EUROPEAN MECHANICAL SCIENCE

Research Article

e-ISSN: 2587-1110

Impact of structural and CFD analysis on the cost of biogas-fueled gas engine exhaust pipes

Rabia Kaymaz[1], **Mine Ak**[1], **Kürşat Tanrıver**[1*]

[1] Istanbul Health and Technology University, Faculty of Engineering and Natural Sciences, Department of Mechatronics Engineering, Istanbul, Türkiye

Abstract: In this study, the effects of exhaust pipe design used in biogas-fueled cogeneration systems on engineering performance and cost were investigated. First, the existing system was analyzed by field work, and then structural analysis was applied with CFD (Computational Fluid Dynamics). The exhaust pipe route, pipe diameter, and material thickness of the existing system were evaluated, and design improvements were suggested. It was determined that the shorter pipeline application with the changes made in the pipe route and layout reduced pressure losses. Despite the use of an exhaust pipe with a smaller diameter and made of thinner material in the proposed new design, compliance with the standards was ensured, and it was shown to be safe against wind loads with finite element analysis. Considering the calculated maximum wind load of 5.52 kN and the weight of the system, the maximum stress value was calculated as 108.691 MPa as a result of the Von Mises stress analysis applied to the exhaust pipe system in the finite element analysis. This value showed that the system was 1.56 times safer. In the deformation analysis, the maximum displacement value was measured as 0.13 mm, and this value is ideal. In the cost analysis, it was determined that the proposed new system provides a cost reduction of approximately 53% compared to the existing system. The results obtained emphasize the importance of engineering analysis in exhaust pipe design, and show the applicability of the approach to increase economic and environmental sustainability in industrial facilities.

Keywords: Biogas installation; CFD analysis; exhaust pipe design; energy efficiency; cogeneration; structural analysis

1. Introduction

In the face of growing global energy demand and escalating environmental concerns, the transition to renewable and sustainable energy sources has become more critical than ever. Among these, biogas technologies have emerged as a particularly valuable solution for their dual role in waste management, and energy production. By transforming organic waste—ranging from agricultural residues, to industrial effluents—into combustible gas through anaerobic digestion, biogas plants offer a cleaner alternative to fossil fuels, while also contributing to the reduction of greenhouse gas emissions and promoting a circular economy.

Biogas plants appear as a sustainable solution where organic waste is converted into energy through fermentation. Biogas, which can be obtained from different sources ranging from agricultural waste to domestic and industrial waste, provides an alternative to fossil fuels while also offering environmental benefits such as waste management, and reduction of greenhouse gas emissions.

To maximize the energy yield from biogas, cogeneration systems (Combined Heat and Power - CHP) are frequently employed. These systems enable the simultaneous production of electricity and usable thermal energy, significantly improving the overall efficiency of biogas plants. However, the effectiveness of cogeneration systems heavily depends on the performance of their subsystems, one of the most critical being the exhaust infrastructure. The gases formed in biogas plants are used for electricity production in solutions such as cogeneration systems. In addition to electricity production, cogeneration systems are pioneers in increasing efficiency by utilizing the heat of the exhaust gas released into the atmosphere.

One of the most critical components of cogeneration

*Corresponding author:
Email: kursat.tanriver@istun.edu.tr

Cite this article as:
Kaymaz, R., Ak, M., Tanriver K. (2025). Impact of structural and CFD analysis on the cost of biogas-fueled gas engine exhaust pipes. *European Mechanical Science*, *9*(2): 165-176. https://doi.org/10.26701/ems.1650061

History dates:
Received: 04.03.2025, ***Revision Request***: 07.04.2025, ***Last Revision Received***: 13.04.2025, ***Accepted***: 19.05.2025

systems is the exhaust pipes that come into play during the use of the energy obtained. Exhaust pipes directly affect system safety and efficiency by properly transferring the combustion gases of the biogas burned in generators or engines out of the facility. Thanks to correctly designed and constructed exhaust pipes with appropriate materials, exhaust gases are released safely into the atmosphere. Otherwise, inadequate management of exhaust gas can lead to problems such as environmental pollution, unwanted gas accumulation in or around the facility, and efficiency losses.

While cogeneration systems have been widely adopted in many sectors, insufficient attention is often paid to the exhaust pipe design, which can result in pressure losses, heat dissipation inefficiencies, and environmental hazards. Properly engineered exhaust pipes not only optimize gas flow and minimize backpressure, but also help in complying with stringent emission regulations, both at the national and international levels. Despite the wealth of literature addressing cogeneration performance and emissions, studies that investigate the mechanical and thermofluidic behavior of exhaust pipes using CFD (Computational Fluid Dynamics) and structural analysis in a biogas-specific context remain limited.

In this manuscript, the cost effect of exhaust pipe design principles was effectively investigated by performing CFD (Computational Fluid Dynamics) and structural analysis on exhaust pipes in biogas-fueled cogeneration systems.

Moreover, the study evaluates how exhaust system components can be optimized to meet ISO and local regulatory standards, providing insights into improvement methodologies for future system implementations. By reviewing state-of-the-art research, including applications of exhaust design in industrial furnaces, transport vehicles, and maritime systems, the manuscript establishes a multidisciplinary foundation for understanding and enhancing flue gas management in renewable energy contexts.

In addition, how exhaust systems can be brought into compliance with local and international standards and possible improvement methods will be discussed. Thus, it is aimed to make biogas plants safer, more efficient, and sustainable by adopting correct applications from both engineering and environmental perspectives. The importance of exhaust pipe design stems from the fact that it directly affects the overall performance of the system by regulating gas flow and minimizing pressure losses. In this context, the analyses and design improvements made within the scope of the project aim to contribute to the more efficient operation of cogeneration systems.

Cogeneration systems provide simultaneous production of both heat and electricity from the primary energy source [1]. Studies in the literature have examined the effects of exhaust pipe design on system efficiency and cost with different methods and have drawn attention to the importance of optimizing design parameters.

The study by Tanrıver and Ay [2] used computational fluid dynamics (CFD) analyses and structural optimization methods to understand how it affects the spread of infection in refuse chute throw pipes, and to improve its design. Chootrakul Siripaiboon et al. [3] show that CFD methods are used together with experimental studies in separation gasifiers with integrated syngas burners. Experimental verification of the temperature and syngas composition values obtained in combustion, pyrolysis, gasification, and drying zones provides an important roadmap for increasing gasification efficiency and reducing emissions. Similarly, CFD-based flow and heat transfer analyses are carried out to improve natural gas, air, and flue gas channels in tower type zinc refining furnaces; it is aimed to increase combustion efficiency and thermal homogeneity in zinc refining processes [4].

In steam boilers, the method of flue gas recirculation, although the impact on system performance in controlling the temperature of reheated steam is subject to debate, there are studies suggesting that it significantly shapes the thermal efficiency of steam boilers and emission control [5]. Moreover, ash accumulation in heat exchangers can significantly change the radiation properties of the flue gas-particle mixture and, lead to significant decreases in heat transfer efficiency. Therefore, the development of dynamic accumulation models and non-gray radiation analyses can contribute to the design and optimization of waste heat recovery devices [6].

