Validation of Savings Potential Estimation of Valve-Pump Systems

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ABSTRACT

This paper introduces a new method for estimating the savings potential of valve-pump systems. Compared to traditional methods that have been used to estimate energy savings potential for valve-pump systems, the suggested method is more practical because it does utilize on-line flow or pressure measurements. The magnitude of savings potential in the process industry is not always fully understood and this paper gives an overview of that. Another purpose is to validate the suggested method, based on tests run in a laboratory. The error in the estimation is analyzed, and the error sources are clarified.

1 INTRODUCTION

In the process industry, the majority of flow control solutions are based on pumps and valves. From an economic perspective, it may first feel like a waist to use a pump to lift up the pressure, and a valve to reduce it. However, investment calculations have demonstrated that this is often the most economical solution with respect to lifetime costs.

During the process design phase, the pump is easily oversized because there is always a concern that an undersized pump would become the bottleneck of the process. In that case, the pump produces an unnecessary high pressure, which the valve must reduce to a large extent. Such a solution wastes some energy and it might be difficult to reveal by the maintenance organization because it does not, on its own, cause any disturbances to the production. A clear indication of an oversized pump is when the valve opening remains low (e.g. less that 60%) during production. However, a low valve opening does not alone give the magnitude of the savings potential, in terms of electrical energy.

In practice, investment decisions of a production plants, in this case pump modifications, are difficult to justify without assessments of the repayment period. In order to calculate the repayment period, we must know the energy consumption and the assessment of the savings potential. Traditionally such an assessment has required substantial analysis, utilizing process simulations or additional process measurements. However, by using the method that is presented here, which is based on invariants of pumps, valves, and pipelines, we have managed to provide a good approximation of the savings potential based on some elementary pump parameters, and the valve opening during production.

The contribution of this paper is two-fold. First we give an overview of the methods used, and an overall view of the savings potential. Secondly we show some validation results from experiments in the laboratory.

2 SUGGESTED METHOD

A typical pipeline, with a pump, a control valve, and a pipeline is illustrated in Figure 1. The maximal flow q_{max} is determined by the intersection of the pump curve and the system curve. By changing he control valve opening we can control the flow in the range 0-q_{max}.

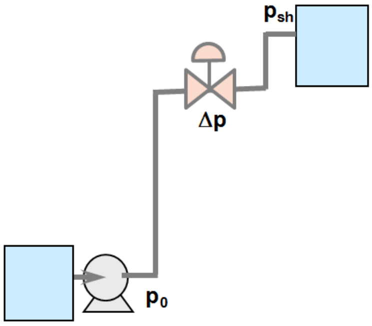

Figure 1. A typical pipeline with one pump and one valve.

The role of the pump is to build up a pressure. Other parts in the pipeline decrease the pressure. The parts that we consider in this paper are: the pressure drop over valve (Δp_v), the pressure drop over pipeline (Δp_p) and the pressure difference due to static head (Δp_{sh}). For a given flow, the pressure over pump equals the net pressure drop in the pipeline. Hence, the pump power is proportional to the net pressure drop, and if we can reduce the pressure drop over valve by opening the valve more we get the pump power ratio between the two pump configurations as /1/

$$\frac{P_n}{P_o} = \frac{\Delta p_{v,n} + \Delta p_p + \Delta p_{sh}}{\Delta p_{v,o} + \Delta p_p + \Delta p_{sh}} \tag{1}$$

Here we have used subscript *n* to refer to new, and *o* to old pump configuration. Other subscripts are *v* for valve, *p* for pipeline and *sh* for static head.

In order to estimate the power savings potential we need to know the actual valve openings during operation (h_o) and provide a new valve opening (h_n), which, in combination with a pump modification, will consume less energy. The new valve opening must be larger than the actual in order to save energy and less than 100% in order to retain the controllability of the flow. Typically we select h_n in the range 70% - 90%.

