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Discussion of "Losses Reduction and Energy Production in Water-Distribution Networks" by Nicola Fontana, Maurizio Giugni, and Davide Portolano

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The paper under discussion is of great interest, for it simultaneously presents three relevant topics by themselves: (1) the optimal location of valves for pressure management, (2) the importance of pressure management in reducing leakage levels, and (3) the possibility to recover energy using pumps as turbines (PATs). The authors present a complete cost-benefit analysis aiming to determine the convenience of a certain investment. This methodology is applied in a real case, a sector of Naples' water distribution network making the work even more interesting, for although there are many theoretical studies on the topic, real applications are certainly much harder to find in the literature, especially with a holistic approach as the one shown in the paper. The discussers therefore believe that this paper is certainly relevant and the topic well approached.

However, it must be mentioned that some of the presented results are difficult to replicate, as some key data are not provided. This is understandable, as summarizing in a single paper the characteristics of a large network is almost impossible. For this reason, the first part of the paper cannot be fully assessed [e.g., the optimal location of the pressure reduction valves (PRVs)] and the discussion is focused on the water audit and the energy recovery potential from the use of PATs.

More specifically, the discussion deals with two key issues: On one hand the water audit presented by the authors and the ratio between real and apparent losses. This ratio is presented as a fixed figure in the paper, and yet, even the results provided in the paper clearly show that such relationship is variable. This issue has implications in the cost-benefit analysis presented later. On the other hand, the calculations leading to the energy recovery figures can be improved in the discussers' opinion. The use of Suter curves to characterize the PATs and modeling the behavior of the PRV derives in energy saving figures significantly different from the ones obtained by the authors.

Water Audit

The water balance presented by the authors shows a significant amount of water loss (66.8%). This figure, and the other components of the water balance are key to the cost-benefit analysis presented in the paper, and given their importance they deserve some comments:

1. The authors present a breakdown of water loss in 70% real and 30% apparent *according to literature* without further backing this assertion. In the discussers' opinion, the two components of water loss are completely unconnected.
2. It does not seem reasonable to allocate all nodes with the same emitting coefficient C. That somehow contradicts the assumption that leaks are mainly associated to metallic pipes' corrosion (not all pipes are metallic). Additionally it renders leakage independent of pipe length or connection density.
3. The data provided in the water balance (Table 1) could be used as part of a basic water audit balance to determine the performance of the system (Almandoz et al. 2005). In this methodology the global efficiency (η_s) can be disaggregated in metering (η_m) and network (η_n) efficiencies, according to

$$\eta_s = \frac{Q_m}{Q} \qquad \eta_m = \frac{Q_m}{Q - Q_{ul}} \qquad \eta_n = \frac{Q - Q_{ul}}{Q}$$
$$\eta_s = \eta_m \cdot \eta_n \tag{1}$$

where Q is the system input flow, Q_m the users' metered volume, Q_u the uncontrolled flow (the difference between the preceding two volumes $Q_u = Q - Q_m$), and composed of apparent (Q_{uc}) and real (Q_{ul}) losses.

Such a balance has full significance when all consumptions are metered (which is the case of Naples). Taking all into account, and using the figures provided by the authors in Table 2 (shown in italics), Table 1 is obtained

The results from Table 1 enter in clear contradiction of the initial hypothesis, as the ratio between real and total losses (Q_{ul}/Q_u) is not constant. As a matter of fact, the ratio evolves from an initial value of 0.7 to a final value of 0.62, showing that apparent and real losses should not be estimated as a fixed percentage of total water loss.

This problem could be tackled with different methods, such as the minimum night flow method (García et al. 2006), or even analytically if a model is available (Almandoz et al. 2005). Even the statistical analysis of network variables collected daily can provide insight into the matter (Armon et al. 2011).

Potential Energy Recovery Assessment Procedure Presented by the Authors

The main objective of the discussed paper is to assess the amount of energy that may be recovered with the installation of PATs in the system. This is achieved by presenting up to six different scenarios, although only scenario A is analyzed in this discussion.

The energy dissipated by the PRV [Eq. (9)] requires previous knowledge of both the flow rate evolution through the valve as well as the head drop. The numerical consumption pattern of the PRV (Table 2) can be obtained using the average flow through the PRV (323.7 l/s for scenario A, Table 2 of the original paper) and the consumption pattern found in Fig. 6. The paper does not provide details on the pressure evolution upstream of the PRV or its set pressure, and as a consequence the head drop throughout the day is not known. The discussers agree with the fact that the piezometric head upstream of the PRV will vary with the evolution of the San Sebastiano reservoir level (107.7 ÷ 111.7 m), which equates to

Table 1. Variation of the Q_{uc}/Q_u and Q_{ul}/Q_u Ratios for Each of the Proposed Scenarios

