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Functioning conditions of the Casale pumping station in Mantova, Italy

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Abstract

This paper aims to analyze data provided by TeaAcque for Casale pumping station in Mantova, Italy. A model based on the affinity laws is used to simulate the behavior of the Casale pumping station where variable speed pumps (VSPs) are installed. Quadratic and cubic polynomial curves are used to fit the pump data given by the affinity laws. Such curves can be used to predict the efficiency when the functioning conditions change. The relationship between the variation in the rotation speed and the efficiency is also derived.

1 Introduction

Variable speed pumps (VSPs), are widely used in water distribution systems because they can vary the functioning conditions more efficiently than fixed speed pumps so as to meet the network requirements. When the system functioning conditions require a change in pump flow and head, the pump speed and characteristic curve vary consequently. In order to interpret the VSP behavior, taking into account the system demand variations and the pump speed variations, a model based on the affinity laws can be used. The model allows to simulate the VSPs curve by means of three dimensionless quantities, depending on the pump speed. Since these relationships cannot take into account the factors that do not scale with velocity, Simpson and Marchi (2013) evaluated the approximation of affinity laws for different pump sizes.

This work comes from a research project involving TeaAcque and the University of Perugia. TeaAcque is the manager of the water supply in Mantova, a town in the north of Italy. TeaAcque provided a set of measures for Casale, one of its pumping station. The purpose of the project is to obtain an analysis of the data acquired at Casale in order to improve the efficiency of the pumping station. A first attempt in the analysis of Casale pumping station is reported in Capponi et al. (2014). A more detailed analysis of the Casale pumping station functioning conditions is presented here. The affinity laws have been used to model the data and fit the pump curves. In particular, a quadratic polynomial has been used to approximate the data in terms of dimensionless head and dimensionless flow, according to Ulanicki et al. (2008). A cubic polynomial has been used for the fitting of the streamflow power and efficiency data. Such curves can be used, for example, to predict the efficiency when the functioning conditions are varied. The relationship between the variation in the rotation speed and the efficiency is also shown.

2 Data collected at Casale pumping station

Data provided by TeaAcque for the Casale pumping station refer to a single VSP working out of the four pumps placed in the station (Fig. 1).

The set of data, provided by TeaAcque for the duration of a week, includes: tank level, h_L (m), pressure at the downstream of the pump, p_{val} (bar), pump flow, Q ($m^3 s^{-1}$), pump speed, N (rpm), input power, P_{att} (kW).

Since local head losses are negligible, with reference to the scheme of Fig. 2, where $z_m = 2.20$ m, to evaluate the pump head, H, the following expression has been used:

$$H = \frac{p_{val}}{\gamma} + z_m - h_L \quad (1)$$

with γ being the specific weight ($N m^{-3}$).

Data of pump head and flow don't lie on a single curve in the Q-H plane, but on several curves (Fig. 3), corresponding to the different pump speeds. Hence, it is difficult to characterize the behavior of the pumping station without a model that takes into account the variation in the rotation speed.

To have a general picture of the pumping station functioning conditions, in Fig. 4 the rate of occurrance of H and Q is shown, i.e. the number of the data collected for a specific range of H and Q values. Two zones with high rate of occurance, that correspond to pairs of values (Q, H) that represent the main functioning conditions of

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the pumping station, can be primarily detected: acting on them, the intervention may be more effective.

3 The model: affinity laws

The dimensionless quantities defined by the affinity laws:

$$C_q = \frac{Q}{N\phi^3} \quad (2)$$

$$C_h = \frac{gH}{N^2\phi^2} \quad (3)$$

$$C_p = \frac{P}{\rho N^3\phi^5} \quad (4)$$

can be used to describe the relationships between the quantities that can be used to analyze VSP data, such as flow, total head and power, and the pump speed (Simpson and Marchi, 2013). In Eqs. (2)–(4), ρ is the density (kg m^{-3}), g is the acceleration of gravity (m s^{-2}), and ϕ is the impeller diameter (m). These three quantities can be used, instead of Q, H and P, respectively, to model the pump curves, thus obtaining a series of mathematical relationships by means of which it is possible to characterize the pumping station.

