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Design of a 52-Seated Bus Shower Tester: Pressure Distribution Analysis

Mohammad Shawkat Ali[1], Md. Rafayet Bin Ali[2,], S. M. Mustakim Mahmud[2], Mohammad Mizanur Rahman[1]*

[1]Department of Mechanical Engineering, Chittagong University of Engineering and Technology, Chittagong-4349, Bangladesh
[2]Department of Mechanical Engineering, Rajshahi University of Engineering and Technology, Rajshahi-6204, Bangladesh

ABSTRACT

This study presents the redesign and hydraulic analysis of a shower tester system for 52-seated bus testing at Pragoti Industries Limited, Bangladesh. The existing setup, originally developed for SUVs, lacked adequate structural strength, uniform nozzle placement, and pressure regulation. A new configuration was designed, featuring an expanded 40 ft × 12.5 ft × 12.5 ft frame and dual centrifugal pumps to ensure sufficient flow and pressure distribution. Hydraulic calculations and CFD simulations in ANSYS were performed to analyze flow rate, head loss, and pressure variations across the network. Results revealed that the modified design achieved stable nozzle pressures of 2.0 bar for SUVs and 2.2 bar for buses, with theoretical and simulated data agreeing within 7%. The upgraded system effectively eliminates negative pressure zones, ensures uniform water coverage, and improves operational safety and efficiency. This research validates the feasibility of adapting existing shower tester infrastructure for large-vehicle applications through optimized hydraulic and structural design.

Keywords: Shower Tester Booth, Hydraulic Analysis, Pressure Distribution, CFD, Vehicle Testing.

1. Introduction

Shower tester booths are widely used in the automotive industry for leakage testing and to verify the water tightness of fully assembled vehicles by simulating real-world rain conditions [1]. G. Ranggatama et al. [2] explained that preventing water leakage is crucial because shower leaks can lead to multiple problems, including damage to electronic components due to water contact, which may result in permanent electronic failures. Leakage inside the vehicle often stems from improper joints, reflecting the overall quality of manufacturing [3]. Additionally, water intrusion causes discomfort to the consumer, affecting their overall experience and satisfaction with the vehicle.

Shower tester booths are used for the leakage test of a fully assembled vehicle. Also known as rain simulating chamber, a shower tester booth helps ascertain the water tightness of vehicles before they are brought to the market for sale. Shower tester systems simulate real-world rain conditions by spraying water at the vehicle from all angles. This allows manufacturers to identify and repair any leaks before the vehicle is delivered to the customer [4] [5].

A shower tester booth consists of essential components including high-pressure nozzles and special full cone type nozzles for effective spray, an air shower booth and air washing risers for thorough cleaning, filters to maintain purity, and a corrosion-proof structure ensuring durability. It features a recycling system to reuse water efficiently, valves to control flow, a centrifugal pump for pressure generation, a pressure gauge for monitoring, transmission pipes to distribute the fluid, and automation for precise and reliable operation [6].

S. Kengar et al. [7] described that the water spraying system simulates various levels of rain intensity to evaluate a vehicle's rain resistance under different harsh weather conditions. The standard nozzle pressure used in a shower tester booth, commonly employed to test vehicles for water ingress, typically ranges from 2 to 3 bars [8].

Additionally, a shower system includes a sewage treatment unit, which filters the circulating water to remove mud, sand, and other impurities, ensuring it meets the standards for recirculated water [9]. W. J. Liu et al. explained [10], Shower testing operation is an important part of the Quality Control (QC) line. After doing the shower testing, other successive QC line operations must be done [11]. Seiji Manabe et al. [12] noted that Shinichi Sasaki (1997) at Toyota’s Tsutsumi Plant introduced shower tests to fix rain leakage in cars, though the method had drawbacks. Mariano Ramirez et al. [13] stated that BMW recycles shower test water, saving about 80% during shower testing.

The existing shower tester booth model is limited to testing Sports Utility Vehicles (SUVs) and Double Cabin (DC) pickups. The primary objectives of this research are to redesign the existing shower tester structure to accommodate larger vehicle geometries such as buses, minibuses, and sedans, while still accommodating SUVs and DC pickups. To optimize the hydraulic network for balanced pressure distribution, and to validate the modified configuration using computational simulations. The results show that while the overhead tank pressure is sufficient for SUV testing, a dedicated pump system is required to ensure adequate pressure for bus testing. In addition, this study emphasizes efficient reuse of existing infrastructure to reduce modification cost while enhancing testing capability. Also,

*Corresponding Author Email Address: rafayet.tasrif@gmail.com

the study aims to ensure the upgraded system maintains uniform water coverage, minimizes energy losses, and meets industrial safety and operational standards for large-scale automotive testing.

