MODELING EVALUATION OF THE PL-525 EFFLUENT FILTER FOR 1/16" AND 1/32" SLOT HEIGHT AND 4" AND 6" OUTLETS

Completion Report Prepared for

PolyLok, Incorporated

by

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TABLE OF CONTENTS

OBJECTIVE

The objective of this study was to use the results of previous work with the Polylok PL-122 filter assembly to estimate the performance of the Polylok PL-525 filter assembly. Filter performance was to be specified in terms of head vs. flow rate curves and was to account for filter maturation.

PROCEDURE

Since the PL-522 filter was only in the design stage at the initiation of the study, a modeling approach was used to estimate its performance. The system to be modeled was considered to be a reservoir (septic tank) from which the fluid (clear water, as used during previous work) flowed through a filter element, through a circular tank outlet, then out of the system. The general procedure was to develop a model that adequately described the performance of the PL-122 filter and then modify the model as appropriate to extend the results to the PL-522 filter.

The tank outlet was modeled as PVC pipe with a circular cross section with hydraulics describe by Manning's equation:

$$Q=\frac{1.49}{n}AR^{2/3}S^{1/2}$$

where Q is flow rate (cfs), n is Manning's roughness coefficient, A is cross sectional area of flow through the outlet (ft^2), R is the hydraulic radius (the ratio of area to wetted perimeter, ft), and S is the slope of the outlet. Cross sectional area A and hydraulic radius R are related to normal flow depth within the outlet by:

$$A = \frac{D^2}{8}(\theta - \sin\theta)$$

$$R = \frac{D}{4}\left(1 - \frac{\sin\theta}{\theta}\right)$$

$$\theta = 2\arctan\left[\frac{\sqrt{\left(\frac{D}{2}\right)^2 - \left(\frac{D}{2} - y\right)^2}}{\frac{D}{2} - y}\right], \quad 0 < y \leq \frac{D}{2}$$

$$\theta = \pi, \quad y = \frac{D}{2}$$

$$\theta = 2\pi + 2\arctan\left[\frac{\sqrt{\left(\frac{D}{2}\right)^2 - \left(\frac{D}{2} - y\right)^2}}{\frac{D}{2} - y}\right], \quad 0 < y \leq D$$

where D is outlet diameter (ft) and y is normal flow depth within the outlet (ft). Head losses through the outlet are assumed to be described as:

$$h_{L,O} = (1 + K_O)\frac{V^2}{2g}$$

where $h_{L,O}$ is outlet head loss (ft), K_O is the outlet head loss coefficient, V is outlet velocity (V=Q/A, ft/s), and g is gravitational acceleration (32.2 ft/s^2). The outlet head corresponding to a given normal depth within the outlet can then be calculated as:

$$H_O = y + h_{L,O}$$

where H_O is outlet head (ft). The above equations were used to describe the behavior of the outlet by assuming a value of y, calculating θ, R, A, Q, V and $h_{L,O}$, then calculating H_O. Repeating this process for a range of y-values enables characterization of outlet performance as a function of outlet head (no filter present).

Predicted outlet performance was compared to observed outlet performance using the data collected during previous work. Values of n, S and K_O were adjusted manually to obtain the closest possible fit to observed data.

After ensuring that the outlet alone could be satisfactorily modeled, the next step was to include the filter element in the system. Head loss through the filter was described as

$$h_{L,F} = K_F \frac{V_F^2}{2g}$$

where $h_{L,F}$ is filter head loss (ft), K_F is the filter head loss coefficient, and V_F is velocity through the filter (ft/s), calculated from

$$V_F = \frac{Q}{A_F}$$

$$A_F = W_S \, L_F$$

where A_F is filtration area (ft^2), W_S is filter slot height (ft) and L_F is total slot length (ft). The filter head loss is then added to the outlet head to obtain total head as

$$H = H_O + h_{L,F}$$

where H is head (ft) relative to the outlet invert. Modeled filter performance was compared to observed data on PL-122 performance. The filter head loss coefficient $h_{L,F}$ was manually adjusted as necessary to obtain the best possible match between modeled and observed filter performance.

The summarized modeling procedure is as follows:

1. Assume a value of y.
2. Calculate θ.
3. Calculate A.
4. Calculate R.
5. Calculate Q.
6. Calculate V.
7. Calculate $h_{L,O}$.
8. Calculate H_O.
9. Calculate V_F.
10. Calculate $h_{L,F}$.
11. Calculate H.
12. Repeat for varying values of y.

The effects of filter maturity on the PL-525 were assessed by modeling maturity as a decrease in filter area and repeating the modeling procedure described earlier.

RESULTS AND DISCUSSION

Figure 1 shows the relationship between modeled and observed outlet performance for the outlet alone (no filter). The modeled values were obtained using a Manning's n of 0.013, an outlet slope of 1% and a negligible outlet head loss coefficient, all of which are reasonable given the relatively low flow rates and velocities. The very good match between modeled and observed values indicates success in this component of the model.

Modeling the filter proved to be more challenging, because no single filter head loss coefficient was identified that satisfactorily matched the observed results. The filter head loss coefficients required for exact matches with observed data points are given in Figure 2. While Figure 2 demonstrates a wide range in filter head loss coefficients (roughly 500 to 2,500), it also demonstrates a consistent relationship to filter velocity. As also indicated in Figure 2, a power function relationship does a satisfactory job of relating filter head loss coefficient to filter velocity over the observed range of data. In subsequent modeling, then, the filter head loss coefficient was calculated from

$$h_{L,F} = 37.9 V_F^{-0.97}$$

Figure 3 compares modeled and observed performance for the PL-122 filter in the single configuration. As indicated, the model does an excellent job of describing single-filter configuration PL-122 performance for H <= 1.5 inches, tending to under predict slightly at higher values of H. The model is thus conservative at higher values of H.

