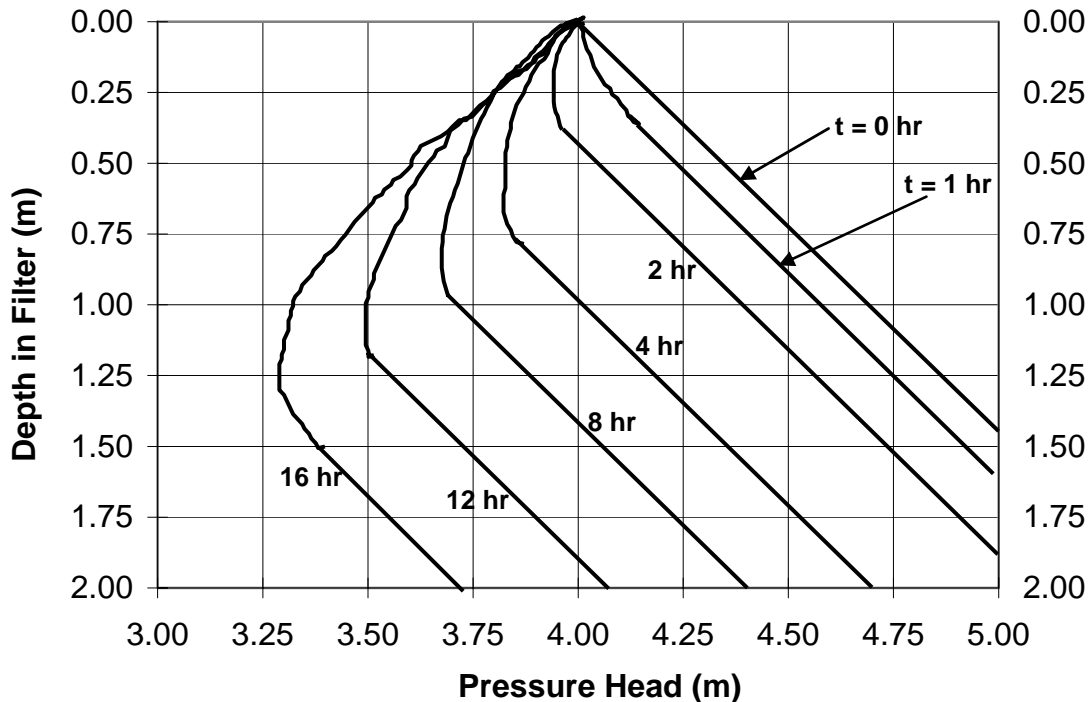


Several curves of pressure versus depth through a sand filter are shown in the figure below, each corresponding to a different time during the filter run. The hydraulic (pressure) head at the top of the sand (indicated in the figure as depth = 0 m) is 4.0 m at all times. The filter bed is 2.0 m deep and must be backwashed when particles start breaking through into the effluent, or when the headloss exceeds 2.2 m. The filter is operated in constant flow mode.



- Why are the curves near the bottom of the filter approximately parallel to one another regardless of how long the run has lasted?
- What is the pressure head at the bottom of the filter under no-flow conditions?
- Estimate the time when you think each of the criteria for backwashing the media is first met, and explain how you made this determination.
- One option available to the system operator is to add 0.5 m of sand to the column. If this were done, what do you think the headloss through the bed would be two hours after the beginning of a filter cycle?
- If the criteria for headloss and turbidity breakthrough remain the same, do you think that adding the sand would increase, decrease, or not affect the length of a filter cycle?

- (a) The headloss curves near the bottom of the filter are approximately parallel to one another because, in those regions of the filter, the headloss is caused by flow through clean sand. Since the filter medium and the flow rate are the same under all these conditions, the headloss per unit length of sand is also the same, so the slopes of the headloss curves are identical.
- (b) When there is no flow through the filter, there is no headloss, and the total pressure at any depth is just the hydrostatic pressure. At the top of the sand layer, the head is 4.0 m, so there must be this much water above the sand. The bottom of the sand is 2 m lower, so there is 6.0 m of water above this level, and the pressure head is 6.0 m.
- (c) The filter must be backwashed when the headloss through the column reaches 2.2 m, i.e., when the total head at the bottom of the column is 2.2 m less than under the no-flow condition. Under the no-flow condition, the pressure at the bottom is 6.0 m, so the filter must be backwashed when this pressure is reduced to $(6.0 - 2.2)$ m, or 3.8 m. This occurs approximately 15 hours after the filter cycle begins. When the particles start breaking through the column, the bottom of the column is no longer clean, and the slope of the headloss curve starts changing at the bottom of the column. After the run has lasted for 16 hours, the particles have only penetrated to a depth of approximately 1.3 m. Therefore, they are not likely to penetrate to the bottom (depth = 2.0 m) until approximately $t = 24$ hr.
- (d) The curve for $t = 0$ (when the bed contains clean media) indicates that the pressure increases by ~ 1.00 m over a depth of 1.40 m, or 0.71 m/m; correspondingly, the headloss for flow through clean sand is 0.29 m/m. The headloss through the bed at $t = 2$ hr in the current operating mode can be determined by extrapolating that line to the bottom of the column. The graph indicates that the head is 5.0 m at a depth of 1.87 m. Therefore, at a depth of 2.00 m, the head would be $5.00 + (2.00 - 1.87)(0.71)$, or 5.09 m. An additional 0.5 m of sand would increase the head loss by $(0.5 \text{ m})(0.29 \text{ m/m})$, or 0.14 m, to 2.01 m.
- (e) In the current operating mode, the filters would have to be backwashed after about 15 hours because of headloss buildup, several hours before the water quality of the effluent started deteriorating. Under the circumstances, it would make sense to switch to slightly larger filter grains or take some other action that would reduce headloss. If that was unrealistic, it would make sense to remove sand from the column, or to withdraw effluent slightly higher in column. Adding sand would increase the headloss and shorten the filter run even more, and this action would not be sensible.