2. Shower Tester Setup

2.1 Existing Older Shower Tester setup

The existing shower tester is unsuitable for testing bus bodies due to size constraints and is limited to smaller vehicles as shown in Fig. 1. Its structural frame is weak, leading to vibrations in wind and cracked welding joints, creating a safety risk. The water pressure is excessively high (above 5 bar) and unregulated due to a lack of pressure gauges and the use of gate valves, which minimize pressure drop. Furthermore, the placement of lateral pipes at incorrect heights (4 ft and 5.5 ft), irregular nozzle spacing, and rapid pipe corrosion further hinder its performance and fail to meet standardization requirements. The existing shower tester has overall dimensions of 20 ft in length, 11 ft in width, and 10.1 ft in height. It comprises four lateral pipes (two of 20 ft and two of 10 ft) of 1.5-inch diameter equipped with 90 flat fan nozzles, spaced at 8-inch intervals, and controlled by eight gate valves. The top side includes seven 20 ft long, 1.5-inch pipes carrying 210 nozzles, while the frame consists of ten pipes (two of 20 ft, six of 10 ft, and two of 11 ft) with a 3-inch diameter but without nozzles. In total, the system integrates 300 nozzles for shower testing. Also, Fig. 2 illustrates flow diagram of the water in the existing shower tester.

(a)

(b)

Fig. 1 Existing Shower Tester setup

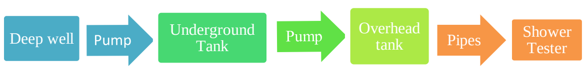
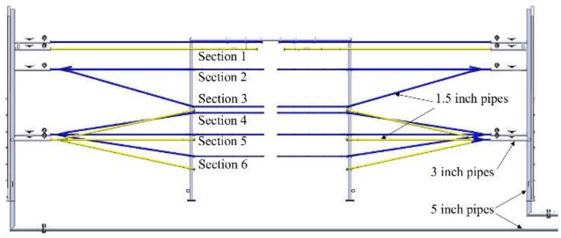


Fig. 2 Flow diagram of the existing shower Tester.

2.2 Proposed Design of the New Shower Tester

The older shower tester had several issues, including lack of pressure gauge use, high/uneven water pressure, limited and uneven pipe distribution, flat fan nozzles with irregular gaps, and a small, weak booth structure. To address these, a new shower tester has been designed with an enlarged booth (Height: 12.5 ft, Width: 12.5 ft, Length: 40 ft), improved pipe placement, and the use of GI pipes to prevent rusting.



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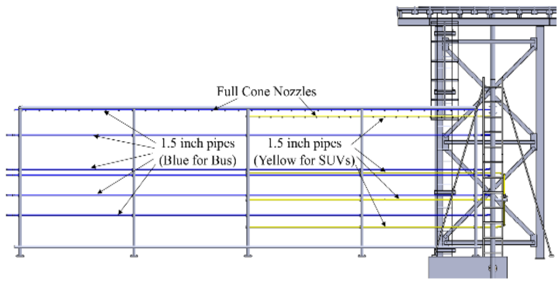

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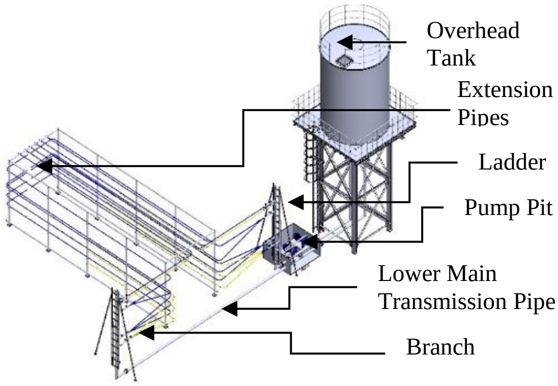


(c)

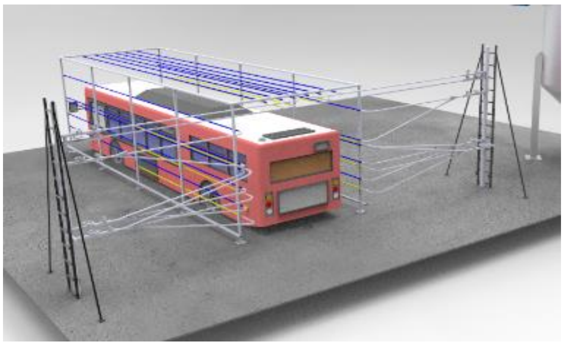
Fig. 3 (a) Front View (b) Side view (c) Isometric View of the new Shower Tester system.

