

Performance Characteristic of a Plastic Bottle Bladderless Pressure Tank

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ABSTRACT: A bladderless water pressure tank system was designed and built with 2 L carbonated beverage plastic bottles for domestic water pump use. Drainage capacity, continuous water flow rate test and drawdown time test were conducted for a pressure tank capacity range of 2 to 20 L in increments of 2 L with a regulating flow meter set at 10 LPM and 24 LPM. The continuous average flow rate was maintained at $8.24 \text{ L/m} \pm 5.3\%$ with the flow meter set at 10 L/m, and $21.04 \text{ L/m} \pm 3.4\%$ with the flow meter set at 24 L/m. A comparison with commercially available bladder pressure tanks of similar capacity showed similar result. The experimental data indicated that the performance characteristic of the plastic bottle pressure tank for the continuous flow and drawdown time were similar to that of commercial bladder pressure tanks of comparable capacity.

KEYWORDS: Plastic bottle, Bladderless pressure tank, Water pump, Drawdown time.

I. INTRODUCTION

Most modern day households incorporate a water pump system to maintain a reliable water supply for everyday use. Modern day appliances and cold/hot water systems all require a minimum water pressure for proper functioning. The pressure tank incorporated in the water supply circuit is one of the critical element for regulating the water pressure [1]. The water pressure is regulated by compressed air within the pressure tank such that when a tap is opened the compressed air pushes the water through the pipe network system [2]. When the pressure drops below the set minimum a pressure switch is activated and the water pump turns on [3]. In this process the pump pushes water through the system and also refills the pressure tank. When the maximum set pressure is reached the pump cuts off and the water stored in the pressure tank maintains the supply without the pump working [4]. Because the pressure tank acts as a reservoir, it reduces the frequency of the pump on/off cycling, thereby prolonging the lifespan of the pump [5]. The pressure tank also reduces the instances of water hammer in the pipe network as it reduces the air and controls the pressure of the water [4, 5].

Plastic bottles are the most widely used containers for the storage of pressurized carbonated beverages. The 2 L bottles are convenient family size and commonly found worldwide. However, the widespread use of plastics has contributed to approximately 90 % of all trash floating on the ocean surface [6], with 46000 pieces of plastics per square mile [7, 8]. Recycling and reusing are two ways of reducing the detrimental effects of plastics [9]. The sport of creating water rockets reuses 2 L carbonated beverage bottles for building the rockets. This sport pushes the bottles to the limit to create more powerful rockets. Burst pressure tests showed that the typical 2 L Pepsi bottle burst at 165 psi [10]. The maximum operating pressure (MOP) is calculated as 70% of the burst pressure, resulting in the MOP for the 2 L Pepsi bottle being 115.5 psi [10, 11].

For most household domestic applications the pump operated water system works between pressures of 30 to 50 psi or between 40 to 60 psi to ensure safety of the plumbing network and appliances [12]. The water operating system MOP is approximately half the MOP from the burst pressure test. Therefore, using 2 L bottles is well within the safe operating range for use as a pressure tank within a domestic pump operated water system.

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II. PLASTIC BOTTLE PRESSURE TANK DESIGN

An assembly base was designed and built to accommodate ten 2 L plastic bottles. A drain valve was incorporated in the base to charge the pressure tank assembly with air. Figure 1 shows the frame that was constructed from ½" PVC pipe and fittings to hold the bottles inverted in the vertical position.

