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Investigation of V-Port Use in Ball Valves Through Design and Analysis: A Comprehensive Review

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Abstract- Ball valves are popular in factories for controlling liquids and gases because they are easy to make, last a long time, and shut off flow well. But regular ball valves are not always great at controlling how much liquid or gas flows through, especially when they are only partly open. V-port ball valves were created to fix this problem. The V-shaped cut in the ball helps to control the flow better. This research looks at how a V-port ball valve works using computer simulations. A 3D model of the valve was made, and simulations were run with different opening amounts and flow rates. The research looked at things like how fast the liquid or gas moves, how much the pressure drops, how much turbulence there is, and the valve's flow rate. The results show that the V-port design does a much better job of controlling flow than regular ball valves. It makes the flow smoother and reduces the chance of bubbles forming. The results also show that computer simulations are helpful for making better valve designs. The simu

Keywords— shut off flow, pressure drops, flow, control, bubbles forming.

I. INTRODUCTION

Valves are super important in systems that move fluids around. You see them all over the place, in things like oil and gas plants, chemical factories, water treatment centres, and power plants. There are lots of kinds of valves, but ball valves are a favourite because they're easy to make, last a long time, and can shut off flow well.A regular ball valve has a ball inside with a hole through it. When you turn the ball, the hole either lines up with the pipe to let fluid through, or it blocks the pipe to stop the fluid. They are good at turning flow on or off completely but aren't the best if you need to control the flow little by little.

That's where V-port ball valves come in. Instead of a simple hole, the ball has a V-shaped cut-out. This V shape makes the flow change more smoothly as you turn the valve. With more subtle changes to flowrate and less swirling of the fluid compared to regular ball valves, that makes it easier to control the amount of fluid flowing through. Because of this, V-port valves are becoming more popular for jobs where you need to both completely stop the flow and precisely control how much flows through.

This study assists in making fluid control systems in factories work better, last longer, and be safer. By understanding the fluid dynamics within V-port ball valves better we reduce the need for physical prototypes and experiments. The optimized design of the V-port valves leads to less energy waste, since the fluid flow is more predictable and manageable. By improving the safety, it reduces the risk of leaks and bursts, due to better pressure management.

II. LITERATURE REVIEW

Ji et al. [1] studies on control valves reveal several ways to up performance. Overlapping port areas can cause energy loss because they create vortices. Tao showed that shaping the flow helps v port ball valves cut back on pressure fluctuations. Tabrizi and Chern found that smaller openings can lead to turbulence and cavitation. Bubble blockage and shear stress are factors, according to Campagne and Sedghkerdar, while Chen looked at how eccentric jets form. Smith tied noise to vortex shedding, Duda studied thermal stress during repeated use and Dong made a quick solenoid valve. All this research points to v port designs to make things more stable, cut down on losses, and give better control.

Study by Himr et al. [2] assessed a ball valve's control in a test setup. Ball valves are mainly for on/off, but we checked how well they regulate flow by looking at flow, torque, and vibration. The valve only controlled well between 55-66% open. Below 45%, control was bad, and cavitation was a risk. Torque tests saw high initial friction, but stable values when moving. Vibration tests found main frequencies around 300-370 Hz tied to the valve, strongest when mid-open. Ball valves aren't great for control because they wear out and vibrate a lot. It's better to use proper control valves for reliable, ongoing use.

Wang, Zhang el al. [3] researched erosion wear in metal seal floating ball valves exposed to gas, solid, and liquid mixes. The study concentrated on how particle erosion leads to leaks and reliability issues in high-pressure acid systems. By Using Euler-Lagrange and CFD-DPM models, validated through experiments, they looked at flow resistance, particle distribution, and erosion patterns at the different valve openings. The research showed that as the valve opening narrowed from 80% to 20%, both erosion and particle buildup increased, with smaller particles causing more erosion. The simulations closely matched experimental results, indicating that erosion mainly happened on the valve's upstream and internal surfaces due to jetting and cavitation. The study concluded that valve particle size and opening angle greatly affect valve reliability and that erosion-resistant designs are needed to extend the valve's lifespan in harsh conditions.