On the other hand, in terms of energy efficiency and emission reduction in the transportation and maritime sector, it can be shown that the gases in the exhaust systems cause an energy loss of approximately 25%, but it is possible to recover this energy by using thermoelectric generators [7, 8].

It has been shown that emission control can be performed with real-time data using deep learning-based time series approaches for monitoring and predicting exhaust pipe emissions from heavy trucks in road transport [9]. Exhaust pipe vibration analysis is also a critical issue in terms of reliability and durability in the automotive industry, and stress and failure points in flanges or other components can be detected with modal and random vibration analysis [10].

Nejatzadegan et al. [11] investigated the efficiency between the exhaust manifold and engine parts according to two different types of exhaust manifolds. Hasan Üstün Başaran [12] conducted a study to determine the relationship between exhaust gas and temperature in diesel engine systems. In their study, they showed that delayed fuel injection moderately improved the exhaust temperature. Zhang et al. [13] showed that when flue gas waste heat is applied together with an absorption heat pump and staged heat recovery technologies, boil-

 https://doi.org/10.26701/ems.1650061

er efficiency can be increased by more than 12%. Shi et al. [14] have conducted an alternative study to the traditional exhaust cooling systems used in diesel engines. The study not only complies with safety standards, but also provides fuel savings of over 4%. In addition, it has shown superiority in terms of environmental and performance by offering up to 90% emission reduction. Li et al. [15] studied the use and cost effectiveness of devices required for air pollution control in flue gas of coal-fired plants. Tomasz Kalak [16] has shown that industrial waste biomass can be an environmentally friendly, low-cost, and sustainable energy source that can be used as an alternative to fossil fuels in the production of electricity and heat, and can be efficiently evaluated with different conversion methods.

These literature reviews have provided a solid theoretical basis by supporting the engineering tools and design approaches used in the project. Existing studies clearly demonstrate the importance of parameters such as gas flow rate, pressure loss, and material selection in the project. In the light of this information in the literature, the problems aimed to be solved during the project process have been clearly revealed.

Ultimately, the aim of this research is to present a cost-benefit analysis of alternative exhaust designs in a real-world biogas cogeneration facility. The comparative evaluation of existing systems and newly proposed configurations is intended to offer engineers, plant designers, and decision-makers practical guidance in making sustainable, safe, and economically viable design choices. Through this study, we hope to underscore the broader role of intelligent engineering in advancing the efficiency and reliability of renewable energy systems.

The purpose of this article is to reveal the efficiency of the exhaust pipe design used in cogeneration systems in terms of engineering and cost within the entire system. For this purpose, an existing biogas-fueled cogeneration plant was examined, the design deficiencies of these existing systems were determined, and a new system was proposed. A cost analysis was performed by comparing the existing system with the proposed new design. Thus, it is aimed to provide readers, designers, and engineers with a new perspective on exhaust pipe design, demonstrating that design changes can lead to more cost-effective and efficient engineering solutions.

2. Site Inspection

2.1. Biogas Plant

In order to increase the effectiveness of this study, a field study was conducted at the Izaydas (Izmit Waste and Residues Treatment, Incineration and Evaluation Inc.) facility. Izaydas is the first hazardous and industrial waste incineration and disposal facility in Turkey. Operating under the Kocaeli Metropolitan Municipality, the facility has an integrated infrastructure that allows both domestic and industrial waste to be disposed of without harming the environment. The facility offers services such as waste incineration, biogas production, hazardous waste storage, and energy production. The facility uses cogeneration systems to recover the energy generated during waste disposal, and generates electricity and heat. The facility converts organic waste into an energy source by using the anaerobic digestion method during the biogas production process. The stored biogas is transmitted to the cogeneration engines. The electrical energy generated in the engines is transferred to the grid, while the heat released is used in energy systems or in-plant operations. The cogeneration system of the facility is shown in ▶**Figure 1**.

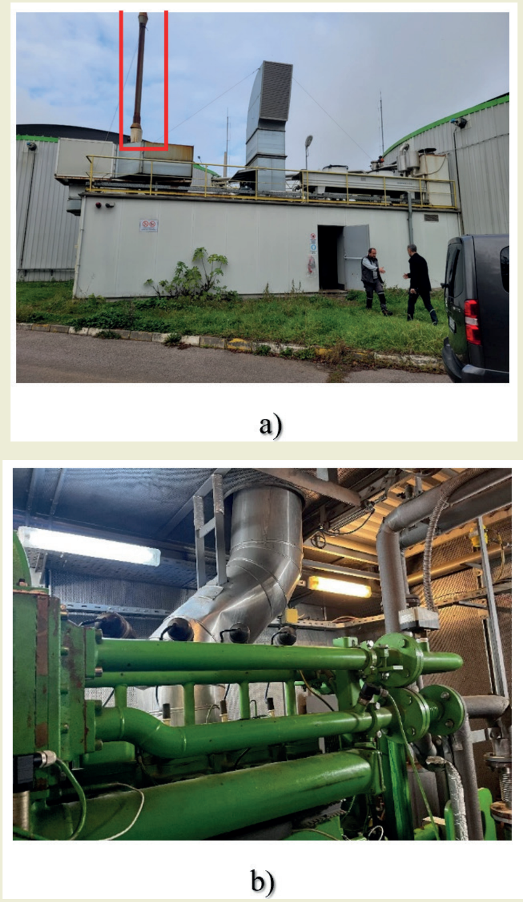


Figure 1. Biogas fueled cogeneration unit a) General view b) Gas Engine

2.2. Exhaust Pipe Production Facility

An inspection was carried out at the Rotek Exhaust Pipe System factory to observe the exhaust pipe production on site. In the inspections, it was seen that the designers manufactured the exhaust pipe in accordance with EN 1856-1 [17] standards. In the exhaust pipe design, the exhaust pipe height, diameter, and material are determined based on EN 13384 [18] standard. Different types of exhaust pipes are shown in ▶**Figure 2**.