4 Implementation of the model

In the measurement session, data of pump speed, N, were available. These data allow to apply Eqs. (2)–(4) in order to interpret the pumping station functioning conditions.

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4.1 Pump hydraulic characteristics

Dimensionless pump head, C_h, and flow, C_q, data are on a single curve (Fig. 5). Thus, the quadratic polynomial proposed by Ulanicki et al. (2008) is used to fit the experimental data:

$$C_h = -2.8581 \times 10^4 C_q{}^2 + 0.2274 C_q + 5.7663 \times 10^{-6} \quad (5)$$

It can also be seen that there is a good agreement between the fitting and the experimental data distribution ($R^2 = 0.9967$).

On the same figure, also the pump characteristic curve, supplied by the manufacturer, is plotted. As can be seen, it does not allow to interpret the experimental data. This difference could be explained considering that the pump characteristic curve is related only to one pump, while the dashed characteristic curve takes into account more factors related to the system actual conditions.

4.2 Power

Evaluating the streamflow power, P_{th}, by the following expression:

$$P_{th} = \gamma Q H \quad (6)$$

and scaling this quantity with respect to the pump speed by means of Eq. (4), the dimensionless input power, $C_{p,\,att}$ and the dimensionless streamflow power, $C_{p,\,th}$ can be compared (Fig. 6). The 45° line, the dashed line in Fig. 6, corresponds to ideal conditions and the distance of the data from it measures the energy dissipation. The $C_{p,\,att}$ values are about twice the $C_{p,\,th}$ ones.

If $C_{p,\,th}$ data are plotted against C_q data, the points have a shape that reminds a third degree curve (Fig. 7). Experimental data can be fitted by means of a cubic polynomial, after Ulanicki et al. (2008):

$$C_{p,\,th} = -6.492 \times 10^5 C_q{}^3 + 13.17 C_q{}^2 - 4.883 \times 10^{-5} C_q + 3.294 \times 10^{-10} \quad (7)$$

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Also in this case, the agreement between data and fitting is quite good ($R^2 = 0.9874$).

4.3 Efficiency

The efficiency, η, is a dimensionless parameter that allows to evaluate the performance of the pumping station. It can be calculated as the ratio between the streamflow and the input power:

$$\eta = \frac{P_{th}}{P_{att}} \quad (8)$$

Values obtained by means of Eq. (8) are reported in the η-C_q plane in Fig. 8. Firstly it can be noted that the η values are rarely above 0.6. It must be said that such an efficiency is a "wire to water" efficiency, which takes into account many factors and so it is not surprising to find such values. Secondly, although the data spreading is higher than in the previous graphs, a fitting has been made by a cubic polynomial:

$$\eta = -1.185 \times 10^5 C_q{}^3 + -5.66 \times 10^9 C_q{}^2 + 1.144 \times 10^5 C_q \quad (9)$$

with $R^2 = 0.1596$. For the sake of clarity, both fittings of C_h (Fig. 5) and η (Fig. 8) in terms of C_q are plotted on Fig. 9. These two curves allow to characterize the Casale pumping station in its actual functioning conditions.

5 The effects of the inverter

When the system functioning conditions require a change in pump flow and head, the pump speed and characteristic curve are varied consequently by means of an inverter installed in the system. In particular, the pump speed is adjusted so that the pump works at a chosen pump head value within a certain time slot: this value is usually called "set point". So, for each hour of the day, a set point is determined. Within each

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interval defined by the set points, the pump speed, N, increases with the flow, according to the trend represented in Fig. 10. On the same figure the efficiency values against flow, Q, are plotted. It can be observed that for the lower values and for the higher values of N and Q, η values decrease. By means of this analysis it is possible to predict the behavior of the pumping station in terms of efficiency, for the given set points.

