Horizontal or Vertical? High-Service Pump Selection

Mark Ludwigson, Len Rago, and Jeff Greenfield

Mark Ludwigson, P.E., is a senior engineer, and Len Rago is a senior client service manager with Carollo Engineers in Lake Worth. Jeff Greenfield, P.E., is a project manager with Broward County.

Water engineers and utilities are often faced with a decision concerning the best type of pump when designing a high-service pump station for delivery of potable water to the distribution system. For this application, the two most common types of pumps are horizontal split case (HSC) pumps and vertical turbine (VT) pumps.

The decision between horizontal and vertical is not trivial. There are strong supporters on each side who will indicate why one type of pump is better than the other, and in Florida, both types of pumps are common for high-service pumping. This article addresses the challenge of summarizing each pump type, listing key factors for making a comparison, explaining which pump type has the advantage for each factor, presenting a decision tree, and providing examples of applications through case studies.

Pump Types

Horizontal Split Case Pumps

The HSC pumps are a type of centrifugal pump installed at floor level with the suction and discharge nozzles typically spaced 180 degrees apart. The pump is "split case," meaning the casing can be unbolted and opened, allowing for removal and repair of pump rotating elements.

The pump is double suction, which means that liquid may enter the center of enclosed impeller blades from both sides simultaneously. This differs from single-suction pumps, such as end-suction pumps or inline pumps, in which liquid enters the center of the impeller from a single direction. The dual suction design has the shaft supported by bearings on both sides of the impeller. When the motor is mounted horizontally, the pump is known as a "horizontal" split case pump; when the pump is rotated 90 degrees, with the motor rotated vertically, the pump is known as a "vertical" split case pump. Figure 1 shows an HSC pump for high-service pumping.

Vertical Turbine Pumps

The VT pumps have the motor mounted at floor level with a vertical shaft down to the impeller(s) at the bottom of the pump. The pump body is either partially submerged in a wet well or mounted inside a cylindrical barrel (also known as a "can"), with the suction line connected to the barrel. Mounting the pump inside a barrel with a buried suction line is most common for high-service pumping. The discharge line is at floor level just below the motor. Water enters the pump through a suction bell, moves up into the first-stage impeller, and enters the diffuser bowl above the impeller, where the high-velocity energy is converted into high pressure. Water is then directed into the second-stage impeller located immediately above the bowl, and this process continues through all of the stages of the pump. Turbine pumps have enclosed impellers, which direct the water upward. This differs from axial and mixed flow pumps, which have open impellers that impart a radial motion and swirling to the water.

Figures 2 and 3 show photographs of VT pumps for high-service pumping.

Figure 1. Horizontal split case pump in a pump station building (left) and the same kind of pump with the top case removed (right).

Figure 2. Installation of vertical turbine pumps in barrels; motors have not yet been installed.

Figure 3. Vertical turbine pumps in a pump room.

Key Factors for Pump Type Selection

Many factors must be considered in selection of a pump type. For high-service pumping, the following factors are commonly considered, with potential advantages and disadvantages of each pump type discussed.

Suction Conditions

Neither VT nor HSC pumps are capable of drawing suction in the absence of a liquid; thus, the pump needs to be located where flooded suction conditions exist, or a vacuum priming system needs to be implemented.

The VT pump may be lowered by extending the pump column in order to achieve flooded suction conditions. Lowering a HSC pump requires lowering the entire pump station building, with associated water table and flood elevation issues. For a HSC pump, if a flooded suction cannot be provided, a vacuum priming system would need to be provided.

The net-positive suction head (NPSH) is not typically an issue with VT pumps, as the pump stages are located at a low elevation inside of the barrel, which acts as a wet well and eliminates suction lift. Similar to wet well applications, the submergence of the VT stages is the driving factor. Accounting for proper submergence will inhibit vortexing, which can adversely affect the efficiency and longevity of the pump. Typically, a VT pump can completely drain a ground storage tank, and start up with the water level at ground level.

The HSC pumps require careful consideration of the NPSH to avoid cavitation. The suction lift is determined by the elevation of the pump room floor compared to the low water elevation of the source, such as a ground storage tank. A HSC pump can only drain a ground storage tank to a limited elevation, and may require enlarged suction pipes and/or a vacuum prime system for operating at design flows when the water level is low in the tank.

Conclusion: The VT pumps typically have the advantage for suction conditions, both in terms of priming and NPSH.