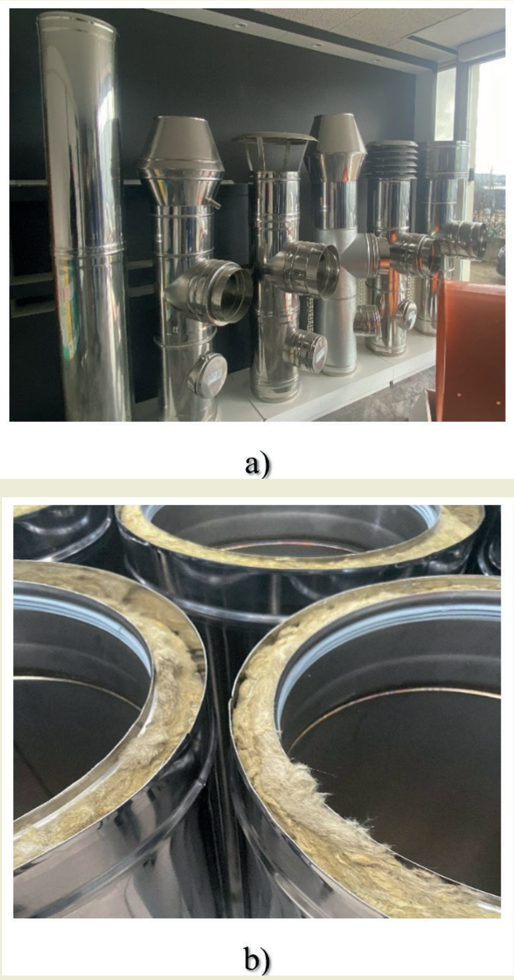


Figure 2. Types of exhaust pipes a) General view b) Insulated pipe

3. Material and Method

3.1. Material

The main source of CFD analysis in cogeneration plants is the gas engine. Calculations are made by considering the data sheet information given according to the type of gas engine. In this manuscript, the J 208 GS/C21 General Electric Jenbacher gas engine is used as the gas engine. The J 208 GS/C21 is a gas engine with approximately 330 kW electricity and 480 kW heat production capacity. Thanks to the cogeneration (CHP) system, total energy efficiency can reach 85-90% [19]. The engine offers flexibility by operating with various combustible gases such as biogas and natural gas. The biogas produced by the plant from organic waste is converted into energy by this engine. The gas engine is shown in ▶**Figure 3** and the data sheet parameters are shown in ▶**Table 1**.

CE certified high temperature and corrosion resistant products in accordance with EN 1856 -1 [17] and EN 1859 [20, 21] standards were selected for the exhaust pipes of the system. Since these products are made of stainless steel, they are resistant to corrosion from the exhaust gas [22]. Considering these references, a 1 mm thick Ø180 mm diameter AISI 304 stainless steel exhaust pipe was selected. 50 mm thick, 80 kg/m3 density rock wool thermal insulation was applied on the inner pipe. As the outermost coating, an exhaust pipe made of 0.50 mm thick AISI 430 quality stainless steel was selected in order to ensure that the exhaust pipe is located outside the building and is resistant to rain effects.

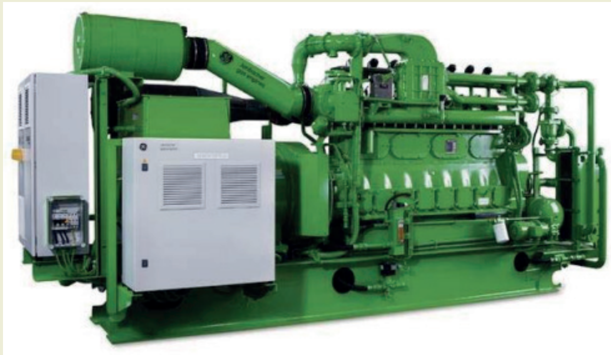


Figure 3. General Electric Jenbacher J 208 GS-C21 Gas Engine

Table 1. Gas Engine Data Sheet

Parameter	Unit	Value
Exhaust gas temperature at full load	°C	508
Exhaust gas temperature at bmep = 12.4 [bar]	°C	~527
Exhaust gas temperature at bmep = 8.3 [bar]	°C	~546
Exhaust gas mass flow rate, wet	kg/h	1.858
Exhaust gas mass flow rate, dry	kg/h	1.725
Exhaust gas volume, wet	Nm³/h	1.444
Exhaust gas volume, dry	Nm³/h	1.278
Max. admissible exhaust back pressure after engine	mbar	60

3.2. Method

In order to evaluate the effects of exhaust pipe design on energy efficiency and cost effectiveness, software performing CFD analysis was used, taking EN 13384-1 [18] standard as reference. Kesa Aladin program [23, 24], which was also used in previous studies, was used to optimize gas flow, pressure loss, and diameter calculations for exhaust pipe design. Solidworks was used for 3D design of exhaust pipe, and Solidworks Simulation [25, 26] software, which can be used in structural analysis, was used for static analysis. Wind load equations expressed in TS 498 standard [27] were used in structural analysis [28, 29, 30]. Cost analysis was performed using Excel program for Material Quantity and Cost Analysis.

4. Results and Discussion

4.1. Exhaust Pipe Calculation and CFD Analysis

The full-load operating parameters of the Janbacher J 208 GS-C 25 gas engine used in the system are report-

 https://doi.org/10.26701/ems.1650061

ed by the manufacturer. In addition to the gas engine data sheet information, the information provided by the boiler and silencer manufacturer is presented in ▶Table 2. The total thermal capacity of the gas engine (851 kW), exhaust flow rate (1858 kg/h), exhaust outlet temperature (508 °C), and pressure losses in the exhaust pipe system are shown in detail.

Table 2. Data Summary for CFD analysis

Motor Type: Janbacher Gas Engine J 208 GS-C 25		
Specification	Full Load	Unit
Thermal capacity (Total)	851	kW
Exhaust gas mass flow rate	1858	kg/h
Exhaust gas temperature	508	°C
Max. admissible exhaust back pressure	6	kPa
Boiler inlet temperature	508	°C
Boiler outlet temperature	161	°C
Boiler pressure loss	0.95	kPa
Silencer pressure loss	1	kPa

4.1.1 The Existing System

The current system is shown in ▶Figure 4. The system consists of a gas engine, boiler, muffler, and exhaust pipe. The exhaust pipe has a section with a diameter of Ø 273 mm and another section with a diameter of Ø 219 mm. To ensure the exhaust pipe remains self-supporting, its thickness has been increased, and it has been supported by a base plate and flags mounted on the cabinet.

The performance analysis of the existing exhaust pipe design, based on the information in ▶Table 2 and ▶Figure 4, was performed using the Kesa Aladin software in accordance with EN 13384-1 standard. The calculation result is shown in ▶Figure 5.

According to the calculation results, it has been shown that the current exhaust pipe design complies with the standards by meeting both temperature and pressure requirements.

