PUMPCOM - A Simulation Model for Operating Characteristics of Pumping Stations through Combination of Individual Pumps

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Abstract

The computer model PUMPCOM has been developed to combine pump curves in series and in parallel for a variety of pumping stations using a WINDOWS environment. The model determines the performance of a pump station and of individual pumps within the station via construction of head-discharge curves, efficiency curves and curves indicating net positive suction head requirements. A graphical interface allows the user to draw the pump station layout on screen, to view discrete data entered, and to view the fit of polynomial equations. An icon "tool box" allows the user to select an appropriate pipe fixture and place it in the layout between pumps. This allows the pump station drawing to resemble as closely as possible the real pump station. Data tables, plots of the curves and equation coefficients, and station layout can be printed. Polynomial equations are fitted to individual pump curves and to the combined pump station curves. Cubic spline interpolation is employed to combine curves of pumps having different sizes. Performance indicators of the station and of each pump within the station are calculated over flow rate range for the entire station.

Keywords: Design Programs, Pumps, Irrigation,Windows

Introduction

The PUMPCOM model is part of a larger model, SPRINKMOD, developed to simulate pressure and discharge in pressurized irrigation systems (Andrade, 1997; Andrade and Allen, 1997). The PUMPCOM tool combines various sizes of pumps in series and in parallel and generates the head-flow rate tables and equations to be used by SPRINKMOD. PUMPCOM runs in WINDOWS 95 and 3.1 environments and provides a user-friendly interface for data entry and displaying of results.

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Pumps are normally selected to match the hydraulic requirements dictated by distribution geometry and hydraulic variability. Many hydraulic systems operate over a dynamic range of flow conditions due to changes in demand, reservoir elevations, position of laterals, friction, local losses caused by valve operation, or by the aging process (leaks). In these situations it may be desirable to use multiple pumps that are combined in series and/or in parallel.

When combining pumps in parallel and/or in series, it is important to analyze the total and individual pump efficiencies, the required net positive suction head (NPSHr) and the power input required over the entire range of system flows. It is desirable to have the operating point as close as possible to the point of best efficiency of the combined and individual pumps. Mismatched pumps can reduce efficiency and can close an adjacent pump's check valve, or in the worst case, cause water to be pumped backwards past through a weaker pump's impellers. In these situations energy is wasted and the motor or engine of a mismatched pump can be damaged.

Conducting the analysis of combined pumps by hand is tedious. In many cases, simply finding a "modest compromise" in pump (design or operational) selection to produce given Total Dynamic Head (TDH) and flow requirement can provide substantial energy savings. In general, computer software or spreadsheets are needed to simplify a series of static analyses.

The major objective of this study was to develop a user-friendly computer model for combining pump curves in series and/or parallel so that power, efficiency, NPSHr, flow, and head could be comprehended and visualized, even in complex pump station configurations.

Background Relationships

Pump Head-Flow Rate Curve

A manufacturer generates a "pump characteristic curve" for fixed speed and a specific impeller diameter by holding either the head or the flow to a known level and measuring the corresponding unknown value. This flow versus head curve is normally supplemented with additional observed efficiency, power, NPSHr, and thrust data collected during the procedure that may be represented in tabular or graphical form.

Most pump curves can be described mathematically through use of a polynomial equation. The second degree polynomial is commonly used (Tullis, 1989), although Wheeler (1993) found a fourth degree to be the best model for some systems. Higher order polynomials might be used to describe some unusual characteristic curves although care must be taken as higher degree polynomials can "wiggle" between data points (Mathews, 1987).

An alternative equation to describe pump characteristic curves is the cubic spline. Wheeler (1993) suggested the use of splines in place of the fourth degree polynomial. Kincaid and Cheney (1991) describe the methodology to derive cubic spline functions for a set of data.

Pump Efficiency and Power Consumption

Efficiency (energy efficiency), E_p is the ratio between the useful energy transferred from the pump to the water, W_p, and the energy needed to drive the pump B_p (Tullis, 1989):

$$E_p = \frac{W_p}{B_p} 100$$

where,

E_p	= pump efficiency	[%]
W_p	= water power output	$[ML^2/T^3]$
B_p	= brake power input	$[ML^2/T^3]$

The energy transferred to water is:

$$W_p = \frac{H\ Q}{K}$$

where,

H	= total operating head	[L]
Q	= flow rate	$[L^3/T]$
K	= conversion constant	$[L^2T^2/M]$

The energy supplied to the pump shaft is:

$$B_p = \frac{H\ Q}{K\ \frac{E_p}{100}}$$

Pumps in Series

In general, pumps in series are used when the total head generated by one pump is not sufficient to meet the total system pressure requirement. For pumps operating in series, each pump imparts additional energy to the same stream of water. The combined head is essentially equal to the sum of the individual heads for the same flow rate. The combined efficiency for two pumps in series is given by (Tullis, 1989) (ignoring minor coupling losses):

$$E_{ps} = 100 \frac{Q\ (h_{p1} + h_{p2})}{K\ (B_{p1} + B_{p2})}$$

where,

E_{ps}	= combined efficiency	[%]
h_{p1}	= head of pump 1	[L]
h_{p2}	= head of pump 2	[L]
B_{p1}	= brake power input of pump 1	[ML^2/T^3]
B_{p2}	= brake power input of pump 2	[ML^2/T^3]

Pumps in Parallel

Pumps may be connected in parallel to increase station discharge for a given pressure head, for safety or to simplify maintenance. In municipalities, it is common to use three pumps in parallel, each one having the capacity for supplying 50% of the required design flow rate (Tullis, 1989).

