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Dynamic Modelling and Simulation of Industrial Plant Fire and Gas Detection Systems: Parametric Analysis of Nozzle Flow

Anacleto M. Cortez Jr[1], April Joy D. Dumagpi[2]

[1]Faculty-Program Chair
[2]Student

Abstract:
Industrial plant safety is of paramount importance, and the effective operation of Fire and Gas Detection Systems (FGDS) plays a critical role in preventing and mitigating incidents. This study presents a comprehensive parametric computational fluid dynamics (CFD) analysis of nozzle flow, aimed at enhancing our understanding of the complex fluid dynamics within nozzle geometries. Nozzles find wide applications in industries ranging from aerospace propulsion systems to industrial processes. The analysis employs CFD simulations with varying geometric parameters, such as nozzle shape, throat diameter, and expansion ratio, to investigate their influence on flow characteristics, including velocity profiles, pressure distributions, and shock formations. The parametric study involves systematic variations of these geometric parameters, allowing for the identification of optimal configurations for specific applications. The results shed light on the intricate interplay between nozzle geometry and flow behavior, providing valuable insights for nozzle design and optimization.

For 3D modeling and simulation, the study utilizes SketchUp Pro 2021 and Ansys Fluent 2023. The Mach number of 1.14838 indicates that the flow inside the nozzle is supersonic. The back pressure of 76.96 kPa represents a subsonic pressure condition at the outlet of the nozzle. This suggests that the flow is being expanded from a supersonic condition to a subsonic condition as it exits the nozzle. The expansion process is associated with changes in velocity, pressure, and temperature. To test the validity of these findings, additional study and simulation on this design using alternative software are needed.

Keywords: Simulation, Industrial plant, Fire detection system, Nozzle Flow, CFD

I. Introduction

Industrial plants are intricate environments where safety and operational efficiency are of paramount importance. Among the many critical safety considerations, the prevention and rapid response to fire and gas hazards stand as vital imperatives. Ensuring the security of personnel, assets, and the surrounding environment necessitates the deployment of advanced fire and gas detection systems. These systems are designed to swiftly identify, assess, and mitigate potential threats arising from leaks, releases, or combustion events.

Traditionally, the design and evaluation of fire and gas detection systems have been carried out through physical testing and empirical assessments. However, in today's technologically driven landscape, the power of simulation and dynamic modelling offers a transformative approach to understanding, optimizing, and enhancing the performance of such safety-critical systems. This paper delves into the realm of dynamic modelling and simulation as applied to industrial plant fire and gas detection systems.

The fundamental premise of this work is the recognition that real-world incidents are complex and often influenced by intricate interactions between various factors. These factors span from the physical properties of the hazardous materials, their dispersion patterns, the response characteristics of sensors, to the human element involved in decision-making and response execution. Capturing this complexity requires a holistic and integrated approach that dynamic modelling and simulation techniques can provide. By creating a virtual representation of the fire and gas detection system, encompassing its components, algorithms, and interactions, we can unravel the intricate dynamics that govern its behavior. Through meticulous mathematical formulation and computational simulation, we can emulate diverse scenarios, ranging from minor gas leaks to extensive fire outbreaks. Such simulations not only illuminate the spatial and temporal evolution of hazards but also enable the assessment of system responses and operator actions.

The objectives of this paper are multifaceted. We aim to elucidate the methodology behind the development of a dynamic model for industrial plant fire and gas detection systems. Subsequently, we explore the various scenarios simulated, ranging from single to multiple hazard scenarios, allowing us to dissect the system's behavior under varying conditions. Through this exploration, we uncover optimization opportunities that can enhance the overall robustness and efficacy of the system.

In the pages that follow, we embark on a journey through the conceptualization, mathematical representation, and computational realization of a dynamic model for industrial plant fire and gas detection systems. By bridging the gap between theoretical principles and practical safety enhancement, we strive to contribute to a safer industrial landscape through the power of dynamic modelling and simulation.

2.1 Related readings

The OSHS in the Philippines is primarily governed by the Department of Labor and Employment (DOLE). These standards are designed to ensure the safety and health of workers across various industries, including those in industrial plants. OSHS includes specific provisions related to fire safety and emergency preparedness in the workplace, which may involve the installation and maintenance of fire and gas detection systems. Employers are generally required to implement safety measures, including fire prevention and control, and provide training to workers on responding to fire and gas-related emergencies. OSHS also mandates regular workplace inspections and assessments to ensure compliance with safety standards.

The Philippine Environmental Impact Statement System (PEISS), established under Presidential Decree No. 1586 and its implementing rules and regulations, focuses on assessing the potential environmental impacts of various industrial activities. Projects with potential environmental impacts, such as industrial plants, are required to undergo an Environmental Impact Assessment (EIA) process. While primarily focused on environmental concerns, EIAs may also consider safety aspects, including fire and gas hazards, especially when these hazards could result in environmental harm. The EIA process may require industrial plant operators to detail their safety measures, including fire and gas detection systems, in their project documentation.

Local government units (LGUs) in the Philippines have the authority to create their own ordinances and regulations related to safety and environmental protection. Depending on the location of an industrial plant, operators may need to comply with specific safety and environmental requirements set by the LGU where the plant is situated. These local regulations may include fire safety standards and guidelines for the installation and maintenance of fire and gas detection systems.

For industrial plants engaged in energy-related activities, the Department of Energy (DOE) may issue specific guidelines and regulations concerning safety and environmental protection. The DOE regulations may cover areas such as safety measures for handling hazardous materials and ensuring the integrity of energy infrastructure. Fire and gas detection systems are critical in preventing and mitigating incidents in energy facilities, and their installation and maintenance may be subject to DOE oversight.

