FLOW-INDUCED VIBRATION IN PIPES: CHALLENGESS AND SOLUTIONS - A REVIEW

M. SIBA¹,², W. WANMAHMOOD¹, M. ZAKI NUAWI¹, R. RASANI¹, M. NASSIR¹,²

¹Department Mechanical and Material, Faculty of Engineering and Built Environment; National University of Malaysia, Selangor, 43600 Bangi, Malaysia
²Institute of Technology-Baghdad, Foundation of Technical Education, Baghdad, Iraq
³Programme of Chemical Engineering, School of Engineering, Taylor’s University, Taylor’s Lakeside Campus, No. 1 Jalan Taylor’s, 47500, Subang Jaya, Selangor DE, Malaysia

*Corresponding Author: mohamedh.nassir@taylors.edu.my

Abstract

The Flow-induced vibration has recently been the topic of experimental, numerical, and theoretical studies. It was intended to implement better applications for controlling the flow using orifice technique. Having the flow under control, the orifice becomes an instrument for measuring the flow. The flow of all fluid such as water, oil, gas and vapours through an orifice was tested and mathematical models were developed adequately. The basic theme for these enormous studies was the need for the very accurate flow measurements through orifices. All experimental, theoretical, numerical, and analytical studies have agreed that there is more than one avenue to develop, modify, and enhance such measurements. However, one factor that affects the flow measurements is the vibration which was not treated as required until the mid-20th century due to enormous discoveries that damages could be rooted to vibration. Researchers have studied vibration and then proposed mathematical models in conjunction with the pressure and velocity measurements of the flowing fluids and then the effect of the vibration, induced or not induced, has been under continuous investigation. This paper is an attempt to review the previous studies regarding understanding the nature of the vibration and the possible effects of vibration on the flow and on the piping structure in order to limit the damage caused by the vibration. This study shows that the need for more experimental studies and more comprehensive analytical approaches are, in particular, very essential to develop better results.

Keywords: Orifice, Vibration, CFD and Vibration, Numerical analysis, Navier-Stokes theorem.
1. Introduction

Ashley and Haviland, 1950 [1] studied the flow-induced vibration of the trans-Arabian pipeline. This introductory study was followed by a series of other studies through which the nature of the vibration was deeply investigated [2] and then analysed theoretically and analytically [3, 4]. It was until mid-twentieth century when the nuclear technology has emerged beside other energy sources, vibration was found to be one of the most important factors that cause damages to some parts of these power plants. The damage and possible causes were documented by researchers, governmental institutions, and private agencies [5-8]. Since then, vibration and vibration-induced damages were reportedly and heavily studied. These studies have been focusing on three different areas: experimental [9-13], investigation using numerical analysis [14-17], and investigation using simulation techniques [18-20]. The heavily investigation in power plant accidents has its own impact on governments to set rules and regulations to avoid such increasing number of unfortunate accidents. The rules are listed and implemented in all power plants, aircrafts, military and civil ships, automobile, and many more. Another confirmation for setting and monitoring these rules and regulations came from the American Society of Mechanical Engineers (ASME) and the International Organization for Standardization (ISO). Both non-governmental agencies have issued a code to ensure safety measures [21, 22].

The vibration induced by flow through orifice has another impact on the flow measurements which is considered as dangerous as the safety measures. Traditionally, the orifice plate has been used as a device to control the flow rate in piping systems. In industry, as well as in research, accurate measurements of the flow rate are very crucial especially in pharmaceutical plants and refineries when additives and/or catalysts are subjected to very sensitive measurements. To successfully achieve precise flow measurements, the impact of the vibration caused by pressure inside the pipes should be closely considered by studying its impact experimentally, theoretically, and numerically. The vibration could cause damages to the pipes or the pipe components [17]. Consequently, studying and then analysing the vibration phenomena becomes an essential and important to avoid such possible mishap [15, 17].

The fabrication, installation, and using the orifice plate for flow measurements are very simple and inexpensive. Beside simple fabrication, orifices do not require serious and lengthy maintenance which results in very low cost [16]. At this stage, it is very important to mention that there are some, even limited, malfunctions caused by orifice plate such as homogeneous fluid, turbulent flow (Re > 4000), and causing vibrational resonance [3, 6, 7]. Figure 1 shows installation and operation for a typical orifice plate.

