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A study of waste and delivery valve design modification to the pump performance

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Abstract. This paper objective is to share design revolution of waste and delivery valve that contribute to the overall pump performance. In this paper, 3 new designs of waste and delivery valve pump are presented with comprehensive internal flow analysis using computational fluid dynamics (CFD) simulation over 4 cases that have been deeply study for one of the design chosen. 4 cases involving opening and closing both valve or either one. 0.265m height size of customized waste valve with an opening limiter and spring was used to demonstrate cyclic closing and opening valve operation extended up to 0.164m gap. Based on result, this characteristics contribute to 10-20% waste water reduction and enhancement of flow rate height up to 80m. Apart from that this paper also share some of pressure (dynamic, total, static), velocity (x, y, z axis) simulation including the vector flow were under different flow cases.

1. Introduction

Research with regards to hydraulic ram pump has been conducted extensively. Over the past 30 years, much more information has become available on new design approach and enhance performance of hydraulic ram pump. The first ever hydraulic ram had been constructed by Whitehurst in 1775, which had to be operated manually the opening and closing of the stopcock. This pump capable to raised water up to a height of 4.9m. Meanwhile, in 1796 the first automatic or self-acting ram pump was invented by the Frenchman Joseph Michel Montgolfier in order to raise water in his paper mill at Voiron [1]. Furthermore, despite many advantages such as free energy, self-maintenance and long service life, hydraulic ram pump also has been intensively investigated especially at the waste valve area recently due to high water losses and pressure [2].

In an analysis and enhancement of hydraulic ram pump using computational fluid dynamics (CFD), Piyush et al. [3] specifies that mass flow through the waste valve of hydram is excessive, so to reduce it, several enhancement is done and a new design is created. These are based on a systematic study of hydraulic ram pump and testing of on hydraulic ramp pump model. In another major study [4], established a suitable methodology including turbulence model selection for simulating both water and solid distribution data on different geometries using commercially available CFD software Fluent 6.1.22. The simulation results are validated with experimental data generated in the laboratory. Apart from that [5] describes the techniques and guidelines to successfully install the modern customized hydraulic ram pump. The proposed technique illustrates the methodology that can be used for the primary design considerations and applications in various ways. For this experiments, waste valve has been identified as a major contributing factor to the decline of pump performance, resulting elimination

of retainer spring and additional of weighted valve. These research are supported by the findings of Awari et al. [6] which evaluate the performance of a pump under predetermined operating conditions in order to optimize the related parameters for the use of the pump under two-phase mixtures of air and water.

Surprisingly, internal flow of any hydraulic ram pump new design still not yet been closely investigated. There is a relative paucity of high quality research describing the impact of design improvement on the overall pump internal flow simulation and performance. Although studies have recognized waste valve as the main water losses area, research has yet to systematically investigate flow condition around the area. For this purpose, the aim of this work to improve the design by the additional waste control mechanism and also undergo CFD simulation classified into 4 different cycles.

The present study will demonstrate design improvements that have been made on both valve (delivery and waste valve) that will justify every cycles and stages including during acceleration, delivery and recoil period in the aspects of pressure and velocity within same new design pump. The contribution of this study is obvious as the resulting outcomes can be capitalized as guidelines to study internal flow simulation for another well improve designs and become remarkable design information to engineers for actual prototype and fabrication.