Qu el al. [4] studied how to make a micro flow control valve better. They wanted to solve issues like the valve core getting stuck and high torque needed for rotation. The study used fluid-solid coupling simulations in Ansys WorkBench and a bird swarm algorithm to test different buffer groove shapes: triangular, U-shaped, and combined. The triangular shape lowered pressure well but caused big impacts. U-shaped grooves had smooth pressure but didn't lower it as much. The combined groove was both steady and lowered pressure well. The best combined groove had a 72° cut-in angle, 60° plane angle, and 1.65 mm depth. The study found that this groove helps reduce valve core deformation and sticking. It's a good fix for making micro hydraulic control valves more reliable.

Jin et al. [5] examined how spool design affects flow and damage in valves that regulate liquid levels during coal liquefaction. In study simulations were ran with spool angles from 72° to 120° to check jet behaviour, cavitation, and erosion from particles. The tests showed a 90° spool angle gave the best pressure balance, lessened jet issues, and cut down on particle wear. Cavitation wasn't changed much by the spool shape. Angles of 72° and 90° lowered wear, with 90° being the best for flow and resisting erosion. The study finds spool angle greatly impacts jet shape and erosion, and a 90° design can make valves last longer when dealing with tough flow conditions.

Wang, Cai et al. [6] reviewed erosion wear in high-pressure throttle valves, which is a big issue in gas fields because solid particles damage the valve seat and core. The study looks at different ideas about erosion, like micro cutting and deformation wear, but found that none of them completely explains how erosion works. The review covers the main equations, turbulence models, calculation methods, particle behaviour, and erosion models used in research. Valve design, flow conditions, particle qualities, and material types all affect erosion wear were noted. The review talked about using experiments and computer simulations together to study the problem.

Kurosawa et al. [7] explored how inlet pressure affects flow in perforated cage control valves, using experiments and CFD simulations. The CFD model was checked against experimental data for flow coefficient (Cv) and liquid pressure recovery factor (FL), with errors staying below 6%. Cavitation was seen at the perforation inlet because of flow separation, and increased inlet pressures made the void fraction larger near the outlet. The erosion index went up with inlet pressure, focusing damage on perforation walls where flow wasn't in line with the valve body. The research team found that high inlet pressures worsen cavitation and erosion in these valves, and CFD imaging helps anticipate where erosion will occur, helping improve valve designs.

Koesters et al. [8] showed how to build a digital twin for an industrial valve to predict when maintenance is needed and avoid expensive shutdowns. A test setup with a tank, the valve, and an outlet to gather data, was built. Vibration, temperature, and pressure sensors were added, and the data was processed using QuantumX hardware and catmanEasy software. The digital twin model looked at vibration signals to find damage, comparing valve states to thresholds to spot leaks or wear. The IT system kept the valve status secure and easy to see. In conclusion, their digital twin setup combines sensor data, modelling, and IT, giving real-time monitoring and early warning of valve damage in industrial uses.

Thongnueakhaeng, De Haaset al. [9] introduced a new way to linearize nonlinear flow in standard control valves by using a variable gear ratio. Typical globe and ball valves have quick-opening or equal-percentage behaviours, which complicate exact flow control. In their work, the valve capacity coefficient was found by experiment, normalized, and then an inverse function was applied to create variable gear ratios. These ratios change how the driving and driven gear move in relation to each other. A test system using a stepper motor, pressure sensors, and a flow meter verified this method. The results indicated that the changed gear setup converted the nonlinear, quick-opening trait into a linear one. The experimental data correlated with linearity at $R^2 = 0.9984$. The authors decided that using a variable gear ratio is a useful, simple solution to get linear valve action across all opening ranges.

Zheng et al. [10] did a study using both computer models and experiments to look at how bubbles form and cause noise in electronic expansion valves in air conditioners. Special computer programs were used to model the flow, bubble formation, and noise, also considering the forces on the valve parts. The study showed that sudden changes in the valve shape cause bubbles to form, which then makes noise. To fix this, they came up with a new valve design that lowers the noise by 10 dB. The study shows that designing valves with the help of computer simulations can cut down on noise from bubble formation, which makes the valves and air conditioners work better.