Estimated PL-525 Performance

Figures 4 and 5 demonstrate modeled performance of the PL-525 for all combinations of slot and outlet size with data on the PL-122 included for reference. As indicated, all variations of the PL-525 outperform the PL-122 due to the greater filtration area. For a given outlet size, the 1/16" slot model outperforms the 1/32" slot model due to greater filtration area and lesser head loss through the filter. For a given slot size, the 6" outlet model outperforms the 4" outlet model due to less head being required to convey a given flow rate.

Maturation

Figures 6-10 demonstrate modeled performance of the PL-122 and all models of the PL-525 under varying degrees of maturation. As indicated, substantial maturation is required to significantly degrade filter performance. Approximately 80% maturation is required, for example, to diminish filter performance by 50%. At higher degrees of maturation, however, performance will degrade at an accelerated rate due to reduced filtration area, increased velocity, and increased head loss through the filter (which is proportional to the square of velocity).

CONCLUSIONS

The preceding material indicates an effort to predict the performance of one filter based on characteristics of a presumably similar filter. As in all studies of this nature, it is well to be cautious in the use of the results, and it is advisable to supplement the results of this study with experimental data as soon as practical. Extension of the results of this study outside the range of observed data (2" of head or less) is inadvisable unless and until these results are verified with experimental data. Fortunately, the range of observed data is likely to encompass most reasonably anticipated conditions. Finally, the validity of the approach used to describe the filter head loss coefficient is likely to be influenced by filter fabrication methods. Head loss coefficients are generally related strongly to small-scale geometry, which is in turn related to specific methods of fabrication. If the same methods used in fabricating the slots for the PL-122 are to be used for the PL-525, the likelihood of error is minimized. Fabrication methods that result in smoother or rougher slots can be expected to result in head loss coefficients that are lower or higher, respectively, than those that were used in this study.

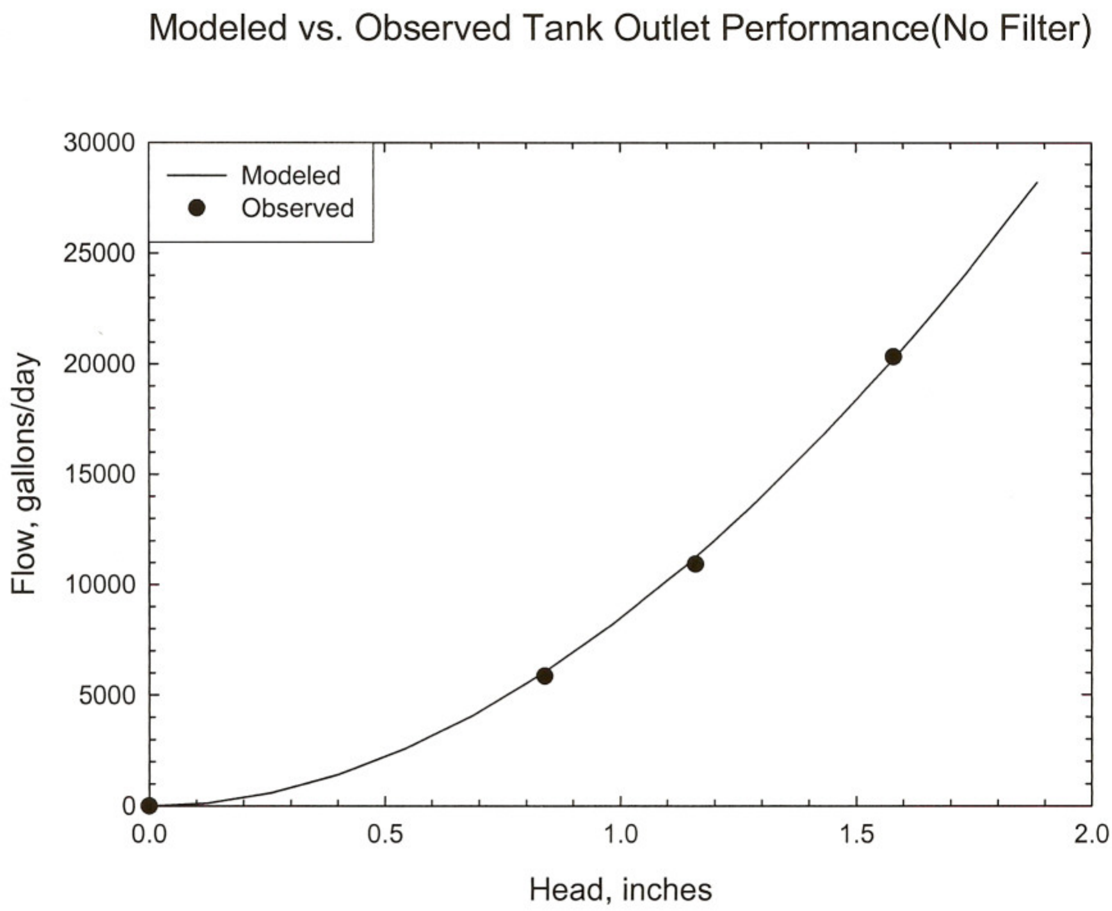


Figure 1. Modeled vs. observed tank outlet performance (no filter included).