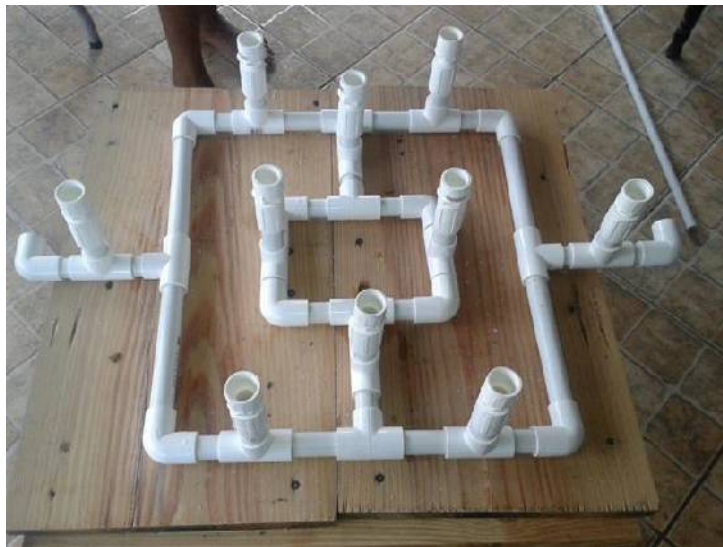


Fig. 1. PVC Base Frame Assembly

Figure 2 shows a schematic of the assembly with ten 2 L bottles in the inverted vertical position. As the water filled the bottles the air got trapped inside and was compressed. The base spaced the bottles so that there was no contact when assembled.

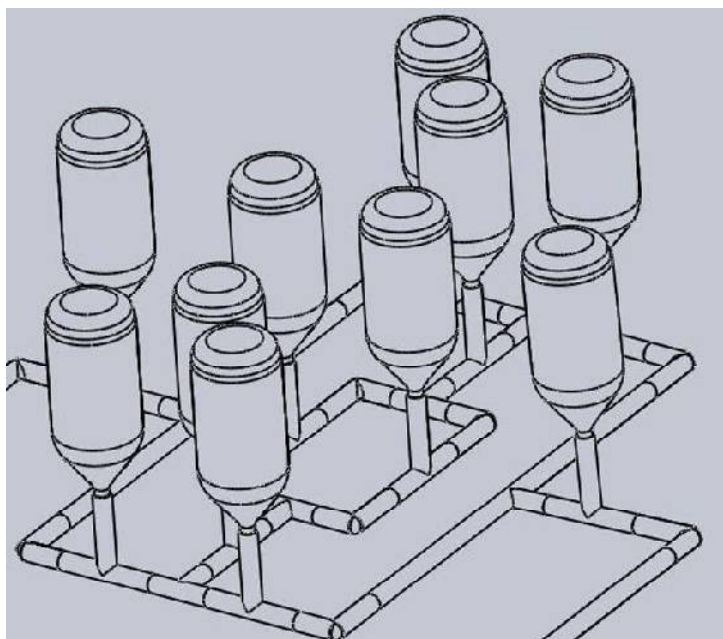


Fig. 2. Schematic of Pressure Tank Assembly

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Figure 3 shows an assembly with a pressure tank capacity of ten litres (five 2 L bottles). The bottles were attached to the assembly with a male adapter secured onto a female adapter on the base. The number of bottles can be varied by replacing the bottle with a male adapter and an end cap fitting. This enabled pressure tank capacity to be varied between 2 L to 20 L in increments of two litres.



Fig. 3. Picture of 10L Capacity Plastic Bottle Pressure Tank

III. EXPERIMENTAL RESULTS

To ascertain the performance characteristic of the plastic bottle pressure tank system, experiments were conducted for pressure tank capacity range between 2 L to 20 L in increments of two liters. The pump was set to operate with a 20 psi differential pressure between a low of 30 psi and a high of 50 psi. A calibrated flow meter on the outlet pipe regulated the flow rate and readings were recorded for 10 liters and 24 liters per minute. Measurements of drainage capacity, average continuous flow rate and drawdown time were recorded. To reduce the experimental error, for each test condition a minimum of ten readings were recorded and the average value calculated and are shown on Tables 1 to 5.

For the drainage capacity test the exit valve was closed and the pump filled the pressure tank. When the pressure in the system reached the high pressure cut-off the pump turned off. The valve between the pressure tank and pump was then closed and the exit valve was opened to allow the pressure tank to drain. The drainage volume was measured over the pressure tank capacity range 2 L to 20 L and the respective average values shown on Table 1.