2. Method

In this work, the novel design idea and arrangement are adapted from [7], where this research managed to obtained 70% overall efficiency of delivery heads control and regulation of the hydraulic ram pump by adding adjustable local resistance components in parallel with the delivery pipes. Basically for this research, 3 designs as shown in Figure 1 were presented, but for analysis only 1 design will be selected for this paper. Basically, a customized dimension of 1.064 m length, 1.106 m height and 0.362 m width of hydraulic ram pump as shown in Figure1 was sketched by using Solid Work software. Next Figure2 shows a dedicated spring attached to the delivery instead of conventional loaded spring type valve to eliminate unnecessary mechanical movement. Waste valve in Figure3 uniquely customized with opening/closing regulator which explain the significant improvement and pressure chamber was designed longer height than usual to provide significant effect on the delivery flow rate [8].
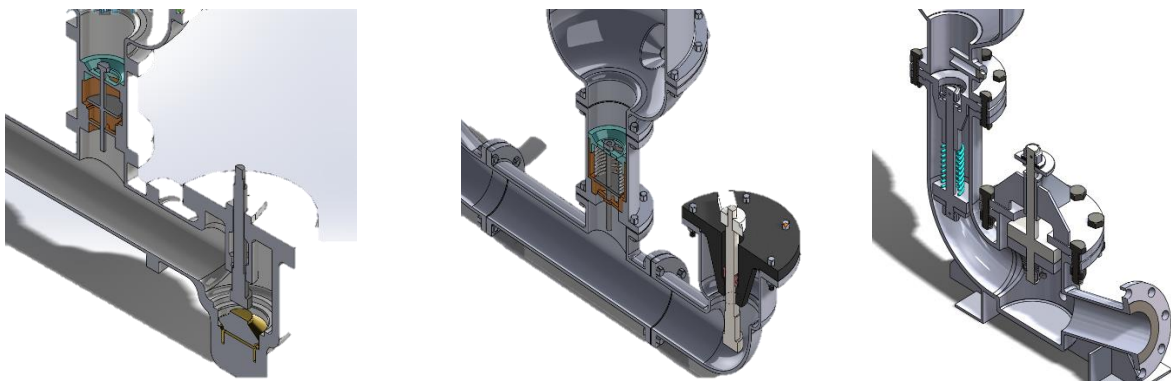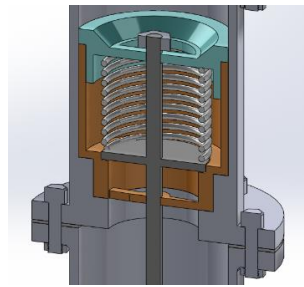

Figure 1. Isometric View for 3 Propose Designs.

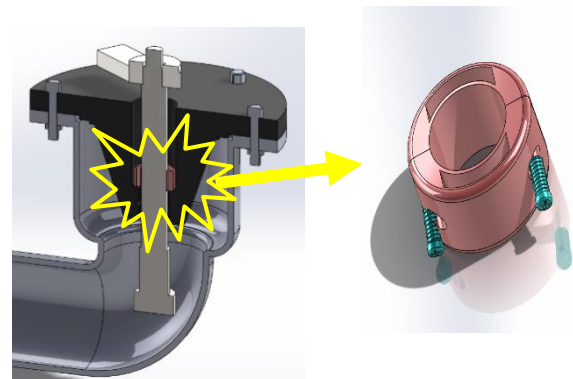**Figure 2.** One of the Delivery Valve Design.

Figure 3. One of the Waste Valve Design with Customized Opening Regulator.
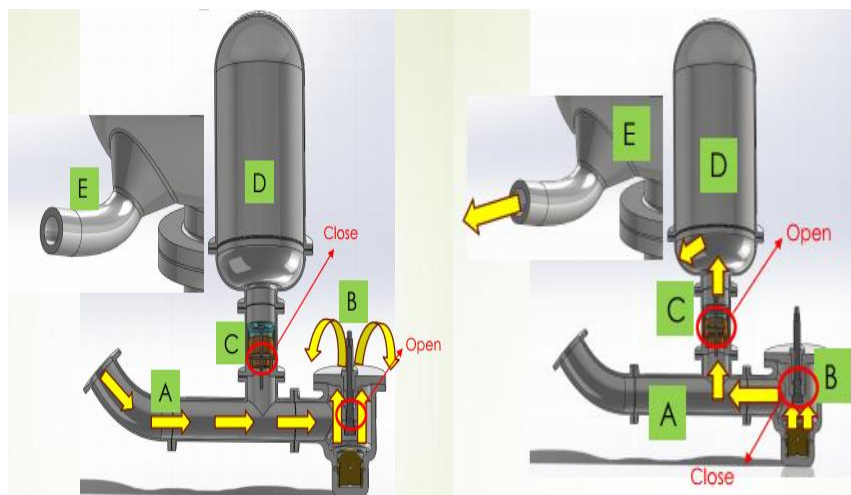
2.1. Working Principle of Design Selected

