Pump ED 101

Pump Selection for VFD Operation

Part 3 – ΔQ / ΔH – Pump Down vs Level Control

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Introduction

In Part 2 we took a look at the pump selection process for VFD operation in closed and open loop circulation applications. In those applications pressure declines as flow is reduced. In this section we will review a different type of variable flow application - pump down - one where pressure increases even if flow, or the flow requirement decreases. Here, we will take a close look at pump down applications and show how they can often benefit from conversion to level control.

Constant pressure (with the exception of certain industrial applications) is a relative new comer to variable speed operation but, pump down applications have used variable speed drivers for decades. A major reason that these applications took advantage of this technology early on, was simple. Large motors, used on pumps in sewage (and other) lift applications, were often limited to two or three starts per hour even if current limiting, starting techniques were employed. By varying the speed of these large pumps the wet well could be maintained at or near some predetermined level and thus frequent starting became a non-issue. Before the advent of the VFD, speed control was costly and difficult. Today it is relatively simple and, although there other cost benefits, power savings alone can often justify level control operation in many installations.

Pump Down vs Level Control

Pump Down

Although there are many "pump down" applications, municipal waste water is one of the most common. Typical installations include treatment plants and gravity line lift stations. Waste water pumping stations usually incorporate several pumps with different capacities that can be sequenced to meet changing demand. Although pump size varies by installation, some of the smaller ones are often 50 - 100 hp and the larger ones can be 1000 hp or more.

These stations consist of two basic designs -- "wet pit" and "dry pit". A wet pit station consists of a single collection well with submersible or vertical column pumps installed directly in the well. Some, relatively shallow wells, may utilize self or "assisted" priming pumps.

The dry pit design consists of a "wet" collection well that is bottom piped to a nearby "dry" pit that contains shaft driven or close coupled pumps. The purpose of the two pit design is to allow use of standard, solids handling centrifugals and still take advantage of the elevation of the waste water in the collection basin. Like some submersible pumps, dry pit pumps are often designed to utilize the additional NPSHA in order to provide a higher efficiency at BEP than might otherwise be obtainable. Figure 1 compares the two designs. Please note that the capacities of the wet wells seen in the illustrations can vary from a few thousand to tens of thousands of gallons.