2.2 Related literature

Human factors influencing the reliability of fire and gas detection system (Idris et al., 2019) delves deeply into the intricate relationship between human factors and the reliability of fire and gas detection systems in industrial settings. This study emphasizes the pivotal role of human behavior, decision-making, and interactions with technology in shaping the effectiveness of these safety systems. Understanding the nuances of how operators and personnel interact with these systems is vital for improving their overall reliability and performance. The research highlights the significance of human-centric design and training in ensuring that fire and gas detection systems function optimally, ultimately contributing to safer industrial environments. The paper underscores the importance of this human-centered approach in the broader context of industrial safety, making it a cornerstone reference for those interested in the dynamic modeling and simulation of fire and gas detection systems.

A Voting Algorithm for Fire and Gas Detection and Monitoring System (Nadzir & Nazruldin, 2015) introduces an innovative voting algorithm designed to enhance the reliability and accuracy of fire and gas detection systems within industrial plants. By leveraging multiple sensors and implementing an intelligent decision-making process, this algorithm offers an advanced approach to detecting and monitoring hazardous events. It addresses the challenge of false alarms and missed detections that traditional systems may encounter. The research underscores the practical significance of this algorithm, as it has the potential to significantly improve safety outcomes in industrial environments. Moreover, it aligns with the broader industry trend of integrating artificial intelligence and machine learning into safety systems, making it a noteworthy contribution to the evolving landscape of fire and gas detection technology.

In Hydrogen hazards and gas detection—Electrolyzer case study (Marszal & Smith, 2023), the authors present a compelling case study that focuses specifically on hydrogen hazards and gas detection within the context of an electrolyzer system. This work delves deeply into the intricacies of hydrogen-related industrial processes and the safety considerations associated with them. Given the increasing importance of hydrogen as a clean energy carrier, understanding the unique challenges and safety protocols surrounding its production and utilization is paramount. The case study provides valuable insights into gas detection strategies tailored to the risks posed by hydrogen systems, making it an essential reference for professionals working in hydrogen-related industries. It also reflects the broader commitment to safety in emerging energy technologies and underscores the importance of dynamic modeling and simulation in optimizing gas detection systems for evolving industrial processes.

A risk-based methodology for the optimal placement of hazardous gas detectors (Cen et al., 2018) introduces a comprehensive risk-based approach for strategically placing gas detectors in industrial settings. The methodology proposed in this research accounts for various critical factors, including risk assessment and potential hazard scenarios. By optimizing the placement of detectors based on rigorous risk analysis, it aims to enhance the overall effectiveness of gas detection systems in safeguarding industrial facilities. This research aligns with the broader industry trend of shifting from prescriptive to risk-based safety approaches. It underscores the importance of proactive risk management and dynamic modeling in designing safety systems that not only comply with regulations but also provide robust protection against potential hazards.

Expand the Use of Open Wireless Gas Detection Systems for Life Safety and Asset Integrity (Yeo & Chin, 2018) explores the application of open wireless gas detection systems, shedding light on their potential to revolutionize safety and asset protection in industrial settings. The paper discusses the advantages and challenges of implementing such systems, which offer increased flexibility and scalability compared to traditional wired systems. This research reflects the industry's ongoing efforts to adopt cutting-edge technologies for enhancing safety outcomes. Furthermore, it underscores the significance of wireless communication and sensor networks in modernizing safety infrastructure. This study's findings resonate with the broader push for digital transformation and automation in industrial safety, making it a noteworthy contribution to the field of fire and gas detection technology.

In A fuzzy multi-objective optimization model of risk-based gas detector placement methodology for explosion protection in oil and gas facilities (Idris et al., 2022), the authors present a sophisticated fuzzy multi-objective optimization model tailored to the placement of gas detectors in oil and gas facilities. This research takes a holistic approach to risk assessment and detection system design, aiming to enhance explosion protection through precise placement strategies. By incorporating fuzzy logic, the model can handle uncertainty and multiple objectives simultaneously, making it a valuable tool for optimizing gas detection systems in complex and high-risk environments. This work aligns with the broader industry trend of leveraging advanced computational techniques to enhance safety measures and underscores the importance of dynamic modeling and simulation in achieving these goals.

A CFD-based approach for gas detectors allocation (Vázquez-Román et al., 2016) introduces a computational fluid dynamics (CFD)-based approach for optimizing the allocation of gas detectors. By simulating gas dispersion scenarios, this research provides a means to evaluate the performance of different detector placement configurations. This approach offers a valuable tool for engineers and safety professionals seeking to enhance gas detection system designs by aligning them with real-world conditions. The integration of CFD into the optimization process underscores the growing importance of digital tools and simulation techniques in industrial safety. It reflects the industry's commitment to data-driven decision-making and dynamic modeling as essential components of effective safety strategies.

A quantitative assessment on the placement practices of gas detectors in the process industries (Benavides-Serrano et al., 2015) conducts a quantitative assessment of gas detector placement practices in process industries. The research offers insights into the current practices and challenges associated with detector placement, highlighting areas for improvement and optimization. By quantifying the performance of existing placement strategies, this assessment provides valuable guidance for refining the design and implementation of gas detection systems. The study underscores the importance of evidence-based decision-making in safety engineering and emphasizes the role of quantitative analysis in achieving more effective safety outcomes.

A risk-based approach to flammable gas detector spacing (DeFriend et al., 2018) presents a risk-based methodology for determining the spacing of flammable gas detectors in industrial settings. By considering factors such as gas dispersion and potential consequences, this research offers a practical framework for safer industrial environments. The study aligns with the broader industry trend of transitioning from rule-based approaches to risk-based safety measures. It underscores the importance of incorporating risk assessments into the design of gas detection systems, particularly in industries where flammable gases pose a significant hazard. This research contributes to the ongoing dialogue on risk-informed safety strategies and dynamic modeling techniques for achieving them.