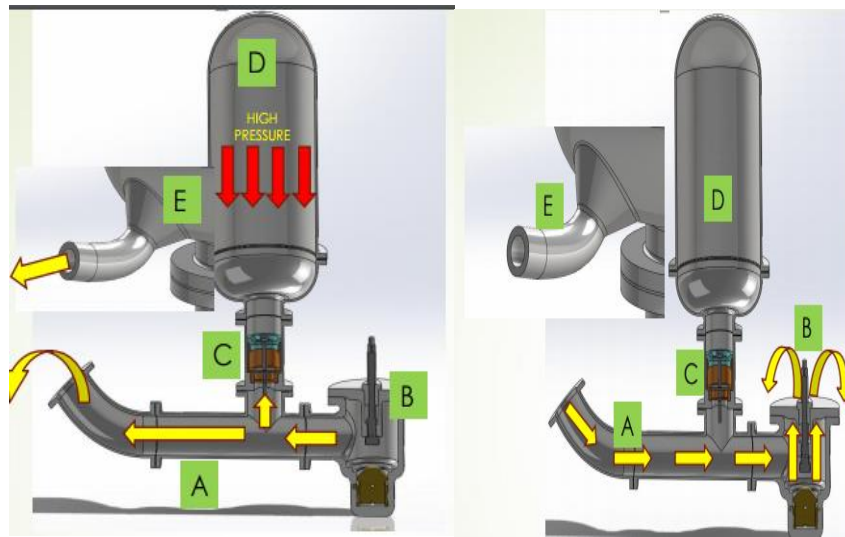**Figure 4.** Case 1 and Case 2 Condition.

Figure 5. Case 3 and Case 4 Condition.

Figure 4 case 1 and 2 shown the initial process of pump operation by which the waste valve (B) in open condition whereas delivery valve (C) in close condition state. At a consistent flow, water flow from inlet (A) towards (B) pass through (C). When it reach (B), the water gain enough momentum to close (B). At the same time water continue flow in and create pressure to the (B) surface. As a result vigorous water flow that collide with valve surface, hammering effect is created that lead to surge pressure. This caused water to recoil back towards (C) and provide significant pressure to the chamber. During this process pressure along pipeline (A) and (B) dropped drastically.

Figure 5 case 3 illustrates how accumulation of pressure inside the chamber caused the delivery valve to close and water to be pump out towards greater heights. After the water flow out, the pressure in the chamber become low. Case 4 where all the process will start again in cycles. This processes will continue to occur with condition of consistent low viscosity clean water.

2.2. Application of ICEM and CFD

Increasing interest in the performance characteristics of hydraulic rams made clear that there is a lack of simulation skills [9]. In this research, 2 engineering analysis software being used. One of them was the ICEM computational fluid dynamics (CFD) which function as to initiate mesh preparation and generator settings as shown in Figure 6. Meanwhile, Ansys Fluent software specifically to solve flow problem and result simulation over required stages.
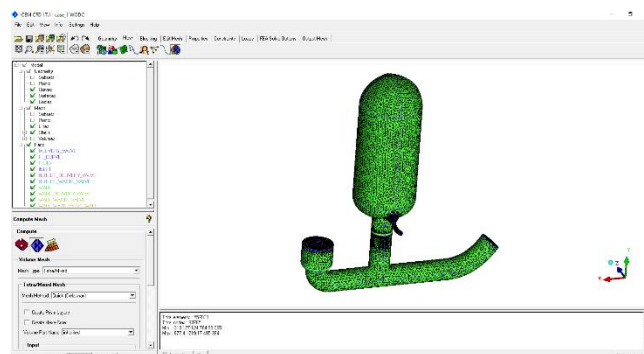

Figure 6. Application of ICEM CFD.

Before run the simulation, good meshing quality process as shown in Figure 7 is required to ensure accurate determination of numerical study and give more accurate insight into the physics of complex problem that would very impractical to study experimentally. Thus a grid and mesh independence study must be conducted to ensure good quality of mesh selection and result consistency over a selected period of iterations. For this research, the overall skewness value generated is 0.7 for surface and volume mesh as shown in Table 1 that clearly good enough for accuracy and convergence.
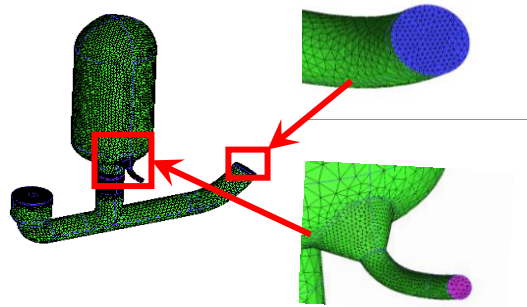

Figure 7. Surface Meshing.