Area Required

The footprint required for HSC pumps is typically three times more than that of VT pumps (Mann, 2006); this is primarily due to the vertical mounting of the VT pump motor, which decreases the footprint compared to HSC pumps. For interior installations, increasing the pump room area effects the base slab; walls; topping slab; roof; sprinklers; and heating, ventilation, and air conditioning (HVAC).

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Conclusion: The VT pumps typically have the advantage for the area required.

Vertical Space Required

The VT pumps typically require 1.8 times the vertical height compared to HSC pumps (Mann, 2006). This is due to the VT pump motor mounting above the pump housing with a vertical shaft, which is significantly higher off the pump room floor than for HSC pumps. For interior installations, increasing the pump room height affects the wall design and HVAC. In addition, when performing repairs or maintenance on the pump stages, the entire VT pump must be removed from the pump can. This can be addressed by either providing roof openings over each pump, or further increasing the height of the building.

Conclusion: The HSC pumps typically have the advantage in areas with low vertical space.

Crane Requirements

The HSC pumps require an installed overhead bridge crane or monorail system for pump replacement. For VT pumps, the height of the building would need to be greatly increased to allow an overhead bridge crane to lift the entire pump out of the barrel. Since such a building height is not economical, roof openings are typically provided over each pump and crane rental is required for pump removal. Site access and an open area next to the pump station building must be provided to allow a crane to maneuver and set into position.

Conclusion: For interior installations, HSC pumps typically have the advantage for crane requirements. For exterior installations, there is typically no significant difference for this factor.

Ease of Maintenance

The HSC pumps can be completely rebuilt from the pump floor without removal of the motor or the pump from the piping system. The pump is "split case," which means the casing can be unbolted and opened, allowing for removal and repair of pump internals. This makes several maintenance tasks relatively easy. The HSC pumps often require a higher speed, which is known to increase overall maintenance, with all other factors being equal; however, this is not considered a significant disadvantage.

Repair of VT pump bearings or impellers requires the complete removal of the pump from the piping system, including the motor. The pump internals are located inside of the pump barrel and cannot be accessed without isolation of the discharge and the suction supply, removal of the motor, removal of the discharge head from the piping system, and lifting the pump entirely out of the wet well or pump barrel. The VT pumps typically require influent piping and valves to be located below floor level (buried or in a pipe trench), which is more difficult to access for maintenance.

Conclusion: The HSC pumps typically have the advantage for ease of maintenance.

Corrosion Protection

The wetted area of a VT pump is significantly greater than a HSC pump, which increases the potential for corrosion. Also, there are several components, including bearings, couplings, and collars, which are submerged on a VT pump but that are outside the wet area on a HSC pump. In addition, on VT pumps the bearings are lubricated by the fluid being pumped, which introduces a potential for corrosion and abrasion, although this is a minor issue when pumping finished water. Note that HSC pump bearings are usually oil- or grease-lubricated and are completely isolated from the fluid being pumped.

Conclusion: The HSC pumps typically have the advantage for corrosion protection.

Efficiency

Since high-service pumps often operate continuously, a small difference in efficiency can add up to a significant difference in annual energy consumption and associated electricity costs. The theoretical maximum pump efficiency can be compared for each pump type by considering the specific speed, which describes the geometry of the pump impeller. The formula for specific speed is as follows:

$$Specific\ Speed\ (N_S) = \frac{N * Q^{\frac{1}{2}}}{H^{\frac{3}{4}}}$$

$$\text{where:}\quad \begin{aligned} N_S &= Specific\ Speed\ (unitless) \\ N &= rpm \\ Q &= Flow\ (gpm) \\ H &= Head\ (ft) \end{aligned}$$

High specific speeds indicate more axial flow (flow generating) characteristics and lower specific speeds indicate more radial flow (pressure generating) characteristics. In general, the efficiency at the best efficiency point increases as the specific speed increases.

Due to the use of multiple stages on the VT pumps, the head is divided by the number of stages and the VT pumps will have a higher specific speed, and theoretically, a higher efficiency. Figure 4 shows the theoretical maximum pump efficiency based on the specific speed of the pump and flow rate; the typical specific speeds of HSC and VT pumps are indicated. Note that at each flow rate, a VT pump has a theoretically higher efficiency than a HSC pump; however, an analysis of application specifics and pump sup-