Scenario	Q	Q_u	Q_{ul}	Q_m	Q_{uc}	Q_{uc}/Q_u	Q_{ul}/Q_u	η_s	η_m	η_n
0	**340.2**	**226.6**	**157.6**	**113.6**	69	0.30	0.70	0.33	0.62	0.54
A	**323.7**	**210.1**	**141.1**	**113.6**	69	0.33	0.67	0.35	0.62	0.56
B	**321.4**	**207.7**	**138.7**	**113.7**	69	0.33	0.67	0.35	0.62	0.57
C	**307.0**]	**193.4**	**124.4**	**113.6**	69	0.36	0.64	0.37	0.62	0.59
D	**303.3**	**189.6**	**120.6**	**113.7**	69	0.36	0.64	0.37	0.62	0.60
E	**301.1**	**187.4**	**118.4**	**113.7**	69	0.37	0.63	0.38	0.62	0.61
F	**295.2**	**181.6**	**112.6**	**113.6**	69	0.38	0.62	0.38	0.62	0.62

Table 2. Demand Pattern and Head Drop at the PRV (from 0 to 24 h)

Time (h)	0–1	1–2	2–3	3–4	4–5	5–6	6–7	7–8	8–9	9–10	10–11	11–12
Flow (l/s)	220.1	168.3	145.7	145.7	145.7	168.3	259.0	420.8	469.4	462.9	437.0	401.4
ΔHi (m)	9.0	9.4	9.9	10.5	11.0	11.6	12.0	12.4	11.9	11.6	11.0	10.8
Time (h)	12–13	13–14	14–15	15–16	16–17	17–18	18–19	19–20	20–21	21–22	22–23	23–24
Flow (l/s)	385.2	391.7	401.4	382.0	362.5	349.6	339.9	339.9	387.7	385.2	333.4	275.2
ΔHi (m)	10.5	10.1	9.7	9.4	9.1	8.9	9.0	9.1	8.9	8.4	8.4	8.7

neglecting friction in the pipe between both elements. If, additionally, the head drop in the PRV is adjusted so the dissipated energy is the one proposed by the authors (773.2 kWh) the result is 10.4 m. Table 2 also provides the adjusted results, with head drops ranging from 8.4 to 12.4 m, following the hourly variation of the reservoir's level.

Although no explanation is provided as to why three PATs in parallel are selected, the calculations leading to the figure of the potential energy recovery are well detailed. This allows calculating their characteristic curves following Eqs. (5) and (6), which for the NC 150-200 model are

$$H_t = 1,147.40Q_t^2 - 77.97Q_t + 9.68$$

$$P_t = -2,707.66Q_t^3 + 2,402.81Q_t^2 - 126.77Q_t + 0.83 \quad (2)$$

with Q_t in $\mathrm{m^3/s}$, H_t in m and P_t in kW. With a zero flow rate, the power curve [Eq. (2)] provides a positive value (0.83 kW) while the curves in the paper (Fig. 10) provide negative power values for flow rates below $0.05\ \mathrm{m^3/s}$.

Regardless of the head required by the turbines, using the available flow rate (Table 2) with the three PATs working in parallel [with the hourly flow rates from Table 2 and the power curve from Eq. (2)] the energy obtained is 972.3 kWh/day. However, if Eq. (4) is applied, with 70.3% efficiency from Table 4, 937.6 kWh/day are obtained. Despite the fact that the order of magnitude of both values is the same to the figure provided by the authors (821.6 kWh/day) the discussers cannot replicate their results.

Alternative Proposal

Replicating the authors' results shows that the entire flow rate is used in the PATs, which would lead to a lack of guaranteed pressure downstream from the PATs or the PRV. To guarantee a minimum vae, the authors place both elements in parallel (Fig. 11). However, the results from the suggested setup are not modeled or calculated. The discussers have estimated the potentially recoverable energy in this setup using Allievi (www.allievi.net), a transient modeling software of their creation. The additional hypotheses used are:

- The available flow rate is the one provided in Table 2.
- The water level at the San Sebastiano reservoir follows the daily evolution provided in Fig. 4.
- The pipe connecting the reservoir and the VRP has a 1,000-mm diameter (the largest in the system). Friction losses are neglected.
- The energy recovery system is installed at the 79.3-m elevation mark, leaving the entry pressure to the system oscillating between 28.4 and 32.4 m.
- The PRV set pressure is 20 m to guarantee supply pressures at delivery nodes of 25 m or higher.
- With the former values, the pressure dissipated at the PRV oscillates between 8.4 and 12.4 m. Its evolution will be the same as the one shown in Table 2.