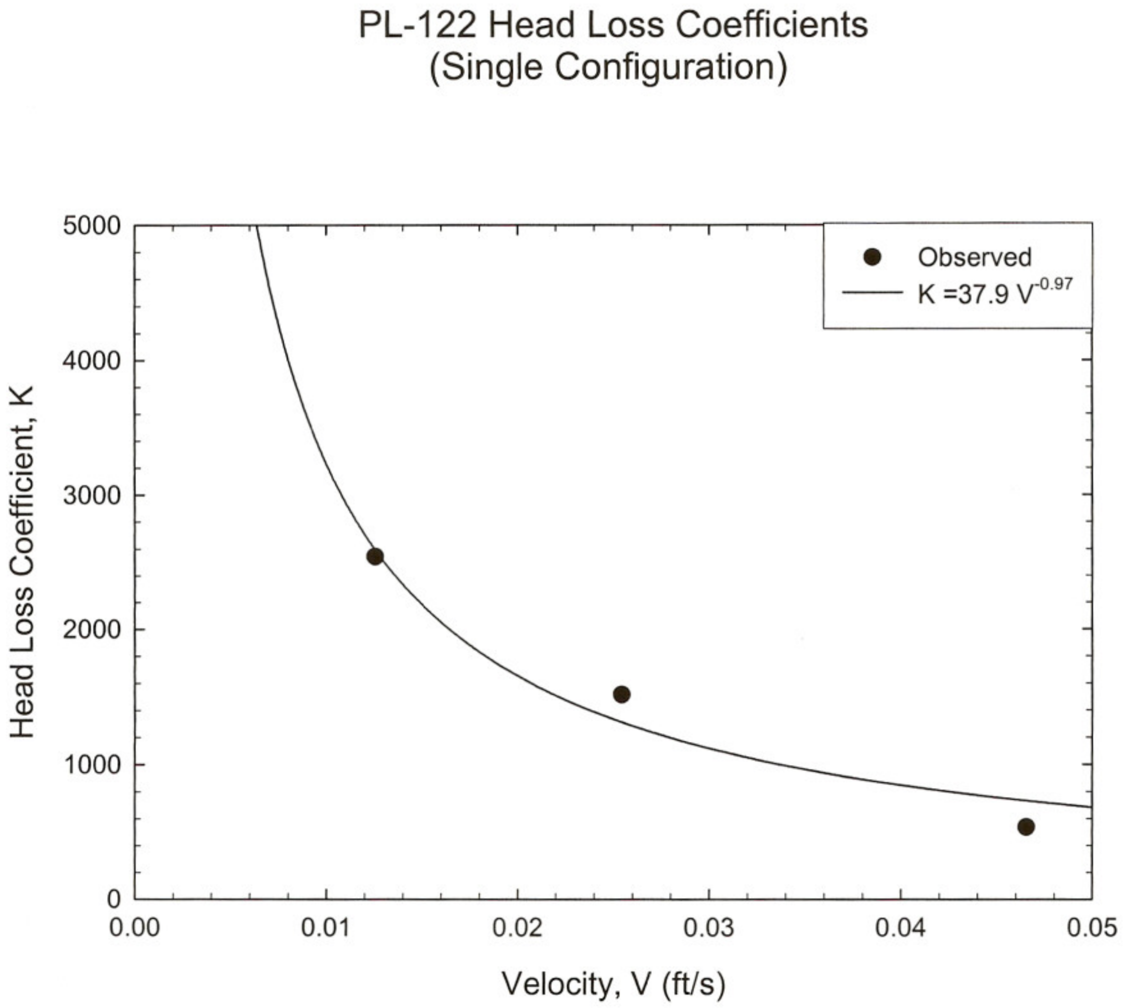


Figure 2. Calculated head loss coefficients for the PL-122 filter (single configuration).

