GRUNDFOS WHITE PAPER

DIAPHRAGM TANKS FOR VARIABLE SPEED BOOSTER SYSTEMS

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Introduction

There have been a lot of discussion around whether diaphragm (bladder[1]) tanks are needed for variable speed booster systems. Technically speaking, the diaphragm tank is not "needed" by the booster system, as water pressure will be increased whether or not the tank is present. However, the diaphragm tank is part of the engineered plumbing system. It is a bit unclear how a diaphragm tank can suddenly stop adding value to a pressure boosting system. Even before the advent of variable frequency drives and energy codes, plumbing system designers would see booster system catalogs and brochures advertising an '*Energy Saver*' or '*Econo-Phase*' option with pressure boosting systems. This option was simply the addition of a diaphragm tank and a low flow shutdown control sequence.

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Introduction to Diaphragm Tanks for Variable Speed Booster Systems

So what changed? We should all agree the one thing that has not changed is a pump switched off uses a lot less energy than one switched on. The main difference now is the ever-increasing use of variable frequency drives (VFD) and controls. Over the years drive manufacturers have put more pump related functions into VFDs, making pump systems more plug and play, or rather plug and pump.

One of the things that modern pump controls can help with is pump protection. One of the worst things you can do to a pump is operate the pump against a closed valve. A pump operating against a closed valve will result in a substantial temperature increase in the pump casing. Most of the power going into the motor is now being transferred to the pump in the form of heat energy. The first thing this excessive heat will affect is the shaft seal, which will then need to be replaced. Many commercial buildings will experience long periods of time where no service water is required. How was this addressed before the advent of VFDs?

Thermal relief system: Temperature was monitored in the pump casing using a temperature sensor. When the temperature reached the high limit, a solenoid valve was opened, allowing for the hot water to move out of the pump casing and down to a floor drain.

Diaphragm tank: Flow was monitored using a flow switch or flow sensor. When the flow reached the low limit, the pump was switched off, as there was sufficient water storage in the diaphragm tank to service low flow demand for a short time.

Modern pump controls today have functions that will switch a pump off that is running against a closed valve. Once a variable speed pump starts operating against a closed valve, the speed will continue to drop with no reduction in discharge pressure since all valves are closed. The water is essentially “trapped” in the piping system. This function is sometimes referred to as a “sleep” mode. In a price competitive market, this feature has been recognized as an alternative to the diaphragm tank method of low flow energy savings. The challenge with this no flow stop method is the flow rate must reach zero. Any system with small leaks or flow rates that does not quite reach zero flow will never be able to take advantage of this feature. This feature does serve its purpose in terms of pump protection; it will stop the pump from running against a closed valve for extended periods of time, but it is not the optimum solution for low flow energy savings. There’s a difference between a no flow shutdown sequence and a low flow shutdown sequence. Why not stop the pump before is operates against a closed valve?

Low Flow Energy

To better illustrate this, consider the pump performance curve shown in **Figure 1.** The nominal performance for this pump is 90 gallons per minute at a total head of 206 feet. This pump would typically be supplied with a 7.5 horsepower motor. It is not uncommon to see a duplex or triplex variable speed booster system with individual pumps in this capacity range. Let's say the design requirements are 200 gpm at 80 psi boost (173 feet of head), where a duplex system has been selected (each pump rated at 100 gpm/173 feet). If this pump system were to supply water to an office, multi-use or an apartment building, there would definitely be periods of very low flow, including zero flow conditions. **Figure 2** shows the pump performance at just over 2 gallons per minute. At this flow rate, the variable speed controller will reduce the pump speed to 80% (2878 rpm) to maintain the required boost pressure of 80 psi. At this low flow, the power required is only 1.3 brake horsepower which is only 17% of the motors rated power. The pump efficiency however, is only 7.3%, as compared to the efficiency at design conditions of nearly 72%.

