GRUNDFOS
WHITE PAPER

SYSTEM CURVES

by Steve Wilson

The impact of flow in any piping system is very predictable and can be graphically represented as a system curve. Understanding the impacts of flow through a pipe (or hose) is of paramount importance in pump selection and evaluation because the pump is only one component in the system. In this White Paper, we will discuss system curves.

SYSTEM DESIGN

Before delving into system curves, let's first discuss system design parameters. Design parameters required to determine what will happen to fluid in an installation are twofold:

- How much fluid will be required at design?
- How much pressure will be required to deliver that fluid to the farthest fixture requiring it?

Both of these parameters are determined by designers well versed on the matter and application. The amount of fluid required is first determined, then the required pressure is determined using design flow(s). The pressure component will be covered later in this paper.

SUCTION CONDITIONS

The suction to the pump is part of the system. Systems are designed with regard to need, not the pump; in this regard, the system is independent of the pump. In application, the performance of the pump and system are directly related.

Suction conditions either will or will not provide adequate water (for this discussion, we'll assume they will. The pump will not make water!). Suction conditions (Suction Head) will either add pressure into the system or not. The amount of pressure added may, and often does, vary.

CALCULATING DESIGN HEAD

Once the designer has determined flow requirements at design point, that information is then used to calculate design head, or pressure requirement for the installation. There are two components in the design head:

Independent Head

This term is often (erroneously) called static head. It consists of pressure requirements that do not change with flow. These requirements include static head (the height the fluid must be lifted) and head (pressure) required at the end of the system.

In closed systems (those not open to the atmosphere and pumping in a closed loop, such as a chilled water loop in an HVAC system), there is static head and no independent head.

In open systems, both the height the liquid must be lifted and the suction conditions must be considered. These components in the independent head (static and pressure at the end of the system) are calculated at a worst-case scenario. For example: If pumping out of a sump, it must be assumed that the sump will be nearly empty in order to assure the fluid will get to where it needs to go.

Friction Head

Two basic formulae have been developed to calculate head loss in piping due to friction and should be mentioned: The Hazen-Williams formula and the D'Arcy Weisbach formula.

The Hazen-Williams formula can be written as:

$$P_d = 4.52\ q^{1.85} / (c^{1.85}\ d_h^{\ 4.8655})$$

where:

P_d = Pressure drop (psi/ft. pipe)

c = Design coefficient determined for the type of pipe; the higher the “c” factor, the smoother the pipe. (This will change with type and age of pipe. Designers must take life expectancy into consideration.)

q = Flow rate (gpm)

d_h = Inside hydraulic diameter (inch)

The Hazen Williams formula gives accurate head loss due to friction for fluids with kinematic viscosity of approximately 1.1 cSt.

The result of the formula is then acceptable for cold water at 60°F (15.6°C) with kinematic viscosity of 1.13 cSt. For hot water with a lower kinematic viscosity (0.55 cSt at 130°F [54.4°C] for example), the error will be significant.

Since the Hazen Williams method is only valid for water flowing at temperatures between 40 to 75°F, another formula is used elsewhere and more predominantly. This formula is the D’Arcy Weisbach formula (also known as the D’Arcy Weisbach equation, D’Arcy Weisbach method, or simply “Darcy”). The formula can be written as:

$$\Delta p = \lambda(l/d_h)\ (\rho\ v^2/2)$$

where:

Δp = Pressure loss (Pa, N/m^2)

λ = D’Arcy Weisbach friction coefficient

l = Length of duct or pipe (m)

d_h = Hydraulic diameter (m)

ρ = Density (kg/m^3)

Calculation of the D’Arcy Weisbach friction coefficient is a separate set of calculations because of:

- The complexity of these formulae due to the fact that a piping system will have numerous changes in diameter and perhaps even changes in pipe type. Tables have been developed to allow a simpler method, and numerous computer programs have been written to provide the designer with needed tools.
- Losses in the lengths of pipe, where each elbow, fitting, and appurtenance included in the piping must be considered.
- Required head at the end of the pipe is added to the number obtained either through calculation or a table to yield a design head, which will be a single point.