Piping-induced vibration in industry represents the main drawback for the simplicity of piping circuit establishment. Broken pipes, heavily continual maintenance, and sudden erupted fire are the current challenges that are facing pharmaceutical, refineries, and research labs. Within the last 30 years, the damage due to inaccurate flow measurements, delay in production, and fire exceed billions of dollars [8]. Avoiding such technical serious issues, the vibration, using pressure techniques, should be tested and evaluated for precaution and possible improvement. Having vibration determined, safety measures should be implemented especially with excessive vibration by using enough support.
structure, span length, or using different suitable vibration absorbent materials. All practical modifications to the current piping systems have to consider the impact of resonance—the cornerstone in vibration.

Fig. 1. Orifice plate installation and operation [23].

As mentioned earlier, installation of the orifice is technically simple, however the conditions for fully developed and swirl/pulsation-free flow upstream of the flow should be always considered. Secondly, since the orifice is an additional fitting to the piping circuit, proposed mathematical models should always consider the distortion in flow velocity before entering and after exiting the orifice which means studying the associated velocity profiles with varying degrees of swirl at the inlet of the meter. It is suggested by some researchers that the error associated with the discrepancy of the flow measurement should not exceed 2° swirl angle and within 5% ratio of axial velocity [24, 25].

The causes of the vibration are not limited to the bending of the pipe line [1, 26] but also to differential pressure which is normally created across the orifice plate [27]. This differential causes Newtonian force on the plate and, consequently, a non-balanced force will develop on both sides of the orifice. This force causes vibration on the wall of the pipe as well as on the orifice plate. Several studies have emerged to study this phenomenon [10, 12]. The installation of orifice plate has another vibrational impact on the structure [28]. In addition to this force, the differential pressure across the orifice plate causes swirling and back stream which are the main causes of vibration. The vibration affects both the orifice plate and the pipe wall in the neighbouring area of the orifice plate. The vibration itself is not always the main concern in damaging pipes, but, to a more extent, the vibration and its associated resonance are the main factors in destroying the structure. It is well-known that each structure, small as orifice plate or big size as a bridge, has a natural frequency which depends on its physical and engineering settings. As the vibration of the flow has same frequency, a severe impact on the structure will be carried out which is accompanied by flowing big force (energy) to the structure. This force is normally much bigger than the force which was caused by the differential pressure. This is why fabricating an orifice plate requires forecasting such a force to avoid any possible damage to the structure [7, 8].
Theoretically, the calculations of the velocity, pressure, vorticity, and the mechanical properties should be conducted based on Navier-Stokes (N-S) equations [15] and subsequent models. Researchers in the last three decades have developed and/or enhanced variety of software to study some complex structures such as the flow through the orifice plate. N-S equations were, in part, simplified to fit certain requirements and boundary conditions. However, more general solutions require more sophisticated software such as Fluid Structure Interaction (FSI) and Computational Fluid Dynamics (CFD). The flow-induced vibration is studied using FSI technique while predicting the whistling of an orifice plate in a flow duct was studied by CFD.

The flow-induced vibration is the core of this review. The study includes, but not limited to, turbulence-induced vibration, vorticity shedding-induced vibration, and the fluid elastic-stability. As many previous studies were considered laminar flow (Re < 2300), this study focuses on turbulent flow for which Re > 4000. Within the realm of turbulent flow, the study focuses on vibration, static pressure, vorticity and then velocity profile of the fluid. Finally, the mechanical properties (stress and strain) were reviewed exclusively.

2. Literature Review

2.1. Flow past Orifice Plate/Flow in Pipes

Orifice plate flow meters are simple and inexpensive device that contributes to about 80% of the flow meters used in chemical industries [28]. As the fluid flow passes through the orifice, a significant differential pressure is created between the inlet and outlet or, more specifically, across the orifice plate which results in high pressure loss. Thus, the flow requires high power pump to overcome this loss and to maintain the velocity of the flow [12, 29]. The boundaries around the orifice plate become source of a wide spectrum of frequencies [10]. Literatures are rich in considering valves- and pumps-induced vibration but, to a lesser extent, considering orifice-induced vibration [10]. This review focuses on orifice-induced vibration as an attempt to shed the light on the important topic for more studies and consideration.

