9. FILTER-TYPE UNITS

Vertical limestone filter type units, connected in series, were operated continuously in a semi-fluidized upflow mode and in a downflow mode with periodic upflow backwashing. The performance of the process was evaluated by the methods previously described for the static barriers. Selected profiles of pH versus load factor are compared with profiles computed for limestone reactivity coefficients of 1.0, 0.2 and 0.05 in Figures 9.1 through 9.6. Complete results of the processes are presented graphically in Appendix "C ".

Upflow Units: The upflow units were operated in fluidized and semi-fluidized conditions. Observed versus (computed performance data for the upflow beds are shown in Figures 9.1 through 9.3. Due to physical limitations, there was insufficient stone volume in the units to achieve a pH greater than 6 when they were operated in a completely fluidized condition. The flow velocities necessary to suspend the entire bed resulted in load factors (i.e. detention times) less than those required to neutralize the AMD to a pH of 6. However, even in a semi¯fluidized state, the units were able to sustain a reactivity coefficient of 1.0, or greater, for long periods of time as shown on Figure 9.1.

In terms of reagent utilization, the upflow units were the most efficient process used at the Quakake demonstration project. The units were capable of producing treatment levels beyond those predicted for passive beds. The increase in effluent pH above that predicted for a reactivity coefficient of 1.0 is attributed to limestone fines production created by particle abrasion in the suspended bed.

During the first sampling run, the units maintained a reactivity coefficient greater than 1.0 for approximately one month. No deterioration in process performance was observed until clogging of the stone reduced the influent flow to the point where none of the stone was in suspension. The clogging of the lower unfluidized layers was caused by fines washed from the adjacent upper unit. These fines, together with precipitates of iron and aluminum, accumulated on the inlet screens of the upflow units. The clogging further reduced the available hydraulic head, so that both the loss of fluidization and clogging were progressive with time. When the stone retaining screens at the base of the units were removed, they were found to be almost totally clogged with limestone particles and a brownish gray waxy clay-like coating.

The inlet screens were replaced with a graded stone filter for subsequent runs. However, when the units were refilled, a less reactive limestone was inadvertently placed in some of the units. This stone was similar in size, but was the dolomitic limestone obtained for use in the tumbling drums for comparison with the performance of higher grade limestone. Subsequent testing of the stone identified its use in at least two of the units. Figure 9.2 shows the approximate corrections for the $MgCO3$ content of the stone, which gives results similar to the high calcium stone. The upflow units were operated during Run No. 4 for a short period in order to confirm these conclusions.

Performance during Run No. 4 is presented in Figure 9.3 The upflow units kept the process effluent consistantly above the treatment levels predicted for a reactivity coefficient of 1.0. This indicates the abrasive action in the upflow mode maintained a clean stone and produced small, more reactive limestone particles than the bed would have under static conditions.

