Flow Controller Calibration

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Introduction

The flow controller design tool on the Flow Controller page is used to calculate the tube length necessary to achieve a desired flow rate with a certain head loss. It has been observed that the actual flow rates that occur when using the lengths of tube provided by the design tool were consistently much slower than they theoretically should have been. This indicated that there was some problem with the assumptions made by the design tool. The error was most likely due to one of two things. It was possible that the actual diameter of the tubing being used was slightly smaller than the diameter published by the manufacturer, or that there were significant minor losses in the flow controller not being taken into account by the assumption of a linear relationship between flow rate and head loss/tube length. It was decided that rather than having to manually calibrate every new flow controller, it would be better to come up with a new method for finding the tube length needed. The new method would need to take into account the smaller diameter of the tubing and/or the minor losses, and would predict a more accurate flow rate without having to do further manual calculations or having to cut the tube after construction of the flow controller.

Theory

The design tool uses the Hagen-Poiseuille equation to calculate tube length using head loss and flow rate. The equation gives the laminar flow relationship between head loss (h_l), pipe length (L), tube diameter (D), and kinematic viscosity (nu), assumed to be linear.

$$Q = \frac{\pi D^4}{128\mu}\frac{\rho g h_l}{l}$$ Q Hagen-Poiseuille

The nonlinear relationship between head loss and flow rate can also be modeled if minor losses are taken into account using a minor loss coefficient (K).

$$h_l = \frac{K8Q^2}{D^4\pi^2 g} + \frac{128\nu QL}{g\pi D^4}$$ hl Hagen-Poiseuille and Minor Loss

Procedure

Initial Calibration Trial

It was initially thought that calibrating a flow controller might be accomplished with a simple adjustment once the design tool was used to determine the tube length needed. The demo plant flow controller was set up and the flow rate was manually measured with a stopwatch and bucket. The ratio of the experimental flow rate to the theoretical flow rate was then multiplied by the theoretical tube length in order to obtain a new tube length. The flow rate of the apparatus with the new tube length was then manually determined again in order to determine if the calibration produced an accurate flow rate. It was found that this method was not sufficient for calibration of the flow controller, as it was necessary to cut the tube several times in order to achieve the desired flow. If it was simply the case that the tube diameter was slightly smaller than it was supposed to be, this method should have worked; the flow rate to tube length relationship would still be linear, and the flow rate miscalculation would have been easily adjusted because it would have been due to the use of a slightly incorrect diameter in the equation.

Calibration Accounting for a Nonlinear Relationship Between Flow Rate and Head Loss