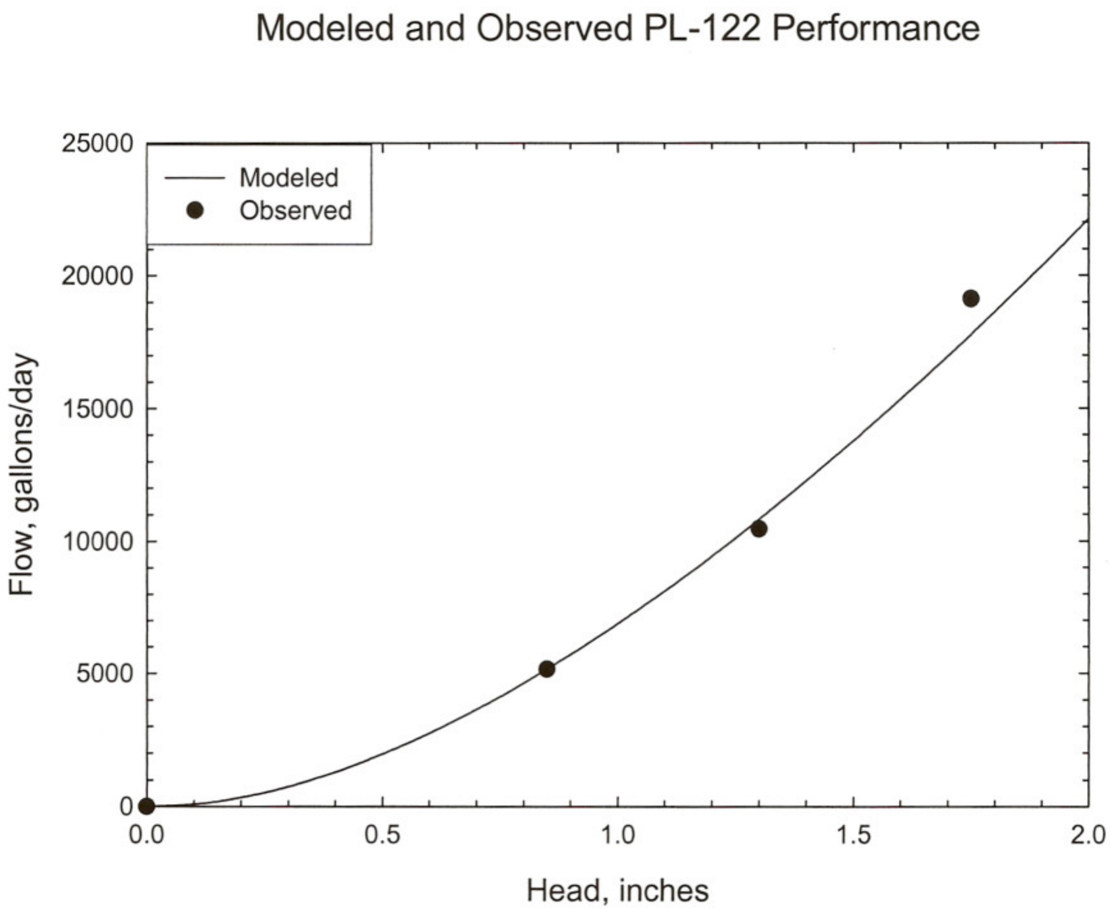


Figure 3. Modeled vs. observed PL-122 performance (single filter configuration).

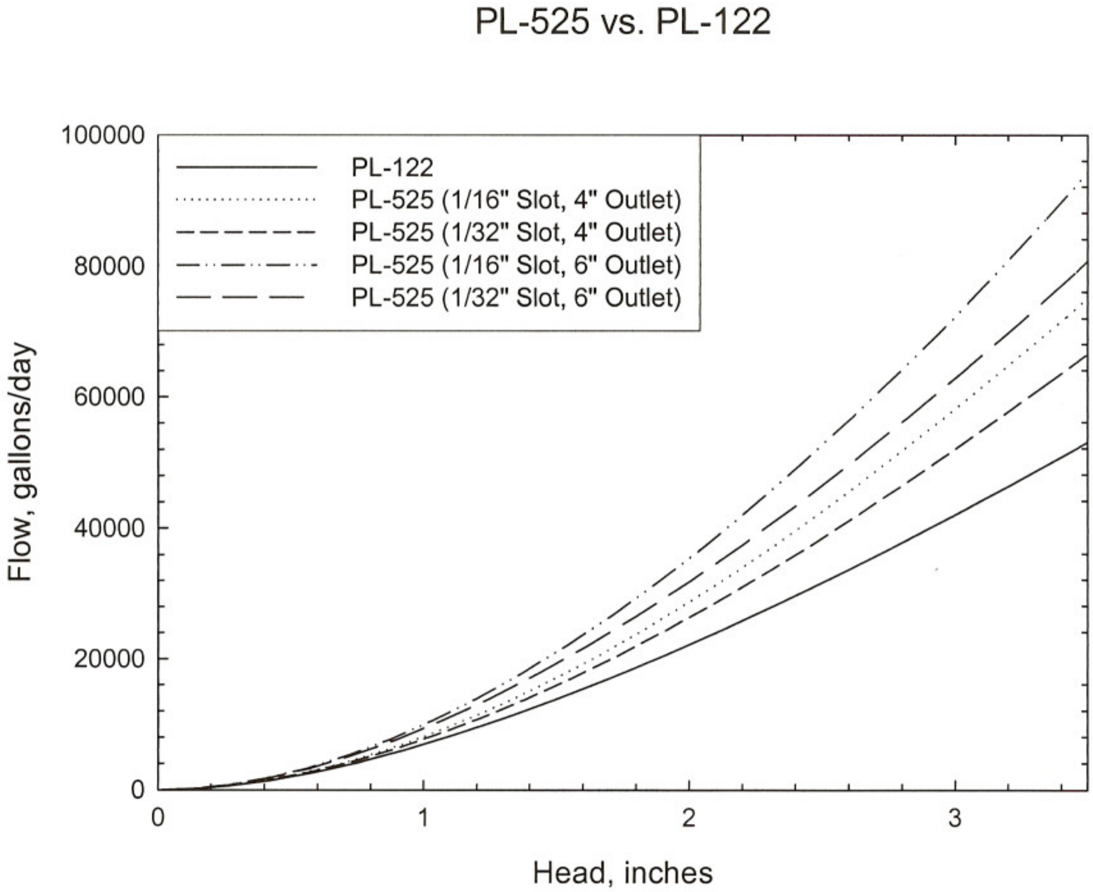


Figure 5. Modeled performance of the PL-525 and PL-122 filters, 0-3.5" head.