Zanker’s orifice plate (Fig. 2) was used in studying five turbulence models through which he determined the most suitable models to simulate such flow problems [18]. The Zanker’s orifice plate is characterized by different thickness. The Zanker’s study has shown the flow separation and recovery within the plate holes as well as visualizing the swirl removal effect.

The aspect ratio or the ratio of orifice diameter, d, to the pipe diameter, D, (β=d/D) is one of the parameters that has been used in orifice techniques to control the flow. It was found that β has severe impact on the velocity distribution in the pipe (velocity profile) and, consequently, the differential pressure in both directions axial and radial. Smith et al. [16] has developed numerical solution using CFD for three aspect ratios of 0.5, 0.6, and 0.8. In their study, the flow was kept unchanged and by changing the aspect ratio they examined the turbulent scheme by employing the standard k-ε turbulence model and compare the results with the Reynolds Stress Mode (RSM). Figure 3 shows the velocity distribution (velocity profile) of the flow through the orifice at different aspect ratios.
Fig. 2. Zanker’s orifice plate: (a) fabrication and (b) properties [18].

(a) Re=5000, β=0.2.

(b) Re=5000, β=0.5.
In most studies, the shape of the orifice plate is circular but a rectangular orifice plate was employed in some research [31]. The circular orifice plate itself has few designs depending on the position of the orifice hole. Researchers were not stopped at varying the aspect ratio but also changing the number of the holes and their positions. In addition to these varieties of the orifice plate, a study by El-Azm et al. [9] was performed using irregular orifice shape (normally known as fractal-shaped orifices). El-Azm’s study has shown that the fractal shape orifice has severe impact on the differential pressure across the plate. It was found that the pressure drop in the fractal shape-orifice shape is lower than that of the regular circular shape for the same employed area. The result suggests that the fractal shape causes less pressure loss which has its own impact on the flow-induced but no interpretation was suggested by the researchers. An extended study conducted by Manshoor et al. [32] in which they designed irregular shape orifice independent on flowing fluid unlike El-Azm’s approach where the flow was fixed. The simulation results have shown that the device can be used as a part of a flow metering package that will considerably reduce installation lengths. The results of using a combination of the fractal flow conditioner and orifice plate for non-standard flow conditions including swirling flow and asymmetric flow showed that this package can preserve the accuracy of metering up to the level required in the standards.

Arun [19] studied the discharge coefficient $C_d$ (the ratio of the actual discharge to the theoretical discharge) that Arun [19] has used non-Newtonian fluid at fixed aspect ratio of $\beta = 0.4$ for laminar and turbulent flow where Reynolds number ranges between 1000 and 10000. Generally, investigating the discharge coefficient is aimed to find the ideal nozzle (the orifice structure in this study). It is shown that discharge coefficient decreases as the pipe diameter...
increases at constant $\beta$ while $C_d$ increases with the increase in $\beta$ ratio for the same pipe diameter for all the fluids as shown in Fig. 5. The discharge coefficient reaches its maximum values at Reynolds number between 800 and 1200, and then slightly decreases before it becomes independent on Reynolds number of $Re = 100,000$ and higher. All results based on the CFD predictions were successfully validated as they were compared with that of the literature available.

![Image of a graph showing the standard orifice plate discharge coefficient](image)

**Fig. 5. Standard orifice plate discharge coefficient [33].**

The structure of the flow in pipes containing orifice plate was studied and numerically analysed by Sobey [24] who used the time dependent two-dimensional Navier-Stokes equations. The study has shown that the flow could be separated at sufficiently large Reynolds number. For instance, the study has shown that there was a critical Reynolds number at which the separation could be attained. In unsteady flow, for small Strouhal number the flow development during acceleration occurs in a quasi-steady manner. In order to have a vortex mixing, the peak Reynolds number must be sufficient to cause an equivalent steady flow to separate. In a related study, Dennis and Dunwoody [34] presented a solution to the flow up to five term truncation to approximate the solution for laminar steady. Parameters such as drag coefficient, pressure coefficient, standing eddy, length and stream lines patterns were compared with other experimental and numerical solutions.

One of the features of the flow in pipes with orifice is the velocity profile of the flow passed an orifice. The mechanism of decaying velocity (or the velocity profile) in the laminar and turbulent flow was studied extensively by Uberoi [14]. The study shows that the mechanism depends on estimating the swirl and their corresponding trailing. The most important results of this study were focused on the creation of the radial convection as a result of increasing differences between the core trailing vortex and the velocity in the surrounding region. The analytical analysis has shown clearly the disturbance in the flow pattern passed the orifice plate.