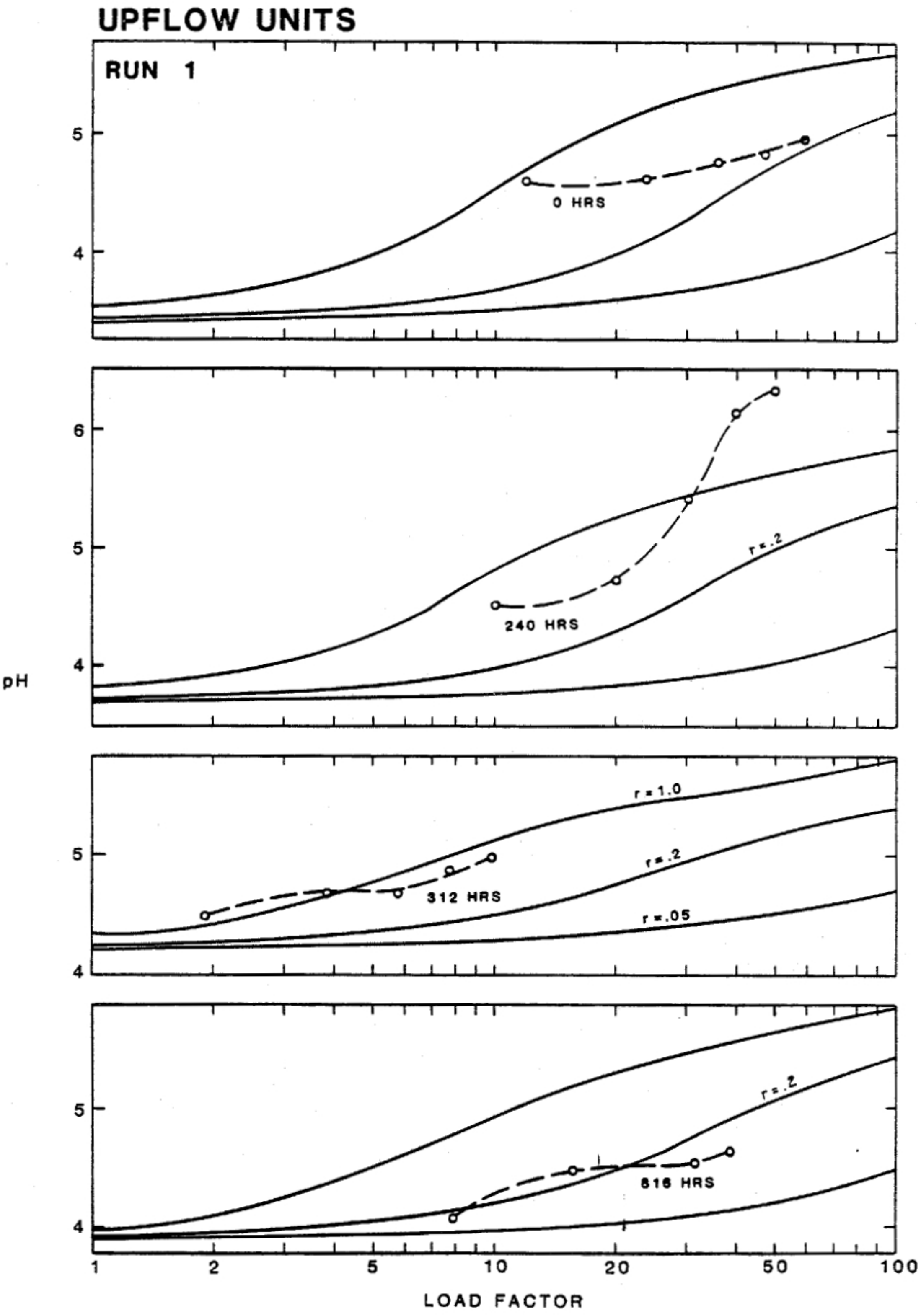


Figure 9.1 Typical Prototype Results - Upflow Units - Run 1

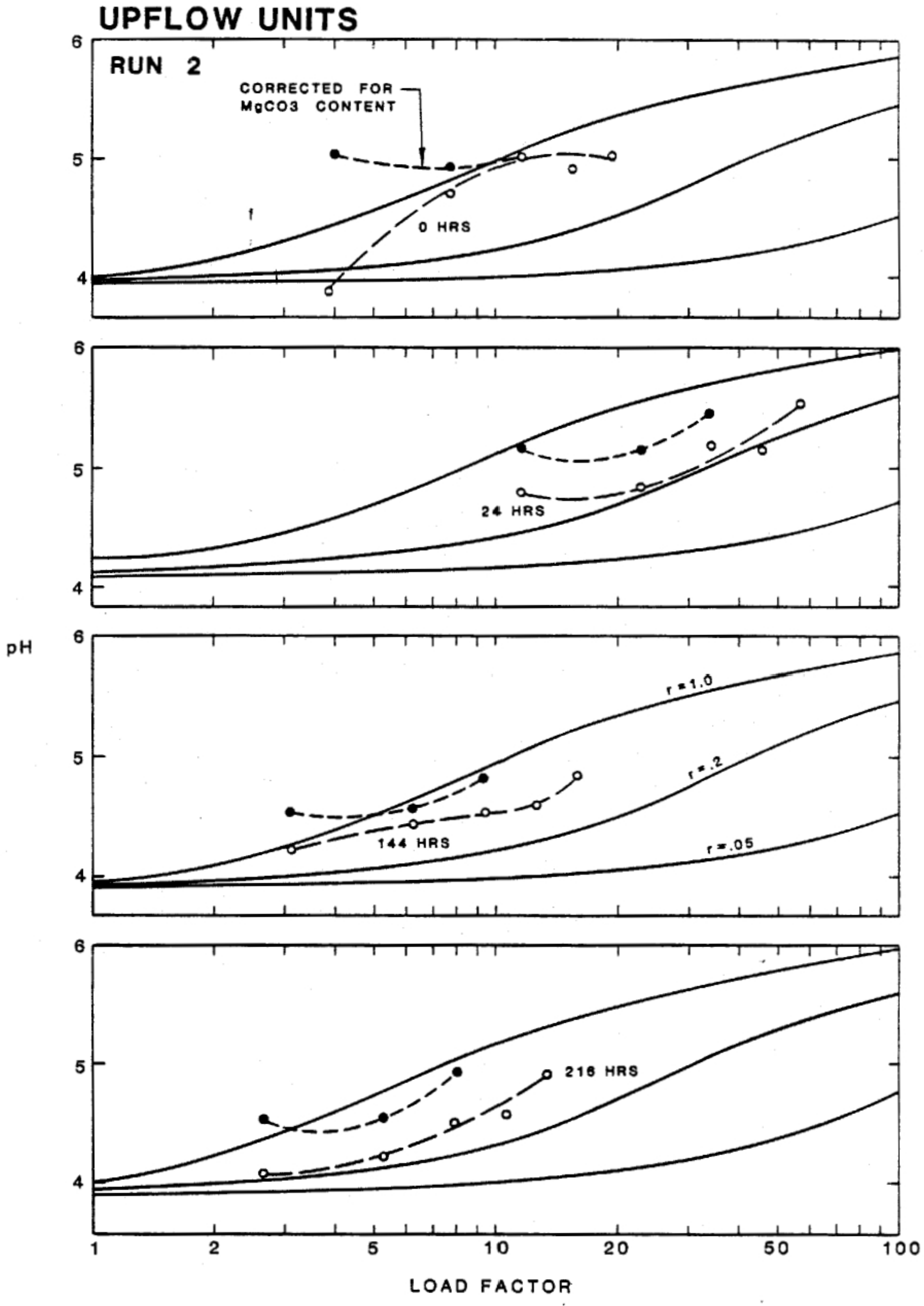


Figure 9.2 Typical Prototype Results - Upflow Units - Run 2

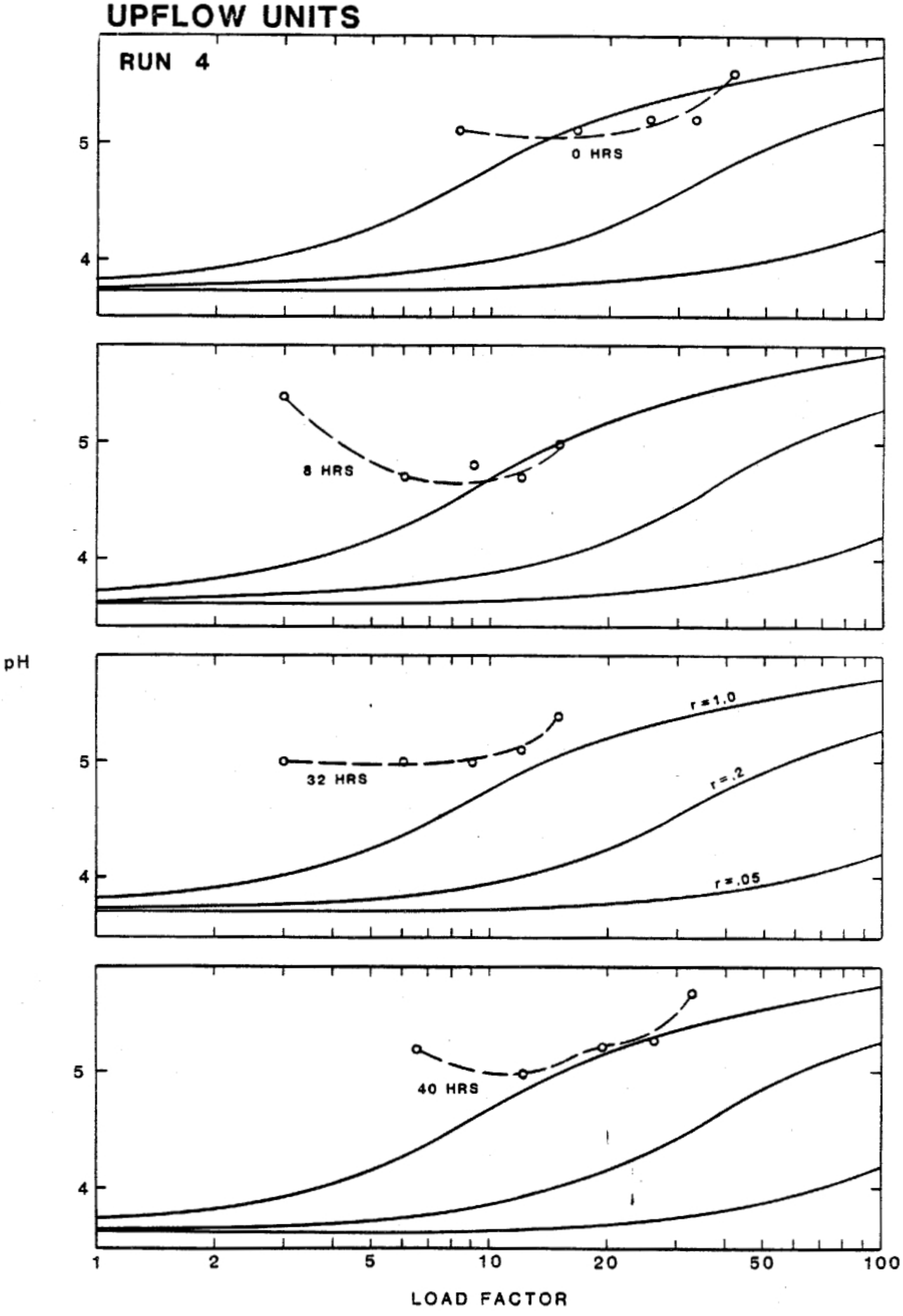


Figure 9.3 Typical Prototype Results - Upflow Units - Run 4

Downflow Units: Figures 9.4 through 9.6 show pH versus load factor profiles for the downflow units. The results for Run No. 1 are similar to the results obtained for the barriers with the stone reactivity gradually diminishing with increased clogging. Treatment levels with a reactivity coefficient greater than 0.2 were sustained in Run Nos. 2 and 3 by backwashing the units, thereby rejuvenating the stone surfaces. The backwash frequency in Run No. 2 was 24 hours or greater whereas backwash frequencies for Run No. 3 were 4 and 8 hours. The smaller backwash intervals in Run No. 3 produced a consistently higher effluent quality as would be anticipated.