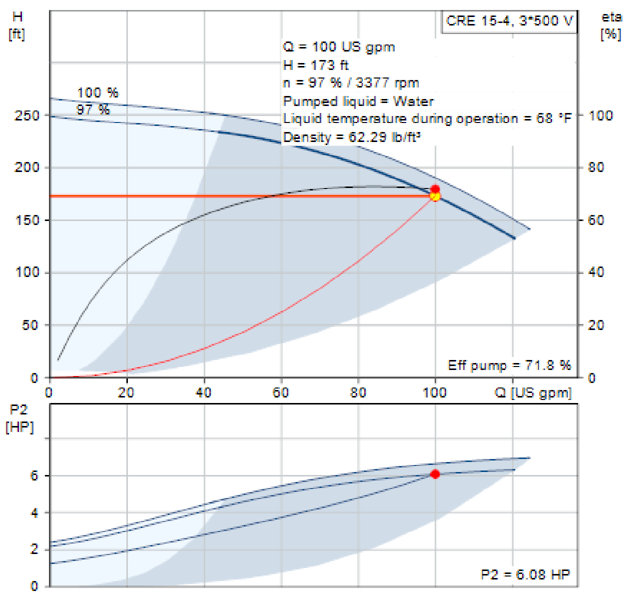

Figure 1: *Pump performance at design flow*

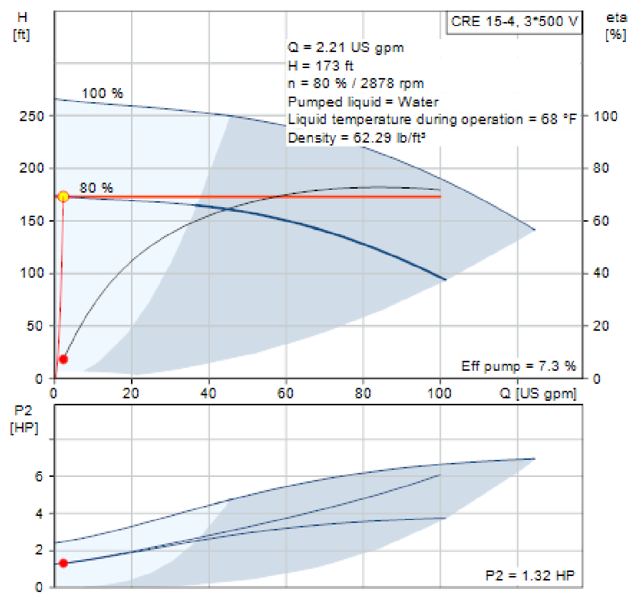

Figure 2: *Pump performance at 2 gpm*

For variable speed booster systems without diaphragm tanks, this very inefficient mode of operation will be the norm during low flow periods for hundreds, if not thousands, of hours annually. There are many systems today operating in this manner and to the owners, maintenance staff and tenants of these buildings, this is considered satisfactory performance. Running centrifugal pumps at this low a flow will result in shorter shaft seal lifetime and increased electrical costs. Neither of these added costs are catastrophic in nature, which is why they are often considered "normal" for modern day variable speed booster systems.

LOW FLOW **ENERGY SAVINGS**

- Pump from Figure 2
  Operating constantly at 2 gpm — $631
- On/Off mode with diaphragm tank — **$210**

67% COST SAVINGS
with diaphragm tank

What will not be obvious to the building owners is the added electrical cost of running a pump when it could indeed be switched off. What is the consequence of letting a pump run continuously at 2 gallons per minute? In **Figure 2**, the brake horsepower consumed by the pump at 2 gallons per minute is 1.32 which equates to about 1.45 kilowatts of electricity *(assuming modern motor and drive technology is being used)*. If this pump averaged 10 hours per day at this flow rate, the annual energy cost at 2 gpm would be $631 *(at 12 cents per kilowatt-hour)*. If a low flow shut-down sequence was used along with a diaphragm tank *(25-35 gallon nominal capacity)*, this low flow energy cost could be reduced by over two thirds. The ability to periodically stop the pump would reduce the annual energy cost to approximately $210. **This results in an annual savings of $421, and after 5 years a savings of $2,105. This will easily pay for the initial cost of the diaphragm tank, not to mention the prolonged life of the shaft seals in the pumps.**

The Energy Code

Speaking of energy savings, the 2010 version (and subsequent versions) of the ASHRAE 90.1 Energy code, which has been adopted by 24 U.S. states, requires service water booster pumps to be switched off at no flow. The code requirement is as follows:

10.4.2 Service Water Pressure Booster Systems

Service water pressure booster systems shall be designed such that the following apply:

a. One or more pressure sensors shall be used to vary pump speed and/or start and stop pumps. The sensor(s) shall either be located near the critical fixture(s) that determine the pressure required, or logic shall be employed that adjusts the setpoint to simulate operation of remote sensor(s).

b. No device(s) shall be installed for the purpose of reducing the pressure of all of the water supplied by any booster system, except for safety devices.

c. No booster system pumps shall operate when there is no service water flow.

Important Note

Above is the entire section pertaining to service water boosters in the ASHRAE 90.1 Energy Code. The only requirements are, a, b and c.

From an energy conservation standpoint, item c) makes perfect sense. Pumps should not be running when there is no water demand in the building.