6 Conclusions

When the behavior of variable-speed pumping station has to be analyzed, measurements of pump speed and input power, more than pressure and flow data, can be useful for management purposes. Pump speed data allow to scale hydraulic pump characteristics, i.e. pump head and flow, and to model the pump behavior, in terms of pump characteristic curves, according to affinity laws. In this paper a set of measures from the Casale pumping station is considered, for the duration of a week. The measures are firstly analyzed in terms of pump head and flow, evaluating the rate of occurance, in order to find the main functioning conditions of the pumping station. Secondly, data are analyzed using the three dimensionless quantities introduced by affinity laws. The data in the dimensionless plane C_q-C_h can be fitted with a quadratic polynomial, with a good agreement and there is no correspondence with the design characteristic pump curve. The dimensionless streamflow power, $C_{p,\,th}$ can be expressed in terms of C_q by a cubic polynomial, with a quite good agreement. The streamflow power is also compared with the measured input power: the ratio between these two quantities allows to evaluate the “wire to water” efficiency, η, of the pumping station. The η experimental data show a high spreading and the fitting is characterized by a worse agreement if compared with previous fittings. By means of these elaborations and fittings, the Casale pumping station is characterized in its actual functioning conditions. Trends of pump speed and efficiency against pump flow, if plotted on the same figure, show how the efficiency changes with the variation in the rotation speed, which is related to the setting of the inverter. Combining this analysis with a larger set of data will allow to improve

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the pumping station functioning conditions and so to reduce the costs of the system management. The knowledge of the network could be combined with the results presented in this paper in order to predict the response of the network to any changes in the pumping station functioning conditions.

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Fig. 1. A photograph taken inside the Casale pumping station, with the four pumps in parallel.

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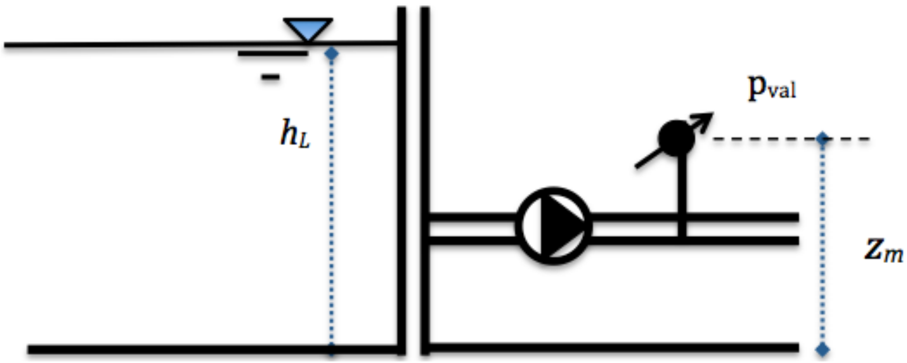

Fig. 2. The scheme of the pumping station.

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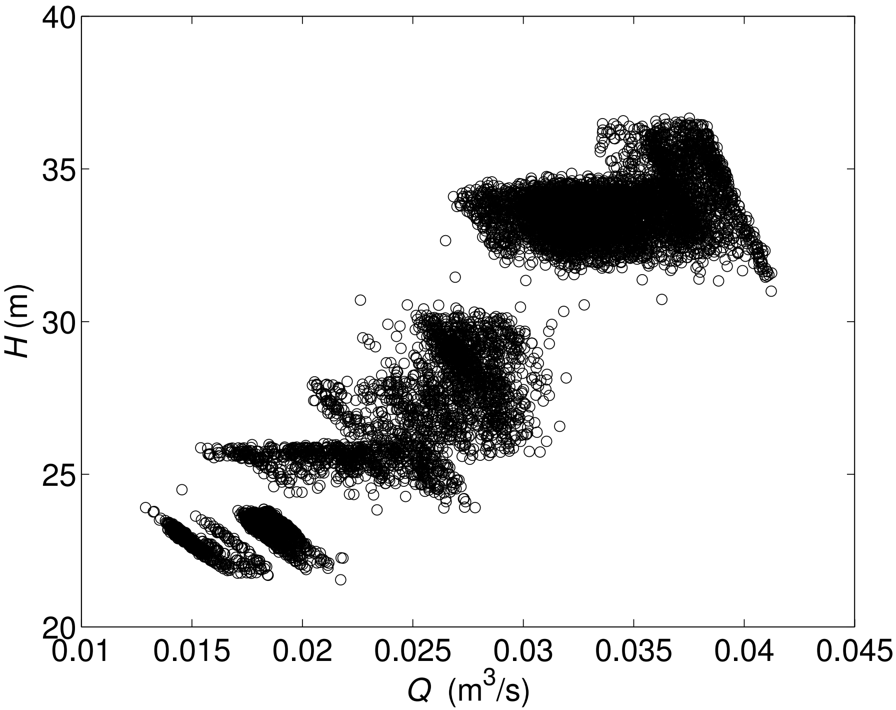

Fig. 3. Plotting of data acquired of pump head, H (m) against pump flow, Q ($m^3 s^{-1}$).

