]. Particles commonly used are metals (iron, cobalt, nickel etc.) or metal oxides, while dispersion mediums include polar solvents (water and ethylene glycol) and non-polar solvents like kerosene, silicone oil, mineral oil, *etc*. Most of the experimental research refers to Fe_3O_4 - water nanofluids with applying the external constant and alternating magnetic field under the laminar forced convective heat transfer in the tube. Published studies showed that the convective heat transfer is increased with the increase in the magnetic field strength and nanoparticle concentration, in the heat exchangers operating at low and moderate Reynolds numbers. Depending on the investigated magnetic intensities, particle concentrations and flow conditions the heat transfer coefficient of a ferronanofluid increases by approximately 13 to 75 % when using a magnetic force as compared to the one without a magnetic force, as summarized by Narankhishig *et al.* [16].

Of course, many challenges have to be faced before the practical application of nanofluids. After determining the impact of nanoparticles, especially their shape, size, type, concentration, and dispersion on the base fluid as well as the need for a surfactant to improve the nanofluid stability, still several issues arise before practical implementation. Some of these are conditions under which the nanofluid will be used, its behaviour during some extended periods, its scale-up capacity and inevitable increase in viscosity. Viscosity is important in designing nanofluids for flow and heat transfer applications because the pressure drop, and the resulting pumping power depend on this parameter. Another issue, sometimes even more important, is the cost of designing nanofluids and accompanying costs of introducing this new class of fluids in everyday use.

One more aspect that needs to be addressed and relates to non-engineering applications is the influence of nanofluids on the human health. Although nanofluids already found applications in medicine and cosmetic industry (nanodrug delivery, cancer therapy, sunscreens, *etc*.), tolerability and safety for human body during use of numerous products (textiles to cosmetics) have to be further investigated for possible long-term effects.

4. CONCLUSION

Although a lot has been done in the field of nanofluid research, there is still a lot of work ahead of us. The search for efficient methods of producing stable nanofluids on a large scale is still ongoing. Investigation of thermophysical properties of nanofluids requires more effort. To deduce adequate equations for a wide range of conditions, more and better coordinated basic research is needed. At present, experimental data and measurement methods and techniques are lacking consistency.

Having all this in mind let's try to answer the questions from the beginning of the text: Is it just a matter of fashion or something more is hidden behind the popularity of nanofluids? The most honest answer would be: Yes, it seems that nanofluids really have the potential for significant practical applications, but we are still far from fully exploiting it.

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Nanofluidi: Zašto ih volimo?

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(Stručni rad)

Izvod

Rastuća potreba za fluidima sa značajno poboljšanim svojstvima za prenos toplote dovela je do razvoja nanofluida. Prvi eksperimenti su pokazali ohrabrujuće rezultate koji se ogledaju u povećanju toplotne provodljivosti i koeficijenta prenosa toplote praćene boljom stabilnošću od koloidne suspenzije. Mnoge istraživačke laboratorije i kompanije uočile su potencijal nanotehnologije za specifične industrijske primene. Međutim, mnoga pitanja su se pojavila nakon objavljivanja brojnih radova sa kontradiktornim rezultatima za iste ili slične nanofluide. Iako su u nekim granama industrije nanofluidi već našli praktičnu primenu, istraživači su se u nekom trenutku vratili osnovama, pokušavajući da objasne uticaj nanočestica na termofizička svojstva nanofluida sprovodeći opširne studije i uporedne testove. Konačni cilj cele naučne zajednice je proizvodnja nanofluida sa dugotrajnom stabilnošću i dobrom fluidnošću, uz niske troškove, kao tri najznačajnija preduslova za praktičnu primenu u oblasti prenosa toplote.

Ključne reči: termofizička svojstva; toplotna provodljivost; stabilnost disperzije

Shape memory alloys:
Properties, demands and opportunities in engineering applications

PART I

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Abstract

Shape memory alloys (SMAs) are a subclass of shape memory materials (SMMs), which are materials that, in response to a specific impact like thermal, mechanical, or magnetic changes, can "memorize" or hold into their prior form. This review addresses the properties, demands, and application prospects of SMAs, and provides a synopsis of recent advancements, as well as a historical background. Due to their special and exceptional qualities, SMAs have attracted a lot of interest and attention recently in a wide range of commercial applications; basic and applied research investigations have supported this commercial development. In order to shed light on design, issues faced by SMA developers, this paper explains the characteristics of these materials that make them perfectly suited for variety of applications, addressing also the accompanying constraints. This paper offers a pertinent overview of current SMA research.

Keywords: History; metal materials; ceramics; polymers, composites.

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1. INTRODUCTION

A smart material is a material with one or more properties that are susceptible to change with the impact of an external force or stimulus making them interesting engineering materials. This change has to be either tangible or visible for the material to qualify for 'smart' status and can be induced by electrical, chemical, thermal, magnetic, or mechanical impact. A very wide range of different materials could be considered as smart, such are piezoelectric materials, shape-memory materials, chromato-active, and magnetorheological materials. The shape memory materials (SMM) also include very different types of materials, such as metal materials, ceramics (piezoceramics), polymers, and different types of composite materials, as presented in Figure 1 [1-5].

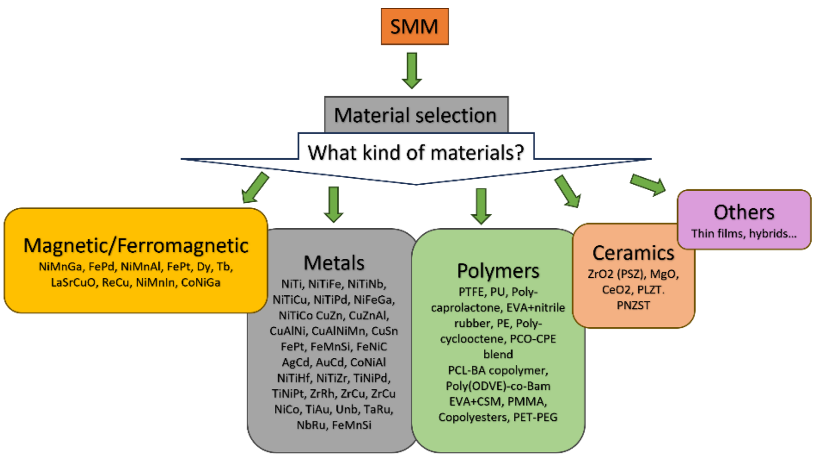

Figure 1. Materials selection for SMM materials

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Shape memory alloys (SMAs) possess special properties like superelasticity, thermomechanical properties, and a memory effect. Thermal and mechanical properties allow a smart material to return to its previous shape or size when it is subjected to significant plastic strain by heating or cooling [1-3]. The ability of a material to instantly return to its initial shape under nonlinear strain after stress or load is removed is known as superelasticity [1-4].

