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TECHNICAL INFORMATION
Bulletin

NUMBER FOUR

INTERPRETATION of AFFINITY and SYSTEM CURVES

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Several years ago I was asked to explain how and why some pumping problems could be minimized, or even eliminated, by giving certain basic considerations to the design and selection of non-clogging pumps. Since that time new problems have become apparent and now I have been requested to describe how some troubles could result when pumping conditions are varied within an existing piping system.

The last few years have placed an additional burden upon some engineers and plant operators because of increased populations and a demand to get temporary additional capacity out of an existing pump installation. A first reaction to this problem would be to apply the “affinity laws” and check whether or not it would be possible to sufficiently increase the impeller diameter or, if this is not practical, to increase the pump speed.

Let us review the applicable “affinity laws.” They simply state that, SIMULTANEOUSLY AND WITHIN LIMITS, the capacity of a centrifugal pump will vary directly as the speed; the head will vary as the square of the speed; the horsepower will vary as the cube of the speed. The same relationship exists when we substitute “impeller diameter” for “speed.” Also, note that the conditions of capacity, head and horsepower are all affected at the same time and not separately. Later we will show how erroneous conclusions drawn from the misapplication of the “affinity laws” could cause pumping troubles.

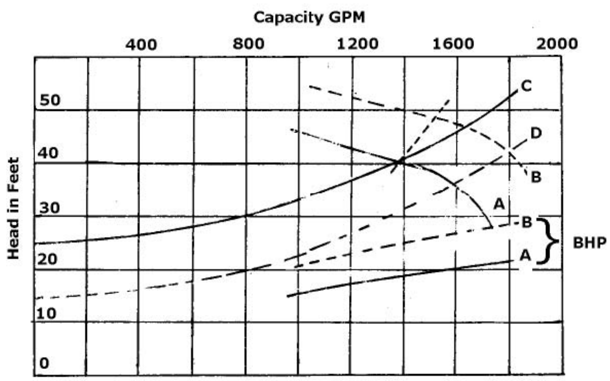
Use of the “affinity laws” will be illustrated by a hypothetical problem wherein we will arbitrarily increase the speed of an existing pump by 10%. If the existing pump handles 1400-gpm when pumping against a total dynamic head of 40 feet and requires 20-bhp at a speed of 1160-rpm; then, by using the affinity formulas, we will get the following equivalent conditions for this one point, as follows:

1 – Capacity………….110% of 1400 = 1540-gpm
2 – Head……………...121% of 40 = 48.4 feet
3 – HP……………….133% of 20 = 26.4-bhp

Similarly, various other points on the basic pump characteristic curve “A,” Fig. 1, can be selected and equivalent points established for constructing a curve for the increased speed. The head-capacity and separate bhp curves for both conditions of speed are shown on Fig. 1 and are respectively labeled “A” for the slower speed and “B” for the increased speed.

Let us emphasize that the conditions as shown by curves “A” and “B” represent only the potentialities of the pump for the given speeds and, except for one point on each curve, they do not graphically show the actual pumping conditions within the system. We can determine the actual pumping conditions by constructing a "system curve." When the system curve is superimposed upon the pump characteristic curves, the actual pumping conditions are represented by the points of intersection.

CAPACITY – GPM



A – Basic Pump Characteristic Curve
B – Calculated Affinity Curve
C – Basic System Curve
D – Auxiliary System Curve

A system curve is a graphical illustration of the various flow conditions in a given piping system. Simply stated, the curve is constructed through points established by adding the total head loss for each possible separate flow condition to the static head against which the pump must operate.

For illustrative purposes, let us assume that the pump must operate against a static head of 25 feet. The points for constructing the system curve may be determined, as follows:

1. For a flow of 800-gpm; let us assume that the total head loss; including piping, valves, fittings, etc.; is 5 feet. The required system head condition then becomes 5 + 25 = 30 feet.

2. In the same way; let us assume that the total head conditions for 1000-gpm is 32 feet; for 1200-gpm it is 35 ½ feet; for 1400-gpm it is 40 feet; for 1600-gpm it is 45 feet and for 1800-gpm it is 51 feet.

From the tabulated results, we can construct curve "C" and superimpose it over curves "A" and "B," Fig. 1. We now have a clear picture of the actual pumping conditions for this system at either selected speed.

Note that at the intersection of curves "A" and "C" we show that our original conditions of 1400-gpm and 40 foot head is verified. Directly below this point of intersection and on the HP curve "A" we also verify the 20-bhp requirement. Similarly, for the increased speed, as shown on curve "B," we establish that the new pumping conditions will be approximately 1650-gpm at 46 feet and, directly below on the HP curve, "B," we determine that 27-bhp is required.

It is evident that accurate appraisal of system pumping conditions cannot be made without considering the system curve. Attempts to evaluate pumping conditions from either or both the basic pump characteristic curve or curve established by use of the affinity laws may be very misleading.

Pumping troubles can usually be traced to the consideration of one condition on the affinity curve and the ignoring of the others. That is:

1. The revised capacity condition is accepted but either or both the head and horsepower conditions are ignored.

2. Sometimes the equivalent capacity point on the affinity curve is accepted as the actual system pumping condition.

3. Sometimes the capacity on the affinity curve is accepted for the head condition against which the original pump operated.

4. When the pump operates from a suction well in which there is a considerable difference in the high and low liquid levels. Refer to curve "C," Fig. 1 which represents conditions at low water level and curve "D" which represents conditions at high water level. Note that the system curve "D" intersects both the "A" and "B" curves within the "break" of the sharp decline in head conditions. Invariably the pump will cavitate when operating at and near the high water level and will continue to do so until

the head increases sufficiently to safely retreat from the “break” point. The cure for this condition would be to decrease the pumping differential by lowering the high water level.

The curves shown on Fig. 1 have been constructed only to illustrate our various hypothetical problems and without any regard for accuracy. Nevertheless, this discussion will emphasize that both the pump characteristic curve and system curve are required if accurate appraisal of the actual pumping conditions within a system is to be illustrated.