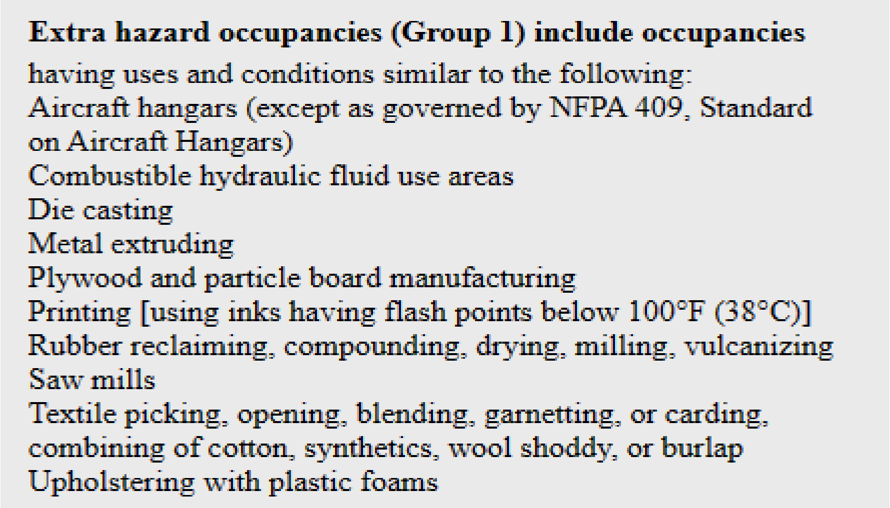
Recent Advances in Sensors for Fire Detection (Khan et al., 2022) provides a comprehensive overview of recent advancements in sensor technology for fire detection. The paper explores emerging sensor technologies and their applications in fire detection systems, highlighting their potential to improve accuracy and reliability. These innovations play a critical role in enhancing the early detection of fires, a cornerstone of fire safety in various settings. The paper underscores the significance of ongoing research and development efforts aimed at advancing sensor capabilities and their integration into dynamic fire detection systems. It reflects the industry's commitment to staying at the forefront of technological advancements for improved safety outcomes, making it a valuable reference for professionals and researchers in the field.

2.3 Related Studies

A survey of fire detection technology was conducted by the FAA for evaluation and certification of their suitability in cargo compartments on airplanes (Cleary, 1999). The study determined that there were multiple, suitable goals for fire detection inside of cargo compartments: faster detection of real fire threats, improved nuisance source discrimination, enhanced reliability, and greater indication of hazard level. Enhanced fire detection is desired by all airlines, however, the constraints found from the research identified cost as a key player that inhibits innovational technology from entering aircraft cargo compartments. Cost effective solutions are essential for new technology to be considered in the commercial business. In-flight testing can also present a time delay to new smoke detection technologies (Advisory Circular, 1994). Operational constraints also impact the implementation of successful fire detection such as temperature, pressure, humidity, and vibration conditions. The analysis suggested improving photelectric or ionization type detector behavior by applying advanced signal processing algorithms to inhibit nuisance alarms by reducing spurious signals that are not found in fire signatures in the sensing chamber. Using a multi-sensor detector was also prescribed as a potential solution after the survey was complete as this would better discriminate between nuisance and fire sources.

Comprehensive testing of smoke detector technologies for application in aircraft requires that fire sources be selected to provide a range of smoke conditions. In 2006, a report by David Blake was created to develop standardized fire sources for aircraft cargo compartments fire detection systems (Blake, 2006). A satisfactory fuel must release a plume of smoke and gases to eliminate any ambiguity of the fire's time of origin, generate all products of combustion expected from actual cargo fires, and have the ability to remotely activate from an unoccupied compartment. Chosen fire sources were based on their ability to generate quantifiable heat release rates, mass loss rates, and smoke and gas species production rates. The results from testing demonstrated the smoldering fire sources failed to generate a fire signature that would be useful in the development of multicriteria fire detectors with the potential of avoiding nuisance alarms. [88]

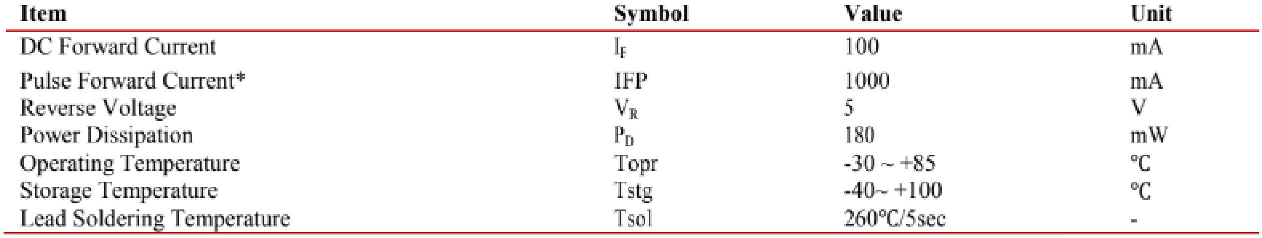
Figure 1. Occupancy



Extra hazard occupancies (Group 1) include occupancies
having uses and conditions similar to the following:
Aircraft hangars (except as governed by NFPA 409, Standard on Aircraft Hangars)
Combustible hydraulic fluid use areas
Die casting
Metal extruding
Plywood and particle board manufacturing
Printing [using inks having flash points below 100°F (38°C)]
Rubber reclaiming, compounding, drying, milling, vulcanizing
Saw mills
Textile picking, opening, blending, garnetting, or carding, combining of cotton, synthetics, wool shoddy, or burlap
Upholstering with plastic foams

Identifying the type of occupancy is paramount in the design and implementation of fire protection systems because it directly influences the safety measures required to protect occupants and property. Different occupancies, such as residential, commercial, industrial, or healthcare facilities, have distinct fire risk profiles and unique safety needs. For instance, a residential building will have different fire hazards and evacuation considerations compared to an industrial plant. Tailoring fire systems, including alarms, sprinklers, and evacuation plans, to the specific occupancy type ensures that the response is both effective and efficient. This targeted approach helps minimize false alarms, optimize the allocation of resources, and ultimately enhances the overall safety and protection of people and assets in various environments.