2. HISTORY OF SHAPE MEMORY ALLOYS

Gustav Arne Ölander, a Swedish scientist, discovered this type of alloys in the 1930s while working with a gold and cadmium alloy [1-2]. He discovered that the alloy could remember, or plastically deform, to its original dimensional structure when heated after cooling. Even though this provided advancements in the science of metallurgy, the shape memory effect was not as great as that of nitinol, a novel material that was found in the early 1960s [1-3].

The nitinol material is a mixture of titanium and nickel. US metallurgist William J. Buehler discovered the material's double-state, *i.e.* two distinct combinations of chemical energy within the solid. This observation occurred when he observed the difference in sounds when a cooled ingot was dropped on the floor landing with a dull thud as opposed to the metallic clang of a non-cooled one [1-5]. Superelasticity, the term used to characterize this capacity, is defined as an elastic or reversible response to an applied stress and it is sometimes compared to the stretching and releasing of a rubber band.

Subsequent research showed that nitinol could be bent and twisted indefinitely until the object lost all recognition of its original form. At this point, heat could be employed to accelerate a complete reversal to restore the original shape of the object. Before being employed in eyewear by a number of companies, including the sportswear major corporations, and then in dental and medical equipment, it took another twenty years or so of research to determine exactly how the shape memory effect occurred in nickel [1-5]. Discoveries related to SMA materials over decades are presented in Table 1 in order to point out how interesting, dynamic and how applicable SMA materials are.

Table 1. Some of the significant points in history of SMA development [5,6]

Year	Discovery	Author	Application
1932	Discovery of SMA Au Cd alloy	Gustav Arne Ölander	
1949	The basic phenomenon of the memory effect governed by the thermoelastic behavior of the martensite phase	Kurdjumov and Khandros	
1951	Thermoelastic transformation	Chang and Read	
1958	Nitinol discovery	William J. Buehler	
1962 to 1963	Nitinol development and commercialization	Naval Ordnance Laboratory	
1968	Satellite Nimbus shutter actuation system	H. Schuerch	Demonstrations
1970	SMA couplings for F-14 fighter jets	U.S. Navy	Airframe application
1982	Pipe couplings on Salyut-7	Gutskov *et al.*	Space devices
1988	Propulsion system on the Soviet shuttle Buran	USSR	Space devices
1989	Large space structure-cargo spacecraft Progress-40	Mir space station (MIR)	Space experiments
1991	Sofora experiment- Mir station	Cosmonauts A. Artsebarsky	Space experiments
1992	SMAAC shape memory alloy adjustable camber	Beauchamp	Airframe application
1994	Release devices Frangibolt	Spacecraft Clementine	Space devices
1996	Mars pathfinder-materials adherence experiment	Material adherence experiment	Space devices
1996 to 1998	The smart wing program	Defense Advanced Research Projects Agency (DARPA), The Air Force Research Laboratory (AFRL), National Aeronautics and Space Administration (NASA), Northrop Grumman Wing twist & flexible leading and trailing edges	Airframe application
1999	SMA release device (SMARD)-MightySat, LFSA-lightweight flexible solar array, Reversible hinge for deployment	AFRL, STS-93, Moignier	Space experiments
2000	SAMSON program, The smart aircraft and marine project system demonstration F15 fighter engine inlet, fan cowling, inlet lip shaping, Miniature mechanisms for small spacecraft, SMA release mechanisms, FalconSat spacecraft	Navy's Office of Naval Research (ONR), DARPA, NASA	Engine application Space devices

Year	Discovery	Author	Application
2001	Active jet engines chevron, Pitch active shape - memory alloy wing UAV, Helicopter rotor blades	Turner, Barrett, Prahlad	Engine application Airframe application Helicopter
2002	Variable Stiffness Spar - Modified F-16 wing increase in roll effectiveness	Nam	Airframe application
2003	Shape morphing airfoil, Solar paddle actuator for small satellites, Cosmic hot interstellar plasma spectrometer spacecraft	Elzey, Iwata-Japan, CHIPSat	Airframe application Demonstrations Space devices
2004	ROSETTA-pinpushers, SMA actuated satellite valve	Murray	Demonstrations
2005	Active tip clearance control, REIMEI-frangibolts	DeCastro, Japan	Engine application Space devices
2006	VGC - variable geometry chevron, STEREO-rel. Dev.	Boeing, UC Berceley	Engine application Space Devices
2007	THEMIS program, Mars Phoenix-pinpuller deployment	25 SMA actuators flying on THEMIS, TiNiAero	Space Devices
2008	VAFN variable area fan nozzle, RRB - Reconfigurable rotor blade, Antagonistic flexural actuating cell	Mabe, Ruggeri, Sofla	Engine application Helicopter Airframe application
2009	Adaptive wing demonstration system, LCROSS-pinpullers, SMA spacecraft tribo-elements	Lv, NASA Ames, DellaCorte	Airframe application Space devices Demonstrations
2010	Attitude control of nanosatellites	Iai *et al.*	Demonstrations
2011	DTE - Divergent trailing edge, Juno two-way actuation	Boeing, JPL/Lockheed	Airframe application Space devices
2012	ATE-adaptive trailing edge, SIMPLE-single crystal SMA Shape memory composite hybrid hinge, Deployable auxetic SMA cellular antenna	Boeing, Japan, JPL, Jacobs	Airframe application Space devices Demonstrations
2013	AFB-adaptive fan blade, Slat-cove filler, MAVEN-pinpullers	NASA-GE, NASA-LaRC NASA/UC berckley	Airframe application Space devices
2014	SMA Interference coupling	Crane	Demonstrations
2015	Slat-gap filler, ATE-SMART-VG, SMARS-rock splitter, Spring Tire	NASA-LaRC, Boeing-NASA-AFRL, Benafan, Padula et al.	Airframe application Demonstrations
2016	Spanwise adaptive wing, AlBus CubeSat	NASA-Boeing-Area-I, NASA GRC	Airframe application Demonstrations

3. SHAPE MEMORY EFFECT

When exposed to an external influence, a shape memory alloy exists in two distinct phases with varying crystal structures. The basic function of SMAs is to deform under applied force and then to return to the original shape by applying heat or a magnetic field. Four phase transition temperatures from low to high are possible for SMAs: martensite transition finish temperature Mf, martensitic transition start temperature Ms, reverse martensitic transition start temperature As, and reverse martensite phase transition finish temperature Af (Figure 2).

