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Development of an Innovative Computer-Controlled Water Deairing System for Hydraulic Testing of Geosynthetics

**ABSTRACT:** Use of deaired water is essential in many hydraulic tests conducted on geosynthetics. This is because air bubbles present in tap water adversely affect the test results. Additionally, long-term flow should be maintained, which requires large quantities of deaired water. An innovative computer-controlled fully automated system was developed to provide this continuous supply of deaired water and the approach is presented in this paper. The system is composed of two water deairing tanks and a control unit (hardware and software). These units were constructed to take advantage of the most recent technology available in the area of instrumentation. The efficiency of the system was checked through gradient ratio tests conducted on various soil/geotextile combinations.

**KEYWORDS:** water deairing system, automation, geosynthetics, hydraulic testing, long-term flow testing

**Introduction**

Deaired water has been used traditionally as part of some material and soil testing procedures, such as the triaxial test. In most cases, a small amount of tap water is deaired before the test using commercially available apparatus. Alternatively, flow tests conducted on synthetic materials used in civil engineering (geosynthetics) or on soil/geosynthetic combinations, such as the permeability test, transmissivity test, and gradient ratio test, require larger quantities of water and, in most cases, the water needs to be deaired continuously and supplied to the test system. The ASTM standards applicable to these performance tests usually require the use of deaired water, because the air bubbles present in tap water could adversely affect the test results by providing erroneous measurements. The continuous supply of deaired water should be provided through a fully automated system, which is customized in most cases. Even though systems are being used increasingly in the testing of geosynthetics [1–3], either the systems are operated manually or are not fully computer-controlled. Furthermore, little information is available about their design.

This paper presents the details of an automated, computer-controlled, and continuous water deairing system constructed at the University of Maryland. The system is composed of two units: (1) a deairing unit (water deairing tanks), and (2) a control unit (hardware and software). These units were constructed to take advantage of the most recent technology available in the area of instrumentation.

**Water Deairing System**

A dual-tank system was constructed to continuously deair the tap water and supply it to the test setup. The tank system is operated by a series of input/output modules controlled by a computer program developed in LabView® [6]. Each tank was constructed by gluing flat base caps to the two ends of PVC pipes measuring 0.3 m in diameter and 0.9 m in length. The water storage capacity of each tank is approximately 55 L. Slow-curing PVC cement, providing good workability conditions, was preferred for the gluing operation. A series of solenoid valves and float switches are used to cycle the filling and draining process. Figure 1 shows a schematic of the tank system.

**Deairing Unit**

Each water tank is instrumented with four solenoid valves that controlled the inlet and outlet of water, vacuum, and air relief as shown in Fig. 1. The system is activated by filling Tank 1 and emptying Tank 2. At this time, solenoids trigger the vacuum and water valves of Tank 2, and the drain and air relief valves of Tank 1. This operation turns the normally closed valves on, and provides the flow of water from Tank 1 to the test setup, and starts filling Tank 2. The drain valve of Tank 2 remains off until Tank 1 is empty. In the same way, Tank 1 is filled and the process is repeated after Tank 2 is emptied. Similar logic was used in the electromagnetic relay-operated water deairing system developed by Fischer [1], with the exception that the vacuum valves are turned off after filling each tank in the current system.

Tap water is passed through a series of filters with openings of 5 µm and 1 µm before entering into the tanks. This minimizes the intrusion of suspended solids, which potentially could affect the flow regime and contaminate the system. Because of the relatively low amount of suspended solids in College Park tap water, the filters
need to be replaced only once a month. Suspended solids present in the tap water cause a decrease in hydraulic conductivity values, and their intrusion into the tanks is prevented by installing a series of filters. Comparing the time plots of Fig. 2 shows the beneficial effect of filter usage on the measured hydraulic conductivity in a gradient ratio test (ASTM D 5109). The test used a uniform sand specimen placed over a woven geotextile. The properties of the sand and geotextile are given in Table 1. Similar findings about the beneficial effect of filter installation were reported by Fischer et al. [4]. Preliminary analyses indicated that the introduction of vacuum before supplying the water into the tanks was essential for sustaining a high level of suction (600–650 mm Hg) during the filling process. To accomplish this, the solenoid responsible for turning the water valve on was delayed about 5 min. This allowed sufficient time to maintain a good level of suction in the empty tank. A single-stage fixed-flow vacuum pump generated the necessary vacuum by inverting the compressed air through its orifice (Venturi nozzle). Because of its operational procedure, the pump usually is called an air-driven Venturi vacuum pump. The level of generated vacuum was adjusted by simply increasing the air pressure. The valves used in the system are two-way, normally closed, pilot-operated solenoid valves with a 19 mm diameter female inlet and outlet, and have a process temperature range of –10 to 130°C. The valves operate at 120 V AC, and their opening and closing times range from 100–1 000 ms and from 700–4 000 ms, respectively. The valves open fully under gravity. They have a continuous duty cycle; therefore, there are no limitations on the number of switching operations throughout the life of the valves.

