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Energy potentiality assessment by mean of intelligent pressure management in the hydraulic network of Trondheim

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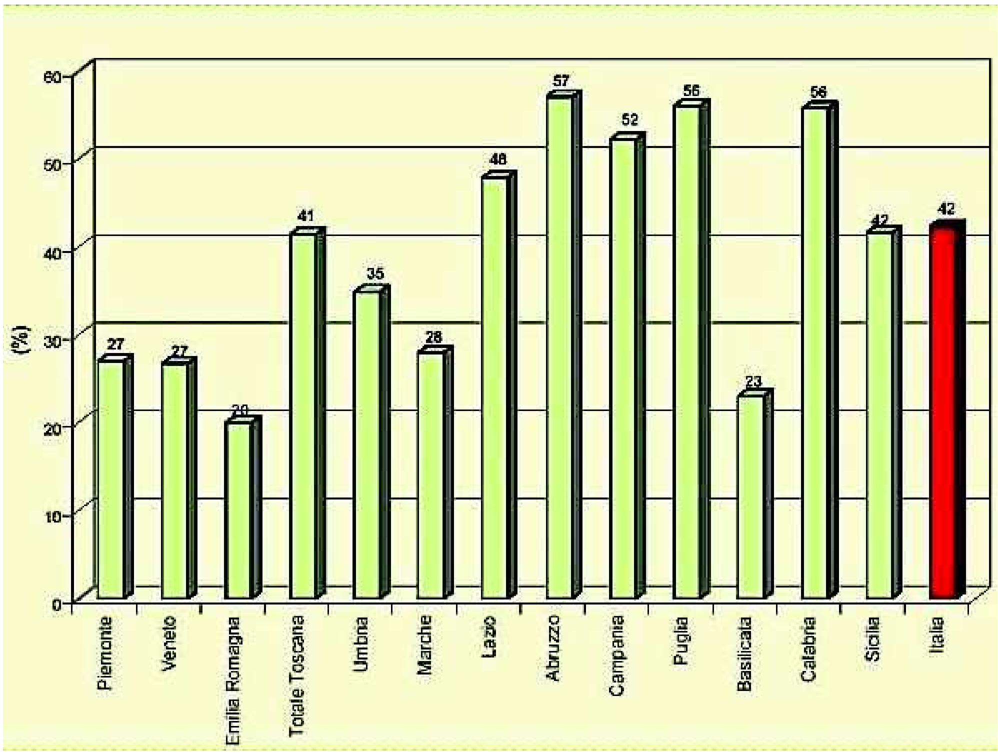
1) INTRODUCTION

1.1) Description of the problem

In the last decade the interest in issues concerning sustainable management of water distribution systems (WDN) has been increasing, aiming at reducing leakage through a pressure management strategy. Control and mitigation of non-revenue water (NRW) are important tasks for almost any urban water distribution system manager, since reducing NRW is equivalent to improving the economical and operational efficiency of the system.

Italy is one of the most water-rich countries, but the population demand of water is not completely satisfied. This is due to the increasing demand but also to structural shortages in management and maintenance. Although water loss occurs in all distribution systems, in many water networks losses are even larger than 30 to 40%, attributable to aging, deterioration of system components (such as pipes and valves), and incorrect management.

Available data about leakage in Italy are contradictory. The Committee for the Vigilance on the Use of Water Resources (2006) stressed that, in Italy, the total water losses calculated by WDS managers ranged between 20–65% (Fig. 1.1), with an average national value around 42%.



(Fig. 1.1 Percentage of leakage in the Italian regions)

In the 2009 Coviri Report, it is stated that the data about NRW are only a rough estimate with a mean annual percentage of the input volume of 29.3% (2004), 30.7 (2005) and 30.9% (2006).

Based on data provided by ISTAT, Italian National Institute for statistics, in 2012 and 2015 the leakage was 35.6% and 38.2% of the input volume, respectively.