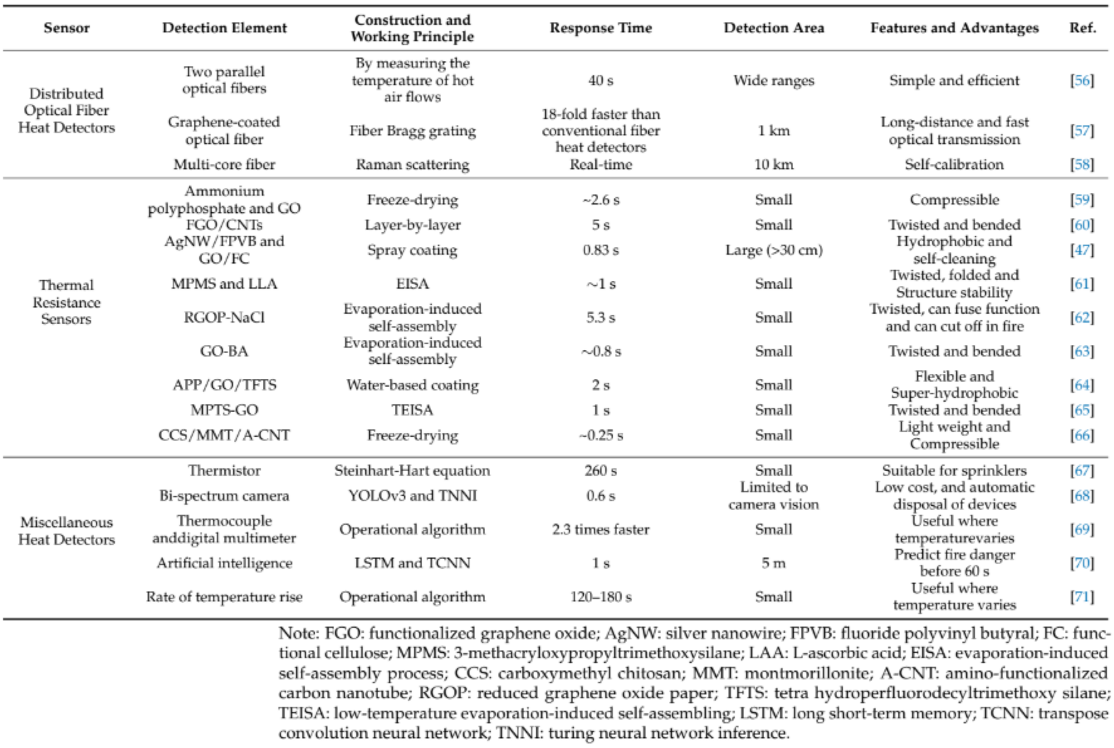
Table 1. Specification of the flame sensor



Item	Symbol	Value	Unit
DC Forward Current	I_F	100	mA
Pulse Forward Current*	IFP	1000	mA
Reverse Voltage	V_R	5	V
Power Dissipation	P_D	180	mW
Operating Temperature	Topr	-30 ~ +85	℃
Storage Temperature	Tstg	-40~ +100	℃
Lead Soldering Temperature	Tsol	260℃/5sec	-

Fire precaution action is required in most of the buildings and any of the institution for the prevention of fire disaster. This research discusses on detection of fire hazards using sensors as the parameter that indicates for fire. The fire hazard detection system is an intelligent sensor assembled with the Arduino Microcontroller to detect flame, smoke, and gas. Most alarm system that is being used nowadays has high sensitivity to the surroundings which tends to give a false alarm. This research describes a prototype alarm system that will activate the alarm accurately based on the fuzzy logic approach that has been implemented in the system. The system uses fuzzy logic to connect with Arduino and implemented with 125 rules of fuzzy logic with three levels of output namely dangerous, potentially dangerous and not dangerous. As a result, the output of the system shows 88% accuracy.

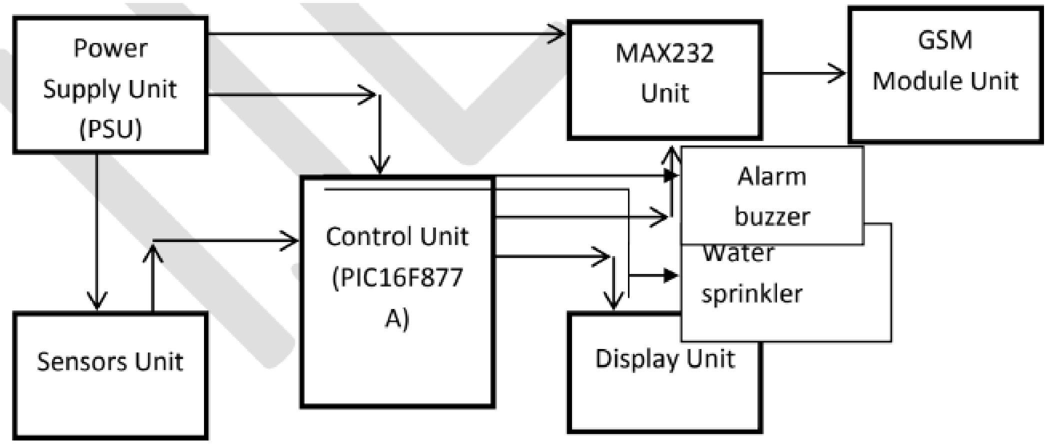
Table 2. Recent developments and comparison of different heat sensors and their characteristics. [10]