In addition to the variances obtained through piping that is not exactly as predicted, further variances may be caused through the addition of safety factors, erring on the side of caution.

In many systems, the same pump may be used to pump through different sets of piping. In a municipal system, for example, there may be a primary flow path and a diversion (or bypass) path. Since each path has different lengths and sizes of pipe, separate system design points must be calculated.

DEVELOPING A SYSTEM CURVE

The first step in developing a system curve is to indicate the design point. While this is typically done in a spreadsheet or computer program, it would graphically be represented as in *Figure 1*.

For the purpose of this exercise, and throughout the remaining discussion, we will use a primary design point of 1000 gpm @ 110 ft. TDH.

Unless specifically mentioned otherwise, we will use 10 ft. of independent head. The total head requirement ***includes*** the independent head. These figures are arbitrarily selected for points of illustration in this exercise.

The next step is to plot the independent head, which will be a constant – the same regardless of flow, and the point of the plot made at 0 (zero) flow. If it were expressed on the curve throughout, it would be a horizontal line.

In closed systems, the independent head is also 0 (zero). In *Figure 2*, the independent head is added to our example.

The system curve represents flow through a piping system at any given time. While the independent head would change with changes in suction pressure, the total head would change as well.

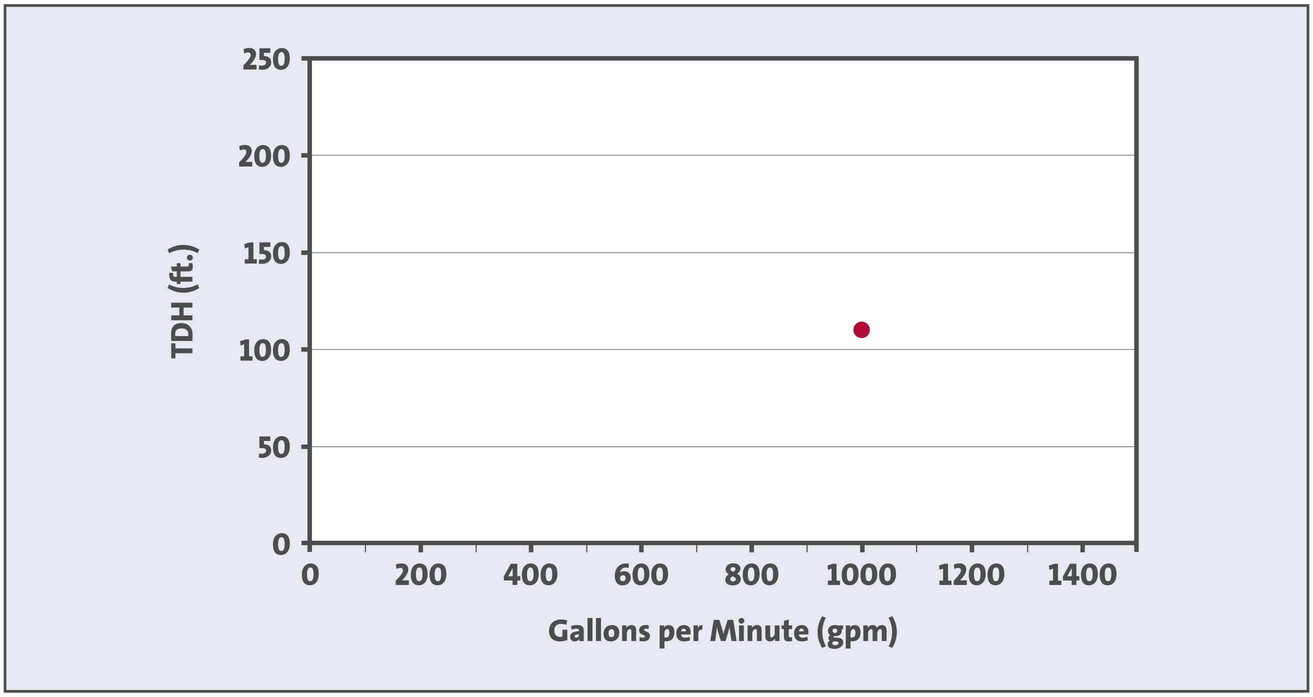

Figure 1. Design Point Plotted

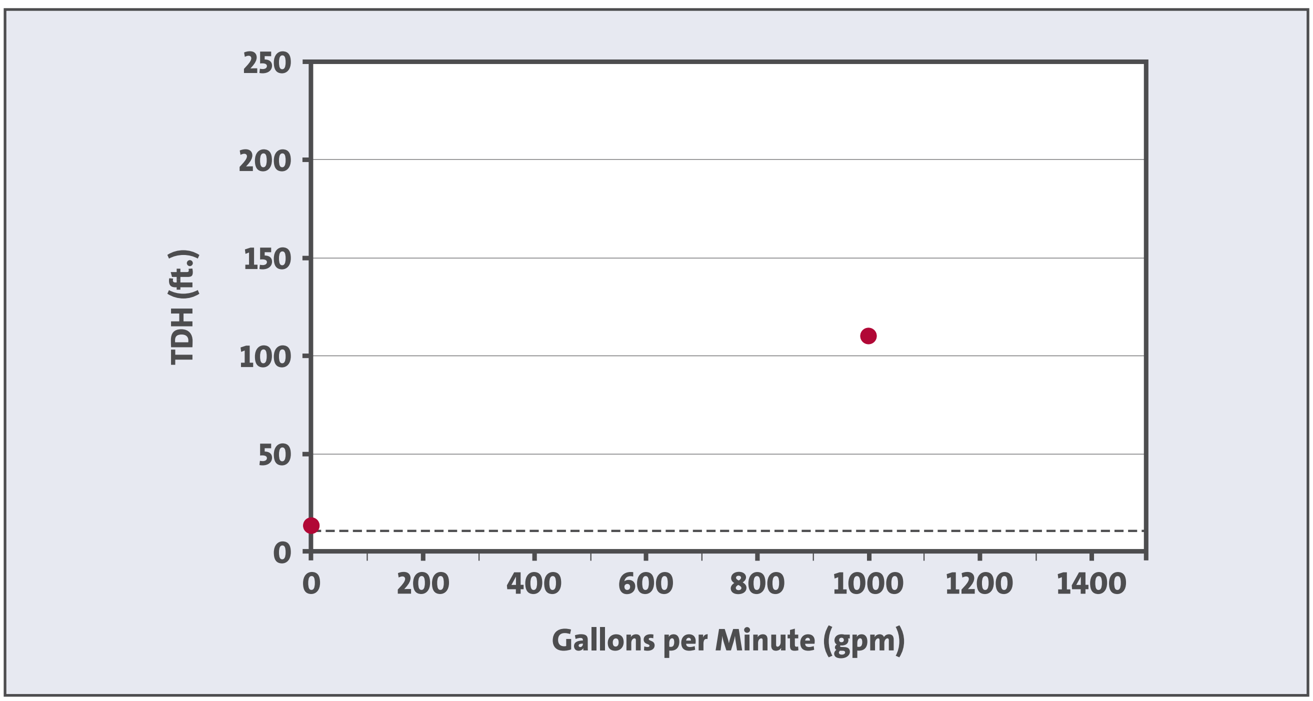

Figure 2. Design Point and Independent Head Plotted

Now that we have two given points plotted, we need to plot how the fluid and system behave at other points as they flow through the piping.

PLOTTING THE FRICTION LOSS PORTION OF THE SYSTEM CURVE

Both D'Arcy or Hazen Williams may be used to plotting the other points. Arbitrary flows can be selected and their corresponding heads then calculated. However, this is cumbersome and seldom necessary.