As a general demark, whatever data are considered, leakage is a significant fraction of the NRW balance in a WDS, and leakage reduction is therefore a fundamental aspect of NRW management. Leakage means inefficient resource consumption as well as increased risk of pathogen intrusion.

Norway has a particularly high leakage amount compared to other industrialized nations. The Norwegian benchmarking survey bedreVA of 2013, in which 77 of the 428 municipalities -amounting to 60 % of the population- in Norway participated, showed that over half (55 %) of the utilities in the survey had NRW levels above 40 %, and that only 8 % of them had a NRW below 15 % (Norsk Vann, 2013). Data reported from all the Norwegian municipalities show that the total leakage in 2012 was 27.4 % (2013), which is much higher than in the neighboring nations Sweden and Denmark, which have 16 % and 10 % leakage, respectively (Perdikou et al., 2014). Based on the available limited amount of data, in Trondheim the leakage is about 30% of the input volume. Although it may be economically viable to allow such levels of water loss in a nation with abundant water resources, it may still be a politically, socially and environmentally questionable situation.

The aim of this thesis is to study the leakages in the water distribution network of Trondheim (Fig.1.2) and to evaluate the possible energy recovery by mean of intelligent pressure management and PAT (pump as turbines) implementation.

The model of the network was available for this study, implemented in two software (Epanet and WDNetXL). In the original models, the leakages were assumed as constant in time and the dependence on pressure was not considered.

In this study the model has been modified to take into account the dependence of leakage on pressure, moving from demand driven to pressure driven simulations. The pressure driven models allow to verify and test if pressure control for leakage reduction can lead to an energy recovery.

(Fig.1.2 The Scandinavian region. The arrow points out the location of Trondheim)

In fact, one of the simplest measures used to reduce the leakage level is to reduce the pressures (Germanopoulos and Jowitt, 1989). In this case, efficient operating conditions should be guaranteed in time over the network; especially for peak hours demand, in the event of a break in transmission mains, and for fire hydrant service.

Usually pressure control has been done with pressure reducing valves (PRV) which reduce the overall hydraulic capacity by introducing minor head losses. In recent years, the opportunity to combine water saving with power generation was highlighted, replacing PRVs with turbines or pumps as turbines (PATs). Micro (< 100 kW) and minihydro generators (100 kW–1 MW) can be installed in water distribution systems to ensure both pressure control for leakage reduction and energy production. The economical gain introduced by replacing valves with turbines needs an appropriate cost-benefit analysis, to determine how many and which PRVs to replace.

1.2) State of the art

An increasing number of Autor in the last decade addressed the issues related to the use of pumps as turbines (PATs) instead of pressure reducing valves (PRVs).

Fontana et al. (2012) show how PRVs and PATs can be used to pressure control to minimize losses and energy production in the Napoli Est network. Based on their result, pressure management is one of the most effective ways to reduce losses in water distribution systems and PRVs are often used to reduce excess pressure. In (Fontana et al.,2012) a normal PRV dissipates simply the excess pressure while in-line turbines can be used in water systems to combine pressure control and hydropower generation. Given lower costs, PATs can be an attractive alternative to the classic turbines to recover energy.

A simulation model utilizing genetic algorithms was developed to assess the optimal location of PRVs for reducing losses. In a following phase, some or all PRVs were replaced by PATs for hydropower generation. Although PATs do not allow a fine regulation of the head drop, adequate pressure service was still guaranteed. The potential revenues and the water loss reduction were estimated for the case study, showing that a relatively large energy recovery could be coupled to a significant reduction in water loss. The authors also stress that the optimal location of PRVs to reduce water losses does not necessarily maximize energy production. If the recovered energy has to be maximized, a different fitness function should be defined within the optimization process, or a multi objective approach could be used to account for both conditions. A preliminary economic analysis for PATs installation was also developed, showing attractive profits and capital payback period. Obviously, the obtained results should be confirmed by monitoring one or more PATs and comparing numerical simulations using a field survey.

