Bulletin of Electrical Engineering and Informatics
Vol. 12, No. 4, August 2023, pp. 2105~2116
ISSN: 2302-9285, DOI: 10.11591/eei.v12i4.4790

Modeling and simulation of a pipeline leak detection using smart inspection ball

Marwa H. Abed, Wasan A. Wali, Musaab Alaziz
Department of Computer Engineering, College of Engineering, University of Basrah, Basrah, Iraq

Article Info

Article history:

Received Sep 14, 2022
Revised Oct 16, 2022
Accepted Dec 5, 2022

Keywords:

Computational fluid dynamics
Fluid flow
Heat transfer
Leakage
Pipeline

ABSTRACT

Recently, pipelines have replaced more carbon-intensive transportation methods making them more environmentally friendly for transporting energy and water supplies. However, pipelines can pollute the air, water, soil, and climate when they leak, causing economic, and environmental damage. Pipeline online monitoring provides data analysis and suitable controlling strategies to contain the risk. This paper proposes a three-dimensional numerical model simulation taking advantage of the fluids moving through pipelines at specific speeds. The transport speeds depend on many conditions, such as pipe diameter, the pressure through which the fluid is being transported, and other factors, such as terrain's topography and viscosity of the fluid. Under these conditions, the inspection approach uses a self-charging movable ball. The sensors inside the ball capture data as it travels through the pipe. The simulation focuses on spherical flow and pipe noise with and without leakage based on the COMSOL software platform. The paper shows the effect of several parameters, including leak location, sensor placement, ball diameter, sound pressure level propagation along a pipe and around the sphere, velocity, and temperature distribution that give the background for future smart ball design in a promising practical pipeline test project.

Corresponding Author:

Marwa H. Abed
Department of Computer Engineering, College of Engineering, University of Basrah
Basrah, Iraq
Email: engpg.marwa.abd@uobasrah.edu.iq

1. INTRODUCTION

The World Energy Report 2020 indicates that using natural fluids and fossil fuels for energy production accounts for thirty percent of the world's demand [1]. The rapid growth of the world's population as well as the acceleration of industrialization, have led to a rise in the use of fossil fuels such as petroleum and natural gas [2]. Transporting fuels, such as the delivery of fuels via fluid pipelines, is an example of an essential component of the energy supply that must be considered. The pipes are exposed to many factors, including flow stress, neighborhood circumstances, and sound pressure [3]. In addition to this, the difficult conditions of real-time operations, such as those that take place in the marine environment while it is under the pressure of the seas, in remote regions of deserts, and underground, where they are exposed to the soil stress force, lead to an enormous amount of environmental pollution [4]. Another factor that contributes to the ease with which pipelines might be damaged is the unstable operation of the flow of fluid [5]. The major challenge is discovering leaks due to physical deterioration and the advanced age of pipelines [6]. The issue has been going unnoticed while steadily deteriorating for a considerable time. The alteration in the fluid flow pattern is the tried-and-true approach for detecting leaks [7]. Because of the leakage, there may be an abrupt shift in pressure across the free stream, which will skew the flow [8]. The varying flow may be employed in conjunction with an appropriate sensor to produce vibration; the vibration is consistent over the whole length of the pipe, but the leakage point has a non-uniform behavior [8], [9]. The flow distortion can be altered by manipulating many parameters, including the flow rate, the location of the leakage point, the temperature caused by the leakage, the distance between the leakage point and the detected ball, the diameter of the detected ball, and the type of fluid that is being used [10].

Researchers at academic institutions and professionals in private business have effectively produced a variety of distinct detection techniques. Hearing systems are one of the oldest detection methods, and they use changes in the sound quality and loudness that leakage noise from equipment makes as clues to discover leaks [11], [12]. Hearing systems have been around for a long time. The use of ground-penetrating radar is one method that might be helpful in locating pipeline leaks. This method works by locating holes in the ground responsible for the leak. Because the geological composition of different areas changes, this difficult tactic results in unreasonable prices [13], [14]. Numerous techniques, such as the pressure gradient technique, the wave method of negative pressure, and the balancing method of the flow rate, have been created by researchers to locate comparable leaks [15]–[17]. Although sensitive to the pressure and flow rate, these approaches tend to yield false positive findings if there is a significant variation in the flow rate. This is because the flow rates of pipes are constantly shifting, which is the root of the problem. The frequency of a pipeline's vibrations was discovered to correlate with the state of leaking that the pipeline was in [18] and this frequency was found to be concentrated in the spectrum of leakage signals [18].

Recently, the identification of pipes has been feasible via the use of a method based on the propagation of acoustic waves through the finite element method (FEM) application. It is possible to simulate fluid flow via pipes if one considers the flow profile as a boundary condition. Utilizing several kinds of software on a computer might do this. If the acoustic wave equations being solved are linear, then the FEM will offer one set of answers; however, if the equations are non-linear, the FEM will provide a different set of solutions. It is possible to characterize the fluid-structure interaction by employing a symmetric matrix formulation [19], which is used in various acoustic computation approaches [19]. Gowini and Moussa [20] constructed and tested a finite element model of a surface acoustic wave sensor for hydrogen detection using the ANSYS simulation tool. It was discovered that the fluid density effect on acoustic behavior is obtained momentum of a wave is reduced by increasing H_2 concentration. Kagawa *et al.* [21] provided yet another numerical FEM technique for predicting the non-linear propagation of acoustic waves; the acoustic sound position changing affected the pressure behavior, resulting in an unexpected pressure distribution across the free stream. It was shown that pressure has little effect on the density of the fluid. To phrase it another way, the fluctuation in pressure indicates a non-uniform distribution of fluid density across the channel.