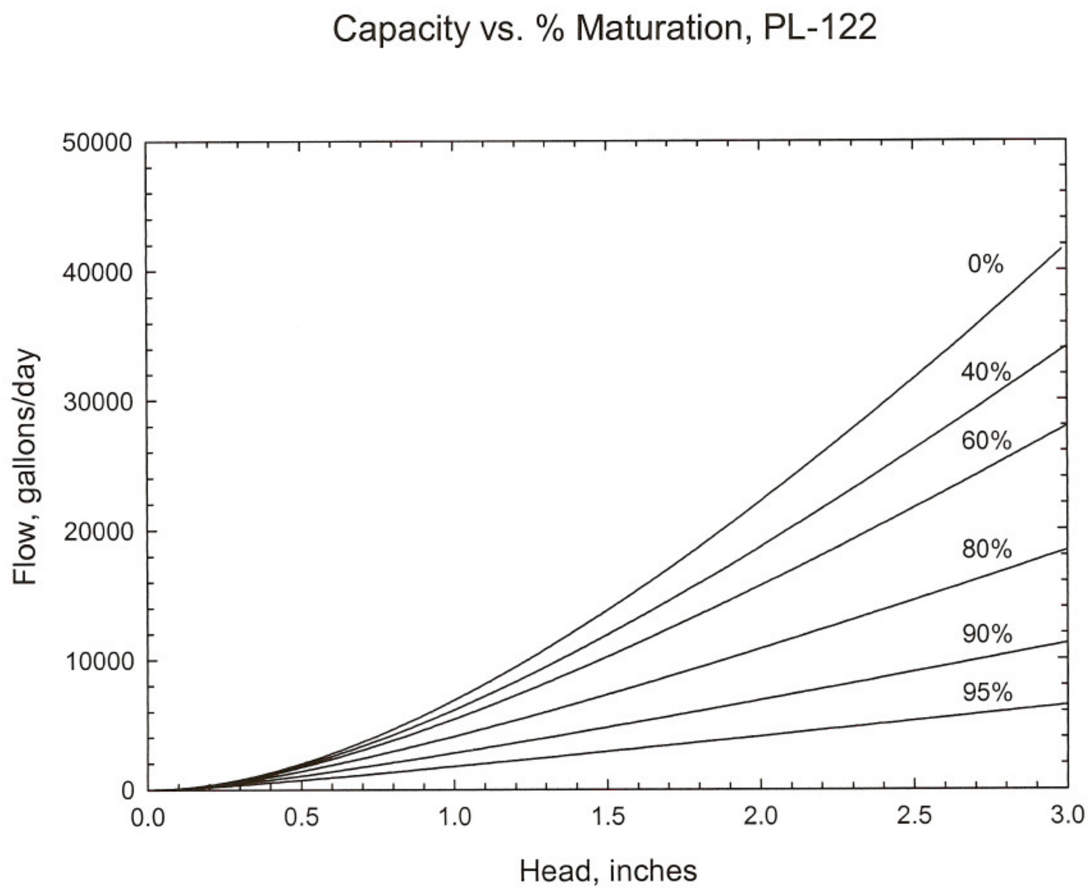


Figure 6. Performance curves for the PL-122 filter. Curve parameter is maturation (%).

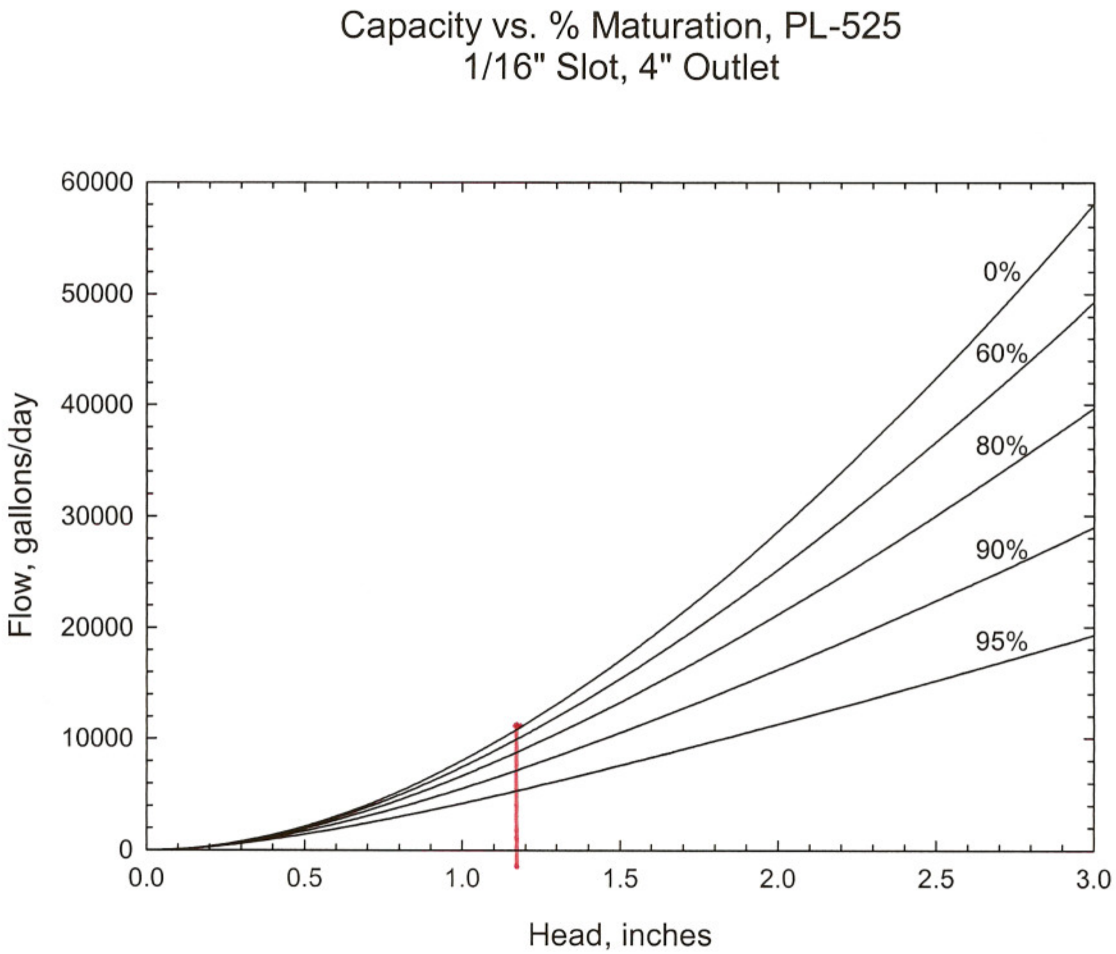


Figure 7. Performance curves for the PL-525 filter (1/16" slot height, 4" outlet). Curve parameter is maturation (%).