When pumps are operated in parallel, they work against a common pressure. The combined characteristic curves are developed in a manner similar to that described for pumps in series, except that flow rates rather than heads are added for a common total head. Because pumps with flat curves are very sensitive to relatively small head changes, there are significant flow shifts when adjacent pumps are turned on and off, or when the station TDH changes because of changes at either the suction or discharge side of the station. The interplay among pumps is increasingly dynamic when the curve slopes of adjacent pumps are not the same. Identifying the performance of a single pump operating in a family of parallel pumps, with changing pump station TDH requirement, and dynamic pump station friction and turbulence losses is difficult.

The combined efficiency for two pumps in parallel is given by (Tullis, 1989) (ignoring minor
coupling losses):

$$E_{pp} = 100 \frac{H\ (Q_1 + Q_2)}{K\ (B_{p1} + B_{p2})}$$

where,

E_{pp}	= combined efficiency	[%]
H	= total head	[L]
Q_1	= flow rate for pump 1	[L^3/T]
Q_2	= flow rate for pump 2	[L^3/T]

The combined NPSHr for pumps in parallel is equal to that for the most limiting pump, the largest NPSHr in this case.

Local Head Loss

When assembling pumps in series or parallel in a pump station small pipe lengths, valves and fixtures are employed causing the loss of head. These losses are normally termed "local" or
"minor" head losses. It is common to express the local losses by an equation of the form:

$$h_l = K_r \frac{V^2}{2g}$$

where,

K_r	= local loss coefficient	[ ]
V	= average velocity	[L/T]
g	= acceleration due to gravity	[L/T^2]

Model Description

The PUMPCOM model allows the user to combine individual pump curves, to generate a lookup table and to fit a polynomial equation to the flow rate-head, flow rate-efficiency and flow rate-NPSHr data. In addition, the performance of the pump station and of individual pumps within the station can be evaluated for a range of flow rates. A pump station can be comprised of one or more individual pumps.

The general procedure for using PUMPCOM consists of: 1— Creating and Editing a Pump Curve Data File for each individual pump, 2— Creating and Editing Pump Station Data Files, 3— Viewing Pump Station Performance Data.

Creating Pump Curve Files

The user must create one file for each of the pump curves that are to be combined. Once created, pump files can be re-utilized in the same station or in other stations. Different pumping stations can use the same individual pump files. Both English and metric systems of units can be used.

Creating Pump Station Files

Pump station files are created by assembling individual pumps in parallel or in series or both. The PUMPCOM program is capable of tracking intricate pump station layouts and of generating a unique pump station curve. Any number of available individual pump curve files can be selected for combination. A dialog box is utilized where the user can draw the layout of the pump station in a grid using icons (figure 1). A previously selected list of pump curve files is stored as a drop-down box. Pumps are selected from the drop-down box and placed onto the grid in any location. In addition, a tool box allows the user to select an appropriate pipe fixture and place it in the layout between pumps. Following this procedure, a pump station layout can be drawn to resemble as closely as possible the real pump station. Local (minor) loss coefficients can be associated with each pump to account for losses from the selected pump to the next downstream pump or intersection (bifurcation or trifurcation) device. Local loss coefficients can also be entered for each intersection device to incorporate losses from the selected fixture to the next pump or next intersection downstream.

Combination calculations are triggered when the user requests to view the graph of head vs. discharge for the total station or to view data for an individual pump by clicking with the right mouse button over the pump icon. During combination, the range of possible flow rates for each pump is subdivided to generate a set of discrete data. The lower limit of the range is set to zero flow rate and the upper limit is the largest flow rate entered by the user for a particular pump. The number of intervals is fixed at 20 (21 data points). For each flow rate value, the corresponding head, efficiency and NPSHr are determined for each pump by using its polynomial equation.

For pumps in series, the heads of individual pumps are added for a common flow rate, while for pumps in parallel, the flow rates are added for a common head. If there is no exact flow rate in common for pumps in series or if there is no exact, common head for pumps in parallel, as occurs if the pumps are of different size or after an upstream combination, interpolation is used to find heads for the common flow rate and vice-versa. The program uses a cubic spline type of interpolation to accomplish this task (Kincaid and Cheney, 1991). Required NPSH for the pump station is found by selecting the highest NPSHr of individual pumps for which the upstream intake is open. This is done for every value in the range of flow rates for the station.