An improved FEM approach was created by [22], and it was based on a modified wave equation. They contrasted it with other methodologies, such as the Holtz-Kirchhoff integral and the ray-tracing technique, and found that it was superior. They discretized the equations and then used a method known as the FEM to solve them. This allowed them to solve the integral equation scheme about time. The discretization error is more obvious for secondary waves, despite the fact that the equations are not incorrect. Tikka *et al.* [23] introduced a finite element (FE) numerical methodology as a method to simulate a three-dimensional acoustic wave correlator. The variations in the system's electrical response as well as the responses of the devices to the different acoustic modes were presented and explained in this article. As a consequence of this finding, they came to the conclusion that FEM is a useful method for examining how well the correlator responds to different modes of propagation. FEM was used in designing and simulating the surface acoustic wave sensor that developed [24]. Kutiš *et al.* [24] used transient piezoelectric analysis to find out the system's eigenmodes and frequencies to investigate the system's harmonic wave propagation characteristics. Because of this, they could investigate the characteristics of the propagation of harmonic waves. Yu and Yan [25] conducted a computer analysis of the wave propagation behavior in wood poles by using a technique known as the FEM. They observed that a hardwood pole with a stronger longitudinal elastic modulus always showed more directed wave behavior, and they empirically demonstrated that their findings were correct. In other words, if you use a hardwood pole, you should anticipate a more directed behavior from the waves. Several research has been conducted to determine the computational effectiveness and validity of the standard FEM technique. Owowo and Oyadiji [26] used the FEM approach in combination with experimental testing to explore the influence that leakage has on the transmission of acoustic waves via an air-filled conduit. The time-of-flight approach was used to locate and precisely localize the leakage in consideration of the projected and observed data. In addition, the motion of acoustic waves was statistically predicted using a wide variety of other methods. Some examples of these types of models are the spectral phase averaged wave model that was created by simulating waves nearshore (SWAN), the boundary element method (BEM), and the statistical energy analysis (SEM). Chen *et al.* [27] investigated the acoustic fluid-structure interaction in a laboratory setting using FEM-BEM. For the simulation of the fluid-structure interaction that was carried out, a method based on FEM-BEM was utilized as the modeling methodology. We employed the Cauchy principal value approach in conjunction with the Hadamard finite part-integral method in order to solve integral boundary equations. This combination of methods resulted in an improvement in the accuracy of the equations. Weryk *et al.* [28] studied ship designs and analyzed such structures using SEM to understand better the mechanism of acoustic wave propagation. The findings of experiments conducted on ships with comparable features were analyzed and compared to the results that had been projected for those ships. Rusu [29] investigated the wave energy propagation patterns in the western portion of the black sea using the SWAN spectral phase averaged wave model. The most current research results indicate that black sea waves move over the surface of the water at a faster rate. Recently, in experimental research, an investigation was conducted regarding commercial accelerometers and associated signal circumstances for acoustic wave analysis in a pipe [30]. According to the experiments, attenuation was found to have the most significant effect on the propagation of the acoustic waves that are utilized for impact detection. Odya *et al.* [31] investigated the movement of sound waves through organ pipes using a method that evaluated the intensity of the sound. Previous researchers collected the sound intensity distributions everywhere around the pipes and illustrated how acoustic energy was traveling. This was done in order to understand the phenomenon better. One of the approaches used in locating flaws in pipes in the time domain was the acoustics pulse reflectometer method. The influence of acoustic energy, smart ball location, fluid type, and ball metal type was investigated by [3] as it relates to the propagation of acoustic leakage. They discovered that the values of certain factors affected the way waves propagated. The behavior of the smart ball for leakage detection is mostly dependent on the momentum-wave propagation interference, which makes sensitive leakage detection possible.

This study develops a method to estimate leak location and rate by developing a model to simulate leak detection in the oil transmission pipeline using a mobile ball that detects leaks inside pipelines using acoustic signals. The paper develops a model to simulate leak detection in the pipeline using a mobile ball. The velocity and pressure profiles will be used to calibrate the control system inside the ball. They will link to heat transfer to calculate the temperature found everywhere around the tubes and how it is transferred to the liquid. The control system establishes a connection between the levels of sound pressure and the detection of leaks. It considers the disturbances brought about by the fluid flow around the ball.

2. COMSOL MULTIPHYSICS

In order to simulate the activities of the moveable ball with sensors that go through the pipeline and collect various parameters to find leaks in the oil/water pipelines, the COMSOL multiphysics software is used. COMSOL multiphysics is a tool for multiphase simulation that also functions as a finite element analysis solver for several platforms. It offers conventional physics-based user interfaces in addition to the coupled partial differential equations systems (PDEs). In addition, it refers to the activity of managing many interconnected projects that are intended to improve the performance of a company. It is often intertwined with industrial engineering, validation sciences, and systems engineering. COMSOL is responsible for monitoring a program's objectives and the current status of all projects within that program. They use this monitoring to support activity at the project level to ensure that program goals are met by providing decision-making capacity that is not possible at the project level. This may be accomplished by acting as a sounding board for the project manager's ideas and methods of problem-solving or by giving the project manager a program perspective when required. Even if a specific function would be necessary for large and intricate projects, COMSOL is in a good position to provide this insight since it actively seeks such information from project managers. Among the COMSOL modules are categories for electrical, mechanical, fluid, chemical, multipurpose, and interface applications. These categories are based on the application areas that may be solved using the software. Each individual simulation included inside the COMSOL multiply program can connect with and interact with other simulations. This appalling circumstance faithfully depicts what takes on in the real world [32]. The current COMSOL multiphysics application, version 5.6, includes tools for addressing fluid, thermal, and mechanical issues. In COMSOL multiphysics, the model builder is a tree system model. The following elements make up the majority of the COMSOL tree [3]:

a. Geometry builder: using a graphic interface where the geometry of solid work is imported.
b. Material specification: this item is used to change the physical characteristics of materials in the COMSOL database or to create new blank properties as new materials.
c. Physics selection: this item selects the physics to apply the conservation equations and their coupling and governing. The boundary condition is required by physics to arrive at the ultimate solution.
d. Mesh generator: in COMSOL, the mesh is automatically created based on physics and geometry. The mesh size may be adjusted by selecting one of the mesh modes: standard, coarse, coarser, very coarse, fine, finer, or extremely fine.
e. Study: this option allows you to choose whether the model-solving study is stable (steady state) or time-dependent (unsteady state).

COMSOL multiphysics was used to build the pipeline form of this autonomous ball, which represents a novel design in mobile inspection equipment. The ball itself is a revolutionary design. The COMSOL computational fluid dynamics (CFD) module was then used to model the velocity and pressure propagation around the ball placed inside the pipeline. It was connected to a heat transfer to compute the temperature around the pipes. Then it was transferred to the fluid in two different scenarios: i) the continuous flow of fluid through the pipeline with no leaks and ii) the fluid flow in the pipeline is caused by a leak along with the ball. The CFD module is used to compute the velocity and pressure profiles located in the vicinity of the moving ball and the temperature, thanks to the heat transfer. The next step is to use the acoustics and vibrations module to simulate the spread of noise created when a leak occurs.

3. NUMERICAL PIPELINE MODE

To simulate the fluid flow around the ball, a section of a typical cylindrical pipeline model was developed having a 10-inch pipe length of 12 m, as shown in Figure 1. Oil was used as the fluid flow, which was given an initial inlet of three velocities of 0.1, 1, and 2.5 m/s, respectively. The ball has 3, 4, and 6 inches, respectively. Figure 2 shows the mesh distribution of the proposed system. The present problem is solved by utilizing the 96,245 mesh elements, which are tetrahedral. The simulation generates 96,245 algebraic square matrices from the atrial differential equations, which are solved using numerical methods such as Jacobean.

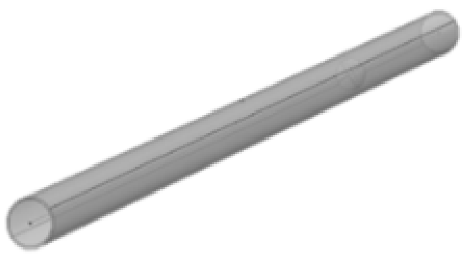


Figure 1. The geometrical view spherical present ball inside the pipe

Figure 2. Mesh distribution of the system

3.1. Physics model

The model under study consists of a fluid flow around a stationary spherical ball placed inside a pipeline and the sound propagation generated from an induced leak. To accurately understand the collected results, multiphysics was made in the model design [3], [21]:

- The use of single-phase laminar flow

$$\frac{\partial\rho}{\partial t} = -\nabla.(\rho U) \quad (1)$$

$$\rho\left[\frac{\partial U}{\partial t} + (U.\nabla)U\right] = \nabla\left(\mu(\nabla U + (\nabla U)^T)\right) + \rho g + F \quad (2)$$

Where μ is dynamic viscosity, ρ is density, U is used velocity, and F is applied momentum force due to pressure sound in specified point. The (1) consists of the conservation of control volume mass with inflow and outflow transported mass. Navier Stoke in (2) refers to the equality of inertia term to the sum of viscous force, gravity force, and volume force due to the acoustic action.