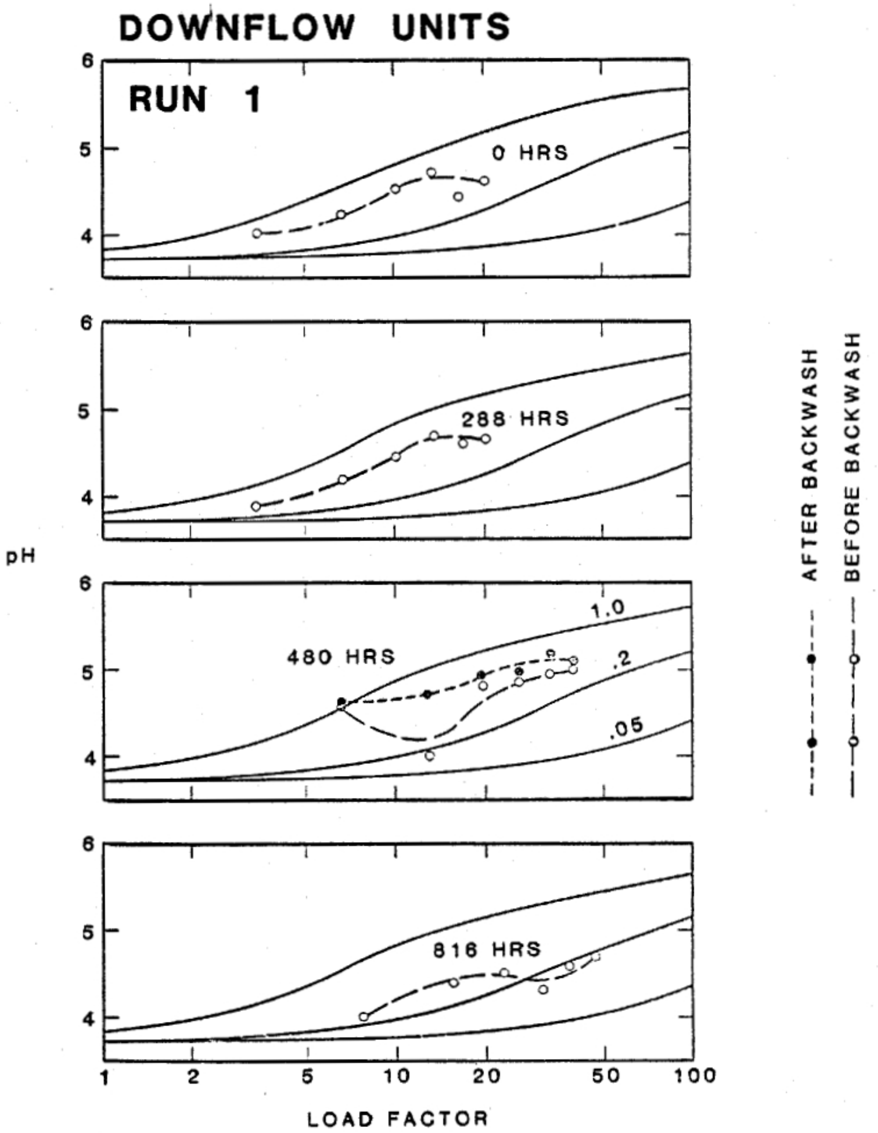


Figure 9.4 Typical Prototype Results - Downflow Units - Run 1

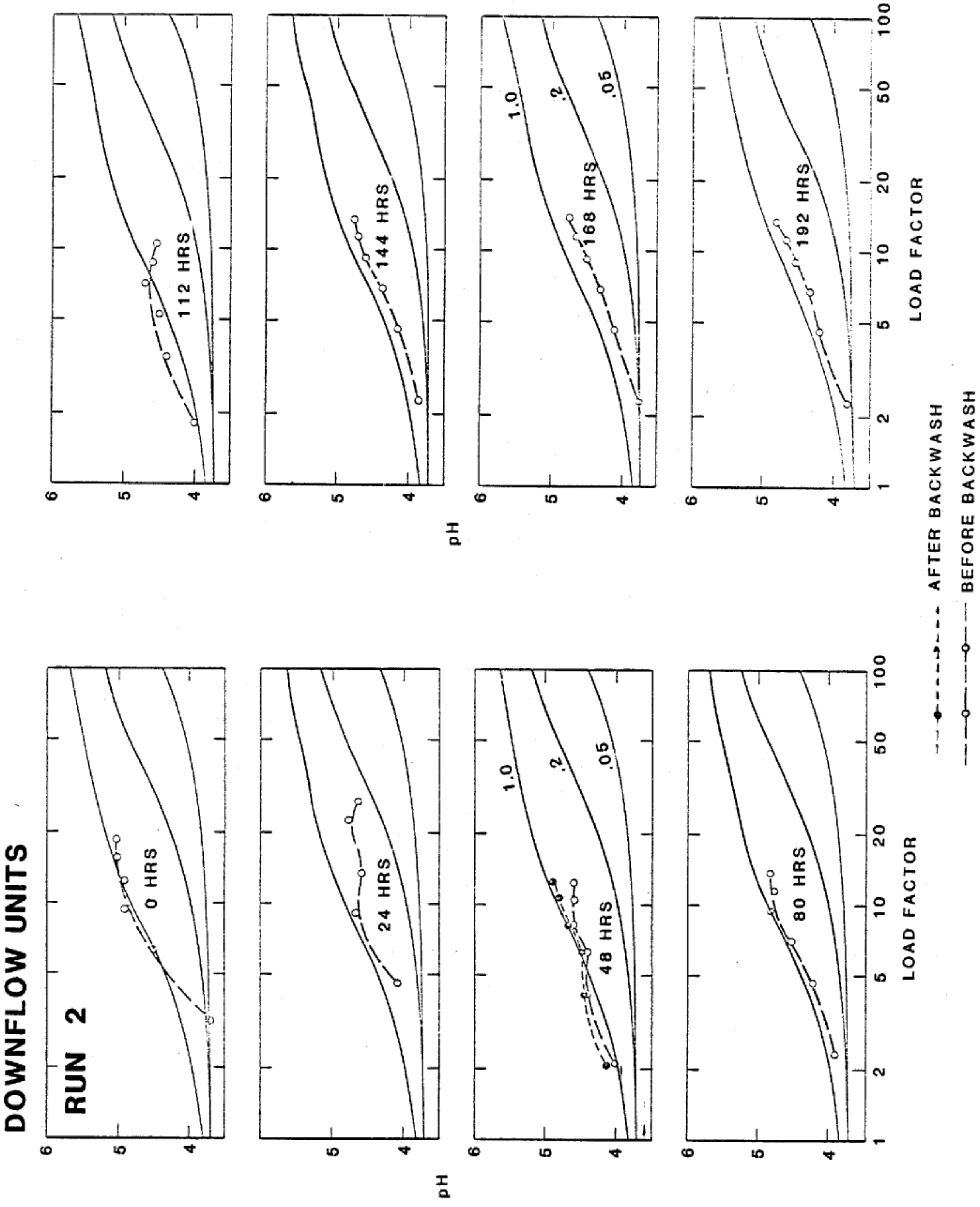


Figure 9.5 Typical Prototype Results - Downflow Units - Run 2

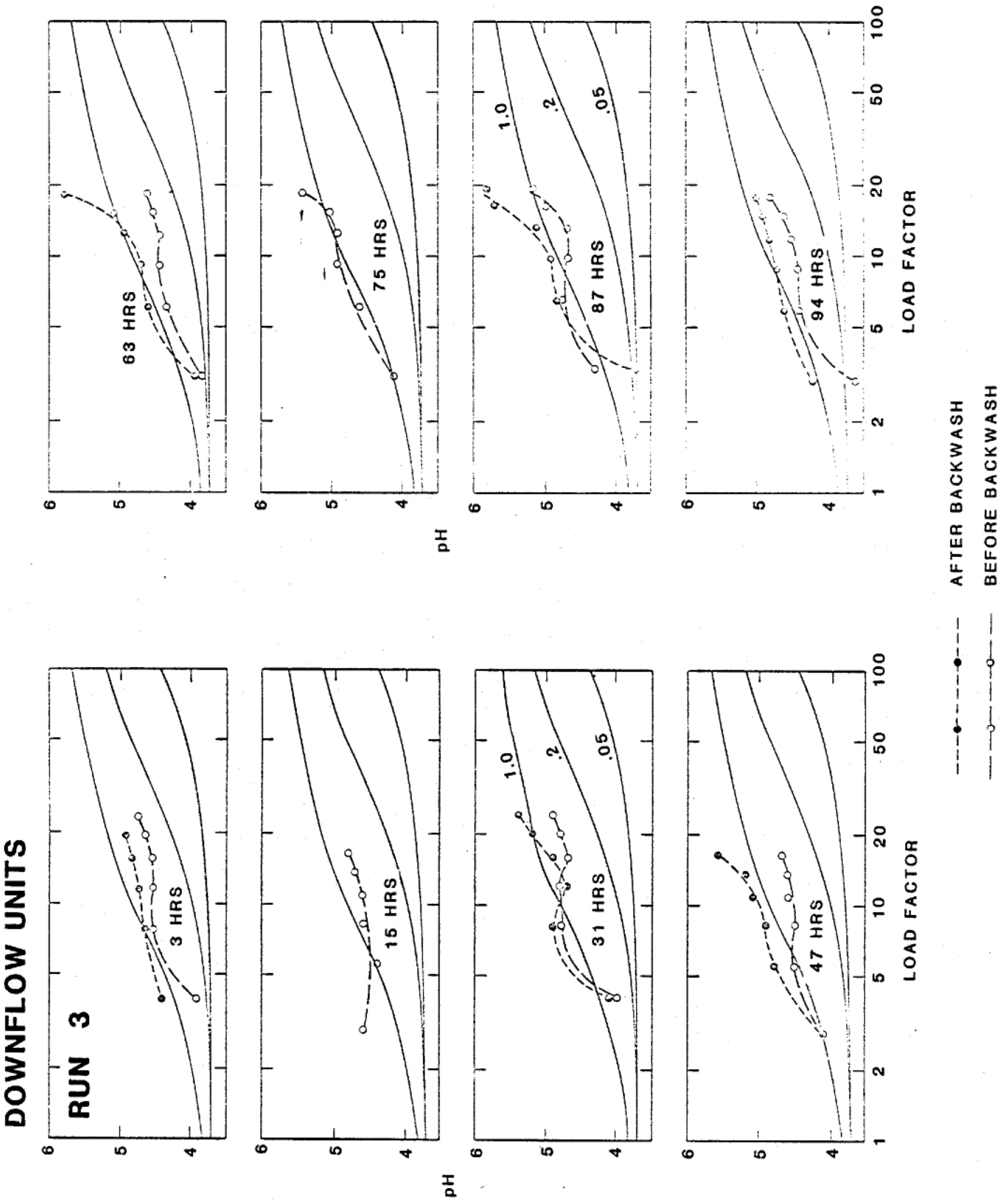


Figure 9.6 Typical Prototype Results - Downflow Units - Run 3

The downflow units were operated during Run No. 4 to obtain data on the accumulation of precipitates and sediment. Limited testing was conducted on the sludge contained in the downflow backwash water. Figure 9.7 shows a representative settling test on the backwash effluent. The graph shown is for a moderately well-defined interface, however, the supernatant was slightly turbid. A detention time of 24-hours was required to achieve a clear supernatant. A fraction of the backwash was diverted to a 300 gallon tank and allowed to settle for 24 hours. The thickened sludge was withdrawn from the bottom of the tank and allowed to resettle in a test column. Approximately one hour was required to produce a clear supernatant. The test was repeated using an anionic polymer (solution) which improved the settling rate to a point that a clear supernatant was obtained in 10 minutes. The settled solids were further tested to determine their dewatering properties. The sludge could be dewatered at a solid concentration of 1.6% to an average of 26% dry solids, in less than two hours, using a vacuum filter process as described in Appendix "E".

In general, the backwash sludge appears to be reasonably easy to handle with conventional methods so that it should present no obstacle to the use of this treatment method. The testing confirmed the easier dewatering and handling characteristics of limestone sludge as previously documented by others.