Since friction coefficients, roughness of pipe, etc., have already been used in determining the design point, they do not have to be used again. Eliminating them from Hazen Williams would yield the result that head changes to the 1.85 power of a change in flow.

But this is also not accurate. Profiles of flow in the piping and other factors must be taken into account, and it is commonly acceptable to state that head will change as the square of a change in flow:

$$(H_1/H_2) = (Q_1/Q_2)^2$$

This is the formula for calculating the friction loss portion of a system curve.

We can now fill out a simple table to express at least three (3) other points on the curve. The flows used can be completely arbitrary (we are plotting a curve) or may be expected alternate points of operation. The results will be the same. One of the three points should also be a point beyond the design point, or the curve plot will end at design (*Table 1*).

It becomes easy to calculate the heads at those alternate flows, as shown in *Table 2*. Remember that the independent head must be subtracted from the design head prior to the calculation and then added back in. These points can then be plotted on the curve as illustrated in *Figure 3*. From there, it's just a matter of connecting the dots (*Figure 4*).

GPM	TDH	
1000	110	Design
0	10	No Flow
1500		(1.5 x Design)
500		(.5 x Design)
750		(.75 x Design)

Table 1. *Alternate Flows*

GPM	TDH	Notes	Head Calculation
1000	110	Design	
0	10	No Flow	
1500	235	(1.5 x Design)	= [(110 - 10) x (1.5 x 1.5)] + 10 = (100 x 2.25) + 10
500	35	(.5 x Design)	= [(110 - 10) x (.5 x .5)] + 10 = (100 x .25) + 10
750	66.25	(.75 x Design)	= [(110 - 10) x (.75 x .75)] + 10 = (100 x .5625) +10