- The inclusion of heat transfer in fluids, the heat equation refers to the equality of convective terms plus body energy and conductive term plus heat due to acoustic action.

$$\rho Cp\frac{\partial T}{\partial t} + \rho CpU.\nabla T = \nabla(-k\nabla T) + Q \quad (3)$$

Where Cp is heat capacity, K is thermal conductivity, and T is temperature, Q is generated heat due to leakage.

- The addition of the acoustic diffusion equation

$$\nabla.(-D_t \nabla w) = q(x) \quad (4)$$

Where Dt is acoustic diffusion, w is sound power, and q is the sound power source. The acoustic equation refers to the equality of acoustic force and acoustic source energy due to leakage action.

3.2. Initial and boundary conditions

In order to calculate the velocity and pressure of a laminar flow, the starting condition requires that v=0 meters per second and p=0 pascals. If there is a leak, the inlet, outlet, wall, and pressure point limitations are considered boundary conditions. The beginning condition for heat transfer is 293.15 degrees Kelvin. Other conditions included in physics include boundary conditions such as fluid, thermal insulation, solid domain heat transfer, inflow, outflow, heat flux, and point heat source. The starting value for the sound energy density must equal zero joules per meter^3 for acoustic diffusion to begin. The leaking action at the designated place produces a sound power point, which serves as the boundary condition. The viscosity and pressure of the fluid flow are calculated using the reference temperature of 293 Kelvin, and the density distribution within the pipe is calculated using the pressure. Both of these calculations require the temperature as a reference. First, the fluid flow, also known as momentum transfer, is solved using the mean on the Navier Stoke equation [10], which is then followed by the development of the velocity profile. In order to solve the equation for heat transfer with the equation for momentum transport, the thermal physical parameters, which include thermal conductivity and heat capacity, are first established by reference temperature. After then, a calm predominance of the temperature distribution emerged. The loop of the trial and error approach is repeated based on the first stage, which involves placing the new temperature distribution rather than a reference temperature, and so on. The increased temperature will change the distribution of physical attributes and velocities; the cycle will be repeated step by step until the error rate in the residence time reaches 0.1% or less. Figure 3 presents the method for your perusal. The heat transfer and the acoustic pressure point contribute to the non-uniform distribution created throughout the free stream. The acoustic pressure point is an extra energy source inside the momentum force.

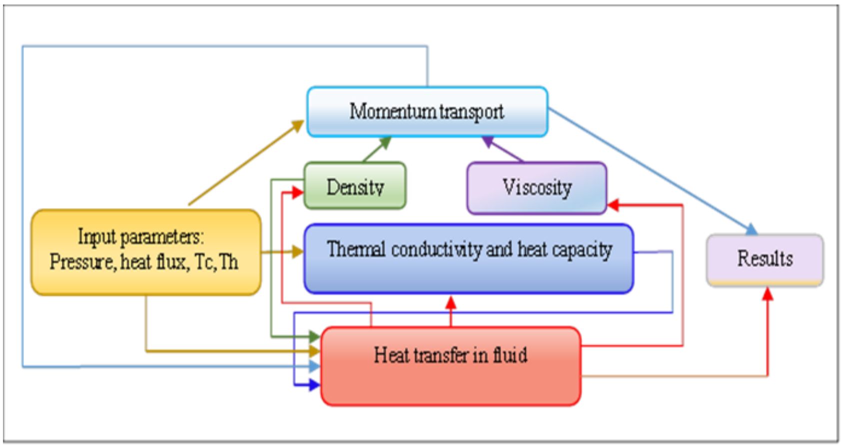
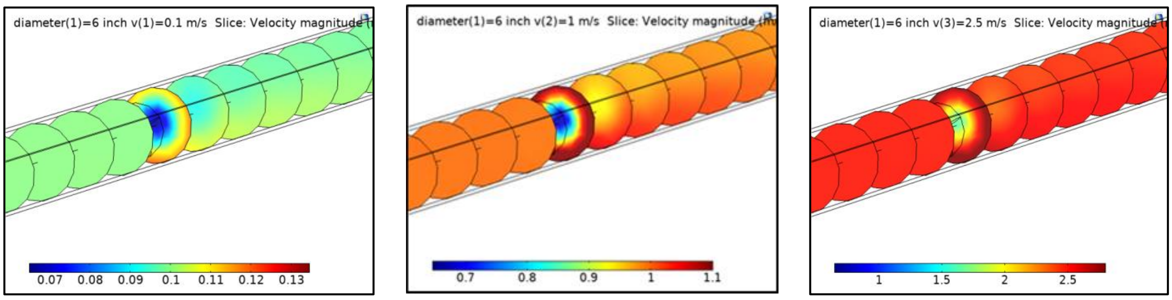