Table 1. Grid Independence Specification.

Condition	Criteria	Value
Waste Valve Open, Delivery Valve Close	Mesh Method	Tetrahedral
	Quality	0.25
	Skewness	0.7
	Elements	557024
Waste Valve Close, Delivery Valve Open	Mesh Method	Tetrahedral
	Quality	0.25
	Skewness	0.7
	Elements	499094

Table 2. Mesh Independence Specification.

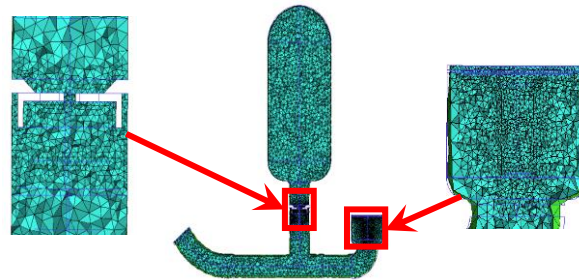| Type of Case	Criteria	Value
Case 1	Total Elements	560249
	Total Nodes	94275
Case 2	Total Elements	431892
	Total Nodes	73264
Case 3	Total Elements	644556
	Total Nodes	108683
Case 4	Total Elements	560249
	Total Nodes	94275

Figure 8. Volume Meshing.

Table 2 explains different geometrical over 4 sequential pump operation as explain previously that affected the simulated geometry result. Then the final stage before simulation is the boundary condition setting as being shared in Table. 3 below. Moreover, based on Figure 7 this new hydraulic ram pump design will have a fixed 1 inlet and 2 outlets for simulation purpose. Other than that, the simulation result is being illustrated in 4 cases as in Table 4 that demonstrate the cyclic opening/closing of both valve over a period of 2 seconds under transient analysis [10]

Table 3. Boundary Condition.

Condition	Setting Data
Inlet flow rate	10 m^3/h
outlet	Mass flow outlet
Environment pressure	101326 KPa
Analysis type	Transient
Turbulence model	Realizable-K epsilon turbulence model
Solver set-up	Second order
Other assumption	Wall as stationary and 4 different cases used for this simulation

Table 4. 4 Cases Description.

Type of Case	Waste Valve Condition	Delivery Valve Condition
Case 1	Open	Open
Case 2	Close	Open
Case 3	Open	Close
Case 4	Open	Open

2.3. Analysis of Convergence

During simulation, convergence is one of the method to check validity of solution or result [11]. Figure 9 provided a fluctuation downwards trend along the analysis, this is normal for the unsteady calculation. Anyhow, by increasing the number of iterations the fluctuations will still be there but can be ignored for a huge number of iterations. Alternatively, in other word increase the scope of analysis.
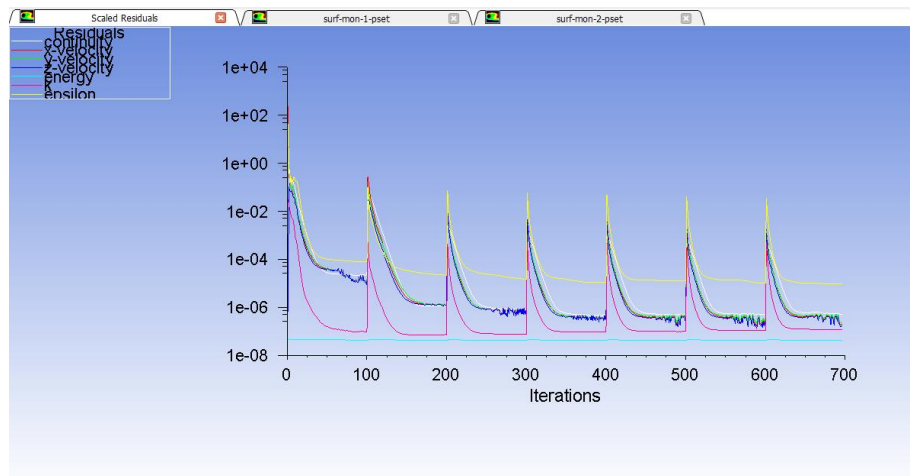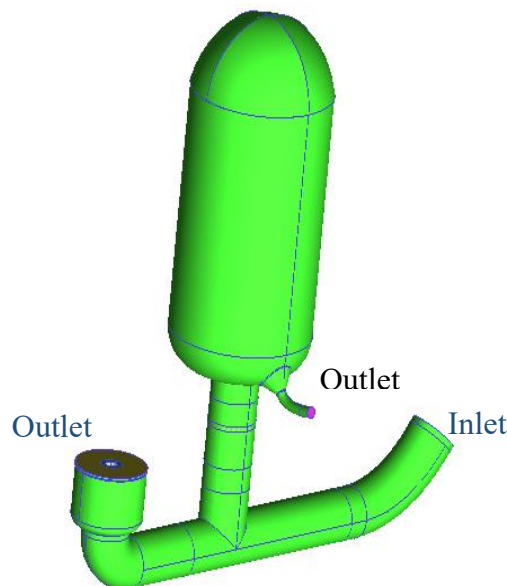
Figure 9. Convergence Data Over Iterations.