Daniel A. Gutierrez et al. [11] looked at a redesigned ball valve that loads from the bottom, aiming for a direct connection between pressure and flow. They used computer simulations and lab tests and found that changing the shape, like adding longer grooves, really makes flow easier to control. The tests matched the simulations well. They checked different ways to simulate flow and found one that worked best. The amount of flow changed in a roundabout way as the valve opened, especially when it was barely open. They made 18 different 3D models to simulate the valve in different positions. The final model was almost correct at the full opening.

Hyo-Lim Kang et al. [12] came up with a valve that has a cylinder inside a ball. It spins to start the flow in the middle. They checked how much flow it could handle and how likely it was to form bubbles, using simulations and tests. It turned out to be better at controlling flow and resisting bubbles than regular valves. The flow increased a lot as the valve opened. The tests lined up with the simulations when the valve was fully open. It's made of a type of steel and uses gears to keep everything moving together. They didn't see many bubbles, even when the valve was only open a little bit.

Zhi-xin Gao et al. [13] showed that adding tiny gaps to valves can make them better at controlling small flows. The size of the flow was directly related to the size of the gap. Gaps that were shaped like rectangles and placed further from the center helped the flow and didn't lose as much energy. They used software to simulate the flow and get good results. How much energy they lost depended on the shape and location of the gaps. The improved valve kept the flow steady when it was wide open and made it flow evenly when it was barely open. The simulations were almost right, compared to the tests.

Hao-nan Zhang et al. [14] talked about how to make a valve core that lets the same amount of flow through as it opens. They made the flow rate more even as it opened. They tried it on two sizes of valves, and it worked well. They used some math to figure out the best shape. The tests showed that the flow was more stable and matched what they expected. The new core made the flow rate way more consistent when the valve was barely open. The tests showed that the improved version was better than the original.

Pratik Raut et al. [15] looked at redesigning a valve to stop leaks and save materials. They made the neck and body one piece and used certain materials that last long and seal well. This made it easier to build and more reliable. The materials they chose don't rust and can handle pressure. The new design cuts down on build time and materials. They said it's important to think about how to build something when you design it, to make sure it doesn't leak.

Mandanaka et al. [16] covered the design and computer-based analysis of a DN25 ball valve. This valve is built for high pressure (350 bar). The work looks at how much stress and bend happens in the sealing cups. They test different materials, using SolidWorks to build the model and ANSYS to run simulations. The team then compares the simulation data with what theory predicts. The study points to TFM as the best material for seals because it can handle a lot of pressure and barely change shape. Also, they check how temps and pressure change things with more simulations. The seats take more pressure than the ball, and this helps pick the right strong material.

Rushil Patel et al. [17] studies go over typical design problems for ball and butterfly valves, like when seats, stems, and discs fail. The paper talks about what kinds of valves there are, how flow works in them, and what materials are used, such as stainless steel, PVC, and elastomers. Seat shape and stem seals matter if you want to stop leaking. The study wraps up by looking at where valve tech is going, like smart valves in factories, and suggests better design tools to help get things right.

Sreekala S. K. et al. [18] looks at how cage hole shapes change how well flow works, using both computer models and tests. They model globe valves with round, oval, square, and triangle-shaped holes. The team finds triangles work best for getting the most flow and least pressure drops. The RNG k-ε turbulence model helps get good predictions. The tests are close to the simulations (under 10% off), so the conclusion is triangle holes are the best bet when you need lots of flow.

Narayan et al. [19] research talks about setting up and testing how three-way ball valves control flow. They use sound wave flow meters and gear to measure pressure differences.

They tested hollow and solid L-port ball designs at different valve positions. They find more flow and pressure drop when the valve is open more, and solid balls do a bit better. They drew some curves to show how the valve acts, which helps to pick and tune them for use in industry.

Bagdi et al. [20] use computer models and tests to get ball valves working their best. They checked pressure drops, speed, and flow rates at different opening amounts. The team then checked simulation results with test data and found they matched up well. Pressure loss goes up when flow is high, and the valve is barely open. The research backs making better designs for valves to work well in various situations.

Wen et al. [21] tweaked a floating ball valve intended for high pressure using some methods. I got a better idea of how things like valve size and seal changes can mess with stress and sealing. The model checks out and helps me link shape to how well it holds pressure at 100 MPa.