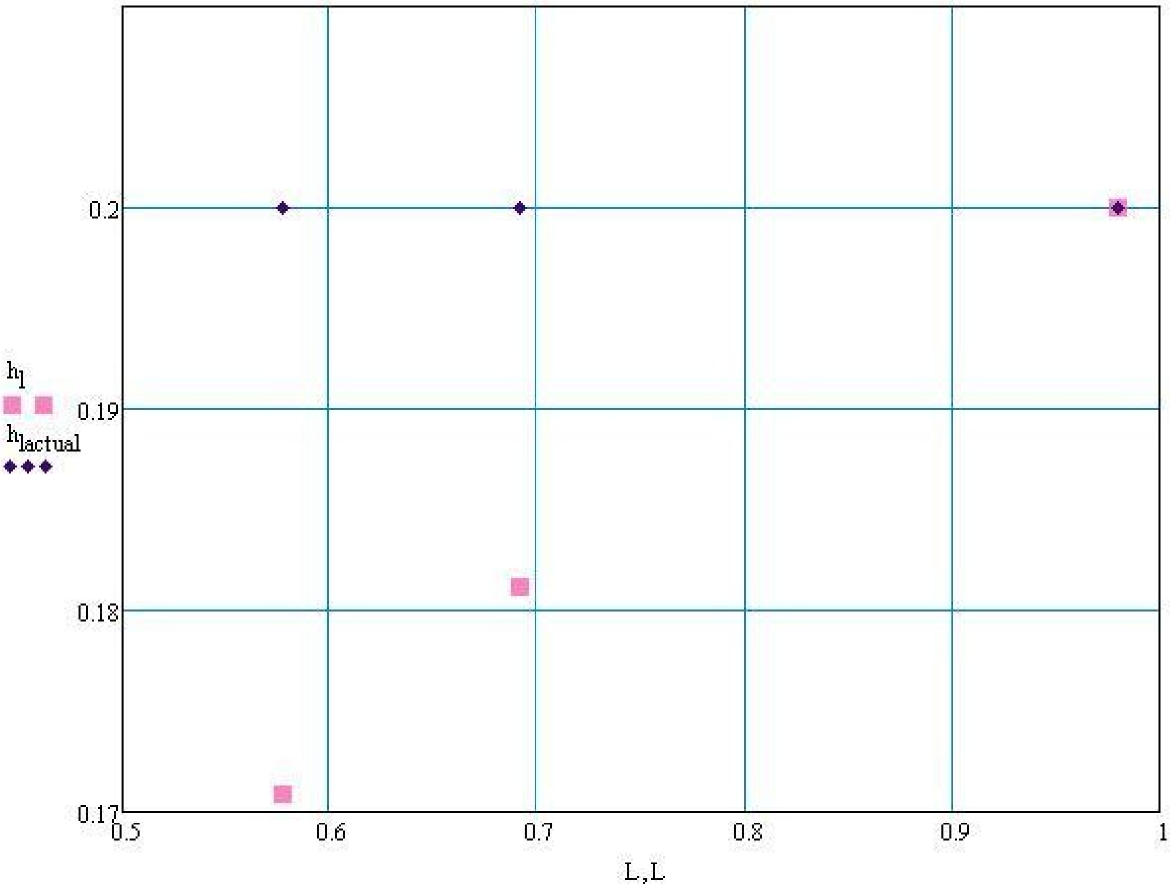
After calibrating the flow controller did not work using the assumption that the relationship between flow rate and head loss was linear, it was necessary to find another way to calibrate the apparatus, this time taking into account minor losses and the possibility of an incorrect tube diameter. A simple Mathcad program was written to determine the correct minor loss coefficient and diameter to be used in the nonlinear equation for head loss, and to ultimately calculate the correct tube length without

adjustments being needed after construction of the flow controllers.
A value of 2 was initially assumed for the minor loss coefficient (K) in order to calculate a diameter (D) via combination of the Hagen-Poiseuille and minor head loss equations in the following form.

