# THE INFLUENCE OF SPECIFIC GRAVITY ON TOTAL HEAD
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The pump performance or characteristic curve is often referred to as a water performance curve (see Figure 1). Water is naturally the fluid of choice for testing pumps because of its availability. *The question is: can the water performance curve be used for other fluids?* **The answer is yes with care.**
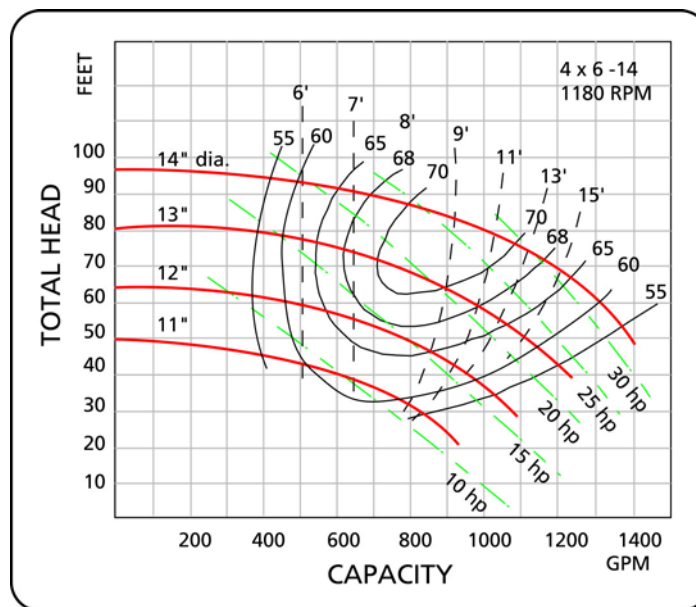
Figure 1 Typical pump characteristic curve.

The pump manufacturers will sometimes identify the unit of the total head axis as feet of water, or sometimes there will be a notice somewhere on the chart saying: tested with water at 70°F. This is the manufacturer's way of telling the user that the pump was tested with water and that the power curves are ONLY valid for water, but careful there are other pitfalls.

Total head is the amount of specific energy that can be produced by the pump, the unit in North America is feet. What is specific energy? Specific energy is the amount of energy per unit weight of fluid displaced.

$$head = specific\ energy = \frac{energy\ (E)}{weight\ (W)} = \frac{E\ (lbf - ft)}{W\ (lbf)} = \frac{E}{W}\ (ft)$$

[1]

Here is the question that you need to think about. Say that you measure the shut-off head of a pump with water, will you get a different value if the fluid is a dense salt solution (assuming the viscosity is the same)? The answer is NO.

The unit for weight in North America is the pound, one pound of water weighs the same as one pound of mercury or one pound of salt solution. Therefore the amount of specific energy required to displace a pound of water or a pound of salt water will be the same. That is why the

total head value or specific energy produced by a pump is independent of how heavy or dense a fluid is. The definition of head makes density irrelevant, which you must admit is very convenient, otherwise the manufacturers' would have to produce curves for 100's of fluids. As we say in Quebec, it's organized with the guy that makes the movie (it sounds better in French).

Power does depend on the specific gravity (SG). Equation [2] provides the relationship between SG, flow (Q), head (ΔH_P) and efficiency (η) of the pump with respect to power (P). If you read power off the performance chart, keep in mind that it is based on water and that you should multiply the value read by the SG of the fluid.

$$P(hp) = SG \times \frac{Q(gpm) \times \Delta H_P(ft)}{3960 \times \eta} \qquad [2]$$

Two other factors need to be considered. One is the viscosity of the fluid and the other the rheological properties (Newtonian or non Newtonian) or the way the fluid behaves under shear.