2.1 Simplifications and Assumptions

Our aim is to estimate the savings potential without access to pressure or flow measurements. Therefore we make the following assumptions in the calculations

1) We assume that the installed system is linear (from valve opening *h* to flow measurement *q*). Linearity is always an objective in the design because it makes PID tuning easier and more robust.

$$q(h) = q_{max} h \tag{2}$$

2) We assume that the pump is ideal and produces constant pressure $\Delta p_{sh} + \Delta p_0$ at all flows. This might sound as a harsh simplification, but we do not have to neglect the pressure drop of pump curve. Instead, we assume that the flow resistance of pump is integrated in the pressure drop of pipeline as a net flow resistance (pressure drop of pump curve + pressure drop of pipeline). Moreover we assume that such a net flow resistance curve is proportional to q^2

$$\Delta p_p = \Delta p_0 \left(\frac{q}{q_{max}}\right)^2 \tag{3}$$

3) Assumption 2 means that net pressure drop (including valve, pipeline, and internal pump resistance) is a constant Δp_0. This means that the pressure drop over valve is

$$\Delta p_{v,o} = \Delta p_0 \left(1 - \left(\frac{q}{q_{max}}\right)^2\right) \tag{4}$$

4) Typically equal percentage valves are used for flow control applications. They have a Cv characteristic that is exponential with respect to valve opening. For simplicity reasons, we assume that the Cv characteristic is proportional to h^2. By using the definition of the Cv value /2/, this assumption implies that if we achieve the same flow with two valve openings, the pressure drop ratio is

$$\frac{\Delta p_{v,n}}{\Delta p_{v,o}} = \left(\frac{h_o}{h_n}\right)^4 \tag{5}$$

With these assumptions, we divide the numerator and denominator in Eq. 1 with Δp_0, and we get the pump power ratio P_n/P_o between modified pump and the original pump as /1/

$$r_P = \frac{\left(\frac{h_o}{h_n}\right)^4 (1 - h_o^2) + h_o^2 + x_{sh}}{1 + x_{sh}} \tag{6}$$

Here we have introduced the static pressure ratio x_{sh} (the static pressure of pipeline Δp_{sh} divided with the maximum pump head). The energy power savings, when the power consumption is P_{po} is then

$$P_S = P_{po}(1 - r_P) \tag{7}$$

Note that the suggested method is rather practical because we, in addition to static pressure ratio x_{sh}, only need to know the valve openings before (h_o) and after (h_n) pump modification. Flow or pressure measurements are not needed in the estimation, which is remarkable in the sense that the power loss for a valve is given by the volumetric flow multiplied by the pressure drop over valve.

3. SAVINGS POTENTIAL

Using Eq. 6-7 we can illustrate the savings potential graphically. If we select the target opening as h_n = 80% we get the savings potential as a function of original valve opening as illustrated in Figure 2. We notice that even for rather typical valve openings, e.g. h_o = 60 %, which are not rare in the process industry, the savings potential is considerable: around 40 %.