$$D = \left(\frac{K8Q^2 + 128\nu QL\pi}{h_l g\pi^2}\right)$$

d Hagen-Poiseuille and Minor Loss

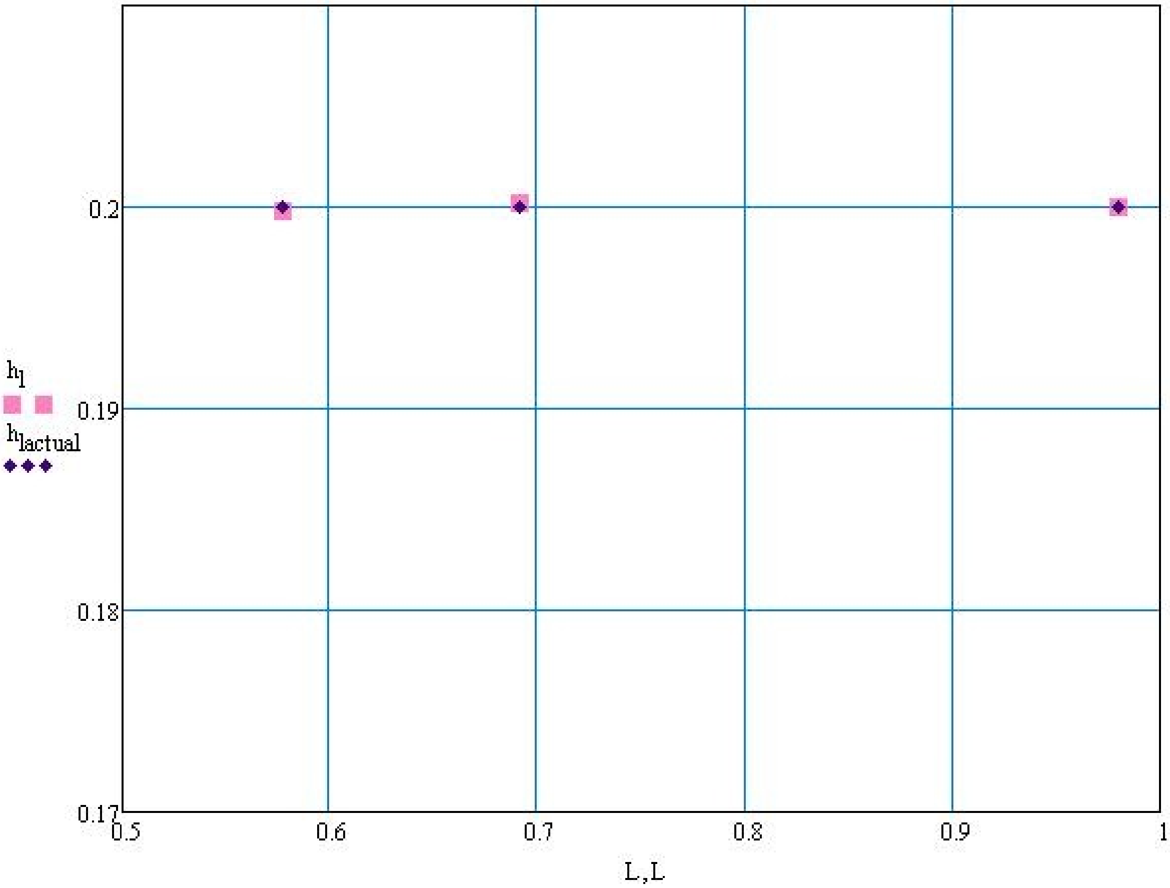
This D and K were then used to calculate the theoretical head losses with experimental values for flow rate (Q) and tube length (L). These theoretical h_l values were then plotted vs. L alongside the experimental values for the same tube lengths. (All of the experimental points were with a 20 cm head loss). With a randomly assumed K value, the plot initially showed a discrepancy between the theoretical h_l values calculated for each tube length and flow rate and the 20 cm h_l actually used experimentally.



The K value was then changed until the theoretical and experimental points on the graph lined up, and this could be assumed to be an appropriate assumption of K. The D calculated using the new K value could be assumed to be the accurate diameter of the tube, and the following equation could be used with those values to calculate an accurate tube length to achieve a certain flow rate.

Results

The K value that caused the following alignment of the experimental and theoretical data points was 5.8. This is a significant minor loss coefficient, and is further evidence that the linear assumption made previously was incorrect.