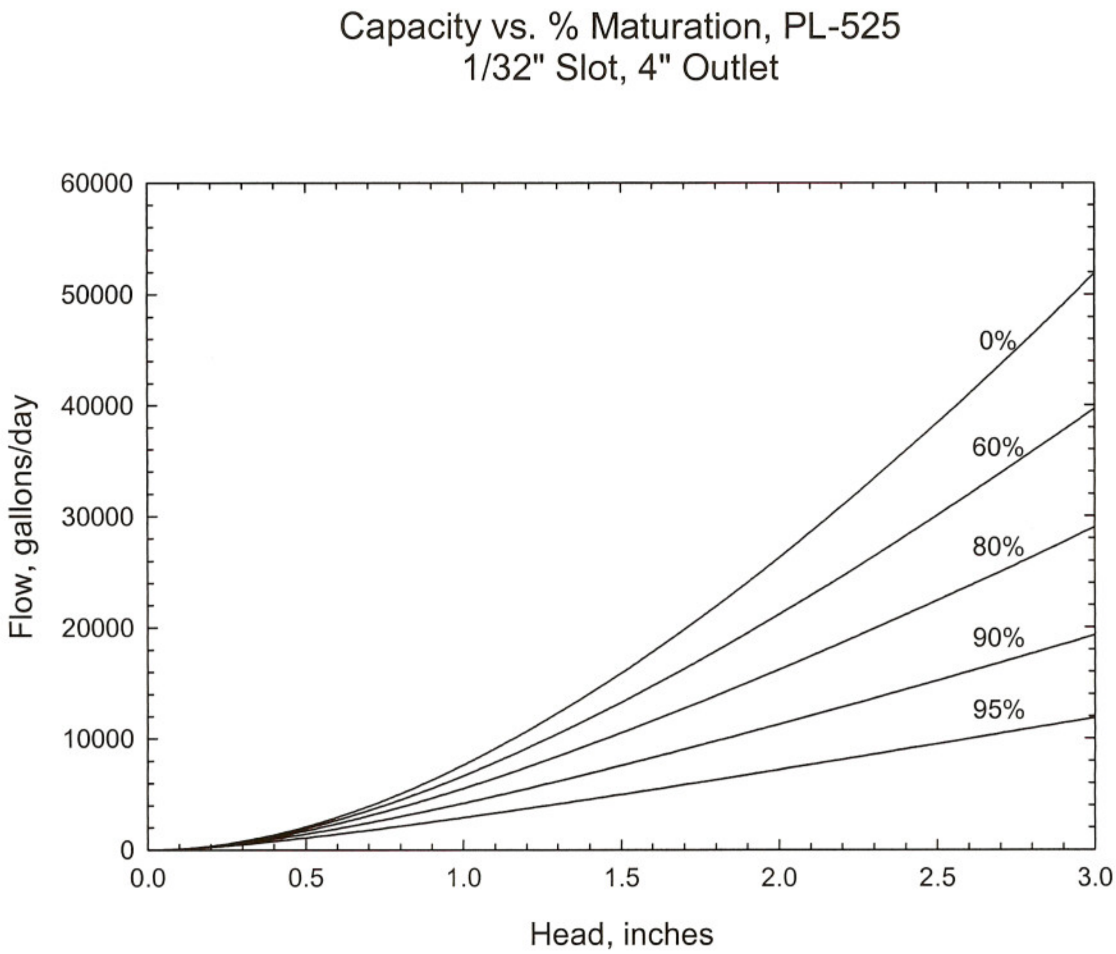


Figure 8. Performance curves for the PL-525 filter (1/32" slot height, 4" outlet). Curve parameter is maturation (%).