Sensor	Detection Element	Construction and Working Principle	Response Time	Detection Area	Features and Advantages	Ref.
Distributed Optical Fiber Heat Detectors	Two parallel optical fibers	By measuring the temperature of hot air flows	40 s	Wide ranges	Simple and efficient	[56]
	Graphene-coated optical fiber	Fiber Bragg grating	18-fold faster than conventional fiber heat detectors	1 km	Long-distance and fast optical transmission	[57]
	Multi-core fiber	Raman scattering	Real-time	10 km	Self-calibration	[58]
Thermal Resistance Sensors	Ammonium polyphosphate and GO	Freeze-drying	~2.6 s	Small	Compressible	[59]
	FGO/CNTs	Layer-by-layer	5 s	Small	Twisted and bended	[60]
	AgNW/FPVB and GO/FC	Spray coating	0.83 s	Large (>30 cm)	Hydrophobic and self-cleaning	[47]
	MPMS and LLA	EISA	~1 s	Small	Twisted, folded and Structure stability	[61]
	RGOP-NaCl	Evaporation-induced self-assembly	5.3 s	Small	Twisted, can fuse function and can cut off in fire	[62]
	GO-BA	Evaporation-induced self-assembly	~0.8 s	Small	Twisted and bended	[63]
	APP/GO/TFTS	Water-based coating	2 s	Small	Flexible and Super-hydrophobic	[64]
	MPTS-GO	TEISA	1 s	Small	Twisted and bended	[65]
	CCS/MMT/A-CNT	Freeze-drying	~0.25 s	Small	Light weight and Compressible	[66]
Miscellaneous Heat Detectors	Thermistor	Steinhart-Hart equation	260 s	Small	Suitable for sprinklers	[67]
	Bi-spectrum camera	YOLOv3 and TNNI	0.6 s	Limited to camera vision	Low cost, and automatic disposal of devices	[68]
	Thermocouple anddigital multimeter	Operational algorithm	2.3 times faster	Small	Useful where temperaturevaries	[69]
	Artificial intelligence	LSTM and TCNN	1 s	5 m	Predict fire danger before 60 s	[70]
	Rate of temperature rise	Operational algorithm	120–180 s	Small	Useful where temperature varies	[71]

Note: FGO: functionalized graphene oxide; AgNW: silver nanowire; FPVB: fluoride polyvinyl butyral; FC: functional cellulose; MPMS: 3-methacryloxypropyltrimethoxysilane; LAA: L-ascorbic acid; EISA: evaporation-induced self-assembly process; CCS: carboxymethyl chitosan; MMT: montmorillonite; A-CNT: amino-functionalized carbon nanotube; RGOP: reduced graphene oxide paper; TFTS: tetra hydroperfluorodecyltrimethoxy silane; TEISA: low-temperature evaporation-induced self-assembling; LSTM: long short-term memory; TCNN: transpose convolution neural network; TNNI: turing neural network inference.

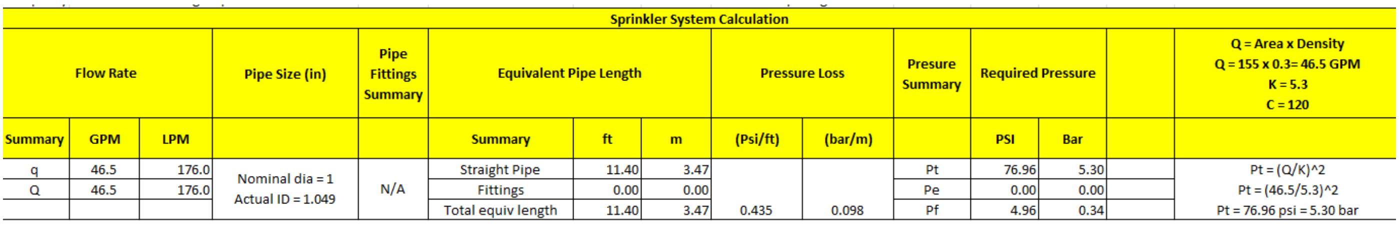
Figure 2 Block Diagram of Fire and Gas Detection System [74]



III. RESEARCH METHODOLOGY

This paper uses SketchUp Pro for the 3D model of the Fire System and Ansys fluent 2023 for simulation of the nozzle flow of a fire and smoke detection system in an industrial plant. Sprinkler System calculation is used to calculate the flow rate and required pressure. An online website is used to calculate the pressure loss in the sprinkler system. The Mach number of 1.14838 indicates that the flow inside the nozzle is supersonic. The back pressure of 76.96 kPa represents a subsonic pressure condition at the outlet of the nozzle. This suggests that the flow is being expanded from a supersonic condition to a subsonic condition as it exits the nozzle. The expansion process is associated with changes in velocity, pressure, and temperature. A detailed calculation of the sprinkler system is given below.