4.1.2 The Proposed New System

Within the scope of the originality of this study, improvements have been made to the existing design. Ac-

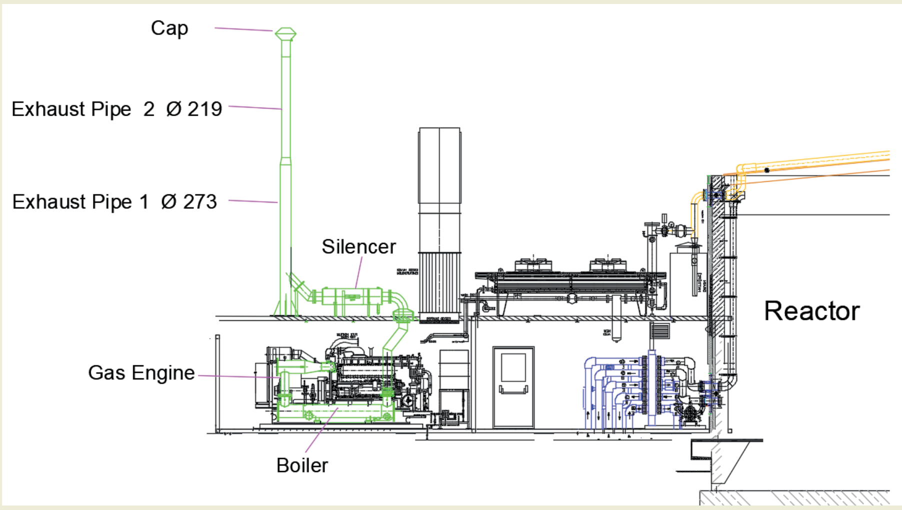
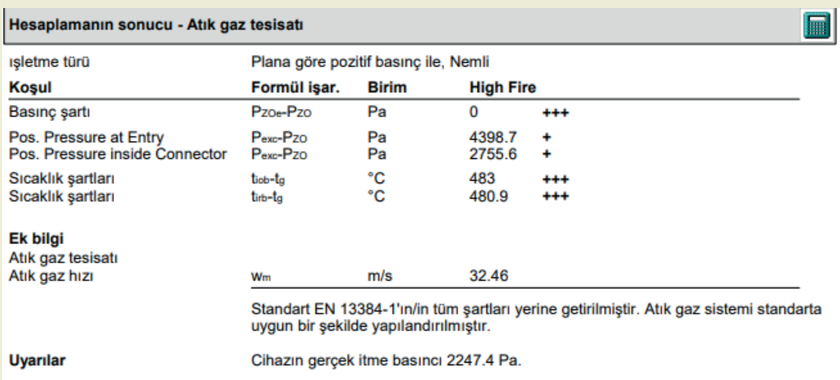


Figure 4. The Existing System Design



Hesaplamanın sonucu - Atık gaz tesisatı

işletme türü: Plana göre pozitif basınç ile, Nemli

Koşul	Formül işar.	Birim	High Fire	
Basınç şartı	P_{ZOe}-P_{ZO}	Pa	0	+++
Pos. Pressure at Entry	P_{exc}-P_{ZO}	Pa	4398.7	+
Pos. Pressure inside Connector	P_{exc}-P_{ZO}	Pa	2755.6	+
Sıcaklık şartları	t_{iob}-t_g	°C	483	+++
Sıcaklık şartları	t_{irb}-t_g	°C	480.9	+++

Ek bilgi

Atık gaz tesisatı			
Atık gaz hızı	w_m	m/s	32.46

Standart EN 13384-1'ın/in tüm şartları yerine getirilmiştir. Atık gaz sistemi standarta uygun bir şekilde yapılandırılmıştır.

Uyarılar Cihazın gerçek itme basıncı 2247.4 Pa.

Figure 5. Results of the exhaust cross-section calculations for the existing system

cordingly, the existing silencer is positioned horizontally, whereas the silencer in the proposed improvement is designed vertically. This way, the length of the exhaust pipe route is reduced, which will decrease the exhaust pipe lengths and resistance losses. The reduction in length and resistance losses represents an engineering improvement and thus leads to more optimal draft. The proposed new system is shown in ▶Figure 6.

Based on the information in ▶Table 2 and ▶Figure 6, the performance analysis of the existing exhaust pipe design was performed with Kesa Aladin software in accordance with EN 13384-1 standard. The calculation result is shown in ▶Figure 7.

According to the calculation results, with the route modification, it has been observed that draft is achieved in the proposed new exhaust pipe design by selecting an exhaust pipe diameter of Ø180 mm, and that it complies with the standards by meeting both temperature and pressure requirements.

4.2. Wind Load Calculation and Structural Analysis for The Proposed New System

4.2.1 Load Calculation for Wind Load Analysis

Wind load values are needed to evaluate the durability of the exhaust pipe and silencer design used in the project. The wind pressure acting on the upper surface of the structure is given in the equation below [27].

$$W = C_p q \tag{1}$$

Here, q is the wind pressure (Wind pressure and Suction pressure) (kN/m^2), and C_p is the suction coefficient.

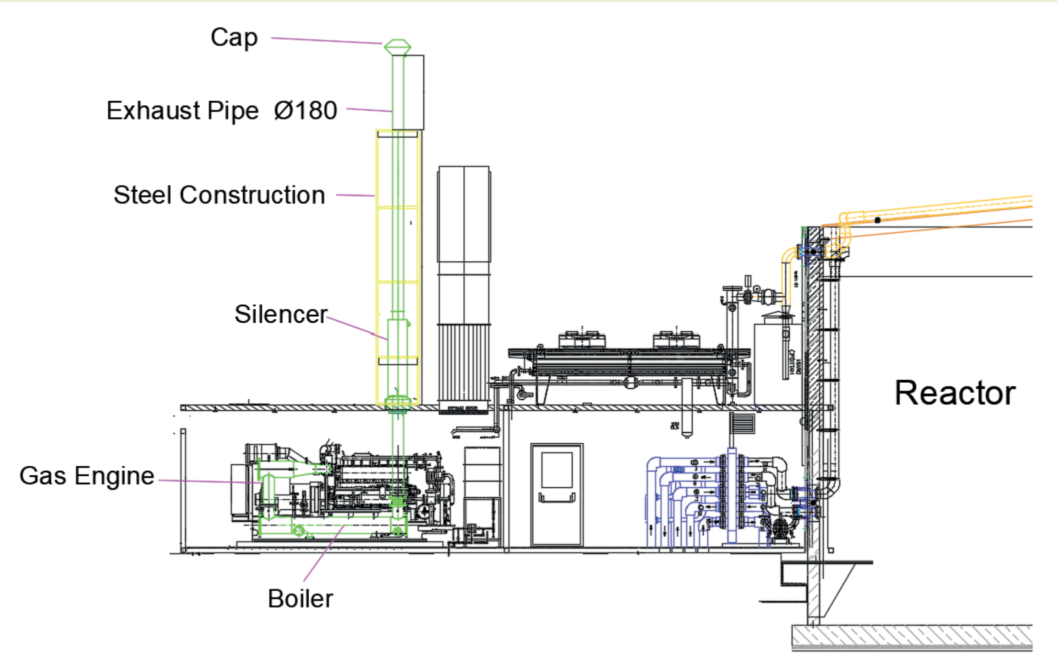


Figure 6. Design of The Proposed New System

Hesaplamanın sonucu - Atık gaz tesisatı

ışletme türü	Plana göre pozitif basınç ile, Nemli			
Koşul	**Formül işar.**	**Birim**	**High Fire**	
Basınç şartı	$P_{ZO\ddot{u}}-P_{ZO}$	Pa	0	+++
Pos. Pressure at Entry	$P_{exc}-P_{ZO}$	Pa	2795.5	+
Pos. Pressure inside Connector	$P_{exc}-P_{ZO}$	Pa	158.4	+
Sıcaklık şartları	$t_{iob}-t_g$	°C	489.4	+++
Ek bilgi				
Atık gaz tesisatı				
Atık gaz hızı	w_m	m/s	49.17	

Standart EN 13384-1'ın/in tüm şartları yerine getirilmiştir. Atık gaz sistemi standarta uygun bir şekilde yapılandırılmıştır.