It is well-known that all fittings distort the flow velocity. The size (impact) of distortion depends on many factors such as the geometrical shape of the orifice, viscosity, the material the fittings are made of, and whether the expansion
(contraction) is sudden or slow. Cherdron et al. [35] studied the effect of the sudden expansion on the flow pattern by direct visualization using laser Doppler anemometry. In a 2-D flow, the study examined a very accurate and detailed description to the velocity profile. The shear layer, the study has shown, is the main causes of the disturbances in unequal regions of flow recirculation. In parallel study, Durst [13] studied the flow structure near the sudden contraction in order to examine pressure losses in that region.

The 3-D studies were also conducted in order to get better insight of the dynamics behaviour of the flow. As a typical example of these studies, Shintaro and Masaki [36] who have shown the dynamics of a hanging tube with different lengths carrying fluid. The experimental structure enabled them to study the static buckling of the system.

Finally, the 3-D flow of unsteady viscous flow was examined by Mateeseu et al. [37]. It was shown that central portion of the outer cylinder executes transverse transitional oscillations in the longitudinal plane. The azimuthal Fourier expansion was presented for numerical solution to solve the time dependent incompressible Navier-Stokes equations.

### 2.2. Vibration in Pipes

This part of the review focuses on orifice-induced vibration. As the flow passes through the orifice, a differential pressure across the orifice and swirling take place. The vibration caused by differential pressure and swirling could reach one of the modes of the natural frequency of the structure which, in turn, results in severe damage to the fittings and the wall of the pipe. In this study, the fluid is flowing inside a pipe and the orifice plate could be treated as a contraction device or an additive fitting. The existence of this device causes severe disturbance to the flow regardless whether the flow is laminar or turbulent; steady or un-steady; forced or natural, and, for all these cases, there will be always flow-induced vibration. For small vibrations effect, there is possibility or chance of damage to the pipe-orifice structure. The vibration could be very high and as normal mode of flow-induced vibration reaches the normal mode of the pipe-orifice structure, the damage becomes eminent. Studying this induced vibration is the subject of enormous studies during the last seven decades. This section of the review discusses the nature of each vibration and the analysis pertaining to it. The focus in this review will be on steady-state vibration and dynamic transient vibration. The second part is discussing the stability of the flow-induced vibrating systems.

### 2.3. Steady-State Vibration

The steady-state pipe vibration occurs for a long period of time. The main cause for this vibration is the differential pressure (pressure loss) which occurs across the orifice plate and causes, in turn, a force on the orifice plate [12, 38, 41]. Other possible reason for this vibration is cavitation or flashing which is very normal occurrence in the pressure-reducing valves [6]. The material fatigue is one possible outcome of the steady-state vibration. The fatigue which is linked to the stress could cause failure to the entire or specific parts of the structure [39].
2.4. Dynamic transient vibration

Unlike the steady state vibration, the dynamic transient vibration can occur for relatively short time by a pulsating system causing huge force across the orifice plate which makes this vibration more dangerous and more dramatic [37]. The occurrence of the dynamic transient vibration is not limited to the pulsating system only, but also to a sudden opening or closing the gate valves or the safety valves. The existing of a turbine in the piping circuit could be another reason for dynamic transient vibration especially at certain time during starting or ending the turbine [39]. The dynamic transient vibration is related to changes in the flow velocity which is subjected to both the fluid viscosity and the geometrical setting of the piping circuit which includes the number of fittings, bending in the pipes, fast closing valves, fast safety/relief valves, and the sudden expansion or sudden contraction [17, 47].

2.5. Stability versus vibration in pipes

Studying the stability and vibration of pipes conveying fluid is relatively new in the field of structural dynamics. Serious effort was intensively concerning this topic started in 1950 when Ashley and Haviland [1] studied the vibration of Trans.-Arabian followed by a similar study by Housner [26]. The recent study by Olson [17] shed the light on analysing the pipe vibration. The previous studies were performed experimentally and theoretically aiming to generate a semi-empirical solution to the effects of the vibration on the construction. The findings suggest that the natural frequency (resonance) decreases as the fluid velocity increases. The physical conditions of the pipe such as the size of the pipe, the force at the supports, the distance between the supports, the materials the pipe made of are related to the natural frequency.