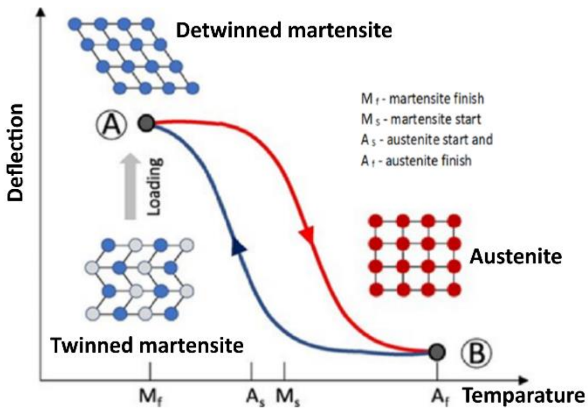

Figure 2. Schematic plot of SMA phase transformation: (A) maximum deflection at a 100 % martensite (detwinned) state, (B) maximum deflection at a full austenite state [2,6-9].

Shear lattice distortion is the method of transformation. The temperature of a SMA rises with heating, and beyond a certain point, the martensite structure starts to change into an austenite structure. The opposite process (*i.e.* austenite to martensite structure) occurs naturally when the alloy is cooled down without the help of an external force. Forward transformation is the term used to describe the phase transition from martensite to austenite, while for the opposite process (i.e. austenite into martensite) the term reverse transformation is used [2,6-9]. A schematic representation of this transformation with characteristic temperatures is shown in Figure 2.

4. PROPERTIES OF SHAPE MEMORY ALLOYS

There are several classes of shape memory alloys that are currently developed and [7-11], as follows.

- NiTi or nitinol is the most developed SMA, with excellent mechanical properties. It is pretty much the only commercially viable SMA [13].
- Cu-Al-Ni, Fe-Mn-Si, and Cu-Zn-Al systems have poorer mechanical properties than NiTi and are still in development, although they may one day offer advantages over NiTi such as higher transformation temperatures [14-17].
- Ni-Mn-Ga is a magnetic shape memory alloy, which is affected by magnetic fields rather than temperature. Magnetic shape memory alloys are also in the developmental stage [18].
- Other alloys also exist, which are even less commercially viable. Alloys with gold, silver, platinum, and palladium have made good SMAs in the laboratory, but they will probably never be worth the cost of the raw materials.

Mechanical and thermal properties of some of the mostly used SMAs are presented in Table 2.

Table 2. Properties of selected SMA alloys [10]

Property	Nitinol (Ni-Ti)	Cu-Zn-Al	Cu-Al-Ni
Melting temperature, °C	1300	950-1020	1000-1050
Density, g cm^{-3}	6.45	7.64	7.12
Resistivity, μΩ cm	70-100	8.5-9.7	11-13
Thermal conductivity, (W cm^{-1}) °C^{-1}	18	120	30-43
Young's modulus, GPa	83 (austenite) 26-48 (martensite)	72 (beta phase) 70 (martensite)	85 (beta phase) 80 (martensite)
Yield strength, MPa	195-690 (austenite) 70-140 (martensite)	350 (beta phase) 80 (martensite)	400 (beta phase) 130 (martensite)
Ultimate tensile strength, MPa	895	600	500-800
Maximum shape memory strain, %	8.5	4	4
Transformation range, °C	-200-110	<120	<200
Transformation hysteresis, °C	30-50	15-25	15-20

Advantages of shape memory alloys can be summarized as follows:

1. **Shape memory effect** as the most significant advantage of SMAs, which allows them to recover their original shape after deformation
2. **High energy density** so that SMAs can undergo large strains and stresses, making them useful for actuators and sensors
3. **High strength** makes SMAs useful in applications that require high load-bearing capacity
4. **High corrosion and wear resistance** making SMAs useful in harsh environments
5. **High power to weight ratio**
6. **Large deformation**
7. **Large actuation force**
8. **High damping capacity**
9. **High frequency response and low operation voltage**
10. **Compactness**

Still, SMAs have some disadvantages such as:

1. **High cost** of SMAs compared to other materials, which can limit their use in some applications
2. **Limited deformation range**, which can limit the use of SMAs in some applications
3. **Temperature sensitivity**: as the shape memory effect is temperature-dependent, this can limit the use of SMAs in applications that require high-temperature resistance
4. **Complex thermal and mechanical properties**

5. **Low energy efficiency**
6. **Poor fatigue properties**

Sometimes additional properties, or much frequently combination of properties is required for specific application, and these demands could include thermal shock conditions or cavitation erosion for monitoring the damage level and changes in morphological characteristics many investigations were performed in order to propose the approach and models of monitoring these changes and resulting effects on mechanical properties. These attempts are closely related to the estimation of the lifetime of investigated materials, as they are used for construction of many parts of equipment applied in engineering and influence the reliability of the parts or equipment [19-25].

5. APPLICATIONS OF SHAPE MEMORY ALLOYS

SMAs find applications in diverse fields out of which few are discussed below.

5. 1. Automotive domain applications

Because of the advantages over conventional electromagnetic actuators, such as compactness, lightweight, simplicity, and noiselessness, SMA actuators have potential applications in the automotive industry for tasks like engine temperature control, locking mechanisms, mirror opening and closing, and micro-valves [1,26]. In literature [29], the SMA application for antiglare rear-view mirrors is described.

