Can One Machine Clean All Permeable Pavements?

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Abstract
Since their advent in the 1990s, municipalities have constructed millions of square meters of permeable pavements in parking lots, alleys and streets. These typically consist of porous asphalt, pervious concrete and permeable interlocking concrete pavements. In many cases, municipalities may own one, two or three pavement types. As more permeable pavements are installed, they require regular maintenance to remove embedded sediment and to maintain their surface infiltration. Considerable research has been conducted using various types of surface cleaning equipment on all of these pavement types. Managing equipment costs, personnel time, or outsourcing costs for surface cleaning all present the desire for a single machine that provides routine maintenance cleaning as well as restoration of clogged surfaces if maintenance is neglected. This paper provides an initial assessment of pre- and post-cleaning infiltration effectiveness using a Cyclone CY5500 machine on porous asphalt, pervious concrete and permeable interlocking concrete pavements in a prototypical residential neighborhood in Northwest Washington, DC. All of the permeable pavements were installed by the District of Columbia Department of Transportation (DDOT) as part of a combined sewer overflow mitigation program.

Background
Considerable research has been conducted using various types of surface cleaning equipment. While this paper is not a review this literature, some salient subject references on cleaning research follow: Winston 2016; Drake 2013; Chopra 2010; Blecken in press; Bean 2007; Al-Rubaei 2013; Sansalone 2008; Fassman 2010; Illgen 2007; Gyllefjord 1989; Backstrom 2000; Boogaard 2014; Gerrits 2002; Balades 1995; Vancura 2012; Dougherty 2011 and Haselbach 2010.

A summary of recommended maintenance practices is found in the book, *Permeable Pavements* (Eisenberg 2015). For regular maintenance of porous asphalt (PA), pervious concrete (PC) and permeable interlocking concrete pavement (PICP), a regenerative air machine is recommended. Regenerative air machines are effective for removing loose sediment, leaves, and litter from permeable pavement surfaces. They are not effective in removing sediment settled into permeable pavements due to weather and traffic impacts.

For these highly clogged surfaces, a true or full vacuum machine is recommended often with water to loosen sediment. True vacuum equipment is reserved for permeable pavement surfaces that offer little loose surface material and instead present sediment that is ground or pressed into the surface from tires or settled into the surface from repeated rainfalls. While exact numbers aren't available, regenerative air machines (of which there are at least four manufacturers) are more common than true vacuum equipment. The former equipment is commonly used by commercial contractors to clean commercial parking lots while the latter is usually purchased by a municipality to clean out catch basins. Such equipment may require modification and expense to include an under-chassis vacuum intake orifice as well as rotating broom sweepers. Regenerative air machines and operators can be rented from a parking lot cleaning service. True vacuum machines are generally not used by such cleaning services due to their higher capital expense, lower maneuverability, and design to remove sediment, not generally required by commercial parking lot clients. Given a site might have either diligent maintenance or none, there is a desire for one machine that can perform routine surface cleaning on all permeable pavements to prevent clogging, as well as one that can restore clogged surfaces. This would benefit municipal and private owners of permeable pavements.

Test Area Locations

Given this need, an opportunity arose to test cleaning equipment on PA, PC and PICP within a block or two of each other in a residential neighborhood in Northwest Washington, DC (near 33rd and Quesada Streets) in June 2015. The pervious concrete was in two on-street parking lanes. One was cast-in-place pervious concrete and the other was a pre-cast pervious concrete panel among several in the parking lane. These two areas received contributing run-on from the impervious center lane of the street. The PA and PICP were situated in alleys, with some or little contribution run-on from impervious surfaces and they received sediment from adjacent vegetated areas. All of the permeable pavements were subject to leaves and debris from a mature urban forest canopy in a residential setting. All of the pavements were no older than a year in service.

Cleaning Equipment

The equipment used was a Cyclone CY5500 powered by a diesel engine. The machine was brought to the site on a trailer towed by a heavy-duty pickup truck. Cyclone manufactures a smaller walk-behind model and a larger truck-size version. This cleaning was done by an off-road vehicle smaller than the truck-size equipment.

The equipment was originally developed to remove tire rubber from airfield runways. This machine carries approximately 1200 liters (300 gal) of water much of which is drawn back into the machine, filtered and re-used.

