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Accelerated Life Testing of a Reused Plastic Bottle Bladderless Pressure Tank

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Author's contribution

The sole author designed, analyzed, interpreted and prepared the manuscript.

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ABSTRACT

Reusing plastic material help mitigate the world wide problem of plastic pollution. In this study a bladderless pressure tank for use with domestic water pumps was designed and built from reused 2 L plastic bottles. Accelerated life testing was conducted to determine the variation of drawdown capacity and recharge time for the plastic bottle pressure tank and comparative tests were conducted with two commercial bladder pressure tanks. The drawdown capacity test for both the 8 L and 18 L bladderless plastic bottle pressure tank showed a linear decrease in drawdown capacity over the accelerated 4 month test period and indicated just over 10% reduction in drawdown capacity after the accelerated 4 month test period. The rate of drawdown capacity decrease per accelerated time test day for the 8 L and 18 L plastic bottle pressure tanks at the 10 L/m and 24 L/m flow rates was 0.7% and 0.55% and 1.43% and 1.30%, respectively. Recharging both the 8 L and 18 L bladderless pressure tanks after the accelerated 4 month test time showed that the drawdown capacity was restored to the original amount. The comparative drawdown capacity test between the commercial pressure tanks and the bladderless reused plastic bottle pressure tank of similar capacity showed similar initial drawdown capacity volume at both the 10 L/m and 24 L/m flow rates.

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This indicated that the reused plastic bottle pressure tank was capable of performing comparable to the commercial pressure tanks. To maintain the drawdown capacity of the bladderless pressure tank within 10% of the original value, the system should be recharged approximately every 4 months.

Keywords: Pressure tank; plastic bottle; accelerated life test; reusing plastic; drawdown capacity.

1. INTRODUCTION

Plastic is one of the most versatile material discovered by mankind. Its touches the very fabric of life on earth today as its use can be seen everywhere. However, the large-scale use and non-biodegradability of plastics has evolved into major disposal issues worldwide. A large proportion of marine debris consists of plastics or synthetics that generally do not biodegrade [1]. The scale of contamination of the marine environment by plastic debris is vast [2]. It is found floating in all the world's oceans, everywhere from Polar Regions to the equator [3]. Reusing and recycling plastic material are some of the ways of lessening the plastic pollution.

The packaging of pressurised carbonated beverages in non-reusable plastic bottles is commonplace in today's society. The 2 L size beverage bottles are a common family size. Hobbyists reuse the 2 L plastic bottles to construct water rockets. One of the critical factors in this sport is the burst test of the bottles to determine the maximum operating pressure (MOP) [4]. From test conducted the 2 L Coke bottle showed a burst pressure of 168 psi and the 2 L Pepsi bottle showed a burst pressure of 165 psi [4]. The MOP is calculated as the 70% of the lowest pressure that caused the bottle to burst [4]. This gives a MOP of 7.96 b (115.5 psi). In general, most water pumps for household applications are set to operate within a 1.38 b (20 psi) range between starting and stopping of the water pump [5]. Most systems operate within the range 2.76 b (40 psi) to 4.43 b (60 psi) or 2.07 b (30 psi) to 3.45 b (50 psi) [5]. The MOP of the plastic bottles is about twice the MOP of the domestic water pumps and can therefore satisfy safe pressure tank operating conditions [6].

The carbonated beverage plastic bottles are made from polyethylene terephthalate (PET) [7,8]. This material is widely used as commercial sale water bottles and certified safe by the U.S. Food and Drug Administration (FDA). FDA has reviewed migration-testing data and has concluded that PET containers do not leach harmful amounts of substances into their contents even under extreme conditions of use as the FDA takes into account exposures to higher temperatures, such as during storage and transportation of bottled water prior to sale, in its estimates of potential levels of migration of substances from the plastic to the water [9]. Accelerated weathering machines testing according to ASTM Practice G155 cycle 1 and impact strength testing according to ASTM D6395 showed that for a simulated 15 weeks UV exposure at 340nm the retention of toughness of extrusion blow molded PET bottles decrease by 15% [10]. Therefore, to prevent premature aging of the PET bottles the plastic bottle pressure tank should not be exposed to direct sunlight [11].