Figure 3. The algorithm steps of solving the current model

4. SIMULATION RESULTS

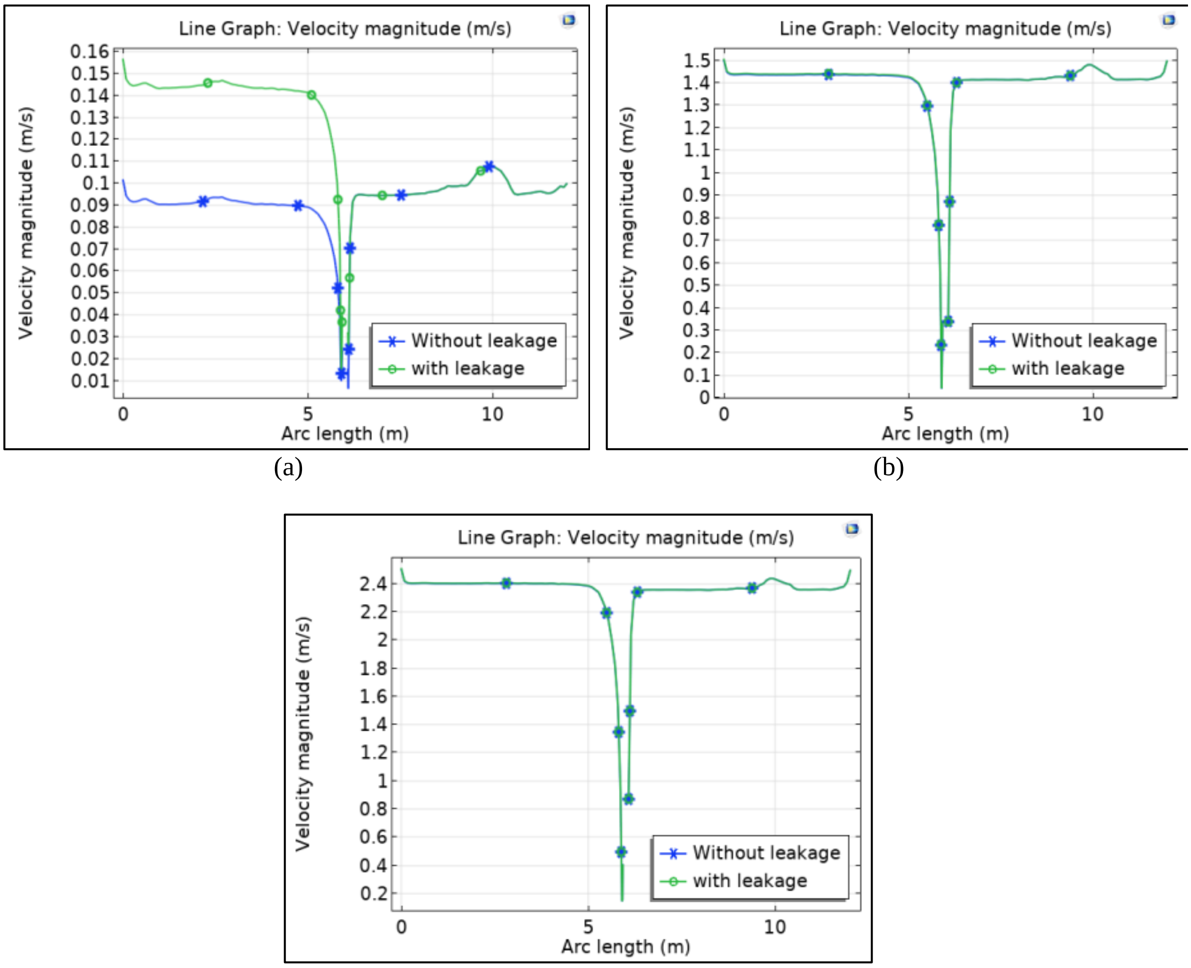
4.1. Velocity

This simulation used the CFD module. Figures 4(a)-(c) show the velocity profile of the fluid flowing inside the pipe with the leak for various flow velocities. The simulation shows how the velocity magnitude of the fluid inside the pipe changes. The behavior of the presence detection ball shows variation in momentum changes, the velocity difference between the ball center and maximum velocity stream increment increasing linearly by increasing inlet flow velocity (0.16, 1.5, and 2.5 m/s for inlet velocities 0.1, 1, 2.5 m/s correspondingly). The momentum changes happen due to the pressure instruction making sudden pressure drop through the presence of solid boundary with relative vortex generating existence. The velocity on the solid surface is converted into pressure force by means of the friction factor generated by the solid surface within the pores and the outer side. Figures 5(a)-(c) show the velocity distribution of various inlet velocities with leaks and without leaks. The free stream momentum behavior interacts with the solid ball domain significantly at low inlet velocity (0.1 m/s). The fluctuation between the two cases in higher velocities has no impact on utilizing leakage presence. The viscous boundary layer at lower velocities presents significantly more than the higher values of inlet velocities. The friction factor is maximum in the free stream. The leakage presence in all velocities improves the velocity distribution by 0.03 m/s. The leakage presence causes additional eddies inside the hole pipes points because of the pressure difference between the leakage point and the free stream, which makes this effect significant.



(a) (b) (c)

Figure 4. Fluid velocity distribution around the ball with leakage at velocity (a) U=0.1 m/s, (b) U=1 m/s, and (c) U=2.5 m/s



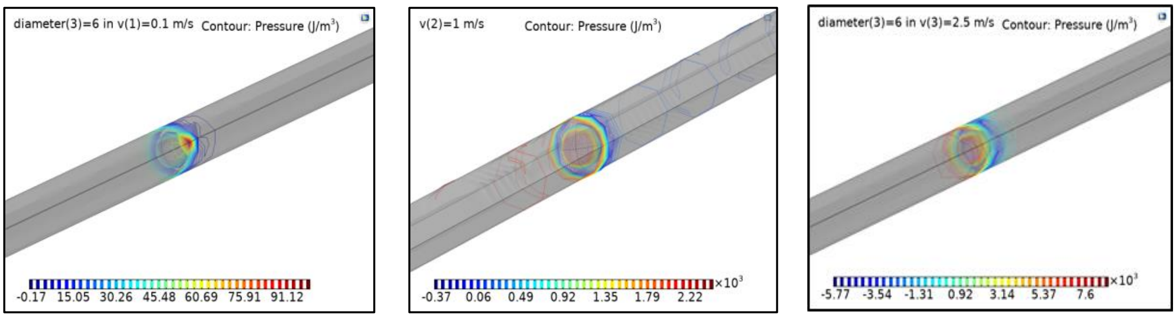
(a) (b)

(c)

Figure 5. Distribution velocity in three inlet velocities in both cases: with leakage and without leakage (a) U=0.1 m/s, (b) U=1 m/s, and (c) U=2.5 m/s