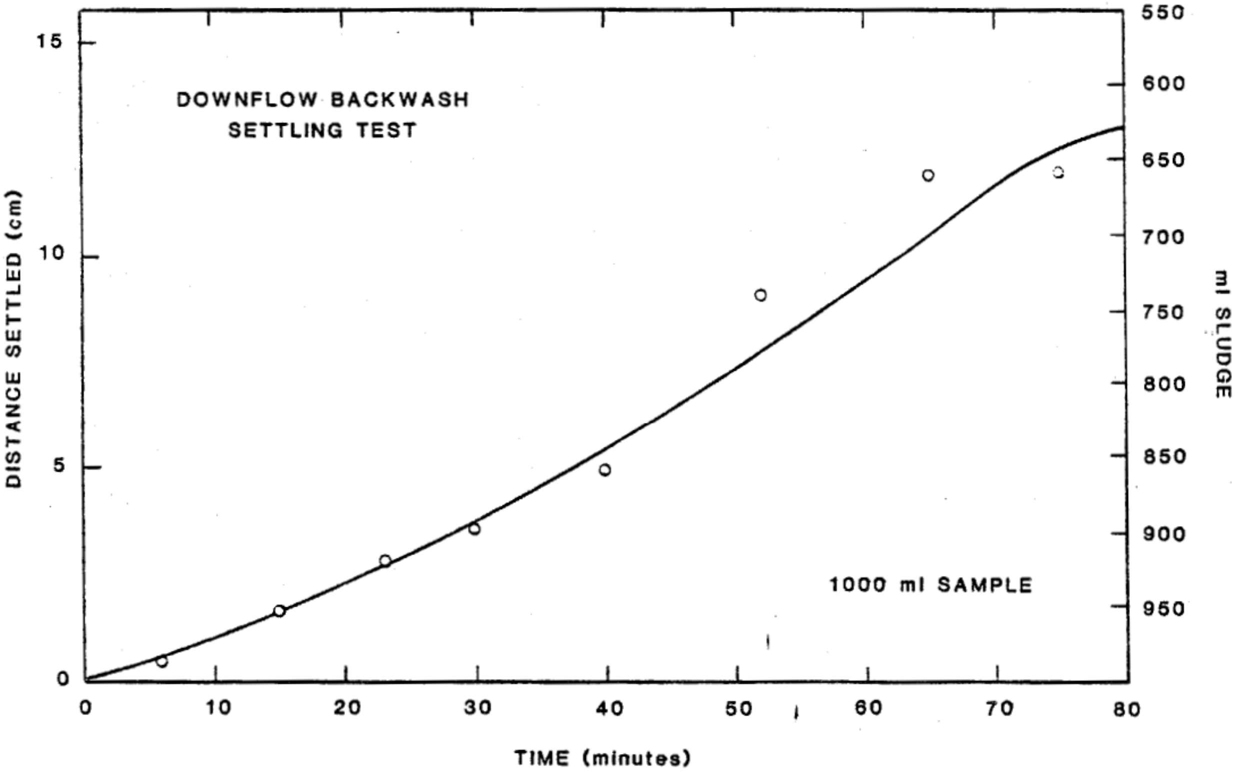


Figure 9.7 Settling Test of Downflow Unit Backwash Effluent

Autogenous Mill: While not strictly a filter type unit, the mill was used as a mechanical cleaning process of limestone beds in lieu of cleaning by fluidization. Normally the mill would operate continuously as a grinding process. At the site the mill was rotated periodically to clean the stone and was stationary for most of the testing period.

Operating conditions and the results obtained, shown in Figure 9.8, demonstrate that occasional rotation of a drum containing crushed limestone maintains the stone sufficiently clean to keep^{+} the reactivity coefficient above 0.2. Detailed operating data are presented in Appendix "C". Rotation of the drum can restore the neutralization efficiency of the limestone to initial levels. An effluent pH approaching pH 7 was achieved following rotation of the drum. These higher pH values result from dissolution of limestone fines abraded during rotation.

Figure 9.9 presents a settling test, performed on an effluent sample that was taken during the rotation of the drum. A clear supernatant was achieved in less than 20 minutes. The settled solids were almost entirely limestone particles with some iron and aluminum coatings.