The pressure tank in a water circuit is critical for the proper functioning of a reliable water supply. The pressure tank stores high pressure water via compressed air and when demand is required the stored water flows without the pump turning on. In this way the pump running time is reduced thereby extending pump life [12]. The pressure tank also reduces the water hammer effect on the pipe network by the air cushioning the sudden high pressure when the pump turns on. Therefore a reliable and durable pressure tank is essential.

Bladderless pressure tanks are not commonly used today as the diaphragm or bladder pressure tanks has the inherent advantage of less maintenance and smaller size. However, in years gone-by bladderless galvanized pressure tanks were used and some homeowners reported to have them for more than 25 years [13]. A bladderless tank requires more attention on the part of the homeowner as forgetting to periodically add air will result in short-cycling the pump [14]. Another issue is that of corrosion if the galvanized tank is not coated properly or there is a crack in the surface coating, but this can also be an issue with the bladder tanks [13,14]. The use of plastic bottles will eliminate the issue of corrosion and the reused carbonated beverage bottles translates into a free pressure tank. The carbonated beverage bottles are already sterile and properly sanitized, therefore, minimal rinsing with potable water (boiled if necessary) of the bottles are required before constructing the pressure tank [15].

The construction of a bladderless pressure tank from reused 2 L carbonated beverage plastic bottles need to be tested to determine the reliability and durability for use in a water network. Accelerated life testing is the process of testing a product by subjecting it to conditions in excess of its normal service parameters in an effort to uncover faults and potential modes of failure in a short amount of time [16,17]. By analyzing the product's response to such tests, engineers can make predictions about the service life and maintenance intervals of a product [18,19]. In this study the accelerated life testing was used to analyze the viability and suitability of using 2 L plastic bottles as a low-cost replacement for pressure tanks.

2. PRESSURE TANK DESIGN

A PVC circuit was designed to accommodate ten 2 L plastic bottles in the vertically inverted position. In the circuit the plastic bottle pressure tank capacity can be varied by removing or adding bottles as necessary to simulate comparative capacity to commercially available pressure tanks as shown in Fig. 1. The PVC circuit was a simple construction that any homeowner can do. The construction involved using a ½ inch PVC 'T' connector in the water line to accommodate the inverted plastic bottle. The ½ inch pipe was glued directly into the mouth of the plastic bottle. To facilitate addition or removal of bottles for testing purposes, the bottles were attached via male and female PVC threaded connectors. The bottles were attached inverted to the circuit arrangement through a male PVC connector and 12.7 mm (1/2") PVC pipe glued to the top of the bottle. The circuit accommodated two commercial bladder pressure tanks for comparative testing as shown in Fig. 2. The capacity of the commercial tanks were 7.57 L (2 gallon) and 16.65 L (4.4 gallon). The area occupied by the ten 2 L bottles were approximately the same as that of the 16.65 L tank (Fig. 2). The specifications of the commercial tanks are shown on Tables 1 and 2. Stop valves were appropriately located in the circuit such that each pressure tank system can be isolated and tested independently. A drain valve was incorporated in the plastic bottle pressure tank circuit to facilitate recharging as the bottles become saturated with water. Recharging was done by isolating the plastic bottle pressure tank and completely draining the water through the drain valve thereby allowing air to completely fill the bottles.