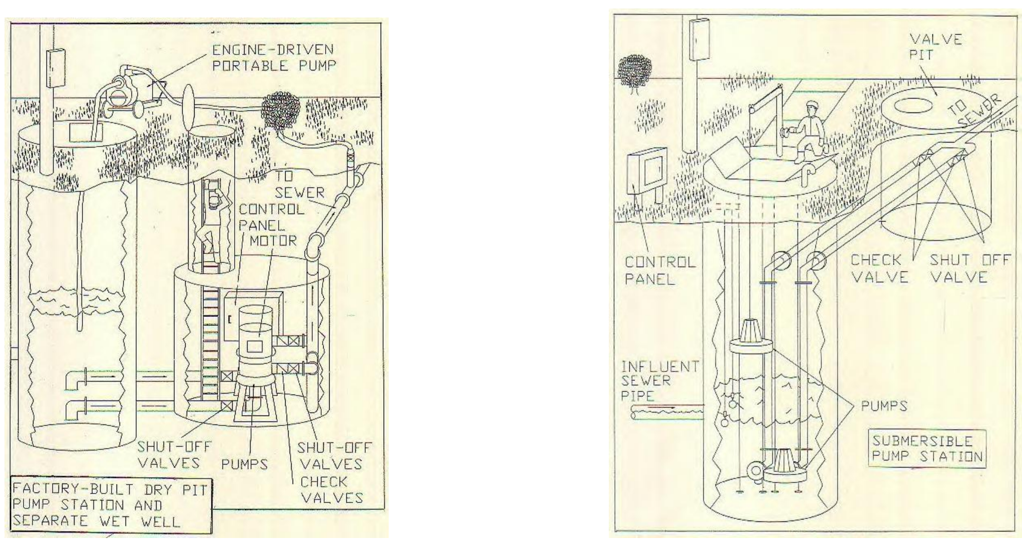


Figure 1

Even though the two designs are quite different, they operate in much the same manner. Under normal "pump down" operation, both begin pumping at some maximum level and stop at some minimum level. These levels may be further defined as staged levels. For example, two or three pumps may be activated when the well approaches its maximum level, one or two may be required at some intermediate level, and only one may remain on when the level is near its minimum. The staging scheme varies by application, pump size, and the number installed. Both wet and dry pit designs will employ a minimum of two pumps, even though each is capable of handling maximum design flow. As you might expect, back up is quite important in waste water applications (especially if a fan is mounted in the upper portion of the wet well).

Consider the example shown in Figure 2. Here we see a wet pit with a maximum liquid level that is 20′ above the suction of the pump. The minimum level is 6′ above the suction of the pump. The distance from the pump's suction to grade is 35′. Ignoring friction, the TDH required to move the waste water from the pump's suction to grade varies from 15′ at the maximum liquid level to 29′ at the minimum level. If we assume a constant flow of 3750 gpm and a hydraulic efficiency of 78%, what is the BHP required at the maximum and minimum levels?