Pumps running in reverse mode can be an effective alternative to using turbines for energy production in WDNs. Many commercial models are readily available on the market and a number of economic and technical advantages for installation, operation and maintenance

can be found. Theoretical and experimental criteria for predicting pump performance in turbine mode and for the optimal installation of a PAT in WDNs can be found in the literature.

Pugliese et al. (2016) consider single-stage and multistage pump trying to understand the reliability of the result published by Derakhshan et al. (2007) who tested in laboratory 4 centrifugal pumps introducing an innovative approach to predict the Best Efficiency Point (BEP) of a PAT and defining procedure to predict the PAT characteristic curves starting from BEP of the pumps functioning in the direct mode.

Carravetta et al. (2012) explain how to replace a PRV with a PAT in the same hydraulic condition. There are two ways to regulate the behavior of a PAT. The first is the PAT installation in a series-parallel combination with valves as represented in Fig. 2.14. The second way consists in an electrical regulation of the rotational speed. The angular velocity of the runner can be changed by varying the frequency of the electric signal by using an inverter. The series-parallel combination system (Fig. 2.14) allows to convert the PRV operating points in PAT operating points. The proposed method is based on the preliminary introduction of an overall plant efficiency defined as

$$\eta_p = \frac{\sum_{i=1}^{n} H_i^T * Q_i^T * \eta_i^T * \Delta t_i}{\sum_{i=1}^{n} H_i * Q_i * \Delta t_i}$$

(Eq.1)

being η_p the overall plant efficiency, namely the fraction of the hydraulic energy that can be transformed in electric energy by the power plant, *n* the number of available operating points, H_i^T and Q_i^T the head drop and the discharge delivered by the PAT, η_i^T the PAT efficiency, H_i and Q_i the available head drop and discharge and t_i the time-interval discretization of discharge-head drop pattern, i.e. the operating points.

Then the following PAT design variable operating strategy (VOS) is suggested:

1. A measured pattern of flow-rate and pressure-head conditions is assigned and
available head is determined based on required backpressure (*BP*);
2. PAT type is considered (e.g. centrifugal, semiaxial.);
3. A wide set of PAT characteristic curves is considered in the PAT operating
region;
4. For each curve the overall plant efficiency is calculated by Eq.2.11;
5. The PAT that maximize, the produced energy, i.e. the PAT having the largest *ηp*,
is considered the optimal design solution;
6. The near-optimal machine is selected from the market and its turbine mode
curves are calculated by Eq.2.12 to verify the actual efficiency.

In order to perform steps 3 and 4, the characteristic and efficiency curves for a whole set of PATs, having their BEPs in the operating region, are necessary (Pugliese et al., 2016).

In the following, after the first chapter of an introductory nature, the second chapter illustrate the theoretical principles related to leakages, pressure reducing valves (PRV) and pumps as turbines (PATs). In the third chapter, a Norwegian case study is presented, with reference to the water distribution network of Trondheim. In the fourth chapter, the results are reported and the conclusion are drawn.