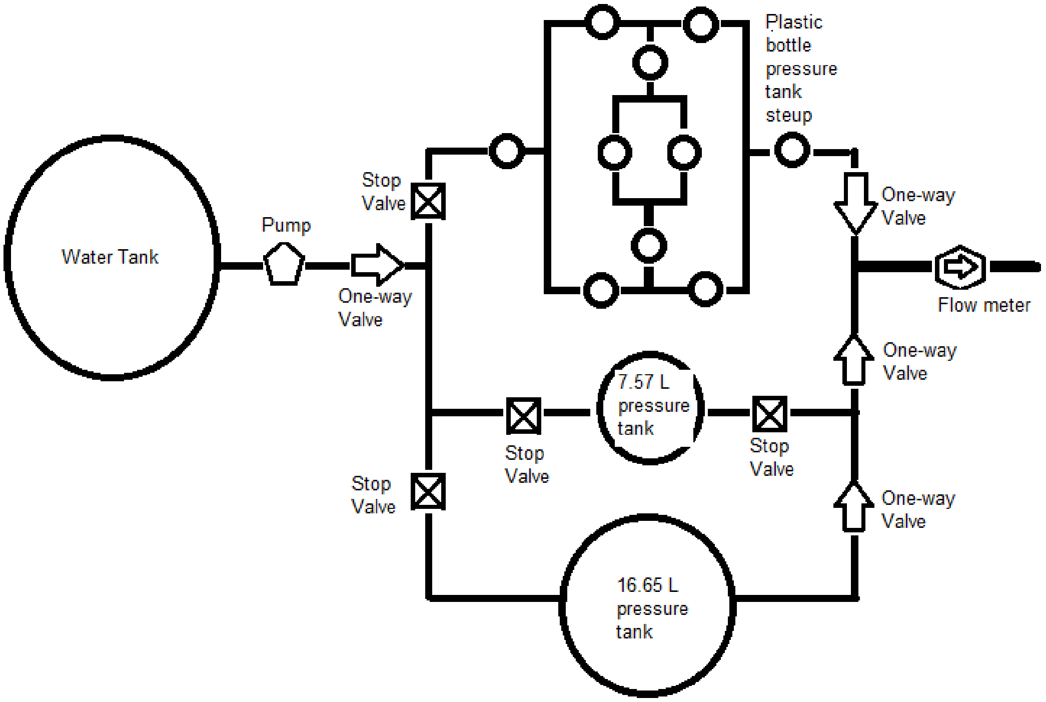

Fig. 1. Schematic of PVC circuit to accommodate plastic bottles and commercial pressure tanks

Table 1. Specifications for the 7.57 L pressure tank used for comparative testing – Amtrol – Model WX-101 [20]

Feature	Specification
Capacity (gallons)	2
Maximum working pressure, bar (psi)	10.34 (150)
Maximum relief pressure, bar (psi)	8.62 (125)
Material	Polypropylene liner, stainless steel waterway, butyl rubber diaphragm
Date of manufacture	9/6/2011
DOT Test Pressure, bar (psi)	10.34 (150)

Fig. 2. Picture of pressure tank test assembly showing commercial pressure tanks and plastic bottle pressure tank of 10 L capacity

Table 2. Specifications for the 16.65 L pressure tank used for comparative testing – Amtrol – Model WX-102 [20]

Feature	Specification
Capacity (gallons)	4.4
Maximum working pressure, bar (psi)	10.34 (150)
Maximum relief pressure, bar (psi)	8.62 (125)
Material	Polypropylene liner, stainless steel waterway, butyl rubber diaphragm
Date of manufacture	3/1/2011
DOT Test Pressure (psi)	10.34 (150)

3. EXPERIMENTAL PROCEDURE AND TEST RESULTS

To design the accelerated life testing model for the plastic bottle pressure tank system, preliminary cycle time test were conducted on the two commercial pressure tanks. A calibrated flow control meter on the exit line was used to regulate the flow rate. Tests were conducted with the 7.57 L and 16.65 L pressure tanks with the flow rate regulated at 10 L/m and 24 L/m, respectively. For each test condition the pump cycle time was recorded as the number of times per minute that the pump cycled between on and off. For each test condition ten readings were recorded and the average value calculated and shown on Tables 3 and 4.