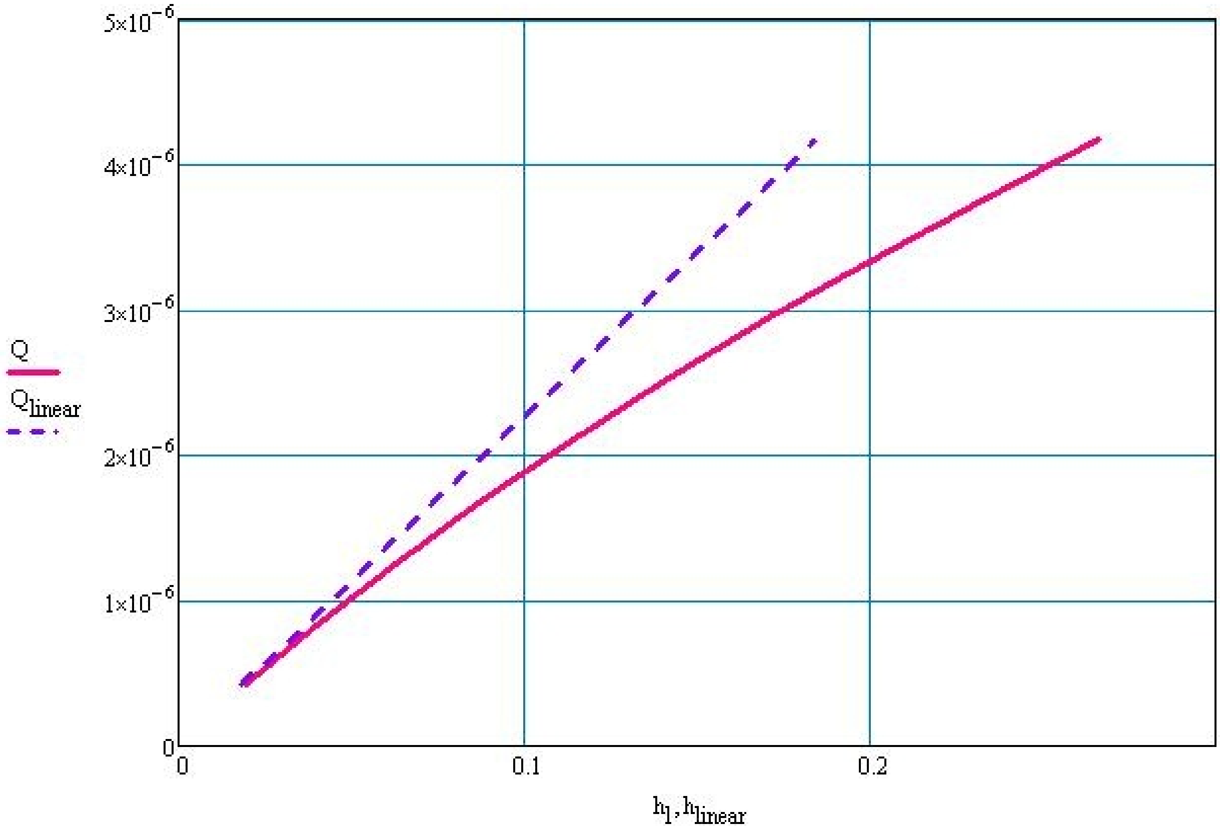


The diameter calculated using the new K value was found to be 3.175mm, which is the same as that published by the tube manufacturer. It appears that the minor head losses were the sole cause for the problems with inaccurate flow rate calculations.
The new K can be used to calculate an appropriate tube length for a target flow rate using the following equation, included in the Mathcad program.

$$L = \frac{D^4 h_l \pi^2 g - K8Q^2}{128\nu Q\pi}$$

L Hagen-Poiseuille and Minor Loss

The following graph shows a range of flow rates plotted vs. the corresponding head loss values for a tube length of 108 cm. The purple dotted line represents the head loss calculated according to the original linear assumption, and the pink line represents the head loss calculated with minor losses taken into effect. It can be seen that as the head loss and flow rate increase, the error of making an assumption of linearity increases.



Demo Plant Applications

In the past, the flow rates for the demo plant flow controller were manually measured in order to provide an idea of what the flow rate was for head loss level as the tube outlet was moved up and down. The Mathcad program used here can be used in the future for calibration of the demo plant, although a new D and K will have to be determined due to the use of different tubing in the demo plant than in the actual AguaClara plants in Honduras. In this way, the flow rates will be easily predicted at each level of the flow controller, rather than having to be measured individually.

No labels