Mao et al. [10] presented a theoretical approach to the hydraulic test for the orifice induced pressure fluctuation (PSD) and vibration in pipeline. In this study [10], the vibration was studied with the aid of fluctuating pressure and the acceleration due to the structure of piping circuit. The natural frequency of the whole structure was statistically evaluated based on the fluctuating pressure and the acceleration. The study has shown how the orifice, as an additional fitting, disturbs the pipe flow which results in increasing the fluctuating pressure. At this level of fluctuating pressure-induced vibration, all other factors causing the vibration have become secondary in their effect leaving the fluctuating pressure as the main source of vibration. Numerically, Mao et al. [10] have shown that the location of the highest fluctuating pressure is beyond the orifice at 1.7 orifice diameter in the axial direction. The velocity and pressure distribution (profile) are shown in Figs. 6(a) and (b) respectively.

The pressure and pressure drop across the orifice plate were extensively investigated by researchers. Smith et al. [16] has investigated the effect of temperature on pressure (Fig. 7) while Wang, et al. [49] have numerical analysis show the variation of the flow discharge and the pressure, Figs. 8(a) and (b).
Fig. 6. The flow velocity (a) and pressure (b) along the axis of the tube [48].

Fig. 7. Comparison between measurements and predicted profiles with different numerical schemes by k-ε turbulence model [16].
Later Mao and Zhang [38] published their findings comparing the experimental data to a numerical mathematical model through which the natural frequencies and the strain response of the structure were considered. The numerical model is based on dividing the vibration into three categories: turbulence induced vibration, vorticity shedding induced vibration, and the fluid elastic instability.

The numerical modelling has been expanding by Mathew [39] who utilized the Fluid-Structure Interaction (FSI) model to clarify the effect of the physical characteristics of turbulent flow and the pipe wall vibration. The FSI software used by Mathew [39] in this analysis was the commercial FSI software packages which is based on Reynolds Averaged Navier-Stokes (RANS) and another model known as the Large Eddy Simulation (LES).
The accuracy of numerical modelling was tested by Shah et al. [50]. The peak of the centreline velocity, Fig. 9(a) has shifted to the right as the number of cells used in analysis increased. The effect of the increasing number of cells has shown that the pressure decreased by about 10%, Fig. 9(b).

![Graph](image1)

**Fig. 9.** Effect of grid size on (a) centreline axial velocity and (b) centreline pressure profile with (1) 321,360 cells, (2) 1047,560 cells [50].

The two important factors (velocity and pressure) in the analysis of the flow through an orifice plate were investigated by Smith et al. [16]. In this analysis was examined for accuracy by comparing to experimental work. The analysis has shown that there is a slight disagreement between the experimental work and the CFD simulation analysis. The result of Smith et al. [16] and more recent study by Shah et al. [50] suggest the need for more work in both directions: experimental and numerical.
The controlling of the resonance frequency of a system was studied by Yakut and Canbazoslu [40] who employed attenuators such as volume addition, compliant boundaries, and vortex generators. It is shown that the volume addition changes the resonance frequency and reduces the amplitudes of the pressure fluctuations. The resonance frequency has also shown changes when the compliant boundaries are made from plastics material. Regarding the vortex generators, it has shown that the manganese based alloy causes reduction in the resonance frequency.

A study carried out by Bagchi, et al. [41] has shown multiple effects of the vibrating systems. The study, experimental in nature, has tested the effect of the pipe oscillation on wall pressure. It is shown that there is a correlation between frequencies of pressure oscillations in a non-oscillating pipe and the natural frequencies of the structure. This result suggests that there is an influence of structural properties on the flow scheme in fluid dynamics. The wall pressure is subjected to both temporal and spatial oscillation if the pipe is forced to oscillate periodically. The calculation of the mean pressure is affected by the type of periodic oscillation. The study has shown analytically that about 7% variation for forced oscillating pipes.

In a recent study, Song et al. [42] carried out a laboratory implantation tests on vortex-induced vibration (VIV) in which the riser model has an external diameter of 16 mm and a total length of 28.0 m. The experiment was carried out for turbulent flow (4000 < Re < 10000). To measure the dynamic response in cross-flow and in-line directions, fibre optic grating strain gages were used and the results have shown that the number of modes in in-line direction is doubled from 6 to 12.