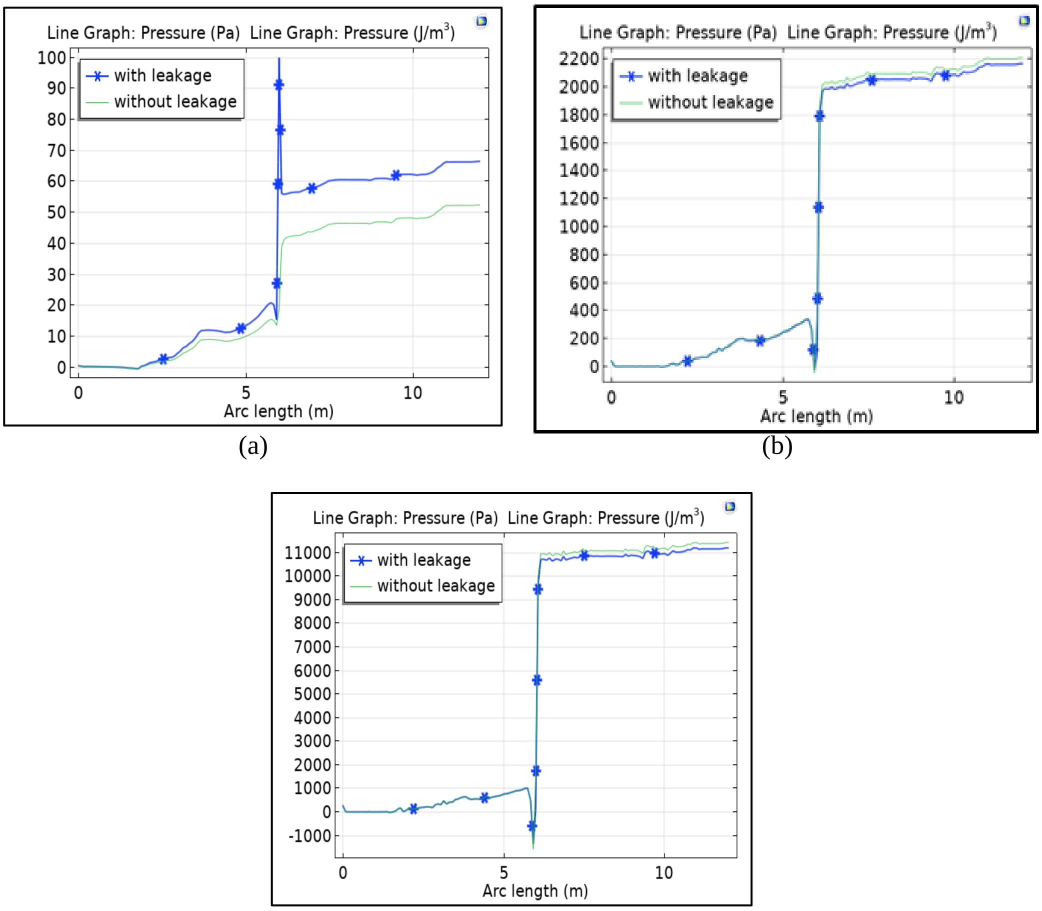
4.2. Pressure

Figures 6(a)-(c) show the pressure distribution on the ball wall for various inlet velocities. The pressure difference between the forward and backward ball faces increases by increasing inlet velocity. The solid wall of exterior ball faces and solid boundary inside ball pores convert the velocity momentum force into pressure force in the forward face and vice versa for backward force. The leakage case promotes a higher pressure drop than the without leakage case; the difference is significantly shown at lower inlet velocity, and the leakage presence increases the pressure distribution of about 11 Pa for whole velocities at the ball domain, making a significant effect shown at lower inlet velocities. This behavior leads to understanding the fact of leakage sensitivity at various values of velocities, as shown in Figures 7(a)-(c).



(a) (b) (c)

Figure 6. Distribution of pressure in various velocities (a) U=0.1 m/s, (b) U=1 m/s, and (c) U=2.5 m/s



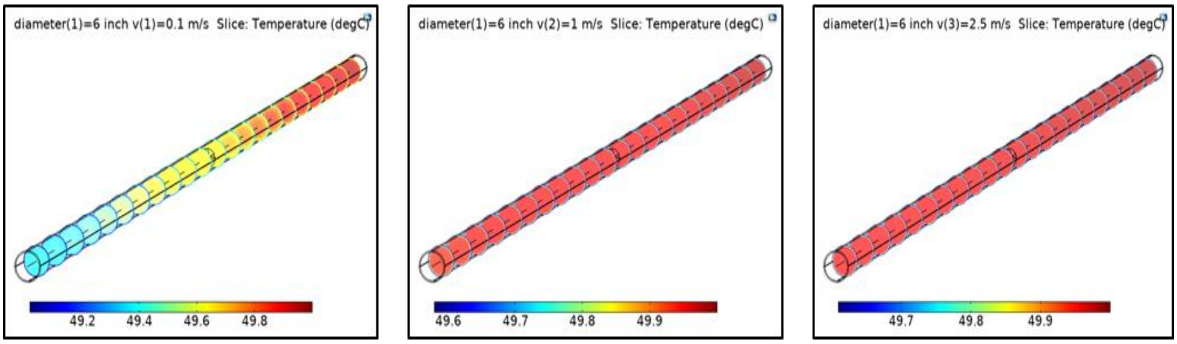
(a) (b)

(c)

Figure 7. Line graph of the pressure distribution in case of leakage and without leakage at three velocities (a) U=0.1 m/s, (b) U=1 m/s, and (c) U=2.5 m/s

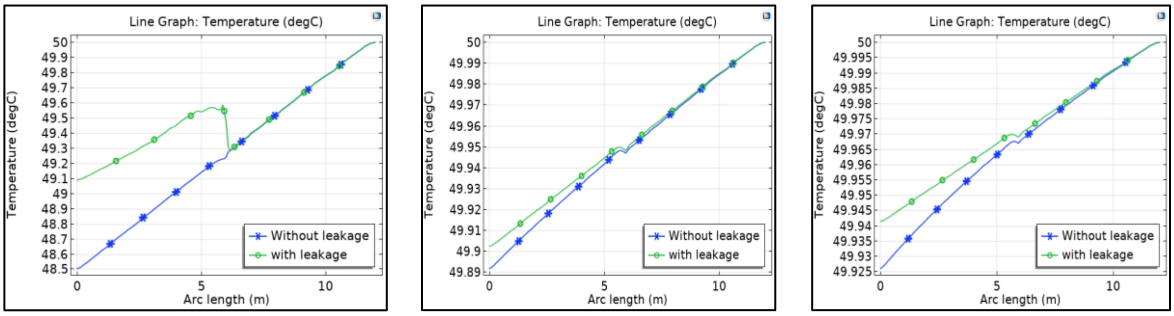
4.3. Temperature

Figures 8(a)-(c) show the temperature distribution for various velocity values. The minimum velocity (0.1 m/s) shows the larger temperature difference, and the slow flow promotes higher contact time with the leakage point making a hot spot in the ball region (detection region). The hot spot is generated due to the pressure difference due to the thermodynamic issue. Figures 9(a)-(c) show the temperature distribution for various velocity values at leakage and without leakage—the temperature increases by 0.05 k for the whole pipe points and velocities at 0.1 m/s inlet velocity. However, the temperature distribution of higher velocities can be neglected. The temperature of the leakage case at a lower velocity happens due to the conversion of the viscous dissipation rate of energy into temperature energy through friction action.



(a) (b) (c)

Figure 8. Temperature distribution of various inlet velocities (a) U=0.1 m/s, (b) U=1 m/s, and (c) U=2.5 m/s

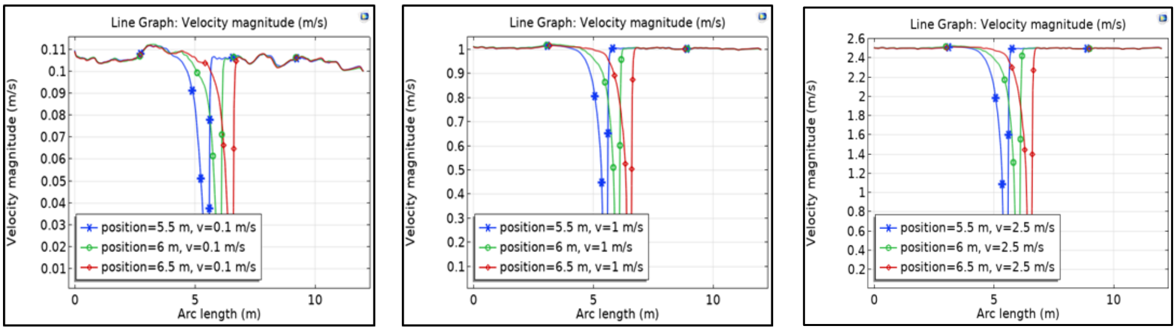


(a) (b) (c)