Figure 7. Results of The Exhaust Cross-Section Calculations for The Proposed New System

 https://doi.org/10.26701/ems.1650061

C_p is determined depending on the different wind directions for the surface under consideration. Wind pressure acts perpendicularly to the surface. In tower type structures such as exhaust pipes, this value is taken as 1.6. Thus, wind pressure in the exhaust pipes is expressed as follows [27].

$$W = 1.6 \ q \tag{2}$$

Wind pressure is determined by the following equation.

$$q = \frac{\rho \, v^2}{2g} \tag{3}$$

If the approximate unit volume mass of air is taken as q = 1.25 kg/m^3, and the acceleration due to gravity is substituted in m/s^2, the wind pressure is expressed in the following equation.

$$q = \frac{v^2}{1600} \tag{4}$$

Although different wind speeds may occur due to local topographic conditions, in general, the wind speed is shown in ▶**Table 3**, according to the values specified in TS 498 September 2021 standard [27], based on the structure's height above the ground. This table also summarizes the wind pressure associated with the speed, in practical terms.

Due to local topographic conditions, different wind speeds may occur, and these speeds may deviate from the given values. Therefore, considering that the wind effect will be severe in structures located at high altitudes or on steep slopes, the wind pressure should be taken as q = 1.1 kN/m^2 [27].

Table 3. Summary of Wind Speed and Wind Pressure Based on Height [27].

Height above ground (m)	Wind speed v (m/s)	Wind pressure q (kN/m²)
0 ~ 8	28	0.5
9 ~ 20	36	0.8
21 ~ 100	42	1.1
> 100	46	1.3

Taking into account the wind pressure, the wind load acting on the exhaust pipe system is calculated using the following equation.

$$F_n = q \ c \ H \tag{5}$$

$$F_n = \frac{v^2}{1600} \ c \ H \tag{6}$$

$$C = \pi \ D_2 \tag{7}$$

$$D_2 = D_1 + 2 \ t_i \tag{8}$$

Here, v represents the wind speed at different heights and speeds, F_n represents the wind load, H represents the ground height, c represents the exhaust pipe outer wall perimeter, t_i represents the insulation thickness,

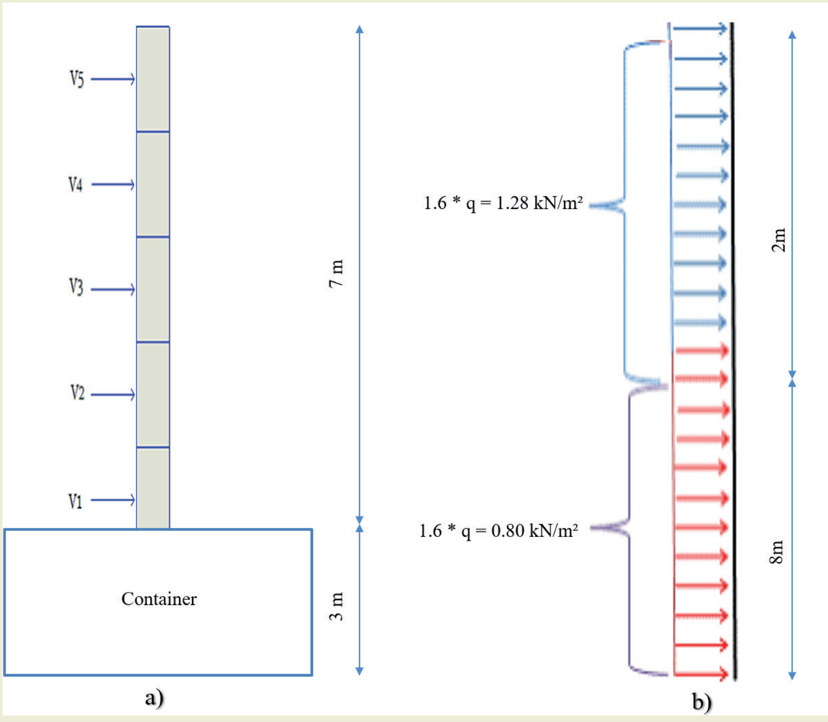


Figure 8. Schematic representation a) Exhaust Pipe b) Wind Pressure

D_1 represents the pipe inner diameter, and D_2 represents the pipe outer diameter after the insulation coating.

Here, when D_1 is taken as 180 mm and t_i as 50 mm, D_2 has been determined as 280 mm. The distribution of the wind load on the exhaust pipe is schematically shown in ▶Figure 8. Since the length of the proposed new exhaust pipe on the cabinet is 7 m, the load distribution has been considered accordingly.

As seen here, different wind loads are effective in the first 5 m and the following 2 m lengths of the exhaust pipe, due to the change in wind speed. Therefore, customized wind load calculations are shown in the equations below. Thus, wind load calculations are made for different wind speed (ν) and ground height (H) combinations.

$$F_1 = 1.6\ v_1^2\ c\ H_1 \tag{9}$$

$$F_2 = 1.6\, v_2^2\, c H_2 \tag{10}$$

Here, v_1= 28 m/s, H_1 = 8 m, v_2 = 36m/s, H_2 =2 m, so F_1=5.52 kN, and F_2=2.28 kN are found.

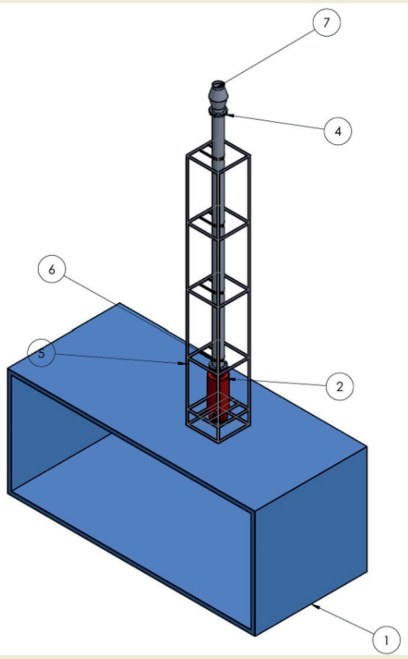
4.2.2 Structural Analysis

In the above section, the wind load calculations and the weight of the system have been defined as a force on the exhaust system in the structural analysis module. Although it is possible to apply different loads to different regions in accordance with the standards, in this project, a single force of 5.52 kN, the maximum wind load-critical load, has been applied equally across the entire system. The purpose of selecting the critical load in the calculations is to test the maximum durability in all areas of the exhaust pipe design.

Before the structural analysis, the 3D design of the exhaust pipe was made in the academic-student module of the Solidworks program. The 3D design is shown in ▶Figure 9.