5. 2. Aerospace applications

Due of special material qualities of SMA couplers, they were employed in F-14 fighter jets [30]. Shape morphing of the aircraft wing, which can be accomplished by an SMA, is utilized to increase aerodynamic performance [31]. The SMA can be used to install the adaptable wings for tiny aircrafts, which help with improved flying control [32]. Since SMAs offer jerk-free actuation, low-shock release devices are preferred in space applications to prevent damage to delicate equipment [11].

SMAs can be used to develop components for small spacecrafts such as micro- and mini-separation nuts, mini rotary actuators, micro burn wire release, linear actuators, and redundancy release mechanisms [11].

5. 3. Marine applications

A hydrostatic robot designed using an SMA, which can manoeuvre itself in areas that cannot be accessed by conventional devices in the ocean is presented in literature [11,33]. Bearings for rotary elements in water clad environment and in applications that require a material that is stable and non-magnetic in nature, for example, non-magnetic hand tools, can be made using nitinol-60 which exhibits high hardness, strength and is marine corrosion resistant [11,32-37].

5. 4. Field of robotics

Robotics can benefit from the development of miniactuators [37] made possible by SMAs. The work [38] presents the investigation of different driving concepts for microactuators. Application of a millimetre-sized joint actuator made of an SMA is applied for moving very low size joints in a robot [39]. A prosthetic hand can be designed using SMA artificial muscles that were previously addressed in [40] as robotic actuators [41]. Nitinol, could be used as a novel actuator for a joint mechanism that could assist the creation of microactuators or micro-robots [42,43].

5. 5. Field of mining

The Alliance for the Advancement of Additive Processing Technologies (ADAPT) at the Colorado School of Mines was part of an international research team that developed a new elastocaloric cooling material that is highly efficient, environmentally friendly, and easily scalable for commercial use [44].

Due to its characteristics, it can be applicable for difficult and complex conditions of various structural systems in the construction, mechanical and mining industries exposed to high stresses and temperature changes through the seismic response control system. It would be feasible to seismically monitor changes in ground deformation with sensor models of the SMA type. This will be made feasible by rheological changes in the mechanical rock material or on the surface of the terrain during the mining of mineral raw materials through boreholes. In addition to landslides on the final and working slopes of surface mines and landfills, as well as on geotechnical works of infrastructural, hydrotechnical, and other engineering facilities, the formation of excavated submerged caverns, exceptionally deep surface mines, and the construction of underground rooms for the needs of underground exploitation of mineral deposits or their stockpiling [45].

5. 6. Seismic monitoring systems

Seismic monitoring systems are widely used in mines with underground exploitation to monitor seismic changes caused by mining operations, especially those at great depths due to high loads or in neglected, so-called old pit operations. In addition, one could monitor ground tremors and seismic changes caused by extraordinary unfortunate circumstances in mines, caused by explosions of coal dust, methane, or due to mountain shocks, as well as earthquakes with known devastating effects on all objects. Also, application in the splitting of seismic waves is also possible due to drilling and blasting in all mining works and methods of excavation, tunnelling, and construction of the entire underground construction.

A possible system of seismic monitoring with SMA sensors of large vibrations and dynamic shocks on the working organs of mining and loading, disposal equipment and auxiliary machinery and transport systems in discontinuous and continuous exploitation, both surface and underground exploitation and in the mineral processing, should also be taken into account where we are dealing with large mechanical dimensions of machinery and huge capacities and volumes of overburden, interlayer tailings and useful raw materials [46,47].

5. 7. Fields of civil engineering and architecture

SMA materials also find their place in the field of building construction materials. For example, adaptive composite panels with surface-bonded shape memory alloy strips are used as building construction materials due to their excellent thermal and mechanical properties [48]. Some of the applications were related to the use of SMA materials for dampers, because for this purpose the material has to have a suitable structure with a very high resistance to external forces, as well as having the ability to self-repair after an applied external force [49,50]. Research and application of SMAs in the active management of structures gave rise to the smart concrete beam [50,51] and the SMA concrete beam, i.e. concrete beam with superelastic wire made of a shape memory alloy as the main reinforcement [50,51].

By using new design methods, such as 3D printing, new possibilities arise in the field of architecture accompanied with new materials and methods of construction. Several papers attempted to find design and construction methods, which will be reliable, but at the same time low cost and flexibly adaptive in building design. Some of the papers focused on using 3D-printed kinetic shading devices. This attempt is focused on a selective actuator by a switch between a geared DC motor and a thermomechanical shape memory alloy actuator [52].

5. 8. Textile industry

Using SMAs in textile industry was expected due to the unique properties and behaviour of these materials. Their use as part of a material for protective clothing was reported [53,54]. Also, some of the research attempts were related to the development of active textile systems with SMA elements for protection against the cold [55-57].

5. 9. Biomedical applications

SMA materials have found the irreplaceable place as biomedical materials due to their mechanical properties, anticorrosive behaviour, as well as biocompatibility of many alloys, which is crucial for biomedical implementations. A large number of investigations are related to using SMAs as biomedical material, which will be discussed in more detail in Part II of this paper. Some of the studies related to this wide group of materials were reported in many papers [3,5,58-62].

6. CONCLUSION

Smart materials draw attention as very interesting being utilized also as engineering materials. One of the mostly used class among smart materials are shape memory alloys. In this paper some of the relevant properties and behaviour of these materials are presented with the aim to understand possibilities for variety of applications.

Also, a wide range of fields utilizing SMAs, were discussed, including automotive, aerospace, marine, robotics, mining, civil engineering, and textile engineering.

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Legure sa svojstvom pamćenja: Osobine, zahtevi i mogućnosti u inženjerskoj primeni

Prvi deo

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(Stručni rad)

Izvod

Legure sa svojstvom pamćenja (engl. shape memory alloys, SMA) su podgrupa velike familije „pametnih“ materijala, koji predstavljaju materijale koji posle spoljašnjeg uticaja koji može biti termički, mehanički i/ili magnetni, imaju osobinu da „memorišu“ ili zadrže prethodno stanje. U okviru ovog rada predmet interesovanja su svojstva, zahtevi za specifične primene, pregled skorašnjih istraživanja, kao i istorijski razvoj ove grupe materijala. Zahvaljujući svojim posebnim i izuzetnim svojstvima memorijske legure su u poslednje vreme privukle veliko interesovanje i pažnju u širokom spektru komercijalnih primena. Osnovna i primenjena istraživanja su podržala ova komercijalna interesovanja. Da bi se pojasnili izazovi sa kojima se suočavaju inženjeri koji se bave dizajnom ove grupe materijala, u okviru ovog rada su date karakteristike ovih legura koje ih čine veoma prikladnim za različite primene ali se rad istovremeno bavi i ograničenjima koja idu uz njih.