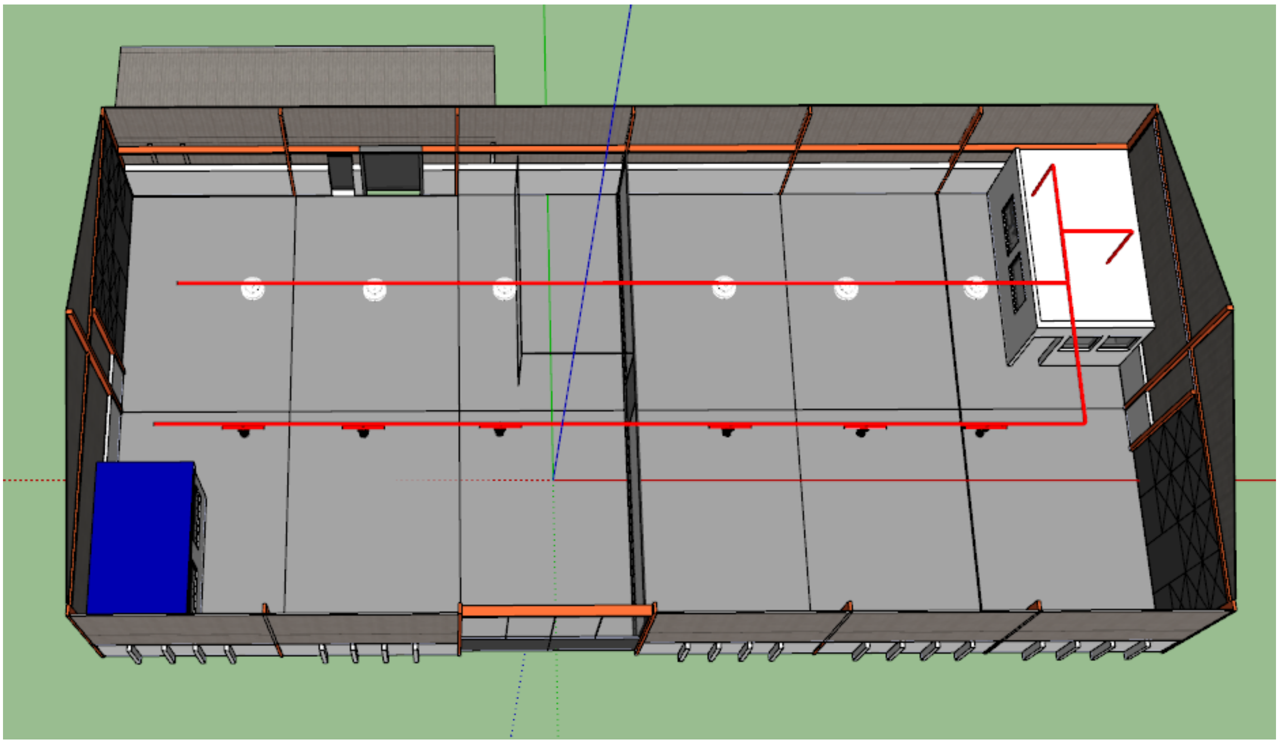
Table 3 Sprinkler System Calculation

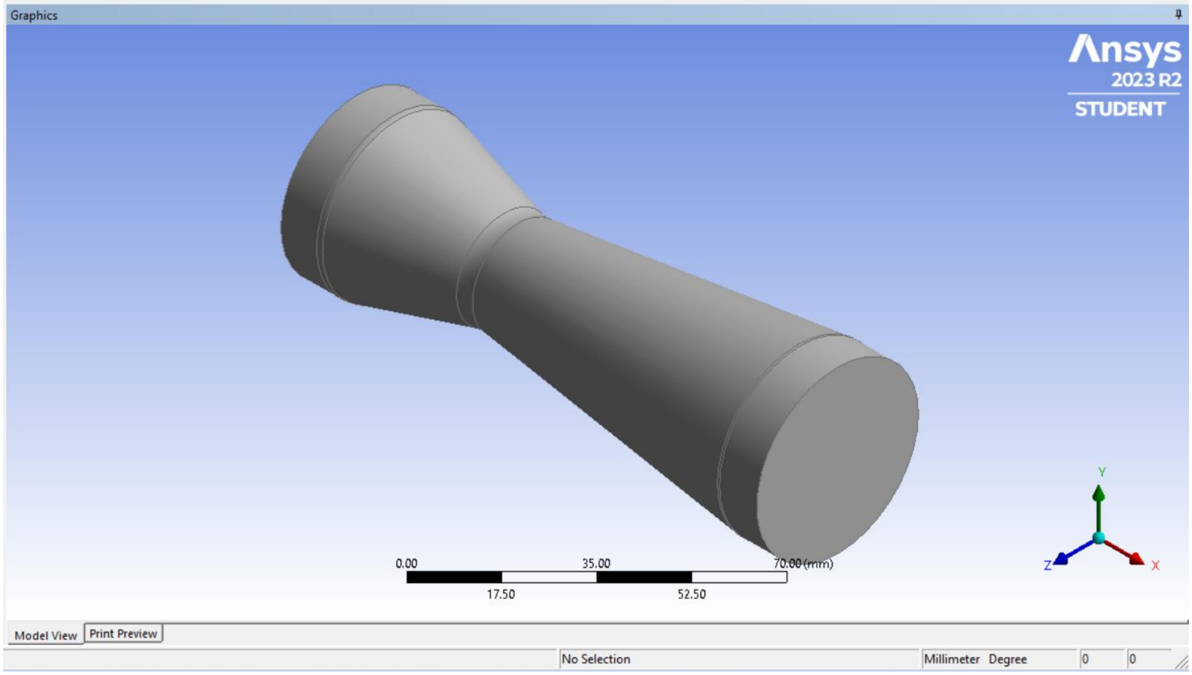


Sprinkler System Calculation														
Flow Rate			Pipe Size (in)	Pipe Fittings Summary	Equivalent Pipe Length			Pressure Loss		Presure Summary	Required Pressure			Q = Area x Density Q = 155 x 0.3= 46.5 GPM K = 5.3 C = 120
Summary	GPM	LPM			Summary	ft	m	(Psi/ft)	(bar/m)		PSI	Bar		
q	46.5	176.0	Nominal dia = 1 Actual ID = 1.049	N/A	Straight Pipe	11.40	3.47	0.435	0.098	Pt	76.96	5.30		Pt = (Q/K)^2
Q	46.5	176.0			Fittings	0.00	0.00			Pe	0.00	0.00		Pt = (46.5/5.3)^2
					Total equiv length	11.40	3.47			Pf	4.96	0.34		Pt = 76.96 psi = 5.30 bar