The 3D design of the exhaust pipe was created in the SolidWorks (academic-student simulation model) program, and the steel construction was included in the simulation model as fixed to the ground. A total of 167691 nodes and 83229 elements were used in the analysis. In addition, mesh quality analysis was performed in the study. Mesh quality was found to be a minimum of 0.052 and maximum 0.99. The Fixed Support, Mesh structure, and load definitions have been established. While defining the loads, wind load and system weight were taken into account. Wind load was defined in the program so that it would apply to both the exhaust pipe and the construction. The Fixed Support, mesh structure, and load definitions are provided in ▶Figure 10.

Carbon steel (S275JR) has been used in the design of the construction and silencer, while AISI 304 grade stainless steel materials have been used for the exhaust pipe. These materials have been defined within the SolidWorks simulation module. Subsequently, finite element analysis was performed. The finite element analysis is shown in ▶Figure 11.



ITEM NO.	PART NUMBER	MATERIAL	QTY.
1	Container	ST 37	1
2	Silencer	ST 37	1
3	Upper Chimney	AISI 304	1
4	Flans	ST 37	3
5	Konstrüksiyon	ST 37	1
6	Clamp	ST 37	4
7	cap	ST 37	1

Figure 9. Exhaust Design for The Proposed New System

Accordingly, the maximum stress on the exhaust pipe was found to be 108.691 MPa according to the Von Mises criterion. This value is within safe limits compared to the yield strength of the steel material used (170 MPa). Thus, it was seen that the exhaust pipe is approximately 1.56 times more resistant to the loads caused by wind and the weight of the system. In the deformation analysis, the displacement and strain values of the exhaust pipe were examined in detail. With the rise of the exhaust pipe upwards, it was determined that the displacement values in some areas were a maximum of 0.13 mm. This value is within acceptable limits for the system and does not threaten the stability of the design.

4.3 Exhaust Design Cost Relationship

The proposed new exhaust system has shown that it meets the system requirements in terms of both CFD and structural analysis, just like the existing working exhaust system, even when the pipe route is reduced. In this section, cost analysis is performed by comparing the costs of the proposed new system that meets the system requirements with the existing system. The cost of the existing system is shown in ▶**Table 4**, and the cost of the proposed new system is shown in ▶**Table 5**.

As a result of the cost analysis, it was determined that the total cost of the existing exhaust pipe system was 5,133.00 USD. However, thanks to the design optimizations and savings in material usage, the cost was reduced to 2,402.80 USD. This means a cost reduction of approximately 53%. This saving was achieved by opti-

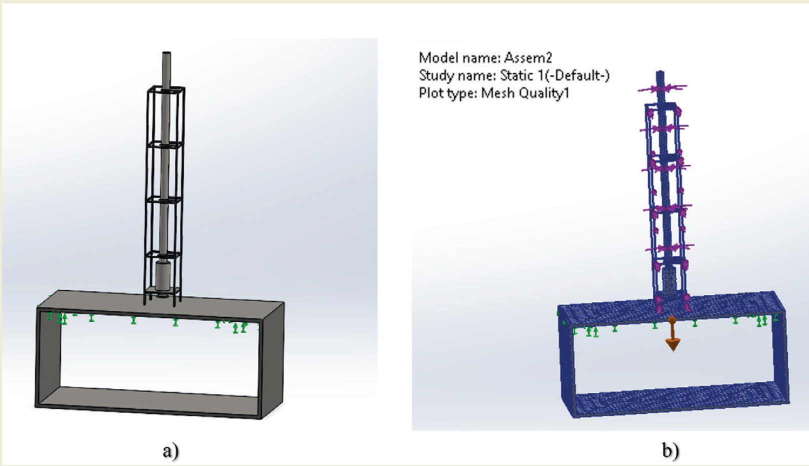


Figure 10. Design definitions: a) Fixed support b) Mesh configuration and load definitions

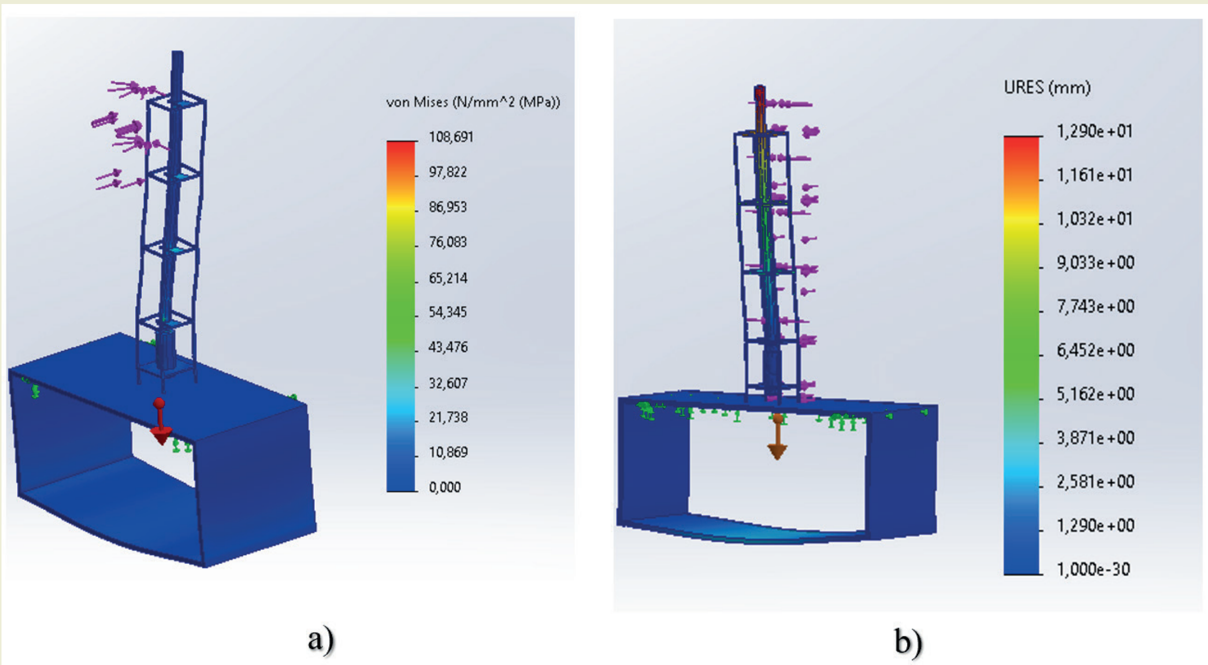


Figure 11. Finite element analysis: a) Von Mises b) Deformation

Table 4. The Cost of The Existing System

No	Description	Quantity	Unit	Total
	Vertical Sistem			
1	Ø 219 Length module	3.0	pc	$270.00
2	Ø 219 Adaptor	1.0	pc	$90.00
3	Ø 219 Cap	3.0	pc	$675.00
4	Ø 273 Length module	3.0	pc	$300.00
5	Ø 273 Condense module	1.0	pc	$120.00
6	Ø 273 Te Module	1.0	pc	$120.00
7	Ø 273 Base plate and ribs support	1.0	pc	$846.00
8	Ø 273 Flanges	0.0	pc	$0.00
	Connection pipe			
9	Ø 219 Length module	7.0	pc	$630.00
10	Ø 219 Adaptor	2.0	pc	$180.00
11	Ø 219 Te module	2.0	pc	$216.00
12	Ø 219 Dirsek 90	2.0	pc	$216.00
13	Ø 219 Dirsek 45	3.0	pc	$270.00
14	Ø 219 Flanges	10.0	pc	$1,200.00
	Total amount:			$5,133.00

