The Hydraulic Analysis of a Water Tank

By Dr. Sang H Wong

Tanks are storage devices for stabilizing the pressure and flow in pipes that supply water to fire sprinklers and fire hydrants. In areas not served by public water supplies, a tank and booster pump may be the only source of water. The pressure or head (feet-of-water) exerted by water stored in a tank depends on the elevation of the tank water surface above sea level (ASL), headloss in the suction piping, atmospheric pressure, and fluid vapor pressure. We will see how these variables are used to calculate the Net Positive Suction Head Available (NPSHa), an important parameter affecting the performance of a fire pump.

Background

This true story began when a building contractor in Connecticut invited us to study their water storage tank. They wanted to know how a 3' increase in the height of the tank would affect their fire pump. The existing 125,000-gallon water storage tank would be the only source of water to satisfy the fire sprinkler system demand of 1,000 gpm. The pump suction header would be connected to the water tank by a 310' length of 6" cast iron pipe. In addition, there were several fittings and a 6" gate valve between the water tank and the pump suction header. The tank had an initial water surface elevation of 426'. This was to be increased by 3', resulting in a tank water surface elevation of 429' ASL.

The fire pump would be an AURORA Series 912 split case centrifugal pump rated 90 psi @ 1,000 gpm as shown in *Figure 2*. It would be installed in the basement of Building 1A. The pump suction centerline would be 3' above the basement finished floor. Since the basement finished floor is at an elevation of 418.88' above sea level (ASL), the pump suction centerline would be at 421.88' ASL. The difference in elevation between the tank water surface (429') and the pump suction centerline (421.88') is the tank static pressure (z) of 7.12' exerted against the suction side of the pump.

The atmosphere exerts pressure on the water surface in the tank. This pressure decreases with elevation relative to sea level. Vapor pressure data is based on *Figure 3*. The next section will apply these concepts by calculating the NPSHa affecting the suction side of the fire pump.

Calculating Net Positive Suction Available

The NPSHa is a function of headloss in the suction pipe, the static pressure in the tank, and the difference between atmospheric pressure and the vapor pressure of the fluid as depicted in *Figure 3*:

$$NPSHa = -Hf + z + (Ha - Hvp)$$

A pump will perform at the manufacturer rated pressure and flow if the NPSHa on the suction side of the pump exceeds the Net Positive Suction Head Required (NPSHr) by at least 2-3' of head. Ignoring this basic principle can lead to poor performance and serious damage to the pump impeller. For over 20 years pump manufacturers have determined the value of the NPSHr based on a 3% head drop i.e. that amount supplied to a pump that creates a reduction in the total head not exceeding 3%.

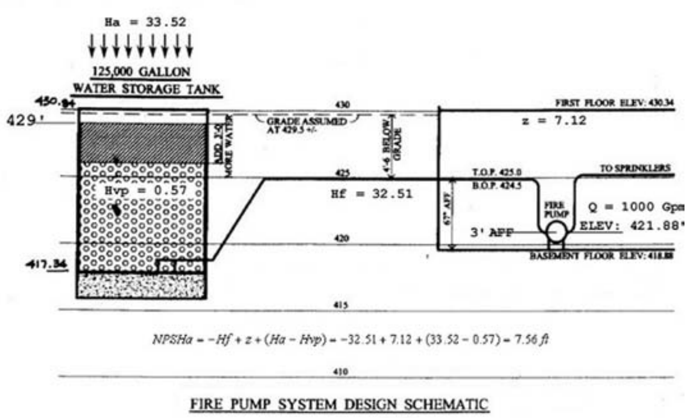

Figure 1: The Storage Tank and Fire Pump

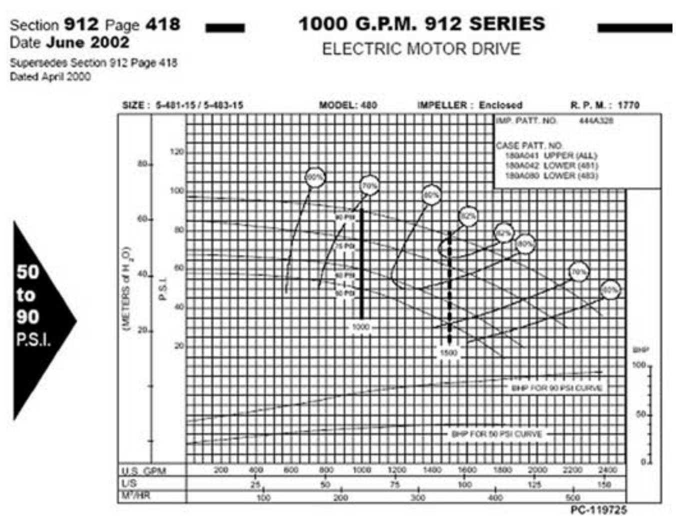

Figure 2: The Pump Curve

1. Pipe Headloss

Headloss varies with the flow through the pipe (Q), the pipe smoothness factor (C) and the pipe diameter (d). The friction loss in the pipe (p) is estimated using the Hazen-Williams Equation:

$$p = \frac{4.52Q^{1.85}}{C^{1.85}d^{4.87}}$$

p = friction loss (psi/ft)
Q = flow (Gpm)
C = Hazen-Williams C-Factor (dimensionless)
d = pipe diameter (ins)