Figure 9. Line graph of heat transfer distribution in fluid in case of leakage and without leakage at three velocities (a) U=0.1 m/s, (b) U=1 m/s, and (c) U=2.5 m/s

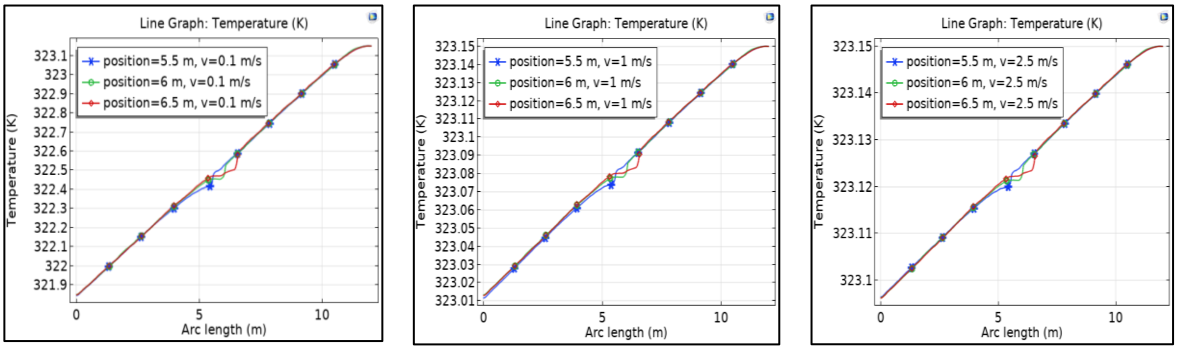
4.4. Effects of ball's position and its diameter

Figures 10(a)-(c) show the velocity distribution for various inlet velocity values at different ball positions. The ball position has no significant changes in momentum behavior; the ball presence gives the same behavior at any point at velocity action for free stream. For the fluid–adjacent ball region, the velocity value decreases with increasing distance from upstream (6.5 m higher than 6 m and 5.5 m), and the same response is observed on the ball existence side. The higher distance from the entrance point promotes the lower ball velocity distribution. Figures 11(a)-(c) provide the temperature distribution of various inlet velocity distributions and ball positions from the leakage point. The temperature is affected by the distance (ball position) at a lower velocity (0.1 m/s) higher than the other velocities. The higher velocities (1 and 2.5 m/s) neglect the effect of position in temperature distribution. The maximum temperature values are observed at 6 m, where the ball is in the leakage point. The minimum temperature value is at 5.5, where the minimum contact time is observed with a higher rate of eddies generation (the ball near the entrance can make vortices more than the near exit stream).



(a) (b) (c)

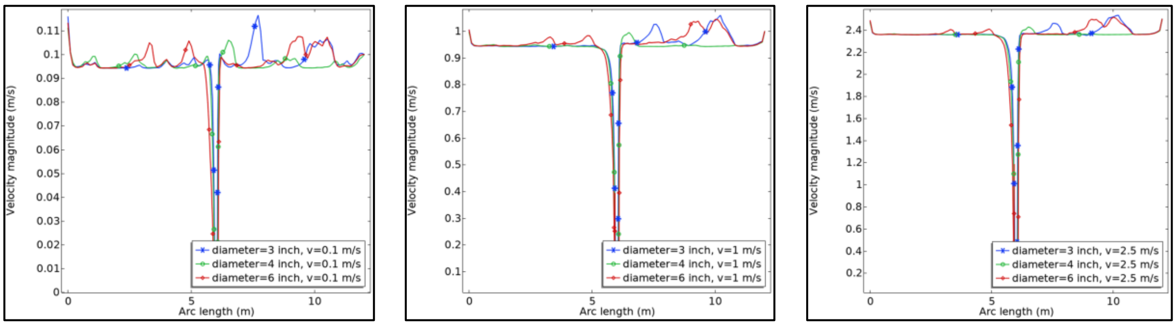
Figure 10. The velocity distribution for various velocities and ball positions (a) U=0.1 m/s, (b) U=1 m/s, and (c) U=2.5 m/s



(a) (b) (c)

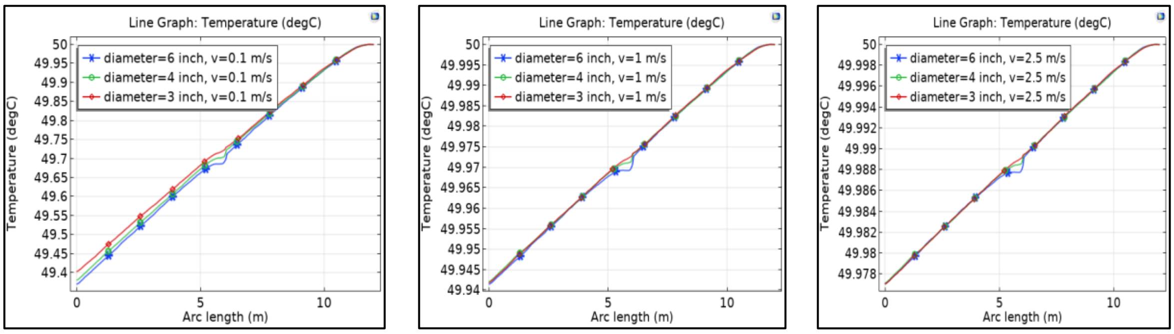
Figure 11. The temperature distribution for various velocities and ball positions (a) U=0.1 m/s, (b) U=1 m/s, and (c) U=2.5 m/s

Figures 12(a)-(c) develop the velocity distribution for various inlet velocities and ball diameters. The increasing ball diameter makes the minimum velocity values at the ball face in the entrance direction for higher velocities. The lower velocities promote irregular behavior for velocity distribution. The higher the velocities, the greater the momentum forces converted into pressure force insignificantly with velocity increasing. The viscous forces tend to increase pressure forces generation by making a viscous sub-layer around the ball. Figures 13(a)-(c) show the temperature distribution for various inlet velocities and ball diameters. The larger ball diameter develops the minimum temperature distribution; this effect increases by increasing the inlet velocity values. The increasing diameter results in less impact on leakage, and the heat generation due to the acoustic energy has a minimal effect when a larger ball is used.



(a) (b) (c)

Figure 12. Velocity distribution for various ball diameters and inlet velocities (a) U=0.1 m/s, (b) U=1 m/s, and (c) U=2.5 m/s



(a) (b) (c)

Figure 13. Temperature distribution for various ball diameters and inlet velocities (a) U=0.1 m/s, (b) U=1 m/s, and (c) U=2.5 m/s

4.5. Numerical simulation of sound pressure level propagation inside the pipeline

The choice of ball diameter is based on the vibrating action inside the pipe. Figure 14 shows sound flux and sound pressure for various ball diameters. The minim ball diameter vibrates significantly more than the other diameter. The smaller ball diameter can sense the small relative leakage; the smaller ball can generate more irregular flow than the larger size. Figure 15 shows the local sound flux for various sound flux point values. The maximum sound flux is observed here the 100 W/m^2 is applied in the ball region.