Table 3. Pump cycle time test results at 10 LPM

Commercial pressure tank	
Capacity (L)	**Cycles per minute**
7.57	7
16.65	5

Table 4. Pump cycle time test results at 24 LPM

Commercial Pressure Tank	
Capacity (L)	**Cycles per minute**
7.57	12
16.65	6

The results indicated that the shortest cycle time of 12 per minute occurred at a flow rate of 24 L/m for the 7.57 L pressure tank. Using this value and the approximation that the average cumulative pump running time per day for a domestic household pump as three hours, the number of cycles per month is calculated as 64800. For accelerated life test conditions with the pump cycling continuously at 12 cycles/m, the 64800 cycles would be covered in 3.75 days. Therefore, the accelerated life testing for 4 days will simulate the pressure tank operation for 1 month.

The accelerated life testing of the 2 L reused plastic bottle pressure tank was designed to determine the drawdown capacity variation with time and the frequency of recharging the pressure tank with air after a 10% capacity reduction. For each of the pressure tank system; the commercial 7.57 L bladder pressure tank; the commercial 16.65 L bladder pressure tank; the 8 L (4 bottles) reused plastic bottle bladderless pressure tank; and the 18 L (9 bottles) reused plastic bottle pressure tank; tests were conducted at flow rates of 10 L/m and 24 L/m. For each test variation the initial drawdown capacity was recorded. The system then allowed to cycle and drawdown capacity recorded at 4 days interval for 16 days. The bladderless pressure tanks were then re-charged with air and the drawdown capacity rechecked. Each tabulated test result is the average value of 10 measurements. The test results are shown on Tables 5 and 6. Figs. 2 and 3 are plot of the test results. The Method of Least Squares was used to determine the best fit straight line to the results and the respective equations determined for the plastic bottle pressure tanks.

Table 5. Drawdown capacity variation with time at a flow rate of 10 L/m

	Drawdown capacity (L) @ 10 L/m flow rate			
	7.57 L pressure tank (L)	**16.65 L pressure tank (L)**	**8 L plastic bottle pressure tank (L)**	**18 L plastic bottle pressure tank (L)**
Initial test	0.92	2.06	1.03	2.20
After 4 days	0.93	2.10	0.99	2.06
After 8 days	0.92	2.00	0.96	1.99
After 12 days	0.91	2.04	0.93	1.97
After 16 days	0.93	2.06	0.92	1.96
Air recharge			1.01	2.21