Two separate plumbing configurations are included: one for SUVs and DC pickups, with 10 branch pipes (6 lateral and 4 top, 11.9 ft above ground), and another for buses, with 16 branch pipes (10 lateral and 6 top, 12.4 ft above ground). To ensure proper coverage, pipes are evenly distributed (SUVs: 52-inch roof span; buses: 82-inch span), supported on L-shaped brackets and stabilized with clamps. The branch pipes for SUVs and DC pickups are painted yellow, while those dedicated for bus testing are painted blue for easy identification. Before installation, full-cone nozzles are pre-fitted to all branch pipes, spaced at 12 inches for yellow pipes and 14 inches for blue pipes, ensuring uniform water distribution and consistent pressure throughout the shower test area.

Since the calculations for bus testing indicated insufficient water pressure, two centrifugal pumps were added to the main transmission line. Full cone nozzles are fixed on all pipes at standard intervals (SUV/DC pickup: 12 in, bus: 14 in) to provide uniform water distribution.

Though the previous design had limitations in conducting shower tests at the front and rear sections of the bus, the updated and modified design of the shower tester, as shown in Fig 3, addresses these issues. To enable front-side showering, both the right and left lateral blue pipes have been extended toward the front portion of the structure using elbow connections. Each front extension pipe has a length of 66.50 inches. Additionally, to provide rear shower functionality, three consecutive nozzles will be installed at a slightly inclined position at the entry points of all branch pipes, including both lateral and top sections.

The water pressure through the branch pipes will be controlled by ten globe valves on the lateral side. While the two lower valves are easily accessible, the upper three require elevated access. To facilitate safe operation, two ladders made of 1.5" × 1.5" MS angle will be installed on each lateral side, securely attached to the main transmission pipe with welded base plates. To prevent vibration and ensure operator safety, each ladder will be reinforced with solid square bars running from top to bottom.



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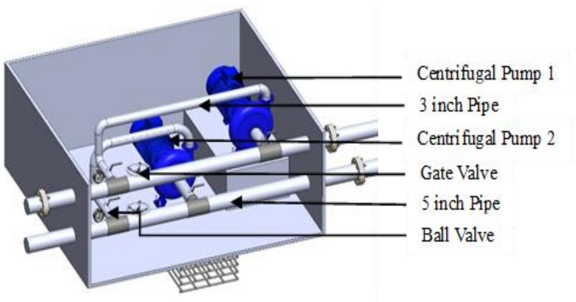


(b)

Fig. 4 (a) Rendered view (b) Pump pit view of the new Shower Tester

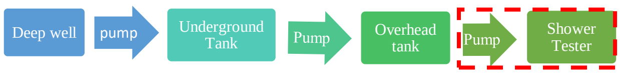


Fig. 5 Flow diagram of New shower tester with modification zone (red box)

Fig. 5 illustrates the water flow of the new shower tester system. As before, water is drawn from the deep well into the underground tank using small pumps, then transferred to the overhead tanks. During SUV testing, water flows from the overhead tank to the nozzles by gravity, and calculations confirm that this pressure is sufficient. However, for bus testing, the gravitational pressure alone is inadequate. Therefore, an additional high-capacity pump system (red box) will be installed in the pump pit to ensure adequate pressure for the nozzles in the blue-pipe bus shower tester setup as shown in Fig 4.

3. Mathematical Equations

Flow rate equation:

$$Q = A \times V \tag{1}$$

Head loss (Darcy–Weisbach):

$$h_f = f \frac{L}{D} \frac{V^2}{2g} \tag{2}$$

Reynolds number:

$$Re = \frac{\rho V D}{\mu} \tag{3}$$

Pump power requirement:

$$P = \frac{\rho g Q H}{\eta} \tag{4}$$

Energy consumption:

$$E = P \times t \tag{5}$$

From Bernoulli's Principle,

$$P_1 + \frac{1}{2}\rho v_1^2 + \rho g h_1 = P_2 + \frac{1}{2}\rho v_2^2 + \rho g h_2 + \rho g h_L \tag{6}$$

Hydraulic Power of the pump,

$$P_{kWh} = \frac{QP}{3.6 \times 10^6} \tag{7}$$

4. Results And Discussion

4.1 Flow Rate and Velocity Calculations

The shower tester system is designed to handle a total flow rate distributed across multiple pipe branches and nozzles. The total flow rate for the bus setup is determined by multiplying the individual nozzle discharge rate (Q) by the total number of nozzles, giving $Q_t = Q \times 544$.

