DETERMINATION OF PUMP CURVES BASED ON HISTORICAL DATA

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Abstract - Hydraulic models used to simulate operational conditions in pipelines depend heavily on the availability of pump curves. However, in several situations the pump datasheets are missing or are outdated, not reflecting the current conditions and leading to inaccurate simulations. This manuscript presents a methodology that can be used to estimate the pump curves based on historical data collected from the pipeline operation, improving the accuracy of the simulation models.

Keywords: pump, simulation, hydraulic model

1. INTRODUCTION

Transpetro is a company that belongs to Petrobras and is responsible by the various modes of transportation of oil, gas and its derivatives.The company operates ships, oil and gas pipelines. Its National Operational Control Center, CNCO, is situated in the city of Rio de Janeiro, Brazil, and is responsible by the centralized operation of more than one hundred segments of pipelines, distributed throughout the country. Most of these pipelines are operated by full control and supervision, that is, starting and stopping of equipment, control and process variables monitoring can all be done remotely. The CNCO works twenty-four hours a day in three shifts.

In order to guarantee a high level of operational efficiency, simulation is used in a daily basis. The operational engineering team is responsible by giving support to the operational technicians and sometimes, in order to face different situations, a specific simulation is demanded in order to verify the feasibility of certain scenarios. Moreover, some of these simulations are emergency ones and to accomplish this task the model needs to represent the reality with a low uncertainty which is not always the case. Considering the well known precept in the simulation area: garbage in, garbage out, it must be assured that the model represents the reality with a high degree of confidence. Sometimes, especially for old pumping stations, there is a lack of documentation. Some of the datasheets do not exist anymore or, because of modifications in pumps components, the documentation is outdated. For instance, if the impeller size is trimmed, pump curves do not remain the same.

For a better understanding of the main objective of this work, Fig. 1 shows typical pump curves. The main work was focused in the curve of head versus flow, which is labeled Head in this figure.
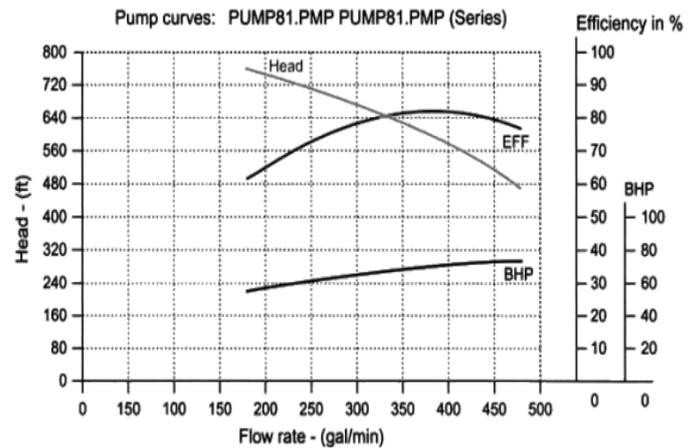

Fig. 1. Centrifugal Pump Curves[4].

This curve is usually supplied by the pump manufacturer but, as mentioned before, there are some cases, when this information is not available or reliable.

Fig. 2 shows a typical pumping station operated by Transpetro, and depicts the case study herein considered. In this case, four pumps are connected in series in the bottom of the diagram, the shading representing the status of each pump (on or off). An analogue convention is used to represent the status of the valves, distinguishing opened valves from closed ones.

The methodology explained in Section 2 is based on the acquisition and processing of real process variables such as discharge pressures, suction pressures, flows, specific gravity, electrical motor current[1], status of pump. In this work, care was taken to ensure that data was only acquired when there was only one active pump as it is the case shown in Fig. 2. Even though it could be possible to calculate associative pump curves, at the first moment this analysis was simplified to collect data from only one pump at each time. There are some cases in which the pumps are different and this could be a problem when determining the resultant curve, so this situation was avoided.