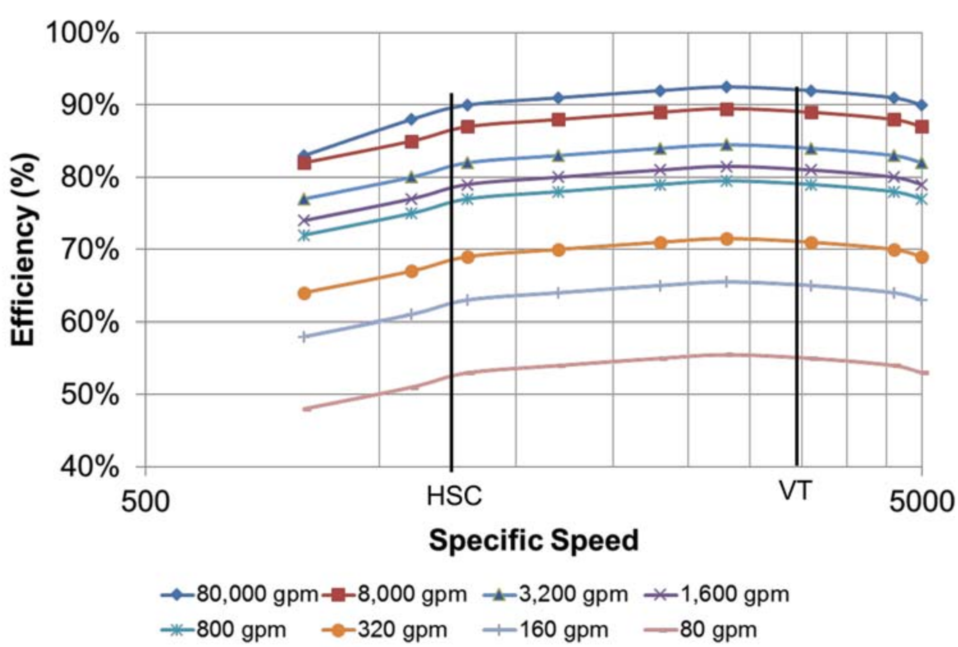

Figure 4. Theoretical maximum pump efficiency
(Source: Hydraulic Institute and Europump)

plier curves with actual operating points is required to confirm this for the application.

Conclusion: The VT pumps are likely to have a slight advantage for pumping efficiency.

Potential Operating Range

The future operating conditions or changes to the distribution system may cause changes in the total dynamic head (TDH) of the pump station. The addition or removal of stages on VT pumps and the trimming of HSC pump impellers can be done to account for the new operating conditions.

The removal of stages from VT pumps does not require any modification to the existing pump station layout; however, if the addition of a stage is required to increase capacity, the pump station barrels will need to be initially designed with oversized diameter and additional column length to account for the additional space required for a new stage.

Trimming of HSC impellers can also be completed without changes to the pump configuration; however, it is usually not possible to increase the size of the impeller unless the pump volute was initially oversized to accommodate the larger impeller, which reduces efficiency, especially if variable frequency drives (VFDs) are utilized. Oversizing the pump volute most often has a negative effect on the hydraulic pumping efficiency as well.

Conclusion: The VT pumps typically have the advantage for operating range.

Pressure Control

High-service pump stations are typically designed to maintain a set pressure, with one or more pumps on VFDs. A steeper pump curve allows more precise pressure control when adjusting the speed of a pump. Pump curves associated with VT pumps are steeper than the HSC pumps, allowing for better pressure control.

Conclusion: The VT pumps typically have the advantage for operating flexibility.

Horsepower

The VT pumps typically have lower overall horsepower (hp) requirements due to the slope of the curve and increased efficiency, which potentially results in one motor size smaller. This could also result in a smaller standby generator requirement. Pump selections are required to confirm any hp difference.

Conclusion: The VT pumps typically have the advantage for hp.

Capital Cost

The purchase price of a VT pump is typically more than a HSC pump of the same capacity, mostly due to the large barrel required for the VT pumps. For an interior installation, the installation cost savings for a smaller floor space footprint of a VT pump station is offset by the need for a taller structure, hatches in the roof, and the costs to install deep barrels; therefore, the installation cost advantage varies by application. For an exterior pump station, the installation cost is typically similar between a VT pump and a HSC pump. The cost savings for a smaller floor space footprint of a VT pump slab is offset by the costs to install deep barrels; therefore, the installation cost advantage varies by application.

Conclusion: The HSC pumps typically have the advantage for capital cost due to the lower purchase price.

Life Cycle Cost

The VT pumps typically have a greater efficiency, and thus a lower operations cost for energy consumption. In some cases, this will result in a lower life cycle (20-year) cost for VT pumps. In other cases, the lower capital cost of the HSC pumps will not be overcome by operations savings over a 20-year period. The life cycle cost requires an analysis of application-specific information and pump supplier information to determine which pump type has the advantage for the application.