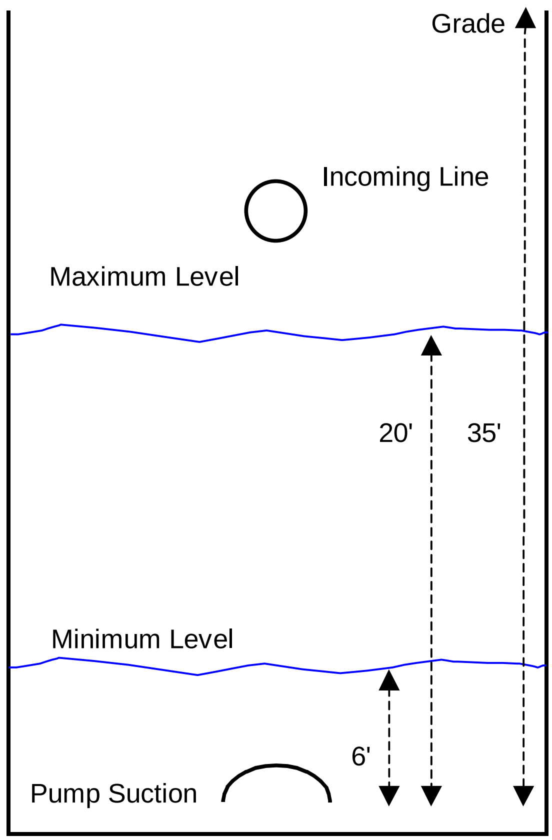


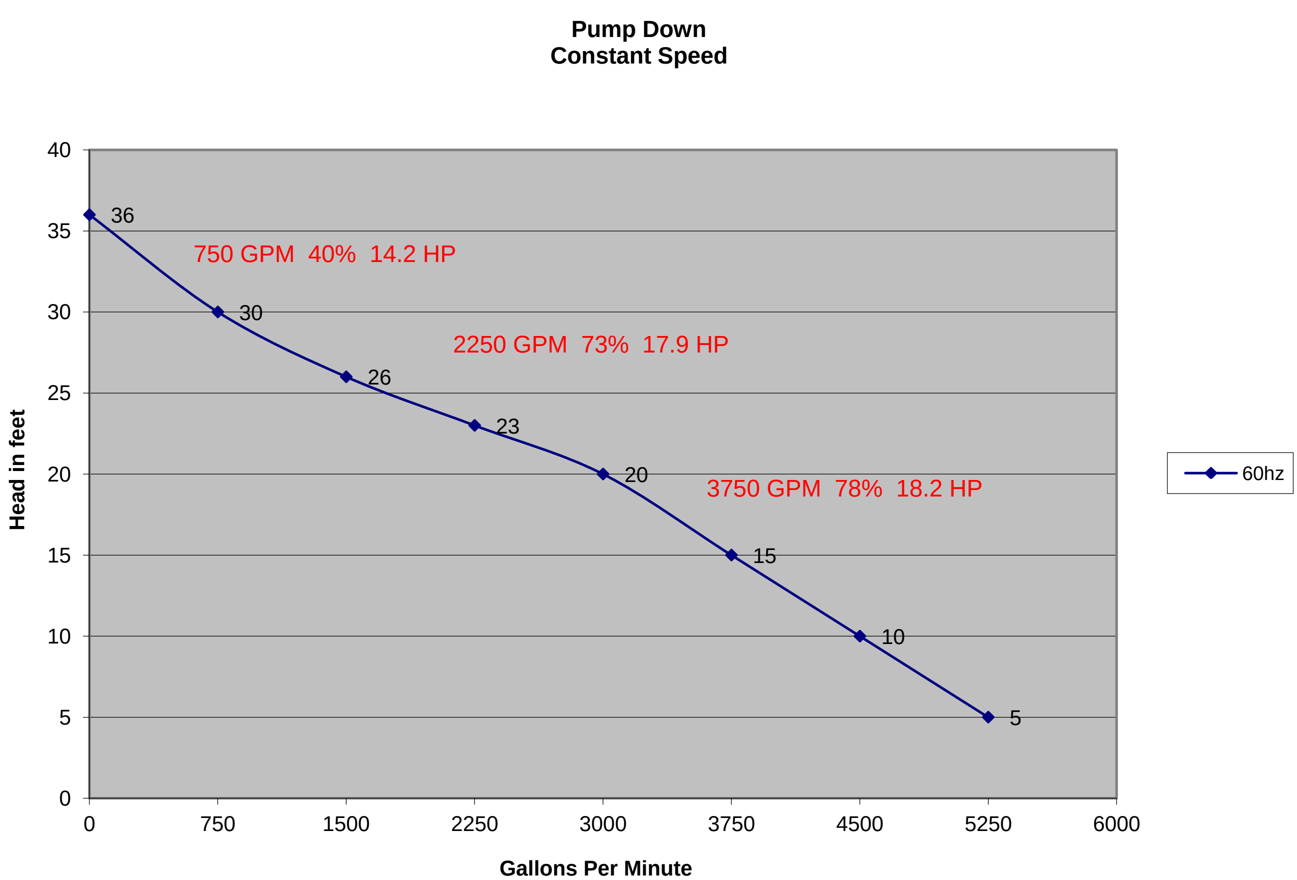
Figure 2

Using the BHP equation - BHP = (GPM x Head) / (3960 x Pump Efficiency) – we will calculate 18.21 BHP at the maximum level and 35.2 BHP at the minimum level. If we further assume that there is no additional flow into the wet well once the pump down operation begins, the average power required to bring the level from maximum to minimum is 26.7 BHP. Although this example utilizes an "ideal" pump (flow and efficiency remain constant during pump down), it illustrates the power range required by a pump down application due to decreasing wet well level and the corresponding increase in TDH that the pump must provide.

This example also suggests that minimizing wet well drawdown could result in a significant savings in power. Unfortunately, in many pump down applications , it is difficult to further minimize drawdown because the volume of the wet well is designed to accommodate varying incoming flows, minimum run time, and pump staging. Open trench type designs can minimize drawdown (due to a high surface area to depth ratio) but are usually limited to treatment sites. All that can be done with standard wells is to select the most efficient combination of pump sizes that will meet demand under varying conditions.