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[1]This is only needed if other curves are to be reconstructed, but they are out of the current scope of this article.
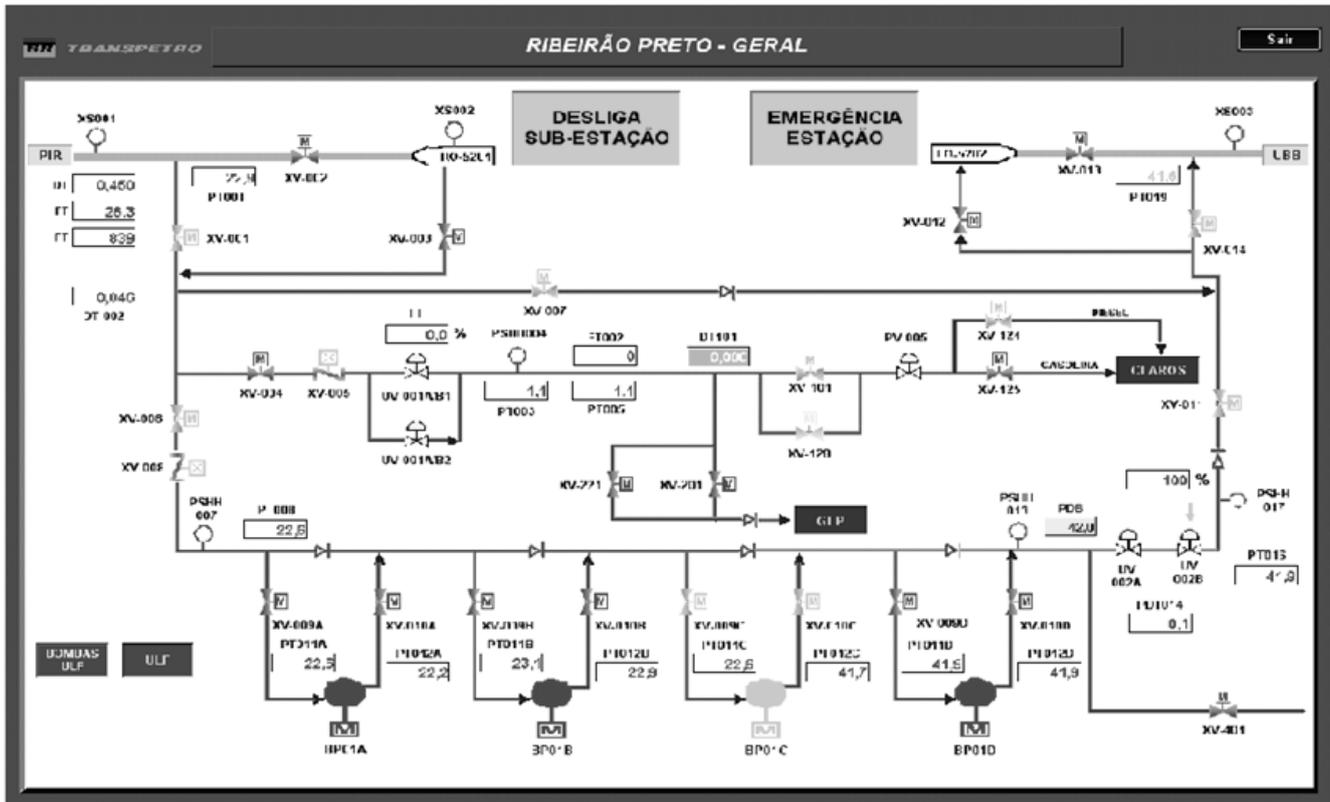
Fig. 2. Typical Pumping station operated by Transpetro with four pumps in series.

2. METHODOLOGY

The methodology adopted in this work consists in few steps as described below, implemented as an integrated system. The previous version was running in different environments, part in EXCEL, part in R, and the other part in VB.NET. Now, the whole solution is integrated inside VB.NET in order to be easily used by Transpetro Operational team. The GUI can be seen in Fig. 3. The system developed is able to import, from EXCEL spreadsheets, process variables such as: suction pressure, discharge pressure, flow and specific gravity. Another option is to import the pump curve, head versus flow, from spreadsheets also.

The input signals do not need to be preprocessed and can be sent as they are, leaving the synchronization to the software in the first step regarding data acquisition below described. The pump curve, if not imported directly, can be built from the process variables previously imported. This curve can be seen in Fig. 3 inside the chart.

Another software capability is data filtering (removal of outliers). There are two types of filtering: manual filtering, where the user can choose the limits to be excluded, or a statistical filter known as Chauvenet filter. The chart seen in Fig. 3 shows the limits imposed by the Chauvenet filter (the region colored in gray), all the points inside this window being preserved while points outside it will be excluded.