Viscosity effect

The viscosity of the fluid affects all the operational parameters of the pump: total head, flow and efficiency. The viscosity of water at 70 °F is 1 cSt (centiStoke). If the viscosity of the fluid is 5 cSt or more a correction for viscosity has to be applied. The Hydraulic Institute has produced a chart (see Figure 2) that provides correction factors for flow, head and efficiency. From this chart you can see that a fluid with 400 cSt will have a low correction factor for efficiency, meaning that the motor size will have to be much larger than its equivalent for water (disregarding the effect on flow and head). In that case, you should consider using a positive displacement pump instead of a centrifugal pump.
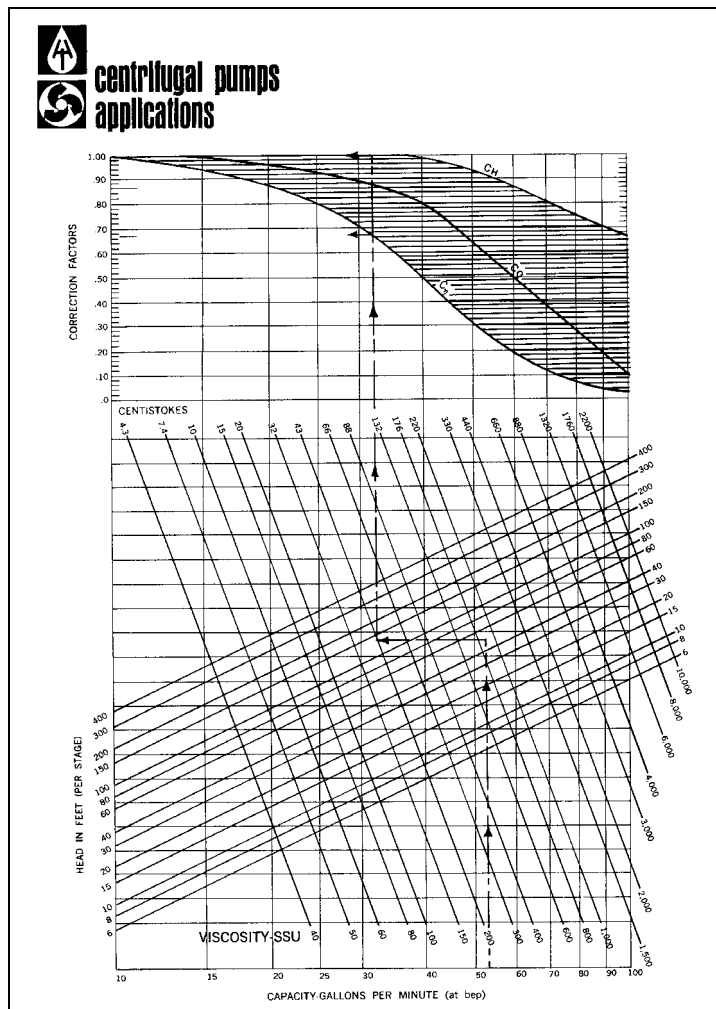

Figure 2 Viscosity correction chart (source: Hydraulic Institute, www.pumps.org).

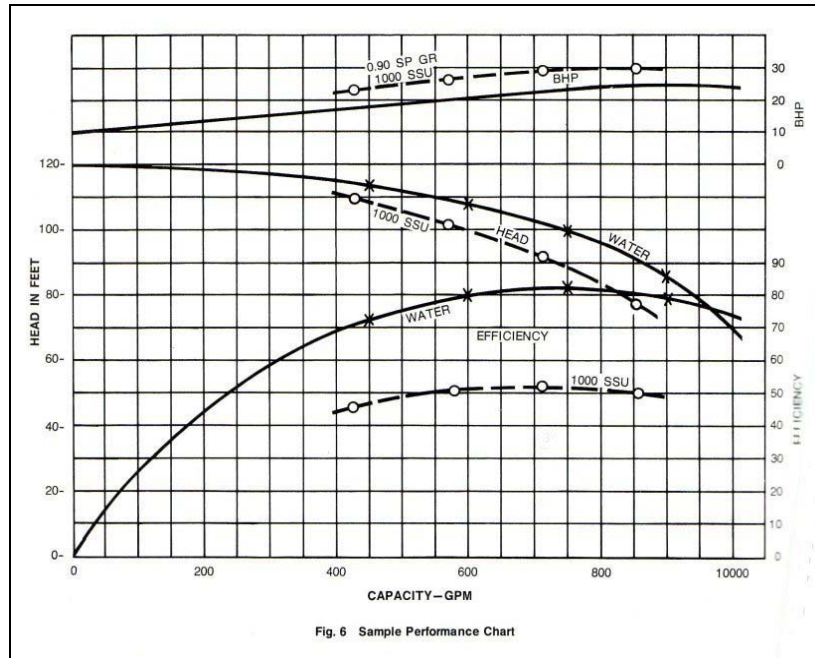Figure 3 shows the effect of viscosity on the water performance curve.

Fig. 6   Sample Performance Chart

Figure 3 The effect of viscosity on the performance of a centrifugal pump (source: Goulds Pump catalogue).

As you can see, Figure 3 gives the viscosity in terms of SSU (Saybolt Universal Second). The conversion from SSU to cSt is given in equation [3].

$$v(SSU) = v(cSt) \times 4.635 \, for \, v(SSU) > 350 \qquad\qquad [3]$$

Effect due to the type of fluid, Newtonian or non-Newtonian

The other issue is whether the fluid is Newtonian or non-Newtonian. Water is a Newtonian fluid. For Newtonian fluids, the relationship between displacement and shear force is linear. If you have trouble visualizing this, imagine a cube of jello, if you push at the top (this is the shear force) and measure the displacement of the top layer with respect to the fixed bottom layer, the relationship between these two is linear. Or the displacement that you get for a given force will be doubled if you double the force. The amount of displacement generated by the shear force depends on the viscosity of the fluid. For the same shear force, a low viscosity fluid will have a large displacement and high viscosity fluids (i.e. jello) a small displacement.