The second requirement, 10.4.2 b), prohibits the use of pressure regulator valves (PRVs) to **reduce** the supply pressure to the building. Variable speed control is the most common method to meet this requirement and some have interpreted the code as requiring **constant pressure.** Nowhere does the code state constant pressure is required for service water boosters, it is an energy code, not a comfort code. The intent of the code is to discourage the use of PRVs to control the pressure, which results in wasted energy. Technically you can meet the requirements of 10.4.2 b) by using fixed speed pumps. Tall buildings often have transfer pumps to deliver water to storage tanks on upper floors where variable speed controls are not necessary. But due to the misinterpretation of the code, the use of diaphragm tanks has been discouraged in some cases. Some people have argued that a variable speed “constant pressure” booster system results in no change in pressure, and therefore will be no water exchange in and out of the bladder, making the tank a location of stagnant water. In the next section, we will address whether or not this is true.

The third part, 10.4.2 c), simply states no pumps shall operate when there is no service water flow. In other words, when nobody’s using water, turn the pumps off. But what about very little water flow, such as the 2 gallon per minute example shown above? There are many scenarios where there are very small, yet unintended, water demands such as leaky toilets, water faucets not fully shut off, or leaks in an irrigation piping system. These very low flow situations should be considered when attempting to optimize pump energy consumption in commercial buildings.

Misconception

This is a good example of what exists in the market today with regards to interpretation of the ASHRAE 90.1 energy code. This was taken directly from marketing material from a pump system manufacturer.

“A small but otherwise ignored section of Section 10.4.2 requires that all booster systems must NOT create or cause a change in pressure anywhere throughout the building....”

This is completely false, and Section 10.4.2 in its entirety is stated above, parts a, b and c. Nowhere does it state anything pertaining to not causing a change in pressure. This is simply a sales tactic to provide systems at a lower price point by eliminating the diaphragm tank.

Diaphragm Tank Location and Installation

The diaphragm tank should be placed as close as possible to the discharge of the pump system. The diaphragm tank can also be mounted in upper floor locations for systems with high discharge pressures which exceed typical diaphragm tank working pressure limits. The piping from the discharge piping to the tank should be kept at the same diameter (or larger) as the tank connection. This will ensure optimal water exchange in and out of the diaphragm. Pre-charge the air in the tank before connecting the water supply. Most variable speed booster systems with a low flow energy saving mode require a pre-charge pressure of 70% of the discharge (system) pressure. Tank volume should be selected based on the pump size that will be in operation during low flow periods. The following table shows typical diaphragm tank sizes for variable speed pressure boosting systems utilizing multistage centrifugal pumps. Actual tank volume is typically determined by the pump system supplier, based on the low flow stop controls methodology.

DIAPHRAGM TANK SIZES
(for variable speed pressure boosting systems)

Pump Nominal Flow* (gpm)	Nominal Tank Volume (gallons)
30	5 - 9
60	9 - 18
90	23 - 45
150	30 - 60
200	45 - 90
300	75 - 150
500	120 - 200

** Nominal flow of each pump, not station flow*

Other Benefits of Bladder Tanks

Many domestic water systems have fast acting valves such as toilet flush valves. The bladder tank can support these abrupt increases of water flow and allow time for VFD controlled pumps to smoothly react to these sudden flow requirements. The bladder will have an immediate effect to these sudden changes and acts as a shock absorber resulting in a more stable supply pressure. Again, during this process, the water in the bladder is exchanged even though the change in pressure might be only 1-2 psi. Pumps and pump systems without bladder tanks can have difficulty in maintaining steady pressure when fast acting valves are present. If several flush valves suddenly open, or a large cooling tower makeup valve, the discharge pressure can drop quickly, which will result in a sudden pump "ramp up' in speed to avoid low discharge pressure. These overshoots can result in pressure spikes and/or water hammer that can be severe enough to cause excessive noise in buildings and even pipe breakage. During these sudden flow increases, the water stored in the bladder rushes into the piping allowing the variable speed controls to softly return the discharge pressure to the set-point. With variable flow applications, bladder tanks provide cushion to the pipe system, this gives the controller reaction time to adjust pump speed without pressure hunting and pressure spikes.

Conclusion

Hopefully this paper has provided insight and has provided some guidance on the purpose and benefits of using diaphragm tanks with variable speed pressure boosting systems. The use of diaphragm tanks can ensure good operating economy at low flow and provides a proven means to energy code compliance.

Notes: *Although there are differences in the construction of diaphragm and bladder tanks, their function is the same with regards to variable speed pressure boosting systems.*

Visit grundfos.us/pei to learn more about Department of Energy (DOE) pump energy index (PEI) requirements and PEI ratings on specific Grundfos models.

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