Table 5. The Cost of The Proposed New System

No	Description	Quantity	Unit	Total
	Vertical Sistem			
1	Ø 180 Length module	6.0	pc	$168.80
2	Ø 180 Cap	3.0	pc	$210.00
3	Ø 180 Condense module	1.0	pc	$33.60
4	Ø 180 Te Module	1.0	pc	$33.60
5	Ø 180 Flanges	4.0	pc	$480.00
6	Ø 180 Steel construction	1.0	pc	$500.00
	Connection pipe			
7	Ø 180 Length module	2.0	pc	$56.00
8	Ø 180 Adaptor	2.0	pc	$56.00
9	Ø 180 Dirsek 90	1.0	pc	$33.60
10	Ø 180 Te Module	2.0	pc	$112.00
11	Ø 180 Flanges	6.0	pc	$720.00
	Total amount:			$2,402.80

mizing elements such as CFD analysis, structural analysis, exhaust length, exhaust pipe diameter, material thickness, and elbow design. Achieving the same durability and efficiency targets with less material usage offers a significant advantage in terms of both economic and environmental sustainability. This study clearly demonstrates the potential benefits of cost-effective design applications in industrial facilities.

The cost analysis in this study shows that the cost analysis of exhaust design is of great importance in terms of increasing recycling rates by encouraging cogeneration systems, achieving energy efficiency targets, and complying with environmental sustainability principles.

5. Conclusions

As a result of the examinations and analyses, it has been revealed that the correct design and positioning of exhaust pipes used in biogas-fueled cogeneration systems are of critical importance in terms of both efficiency and cost. In the current system, the horizontally positioned silencer and long exhaust pipe line increase pressure losses and cause unnecessary material usage, making the design costly. The proposed new design, thanks to the shorter pipe route, not only met the required standards but also achieved a safe structure by using much smaller diameter and material thickness.

The data collected during the field survey and the proposed new system were evaluated using CFD and structural analysis methods; the results obtained showed that there were significant improvements that directly affected the system efficiency and cost. In the current system, it was observed that the gas engine exhaust operating at 508 °C and 1858 kg/h flow (total 851 kW thermal capacity) was carried by two different pipe sections with diameters of 273 mm and 219 mm. In the analysis of this design, it was determined using the Kesa Aladin software that it complied with the standards in terms of pressure losses and gas flow, but created high costs due to unnecessary material usage.

On the other hand, in the new proposed system, the exhaust line was shortened by positioning the silencer vertically, the diameter was optimized as Ø180 mm and the material thickness was reduced. In the CFD analysis, it was seen that the temperature and pressure conditions required by the standards were also provided with this new design. Solidworks Simulation was used in structural analyses; under the wind load (critical condition defined as approximately 5.52 kN) and the weight of the system, a maximum Von Mises stress of 108.691 MPa was calculated. This value corresponds to a safety factor of approximately 1.56 when the material yield strength (170 MPa) is taken into account. The maximum displacement under the same conditions was determined to be only 0.13 mm, thus confirming that the design has sufficient stability.

The cost analysis results are one of the most striking findings in the project. While the total cost of the existing system was calculated as 5,133 USD, this amount was reduced to 2,402.80 USD with the new proposed design. A cost reduction of approximately 53% has been achieved, demonstrating that the use of a shorter exhaust route, smaller diameter, and thinner material not only ensures compliance with standards but also provides a significant economic advantage.

As a result, the new design approach, which is verified both in terms of fluid dynamics and structural aspects, combines efficiency, safety and economic criteria in a holistic way. This study reveals that it is possible to achieve high performance at lower costs in biogas-fueled cogeneration plants and that the same method can be generalized in similar applications.

In future studies, long-term performance of high temperature and corrosion effects can be investigated by using advanced material combinations or multi-layer exhaust systems. In this context, processing the obtained data with optimization algorithms will allow for more comprehensive improvement of exhaust systems in terms of both cost and energy efficiency. Thus, adopting the same methods in similar biogas and cogeneration plants will provide a guiding approach for both operators and engineering applications.

Research ethics

Ethical approval not required.

Author contributions

Conceptualization: [Rabia Kaymaz], Methodology: [Kursat Tanriver], Formal Analysis: [Kursat Tanriver], Investigation: [Kursat Tanriver], Resources: [Rabia Kaymaz], Data Curation: [Kursat Tanriver], Writing - Original Draft Preparation: [Rabia Kaymaz], Writing - Review & Editing: [Mine Ak], Visualization: [Mine Ak], Supervision: [Mine Ak], Project Administration: [Mine Ak]

Competing interests

The authors declare that there is no competing financial interest or personal relationship

Research funding

All analysis was carried out using software, without the need for any additional materials or equipment that would incur extra costs. The resources used during the technical visit were provided by the respective facility, and no expenses were incurred. We would like to extend our gratitude to the officials of İZAYDAŞ and Rotek Exhaust Pipe Systems for their support during the technical visit.

Data availability

Data may be made available on request

Peer-review

Externally peer-reviewed.

Orcid

Rabia Kaymaz https://orcid.org/0009-0008-0912-1374
Mine Ak https://orcid.org/0000-0003-1131-5529
Kürşat Tanrıver https://orcid.org/0000-0002-1723-4108

References

[1] Man, S. S., Lee, W. K. H., Chan, A. H. S., & Tsang, S. N. H. (2023). The economic and environmental evaluations of combined heat and power systems in buildings with different contexts: A systematic review. Applied Sciences, 13(6), 3855. https://doi.org/10.3390/app13063855

[2] Tanrıver, K., & Ay, M. (2024). Modifying the refuse chute design to prevent infection spread: Engineering analysis and optimization. Applied Sciences, 14(21), 9638. https://doi.org/10.3390/app14219638

[3] Siripaiboon, C., Sitthichirachat, P., Sarabhorn, P., Somkeattikul, K., Areeprasert, C., & Scala, F. (2025). Design, CFD simulation, and experimental verification of a novel fixed-bed decoupling gasifier with an integrated syngas burner using high-temperature flue gas. Process Safety and Environmental Protection, 196, 106883. https://doi.org/10.1016/j.psep.2025.106883

[4] Huang, Z., Liu, L., Wang, Z., Wang, C., Liu, Y., Liu, B., Zheng, G., & Yan, H. (2025). CFD analysis of flow and heat transfer enhancement in a tower-type zinc refining furnace with novel structural designs. Applied Thermal Engineering, 263, 125327. https://doi.org/10.1016/j.applthermaleng.2024.125327

[5] Alhashem, A., Almutairi, A. S., & Almokmesh, S. F. (2025). Flue gas recirculation in steam boilers: A comprehensive assessment strategy for energy optimization and efficiency enhancement. Processes, 13(2), 395. https://doi.org/10.3390/pr13020395

[6] An, R., & Zhang, X. (2025). Evaluation of weighted-sum-of-gray-gases models and radiation characteristics analysis for gas-ash particle mixture in ash deposition. Applied Thermal Engineering, 267, 125820. https://doi.org/10.1016/j.applthermaleng.2025.125820

[7] Yolus, A., Kayan, G., Yılmaz, Ş., & Tıkız, I. (2022). Recovery waste heat on exhaust of ship with thermoelectric generators. Journal of Maritime Research: Amphora, 1(1), 43–59.