Figure 10. Fixed Inlet and Outlet Condition.

3. Results and discussion

The single most striking observation to emerge from the data comparison was the velocity vector movement as shown in Figure 8 that illustrate behavior pattern across the pipeline that also justify the real condition for every designated case. For case 1 or known as acceleration as state by [7], the waste valve in open condition state and delivery valve in closed condition. Case 1 begins when water with a flowrate of 10m³/h from the source flows through the drive pipe into the ram pump body, fills pipeline gradually at the speed ranging from -9.73m/s to 10.02m/s (negative due opposite direction of water) and begins to exit through the waste valve with a range of speed between 1.224m/s and 7.345m/s. The delivery valve remains in normal closed position by both the attached spring and no pressure and water being delivered to the outlet destination [12]. The simulation continues with pressure analysis (static, dynamic and total pressure) as shown in Figure 9, Fig 10 and Fig 11 for the remaining case.
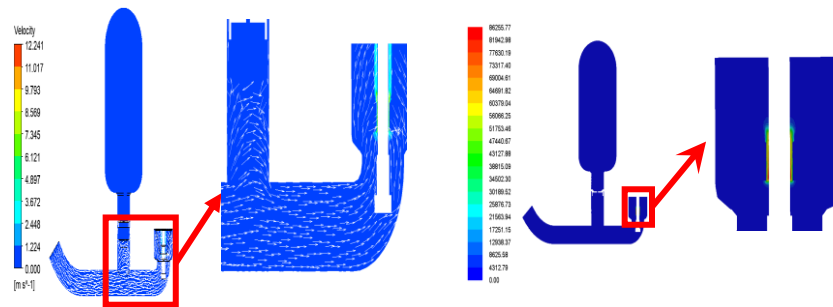
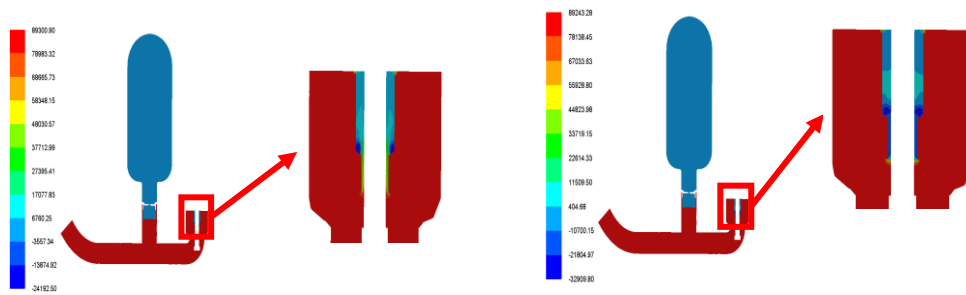**Figure 11.** Velocity and dynamics pressure result for case 1.

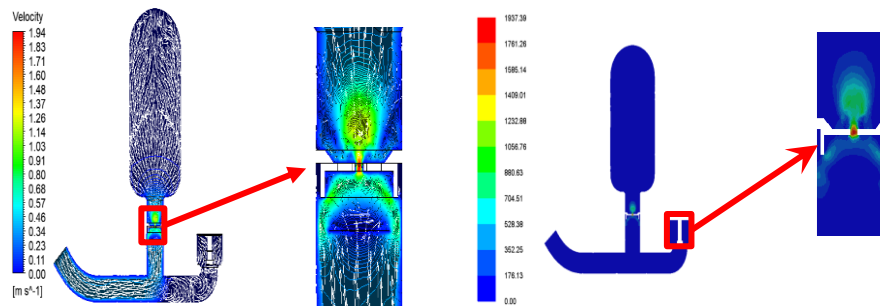**Figure 12.** Total and static pressure result for case 1.