Air, vacuum, and drain valves are connected to the tanks using a 19 mm by 19 mm male-to-male PVC fitting. A removable valve/spray nozzle system is used by attaching the two parts into a 76.2-mm diameter PVC plate, which is then screwed onto each tank. Six spring-shaped helical inserts acting as female threads were placed into the holes drilled on the tank to facilitate the screwing process. For providing an air-tight system, a thin rubber sheet was placed between the PVC plate and the tank. The details of the valve/plate/nozzle system are given in Fig. 3. The connection system was removed once every 3 months to clean the suspended solids that accumulated on the spray nozzle. The 12.7 mm diameter spray nozzle sprayed the water as a mist at a rate of 1.5 L/min., thereby increasing the surface area.

To prevent drained water from flowing back into the tanks because of the presence of a high vacuum, the drain valves were equipped

![Diagram of the dual tank system](image-url)
with spring-loaded check valves that limited the flow of water to only one direction (direction of gravity). The cracking pressure of each check valve, the minimum pressure that is required to open the valve, was 2 kPa. A series of vertical float switches placed at the top and bottom of the tanks were used to control the switching operations between the tanks, as shown in Fig. 3. Both the stem material and the float material of the float switches were made of stainless steel. The normally closed switches had an operating temperature range of −40 to 149°C. The SPST (single-pole, single-throw) switch actuated at approximately half the distance from the end of the stem to the mounting or the halfway point of float travel. Each switch had a 32-mm NPT male adapter and the specific gravity of the float was 0.70. The float switches were connected to the tanks with a prefabricated cap/float switch unit (Fig. 3). Initial observations showed that small water fluctuations in the tanks could adversely affect the operation of the float switches. To control this, the top float switches were extended into the tanks using a 12.7 mm diameter PVC pipe attached to the end of the switches. Additionally, the closing time of all float switches was delayed about 10 s through a signal sent from the control unit.

**Control Unit**

The control unit consists of computer software (tank control software), a relay module, an input module, and a network interface module [6]. Software developed in LabView® (Austin, TX) controls the filling, deairing, and draining operations in an automatic
Results and Conclusion

The effectiveness of the water deairing system was checked by collecting water samples and measuring their dissolved oxygen (DO) contents at different time intervals. The DO contents were measured using a YSI 85 type DO and conductivity meter. The dissolved oxygen content of the deaired water samples is plotted versus time in Fig. 4a. The DO content of water at the initial phase of the filling process was 3.1 mg/L and increased with time. The DO content of water remained in the tank for 4 h is 5.8 mg/L, which is lower than the limit of 6.0 mg/L set for flow testing of geotextiles by ASTM D 5101 and ASTM D 4491 [5,7]. Before the deairing operation, the College Park tap water had a DO content of 9.5 to 10.0 mg/L. The estimated draining time for each tank was about 45 min in a typical flow test (e.g., gradient ratio test), which corresponded to a DO content of 4 mg/L. Thus, the DO content of the deaired water used in the testing program was significantly lower than either that of tap water or the limit set by the ASTM test standards. The system designed herein successfully deaired the tap water to a DO content less than 6.0 mg/L, a limit usually recommended for the testing of geosynthetics.

A second test was conducted to determine the effectiveness of the apparatus. The hydraulic conductivity of a sand/geotextile system was measured in a gradient ratio test (ASTM D 5101). Figure 4b shows the importance of the deairing process, as the tap water with air underpredicted the hydraulic conductivity by about 50%. These results show the importance of using deaired water in flow tests. The apparatus described herein provides long-term deaerating of tap water, which is necessary to ensure homogeneous measurements over the duration of the test.
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References


