THE PUMP GUY

# “Pump Cheat Sheets...Lost Secrets of the Ages”

A number of years ago, I had the opportunity to travel into the Andes Mountains of South America. I was bouncing up and down in a bus on a dirt highway headed to the Inca ruins of Machu Picchu. In a small border town between Bolivia and Peru, up high in the mountains, the ride suddenly improved as though we had moved onto a paved road. Everyone got off the bus to rest and eat lunch. I could see the dirt road we were on and the improved road that crossed our path.

I learned that the smooth brick road was the Inca Highway. I asked my fellow passengers why we were not using the paved road and they said that it leads to an abandoned city and goes nowhere. So, here was a lost paved highway, leading to an abandoned pre-Colombian Inca City. I inquired about the highway from some of the locals in the public square. Who built that highway? They didn’t know. Why didn’t they use the highway today? They didn’t know. Why did they walk down dirt roads instead of using the paved highway? They didn’t know. Why was our highway not paved or smooth? They didn’t know. Why didn’t they improve other roads? They didn’t know.

Later, I learned that the Inca Highway was a system of roads and paths that was built about 1,200 years ago to connect the Inca Empire. The Empire stretched from the Equator almost to the South Pole. The Inca civilization had a postal system, with runners (something like the pony express of U-S history) who delivered messages and goods up and down the chain of mountains. They had doctors who performed brain and eye surgery. They had natural medicines from the jungles for anesthesia, and curing ailments. They had cities, running water, public education, laws, and government. The Incas practiced personal hygiene, preserved foods, and understood advanced math and astronomy. With the arrival of the Spaniards and Europeans in the 16th century, the civilization was lost. Many of today’s Inca peasants, have no idea of the civilization that existed. Most of the knowledge has been lost.

3,000 years ago, the ancient Greeks and Romans had already figured the math and science of water racing through the aqueducts, falling from the mountains through troughs and into the cities. They knew the laws of gravity, and knew how fast the water had to flow in order to pass through a nozzle and squirt 6 or 10 feet up into the air in a fountain in the public square.

Some Greek guy named Pi ($\pi$), was drawing circles in the sand with a stick one day, noticed and calculated the relationship between the diameter and the circumference of a circle. Now, how did he do that without a compass, protractor, and calculator? I can’t even draw a decent circle on a flip chart!! Some 2,200 years ago, another Greek guy named Archimedes, developed a screw threaded device for elevating (pumping?) water up from a river or lake and into an irrigation trough or aqueduct. And he knew how many donkeys or slaves he needed to power the pumps and supply the city with running water. There was only one liquid to consider or deal with in those days, cold water.

Of course, the units of measure have changed, but to this day, pump designers and engineers use the term “head”, measured in “feet or meters”, to measure how high their pumps can lift, or elevate a liquid. And it all comes from this 2,000-year old legacy of ‘ole

Archimedes, with his corkscrew pump, raising or lifting water up out of a river and into a trough. Sadly, modern day pump operators and mechanics are somewhat like...the Inca peasant. The knowledge has been lost.

It's for this reason that The Pump Guy started the CHEAT SHEET, a running series of hints, rules and generalizations that aid in understanding pumps, and recovering the lost secrets of the ages. Many readers have saved all the pump guy articles and have a complete CHEAT SHEET. Other readers started following the pump guy series in mid-year, and have requested an updated list. Here goes, in no particular order.

Pump people use the term feet of head. Maintenance people use the term psi. It's for this reason that most maintenance people have never had a heart to heart conversation with their pump supplier. If you're going to have an intelligent conversation with your pump supplier, you must talk in feet of head. You must understand feet of head to interpret a pump performance curve. In the final analysis, there's not much difference between feet of head and psi. They're practically interchangeable terms, separated by two factors, the number 2.31 and the specific gravity of the fluid. Let's consider the 2.31 first.

2.31 is the conversion factor to change feet of head into pressure in psi. Head in feet ÷ 2.31 = psi. And, psi x 2.31 = head in feet. A pump raising water into a 30-ft high tank will be developing 13-psi. A pump developing 60-psi, would raise a column of water 138.6-ft. high. The 2.31 conversion factor comes from the following: There are 144-square inches in one square foot. A cubic foot of water at room temperature would weigh 62.4-pounds. 144-in$^2$ ÷ 62.4-lbs. = 2.31. Another way to consider this factor is the following: If you poured one pound of water into a one inch squared tube or vessel, the water would fill the vessel to a height of 2.31-ft. Boiler operators use the term "water column inches". 27.7 water column inches is one psi. If you convert 27.7 water column inches into feet, you have the number 2.31. Next is specific gravity.