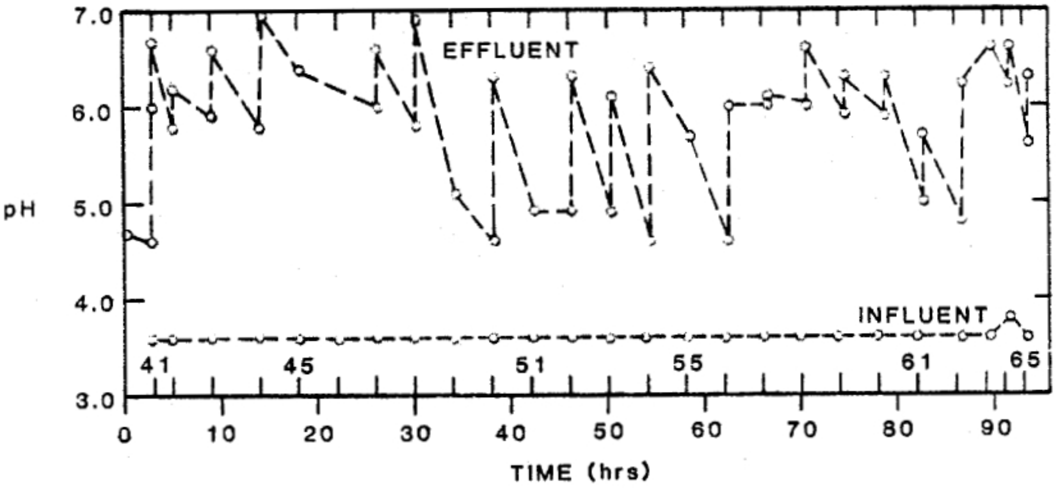


Figure 9.8 pH Performance of Autogenous Mill Operation

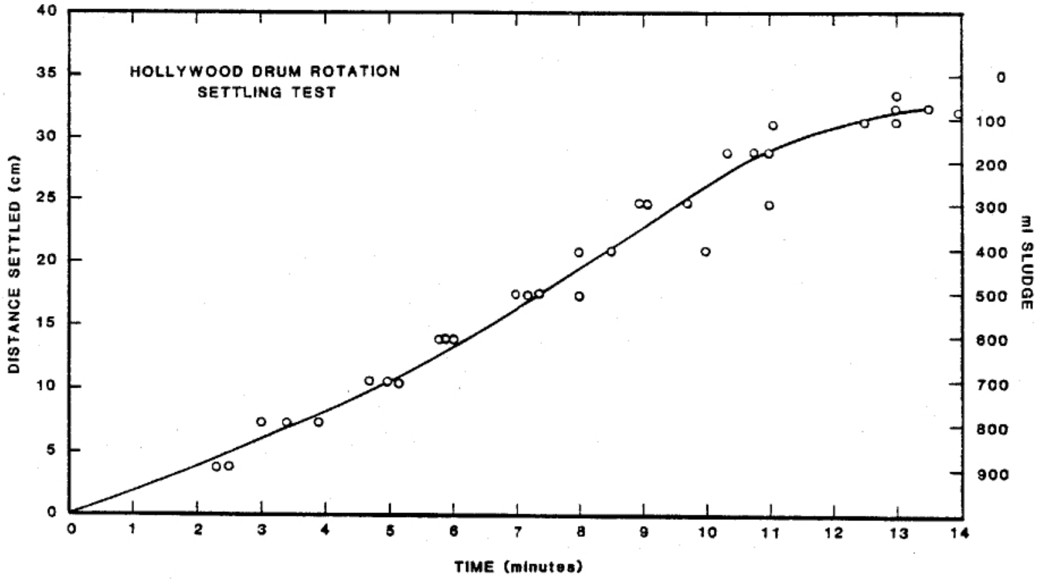
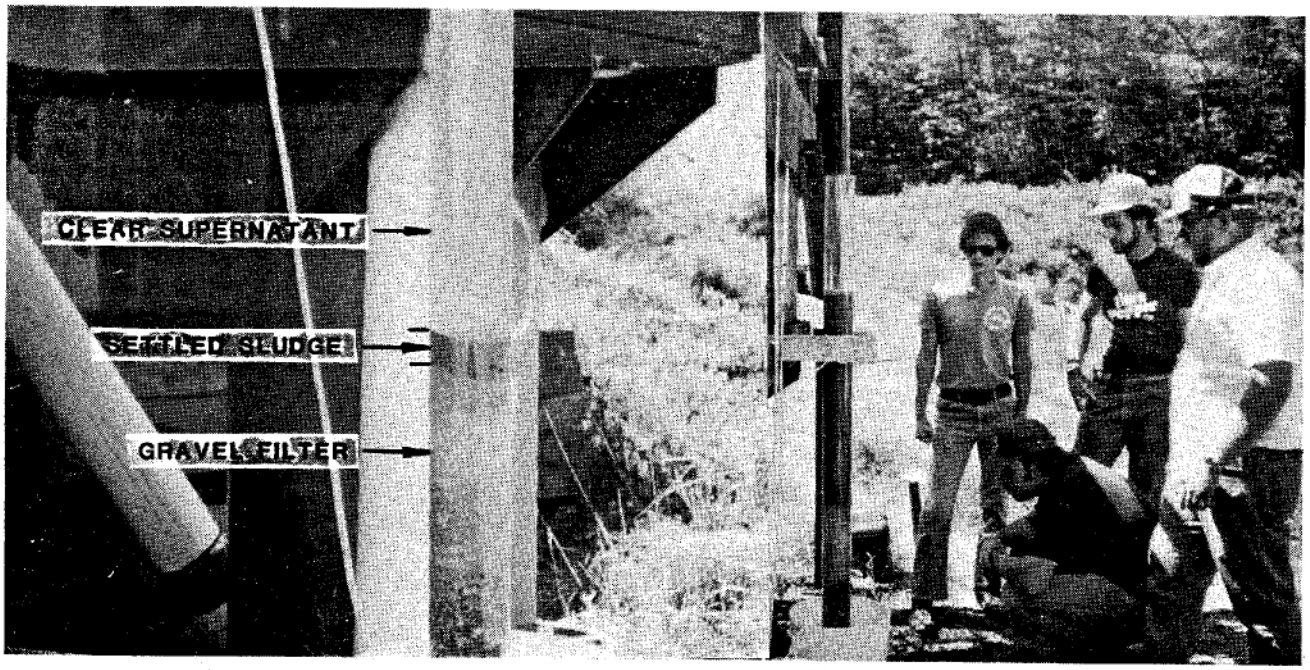


Figure 9.9 Settling Test of Autogenous Mill Effluent



VIEWS OF BACKWASH SLUDGE SETTLING TESTS