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Table 1. Drainage Capacity Test Results

| No. of bottles | Pressure Tank Capacity (L) | Drainage Volume (L) |
|----------------|----------------------------|---------------------|
| 1 | 2 | 1.54 |
| 2 | 4 | 3.08 |
| 3 | 6 | 4.62 |
| 4 | 8 | 6.16 |
| 5 | 10 | 7.70 |
| 6 | 12 | 9.24 |
| 7 | 14 | 10.78 |
| 8 | 16 | 12.32 |
| 9 | 18 | 13.86 |
| 10 | 20 | 15.40 |

Average continuous flow-rate test was conducted with the flow meter set at 10 liters per minute. The exit valve was opened and the pump allowed to cycle between on and off for ten minutes. During this time, twenty samples of ‘time taken to full a 4 L container’ was recorded and the average flow rate calculated. This procedure was repeated for the pressure tank capacity range 2 L to 20 L and the respective average values shown on Table 2.

Table 2. Average Flow-rate Test Results at Flow Meter Set 10 LPM

| No. of bottles | Pressure Tank Capacity (L) | Average Flow-rate (L/minute) |
|----------------|----------------------------|------------------------------|
| 1 | 2 | 8.62 |
| 2 | 4 | 8.68 |
| 3 | 6 | 8.05 |
| 4 | 8 | 7.96 |
| 5 | 10 | 7.93 |
| 6 | 12 | 8.00 |
| 7 | 14 | 8.07 |
| 8 | 16 | 8.23 |
| 9 | 18 | 8.46 |
| 10 | 20 | 8.39 |

Average continuous flow-rate test was conducted with the flow meter set at 24 liters per minute. The exit valve was opened and the pump allowed to cycle between on and off for ten minutes. During this time, twenty samples of ‘time taken to full a 4 L container’ was recorded and the average flow rate calculated. This procedure was repeated for the pressure tank capacity range 2 L to 20 L and the respective average values shown on Table 3.

Table 3. Average Flow-rate Test Results at Flow Meter Set 24 LPM

| No. of bottles | Pressure Tank Capacity (L) | Average Flow-rate (L/minute) |
|----------------|----------------------------|------------------------------|
| 1 | 2 | 20.58 |
| 2 | 4 | 20.53 |
| 3 | 6 | 21.03 |
| 4 | 8 | 21.28 |
| 5 | 10 | 20.64 |
| 6 | 12 | 20.82 |
| 7 | 14 | 21.76 |
| 8 | 16 | 21.70 |
| 9 | 18 | 21.09 |
| 10 | 20 | 20.92 |

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The draw-down time was measured as the period between the stop and start of the pump cycle. The draw-down time test was conducted with the flow meter set at 10 liters per minute. The exit valve was opened and the pump allowed to cycle between on and off for ten minutes. For each test condition, twenty samples of draw-down time was recorded and the average calculated. This procedure was repeated for the pressure tank capacity range 2 L to 20 L and the respective average values are shown on Table 4.

Table 4. Draw-down Time Test Results at Flow Meter Set 10 LPM

| No. of bottles | Pressure Tank Capacity (L) | Draw-down Time (s) |
|----------------|----------------------------|--------------------|
| 1 | 2 | 2.38 |
| 2 | 4 | 3.50 |
| 3 | 6 | 4.72 |
| 4 | 8 | 6.19 |
| 5 | 10 | 8.03 |
| 6 | 12 | 8.35 |
| 7 | 14 | 9.72 |
| 8 | 16 | 11.25 |
| 9 | 18 | 13.21 |
| 10 | 20 | 15.09 |

The draw-down time test was conducted with the flow meter set at 24 liters per minute. The exit valve was opened and the pump allowed to cycle between on and off for ten minutes. For each test condition, twenty samples of draw-down time was recorded and the average calculated. This procedure was repeated for the pressure tank capacity range 2 L to 20 L and the respective average values shown on Table 5.