Table 2. *System Curve Calculations*

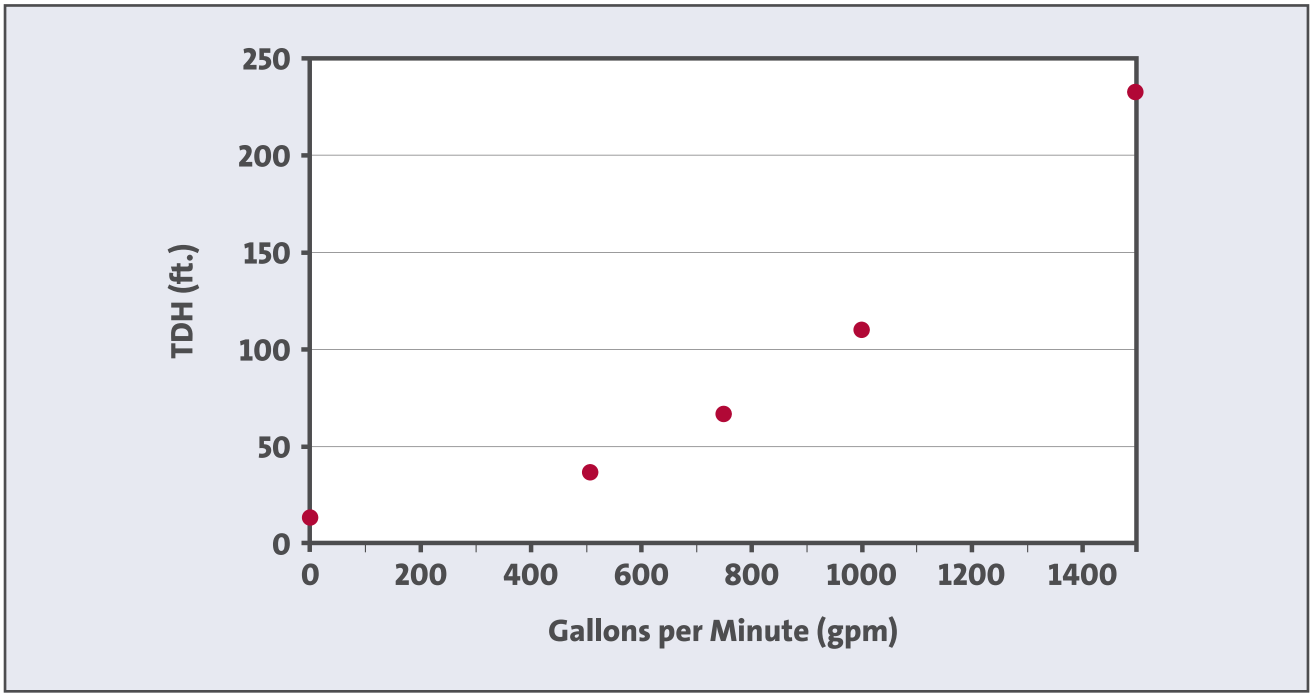

Figure 3. *All Required Points Plotted (Including Independent Head)*

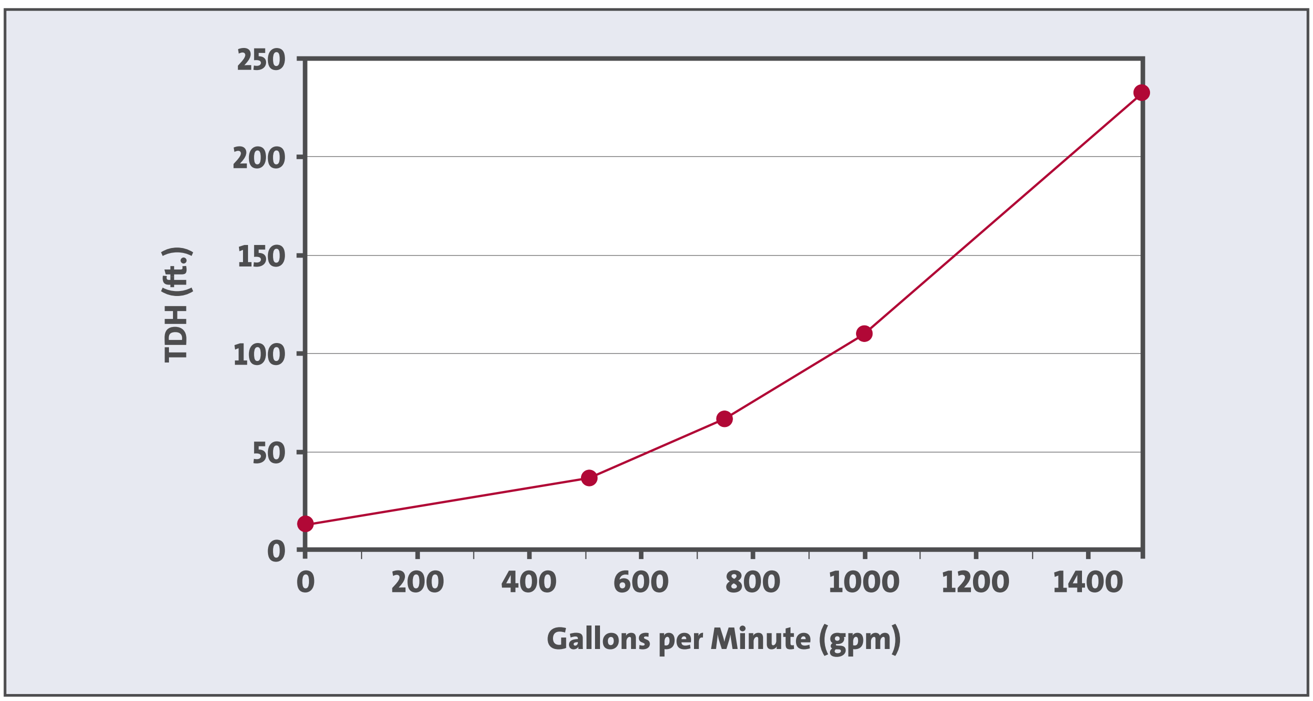

Figure 4. *System Curve Plotted*

Now that we have a system curve plotted, then what? One of the fundamental rules of pump performance is that at any given speed and impeller diameter, a pump will perform along its characteristic curve from shutoff to run-out, but ***only*** at the intersection of the pump curve and system curve. This point is illustrated in *Figure 5*.