Conclusion: Application-specific.

Owner Preference

The owner may have a desire for the same pump type at all of the high-service pumps stations, which provides similarity in operations and training requirements and allows for stocking of common spare parts and tools. Owners may also have a strong preference for pump type based on maintenance and operations history. This preference is likely to sway the pump-type decision, unless there is an application-specific factor that prevents the use of the preferred pump type, such as a suction condition restriction, area restriction, or vertical space restriction.

Conclusion: Application-specific.

Table 1. VT versus HSC Comparison Summary

Factor	Pump Type with Advantage		Notes
	VT	HSC	
Suction Conditions	X		
Area Required	X		
Vertical Space Required		X	
Crane Requirements		X	For interior installations
Ease of Maintenance		X	
Corrosion Protection		X	
Efficiency	X		Verify for application
Potential Operating Range	X		
Pressure Control	X		
Horsepower	X		Verify for application
Capital Cost		X	Verify for application
Life Cycle Cost	-	-	Application-specific
Owner Preference	-	-	Application-specific
Total	6	5	Implies all factors are equal weight/importance

Comparison Summary

Table 1 provides a summary of which pump type has the advantage for each factor.

Decision Tree

A decision tree (flow chart for making a decision) was developed to assist in the selection of pump type for a specific application. The decision tree is presented in Figure 5.

The first four steps are relatively simple questions for which a "yes" answer to any one question is likely to result in a selection without detailed analysis; this can result in a pump-type selection with minimal effort. If the answers are all "no," then steps 5 through 8 should be followed. Step 5 is to obtain pump selections and quotes, and step 6 is to use this information to determine the efficiency, hp, capital cost, and life cycle cost for each pump type.

Step 7 is to assign weights to each factor based on the perceived relative importance of each factor; thus, a higher importance factor would be assigned a higher weight. To reduce

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subjective bias, the weight factors can be calculated using the analytic hierarchy process (AHP) as explained by Ludwigson (2011).

Step 8 is to sum the scores for each pump type. For the VT score, sum the weights for all the factors in which the VT pump had the advantage; for the HSC score, sum the weights for all the factors in which the HSC pump had the advantage. The pump type with the highest score is considered the more favorable alternative.

Case Studies

Broward County

Carollo Engineers (Carollo) designed new pump stations for two sites for Broward County. Each pump station building included a pump room, chemical rooms, electrical room, and generator room. The firm pumping capacities were 7.2 mil gal per day (mgd) and 11.5 mgd. The discharge pressure was to be maintained at 80 pounds per sq in. (psi). Each pump station included three duty pumps and one standby pump. Carollo performed an evaluation of high-service pump alternatives with the following findings:

- The VT pumps provided a more compact pump station layout. However, the proposed pump station sites easily accommodated either pump arrangement.
- Pump selections were made with both pumps at a nominal motor speed of 1800 revolutions per minute (rpm).
- The VT pump purchase price was approximately 2.9 times more than the HSC pumps, mostly due to the large barrel/can required for the VT pumps. For the 7.2-mgd pump station, four VT pumps were quoted at $332,000, while four HSC pumps were quoted at $116,000.
- The overall capital cost savings for HSC pumps was estimated at $65,000 per site. This cost differential included the pumps, building size, overhead hatches, and crane requirements.
- Based on pump selections for both sites, the VT pumps had a minimum efficiency of 81 percent, compared to 79 percent for the HSC pumps.
- The difference in efficiency results and energy cost savings for VT pumps was estimated at $2,000 per year per site, based on a flow rate of 3 mgd and an electricity cost of $0.10 per kilowatt-hour (kW-h). The 20-year present-worth cost differential was approximately $40,000 in favor of HSC pumps.
- The cost differential was approximately 3 percent of the pump station cost, and within the margin of error of the cost estimate; therefore, the cost difference was not significant.
- Broward County has been using HSC pumps for its high-service applications almost exclusively for many decades. Carollo asked county engineering and operations staff about the county's experience with HSC pumps. Staff indicated a positive experience with maintenance and operations of HSC pumps, and expressed a preference for HSC pumps.