Long [43] was the first who studied the problem of vibration and stability of cantilever pipe as well as simply supported pipe. The solution indicated a slight decrease in frequency and no decaying vibration with an increase in flow rate that can be attributed to the flowing fluid for simply supported, fixed, and fixed-simple ends. The theory neglects internal damping of the tube and support damping the effect of the fluid pressure was not included before Heinrich [27] who was the first to show its effect on the vibration. Stein and Tobriner [43] derived the equation of flow motion in a pipe with the effect of fluid pressure being included. They studied the dynamical behaviour of a simply-simply, clamped-clamped, and infinitely long pipe [44].
The vibration-induced internal flow of entirely supported pipe was examined by Faal et al. [45]. In their analysis, a finite length pipe with clamped ends was analysed by Euler-Bernoulli model which is also adopted in engineering mechanics. The equation was solved to determine both transverse and axial displacement. The goal for this study is to determine the natural frequency of coupled pipe-fluid system. The study was extended to evaluate the effects of the stiffness of elastic foundation and the velocity and density of inner fluid.

The dynamic behaviour of the flow through an orifice was extensively studied by Kim [46]. In this study, Kim has utilized the irreversible energy loss which is related to pressure loss for turbulent jet flow. Kim proposed two different models to evaluate the pressure difference by instantaneous inertia model and the frequency-dependent model.

The effect of harmonic fluctuation of the fluid flow was studied by Chen [47] who presented a study of a simply supported tube containing pulsating flow. The equation of motion was first derived to incorporate the unsteady flow. By employing a mathematical method known as Galerkin's method in which a continuous operator problem is converted to a discrete problem, the equation of motion was reduced to a system of coupled equations with multi-harmonic coefficients. Beam and shell theories were used to investigate the vibration and stability of pipes [51]. The effects of the fluid properties and pipe geometry and properties on the vibration and stability in-plane and curved pipes with different end conditions were subjected to numerous studies, for instance, [52-54].

Beside the experimental evaluation and simulation studies, there is a study conducted by Hellum, et al. [55] to determine the empirical parameters by the numerical analysis. The study considered a system consists of cantilever pipes conveying fluid. The goal of this study was to determine the best parameters for stability of the structure.

Investigating unsteady hydraulic characteristics in a short-elbow piping, Yamanoa et al. [56] tested a methodology for one of Japanese reactors. The methodology in this study was experimented and the results were simulated. The results suggest that the pressure fluctuations (not the differential pressure) have less significant effect on the flow-induced vibration and the flow separation region was slightly influenced by the swirl inflow.

In 2008, the forces of the vibration excitation were correlated to the dynamic forces in a study conducted by Zhang et al. [57]. The two forces (excitation and dynamic) have different nature; the excitation forces are developed through the fluid and could be considered as internal forces while the dynamic forces are those forces caused by the differential pressure. Zhang et al. [57] developed semi-analytical models for correlating the two forces resulting in better understanding to the nature of excitation forces.

The three following tables summarize the categories through which the flow in a pipe containing an orifice plate. Table 1 shows typical experimental designs and procedures. Table 2 shows the numerical analyses while Table 3 shows the simulation procedures that were used by researchers.
<table>
<thead>
<tr>
<th>Ref #</th>
<th>Year</th>
<th>Topic, area, and interest</th>
<th>Investigated Parameter</th>
<th>Main Result</th>
<th>Applications of their work</th>
</tr>
</thead>
<tbody>
<tr>
<td>8</td>
<td>2011</td>
<td>Investigation on fluid flow characteristics of the orifice in nuclear power plant.</td>
<td>$D_{pipe}$, $v$, $P$, $Re$</td>
<td>Investigating flow near orifice plate by using a commercial computational fluid dynamics code characteristics, and compared with experimental.</td>
<td>Used flow measurement technique in industrial application including nuclear fields such as pharmaceutical plants.</td>
</tr>
<tr>
<td>10</td>
<td>2006</td>
<td>Experimental studies of orifice induced wall pressure fluctuation and pipe vibration</td>
<td>Flow rate = 15, 25, 40 $m^3/h$, $\beta$ = 0.25, 0.30, 0.335</td>
<td>Study orifice induced random wall pressure fluctuation and vibration in a pipeline.</td>
<td>Engineering pipes conveying fluid often suffer from flow induced vibration and structural failures &amp; nuclear power plant.</td>
</tr>
<tr>
<td>11</td>
<td>2009</td>
<td>Effect of orifice shape in synthetic jet impingement cooling</td>
<td>$v$ = 3-25 $m/s$, $D_{pipe}$ = 50 $mm$, $D_{orifice}$ = 25 $mm$</td>
<td>Experiments are carried out on the effects of velocity and orifice spacing on the frequency of sound generated by flow in a pipeline containing two closely spaced sharp-edged orifice plates.</td>
<td>Orifice plates are widely used as convenient pressure-reduction and flow-regulation devices in a pipe flow.</td>
</tr>
<tr>
<td>41</td>
<td>2009</td>
<td>Experimental study of the decay pressure fluctuations and flow perturbations in air flow</td>
<td>$D_{pipe}$ = 100$mm$, $L$ = 10$m$. Air flow $Re$ = 3 - $11*10^4$.</td>
<td>Concerned with a preliminary study of the decay of swirling turbulent pipe flow and effect on the accuracy of orifice plate flow meter.</td>
<td>The Algerian petroleum natural gas company</td>
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Table 2. Numerical analysis.