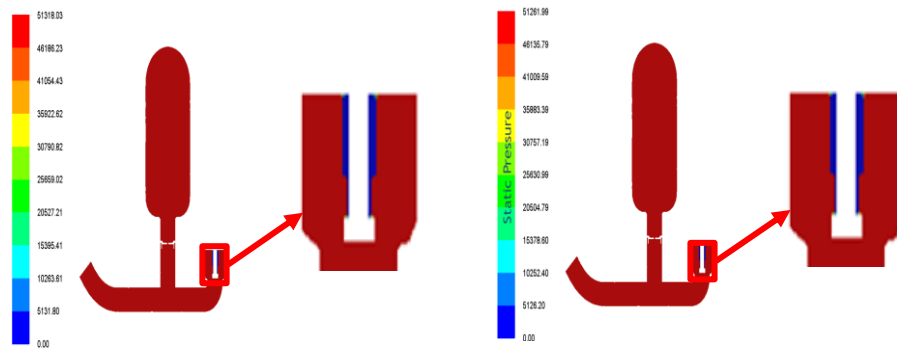**Figure 13.** Velocity and dynamics pressure result for case 2.

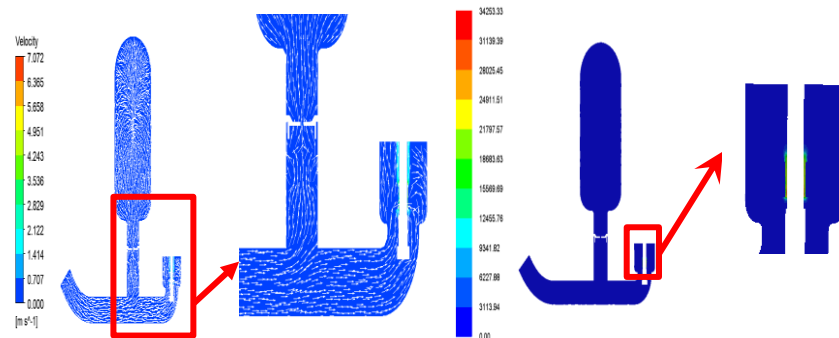**Figure 14.** Total and static pressure result for case 2.

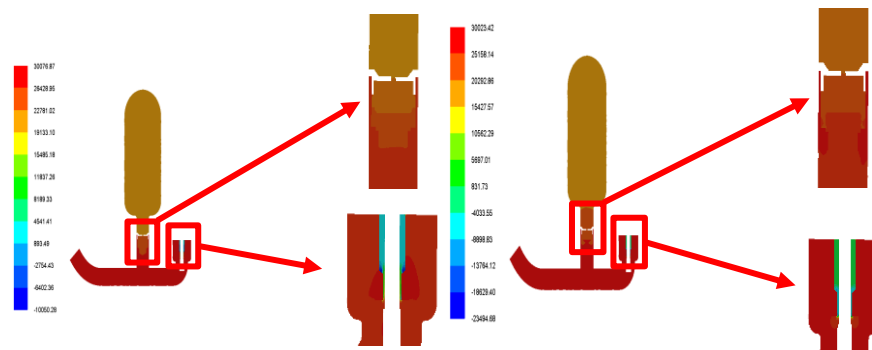**Figure 15.** Velocity and dynamics pressure result for case 3.