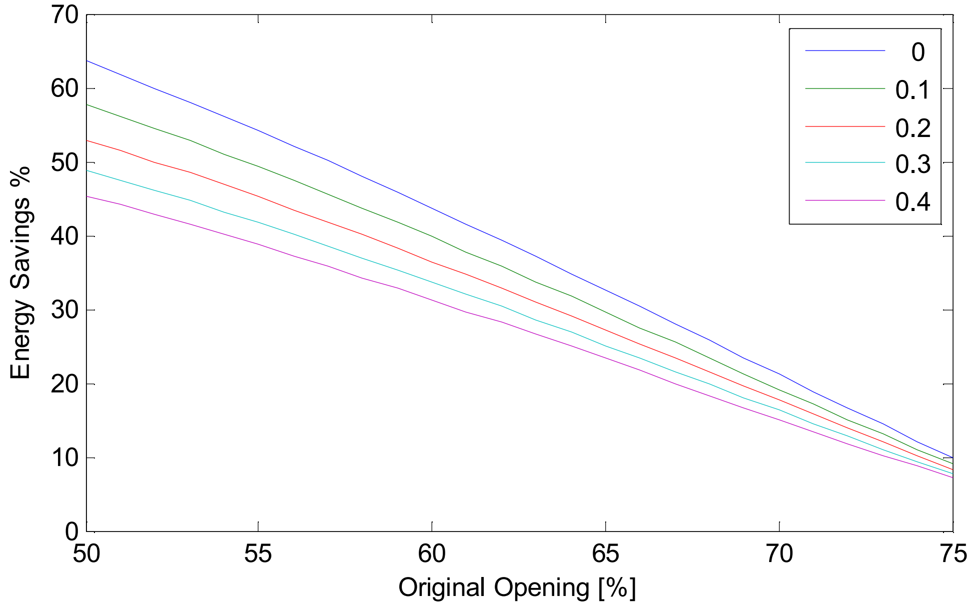

Figure 2. Energy savings potential as a function of valve opening for a valve-pump system when the target valve opening is h_n = 80%. Static head ratio is shown as a parameter.

As an example, consider a large pump (nominal power 500 kW), with an average energy consumption of 300 kW during operation. We assume that the pump is running 75% of the time and that the cost of electrical energy is 40 €/MWh. Then a 40% reduction in pumping energy consumption, would save over 30 000 € annually.

4. VALIDATION

We did some experiments in the flow laboratory in order to validate the accuracy of the pump power ratio estimation. We used two different pumps, both with the ability to modify the rotational speed. Moreover, we used two different pipe sizes, DN100 and DN200. Each test was run in two parts: 1) with high pump RPM's and 2) with lower pump RPM's. During each test we experimented with different valve openings. We collected the necessary measurements, needed to validate the energy savings estimations. Those included flow, valve opening, and pressures before and after control valve. After each test, we studied the interval with similar flow values but different valve openings and pump power consumptions. For each flow value, we registered the valve openings and used Eq. 6-7 to calculate the pump savings. The estimated savings potential was then compared to the measured savings.

There was no explicit power consumption measurement of the pump. Therefore we decided to estimate the pump power from process measurements as volumetric flow times Δp over pump. We are aware that this is not the same as electrical power consumptions as all losses in pump and electrical motor are neglected. However, the efficiency of the pump is expected to be the same even though we modify the rotational speed /3/, and we only need the power ratio at two operating points in the validation, not the absolute values.

5. RESULTS

The results from 7 different experiments, each with 7-11 different flow values are illustrated in Figure 3, where we have plotted real savings vs. measured savings. Different colours refer to different experiments. The results suggest that the method is promising, because most estimation errors are less than 10%.

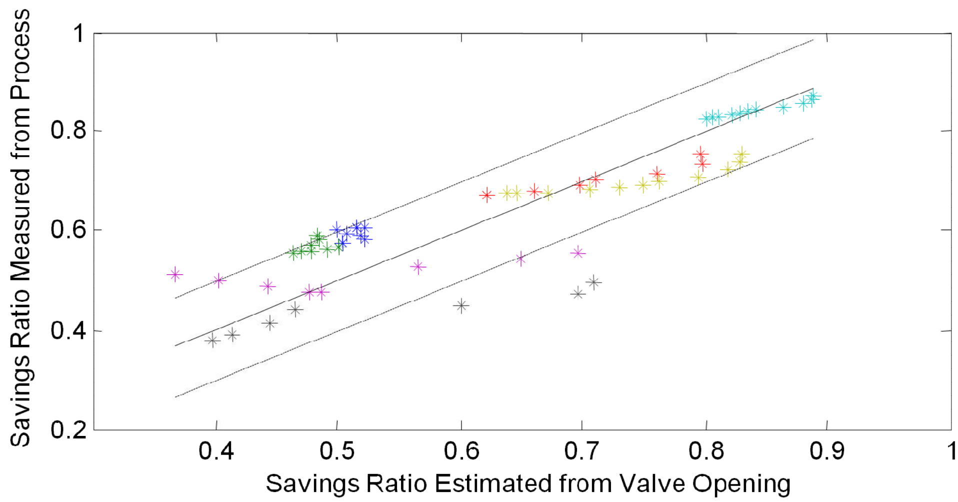

Figure 3. Validation results of savings ratio estimations. Different color values are from different experiments. Estimated ratios are on the x-axis and real (measured) ratios on the y-axis. The dashed lines illustrate the 10% error bands.