Constant speed operation lends itself well to pump down applications as long as the wet well is properly designed and the pumps are properly sized. The reason is that higher flows are usually required at or near the maximum wet well level while lower flows are acceptable at or near the minimum level. This can allow the system curve to follow that of a standard centrifugal pump curve. Unfortunately variable speed, pump down operation is usually difficult. In these applications, the head required increases as flow decreases -- just the opposite of constant pressure or circulation applications. Although not impossible, it is usually difficult to find a single pump with enough head rise from maximum to minimum flow to accommodate the necessary speed changes. Figure 3 shows a pump sized for constant speed use in the pump down example seen in Figure 2.

Figure 3



The curve shown is that of a 12”, 20 HP submersible sewage pump running at 870 RPM. As you can see, it requires 18.2 HP at the beginning of the pump down cycle and 14.2 HP as it approaches the end of the cycle. Normally two of these pumps would be installed and alternated at the beginning of each cycle. (Although it would increase the “first cost”, a more efficient installation might incorporate three pumps with a BEP capacity of approximately half of the one seen in Figure 3. Depending upon incoming flow, one or two pumps would start at the beginning of the cycle while only one would remain on line during the last portion of the cycle.)

Level Control

Level control takes a very different approach to removal of wastewater from the collection well. Rather than pumping the well down and then allowing it to refill, some predetermined level is maintained while accommodating the varying, incoming flow. In doing so, the NPSHA remains nearly constant and thus reduces the power required as incoming flow diminishes. Level control can be accomplished via the sequencing or staging of several smaller, constant speed pumps or by varying the speed of a larger one. Although staging can be effective in some installations, it becomes more difficult with larger pumps due to the multiple starts and stops that they must endure.

Long before the VFD became an acceptable alternative, level control was accomplished with the help of a device known as the “liquid rheostat”. This device varied the resistance of the rotor of a “wound rotor”, AC motor and thus the “slippage” it exhibited during rotation. For example, if the rotor windings are shorted (i.e. no resistance in the rotor circuit), its performance is similar to that of a squirrel-cage motor. When a resistance is inserted into the rotor circuit, rotor current is reduced and a proportional decrease also occurs in the stator. The liquid rheostat varied resistance by raising and lowering electrodes into a tank containing an electrolyte solution. At any point in time, the degree of submersion in the electrolyte was proportional to the resistance of the rotor circuit. The control circuit used a “bubbler” system that translated wet well level into pressure. The result was a variable speed pump that could maintain a reasonably precise level while running continuously. Despite it’s “Rube Goldberg” appearance, the liquid rheostat was popular in waste water installations well into the 1990’s and is still used today in other wound rotor motor applications.

Figure 4 shows the same 20 HP sewage pump operating under VFD control. Rather than pumping the wet well from maximum to minimum, the VFD is receives feed back from a submersible pressure transducer and varies pump speed to maintain the liquid level at or near the maximum seen in Figure 2. The maximum head required, regardless of the flow rate, is approximately 15′. As you can see, this results in a significant power savings during periods of reduced flow. Again, please note that this is a simple example and the system curve may not be a straight line but may rise due to friction at higher flows.