The table provides a comprehensive overview of a sprinkler system's critical parameters, aiding in its design and performance evaluation. It includes details for multiple sprinkler types within the system. The "Flow Rate" column specifies the gallons of water released per minute and liter per minute by each sprinkler when activated, and "Pipe Size" indicates the pipe nominal diameter supplying water to the sprinkler at the same time the actual inside diameter. "Pipe Length" represents the length of pipe from the water source to the sprinkler, influencing friction losses. "Pressure Loss" denotes the pressure drop per 100 feet of pipe, influenced by pipe size, flow rate, and material which is the galvanized steel. The "Required Pressure" column lists the minimum source pressure necessary for effective sprinkler operation, factoring in pressure losses. Designers refer to this table to select appropriate pipe sizes, layouts, and pressure sources to ensure the system meets safety standards and performance criteria.

Design figure





IV. RESULTS AND DISCUSSION

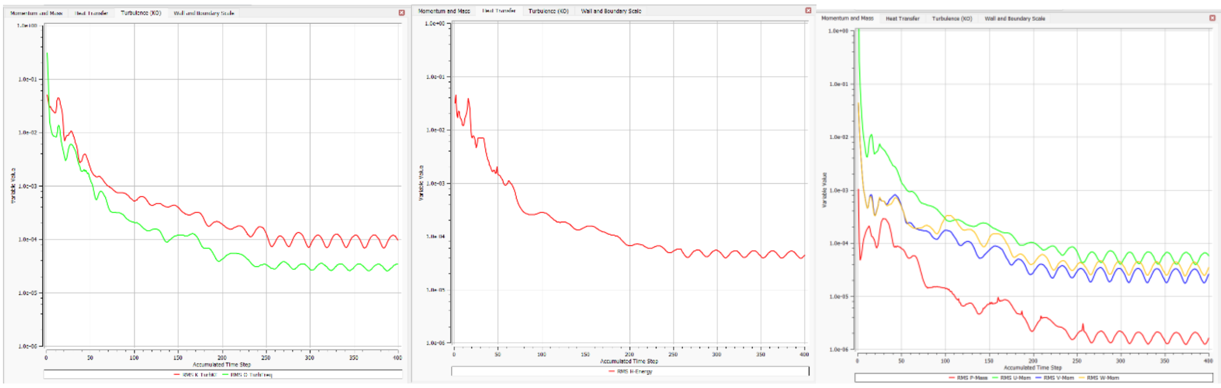
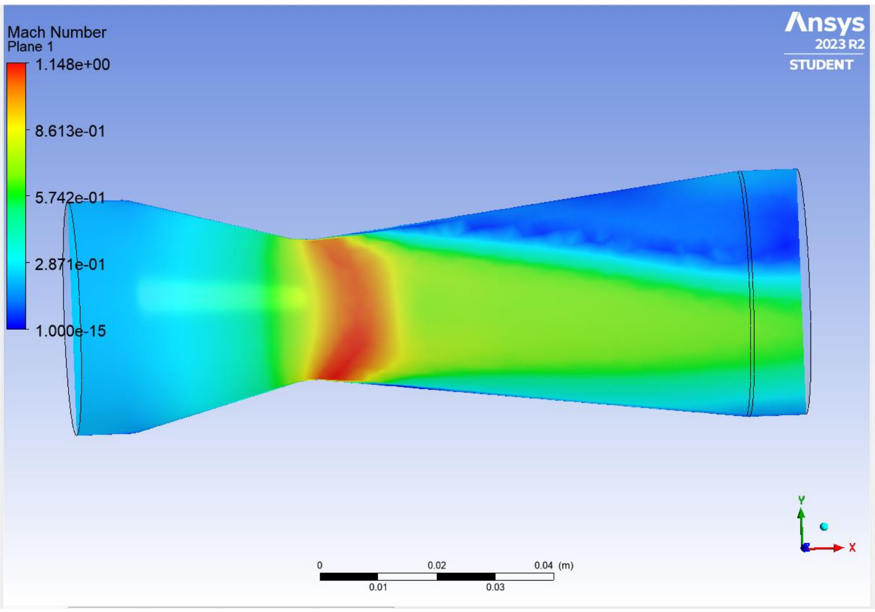


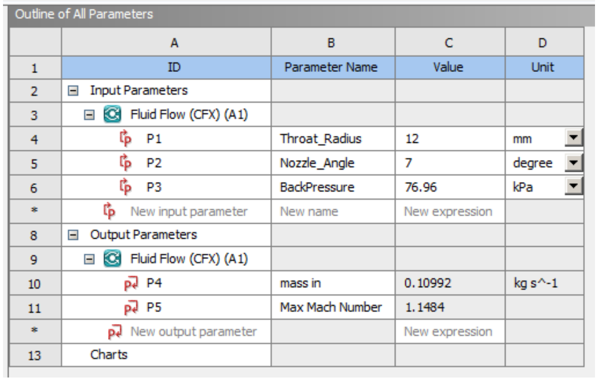
Figure 3 Diagram presenting the Momentum and Mass, Heat Transfer and Turbulence of the flow



In the context of a sprinkler system, the ANSYS CFX simulation results indicating a nozzle flow with a back pressure of 76.96 kPa and a Mach number of 1.14838 hold significant implications. The Mach number exceeding 1.0 reveals that the flow within the nozzle is operating at supersonic speeds, which is rather unusual for typical sprinkler systems. Supersonic flows are characterized by the generation of shock waves and complex compressible flow patterns, which could have a notable impact on the system's performance.