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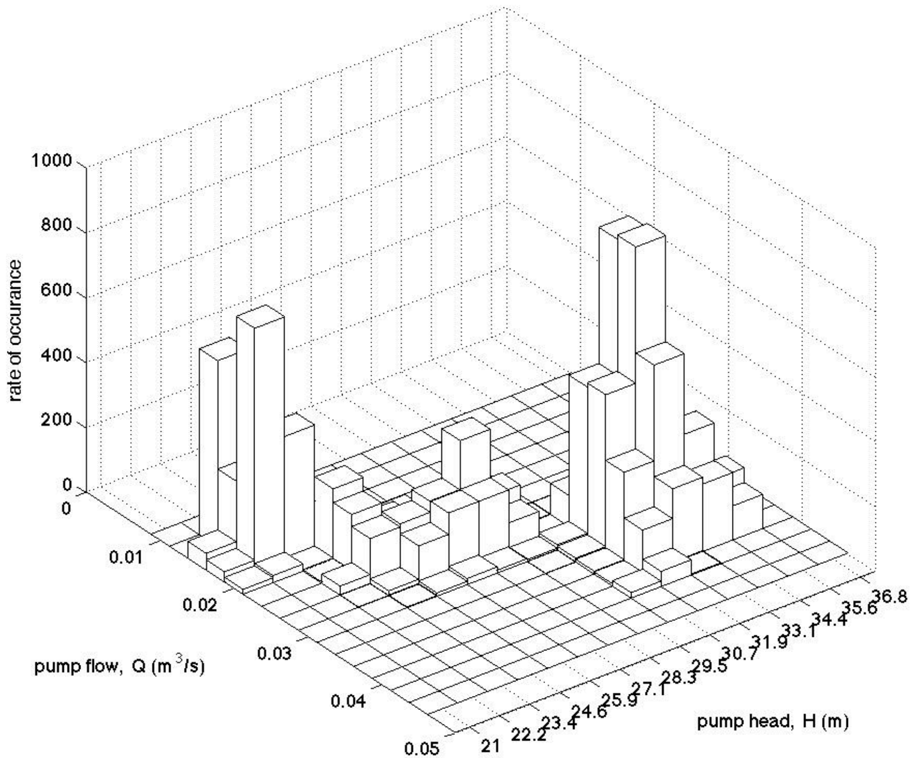

Fig. 4. Histogram of the frequencies with which were measured pairs of *H* and *Q*.

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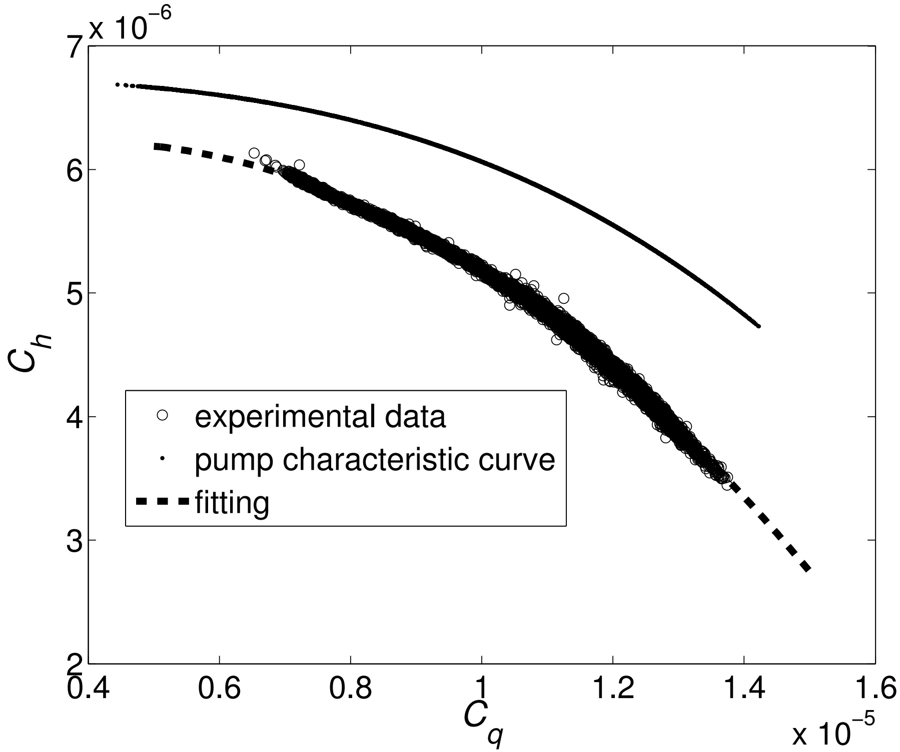