Ivancu et al. [22] used computers to look at a big ball valve. They showed that when it's not fully open, you get swirls and pressure drops, which backs up the idea of needing full shut-off for big valves. This gave me a head up about where seals can fail and why those special seats work to stop leaks and prevent fires in certain setups.

Kim et al. [23] used some numbers to describe how well valves work at different opening speeds. It let me tie flow to valve shape and conditions, and they even made equations to guess flow. This helps when checking my own valve design by giving me ways to measure how well it's doing, no matter the size.

Ma et al. [24] ran simulations on how different motor speeds affect flow. Turns out, motor speed changes flow and resistance, mostly when it's barely open. This showed me how control impacts flow and pressure, which helps me pick the right motor and speed settings for my valve design.

Dhumal et al. [25] used software to look at flow in three-way ball valves. The research pointed out weird flow and turbulence spots, backing up the idea that inner shape matters. This shaped how I model flow and how I check its performance with different port setups and speeds.

Thananchai Leephakpreeda et al. [26] looked at how the size of the opening, the shape of the hole, and where the hole is located affects how smoothly fluid flows through ball valves. The paper shares a math model that mimics the size of the opening based on the angle and backs it up with tests. The results point out that oval-shaped holes at the edge give better valve performance than round holes, which suggests it's doable to make ball valves that have consistent flow. This helps me when I'm trying to make my V-port shape better for even control.

Shivani V. Singh et al. [27] did tests to compare how well ball, butterfly, and gate valves work at different opening sizes. For the 1-inch ball valve they tested, the flow rate went up fast until about 30 degrees, and then it evened out. This proves that ball valves don't have a straight flow, so we must shape the V-port to get smoother control. The info also helps us compare flow trends for small valve designs.

Harshal R. Dorsatwar et al. [28], looked at how to design ball valves using computer flow simulations, putting attention on pressure, what materials to use, and how the valve might deform. The research says using computer simulations can tell us where stress will be and help us make the valve shape better without needing to test it physically. This backs up my idea of using simulations to make sure my V-port design is good and that the materials work well together.

Yogesh Gawas et al. [29] used FLUENT to copy how fluid flows through a 10-inch ball valve to figure out flow rate, torque, and how likely it is to have bubbles form. The results say flow and torque depend on the valve's shape, while bubble forming changes with flow conditions, with more bubbles at small openings. These things will influence my V-port design to balance flow and avoid bubbles in all situations.

Satish M. Silaskar et al. [30] used value engineering to make a 12-inch ball valve better by cutting down on the weight of the body and connections. Computer tests showed that the stress levels were still safe after the changes. This redesign cuts down on how much it costs to make and how much effort is needed to turn the valve. This goes along with my aim to mix structural improvements with better flow control in my V-port valve work.

Satish M. Silaskar et al. [31] made use of value engineering and FEA to cut down on the weight and cost of a trunnion-mounted ball valve, all while keeping it strong. They worked with ANSYS and Taguchi's method to make the wall thickness and cavity sizes just right for parts like the valve body, side bit, ball, trunnion, and shaft. The research gave the all-clear that stress and bending stayed safe, with the highest stress only inching up a bit from 100.84 MPa to 105.9 MPa. The valve's total weight went down from 485.77 kg to 443.71 kg. This lined up with what I'm trying to do with my V-port design. It shows how tweaking things and using stats can pump up valve performance, dial back actuator force, and be more sustainable without messing with rules like API 6D and ASME B16.34.

Femke Tas et al. [32] zoomed in on how pressure in and out, spring power, what kind of stuff flows through (Newtonian, non-Newtonian, or gas), and the ball's shape mess with how the valve pops open, how much drag there is, and how it shuts. The results said that when the pressure going in is higher and the spring isn't as stiff, the valve kicks open sooner. Also, pressure drag is more of a pain than viscous drag. Changing the ball's shape to look a bit like a raindrop knocked off some drag, but it didn't change how the flow acted much. The valve shuts tight without any backflow, so it seals well. This paper kind of steers my V-port design by flagging how fluid and stuff work together and how drag messes with how snappy the valve is and how well it seals, mostly when things are changing fast.