2) ENERGY BALANCE

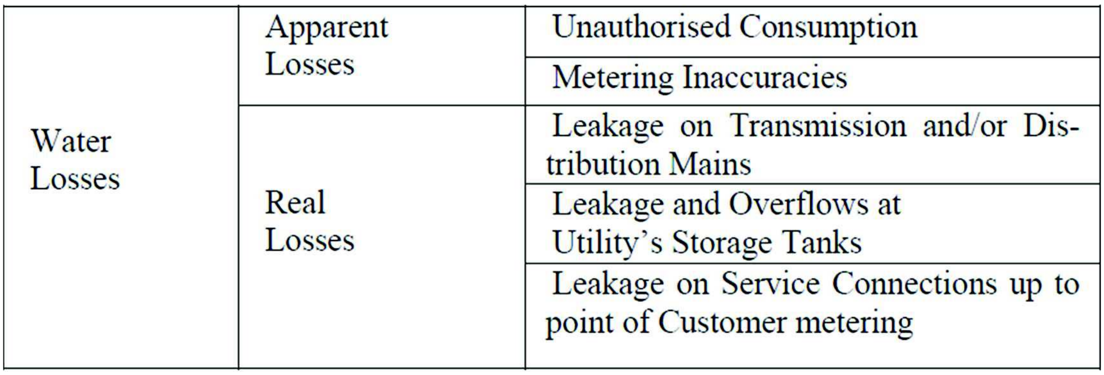
2.1) Energy losses

2.1.1) Leakage

Water is a daily necessary resource for life, health, economic development and the ecosystem all over the world. As water is precious to everyone, its availability and quality are essential. Climate change, droughts, water shortages and population growth are increasing the strain on existing water resources, thereby increasing the necessity to preserve and avoid water wastage through effective management and reduction of water losses. The mains factors that influence the water losses in pressurize pipe systems are type of soil and laying conditions, construction defects and choice of materials used for pipes, presence of a very large number of special parts and equipment of regulation, pipe length and age (in the average, the age of pipes in Italy is 32 years), type and quality of junctions, high pressures and their durations values, stresses induced by external actions such as traffic.

Leakage means water loss but also to energy loss. This second issues is considered in this thesis. Leakages reduce pressures and flow in the system, leading to lower possibility to produce power according Eq.2.9. To use turbines and PATs indicate the volition to gain with energy, so don't waste pressure and flow is fundamental for this process.

According to the standard definition of IWA, we can distinguish losses in apparent Losses and real Losses:



Water Losses	Apparent Losses	Unauthorised Consumption
		Metering Inaccuracies
	Real Losses	Leakage on Transmission and/or Distribution Mains
		Leakage and Overflows at Utility's Storage Tanks
		Leakage on Service Connections up to point of Customer metering

In fact, the term "Losses" means a wide range of problems about water lost. This work is focused on "Leakages on transmission and/or Distribution Mains", so the two terms “Leakages” and “Losses” will be used as synonyms.

The control policies usually consider three activities:

- *Pre-localization by means of water balance, minimum night flow evaluation and step tests*
- *localization (by several techniques) by means* acoustic method, based on the sound waves generated by the spillage of water, optical method through video inspection of empty pipes, method based on unsteady flow through to study of pressure waves, method based on infrared thermography that exploit the abnormalities in the radiation emitted from the surface of the ground, radar method based on GPR where soil saturation, caused by water, reduces the speed of radar waves, tracer gas method where an empty pipe is filled with gas which will exit through the breakage and detected by special tools, magnetic method, ultrasonic system, laser localization system.
- *Reduction.*

(Fig.2 Example of breakage)

As mentioned above, the problem of losses in real hydraulic networks is of primary importance; the reduction of this phenomenon allows a remarkable saving of water, with obvious economic and environmental benefits.

Background leakages are intended as outflows running from small leaking areas (cracks, holes, deteriorated joints or fittings) running from both water mains and connection pipes.

The study of losses starts from the law of Torricelli for steady out flow of an ideal fluid from the orifice on the bottom of a tank

$$Vc=\sqrt{2*g*(h_1-h_c)}$$

(Eq.2.1)

where h_1 is the piezometric head in the tank and h_c is the piezometric head in the section of the vena contracta.

Due to the energy losses in real fluids the flow mean velocity V_c is less than that of Torricelli.

A reduction coefficient (C_v) is introduced together with a second coefficient ($C_c = \frac{A_c}{A}$) depending on the ratio between the area of the vena contracta (A_c) and the opening area (A).

The flow from an orifice can hence be evaluated as

$$Q=C_d*A*\sqrt{2*g*(h_1-h_{GC})}$$

(Eq.2.2)

where $C_d = C_v * C_c$.

On the basis of this, in the past it was assumed that leakage in WDS varies with the square root of the pressures. Following studies have shown that the dependence of losses on pressure cannot be completely described by Eq. 2.2, the classical equation of the foronomia.