Fig. 5. Experimental data, pump characteristic curve and the fitting made by Eq. (5) plotted in the C_q-C_h plane.

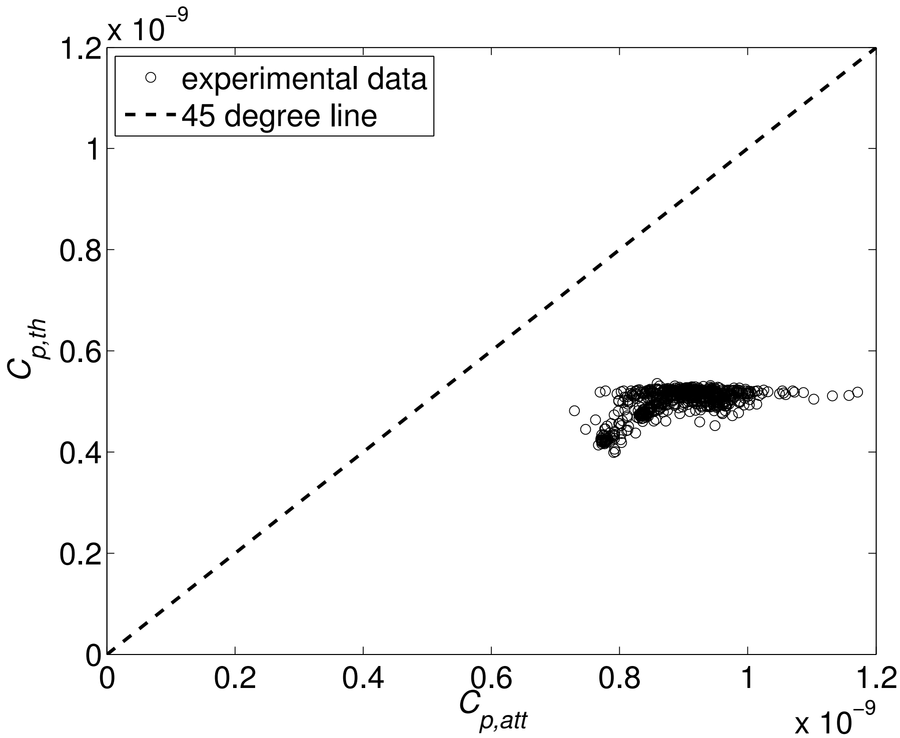

Fig. 6. Dimensionless streamflow power, $C_{\text{p, th}}$ vs. dimensionless input power, $C_{\text{p, att}}$.