Specific gravity is a dimensionless number comparing the density or weight of a liquid to water. Sometimes the liquid under consideration is not water. For other liquids, we must incorporate the specific gravity "sp. gr." The specific gravity of water is 1.0, measured at sea level on a day when the temperature is 60°-F. A liquid is either lighter or heavier (denser) than water. If it is lighter, the specific gravity will be less than 1.0. For example, hydraulic fluid weighs about 85% of water. We say the specific gravity of hydraulic fluid is .85. A container holding one pound of water would weigh 13.75 pounds when filled with liquid mercury. We say that the specific gravity of mercury is 13.75. Ocean water has salt and some other minerals in it that make it about 6% heavier than fresh water. The specific gravity of seawater is 1.06. So for liquids that are not water, the conversion from feet of head into psi is the following: psi = (head x sp. gr.) ÷ 2.31, and in the other direction we have: head in feet = (psi x 2.31) ÷ sp. gr. You'll use psi in the maintenance shop, but you'll need to use feet of head in a confrontation...uh! conversation...with your pump supplier.

Let's talk about Larry's unwritten 'whacko' laws of pumps. You can drive your car around the block and perceive a problem with your car. You can observe your kids and look them in the face, and see if they have a problem, or if everything is going well. You have one or two cars, and one or two kids. You go to work and you're surrounded by 50 or 300-pumps. How can you stand next to a pump, observe it, and tell if the pump is sick or well? First law: At 1800-rpm, the impeller diameter in inches, multiplied by itself or squared, is approximately the shut-off head of the pump in feet. And second law: The best efficiency head of the pump is approximately 85% of the shut-off head.

The impeller diameter, in most cases, is printed on an aluminum tag or plate affixed to the pump. The speed of the electric motor is, in most cases, printed on an aluminum tag or plate affixed to the motor housing. About 80 to 90% of all industrial electric motors spin at 1800-rpm, or a variation of this based on the motor's slip factor. The shut-off head of a 6" impeller at 1800-rpm is approximately 36-ft. ($6^2 = 36$). And the shut-off head of a 13" impeller would be approximately 170-ft. ($13^2 = 169$). The shut-off head of a pump is a point on the pump's curve that represents maximum elevation in feet at 0-gpm. This law is not cast in stainless steel. It has some variables. The efficiency of the pump is a variable. The number of blades on the impeller is another variable. The design of the pump is another variable. This law doesn't apply to special pumps, or multiple stage pumps, or PD pumps. But, if you work among end suction centrifugal pumps, with one impeller, running on 1800-rpm motors, performing general duty, then the law does apply. The pump doesn't want to run at shut-off head. It wants to run at the best efficiency head or point (BEP), which is about 85% of the shut-off head. In almost all cases the BEP is somewhere between 80% and 90% of the shut-off head. What can you do with this information?

Let's say you're standing next to a pump with an 1800-rpm motor. The pump has a 13" impeller, and pumps cold water up into an open vessel. The differential pressure on the pump's suction and discharge gauges is 48-psi. Is the pump sick or well? This pump should have a shut-off head of 169 or 170-feet ($13^2 = 169$). You would expect this pump to have a best efficiency head (BEP) of about 144-ft (169 x 85% = 144). This pump wants to inject about 62 or 63-psi into the system (144 ÷ 2.31 = 62.3-psi). Therefore, 48-psi is unacceptable and this pump is sick. It will be stressing the seal and bearings, vibrating, may go into cavitation, and might trip the breaker on the electric motor. You must increase the pressure differential on this pump. The problem is either inside the pump, or in the discharge piping. If you can't isolate the problem, go to the storeroom and make sure you have another mechanical seal and another set of bearings to install on this pump because this pump is going to fail shortly. Wouldn't you like to do this with all your pumps? In about 80% of what you perceive to be unexplained downtime, unanticipated emergency maintenance, the pump was indicating the problem for hours, days, and weeks, before the breakdown occurred. Learn to read the gauges!!!

Next: The system governs the pump. The pump takes what the suction gives it, and jacks the pressure up to the discharge, according to the impeller and speed parameters. The pump is the victim of the system's demands. The system controls the pump. The pump will do what the system makes it do. If the system makes the pump do what it cannot do, then the pump will shut down, or fail, by taking out its bearings and/or seals. In order to have the best pump installed into the system you must first understand the requirements of the system. There are up to four different requirements in the system. These four requirements of the system are simply added together to determine the pump best suited for the system. These requirements are called the TDH, or Total Dynamic Head. The formula is: TDH = Hs (static head or the elevation change across the system) + Hp (pressure head or the pressure differential across the system) + Hf (the friction in the pipes valves and fittings) + Hv (the velocity head or the pressure developed due to the velocity of the fluid moving through the pipes). Of the four elements of the TDH, the Hs and Hp are determined by observation. The Hf and the Hv can either be calculated, or measured. You'll have to come to my lecture series for this. It's somewhat complicated for this article. In fact, the Hf and the Hv are the reason that design engineers are contracted to specify pumps before the construction phase of a new plant. And the Hf and Hv are the reasons for malpractice lawsuits against the design engineers later.