Ključne reči: Istorijat, metalni materijali; keramički materijali; polimeri, kompoziti

Regional meeting of journal editors: Struggling of small publishers to survive

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Abstract

At the end of May 2024, a traditional regional meeting of editors of small scientific journals in engineering disciplines was held at the Faculty of Mechanical Engineering in Belgrade. This year the meeting gathered about 20 editors who discussed novelties, good practices as well as problems in academic publishing. The primary aim of these journals was to support the local scientific community and industry by providing a platform for presenting scientific advances, connecting research and practice, and assisting young scientists in publishing their research results. However, with the widespread adoption of measuring scientific performance by publication and citation statistics, the scientists lost interest in these journals as underrated in researcher evaluation systems. Thus, low quality of received as well as revised manuscripts, low response rates of reviewers, and, consequently, long processing times and high rejection rates are some of the main problems mentioned at the meeting. All these issues are usually managed by editorial offices, which often have neither technical nor human resources for such endeavors. Still, the conclusion of the meeting was that the benefits of small independent scientific journals are significant and worth efforts particularly for providing an alternative to the profit-oriented publishing and promoting societally relevant research and value-based scientific assessments.

Keywords: scientific publishing; bibliometric indicators; publication pressure; scientific output; market power; engineering disciplines

BOOK AND EVENT REVIEW

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It has been over a decade that editors of regional journals in engineering disciplines meet and discuss common problems faced in the ever-changing landscape of academic publishing. Initiated in 2013 by Profs. Vincenc Butala and Borut Buchmeister and organized by Profs. Milan Kljajin and Pero Raos at the Mechanical Engineering Faculty in Slavonski Brod in Croatia as a friendly meeting of several regional editors it has grown over the years to gather editors of about 20 scientific journals published in Slovenia, Croatia and Serbia. This year, the meeting was organized by Prof. Boško Rašuo at the Faculty of Mechanical Engineering in Belgrade on May 24 (Figure 1). It gathered 17 editors who presented 15 journals:

1. Goran Šimunović, Vice Editor and Đorđe Vukelić, Editorial Board Member, **Tehnički Vjesnik-Technical Gazette** (ISSN 1330-3651, Publisher: Mechanical Engineering Faculty in Slavonski Brod, University of Slavonski Brod, Croatia)
2. Borut Buchmeister, Editor-in-Chief, **International Journal of Simulation Modelling** (ISSN: 1726-4529, Publisher: DAAAM International Vienna, Austria) and Editorial Board Member, **Advances in Production Engineering & Management** (ISSN: 1854-6250, Publisher: University of Maribor, Faculty of Mechanical Engineering, Slovenia)
3. Milan Kljajin, Editor-in-Chief, **Tehnički glasnik - Technical Journal** (ISSN: 1846-6168, Publisher: University North, Croatia)
4. Miladin Stefanović, Managing Editor, **International Journal for Quality Research** (ISSN: 1800-6450, Publishers: Center for Quality, University of Kragujevac, Serbia; Center for Quality, University of Montenegro, Montenegro; International Association for Quality and Quality of Life Research, Serbia)
5. Rodoljub Simović, Editor-in-Chief, **Nuclear Technology & Radiation Protection Journal** (ISSN: 1451-3994; Publisher: VINČA Institute of Nuclear Sciences, University of Belgrade, Serbia)
6. Slobodan Mitrović, Editor-in-Chief, **Tribology in Industry** (ISSN: 0354-8996; Publisher: University of Kragujevac, Faculty of Engineering, Serbia)

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7. Hrvoje Kozmar, Editor-in-Chief, **Transactions of Famena** (ISSN: 1333-1124, Publisher: Faculty of Mechanical Engineering and Naval Architecture, University of Zagreb, Croatia)
8. Vukman Bakić, Editor-in-Chief, Marina Jovanović, Editor and Branka GvozdenacUrošević, Subject Editor, **Thermal Science** (ISSN: 2334-7163, Publisher: VINČA Institute of Nuclear Sciences, University of Belgrade, Serbia)
9. Bojana Obradović, Editor-in-Chief, **Hemijska Industrija** (ISSN: 2217-7426, Publisher: Association of Chemical Engineers of Serbia, Serbia)
10. Uglješa Marjanović, Editor-in-Chief, **International Journal of Industrial Engineering and Management** (ISSN: 2217-2661, Publisher: University of Novi Sad, Faculty of Technical Sciences, Serbia)
11. Kristina Marković, Editor-in-Chief, **Engineering Review** (ISSN: 1330-9587, Publishers: Faculty of Engineering and the Faculty of Civil Engineering, University of Rijeka, Croatia)
12. Dragan Marinković, Editor-in-Chief, **Facta Universitatis, Series: Mechanical Engineering** (ISSN: 0354-2025, Publisher: University of Niš, Serbia)
13. Božidar Jovanović, Deputy Editor-in-Chief, **Theoretical and Applied Mechanics** (ISSN: 1450-5584, Publishers: Mathematical Institute SANU and Serbian Society of Mechanics, Serbia)
14. Boško Rašuo, Editor, **FME Transactions** (ISSN: 1451-2092, Publisher: University of Belgrade, Faculty of Mechanical Engineering, Serbia).