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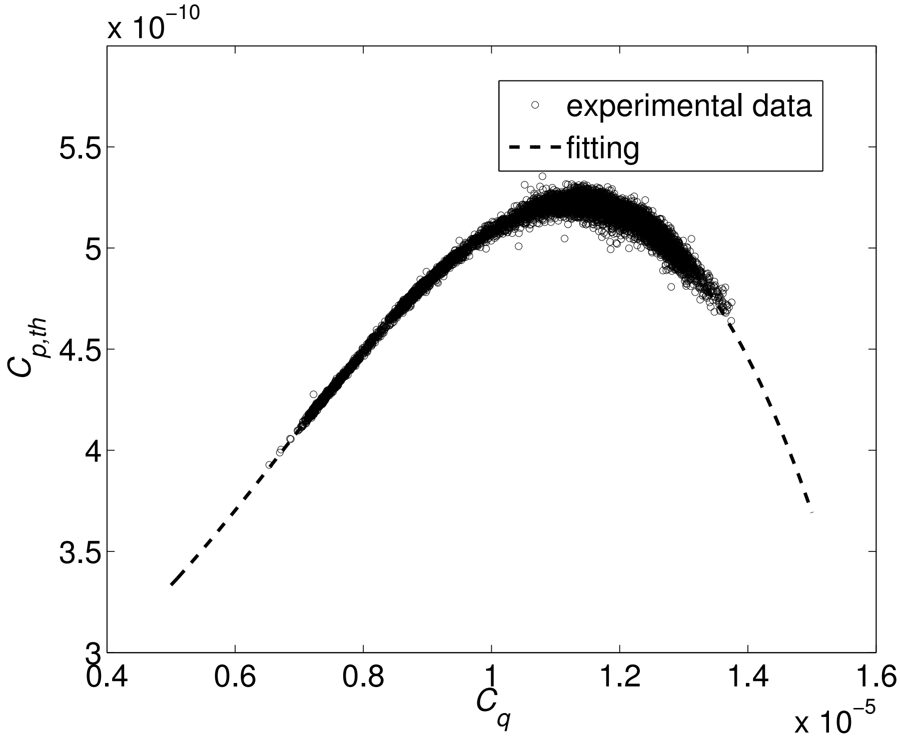

Fig. 7. Dimensionless streamflow power, $C_{\text{p, th}}$, vs. dimensionless flow, C_{q}: experimental data and fitting.

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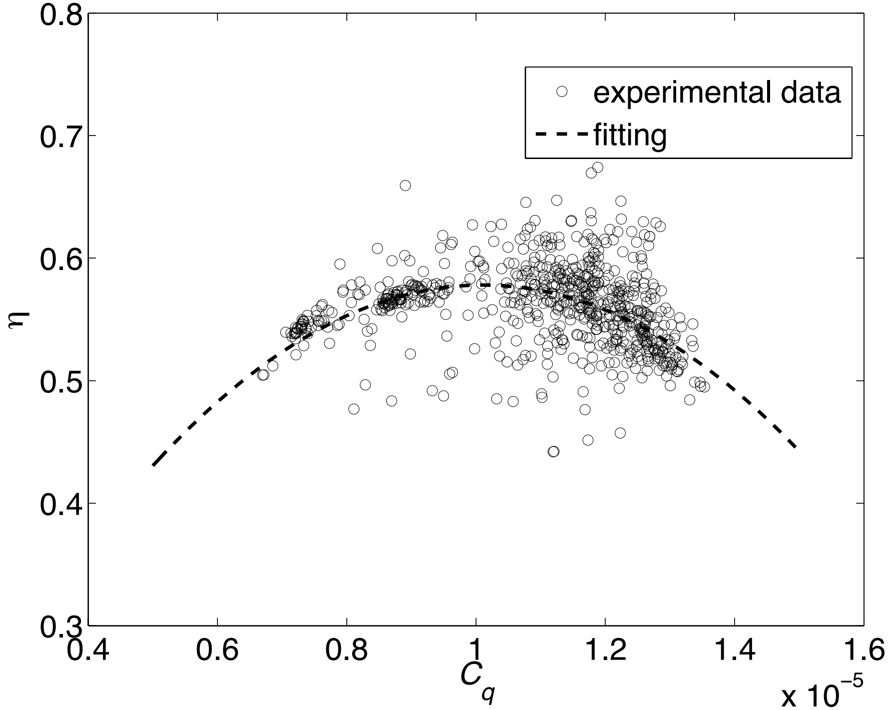

Fig. 8. Efficiency values in terms of dimensionless flow, C_q: experimental data and fitting.