Once the problem has been defined the behavior of the PATs is simulated using Suter universal curves (Suter 1996). These curves have been widely referenced and, despite constant improvements (Dörfler 2010) they are currently in full use, covering the whole range of N_s speeds. This procedure seems better suited than the one included by the authors, which is valid only for N_s ranging between 14 and 60 (when the PATs used in scenario A have $N_s = 70$).

Fig. 1 presents the turbine head H_t as a function of the total flow rate with all three PATs installed in parallel, and the head drop at the PRV for each consumption flow rate when the downstream pressure at the valve is set to 20 m. This last curve is obtained from the hourly consumption flow rates and the head drop values at the PRV (Table 2). Fig. 1 also shows the time of day associated to each flow rate value and the corresponding head drop at the PRV and H_t.

The behavior of the by-pass shown in Fig. 11 is also explained in Fig. 1. For consumption flow rates below 272.5 l/s (point where both curves intersect) the PRV will be closed and the full flow will be distributed through the three turbines, and the bypass downstream pressure will be higher than 20 m. For consumption flow rates higher than 272.5 l/s, part of the flow will also circulate through the partially open PRV, maintaining the downstream pressure at a 20 m value. Fig. 1 also shows the flow distribution through the by-pass for the specific cases happening at 0 and 10 h. At 10 h the operating point with only the PATs would be point A, while working in parallel with the PRV it would be point B. This leads the discussers to think that the maximum potential energy recovery, with a constant behavior of the system (constant pressure downstream from the PRV) will be lower than the predicted one.

Using Allievi and with the aforementioned hypotheses, the energy recovery obtained between the three PATs is 166.1 kWh/day,

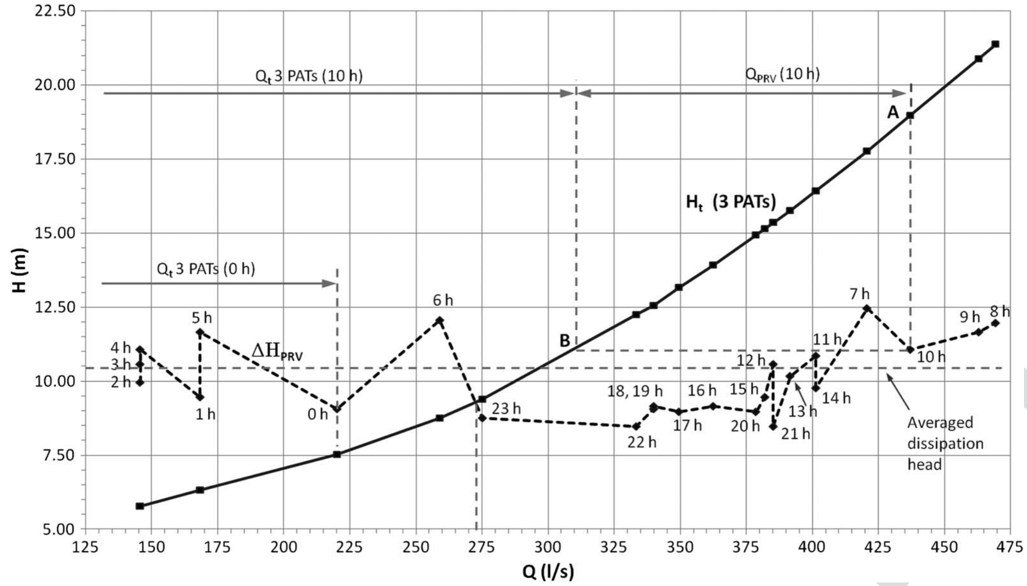

Fig. 1. By-pass behavior (three PATs in parallel with the PRV)

a much lower value than the one suggested by the authors (821.6 kWh/day). This is explained by the fact that for flow rates above 272.5 l/s, the flow is partially derived through the PRV and its energy dissipated, therefore recovering only a part of the energy through the PATs.

With all the flow through the PATs the energy recovery estimated with Allievi is 666.4 kWh/day, a value closer to the one predicted by the authors. However, in this last case, as in the author's calculations, the downstream pressure is no longer maintained.

Final Remarks

The presented cost benefit analysis is surprisingly favorable (the return period for the investment is 2.5 years) especially considering that some Japanese experiences deem this kind of projects not viable without government subsidies (Yano and Kuruma 2008). Although the authors clearly state that these are only preliminary estimations, it does not seem sensible to create higher than reasonable expectations.

The global balance of the paper is very positive. It integrates in an excellent manner the leakage reduction problem and the production of energy by means of PATs. It presents a real case study (with its undoubted added value) and contributes to strengthen a research field with a clear future for it seeks to optimize the use of two key resources. Clearly, once all costs related to urban water (including the environmental ones) are considered, the economic viability of these installations will increase considerably.

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