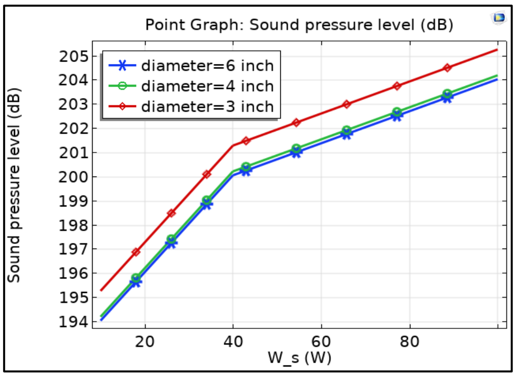


Figure 14. Pressure sound vs energy flux magnitude for various ball diameters

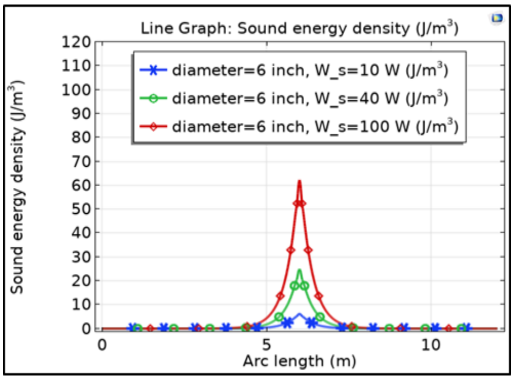


Figure 15. Location energy flux magnitude distribution for various point sound flux values at d=6 inch

5. CONCLUSION

The numerical investigation of velocity, pressure, and temperature distribution was successfully modeled for various velocities and leakage presence and absence cases. In the leakage phenomenon, lower velocities are essential in each case analyzed. At an intake flow rate of 0.1 m/s, it was noticed that the velocity, pressure, and temperature increments were all rising. The leakage does not considerably affect the higher velocities, and the variations can simply be ignored due to their insignificance. The ball with a diameter of three inches is more sensitive than balls of other diameters for detecting leakage, as shown by a greater vibrating propensity. The behavior of pressure, velocity, and temperature produced with the used ball can be optimally employed in developing the most precise detection for fuel pipelines. The values of the velocities on the ball faces are affected by the ball's position; the ball close to the exit direction has the lowest values near the solid ball domain. The increase in ball diameter causes a reduction in velocity. The maximum sound flux is observed here, as 100 W/m^2 is applied in the ball region, which promotes a higher tendency to detect leakage. The minimum ball diameter of 3 inches can significantly sense the small relative leakage. The smaller ball can generate more irregular flow than a larger volume and higher sound pressure values. The leakage case promotes a higher pressure drop than the without leakage case; the difference is significantly shown at lower inlet velocity, and the leakage presence increases the pressure distribution of about 11 Pa for whole velocities at the ball domain, making a significant effect shown at lower inlet velocities. The present work investigation provides accurate approximations of parametric analysis of leakage detection in oil and gas transportation systems; the developed data can be used to make high-quality monitoring systems. The limitation of the present work investigation must be taken into consideration to model the porous indication ball; the sound energy with momentum flow coupling has complex interaction, so it is not easy to model. The side wall gates of certain positions are used to introduce the detection ball; the longer pipes have difficulties in detection ball placement. So, we need gates between one distance and another.

REFERENCES

[1] J. Kim, M. Chae, J. Han, S. Park, and Y. Lee, "The development of leak detection model in subsea gas pipeline using machine learning," *Journal of Natural Gas Science and Engineering*, vol. 94, p. 104134, 2021, doi: 10.1016/j.jngse.2021.104134.

[2] W. A. Wali, "Carbon dioxide conversion control based on microwave plasma technology," in *2020 International Conference on Electrical, Communication, and Computer Engineering (ICECCE)*, 2020, pp. 1–4, doi: 10.1109/ICECCE49384.2020.9179393.

[3] W. R. Chalgham, A. C. Seibi, and M. Mokhtari, "Simulation of the flow of an autonomous spherical ball inside a pipeline," *COMSOL conference*, pp. 1–3, 2016.

[4] I. Barradas, L. E. Garza, R. M. -Menendez, and A. V. -Martínez, "Leaks detection in a pipeline using artificial neural networks," in *Progress in Pattern Recognition, Image Analysis, Computer Vision, and Applications*, Berlin, Heidelberg: Springer, 2009, pp. 637–644, doi: 10.1007/978-3-642-10268-4_75.

[5] J. P. Vítkovský, M. F. Lambert, A. R. Simpson, and J. A. Liggett, "Experimental observation and analysis of inverse transients for pipeline leak detection," *Journal of Water Resources Planning and Management*, vol. 133, no. 6, pp. 519–530, 2007, doi: 10.1061/(asce)0733-9496(2007)133:6(519).

[6] Y. Liu, X. Ma, Y. Li, Y. Tie, Y. Zhang, and J. Gao, "Water pipeline leakage detection based on machine learning and wireless sensor networks," *Sensors (Switzerland)*, vol. 19, no. 23, pp. 1–21, 2019, doi: 10.3390/s19235086.

[7] U. Baroudi, A. A. A. -Roubaiey, and A. Devendiran, "Pipeline leak detection systems and data fusion: a survey," *IEEE Access*, vol. 7, pp. 97426–97439, 2019, doi: 10.1109/ACCESS.2019.2928487.

[8] Y. Song and S. Li, "Gas leak detection in galvanised steel pipe with internal flow noise using convolutional neural network," *Process Safety and Environmental Protection*, vol. 146, pp. 736–744, 2021, doi: 10.1016/j.psep.2020.11.053.

[9] S. Ali, M. A. Hawwa, and U. Baroudi, "Effect of leak geometry on water characteristics inside pipes," *Sustainability*, vol. 14, no. 9, pp. 1–21, 2022, doi: 10.3390/su14095224.

[10] W. R. Chalgham, A. C. Seibi, and M. Mokhtari, "Simulation of sound wave propagation inside a spherical ball submerged in a pipeline," in *Proceedings of the 2016 COMSOL Conference in Boston*, 2016, pp. 1–7.

[11] M. Thompson, C. J. Chapman, S. D. Howison, and J. R. Ockendon, "Noise generation by water pipe leaks," in *Proceedings of the 40th European Study Group with Industry*, 2001, pp. 1–6.

[12] J. Yang, Y. Wen, and P. Li, "Leak acoustic detection in water distribution pipelines," in *Proceedings of the World Congress on Intelligent Control and Automation (WCICA)*, 2008, pp. 3057–3061, doi: 10.1109/WCICA.2008.4594487.

[13] J. A. Goulet, S. Coutu, and I. F. C. Smith, "Model falsification diagnosis and sensor placement for leak detection in pressurized pipe networks," *Advanced Engineering Informatics*, vol. 27, no. 2, pp. 261–269, 2013, doi: 10.1016/j.aei.2013.01.001.

[14] D. A. -Cabrera, M. Herrera, J. Izquierdo, S. J. O. -Levario, and R. P. -García, "GPR-based water leak models in water distribution systems," *Sensors*, vol. 13, no. 12, pp. 15912–15936, 2013, doi: 10.3390/s131215912.