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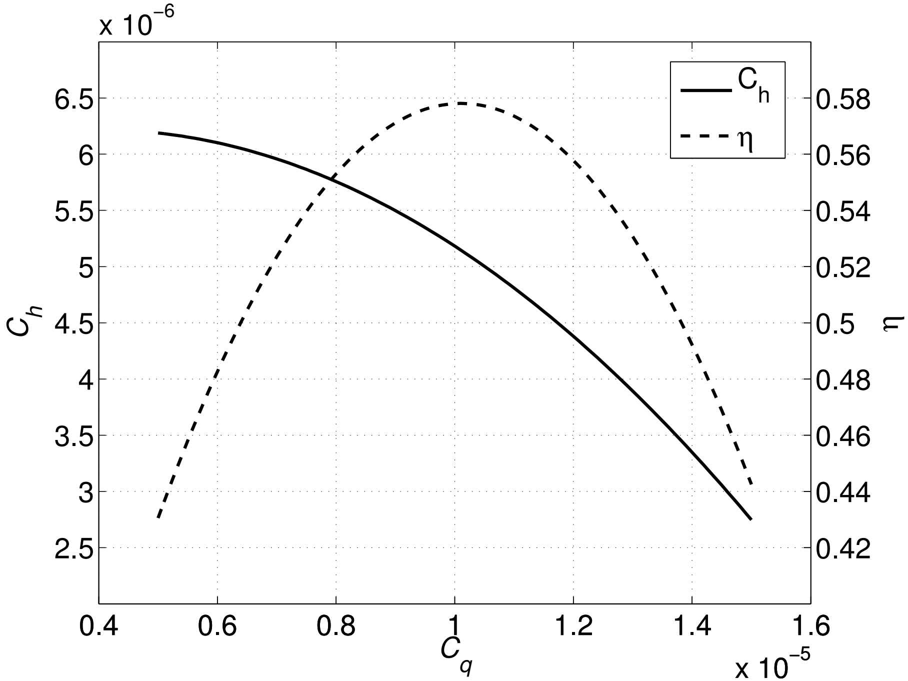

Fig. 9. Fittings of data of Figs. 5 and 8 plotted on the same plane.

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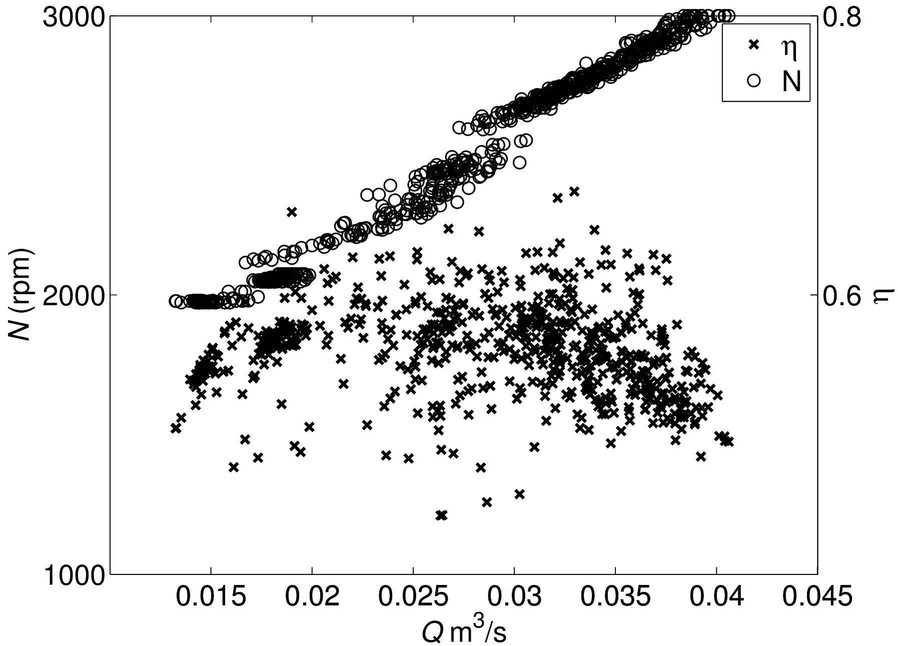

Fig. 10. Pump speed, N and efficiency, η, values against flow, Q.

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