In the literature, instead of displacement the term used is velocity gradient (or rate of shear) which means the rate of displacement (or velocity) divided by the distance between the top layer and the bottom (see Figure 4). Also, instead of shear force, shear stress is used which is the shear force divided by the surface area.

As you can see from Figure 4, Newtonian fluids have a constant viscosity by definition and non-Newtonian fluids have a variable viscosity. When non-Newtonian fluids are moved rapidly, the viscosity can increase dramatically, which results in an increase in tangential stress and an increase in the power required to keep the movement going. A centrifugal pump that rotates rapidly subjects the fluid to a high tangential stress which means that centrifugal pumps cannot be used with certain types of non-Newtonian fluids. A 60% starch/water solution is one of them.
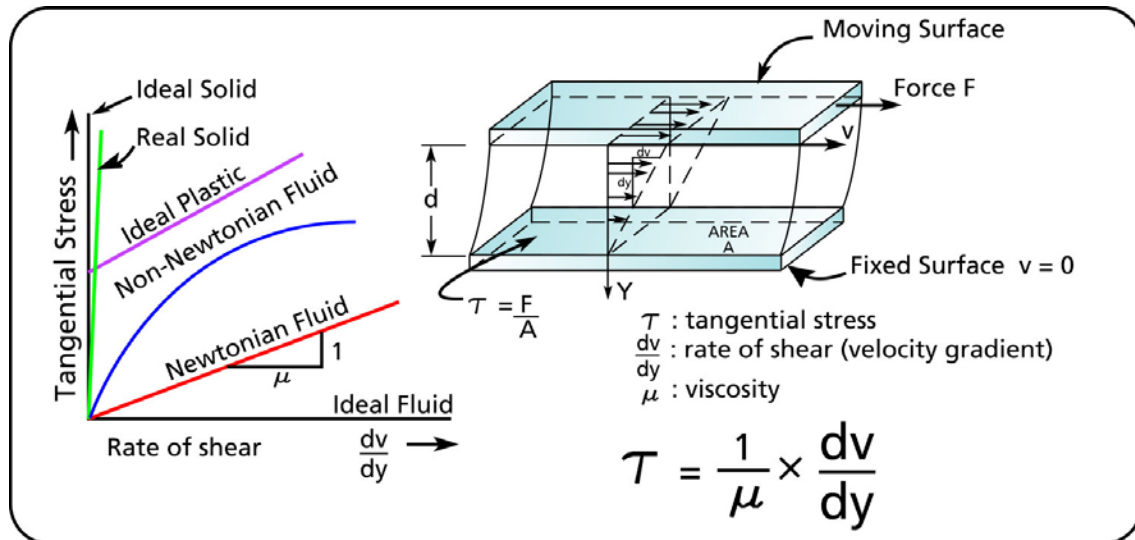
Figure 4 Behavior in shear of Newtonian vs. non-Newtonian fluids.

Try this experiment if you want to understand how viscosity changes with velocity gradient.

In a large shallow bowl make a solution of approximately 1 part water and 2 parts corn starch, try moving this fluid rapidly around with your fingers. When you move your fingers slowly through the solution, it behaves as expected and offers little resistance. The faster you try to move through the fluid, the higher the resistance. At that rate of shear, the solution almost behaves as a solid, if you move your fingers fast enough they will skip over the surface. This is what is meant by viscosity being dependent on rate of shear. Compare this behavior to that of molasses, you will find that even though molasses is viscous its viscosity changes very little with the shear rate. Molasses flows readily and offers little resistance (shear stress) no matter how fast the movement.

Conclusion

You can use the characteristic curves of centrifugal pumps for fluids other than water, assuming that you know the viscosity of the fluid. Depending on the fluid viscosity, you may have to correct the values for the water-based characteristic curve. Use the Hydraulic Institute viscosity correction chart published in their Standards book (www.pumps.org). It is also available in the Goulds pump catalogue and Cameron Hydraulic Data Book.

If the SG of the fluid is different than water (SG = 1.0) then do not use the values for power on the pump performance chart, you can calculate the power very easily using equation [2].

Be careful when trying to pump non-Newtonian fluids, these can become almost solid when subjected to high rates of shear as is the case in centrifugal pumps.