The bottom right part of the GUI shows some output like the coefficients of the second order polynomial and their respective standard deviations.

2.1. Data Acquisition

Initially each process variable required for constructing the pipe curve is collected from the supervisory system: discharge and suction pressure, specific gravity and flow. There is a particularity in the source of this information that is called transmission by exception. This means that each variable has a specific dead-band. The dead-band values are 0.1 $\mathrm{kgf/cm^2}$ for pressure, 5 $\mathrm{m^3/h}$ for flow and 0.002 for specific gravity. Only when the increment or decrement in the value of each variable exceeds the symmetric dead-band limits this value is transmitted.

So, even if the variables had the same dead-band, and this was not the case as different quantities and magnitudes are present, this results in different timestamps. To overcome this situation it was necessary to interpolate each signal and synchronize them in order to make simple math operations. The system uses Lagrange algorithm [1] to interpolate values with a constant sample period of 10 seconds. Also, the synchronization was done considering a single timeline, beginning by finding the first timestamp for each signal and then choosing the latest one as the first timestamp to be processed. From this point, time is interpolated with the sample period mentioned until the last timestamp, which was

Fig. 3. GUI of the integrated system developed.

previously defined by finding the last timestamp for each signal and then choosing the earliest one.

Another improvement regarding syncronization was done considering a single timeline like the previously one, but interpolating timestamps only when at least one of the four signals involved changed. So in that way every signal contains timestamps that belongs to each one. In this way a constant interpolation is not required.

2.2. Head Calculation

The next step is the extraction of the pump curve. The quantity head, which represents the liquid column (pressure converted to liquid column) was then derived by three variables: discharge and suction pressure and specific gravity according to

$$Head = \frac{P_D - P_S}{S_g \cdot g}, \qquad (1)$$

where P_D stands for discharge pressure, P_S stands for suction pressure, S_g stands for specific gravity and g is gravity acceleration. Pairing the head values with the flow values, the empirical curve begins to be constructed, as shown in Fig. 4.

Some data cleaning is necessary in order to eliminate points that do not belong to the population like gross errors and points previously known not to belong to the curve, a knowledge based in hydraulic understanding as
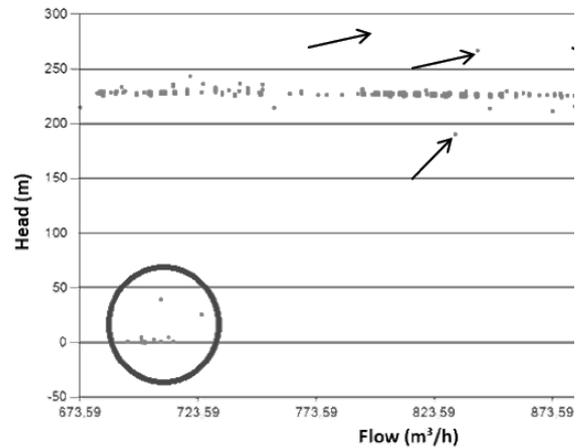

Fig. 4. Values of head versus flow extracted from historical data. Some gross errors are indicated by the circle, and the arrows indicate outliers.