The Cyclone machine relies on water applied in a circular motion within a surrounding chamber in close contact with the permeable pavement surface. The water pressure can be varied by the operator from 8 MPa (1, 200 psi) to 30 MPa (4,350 psi). The water is blasted against the pavement surface and the speed of the rotating head applying the water provides some suction (hence the cyclone name) to pull the most of the water back into the machine where is it filtered for re-use. The machine manufacturer claims cleaning rates as high as approximately 935 square meters (10,000 sf) per hour on most permeable pavements. A picture of the machine is in Figure 1 below.

Figure 1. A Cyclone CY5500 machine used in this test experiment

Cleaning and Infiltration Testing Procedures

The four areas were cleaned in the following order: cast-in-place PC, PICP, PA, then the precast PC panel. Prior to conducting cleaning, ASTM C1701 *Standard Test Method for Infiltration Rate of In Place Pervious Concrete* and C1781 *Standard Test Method for Surface Infiltration Rate of Permeable Unit Pavement Systems* was applied to each surface. The former test method is applicable to porous concrete and both methods produce comparable results. Both ASTM test methods label the initial test procedure "pre-wetting" to determine the extent of surface clogging. This is done by applying approximately 5 kg (8 lbs) (roughly equivalent to 5 liters (1 gal)) of water into a 30 cm (12 in.) diameter ring sealed to the pavement with plumber's putty and while maintaining an approximate head of 10 mm (3/8 in.). This is illustrated in Figures 2 through 5.


Figure 2. Initial or pre-wetting test using ASTM C1701 on pervious concrete parking lane. Note the standing water due to a clogged surface.


Figure 3. Initial or pre-wetting test using ASTM C1781 permeable interlocking concrete pavement alley. Standing water indicates a clogged surface.

Figure 4. Initial or pre-wetting test using ASTM C1701 on porous asphalt alley. Note the standing water due to a clogged surface.

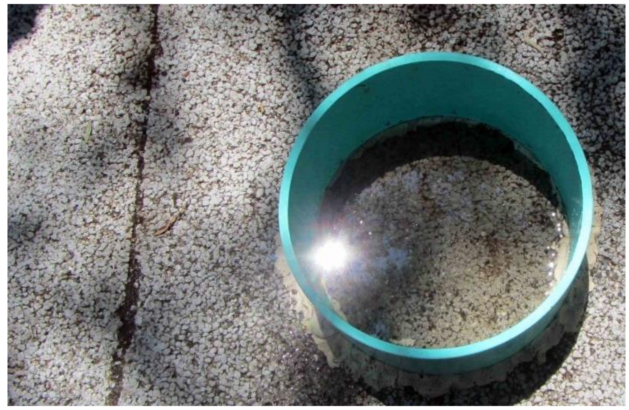

Figure 5. Initial or pre-wetting test using ASTM C1701 on pre-cast pervious concrete panel in the street parking lane. Note the standing water due to a clogged surface.

If the pre-wetting water applied into the ring requires more than 120 seconds to completely infiltrate, then the same amount of water (5 liters) is applied 2 minutes later. Procedures in this experiment deviated from the ASTM procedures by having the Cyclone machine pass twice over the same area of permeable pavement almost immediately after the pre-wetting was completed , requiring a few minutes of time. The pre-wetting initial infiltration test measurement was conducted to determine the extent of clogging. Figure 6 show the Cyclone machine making a typical pass of about 10 m.

After the second pass, the ring with plumbers putty was applied to the pavement surface and an additional (approximate) 5 kg of water was applied and the surface infiltration rate was calculated per the ASTM standards. Both standards use the same surface infiltration calculation. If the surface infiltration rate was under 250 mm/hr (100 in./hour) the Cyclone machine made an additional two passes, the 30 cm diameter ring with plumbers putty was reapplied in the same location and an additional approximate 5 kg of water applied into the ring. Table 1 provides a summary of the surface infiltration test results.

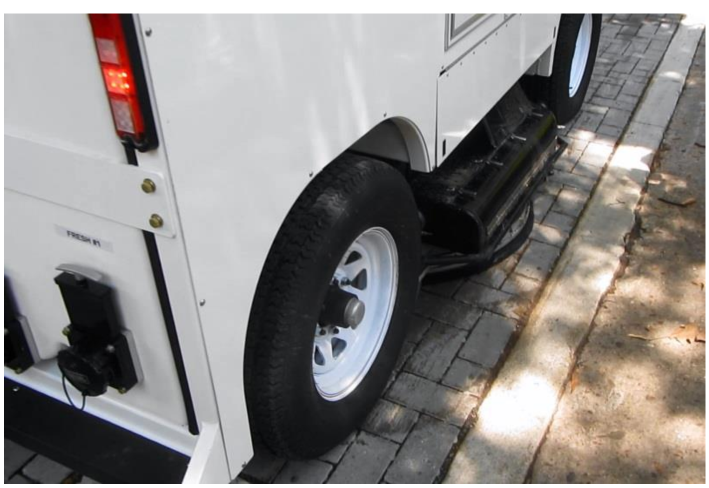

Figure 6. The Cyclone machine cleaning a PICP alley.