The headloss in a segment of pipe (Hf) is a product of the Hazen-Williams friction loss (p) and the total length of pipe plus fittings (L). We first compute p and then Hf:

$$p = \frac{4.52(1000)^{1.85}}{120^{1.85}(6.065)^{4.87}} = \frac{4.52(354813.39)}{7022.39(6492.11)} = 0.0351\frac{psi}{ft}$$

$$H_f = 0.0351\frac{psi}{ft}(401)ft(2.31)\frac{ft}{psi} = 32.51\ ft$$

The pipe fitting loss of 401' was calculated using an Internet-based pipe fitting utility at www.uengineer.com and shown in *Figure 4*.

2. Tank Static Pressure

The tank static pressure (z) is the elevation difference between the tank water level and the pump centerline:

$$z = 429 - 421.88 = 7.12\,ft$$

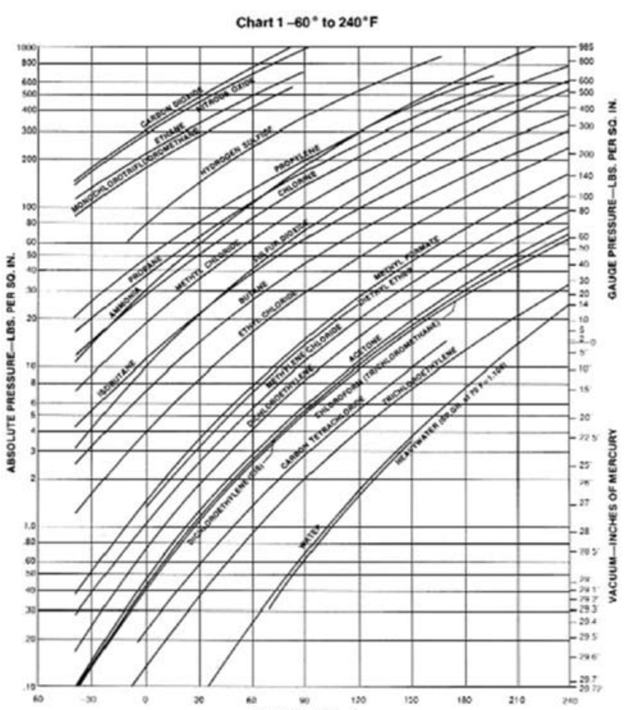

Figure 3: Vapor Pressure Chart

3. Atmospheric Pressure and Vapor Pressure

The atmospheric pressure (Ha) is the weight of air on the free surface of the liquid in the suction tank. At sea level, the atmospheric pressure is equivalent to 34.04' of head. For any elevation above sea level, atmospheric pressure (Ha) is estimated as follows:

$$Ha = 14.55\frac{(56267 - elevation)}{(55545 + elevation)}(2.31)$$

$$Ha = (14.55)\frac{56267 - 429}{55545 + 429}(2.31) = 33.52\,ft$$

Since most pump tests are conducted using water at 60˚F, the vapor pressure interpolated from *Figure 3* is 0.25 psi or 0.57' of head:

$$Hvp = 0.25(2.31) = 0.57\,ft$$

4. Net Positive Suction Head Available

The Net Positive Suction Head Available (NPSHa) is calculated as follows:

$$NPSHa = -Hf + z + (Ha - Hvp) = -32.51 + 7.12 + (33.52 - 0.57) = 7.56\,ft$$

The NPSHa of 7.56' is the pressure available on the suction side of the pump. It must exceed the NPSHr for the selected pump. But what is the NPSHr for this pump? We could not find this information in the AURORA pump catalog. We contacted AURORA representatives who provided a curve for pumps operating under similar conditions as shown in *Figure 5 (page 28)*. The suggested NPSHr was 16.6' of head. We added 2' of head to get a NPSHa of 18.6' of head. This means that we need an additional (18.6 – 7.5) feet or 11' of head for the pump to operate properly.

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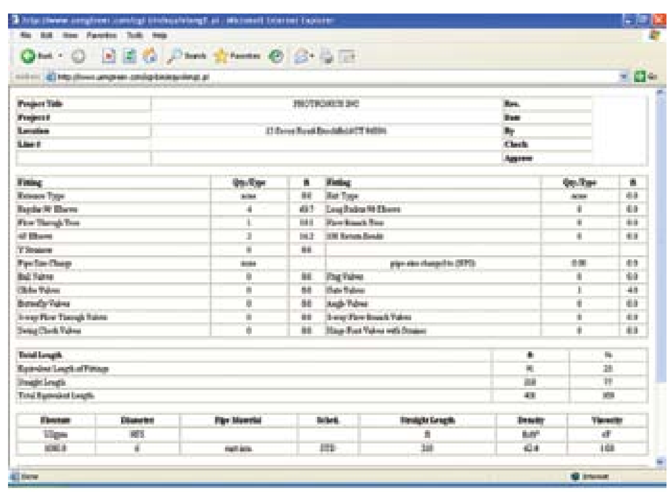