This can mainly be attributed to two aspects:

- the coefficient Cd is constant only for a certain velocity range
- for some types of leaks A depends on pressure

As a consequence, leakage can be considered as given by two terms: the first represents the outgoing flow from constant area and the second term is due to the increase in the orifice area due to pressure.

From experiments on artificial losses, in the case of longitudinal cracks it was found that the area varies linearly with the pressure and the flow rate depends on the change in pressure with exponent 1.5; in the case of slot that opens along the two dimensions (longitudinally and radially) the flow depends on the variation in pressure with exponent up to 2.5 (Artina, 2002). In general the relationship between pressure, *P*, and flow, *Q*, in the network can be expressed as (Khadam et al., 1991; Khaled et al., 1992; Lambert, 2000; Milan, 2006)

$$Q^l = \beta * P^{\alpha}$$

(Eq.2.3)

Where the parameters β and α depend on the characteristics of pipe and leak.

Eq. (2.3) is also implemented in EPANET to represent background leakages lumped at network nodes.

The algorithm used in this software to solve the flow continuity and head loss equations that characterize the hydraulic state of the pipe network at a given point in time can be termed by a hybrid node-loop approach. Todini and Pilati (1987) and later Salgado et al. (1988) chose to call it the “Gradient Method". Similar approaches have been described by Hamam and Brameller (1971) (the "Hybrid Method) and by Osiadacz (1987) (the "Newton Loop-Node Method"). The only difference between these methods is the way in which link flows are updated after a new trial solution for nodal heads has been found. Because Todini's approach is simpler, it was chosen for use in EPANET. Assume we have a pipe network with N junction nodes and NF fixed grade nodes (tanks and reservoirs). Let the flow-headloss relation in a pipe between nodes *i* and *j* be given as:

$$H_i - H_j = h_{ij} = rQ_{ij}^n + mQ_{ij}^2$$

(Eq.2.4)

where *H* is nodal head, *h* is head loss, *r* is resistance coefficient, *Q* is flow rate, *n* is flow exponent, and *m* is minor loss coefficient. The value of the resistance coefficient will depend on which friction head loss formula is being used. For pumps, the head loss (negative of the head gain) can be represented by a power law of the form

$$h_{ij} = -\omega^2 (h_0 - r * (Q_{ij} / \omega)^n)$$

(Eq.2.5)

where h0 is the shutoff head for the pump, ω is a relative speed setting, and r and n are the pump curve coefficients. The second set of equations that must be satisfied is flow continuity around all nodes:

$$\sum_j Q_{ij} - D_i = 0$$

(Eq.2.6)

where D_i *(for i=1,...N.)* is the flow demand at node *i* and by convention, flow into a node is positive. In demand driven simulation, the terms D_i are given while in pressure driven simulation these terms are evaluated by means of Eq. (2.3) and depend on pressure. For a set of known heads at the fixed grade nodes, we seek a solution for all heads H_i nd flows Q_{ij} that satisfy Eqs. (2.4) and (2.6).

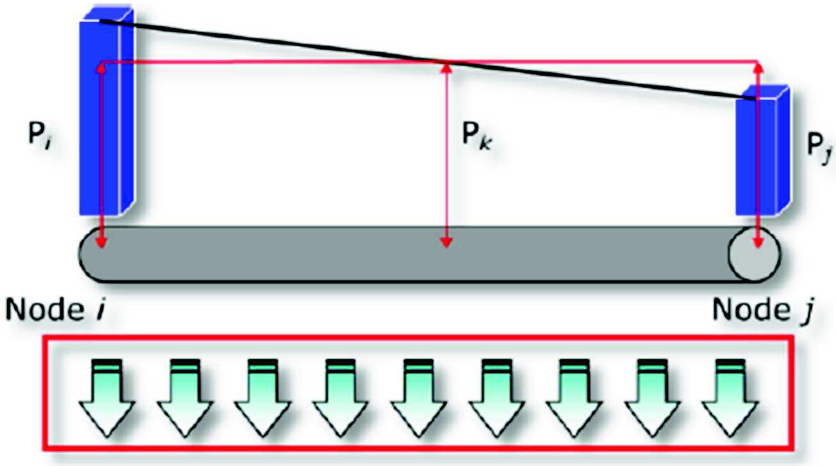
The Gradient solution method begins with an initial estimate of flows in each pipe that may not necessarily satisfy flow continuity. At each iteration of the method, new nodal heads are found by solving the matrix equation:

$$A * H = F$$

(Eq.2.7)

where *A= an (NxN)* Jacobian matrix, *H = an (*Nx1) vector of unknown nodal heads, and *F= an (Nx1)* vector of right hand side terms.