Figure 16. Total and static pressure result for case 3.
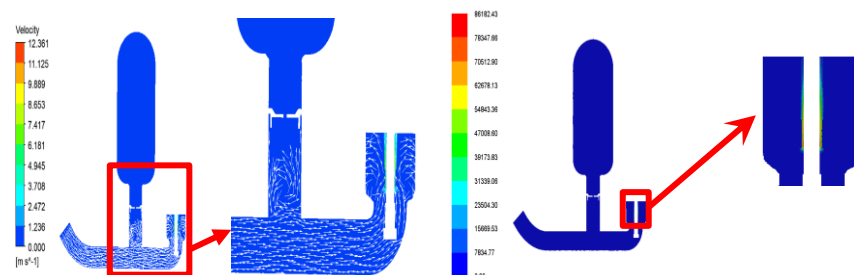

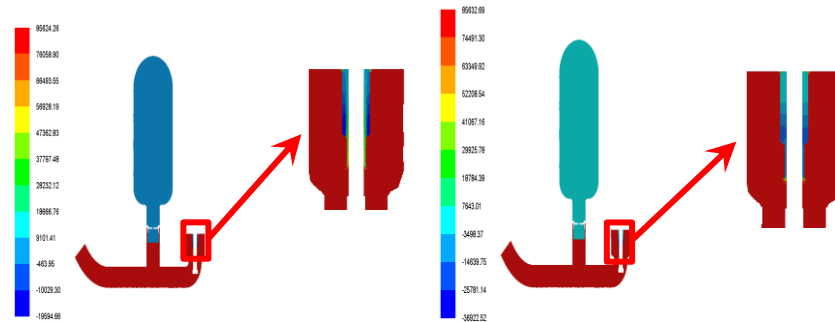**Figure 17.** Velocity and dynamics pressure result for case 4.

Figure 18. Total and static pressure result for case 4.

Based on the internal velocity projection and colour contour from Figure 11 till Figure 18, it clearly show that each case contibute to difference velocity and pressure contour along the pipeline. The colour appear generated much improve up to 60% enhancement perfomance in term of velocity and pressure and only 40% water losses in hydraulic ram pump as shown in Table 5 compare to existing design in the market that recorded over 60-70% water losses [13]. This analysis successfully minimizes losses generated at waste valve and at significantly improve the pumping capacity of newly design pump.

Table 5. Overall simulation result.

Case	Parameters	Min	Max	Mass flow Rate (kg/s)
Case_1	X-velocity (m/s)	-9.73	10.02	2.8 (waste valve)
	Y-velocity (m/s)	-3.00	14.36	
	Z-velocity (m/s)	-9.36	9.16	
	Static pressure (Pa)	-90019.72	89269.26	
	Dynamic Pressure (Pa)	0	103134.7	
	Total pressure (Pa)	-33084.33	101617.5	
Case_2	X-velocity (m/s)	-4.72	4.61	2.8 (Delivery valve)
	Y-velocity (m/s)	-9.82	2.611	
	Z-velocity (m/s)	-9.03	1.97	
	Static pressure (Pa)	-33755.69	59968.68	
	Dynamic Pressure (Pa)	0	60627.01	
	Total pressure (Pa)	0	60247.15	
Case_3	X-velocity (m/s)	-5.71	5.64	1.67 (waste valve) 1.12 (Delivery valve)
	Y-velocity (m/s)	-3.57	8.58	
	Z-velocity (m/s)	-5.24	5.79	
	Static pressure (Pa)	-40669.32	30126.38	
	Dynamic Pressure (Pa)	1.7649e-08	36889.26	
	Total pressure (Pa)	-19625.42	33314.94	
Case_4	X-velocity (m/s)	-9.619028	9.93	2.8 (waste valve)
	Y-velocity (m/s)	-3.070991	14.32	
	Z-velocity (m/s)	-9.281295	9.09	
	Static pressure (Pa)	-88607.82	85683.18	
	Dynamic Pressure (Pa)	0	102462.8	
	Total pressure (Pa)	-32589.2	101365.1	

4. Conclusion

This project was undertaken to design a new model of hydraulic ram pump and evaluate the internal flow analysis to justify improvement on the design that has been implemented. This study set out to assess the effects of new design especially design of the waste and delivery valve towards internal flow within 4 projected cases and specified boundary condition. The results of the investigation show that the projection of velocity vector for every details case and pressure contour. This projection lead to creation of result data in terms of velocity along 3 axis, static pressure, dynamic pressure, total pressure and mass flow rate. The main findings can be summarized as follow:

- Projection of internal flow within new design hydraulic ram pump. Justification for every lowest and highest analysis data for every case.
- Clear statement for every improvement and designated simulation. Reason and comparison from previous researches.

These findings enhance of understanding regarding the adjustment of design towards internal flow changes and overall performance [14]. It is recommended to develop this propose design to actual modelling and may explore the results for future research.

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