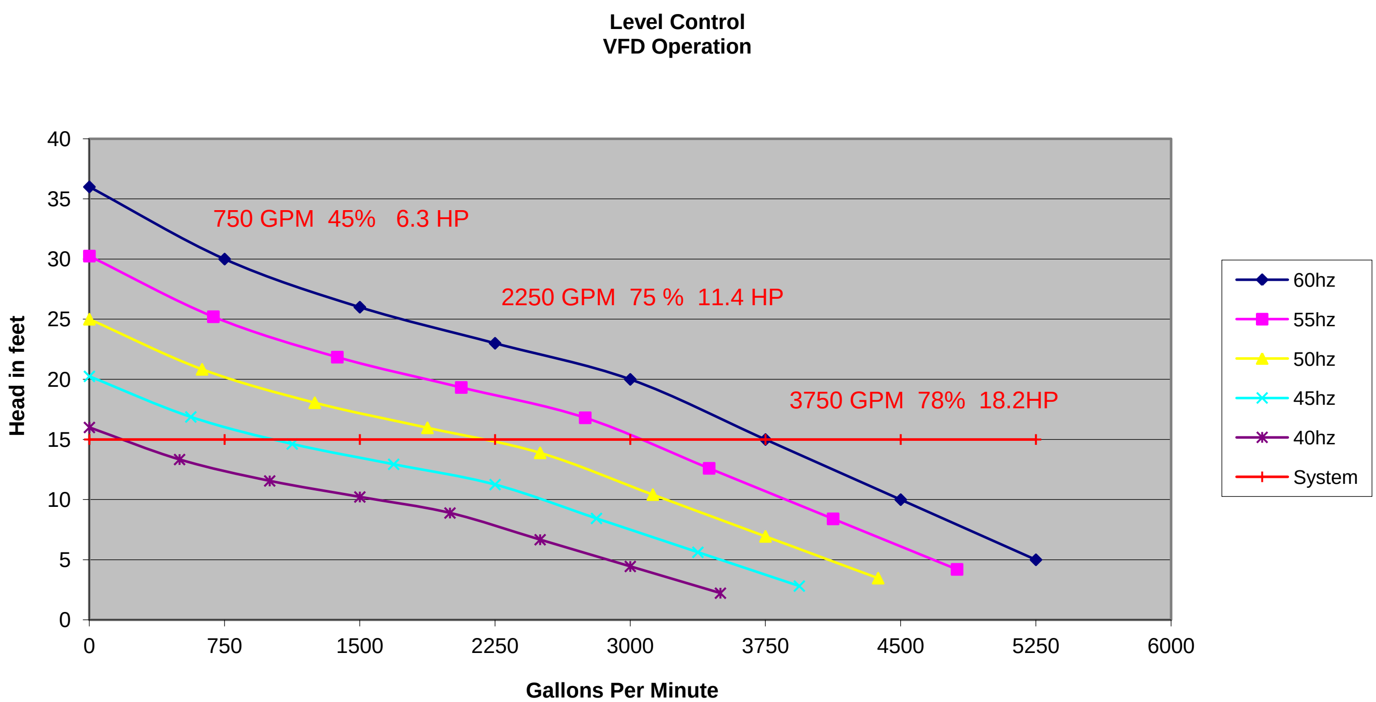


Figure 4

Although this power reduction is pretty apparent, there is a more dramatic method of demonstrating its magnitude. If we convert the HP required at each of the three flow points to HP/Gal pumped we would see the following for the pump down application shown in Figure 3. At the beginning of the cycle HP/Gal is 0.0048. At the halfway point it increases to 0.0079 - - an increase of 65%. And, as it approaches shut off, HP/Gal increases to 0.0189 - - almost four times the amount required at the beginning of the cycle!

Lets use the same method to evaluate the level control application shown in Figure 4. At full speed (60hz) HP/Gal is the same as in the example above - - 0.0048. But the halfway point flow (50hz) it increases to just 0.005 - - an increase of 5%. At minimum flow (about 43hz) it increases to 0.008. Although this represents an increase of 75% it is far, far less than the 4X increase seen in the pump down example.

Pump selection in level control installations is similar to that of other variable flow applications. A major difference is that, depending upon the design, multiple pumps may be operating at the same time and more than one may be under VFD control. But, regardless of the design, the pump(s) must be able to meet the maximum design flow and TDH at synchronous speed. Head rise to minimum flow should be great enough to allow a meaningful power reduction. In my opinion, a minimum operating range of 13 hz or 60% head rise to minimum flow is a reasonable goal. And, as with other variable speed applications, the pump's BEP should be selected to accommodate the range of flows required. It is for this reason that often, two smaller pumps, rather than a single larger one, will be installed and controlled by a single VFD.

Joe Evans September 2004 (Updated June 2006)