Table 1 Flow rate and velocity at different pipe sections

Pipe/Nozzle	Flow Rate (Q)	Diameter (D)	Velocity (V)
Per Nozzle	2.5×10^{-4} m³/s	–	–
544 nozzles	0.136 m³/s	–	–
5″ Pipe (each)	0.068 m³/s	0.13 m	5.123 m/s
3″ Pipe (each)	0.0226 m³/s	0.07 m	5.872 m/s
1.5″ Pipe (each)	8.5×10^{-3} m³/s	0.03 m	12.025 m/s
5″ Pipe – SUV (each)	0.025 m³/s	0.13 m	1.88 m/s

Water is supplied from the main tank through two 5-inch transmission pipes, which then split into three 3-inch branch lines each, ensuring balanced flow distribution. From these 3-inch lines, the flow is further divided into a total of eight 1.5-inch pipes, which directly feed the nozzles. For the SUV setup, 200 nozzles are installed, maintaining a similar distribution network but scaled for a lower flow demand compared to the bus configuration.

4.2 Total Head Loss

For the 5-inch Galvanized Iron (GI) pipe on the right side of the shower tester, the surface roughness was taken as ε = 0.15, yielding a relative roughness of ε/D = 0.0011. Using the Moody chart, the corresponding friction factor was determined as f = 0.02. Based on these parameters, the constant head loss due to friction in the 5-inch pipe was calculated as h_f = 7.534 m. Table 2. summarizes the calculated head loss values for the remaining pipe sections within the system.

Table 2 Head loss calculation

Component / Location	Head Loss (m)
Water inlet (rounded)	0.160
5″ pipe friction (right)	7.534
90° bend in 5″ (flanged)	0.401
Gate valve in 5″ (open)	0.268
Sudden contraction 5″→3″	0.455
3″ pipe friction	0.362
Globe valve in 3″	0.351
Sudden contraction 3″→1.5″	2.949
1.5″ pipe friction	22.48
Additional Head Loss for 5″ pipe	0.325
Head Loss due to 90-degree bend in 1.5" pipes	6.635
Total head loss h_L	42.314

4.3 Water Pressure Calculation

The total head loss in the system was calculated as h_L = 42.314 m. Applying Bernoulli's principle, the pressure at Branch 1 was determined to be P_1 = –97.3 kPa (–0.97 bar). With the addition of the pump, the previously existing negative pressure of –97.3 kPa is overcome, resulting in an overall pressure increase of 310 kPa. Consequently, the net pressure within the system becomes 212.7 kPa, which is equivalent to approximately 2.12 bar.

Table 3 Pressure Calculation

Pipe height / Sections	Pressure	Pressure after addition of Pump
3.5′ (section 1)	P_1 = –97.3 kPa (–0.97 bar)	212.7kPa (2.12bar)
5.2′ (section 2)	P_2 = -102.4 kPa (-1.02 bar)	207.54kPa (2.07bar)
6.9′ (section 3)	P_3 = -107.559 kPa (-1.07 bar)	202.5kPa (2.02bar)
7.38′ (section 4)	P_4 = -112.04 kPa (-1.12 bar)	197.96kPa (1.97bar)
10.3′ (section 5)	P_5 = -120.85 kPa (-1.2 bar)	189.15kPa (1.89bar)
12.4′ (section 6)	P_6 = -63.252 KPa (-0.632 bar)	246.24kPa (2.46bar)

Table 3 summarizes the calculated pressures for the remaining pipe sections, providing a complete representation of the pressure distribution throughout the system. The shower tester has six vertical pipe sections strategically positioned to ensure uniform water coverage over the entire vehicle. Pipes at 3.5 ft and 5.2 ft target the lower and mid-lower areas, while the 6.9 ft section covers the mid-body. Upper pipes at 7.38 ft and 10.3 ft spray the side panels and roof edges, and the topmost section at 12.4 ft ensures full roof coverage, providing complete water distribution for accurate leak testing.