it is exemplified by the circle. After cleaning the data by removing the circled points, the Chauvenet criterion is applied to the remaining points. One should note that instead of using the manual filter to exclude those points, it should be possible to apply the Chauvenet filter directly. The effect is the same since the Chauvenet criterion recognize them as outliers. An example of those outliers can also be seen in Fig. 4 by the arrows pointed to some of them.
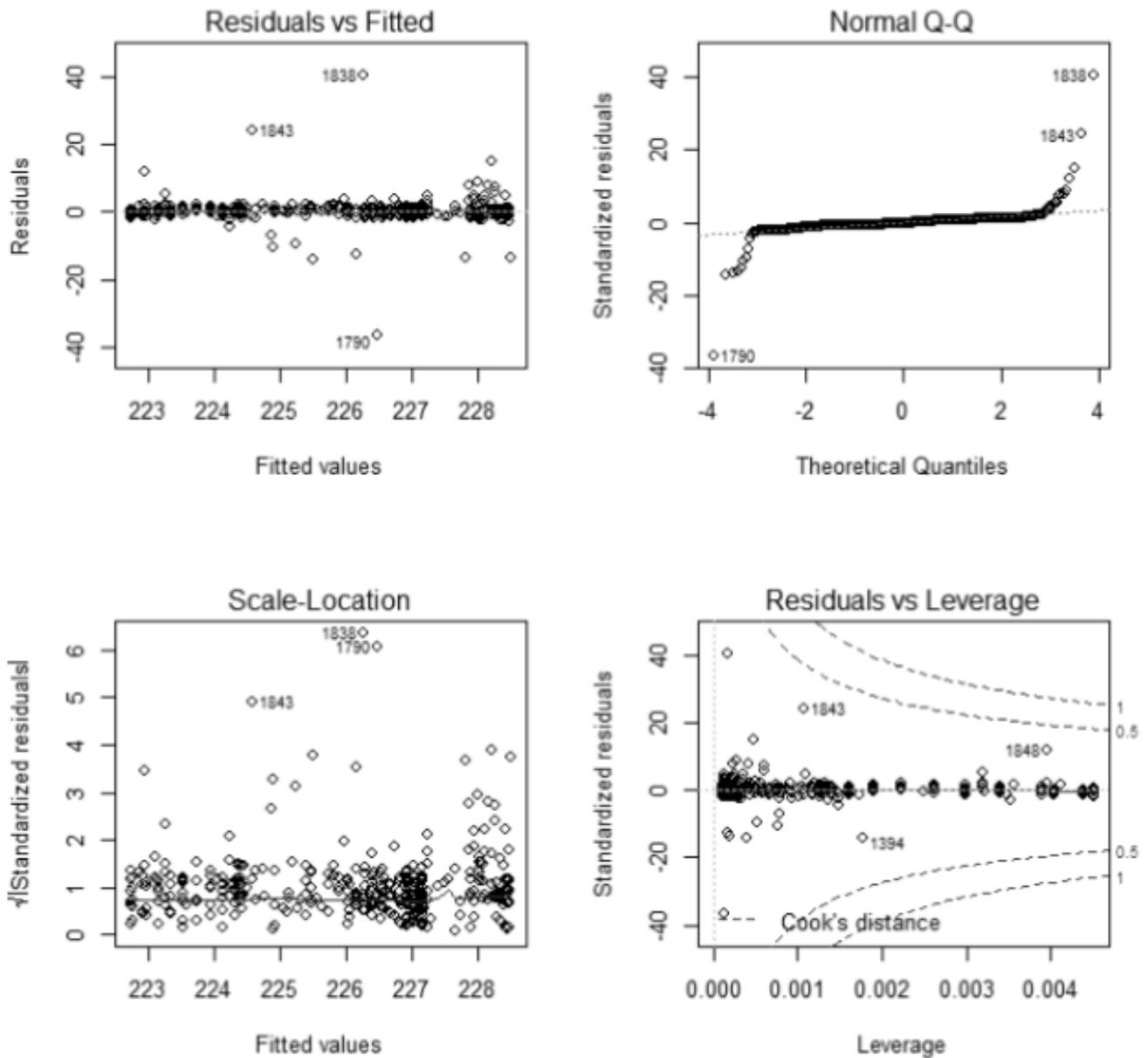
Fig. 5. Regression analysis.

2.3. Estimation of Pump Curve

The pump curve equation was fitted by the least squares method and the order adopted was the second order, which was considered to be the best fit considering the real curve, as can be seen in Fig. 5.

Once the outliers are excluded or at any other moment, with the pump curve built, it is possible to make a regression analysis. This option produces the chart shown in Fig.5. It is possible to see in this figure that some model checking is made. The top left graph shows residuals on the y axis against fitted values on the x axis.The next plot, top right, is the normal quantile-quantile plot which should be a straight line if the errors are normally distributed. The deviations from the straight line are minimal except for the ends, but it indicates a normal distribution. the third plot is like the first but on a different scale, it shows the square root of the standardized residuals (all values positive) against the fitted values. The lower right highlights some influential points; these are the points on the graph that have the biggest effects on parameter estimates. It shows Cook's distance as dashed contours on a plane defined by leverage and standardized residuals.