Anyway, the TDH is the point where you'll want the pump's BEP. If the TDH ≈ BEP, the pump will run for many years without problems. Problem is, once a plant is commissioned, and production begins, the TDH goes ballistic. In the short term, levels change in the tanks, pressures go up and down, valves open and close, and filter screens clog. As maintenance occurs, pipe schedules are changed, equipment is changed, and new equipment is added into the system. In the long term, equipment looses efficiency, scale forms on the internal pipe walls, and the plant undergoes expansion and contraction. And through all this, the pump has a static BEP. BEP needs to be replaced by the BER..."Best Efficiency Range." We spend a lot of time on this in my lectures.

The Affinity Laws deal with speeds other than 1800-rpm, and answer questions about the flow, head, and horsepower requirements of a pump with a change in speed. One of the affinity laws states that flow changes proportional to the change in the speed, or impeller diameter. Another one states that the head changes by the square of the change in speed or impeller diameter. And finally, the horsepower requirement of the pump changes by the cube of the change in the speed or impeller diameter. The affinity laws will become more and more important as variable speed motors become popular in industry.

Now lets talks about the NPSH. NPSH is the minimum acceptable head or pressure on the suction side of the pump, to prevent vaporization of the fluid as it approaches the eye of the impeller. NPSH is responsible for about 30% of all pump failure. You may think the pump is in the shop because the bearings or seal failed. Actually, the pump is in the shop because the NPSHa fell below the NPSHr, and inadequate NPSHa causes the seals or bearings (30%) to fail. NPSHa is Net Positive Suction Head available in the system. NPSHr is Net Positive Suction Head required by the pump. If the pump is draining a closed or pressurized vessel, the NPSHr is a specific number and must be respected. If the pump is draining an open or vented vessel, then there is a safety margin due to atmospheric pressure. In all cases, the NPSHa must always be greater than the NPSHr.

Different studies offer speculation as to how much greater the NPSHa must be over the NPSHr. We won't get into this speculation in this article. Lets just say that the NPSHr is on your pump curve. Go find your pump curve and learn to interpret the information.

NPSHa = 3 Observations, a Judgment Call and a Fudge Factor. The NPSHa is composed of 5 elements that either add or subtract energy from the fluid as it enters the impeller. The formula is: NPSHa = Ha + Hs - Hvp - Hf - Hi. Ha is atmospheric head (atmospheric pressure expressed in feet of head, 14.7 psi x 2.31 = 33.9-ft. at sea level). Hs is the static head or elevation change expressed in feet on the suction side of the pump. If the fluid is below the pump's centerline, then Hs is a negative number. Hvp is the vapor head and is a function of the fluid temperature. Hf is the friction head in the suction piping only. Most pumps are relatively close to the tank that they are draining. In this case Hf is probably insignificant. If there should be a great distance between the suction vessel and the pump, or if the suction piping has a lot of fittings and fixtures, then Hf can be calculated or measured. Hi is the inlet head, or what happens to the fluid between the suction nozzle of the pump, and the eye of the impeller. Sometimes the pump companies incorporate the Hi into the NPSHr of the pump, and sometimes not. And sometimes changes occur. Call it a fudge factor of 2-feet. Of the five elements of the NPSHa, the Ha, Hs, and Hvp are determined by observation.

To determine the NPSHa of any system, observe whether the suction vessel is opened, or closed, or pressurized. If the vessel is opened or vented, then Ha is 33.9-ft at sea level. If the vessel is closed and unpressurized, then Ha = Hvp and they cancel themselves. If the vessel is closed and pressurized, install a compound gauge on the suction vessel and record it’s absolute pressure, convert to head, and this becomes the Ha. Then observe the elevation of the fluid in the suction vessel compared to the pump centerline, and record this elevation change in feet. You may be adding a negative number if the level is below the pump. Next, observe the temperature of the fluid and locate a chart of the vapor properties of that liquid. Hf will be a judgment call. The Hf will either be negligible or significant. If it is significant, then calculate or measure it. Hi is a fudge factor of 2-feet.

There you have it...3-observations, a judgment call and a fudge factor to determine NPSHa. If you need to raise the NPSHa, then you must increase the two elements (Ha and Hs) that add energy to the fluid, or decrease the 3-elements (Hvp, Hf, and Hi) that subtract energy from the fluid. To decrease the NPSHr, you’d need to change the pump, or modify some pump parts or speed of the motor.