4.4 Power of Pump and Water consumption

To achieve the required standard pressure for shower testing, two centrifugal pumps were installed in the two 5-inch main transmission lines to compensate for system head losses and ensure adequate pressure at the nozzles. For a flow rate of 0.068 m^3/s (244.8 m^3/h) per line, the required hydraulic power was calculated as 21.42 kW. Considering operation near the best efficiency point and an overall pump efficiency of 71%, the total electrical power requirement was estimated to be approximately 30 kW. The added pump head offsets the previously calculated head losses of the network, eliminating sub-atmospheric gauge pressures and maintaining nozzle pressures close to the required operating level of 2 bar throughout the system. As a result, stable and consistent pressure conditions are achieved at all branch pipes. The pressure distribution along the right-side branch pipes is presented in Table 3, confirming the elimination of negative pressure zones after pump installation.

For the SUV configuration, 200 nozzles operating at a discharge rate of 15 L/min result in a total water consumption of 3000 L/min, corresponding to 12,000 L for a 4-minute test and 15,000 L for a 5-minute test. With a 200,000 L storage tank, approximately 13 to 16 SUVs can be tested per tank fill.

In the bus configuration, 544 nozzles operating at the same discharge rate require 7960 L/min, resulting in 31,840 L for a 4-minute test and 39,800 L for a 5-minute test. Under these conditions, the available tank capacity allows testing of approximately 5 to 6 buses per fill.

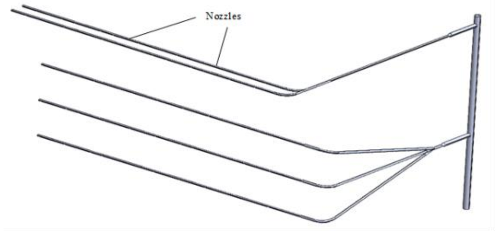
4.5 Simulation

The Assembly was designed in SOLIDWORKS and imported to ANSYS. The assembly is part of the Right-side SUV section and Bus section of the whole shower tester which is shown in Fig. 6.

The simulation used a refined mesh focused on the nozzle areas, consisting of about 1.7 million elements. The mesh quality was evaluated with a skewness of 0.84972 and an orthogonal quality of 0.15028, both within acceptable limits. The k-ω SST (two-equation) turbulence model was employed, with inlet velocities of 2 m/s for the SUV configuration and 5.1 m/s for the bus configuration. Water (liquid) was defined as the working fluid, and the solution method applied was coupled with a second-order upwind scheme. A total of 1200 iterations were performed, and convergence was successfully achieved.

SUV

For effective shower tester operation, a nozzle pressure of approximately 2 bars is required, which was successfully achieved in both the lower and roof section nozzles. As shown in Fig. 7(a), the nozzle region displays a deeper blue shade, corresponding to approximately 2 bars. In contrast, Fig. 7(b) illustrates the pipe flow pressure, where the red coloration indicates about 3 bars.



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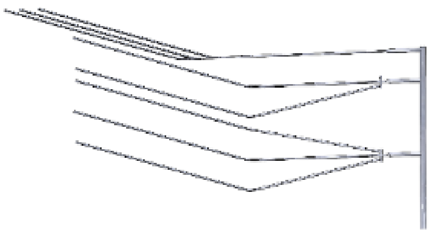

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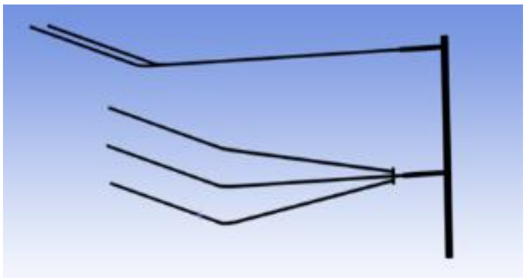

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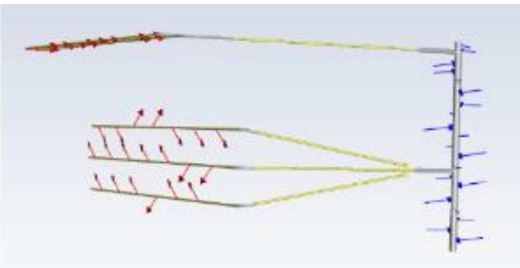
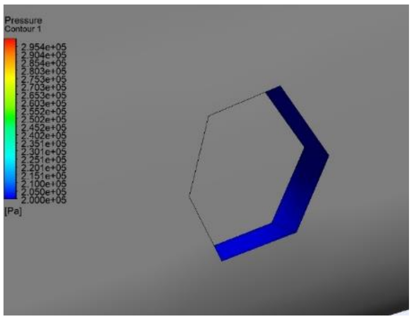


(d)