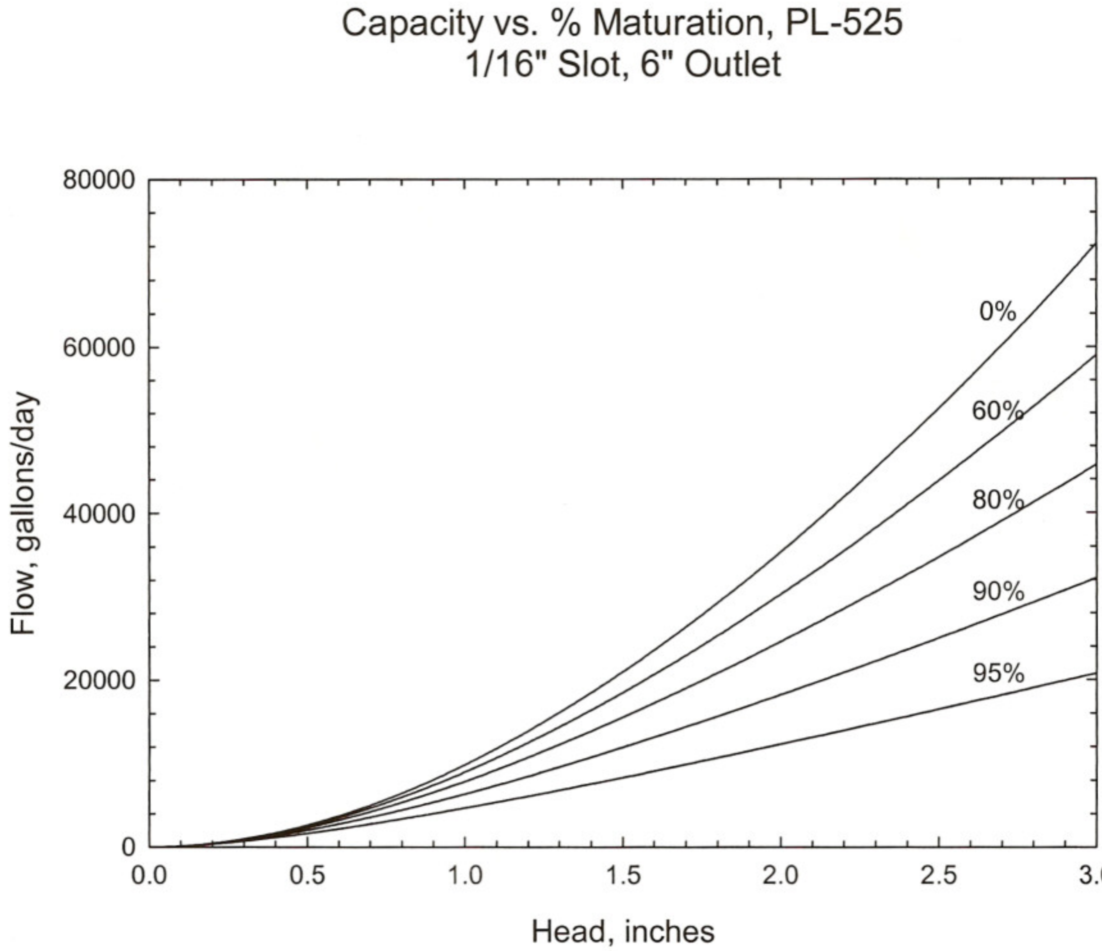
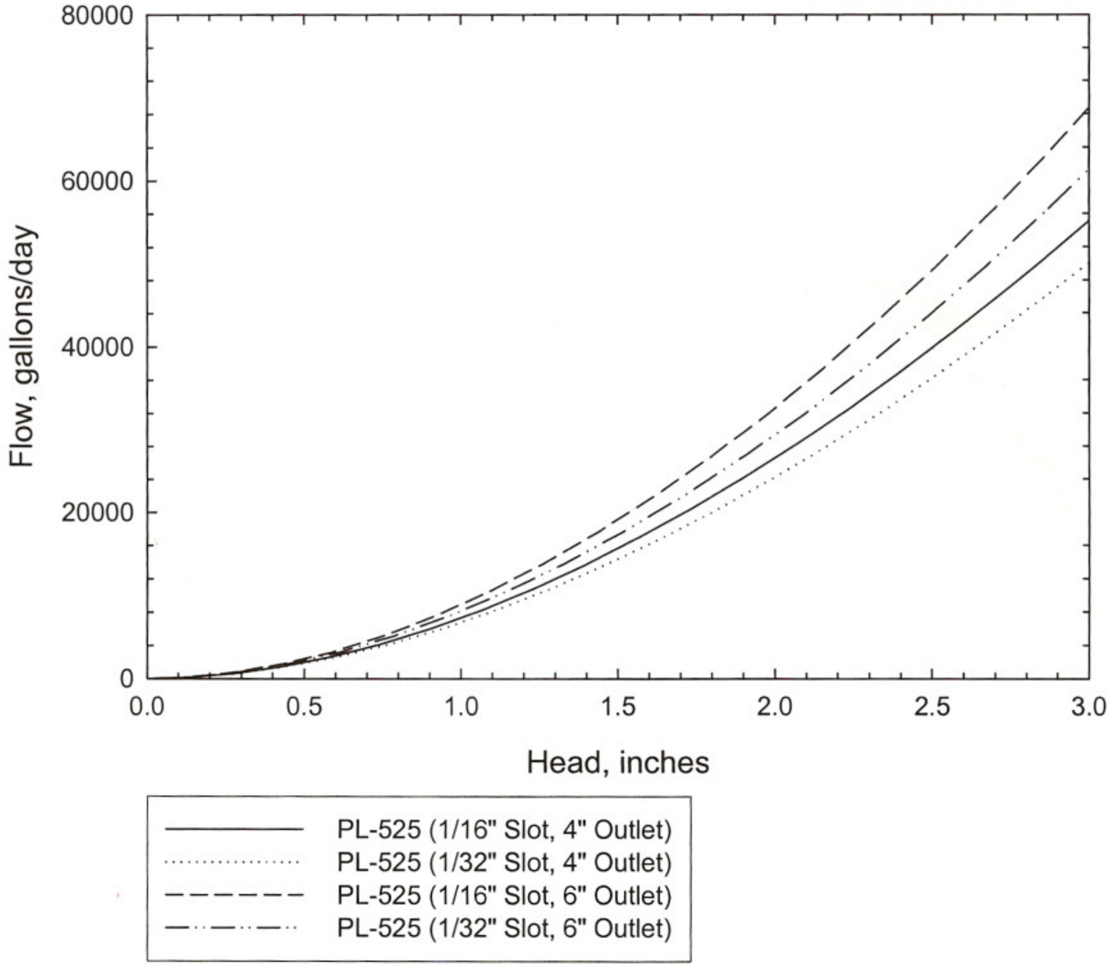


Figure 9. Performance curves for the PL-525 filter (1/16" slot height, 6" outlet). Curve parameter is maturation (%).