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1 Pipe Length                          = 310.0 ft

Fitting Equivalent Lengths for 6-inch Cast Iron Pipe

4 90-elb          = 4 x 15.1          =  60.7 ft
1 Flow-Thru-Tee   = 1 x 10.1          =  10.1 ft
2 45-elb          = 2 x 8.1           =  16.2 ft
1 Gate Valve      = 1 x 4.0           =   4.0 ft

Total Length                          = 401.0 ft

Source: http://www.uengineer.com/equivleng1.htm
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Figure 4: Pipe Fitting Equivalent Lengths →

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Managing The Net Positive Suction Head

There was clearly a discord between the NPSHr of the pump and the NPSHa established by calculation.

Our recommendations were as follows:

1. Raising the Tank Water Level

The addition of 11' to the water level in the tank would increase the water level elevation to 440' ASL. This approach retained the existing 6-inch suction pipe but made it impossible to conceal the tank.

2. Increasing Suction Pipe Size

Switching from a 6" to an 8" suction pipe could reduce friction losses by as much as 75%. This approach may not be a feasible since the existing 6" suction pipe may be expensive to replace. We also suggested using 8" Blue Brute plastic underground pipe, which has a lower C value.

3. Relocating the Tank.

The headloss of 32.5' of head in the suction pipe is clearly a major contributor to the NPSHa. Reducing the total pipe length from 40' to 200' would drop the headloss from 32.5' to 16' and add 16.5' to the NPSHa. While this may seem a promising approach, it requires new piping.

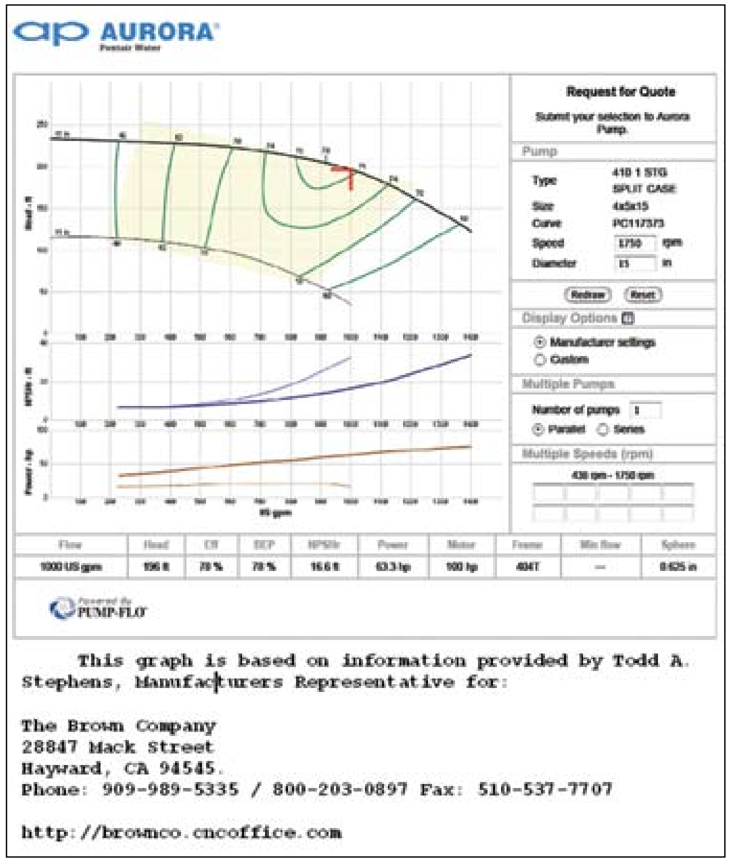

Figure 5: Determination of Net Positive Suction Head Required.

Summary & Conclusions

This type of study is often done to determine the technical feasibility of making relatively minor changes to an existing water storage tank. Since a fire pump was required to boost the water from the tank, we had to determine how the proposed 3' increase in tank height would affect pump performance. We found that this would not be enough to overcome the relatively high losses from flow in the underground piping.

About The Author:

Dr. Sang H. Wong is CEO of Hydronics Engineering. He is a graduate of the University of California, Los Angeles, where he studied computer science and water resources engineering. He has also worked as a fire sprinkler designer for several companies in the San Francisco Bay area including Grinnell Fire Protection in Dublin, California.

Hydronics Engineering develops eight fire sprinkler hydraulics applications for computers running on DOS, Windows, and Apple Macintosh.

For more information contact: Hydronics Engineering, 34119 Fremont Blvd, Suite 609, Fremont, CA 94555; 800-845-9819, Fax 206-600-5861, E-mail: sales@hydronicseng.com, Website: www.hydronicseng.com.

> *"Success seems to be largely a matter of hanging on after others have let go."*
> *— William Feather*