Fig. 6 (a) Geometry of SUV setup (b) Geometry of BUS setup (c) Mesh (d) Inputs and Results



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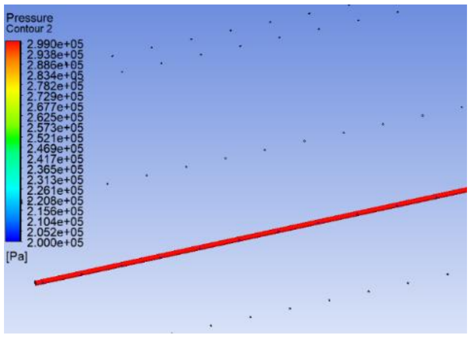

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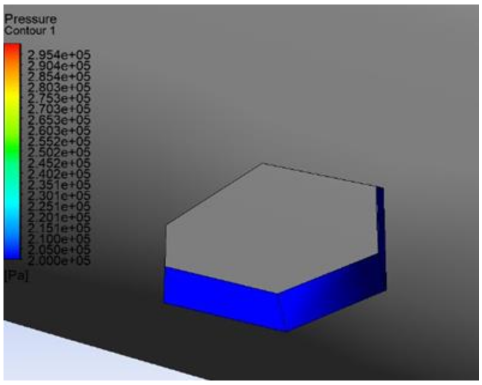

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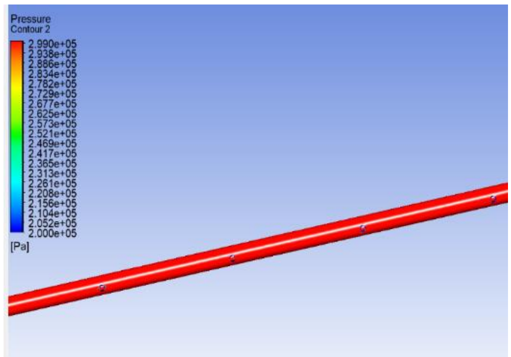

(d)

Fig. 7 (a) Nozzle Pressure for Lower section of pipes (b) Pipe Pressure for Lower section (c) Nozzle Pressure For upper section of pipes (d) Pipe Pressure For upper section (e) Pressure in Nozzle for BUS shower tester

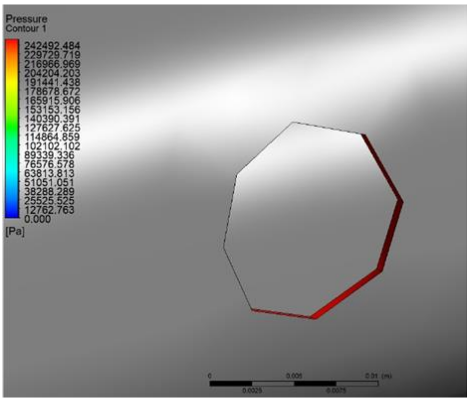

Fig. 8 Pressure in Nozzle for BUS shower tester

Furthermore, Fig. 7 demonstrates that while in the upper section pipes, the nozzles maintain around 2 bars, the pipe pressure remains closer to 3 bars.

BUS

Now for the bus setup, similar results were achieved in the nozzle pressure. Fig 8 shows that the pressure near the nozzle in the BUS pipe sections is approximately 2.2 bars.

From the ANSYS simulations, the velocity distribution and pressure drops were consistent with the theoretical results, with a deviation within 5-7%, validating the accuracy and reliability of the modified shower tester design for both SUVs and buses.

5. Conclusions

This research successfully redesigned and analyzed a shower tester system capable of testing both standard and large vehicles, addressing the limitations of the existing SUV-based setup at Pragoti Industries Limited. The proposed design included an expanded framework with improved pipe arrangements, the integration of a pump pit to ensure adequate pressure during bus tests, and the addition of a maintenance ladder for easier access to gauges and upper pipe joints. Hydraulic calculations of velocity, head losses, and pressure demonstrated that the pump system effectively overcame negative pressures and maintained the required 2 bar nozzle pressure for buses. Water consumption analysis indicated that the upgraded system supports 12,000-15,000 liters per SUV test and 31,840-39,800 liters per bus test, enabling 13-16 SUVs or 5-6 buses per tank fill. These results were further validated through ANSYS simulations, which confirmed nozzle pressures of approximately 2 bars for SUVs and 2.2 bar for buses. Overall, the study successfully presents a reliable and efficient modification of the existing SUV shower tester into an upgraded system capable of accurately and effectively testing both SUVs and buses.

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