Table 1. Surface infiltration test results for the permeable pavements

	Cast-in-Place Pervious Concrete On-Street Parking Lane	**Permeable Interlocking Concrete Units Alley**	**Porous Asphalt Alley**	**Pervious Concrete Precast Panel On-Street Parking Lane**
Pre-wet in seconds, estimated infiltration rate calculated per C1701/C1781	>360 seconds <508 mm/hr (<20 in./hr)	>360 seconds <508 mm/hr (<20 in./hr)	170 seconds 1067 mm/hr (42 in./hr)	>360 seconds <508 mm/hr (<20 in./hr)
Cyclone water pressure, number of passes	30 MPa (4350 psi), 2 passes	30 MPa (4350 psi), 2 passes	19.3 MPa (2800 psi), 2 passes	30 MPa (4350 psi), 2 passes
Seconds to infiltrate, calculated infiltration rate per C1701/C1781	180 seconds 1016 mm/hr (40 in./hr)	22 seconds, 8306 mm/hr (327 in./hr)	180 seconds 1016 mm/hr (40 in./hr)	>360 seconds <508 mm/hr (<20 in./hr)
Cyclone water pressure, number of passes	30 MPa (4350 psi), 2 passes	17.2 MPa (2500 psi) on second two passes on location about 10 feet away to test for aggregate removal; no infiltration test conducted due to high infiltration on first two passes in different location	30 MPa (4350 psi), 2 passes	30 MPa (4350 psi), 2 passes
Seconds to infiltrate, calculated infiltration rate per C1701/C1781	90 seconds, 2032 mm/hr (80 in./hr)	Not needed	100 seconds, 1829 mm/hr (72 in./hr)	55 seconds, 3302 mm/hr (130 in./hr)

Discussion
The authors were surprised that all of the permeable pavements had very low infiltration rates initially as demonstrated by the pre-wetting rates on the first row of Table 1. The water pressure on the first two passes of the Cyclone CY5500 across the PA was reduced from 30 MPa (4350 psi) to 19.3 MPa (2800 psi) out of concern for damaging the surface. However, this was not evident and the pressure was increased to the same level used on the PC and PICP on the second pair of passes as a result. There was no visible damage to the PA at either pressure level.

Table 1 shows the increased infiltration rates after the first two passes on the PC, PICP and PA. Infiltration rates doubled for the PC and PA but still could be considered low. There was little if any change in the infiltration rate of the precast PC panel after the first two passes. The second two passes yielded better results with PC infiltration rate doubling again and the PA almost reaching the same level. The precast panel saw a substantial increase as well, from <508 mm/hr (<20 in./hr) to 3302 mm/hr (130 in./hr) after the second round of two passes. We can only speculate that the water soaked into the surface on the first two passes and helped to loosen sediment so it could be removed on the second pass.

The most notable observation is that the PICP only required two passes of the Cyclone machine rather than four to increase the infiltration rate from <508 mm/hr (20 in./hr) to 8306 mm/hr (327 in./hr). The joints widths in the PICP were narrow, approximately 6 mm (1/4 in.) wide and many of the small aggregates were pulled out with the sediment after the first two passes. Some of the stones were left on the surface of the pavers after the second pass and these could be swept back into the joints. See Figure 6. Additional aggregate should probably be supplied given these results, as that is the recommendation by Eisenberg (2015) in the ASCE book, Permeable Pavements, Chapter 8.

Figure 6. PICP after two passes of the Cyclone machine.
Note aggregate and sediment removed resulting in open joints.

Conclusions

The ability of the Cyclone machine to clean the most commonly used permeable pavements was clearly demonstrated by these infiltration test results on heavily clogged pavements. In this case, the Cyclone machine was assigned to clean highly clogged pavements however it can be set on a lower pressure setting to clean it in a less clogged condition, i.e., remove loose material from the pavement surface. While we cannot decisively conclude that the Cyclone machine can clean all permeable pavements, the machine used demonstrated that potential due to variable pressure settings used, and the resulting vacuum force to simply remove loose leaves, debris and sediment for normal to routine cleaning, with higher settings also used for clogged pavement conditions.