Viewing Pump Station Performance Data

The pump combination model goes beyond the process of simply computing the combined flow rate, head, efficiency and NPSHr for a pump station. Detailed performance information for each individual pump in a pump station is determined for each point on the final pump station curve. Head, efficiency, NPSHr and flow rate for the complete pump station and for individual pumps are retained in arrays, so that when the user clicks on a pump in the grid with the right mouse button, the data for that pump are displayed in a table (figure 2). This is an important feature of the model. The user can analyze the performance of the complete pump station and of individual pumps, as well as for each flow rate condition at the station outlet. Problems of low performance and cavitation can be detected and rectified, or can be avoided if such analysis is done prior to the pump station installation.

Polynomial equations of degree up to five can be fitted to flow rate versus head, flow rate versus efficiency and flow rate versus NPSHr data if desired (figure 3). In this way, a pump curve can be smoothed. PUMPCOM allows the user to modify the degree of the polynomials and to analyze the effect of equation degree on the graphical fit and on the standard error of the regression. Pump station data can be viewed in a chart, printed out and existing files can be edited in the same way it is done for individual pump files as described earlier.

Summary

PUMPCOM is a Windows-based program written in Visual Basic. It is used to combine pumps in parallel and in series. It is also used to evaluate the performance of the ensuing pumping station. The PUMPCOM software is available and can be operated as a stand-along computer program. It is also incorporated into the larger SPRINKMOD simulation software.

Acknowledgments

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References

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Figures

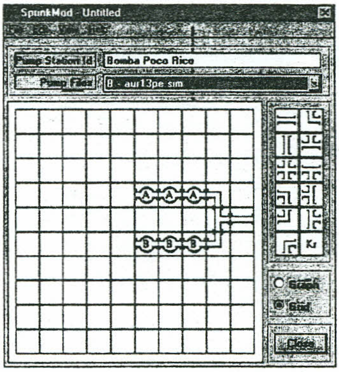


Figure 1- Pump Layout Dialog Box Showing Example Pump Station Layout.

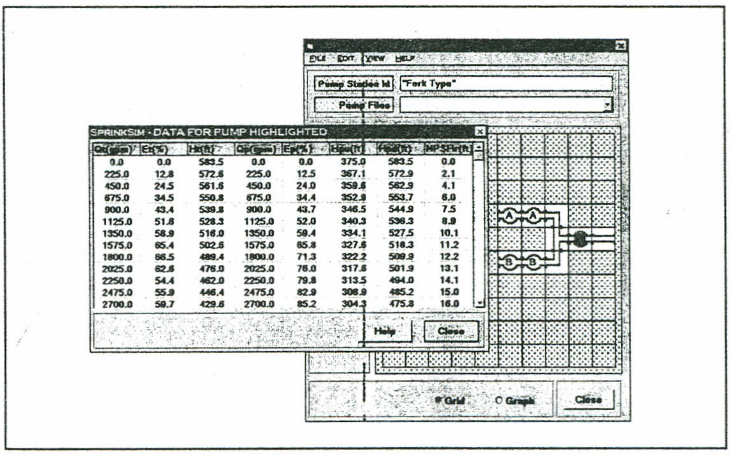
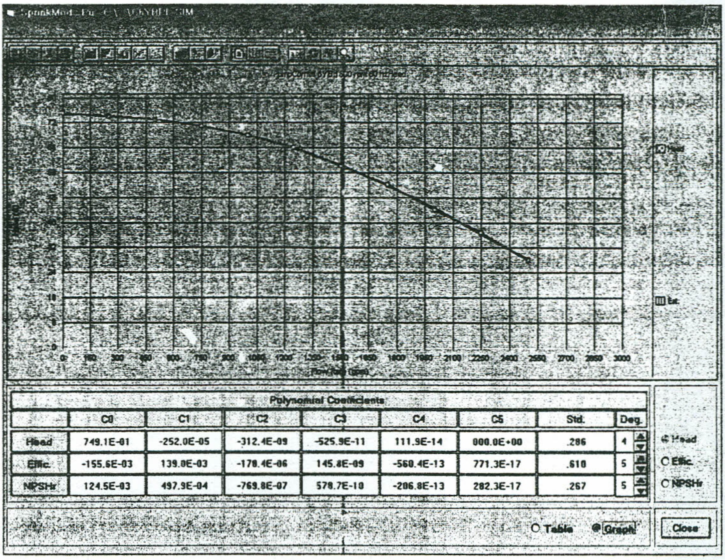


Figure 2- Pump Station (combined) Data and Corresponding Data for One of its Pumps.



	C0	C1	C2	C3	C4	C5	Std.	Deg.
Head	749.1E-01	-252.0E-05	-312.4E-09	-525.9E-11	111.9E-14	000.0E+00	.286	4
Effic.	-155.6E-03	139.0E-03	-170.4E-06	145.8E-09	-560.4E-13	771.3E-17	.610	5
NPSHr	124.5E-03	497.9E-04	-769.8E-07	578.7E-10	-206.8E-13	282.3E-17	.267	5

Figure 3- Plot of Flow Rate Versus Head and Polynomial Equation Coefficients.