5.1 Analysis of Error Sources

The energy savings estimation in Eq. 6 relies on some assumptions. These assumptions are required if we estimate the energy savings without process measurements. In order to understand the sensitivity to errors in these assumptions we calculated the relative errors in some assumptions, and compared them to the errors in the final energy savings estimation. The errors were calculated for the following assumptions

- Linearity (flow is proportional to valve opening) assumption (Eq. 2)
- Valve Δp assumption with original pump configuration: $\Delta p_{vo} = \Delta p_0(1-h_o^2)$
- Valve Δp assumption with new pump configuration: $\Delta p_{vn} = \Delta p_0(1-h_o^2)(h_o/h_n)^4$

The measured errors of these assumptions are plotted in Figure 4 vs. the error in the final energy savings estimation. The plot suggests that the assumed linear relation between valve opening and flow is a major error source (blue symbols in Figure 4). This error is also propagated to the error of original Δp estimation over valve (green symbols in Figure 4), which therefore also correlate with the final estimation error.

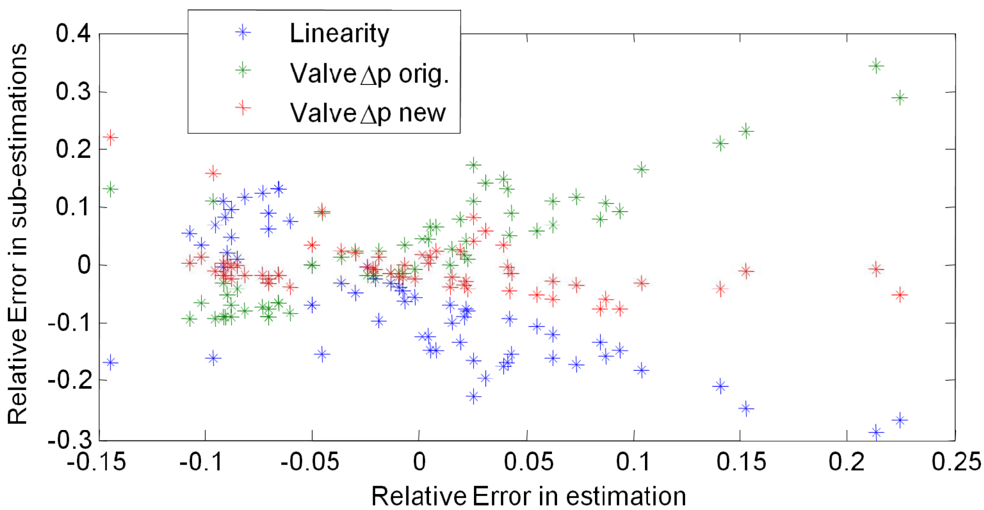

Figure 4. This plot shows that the correlations between errors in the sub-estimations (assumptions) and the error in the energy savings estimation (on x-axis).

6. SUMMARY

In this paper we have suggested a new way to estimate energy savings potential for valve-pump systems. The method is practical because we do not utilize flow or pressure measurements in the calculations.

Moreover, we have shown validation results for the savings potential estimation, which. suggest that the estimated error is usually less than 10%.

Further investigations revealed that a major source of error is because of the assumption that flow is proportional to valve opening of the installed system. The error in this assumption explains why the errors in some estimation exceed 10%. Even though investment decisions seldom require better accuracy than that, we conclude that the results are approximate. Better accuracy can only be obtained with knowledge of measured flow values.

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