Table 5. Draw-down Time Test Results at Flow Meter Set 24 LPM

| No. of bottles | Pressure Tank Capacity (L) | Draw-down Time (s) |
|----------------|----------------------------|--------------------|
| 1 | 2 | 1.15 |
| 2 | 4 | 1.32 |
| 3 | 6 | 1.09 |
| 4 | 8 | 2.22 |
| 5 | 10 | 2.85 |
| 6 | 12 | 3.44 |
| 7 | 14 | 3.62 |
| 8 | 16 | 4.44 |
| 9 | 18 | 4.81 |
| 10 | 20 | 5.50 |

Two commercially available bladder pressure tanks commonly used for domestic household applications were tested to obtain comparative results. From the test results, the average values for the drainage volume, average flow rate and drawdown time were calculated and shown on Table 6.

Table 6. Test Results for Commercial Pressure Tanks

| Commercially available Pressure tank (L) (gallons) | Drainage Volume (L) | Average Flow-rate @ flow meter set 10 L/m (L/minute) | Average Flow-rate @ flow meter set 24 L/m (L/minute) | Draw-down Time (s) @ flow meter set 10 L/m | Draw-down Time (s) @ flow meter set 24 L/m |
|--|---------------------|--|--|--|--|
| 7.57 L (2 gal) | 2.00 | 9.18 | 21.22 | 5.51 | 2.20 |
| 16.65 L (4.4 gal) | 4.95 | 9.07 | 22.79 | 12.34 | 4.38 |

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IV. ANALYSIS AND DISCUSSION

The pressure tank in a water network system serves several functions. It acts as a reservoir such that when a valve is opened water flows without the pump turning on until the reserve capacity reaches the minimum cut-in pressure. This reduces the pump cycling frequency which ultimately prolongs the pump lifespan. The pressure tank also maintains a working pressure range and flow rate in the water system and absorbs the sudden pressure increase in pressure when the pump turns on thereby preventing the water hammer effect in the system.

The drainage volume test results is an indication of the maximum storage capacity of the pressure tank system. This information can be used in sizing the pressure tank capacity for respective application. A plot of drainage volume with tank capacity (Fig. 4) show a straight line. This indicates for the plastic bottle system the required tank size can be varied with a linear variation of the number of bottles.