In a sprinkler system, the primary objective is to deliver a controlled and uniform discharge of water or fire-suppressing agent to extinguish or control fires effectively. The presence of supersonic flow conditions might result in an erratic and turbulent discharge pattern, potentially affecting the system's ability to distribute the extinguishing agent uniformly across the protected area. Moreover, the shock waves generated within the nozzle could lead to pressure fluctuations that may impact the reliability and stability of the sprinkler system.

To ensure the optimal functionality of a sprinkler system, it is crucial to tailor the nozzle design and operating conditions to subsonic flow regimes, which are more typical for these applications. Further analysis and modifications may be necessary to adapt the nozzle configuration and flow parameters to ensure efficient fire suppression while avoiding the complexities associated with supersonic flows.



Outline of All Parameters

	A	B	C	D
1	ID	Parameter Name	Value	Unit
2	Input Parameters			
3	Fluid Flow (CFX) (A1)			
4	P1	Throat_Radius	12	mm
5	P2	Nozzle_Angle	7	degree
6	P3	BackPressure	76.96	kPa
*	New input parameter	New name	New expression	
8	Output Parameters			
9	Fluid Flow (CFX) (A1)			
10	P4	mass in	0.10992	kg s^-1
11	P5	Max Mach Number	1.1484	
*	New output parameter		New expression	
13	Charts			

In the ANSYS CFX simulation of nozzle flow, several key input parameters were considered. These included a throat radius of 12 mm, defining the narrowest point of the nozzle, and a nozzle angle of 7 degrees, which determined the geometric shape of the nozzle. Additionally, a back pressure of 76.96 kPa was applied at the exit of the nozzle, influencing the flow behavior downstream. The simulation yielded insightful results, with a calculated mass flow rate of 0.10992 kg per second. This parameter is crucial in understanding the rate at which mass is transported through the nozzle. Moreover, the simulation revealed a maximum Mach number of 1.1484, signifying that the flow within the nozzle reached supersonic speeds. Such supersonic flow conditions are associated with complex phenomena, including shock waves and high-speed fluid dynamics, making this simulation valuable for applications in aerospace and other fields where precise control of supersonic flows is essential.

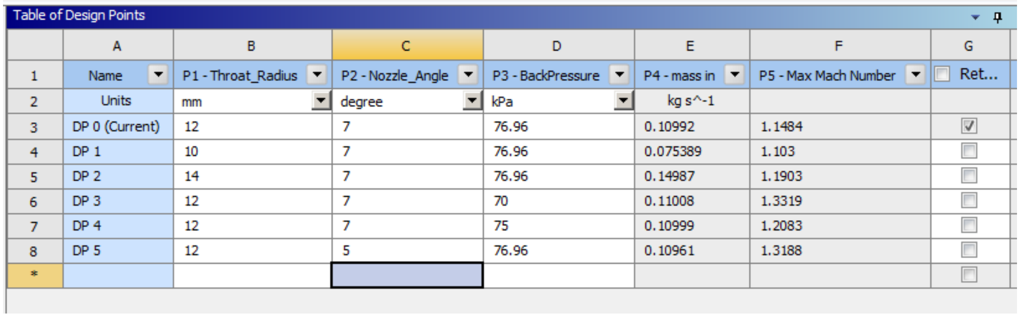


Table of Design Points

	A	B	C	D	E	F	G
1	Name	P1 - Throat_Radius	P2 - Nozzle_Angle	P3 - BackPressure	P4 - mass in	P5 - Max Mach Number	☐ Ret...
2	Units	mm	degree	kPa	kg s^-1		
3	DP 0 (Current)	12	7	76.96	0.10992	1.1484	☑
4	DP 1	10	7	76.96	0.075389	1.103	☐
5	DP 2	14	7	76.96	0.14987	1.1903	☐
6	DP 3	12	7	70	0.11008	1.3319	☐
7	DP 4	12	7	75	0.10999	1.2083	☐
8	DP 5	12	5	76.96	0.10961	1.3188	☐
*							☐

In the Design Points table, we have the flexibility to input alternative values for the parameters. When we adjust the throat radius to 10 mm and 14 mm, the software can automatically compute corresponding values for both the mass flow rate and the maximum Mach number. Similarly, by modifying the back pressure to 70 kPa and 75 kPa, as well as altering the nozzle angle to 5 degrees, we can utilize the software to generate data for these parameters. This versatile feature allows us to explore a range of design scenarios and assess how changes in these input parameters impact critical flow characteristics and performance metrics. By doing so, we can automate the process of carrying out several analyses without having to create additional cases.

V. CONCLUSION

The findings of this study offer valuable insights into the design, optimization, and operational strategies of FGDS, enabling industrial facilities to enhance their safety measures. Through dynamic simulations, the effectiveness of different sensor placements, response times, and alarm triggers can be assessed, contributing to more robust safety protocols and improved incident management. Ultimately, this research contributes to the advancement of industrial plant safety practices by facilitating a better understanding of FGDS performance in real-world scenarios. Moreover, this parametric CFD analysis contributes to the broader field of fluid dynamics by offering a detailed examination of nozzle flows and their potential applications across various industries.

VI. RECOMMENDATION

It is important to note that the behavior and performance of supersonic flows are highly dependent on the specific geometry, boundary conditions, and other factors in the simulation. Detailed analysis of the results, including the pressure, temperature, and velocity distribution within the nozzle, is typically necessary to fully understand the flow characteristics and their implications for the design or application.

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