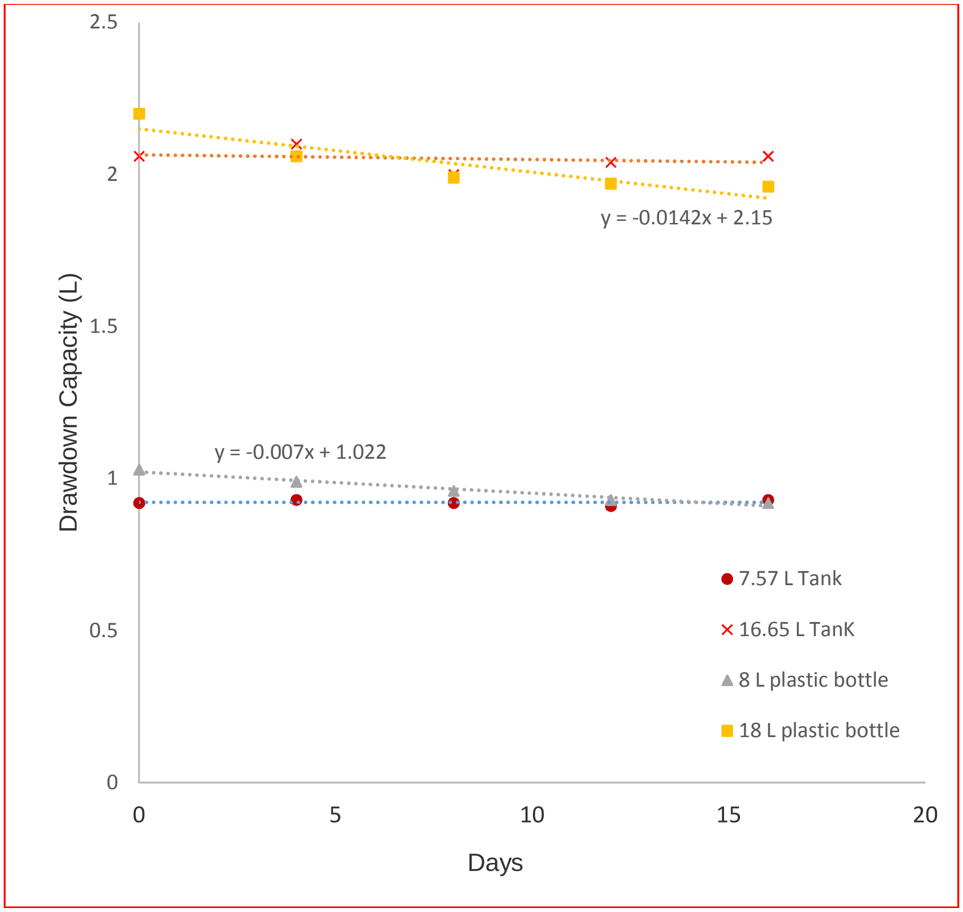

Fig. 3. Plot of Drawdown capacity variation with time at a flow rate of 10 L/m

Table 6. Drawdown capacity variation with time at a flow rate of 24 L/m

	Drawdown capacity @ 24 L/m flow rate			
	7.57 L pressure tank (L)	**16.65 L pressure tank (L)**	**8 L plastic bottle pressure tank (L)**	**18 L plastic bottle pressure tank (L)**
Initial test	0.88	1.75	0.89	1.92
After 4 days	0.87	1.73	0.87	1.85
After 8 days	0.89	1.76	0.85	1.80
After 12 days	0.88	1.75	0.83	1.73
After 16 days	0.87	1.74	0.80	1.72
Air recharge			0.90	1.92