Design and Geometric Considerations

- V-port angle – The V-port angle impacts how the valve controls flow. A small angle (like 15°) gives you very fine control when the valve is barely open, but it also limits the maximum amount that can flow through. A medium angle like 30° tries to strike a balance, giving decent control at low flows without sacrificing too much capacity when the valve is fully open. If you need to move a lot of fluid, you might pick a large angle like 45°, but it won't be as sensitive when making small adjustments.
- Surface finish – Smooth surfaces cut down on friction and leaks. If a surface is prepped well, it can help lower wear, keep seals tight, and allow fluids to flow better.
- Port shape – The V-port valve is designed for steady flow management. Its shape allows flow area to change slowly as the valve opens, ensuring stable control and minimizing sudden speed or pressure changes.
- Seat matching – For reliable sealing and smooth operation, the ball and seat must fit well. Proper seat design ensures even contact, less leakage, and consistent torque when the valve moves. Good alignment and compatible materials boost durability and cut down on wear, even with different flow rates.
- Alignment – To keep flow consistent, it's important to line up the V-port with the stem axis. This makes sure the port opens and closes evenly, which helps prevent uneven flow, lessens stress on valve parts, and keeps the valve sealed, working smoothly, and lasting longer.

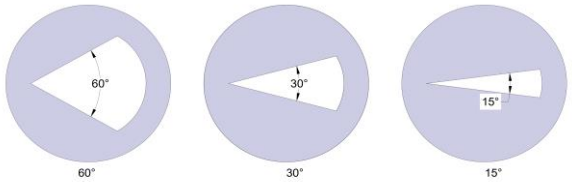

Fig. 1. 2D representation of V-port design.

Analytical investigation

To understand V-port ball valves, we need to grasp how the port shape affects flow and control. The valve's capacity coefficient is determined by how the opening area changes as it turns. Shaping the V-port allows for gradual and expected opening, achieving consistent flow increases. This makes control smoother and avoids quick changes in speed or pressure.

Good seat fitting, surface quality, and V-port alignment ensure consistent sealing and easy use. Looking at different port angles shows that smaller angles are best for fine control at low flows. Medium angles balance control and capacity, while larger angles maximize flow but reduce precision when only slightly open.

Also, it's important to think about how the valve fits into the piping. The downstream passage shape affects pressure recovery and turbulence, impacting cavitation and noise. Smooth transitions and enough straight length downstream are key to steadying the flow and reducing separation.

Material choice matters too. Different materials react differently to erosion, corrosion, and heat. Tough alloys or coatings work well for erosion, while corrosion-resistant steels work for chemicals or seawater. The right material boosts the valve’s lifespan and keeps it sealed tight. These points guide V-port ball valve design for dependable action in various conditions.

Future scope

Future studies will create an integrated system using fluid dynamics, tests, and digital tracking for V-port ball valves. The goal is to make models that link shape, cavitation, erosion, sound, and torque into a single design tool.

Another area to explore is using better materials and coatings to fight cavitation and erosion. Long-term tests in real work conditions will help measure durability, wear, and maintenance needs.

Lastly, the project will move toward smart valve systems using sensor data and digital twin tech. This will allow live tracking of valve condition, predictive maintenance, and better valve performance in various industries. These steps will change V-port ball valve design from simple parts to smart and dependable solutions for industry.

III. CONCLUSION

The investigation of V-port use in ball valves through design and analysis demonstrates that modifying the port geometry can transform a conventional on/off valve into a more effective control element.

By analysing the relationship between port angle, flow characteristics, and mechanical behaviour, the study shows that V-port configurations provide smoother regulation, improved rangeability, and better adaptability to varying process demands.

The design analysis highlights how geometric shaping influences flow stability, cavitation tendency, and energy efficiency. Rounded edges and carefully selected port angles are considered essential for reducing turbulence, minimizing noise, and extending valve life.

Overall, the project establishes that V-port ball valves can bridge the gap between simple shut-off devices and advanced control valves. Through thoughtful design and analytical evaluation, they offer enhanced performance, reliability, and versatility, making them suitable for a wide range of industrial applications where both control accuracy and durability are required.

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