Pump-Path Degradation and Specific-Energy Tracking Via Closure Reconciliation Against a Calibrated 1D Hydraulic Model

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ABSTRACT

Energy optimisation of multi-pump stations requires pump-specific energy, yet many installations measure only total station flow. This simulated feasibility study reconciles discharge pressures, pump electrical powers and station flow against a calibrated 1D hydraulic model to identify degradation. Controlled head-curve and pump-efficiency degradations were introduced into one pump of a three-pump intake model. Calibration signatures separated at 45.9°, and validation cases were estimated as closure coefficients indicating mechanism and approximate magnitude. Closure magnitude increased with the affected path's simulated specific-energy deterioration, providing proof-of-concept evidence for identifying degraded pump paths without branch flow as an estimator input.

KEYWORDS: Pump degradation; specific energy; hydraulic model reconciliation; multi-pump stations

1. INTRODUCTION

Deciding which pump is most efficient to run requires pump-specific energy, yet many stations meter only total station flow. Inferring per-pump flow from the characteristic curve carries errors of 7–15% of nominal [1]. This study evaluates whether commonly available discharge pressures, pump powers and station flow can be reconciled with a calibrated 1D hydraulic model to identify inefficient pump paths where individual pump-flow measurements are unavailable [2]. Hydraulic and pump-efficiency degradations were imposed on one pump of a simulated intake system to assess whether closure coefficients could distinguish degradation type, estimate approximate magnitude and track the affected path's specific-energy deterioration.

2. MATERIALS AND METHODS

A three-pump 1D model was simulated at fixed speed and boundary conditions. The observation vector comprised three discharge pressures, three pump electrical powers and total station flow. Hα denotes an α% head-curve reduction and Eβ a β% pump-efficiency reduction [3]. Baseline-normalised changes from H1.0 and E10 formed $S = [s_H \; s_E]$. Validation closure coefficients were estimated using a least-squares parameter-estimation approach [4]: $\hat{c} = arg\,\min_{c} \|\Delta \boldsymbol{y} - \boldsymbol{S}\boldsymbol{c}\|_2^2$, where $\Delta \boldsymbol{y}$ is the normalised observation vector. Coefficient direction indicated the degradation mechanism, while magnitude was relative to calibration severity. Simulated branch flow was excluded from estimation and used only with electrical power to calculate validation specific energy. H1.5, E20 and combined cases tested reconciliation; a final healthy run checked baseline restoration.

3. RESULTS

Figure 1 summarises the reconciliation. The calibration signatures were separated by 45.9°. For H1.5, the expected position was (1.50, 0), while the estimate was (1.27, −0.16), identifying predominantly hydraulic degradation with limited cross-sensitivity. E20 was estimated as (0, 2.25) against an expected position of (0, 2.00). The combined case was estimated as (1.27, 2.01) against (1.50, 2.00),

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demonstrating simultaneous estimation of both mechanisms. Pump 1 specific energy increased from 183.30 kWh/ML at baseline to 192.23 kWh/ML for H1.5, 229.12 kWh/ML for E20 and 240.29 kWh/ML for the combined case. The post-test healthy case reproduced the baseline.

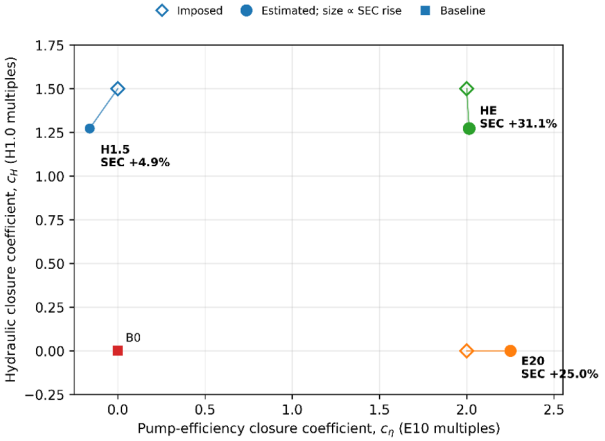


Figure 1. Imposed and estimated closure positions; marker size indicates Pump 1 specific-energy rise.

4. DISCUSSION

The hydraulic and pump-efficiency cases produced distinguishable signatures, and the combined case allowed both mechanisms to be estimated simultaneously. The hydraulic coefficient was underestimated and retained a larger residual, consistent with nonlinear redistribution between parallel paths; the efficiency case was cleaner because it acted mainly through Pump 1 power. Notably, a 1.5% head-curve deficit was detected and correctly attributed. This is well below the 7–15% flow-inference error of curve-based methods [1], and within the few-percent regime relevant to within-station comparison. Closure magnitude increased consistently with the affected path's specific energy in the validation cases.

5. CONCLUSION

Under the tested operating condition, these results provide proof-of-concept evidence for identifying degraded pump paths from commonly available station measurements without branch flow as an estimator input. Model-estimated branch flow and per-pump operational ranking remain future work.

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