[15] W. K. Muhlbauer, "Leak impact factor," in *Pipeline Risk Management Manual*, Oxford, United Kingdom: Elsevier, 2004, pp. 133–175, doi: 10.1016/B978-075067579-6/50010-8.

[16] C. A. D. Sousa and O. J. Romero, "Influence of oil leakage in the pressure and flow rate behaviors in pipeline," *Latin American Journal of Energy Research*, vol. 4, no. 1, pp. 17–29, 2017, doi: 10.21712/lajer.2017.v4.n1.p17-29.

[17] I. B. Macias, S. A. Cariati, A. L. Souza, S. L. Cruz, and J. A. F. R. Pereira, "Leak detection in pipelines. Pressure transient analysis," in *CHISA 2006-17th International Congress of Chemical and Process Engineering*, 2006, pp. 3–8.

[18] M. Henrie, P. Carpenter, and R. E. Nicholas, "Pipeline leak detection basics," in *Pipeline Leak Detection Handbook*, Oxford, United Kingdom: Gulf Professional Publishing, 2016, pp. 19–40, doi: 10.1016/B978-0-12-802240-5.00002-9.

[19] G. Sandberg and P. Göransson, "A symmetric finite element formulation for acoustic fluid-structure interaction analysis," *Journal of Sound and Vibration*, vol. 123, no. 3, pp. 507–515, 1988, doi: 10.1016/S0022-460X(88)80166-4.

[20] M. M. E. Gowini and W. A. Moussa, "A finite element model of a MEMS-based surface acoustic wave hydrogen sensor," *Sensors*, vol. 10, no. 2, pp. 1232–1250, 2010, doi: 10.3390/s100201232.

[21] Y. Kagawa, T. Tsuchiya, T. Yamabuchi, H. Kawabe, and T. Fujii, "Finite element simulation of non-linear sound wave propagation," *Journal of Sound and Vibration*, vol. 154, no. 1, pp. 125–145, 1992, doi: 10.1016/0022-460X(92)90408-P.

[22] P.-C. Eccardt, H. Landes, and R. Lerch, "Finite element simulation of acoustic wave propagation within flowing media," in *1996 IEEE Ultrasonics Symposium. Proceedings*, 1996, pp. 991–994, doi: 10.1109/ULTSYM.1996.584157.

[23] A. C. Tikka, S. F. A. -Sarawi, and D. Abbott, "Finite element analysis of a 3-dimensional acoustic wave correlator response for variable acoustic modes," in *Modeling, Signal Processing, and Control for Smart Structures 2008*, 2008, vol. 6926, pp. 1–8, doi: 10.1117/12.790608.

[24] V. Kutiš, G. Gálik, V. Královič, I. Rýger, E. Mojto, and T. Lalinský, "Modelling and simulation of SAW sensor using FEM," *Procedia Engineering*, vol. 48, pp. 332–337, 2012, doi: 10.1016/j.proeng.2012.09.522.

[25] Y. Yu and N. Yan, "Numerical study on guided wave propagation in wood utility poles: finite element modelling and parametric sensitivity analysis," *Applied Sciences*, vol. 7, no. 10, pp. 1–20, 2017, doi: 10.3390/app7101063.

[26] J. Owowo and S. O. Oyadiji, "Finite element analysis and experimental measurement of acoustic wave propagation for leakage detection in an air-filled pipe," *International Journal of Structural Integrity*, vol. 8, no. 4, pp. 452–467, 2017, doi: 10.1108/IJSI-12-2015-0061.

[27] L. Chen, W. Zhao, C. Liu, and H. Chen, "2D structural acoustic analysis using the FEM/FMBEM with different coupled element types," *Archives of Acoustics*, vol. 42, no. 1, pp. 37–48, 2017, doi: 10.1515/aoa-2017-0005.

[28] M. Weryk, E. Kozaczka, and G. Grelowska, "Study of noise propagation for small vessels," *Archives of Acoustics*, vol. 40, no. 2, pp. 267–272, 2015, doi: 10.1515/aoa-2015-0029.

[29] E. Rusu, "Study of the wave energy propagation patterns in the western black sea," *Applied Sciences*, vol. 8, no. 6, pp. 1–17, 2018, doi: 10.3390/app8060993.

[30] M. A. Adegboye, W. K. Fung, and A. Karnik, "Recent advances in pipeline monitoring and oil leakage detection technologies: principles and approaches," *Sensors*, vol. 19, no. 11, pp. 1–36, 2019, doi: 10.3390/s19112548.
[31] P. Odya, J. Kotus, M. Szczodrak, and B. Kostek, "Sound intensity distribution around organ pipe," *Archives of Acoustics*, vol. 42, no. 1, pp. 13–22, 2017, doi: 10.1515/aoa-2017-0002.
[32] S. J. Flayh, H. S. Sultan, and A. K. Alshara, "Numerical study of drilling fluids pressure drop in wellbores with pipe rotation," *IOP Conference Series: Materials Science and Engineering*, vol. 518, no. 3, pp. 1–10, 2019, doi: 10.1088/1757-899X/518/3/032037.

BIOGRAPHIES OF AUTHORS

Marwa H. Abed currently an M.Sc. student at the University of Basrah under the supervision of Assistant Professor Dr. Wasan A. Wali (University of Basrah) and Dr. Musaab Adil Alaziz (University of Basrah). Her research focuses on using artificial techniques in pipeline leak detection from theoretical and practical points of view with help from Missan Oil Company, Iraq. She completed her B.Sc. degree in computer engineering from Imam Jaafar Al-Sadiq University, in 2016. She is currently a member at South Refineries Company (SC). Her research interests include pipelines, leakage detection, machine learning, neural network, neuro-fuzzy, fluid flow, sound pressure, and intelligent leak detection robotics. She can be contacted at email: engpg.marwa.abd@uobasrah.edu.iq.

Wasan A. Wali holds a PhD in Automation and Control Engineering, Built Environment and Sustainable Technologies Institute (BEST), Faculty of Technology and Environment, Liverpool John Moores University, UK. M.Sc, B.Sc in Electrical Engineering, Department of Electrical Engineering, College of Engineering, University of Basrah, Iraq 1996, 1992 respectively. She is currently an Assistant Professor in the Department of Computer Engineering, College of Engineering, University of Basrah, Iraq. Her research interests are automation and control engineering, artificial intelligent control, microwave and microwave plasma control technologies, renewable energy, and chaotic systems. She can be contacted at email: wasan.wali@uobasrah.edu.iq.

Musaab Alaziz holds a Ph.D in degree in Electrical and Computer Engineering from Rutgers University, the State University of New Jersey, NJ, USA in 2017. MSc, BSc in Computer Engineering from University of Basrah, Basrah, Iraq 2005, 2002 respectively. He is currently a faculty member at University of Basrah, College of Engineering and the Dean Assistant for Administrative Affairs at the same college. His research interests are unobtrusive monitoring and neurobehavioral assessment and computational modeling. Currently he has research about smart rooms that can track people's activities using sensors with smart systems. He can be contacted at email: mosab.adil@uobasrah.edu.iq.