2.4. Viscosity correction

Once the pump curve is developed routines based in [2] and [3] were applied for making viscosity correction if
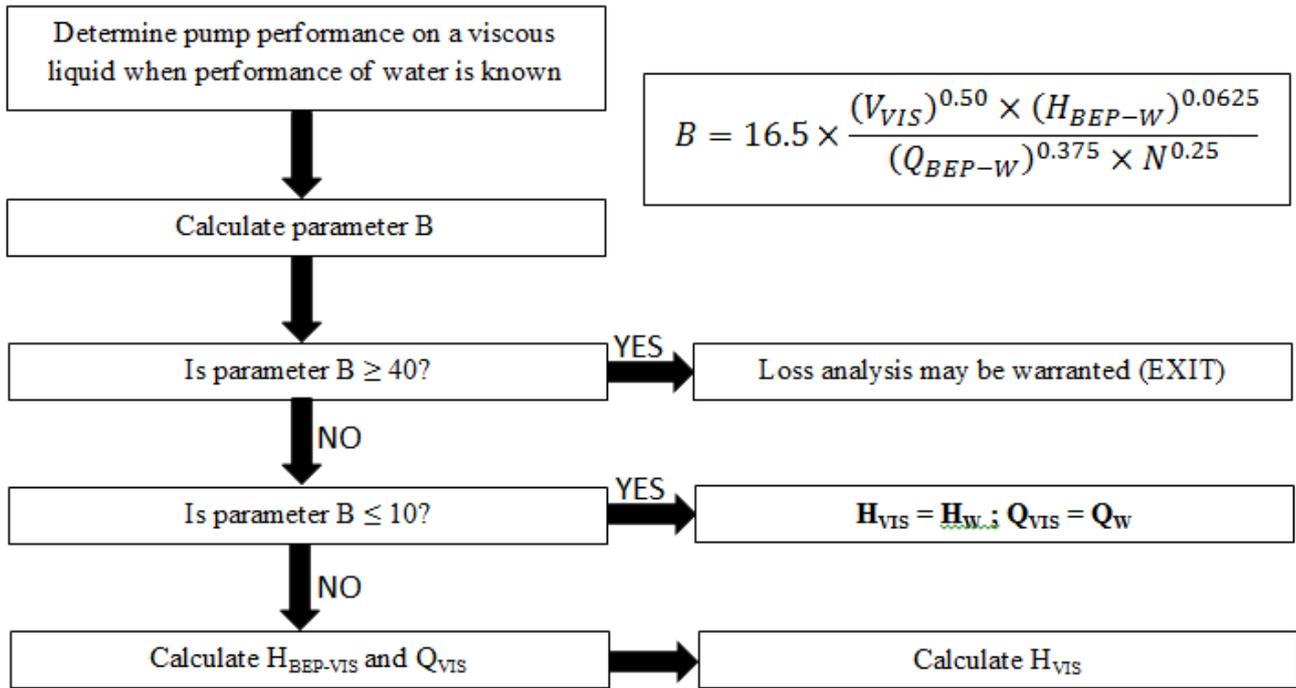
Fig. 6. Viscosity correction flow diagram. Adapted from [3].

necessary. Most of the commercial tools used to simulate pipelines expect that the pump curve is designed for water. So this step tries to convert the experimental curve obtained for other liquids, which usually are different than water, to water curves. The algorithm to make this conversion can be seen in Fig. 6. According to [2] there are more two steps that do not appear in Fig. 6 that could be used to correct the efficiency curve and the power curve but, as mentioned before, they were out of the scope of this work, so those steps were suppressed.

Finally, the pump curve data was provided to a hydraulic simulator and the model output was verified to be within expected values of real world data.

3. CONCLUSIONS

This manuscripts presented a method aiming at improving the accuracy of pipeline simulation models. The pump data is only part of a series of items that have to be adjusted in order to obtain a reliable model. Other items regarding fluid properties, pipe properties, elevation profiles are also important but not considered in this work.

It would be interesting to allow pump combinations. It is very common in the oil industry to have pumps running at the same time in parallel or in series.

The process variables are being interpolated linearly with zero order, it is suggested that a cross validation should be done to verify if this interpolation order leads to the best solution.

Another feature that could be useful is the addition of an uncertainty graphical analysis.

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