Figure 1. Group photo of participants at the meeting held at the Faculty of Mechanical Engineering in Belgrade, May 24, 2024

The meeting was opened by Prof. Vladimir Popović, Dean of the Faculty of Mechanical Engineering, who welcomed the participants and stressed the importance of the local academic publishing for researchers and scientific development in each of the countries in the region emphasizing the need and benefits of collaboration in this area. Next, a brief welcome and introduction was given by Prof. Boško Rašuo, host of the meeting, after which the participating editors presented their journals and exchanged experiences and good practices in journal management, but also discussed challenges that they face in this process. Most of the journals are published by local universities and professional associations and are ranked in Q3 or Q4 category in the SCIE list or are in the ESCI list in Web of Science Core Collection™. These journals were founded with the aim of supporting local researchers and professionals as well as universities, providing opportunities to showcase domestic scientific and industrial advances. Also, no less important is the role in education of students and young scientists offering them a platform to present their research results often in the national language. However, with the adopted practices to measure scientific contributions by publication and citation statistics, scientists are pushed towards highly ranked international journals mostly owned by a handful of large publishing companies [1,2]. Thus, small academic publishers and journals are in a position to compete with large businesses in an only apparently objective evaluation system. It is then expected that most of the editors in the meeting pointed out the problem of receiving low quality manuscripts and/or low number of manuscripts resulting in high rejection rates. Furthermore, a general problem of finding good quality reviewers [3] is even more evident in small national journals, which are largely regarded both by potential authors and reviewers, as marginally relevant for their careers. And this manner is seen in all phases of manuscript processing. Editors are putting substantial efforts in securing comprehensive evaluation of the received manuscripts, a number of times followed with the lack of response of authors or insufficiently revised papers. Plagiarism and selfplagiarism are also frequent instances in submitted manuscripts as well as simultaneous submission to some other journals. This situation inevitably leads to prolonged processing times further damaging the journal reputation. Long waiting times and not clear requirements for a journal to be included in the SCIE or the ESCI list were also mentioned at the meeting. A special concern was provoked by the reported application of artificial intelligence in publishing activities. This process started with ChatGPT (Chat Generative Pre-trained Transformer), a chatbot developed by OpenAI and launched on November 30, 2022. Based on a large language model, it enables users to refine and steer a conversation towards a desired length, format, style, level of detail, and language [4]. It was agreed at the meeting to continue to permanently monitor, support, and implement all positive recommendations proposed by the scientific publishing community of the world but will this be yet another challenge for editors of small journals is to be seen.

All these issues are usually managed by editorial offices, which often have neither technical nor human resources for such endeavors. In specific, the majority of the presented journals are nonprofit and financially supported by the national ministries of science to a limited extent mostly not sufficient for engaging professional editorship and management. The editors that participated in the meeting are academics, typically working on a voluntary basis striving to raise the quality of journals by investing their own efforts, reputation,and networks. However, in the battle with large corporate publishers offering to authors a plethora of journals with high impact factors and quick assessment of their manuscripts, which are also more valued by the science policy makers, such endeavors of small journals are generally ineffective. Still, several strategies for tackling this status problem were mentioned at the meeting, one of them being establishment of a platform consisting of several journals with different access options and article processing charges to attract a larger number of authors. Also all of the journals are constantly receiving offers to be bought by variety of other publishers. However, further destiny of the sold journal is not known with a good chance to be neglected or closed down, which was a point commented at the meeting. Active involvement of international editorial board members is generally seen as highly beneficial with the prospect of attracting more international authors. However, such activities are scarce as internationally leading scientists are usually involved in management of other, better ranked journals and this board usually serves to increase the journal reputation without real contributions of the members.

Thus, in this situation the logical question to pose is why small scientific journals should be kept at all. Yet, this group of mostly overworked but enthusiastic editors answer that the benefits of such journals are still substantial and worth the efforts. Along with providing a direct connection to the local scientific, professional, and academic communities as their initial aim, these journals offer possibilities to researchers to publish studies not necessarily related to topics promoted by major publishing industry players. In specific, as recently noted by Neff [1], publication metrics systematically affect the scientific research priorities, but they are not connected to the societal knowledge needs, but rather to the profit model of the scientific publishing industry. Thus, translational and practically oriented research, studies related to local problems or devising engineering solutions for advancements in existing production processes often require long times, multidisciplinary efforts and substantial resources, while not being attractive for publication in leading international journals [1,5-7]. Small scientific journals supported by academic institutions offer an alternative to the profit-oriented publishing providing greater flexibility towards different topics and problems addressed and appreciating the relevance of the research in the scientific as well as broader societal contexts. Meetings of regional editors of small journals such as the one held in Belgrade in May 2024, hold the power of not only supporting each other but of affecting the local policies and promoting value-based scientific assessments. We hope that the tradition of holding these meetings will continue with increasing in the number of participants and strengthening the position of small independent scientific journals.

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Regionalni sastanak urednika naučnih časopisa: napori malih izdavača da se održe

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Izvod

Krajem maja 2024. godine na Mašinskom fakultetu u Beogradu održan je tradicionalni regionalni skup urednika malih naučnih časopisa iz inženjerskih disciplina. Ove godine skup je okupio oko 20 urednika koji su razgovarali o novinama, dobrim praksama, kao i problemima u akademskom izdavaštvu. Primarni cilj ovih časopisa bio je da podrže lokalnu naučnu zajednicu i industriju pružanjem platforme za predstavljanje naučnih dostignuća, povezivanje istraživanja i prakse i pomoć mladim naučnicima u objavljivanju rezultata svojih istraživanja. Međutim, sa usvajanjem široko rasprostranjenog merenja naučnog učinka putem statistike objavljivanja i broja citata, naučnici u regionu su izgubili interesovanje za ove časopise kao potcenjene u sistemima evaluacije istraživača. Dakle, loš kvalitet primljenih, kao i revidiranih rukopisa, niske stope odgovora recenzenata i, shodno tome, dugo vreme obrade i visoke stope odbijanja radova su neki od glavnih problema pomenutih na sastanku. Sve ove časopise najčešće vode redakcije koje često nemaju ni tehničke ni ljudske resurse za takve poduhvate. Ipak, na sastanku je zaključeno da su prednosti ovakvih malih nezavisnih naučnih časopisa značajne i vredne truda, posebno u pružanju alternative profitno orijentisanom izdavaštvu, kao i promovisanju društveno relevantnih istraživanja i procene naučnih doprinosa zasnovane na vrednostima.