PL-525 6" vs. 4" Outlet



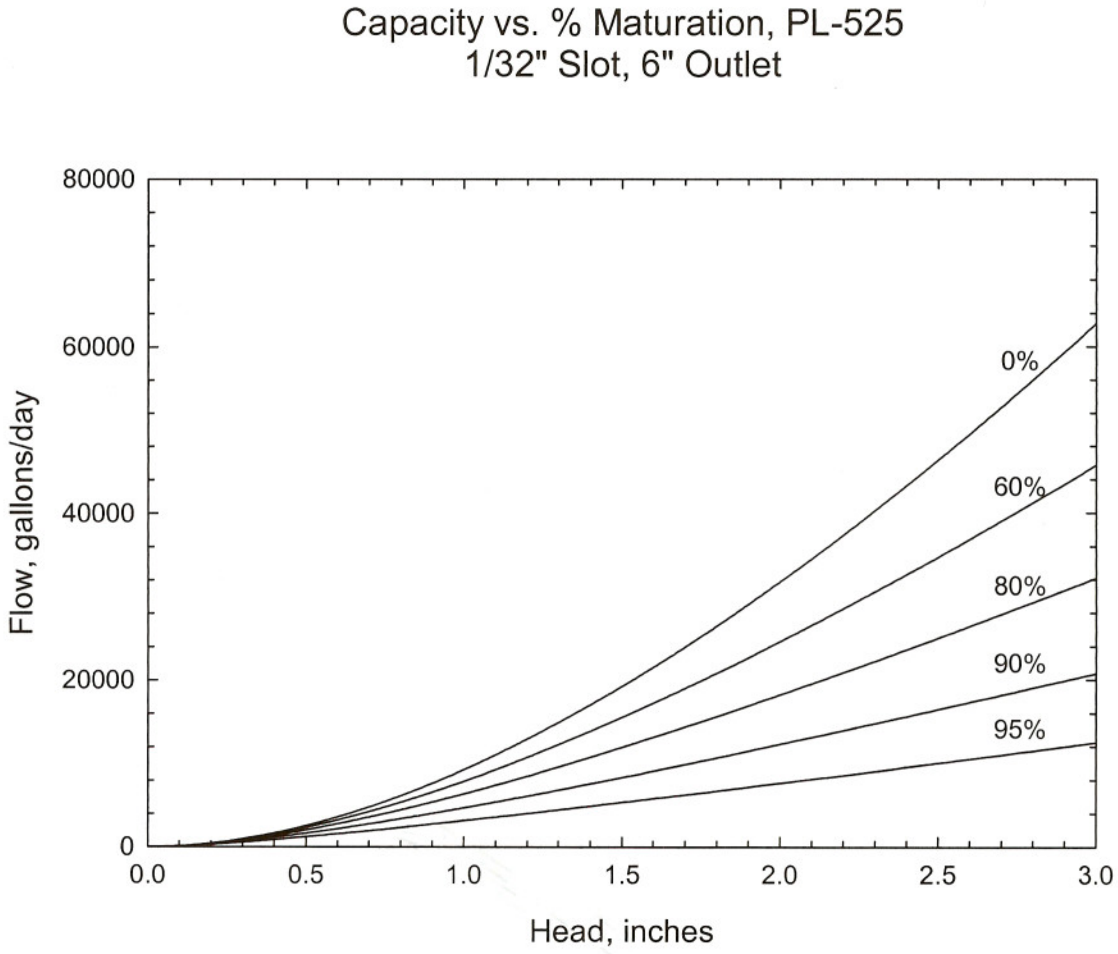
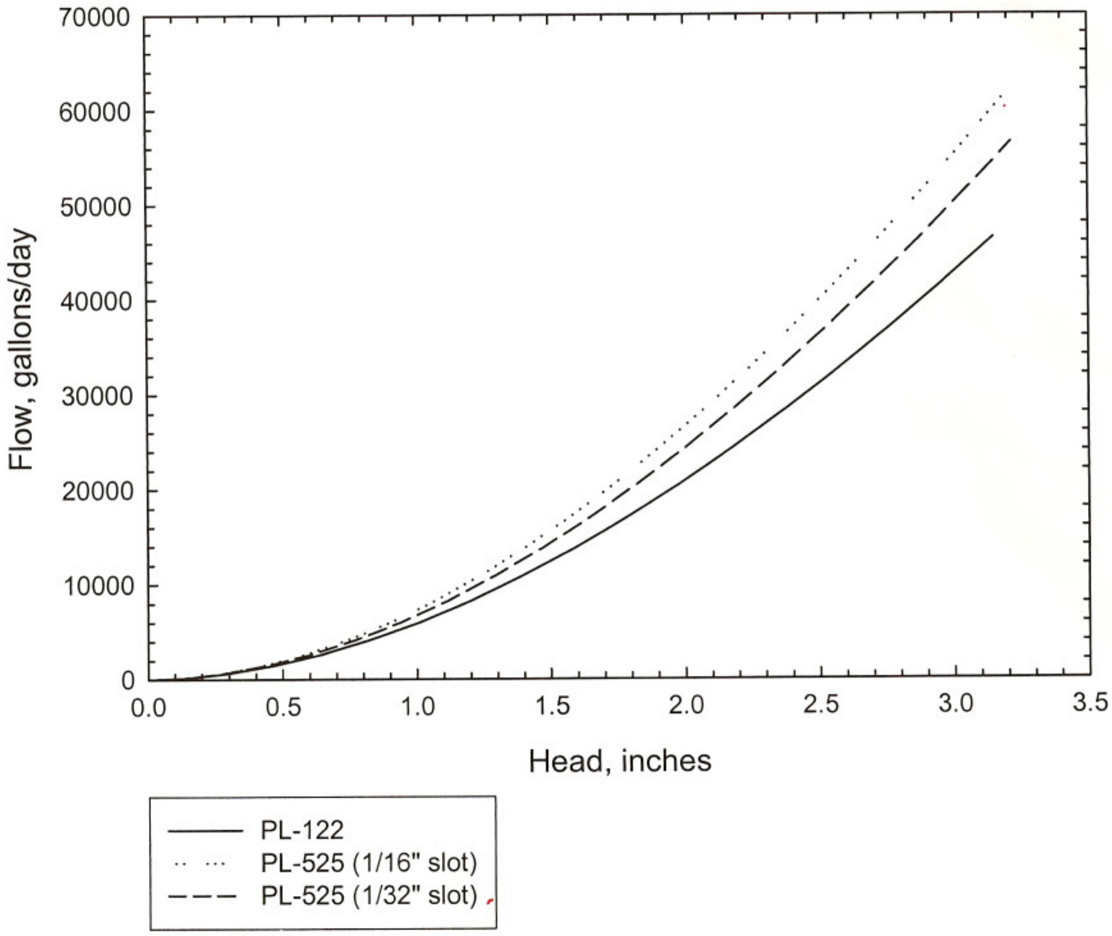


Figure 10. Performance curves for the PL-525 filter (1/16" slot height, 6" outlet). Curve parameter is maturation (%).

PL-525 vs. PL-122



PL-525 6" vs. 4" Outlet