<table>
<thead>
<tr>
<th>Ref #</th>
<th>Year</th>
<th>Topic, area, and interest</th>
<th>Investigated Parameter</th>
<th>Main Result</th>
<th>Applications of their work</th>
</tr>
</thead>
<tbody>
<tr>
<td>15</td>
<td>1970</td>
<td>Numerical solutions for steady past a circular cylinder at Reynolds number up to 100.</td>
<td>Re</td>
<td>Steady-state and transient heat transfer in a rectangular duct with an orifice filled with He II was investigated both experimentally and numerically.</td>
<td>Consider cooling of magnets; it is important to clarify heat flow in a duct with a complicated orifice like so as to resolve the instability of the magnets</td>
</tr>
<tr>
<td>16</td>
<td>2008</td>
<td>Numerical investigation of turbulent flow through a circular orifice.</td>
<td>$\beta = 0.5, 0.6, 0.8$ $Re = 18400$ $D = 25.4$ mm $L = 9$ D $t = 3.2$ mm $d_g = 12.7$ mm</td>
<td>Study the influence of turbulence model on the predicted results, the standard $k-\varepsilon$ turbulence model was employed to compare with the Reynolds Stress Model (RSM).</td>
<td>Natural gas industry</td>
</tr>
<tr>
<td>27</td>
<td>2009</td>
<td>Orifice plate meter wet gas flow performance</td>
<td>P ratio density mass of water mass of gas</td>
<td>Research into the wet gas response of the horizontally installed orifice plate meter is discussed</td>
<td>Used to measure wet gas flows</td>
</tr>
</tbody>
</table>

Table 3. Simulation Procedures
3. Conclusions

Investigating the flow emerging from or within the orifice has become increasingly important due to many industrial and experimental applications. The main purpose of these investigations is to create very accurate measurement procedure for the discharge of the flow in pipes for economic and safety reasons. The current review shows the chronological historical developments for orifice techniques which include the geometry and the shape of the orifice plate, experimental works, and analysis during the last six decades. The following points could be drawn from this review.

- Fabricating of orifice plate has been developing from a single shape to about ten different shapes.
- There are about five theoretical models were developed and utilized in order to validate or simulate the experimental work.
- Disagreement between experimental results and their relevant theoretical models and simulations has always been expected.
- For same theoretical model, changing parameters such as the mesh number or achieving the convergence level could result in an error of about 10%.
- The need for reducing or compiling models is necessary in reducing the arising complexity of this topic.
Improving the numerical statistical methods could represent an important step for reducing the confusion arises from complexity of the boundary conditions.

It was found that previous studies were focusing on aspect ratios started sequentially incremented at 0.1 from the minimum value of 0.2 to mostly 0.7 while no studies have shown studies with increment different from 0.1.

Some studies have shown dramatic change of follow vorticities and swirling activities as the aspect ratio increased from 0.2 to 0.3 and as such more studies are needed to cover the behaviour between these two aspect ratios.

Studies are not unified regarding the principal frequency modes and their relevant second harmonic frequencies.

The need for enhancing software is very important step.

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