[8] Sharma, G., Kumar, J., Sharma, S., Singh, G., Singh, J., Sharma, A., Chohan, J. S., Kumar, R., & Obaid, A. J. (2022). Performance of diesel engine having waste heat recovery system fixed on stainless steel made exhaust gas pipe. Materials Today: Proceedings, 48(5), 1141–1146. https://doi.org/10.1016/j.matpr.2021.07.511

[9] Li, Z., Zhang, X., & Dong, Z. (2023). TSF-transformer: A time series forecasting model for exhaust gas emission using transformer. Applied Intelligence, 53, 17211–17225. https://doi.org/10.1007/s10489-022-04326-1

[10] Kumar, A., Chaudhary, S. K., & Kumar, R. (2024). Vibrational analysis of an exhaust pipe flange with rib using ANSYS software. In A. De, P. P. Mukherjee, S. Pati, & A. Biswas (Eds.), Recent Trends in Mechanical Engineering. ICRAME 2024. Lecture Notes in Mechanical Engineering (pp. 67–78). Springer. https://doi.org/10.1007/978-981-97-7535-4_7

[11] Nejatzadegan, F., Sobhani, V., Pahlavan, M., & Dehghan, A. (2025). Effect of exhaust manifold geometry design on the performance of an internal combustion engine. International Communications in Heat and Mass Transfer, 162, 108593. https://doi.org/10.1016/j.icheatmasstransfer.2025.108593

[12] Başaran, H. Ü. (2024). Enhanced after-treatment warm up in diesel vehicles through modulating fuel injection and exhaust valve closure timing. European Mechanical Science, 8(2), 93–103. https://doi.org/10.26701/ems.1441861

[13] Zhang, S., Shen, M., Kang, Y., & Tang, Z. (2025). The design and experimental study of a deep-condensing waste heat recovery system for boiler flue gas based on Baoneng Heating Plant. Processes, 13(2), 306. https://doi.org/10.3390/pr13020306

[14] Shi, Z., Wei, H., Li, G., Wang, Y., Li, Q., Zheng, X., Song, K., Chen, C., Ma, C., Mozumder, S. A., & Basher, M. K. (2025). Research and analy-

sis of explosion-proof diesel engine performance based on different exhaust gas cooling systems. Energies, 18(3), 610. https://doi.org/10.3390/en18030610

[15] Li, Y., Yu, J., Liu, Y., Huang, R., Wang, Z., & Zhao, Y. (2022). A review on removal of mercury from flue gas utilizing existing air pollutant control devices (APCDs). Journal of Hazardous Materials, 427, 128132. https://doi.org/10.1016/j.jhazmat.2021.128132

[16] Kalak, T. (2023). Potential use of industrial biomass waste as a sustainable energy source in the future. Energies, 16(4), 1783. https://doi.org/10.3390/en16041783

[17] European Committee for Standardization. (2009). EN 1856-1: Chimneys — Requirements for metal chimneys — Part 1: System chimney products. Brussels, Belgium.

[18] European Committee for Standardization. (2022). EN 13384-1: Chimneys — Thermal and fluid dynamic calculation methods — Part 1: Chimneys serving one heating appliance. Brussels, Belgium.

[19] Jenbacher. (2025). Jenbacher J208 Gas Engine. Retrieved February 23, 2025, from https://www.jenbacher.com/en/gas-engines/type-2/j208

[20] European Committee for Standardization. (2009). EN 1859: Chimneys — Metal chimneys — Test methods. Brussels, Belgium.

[21] Tanrıver, K., & Ay, M. (2024). Investigation of flue gas temperature effects in natural gas fueled systems: Experimental thermal performance and structural optimization. International Journal of Heat and Fluid Flow, 107, 109428. https://doi.org/10.1016/j.ijheatfluidflow.2024.109428

[22] Reza Kashyzadeh, K., Ridha, W. K. M., & Ghorbani, S. (2025). The influence of nanocoatings on the wear, corrosion, and erosion properties of AISI 304 and AISI 316L stainless steels: A critical review regarding hydro turbines. Corrosion and Materials Degradation, 6(6), 10006. https://doi.org/10.3390/cmd6010006

[23] Kaymaz, R., Tanrıver, K., & Ak, M. (2025). Chimney installation and thermal-flow analysis in cogeneration systems. Paper presented at the 2nd International Texas Congress on Advanced Scientific Research and Innovation, January 27–28, Houston, Texas.

[24] Tanrıver, K., & Ay, M. (2020). Comparison of calculation programs in a stainless-steel chimney application. Euroasia Journal of Mathematics, Engineering, Natural Medical Sciences International Indexed Refereed, 7(10), 97–111.

[25] Ali, F. A., Hamandi, S. J., & Mohammed-Salih, H. S. (2025). Introducing a novel orthodontic bracket holder with a SolidWorks-based semiautomatic positioner tested via finite element analysis. Discover Applied Sciences, 7, 153. https://doi.org/10.1007/s42452-024-06368-1

[26] Uličný, M. M., Cigánek, J., Kutiš, V., Kučera, E., & Šedivý, J. (2025). Modeling and co-simulation of fuzzy logic controller for artificial cybernetic hand. Multimodal Technologies and Interaction, 9(2), 12. https://doi.org/10.3390/mti9020012

[27] Turkish Standards Institute. (2021). TS 498: Calculation values of loads to be taken into account in the sizing of buildings. Ankara, Turkey.

[28] Yüksel, S., Şirin, T. B., Ay, M., Uçar, M., & Kurt, M. (2024). A study on end mill tool geometry parameters for end milling of 316 L: Finite element analysis and response surface methodology optimization based on resultant cutting force. Journal of the Brazilian Society of Mechanical Sciences and Engineering, 46(8).

[29] Tanrıver, K., & Ay, M. (2023). Experimental, software and topological optimization study of unpredictable forces in bolted connections. Tehnički Vjesnik, 30(4), 1175–1184. https://doi.org/10.17559/TV-20221113121639

[30] Tanrıver, K., Dilibal, S., Şahin, H., & Kentli, A. (2021). A novel design on polymeric material recycling technology. Acta Scientiarum. Technology, 43, e56211.