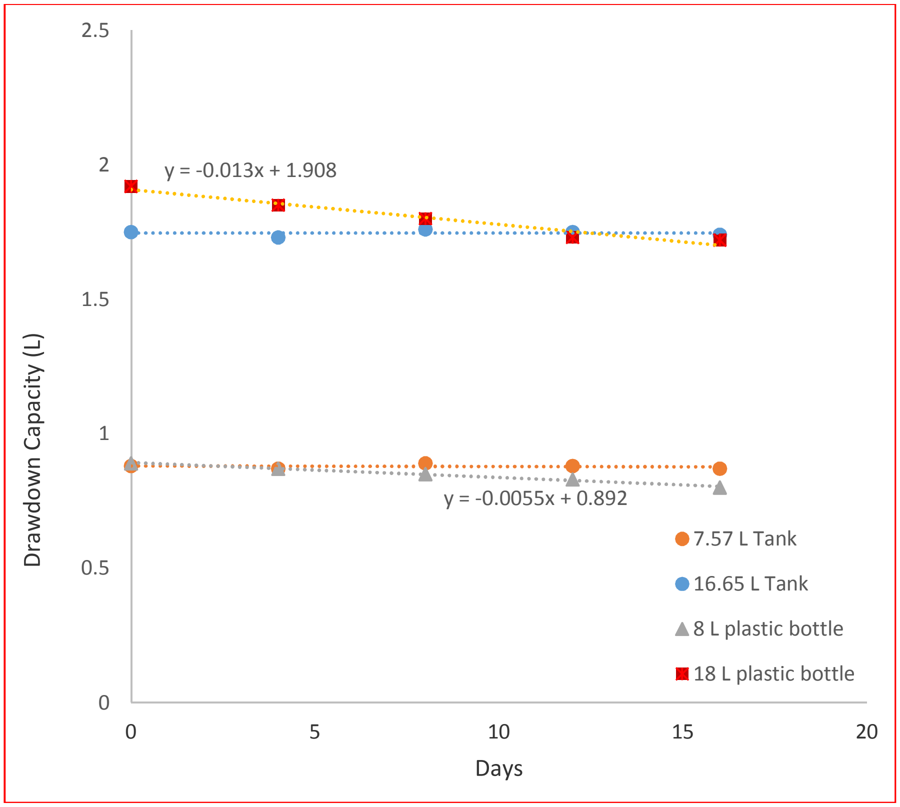

Fig. 4. Plot of drawdown capacity variation with time at a flow rate of 24 L/m

4. DISCUSSION

The accelerated life test of the reused 2 L plastic bottles simulated working conditions for a 4 month period. The comparative drawdown capacity test for the two commercial bladder pressure tanks at both test flow rates of 10 L/m and 24 L/m indicated minimal change in the drawdown capacity for the simulated 4 month test period. This result is consistent with the results for bladder pressure tanks as the air and water in the system do not mix [6]. The drawdown capacity test for both the 8 L and 18 L bladderless plastic bottle pressure tank showed a linear decrease in drawdown capacity over the accelerated 4 month test period. This may be due to the water and air being in direct contact in the bladderless pressure tank. With time and under pressure the air slowly diffused in the water thereby reducing the volume of air in the pressure tank resulting in a lower drawdown capacity. Using the Method of Lease Squares the equations for the best fit straight line to the experimental data were determined (shown in Figs. 3 and 4) for the 8 L and 18 L plastic bottle pressure tanks at the 10 L/m and 24 L/m flow rates, respectively. In each case the drawdown capacity showed a linear decrease with time.

The rate of drawdown capacity decrease per accelerated time test day for the 18 L plastic bottle pressure tank was 1.43% and 1.30% for the 10 L/m and 24 L/m flow rates, respectively. The rate of drawdown capacity decrease per accelerated time test day for the 8 L plastic bottle pressure tank was 0.7% and 0.55% for the 10 L/m and 24 L/m flow rates, respectively. This results shows that the rate of drawdown capacity decrease for the 8 L plastic bottle tank was about half that of the 18 L plastic bottle tank. Recharging both the 8 L and 18 L bladderless pressure tanks after the accelerated 4 month test time showed that the drawdown capacity was restored to the original amount.

The comparative drawdown capacity test between the commercial pressure tanks and the bladderless reused plastic bottle pressure tank of similar capacity showed similar initial drawdown capacity volume at both the 10 L/m and 24 L/m flow rates. This indicated that the reused plastic bottle pressure tank was capable of performing comparable to the commercial pressure tanks. All the pressure tanks indicated a higher drawdown capacity at the lower 10 L/m flow rate. This result may be due to less compression of the air in the pressure tanks resulting from the higher out-flow-rate from the system.

At both 10 L/m and 24 L/m flow rates the 8 L and 18 L capacity bladderless plastic bottle pressure tanks showed just over 10% reduction in drawdown capacity after the accelerated 4 month test period. Therefore, in order to maintain the drawdown capacity of the bladderless pressure tank within 10% of the original value, the system should be recharged approximately every 4 months. This is a disadvantage compared to the bladder pressure tanks that maintained the drawdown capacity after the accelerated 4 months test time. However, the reused plastic bottles were free and the PVC circuit built from low cost PVC components. Also, there are no bladder in the system to fail and the recharging process took about 1 minute time to complete.

5. CONCLUSION

The accelerated life test indicated that the commercial bladder pressure tanks maintained the drawdown capacity over the accelerated 4 month test period. The bladderless plastic bottle pressure tank showed a linear decrease in drawdown capacity over the accelerated 4 month test period. The slope of the best fit line for the for the plastic bottle pressure tank showed the drawdown capacity decrease per accelerated time test day for the 18 L plastic bottle pressure tank was 1.43% and 1.30% for the 10 L/m and 24 L/m flow rates, respectively and for the 8 L plastic bottle pressure tank was 0.7% and 0.55% for the 10 L/m and 24 L/m flow rates, respectively. The commercial pressure tanks and the bladderless reused plastic bottle pressure tank of similar capacity showed similar initial drawdown capacity volume. The bladderless plastic bottle pressure tanks showed just over 10% reduction in drawdown capacity after the accelerated 4 month test period. To maintain the drawdown capacity of the bladderless pressure tank within 10% of the original value, the system should be recharged approximately every 4 months.

COMPETING INTERESTS

Author has declared that no competing interests exist.

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