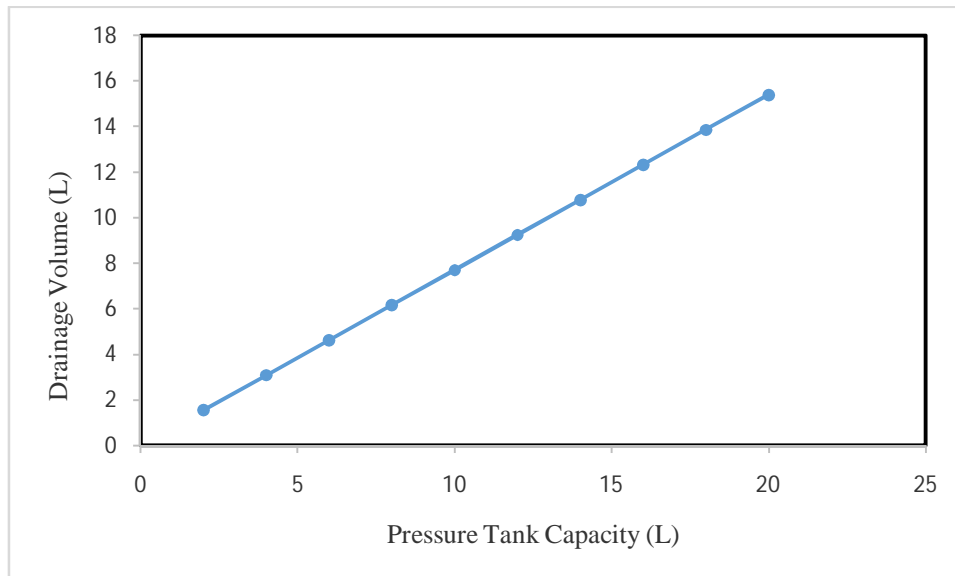


Fig 4. Plot of Drainage Volume with Tank Capacity

The flow rate tests results determines the ability of the pressure tank to maintain a working flow rate (working pressure) within the water network for the proper functioning of equipment and appliances. From the results shown on Table 2 and Table 3, the plastic bottle pressure tank design maintained an average flow of 8.24 L/m \pm 5.3% with the flow meter set at 10 L/m, and 21.04 L/m \pm 3.4% with the flow meter set at 24 L/m. This indicated that the plastic bottle pressure tank was able to maintain a consistent flow rate within the system as the pump cycled between on and off.

The drawdown time indicated the frequency with which the pump turns on/off which directly translates to the wear and lifespan expectancy of the pump. The plot of drawdown time with tank capacity (Fig. 5) indicated a linear relationship for both 10 and 24 L/m flow rate test.

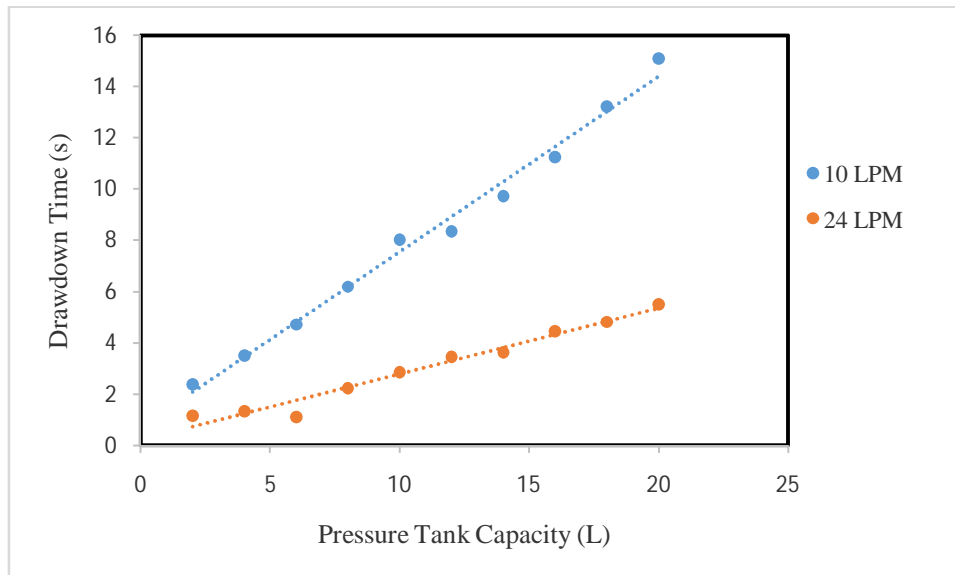


Fig. 5. Plot of Drawdown Time with Tank Capacity

Compared to a similar capacity commercial pressure tank, the drainage capacity of the bladderless plastic bottle pressure tank was almost three times the drainage capacity of the bladder pressure tanks. This may be attributed to the pre-charged bladder system and the restriction on the air compression by the bladder. Test results for the average flow rate and drawdown time were similar for the commercial pressure tanks and the plastic bottle pressure tank. This indicated that the plastic bottles were performing comparable to the commercial pressure tanks of similar capacity.

V. CONCLUSIONS

- The bladderless plastic bottle pressure tank has a higher drainage capacity than the bladder pressure tank of similar capacity.
- The continuous average flow rate maintained at 8.24 L/m \pm 5.3% with the flow meter set at 10 L/m, and 21.04 L/m \pm 3.4% with the flow meter set at 24 L/m.
- The plot of drawdown time with tank capacity showed a linear relationship.
- The performance characteristic for the continuous flow and drawdown time were similar to that of commercial bladder pressure tanks of comparable capacity.

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BIOGRAPHY



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