Given the facts presented earlier in the paper, we can conclude that numerous factors may cause the system curve to be different than proposed. Those factors include

- differences or changes in suction head,
- reduced or increased friction as a result of piping "C" factor,
- the friction coefficient changes deviations from that expected,
- changes in losses resulting from differences in equipment, and
- safety factors.

We may end up with an actual system curve that is different to the predicted one, and the pump will operate along its curve at the intersection with the real system curve (*Figure 6*). As illustrated in *Figure 6*, the flow is greater than predicted, the head lower (reflected by pressure guages, and the power requirement would no doubt be higher than planned.

Also of note is that "partial loading" of a system through either sequencing pumps on and off or via the use of Variable Speed Drives (VSD) will impact the point of operation. Increasing or decreasing the number of stages of impellers in the series also has an impact.

In all of these cases, the system curve will remain constant (with the exception of those deviations already noted and assuming the system curve is not changed through the opening and closing of valves, diverting fluid, etc.), but the pump curve will change. Therefore, the point of operation will change to the point of a new intersection between the pump and the system curves.

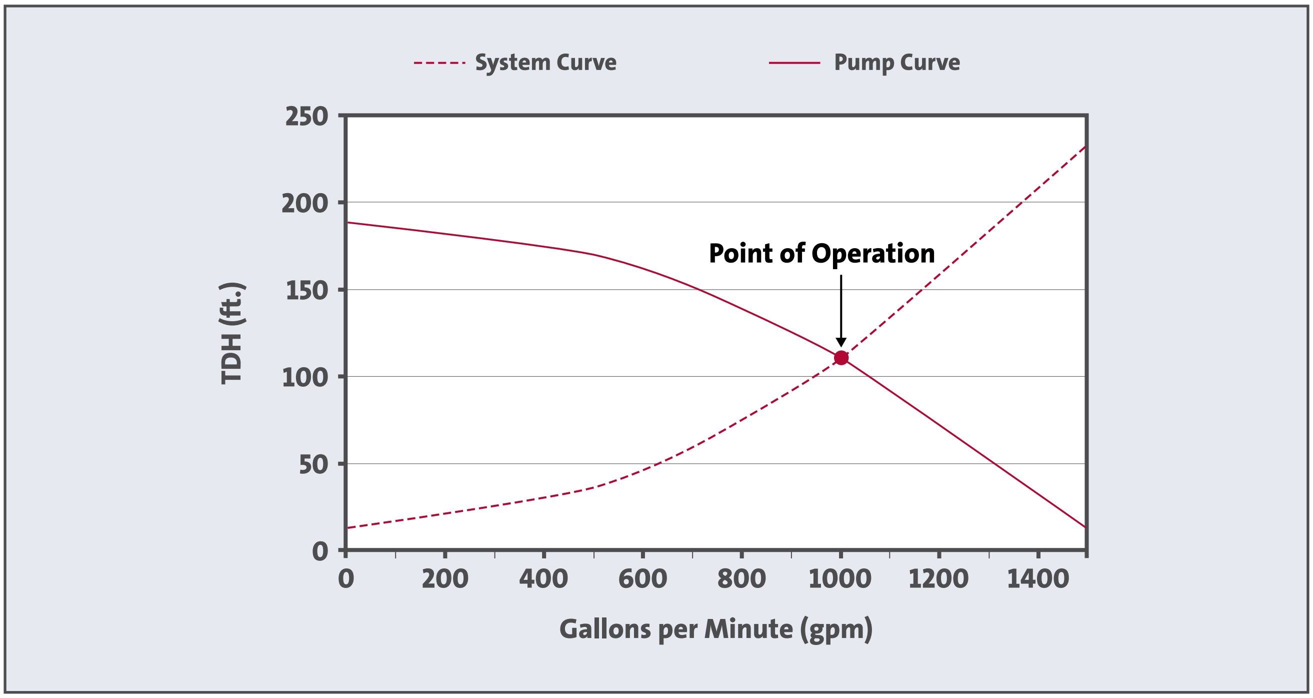

Figure 5. *Point at Where a Pump Operates*

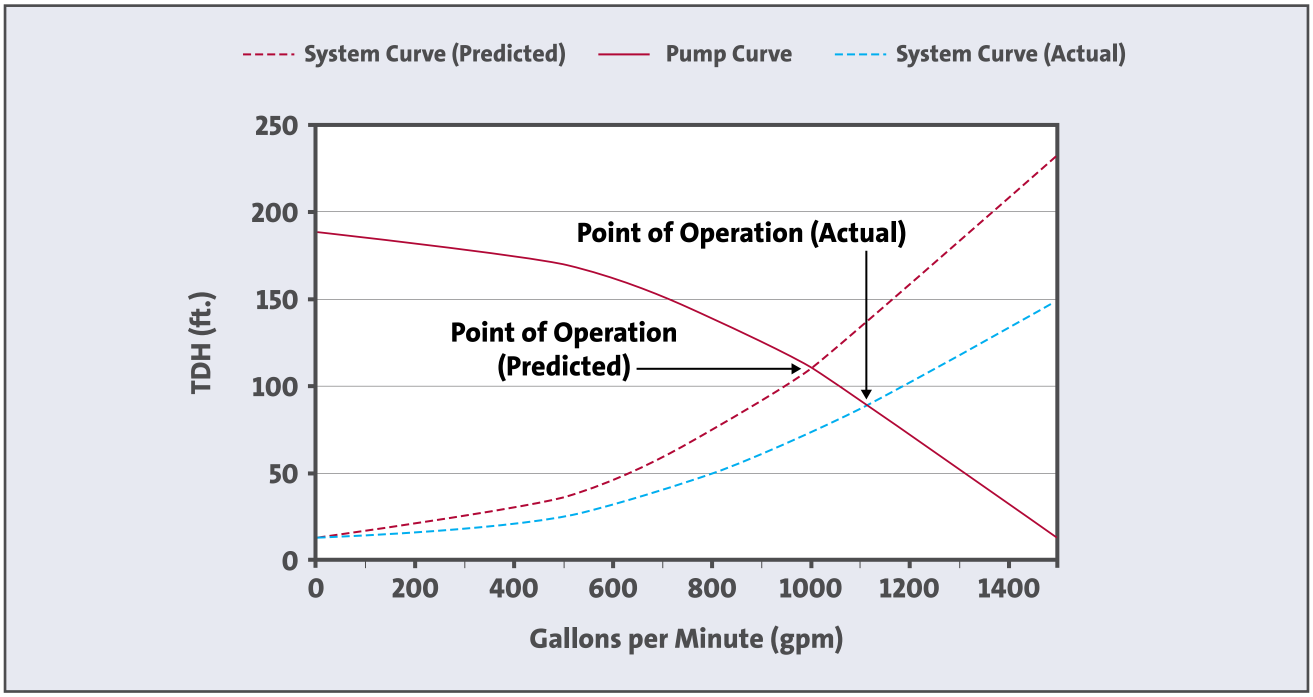

Figure 6. *Predicted vs. Actual Operation with System Curve Deviation*

CONCLUSION

Since a pump is only one component in the system, it's important to understand and predict how the two relate to each other. While many manufacturers now have software programs to assist in those predictions, understanding the basics is valuable in the case where access to such programs is not available and knowing those factors which must go into the calculations.

With this understanding, we are better prepared to ensure the most proper intersection between the pump and system curves. Understanding system curves is key in properly evaluating energy savings in most pump selections as well as in pump maintenance, repair, and replacement in order to assure that duplications of poor selections are not arbitrarily made.

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Being responsible is our foundation
Thinking ahead makes it possible
Innovation is the essence

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