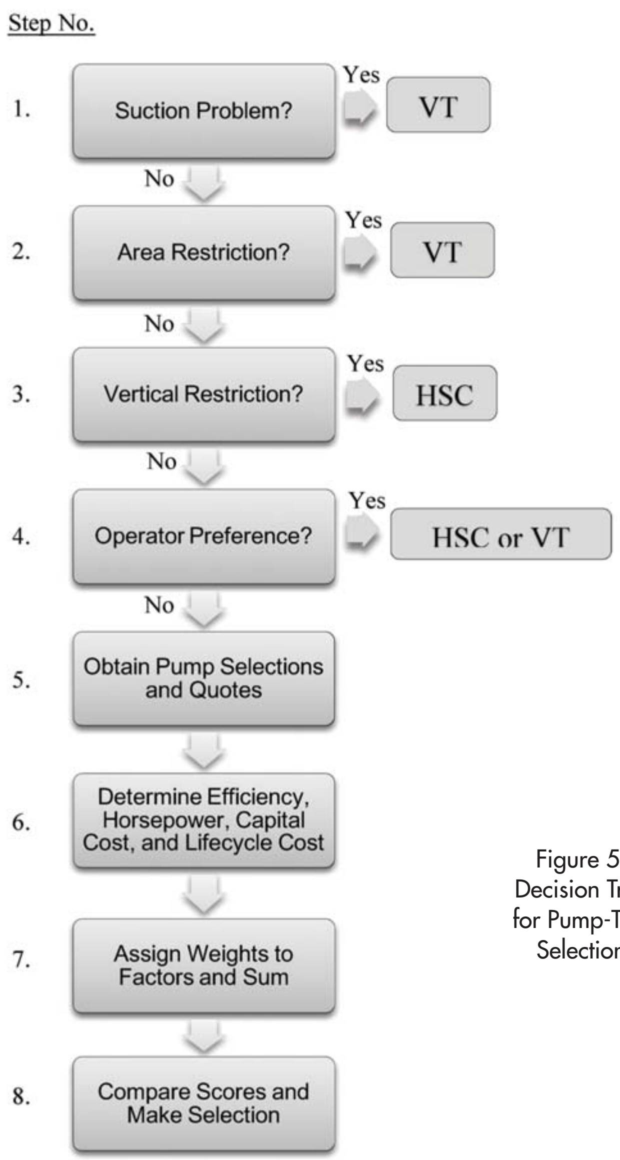

Figure 5. Decision Tree for Pump-Type Selection

Carollo has successfully designed high-service pump stations with both pump types, and either would perform well for this application. Based on the owner's preference for HSC pumps, and given the relative equality when comparing the pump types, it was Carollo's recommendation to design the high-service pump stations with HSC pumps.

Centennial (Colo.) Water and Sanitation District

Carollo designed a new high-service pump station with a 16-mgd firm capacity for the Centennial Water and Sanitation District water distribution system. The pump station was designed in a partially below grade structure with full standby power capabilities. The pump station included three duty pumps and one standby pump. Carollo evaluated VT and HSC with the following findings:

- The overall area of the VT layout was 920 sq ft and the area of HSC pumps was 1,280 sq ft.
- The room-height requirement for the VT pumps was approximately 8 ft greater than the height required for the HSC pumps.

- The capital cost savings for VT pumps due to a decreased area of the building was estimated at $100,000. The capital cost savings for HSC pumps due to a decreased height of the building was estimated at $44,000; therefore, VT pumps resulted in an overall lower capital cost for the building, estimated at $56,000.
- The motor hp size for the VT pumps would have been 350 hp and the size of the HSC pumps would have been 400 hp. This would have changed the connected load of the pump station from 1,400 hp to 1,600 hp and increased the generator sizing by 14 percent.

Carollo recommended VT pumps for the following reasons:

- The VT pumps provided for a smaller building footprint and thus more flexibility for the pump station location.
- The VT pumps were more efficient for the specific speeds discussed.
- The suction conditions were better for the VT pumps.
- The pump curves associated with the VT pumps were steeper than those for the HSC pumps, allowing for more flexibility during operations and better pressure control.

Summary

Choosing between HSC and VT pumps can be difficult, as there is no clear "winner" for typical high-service pumping applications. The VT pumps typically have the advantage for suction condition, area required, efficiency, potential operating range, pressure control, and hp, while the HSC pumps typically have the advantage for vertical space required, crane requirements, ease of maintenance, corrosion protection, and capital cost. An analysis of application-specific conditions and pump supplier information is needed to determine which pump type has the advantage for all the comparison factors. The decision tree provides a path to making a pump type selection, while minimizing the effort in performing detailed analyses.

References

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