Ključnereči: naučno izdavaštvo; bibliometrijski indikatori; pritisak da se publikuje; naučni rezultati; tržišna moć; inženjerske discipline

PRIKAZ KNJIGA I DOGAĐAJA

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Već više od jedne decenije urednici regionalnih časopisa u inženjerskim disciplinama se sastaju i diskutuju o zajedničkim problemima sa kojima se suočavaju u stalno promenljivom okruženju akademskog izdavaštva. Prvi sastanak su na inisijativu profesora Vincenca Butale i Boruta Buhmajstera (Borut Buchmeister) organizovali prof. Milan Kljajin i prof. Pero Raos na Mašinskom fakultetu u Slavonskom Brodu u Hrvatskoj 2013. godine, kao prijateljski susret nekoliko regionalnih urednika. Sastanak je zatim tokom godina narastao i okupio urednike oko 20 naučnih časopisa koji se izdaju u Sloveniji, Hrvatskoj i Srbiji. Ove godine skup je organizovao prof. Boško Rašuo na Mašinskom fakultetu u Beogradu 24. maja i okupio je 17 urednika (Slika 1) koji su predstavili 15 časopisa:

1. Goran Šimunović, zamenik urednika, i Đorđe Vukelić, član Uređivačkog odbora, **Tehnički Vjesnik-Technical Gazette** (ISSN 1330-3651, izdavač: Strojarski fakultet u Slavonskom Brodu, Sveučilište u Slavonskom Brodu, Hrvatska),
2. Borut Buhmajster (Borut Buchmeister), glavni i odgovorni urednik, **International Journal of Simulation Modelling** (ISSN: 1726-4529, izdavač: "DAAAM International Vienna", Austrija) i član Uređivačkog odbora, **Advances in Production Engineering & Management** (ISSN: 1854-6250, izdavač: Univerzitet u Mariboru, Mašinski fakultet, Slovenija)
3. Milan Kljajin, glavni i odgovorni urednik, **Tehnički glasnik - Technical Journal** (ISSN: 1846-6168, izdavač: Sveučilište Sjever, Hrvatska)
4. Miladin Stefanović, izvršni urednik, **International Journal for Quality Research** (ISSN: 1800-6450, izdavači: Centar za kvalitet Fakulteta inženjerskih nauka, Univerzitet u Kragujevcu, Srbija; Centar za kvalitet Mašinskog fakulteta, Univerzitet Crne Gore, Crna Gora; Međunarodno udruženje za istraživanje kvaliteta i kvaliteta života, Srbija)
5. Rodoljub Simović, glavni i odgovorni urednik, **Nuclear Technology & Radiation Protection Journal** (ISSN: 1451-3994; izdavač: Institut za nuklearne nauke "Vinča", Univerzitet u Beogradu, Srbija)
6. Slobodan Mitrović, glavni i odgovorni urednik, **Tribology in Industry** (ISSN: 0354-8996; izdavač: Univerzitet u Kragujevcu, Fakultet inženjerskih nauka, Srbija)

7. Hrvoje Kozmar, glavni i odgovorni urednik, **Transactions of Famena** (ISSN: 1333-1124, izdavač: Fakultet strojarstva i brodogradnje, Sveučilište u Zagrebu, Hrvatska)
8. Vukman Bakić, glavni i odgovorni urednik, Marina Jovanović, urednica, i Branka Gvozdenac Urošević, područna urednica, **Thermal Science** (ISSN: 2334-7163, izdavač: Institut za nuklearne nauke "Vinča", Univerzitet u Beogradu, Srbija)
9. Bojana Obradović, glavna i odgovorna urednica, **Hemijska Industrija** (ISSN: 2217-7426, izdavač: Savez hemijskih inženjera Srbije, Srbija)
10. Uglješa Marjanović, glavni i odgovorni urednik, **International Journal of Industrial Engineering and Management** (ISSN: 2217-2661, izdavač: Univerzitet u Novom Sadu, Fakultet tehničkih nauka, Srbija)
11. Kristina Marković, glavna i odgovorna urednica, **Engineering Review** (ISSN: 1330-9587, izdavači: Sveučilište u Rijeci, Građevinski fakultet i Tehnički fakultet, Hrvatska)
12. Dragan Marinković, glavni i odgovorni urednik, **Facta Universitatis, Series: Mechanical Engineering** (ISSN: 0354-2025, izdavač: Univerzitet u Nišu, Srbija)
13. Božidar Jovanović, zamenik glavnog i odgovornog urednika, **Theoretical and Applied Mechanics** (ISSN: 1450-5584, izdavači: Matematički institut SANU i Srpsko društvo za mehaniku, Srbija)
14. Boško Rašuo, glavni urednik, **FME Transactions** (ISSN: 1451-2092, izdavač: Univerzitet u Beogradu, Mašinski Fakultet, Srbija).

Slika 1. Fotografija učesnika sastanka održanog na Mašinskom fakultetu u Beogradu 24. maja 2024. godine