The machine needs to be tested at different pressure settings to see the extent to which it might dislodge aggregates in PICP joints, especially as joint widths and jointing aggregate sizes vary among concrete paver shapes and patterns. In the case of this brief demonstration however, the PICP surrendering sediment with the jointing aggregate to the Cyclone machine explains the resulting high infiltration rate after two passes rather than four passes, as conducted on the other surfaces. This demonstrates the ability of clogged PICP to experience restored infiltration rates as compared to monolithic surfaces, even when heavily clogged at the time of maintenance work

References

Al-Rubaei, A.M., Stenglein, A.L., Viklander, M., Blecken, G.T., 2013. Long-term hydraulic performance of porous asphalt pavements in northern Sweden. J. Irrig. Drain. Eng. 139, 499-505.

Backstrom, M., Bergstrom, A., 2000. Draining function of porous asphalt during snowmelt and temporary freezing. Can. J. Civ. Eng. 27, 594-598.

J-D. Baladès, J.D., Legret, M, Madiec, H., 1995. Permeable pavements: Pollution management tools. Water Science and Technology, Vol. 32, Issue 1, 49–56.

Bean, E.Z., Hunt, W.F., Bidelspach, D.A., 2007. Field survey of permeable pavement surface infiltration rates. J. Irrig. Drain. Eng. 133, 249-255.

Blecken, G.-T., Hunt, W.F., Al-Rubaei, A.M., Viklander, M., 2016. Stormwater control measure (SCM) maintenance considerations to ensure designed functionality. Urban Water J. http://dx.doi.org/10.1080/1573062X.2015.1111913 (in press).

Boogaard, F., Lucke, T., van de Giesen, N., van de Ven, F., 2014. Evaluating the infiltration performance of eight Dutch permeable pavements using a new full-scale infiltration testing method. Water 6, 2070-2083.

Chopra, M., Kakuturu, S., Ballock, C., Spence, J., Wanielista, M., 2010. Effect of rejuvenation methods on the infiltration rates of pervious concrete pavements. J. Hydrol. Eng. 15, 426-433.

Drake, J.A., Bradford, A., Marsalek, J., 2013. Review of environmental performance of permeable pavement systems: state of the knowledge. Water Qual. Res. J. Can. 48, 203-222.

Eisenberg B., Lindow, K. and Smith, D.R., 2015, Permeable Pavements, American Society of Civil Engineers, Reston, VA.

Fassman, E.A., Blackbourn, S., 2010. Urban runoff mitigation by a permeable pavement system over impermeable soils. J. Hydrol. Eng. 15, 475-485.

Gerrits, C., James, W., 2002. Restoration of infiltration capacity of permeable pavers. In: Proc. 9th Int. Conf. on Urban Drainage, ASCE, Portland, Oregon.

Gyllefjord, A., Kangas, J., 1989. Infiltration Measurements of Permeable Asphalt in the Laboratory ((In Swedish: Infiltrationsmatning på permeabel asfalt i lab- miljo)). Luleå University of Technology, Luleå, Sweden. MSc thesis.
Haselbach, L.M., 2010. Potential for clay clogging of pervious concrete under extreme conditions. J. Hydrol. Eng. 15, 67-69.
Illgen, M., Harting, K., Schmitt, T.G., Welker, A., 2007. Runoff and infiltration characteristics of permeable pavements - review of an intensive monitoring program. Water Sci. Technol. 56, 133-140.
Sansalone, J., Kuang, X., and Ranieri, V. 2008. Permeable Pavement as a Hydraulic and Filtration Interface for Urban Drainage. J. Irrig. Drain Eng., 10.1061/(ASCE)0733-9437(2008)134:5(666), 666-674.
Winston, R.J. Al-Rubaei, A.M., Godecke, T., Blecken, B., Viklander, B., Hunt, W.F., 2016. Maintenance measures for preservation and recovery of permeable pavement surface infiltration rate - The effects of street sweeping, vacuum cleaning, high pressure washing, and milling. J. of Env. Mgt., Vol. 169, 132–144
Vancura, M., MacDonald, K., and Khazanovich, L., 2012. Location and Depth of Pervious Concrete Clogging Material before and after Void Maintenance with Common Municipal Utility Vehicles. J. Transp. Eng., 10.1061/(ASCE)TE.1943-5436.0000327, 332-338.