Skup je otvorio prof. Vladimir Popović, dekan Mašinskog fakulteta, koji je poželeo dobrodošlicu učesnicima i istakao značaj domaćeg akademskog izdavaštva za istraživače i naučni razvoj u svakoj od zemalja u regionu, pri čemu je naglasio potrebu i koristi od saradnje u ovoj oblasti. Nakon toga, prisutnima se kratko obratio prof. Boško Rašuo, domaćin skupa, a zatim su urednici predstavili svoje časopise i razmenili iskustva i dobre prakse u vođenju časopisa, ali i razgovarali o izazovima sa kojima se dnevno suočavaju. Većinu časopisa izdaju lokalni univerziteti i profesionalna udruženja, a rangirani su u kategorijama “Q3” ili “Q4” na listi časopisa *Science Citation Index Expanded* (*SCIE*) ili su na listi *Emerging Sources Citation Index* (*ESCI*) u bazi podataka *Web of Science Core Collection*™. Ovi časopisi su osnovani sa ciljem da podrže lokalnu naučnu i stručnu zajednicu pružajući priliku za prikaz dostignuća u domaćoj nauci i industriji. Takođe, ne manje važna uloga ovih časopisa je i u obrazovanju studenata i mladih istraživača nudeći im platformu da prikažu svoje istraživačke rezultate, često na nacionalnom jeziku. Međutim, sa usvojenom praksom merenja naučnih doprinosa statističkim vrednovanjem bibliografskih podataka, naučnici su preusmereni ka visoko rangiranim međunarodnim časopisima koji su uglavnom u vlasništvu nekolicine velikih izdavačkih kompanija [1,2]. Tako su mali akademski izdavači i časopisi u poziciji da se takmiče sa velikim korporacijama u samo naizgled objektivnom sistemu evaluacije. Stoga nije neočekivano da je većina urednika na sastanku ukazala na problem dobijanja radova lošeg kvaliteta i/ili malog broja radova što dalje dovodi do velikog procenta odbijenih radova. Štaviše, opšti problem pronalaženja kvalitetnih recenzenata [3] još je očigledniji u malim nacionalnim časopisima, koje i potencijalni autori i recenzenti uglavnom smatraju marginalno relevantnim za svoju karijeru. I ovaj odnos prema časopisima se vidi u svim fazama obrade rukopisa. Urednici ulažu značajne napore da obezbede sveobuhvatnu evaluaciju i recenziju pristiglih rukopisa, da bi to u ne malom broju slučajeva bilo praćeno izostankom odgovora autora ili neadekvatno revidiranim radovima. Plagijarizam i autoplagijarizam se takođe često pronalaze u podnetim rukopisima, kao i pojava da autori istovremeno šalju isti rad u više časopisa. Ova situacija neizbežno dovodi do produženog vremena obrade radova što dodatno šteti reputaciji časopisa. Na sastanku je bilo reči i o dugim vremenima čekanja i nejasnim zahtevima za uključivanje časopisa na *SCIE* ili *ESCI* listu. Određenu zabrinutost izazvala je i primena veštačke inteligencije u izdavačkoj delatnosti. Ovaj proces je započeo sa pojavom softverske aplikacije *ChatGPT* (*Chat Generative Pre-Trained Transformer*), koju je razvila kompanija *OpenAI* 2022. godine. Ova aplikacija omogućava korisnicima da preciziraju i revidiraju tekst prema željenoj dužini, formatu, stilu, nivou detalja i jeziku [4]. Na sastanku je dogovoreno da se nastavi sa praćenjem, podrškom i primenom svih pozitivnih preporuka u ovoj oblasti koje predlaže svetska zajednica naučnog izdavaštva, ali da li će i to biti još jedan izazov za urednike malih časopisa, ostaje da se vidi.

Sve ove probleme najčešće rešavaju redakcije, koje često nemaju ni tehničke ni ljudske resurse za takve zadatke. Naime, većina predstavljenih časopisa je neprofitna sa određenom finansijskom podrškom nacionalnih ministarstava nauke koja je uglavnom nedovoljna za angažovanje profesionalnog uredništva i menadžmenta. Urednici koji su učestvovali na sastanku su profesori i naučnici, koji pretežno rade na dobrovoljnoj bazi nastojeći da podignu kvalitet časopisa sopstvenim trudom, reputacijom i kontaktima. Međutim, u borbi sa velikim korporativnim izdavačima koji autorima nude pleajdu časopisa sa velikim faktorima uticajnosti (engl. *impact factor*) i brzim procesiranjem rukopisa, a koje i regulatorna tela za vrednovanje naučnoistraživačkog rada više cene, ovakvi poduhvati malih časopisa su generalno nedelotvorni. Ipak, na sastanku je pomenuto nekoliko strategija za rešavanje ovog problema statusa časopisa, a jedna od njih je uspostavljanje platforme od više časopisa sa različitim opcijama pristupa i naknadama za troškove štampe radi privlačenja većeg broja autora. Takođe, svi časopisi stalno dobijaju ponude raznih drugih izdavača za akviziciju. Međutim, na sastanku je komentarisano da dalja sudbina prodatog časopisa nije sigurna uz dobre izglede da bude zapostavljen ili ugašen. Jedan od korisnih predloga je i aktivno uključivanje članova međunarodnih uređivačkih odbora u vođenje časopisa što može da privuče više autora iz inostranstva. Međutim, takvi slučajevi su retki jer su vodeći međunarodni naučnici obično uključeni u uređivanje drugih, bolje rangiranih časopisa tako da ovi odbori obično služe za povećanje reputacije časopisa bez stvarnog doprinosa članova.

Stoga, u prikazanoj situaciji logično se postavlja pitanje da li su mali naučni časopisi uopšte potrebni. Međutim, ova grupa uglavnom preopterećenih, ali optimističnih urednika entuzijasta odgovara da su koristi od ovih časopisa i dalje značajne i vredne truda. Uz njihov primarni cilj, odnosno pružanje direktne veze sa lokalnom naučnom, stručnom i akademskom zajednicom, ovi časopisi istraživačima nude i mogućnost da objavljuju studije koje nisu nužno povezane sa temama koje promovišu glavni igrači u izdavačkoj industriji. Preciznije, kao što je nedavno primetio Nef [1], primena bibliometrije u vrednovanju časopisa, naučnika i institucija sistematski utiče na prioritete naučnog istraživanja, ali nije povezana sa društvenim potrebama za određenim znanjima, već radije sa modelom profitabilnosti naučno-izdavačke industrije. Tako na primer, translaciona i praktično orijentisana istraživanja, studije koje se bave lokalnim problemima ili iznalaženjem inženjerskih rešenja za unapređenje već postojećih proizvodnih procesa često zahtevaju duže vreme i multidisciplinarne pristupe uz ulaganje značajnih resursa. Međutim, ova istraživanja koja imaju veliki praktični značaj, najčešće nisu atraktivna za objavljivanje u vodećim međunarodnim časopisima [1,5-7]. Mali naučni časopisi koje podržavaju akademske institucije nude alternativu izdavaštvu orijentisanom na profit, obezbeđujući veću fleksibilnost prema različitim temama i problemima i uvažavajući relevantnost istraživanja, kako u naučnom, tako i u širem društvenom kontekstu. Sastanci regionalnih urednika malih časopisa poput ovog održanog u Beogradu u maju 2024. g. ne samo da obezbeđuju međusobnu podršku, već mogu da utiču i na lokalnu regulativu promovišući evaluaciju naučnih doprinosa zasnovanu na vrednostima. Nadamo se da će se tradicija održavanja ovih skupova nastaviti uz povećanje broja učesnika i jačanje pozicije malih nezavisnih naučnih časopisa.