WDNetXL implement an enhanced version of the gradient method implemented in Epanet. Since the location of each single leaking point is unknown, background leakages are represented in WDNetXL models as diffused outflows depending on asset conditions and pressure along the pipes (Eq.2.8). The leakage model implemented in WDNetXL platform (Giustolisi et al., 2008) in based on to the Germanopoulos' formulation (Germanopoulos 1985; Germanopoulos and Jowitt, 1989) and assumes that background leakages outflow ($d_{k,leak}$) from the kth pipe in the network depends on the average pipe pressure on mains ($P_{k,mean}$), according to the scheme reported



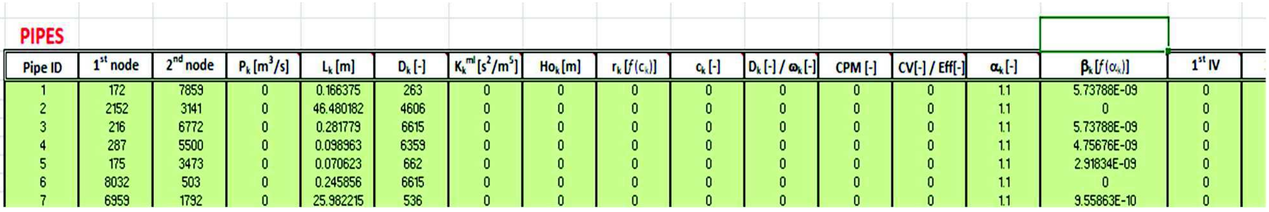
(Fig.2.1 WDNet loss scheme)

$$d_k^{leak} = L_k * \beta_k * (\frac{P_i + P_J}{2})^{\alpha_k} = L_k * \beta_k * P_{k,mean}{}^{\alpha_k}$$

$$P_{k,mean} = \frac{P_i + P_j}{2}$$

(Eq.2.8)

where L_k is the length of the k_{th} pipe α_k, and β_k are two model parameters and $P_{k,mean}$ is the model mean pressure between the end nodes i and j. Indeed, the average pipe pressure is actually the most immediate and technically effective assumption in absence of information about single leaking points. Exponent α_k depends mainly on material representing the deformation response of the leaking holes under pressure. In technical literature the exponent α is reported to vary around values 1.0÷1.2 for a wide range of pipe materials. Considering all the uncertainties surrounding the hydraulic modelling, the exponent α_k can be roughly assumed to be the same for the whole network (i.e α_k=α). Coefficient β_k represents the propensity to leak of the single pipe and might vary within a wider range of variability depending on material, diameter, age and installation conditions. According to Eq. (2.3), background leakages depend on pressure and are consistently computed by pressure-driven analysis in WDNetXL, by setting the parameters α and β for each single pipe, as reported in column α_k and β_k of table “pipes” (an example of the used data is given in Fig.2.2).


PIPES

Pipe ID	1^{st} node	2^{nd} node	P_k [m^3/s]	L_k [m]	D_k [-]	K_k^{ml} [s^2/m^5]	Ho_k [m]	r_k [$f(c_k)$]	c_k [-]	D_k [-] / ω_k [-]	CPM [-]	CV[-] / Eff[-]	α_k [-]	β_k [$f(\alpha_k)$]	1^{st} IV
1	172	7859	0	0.166375	263	0	0	0	0	0	0	0	1.1	5.73788E-09	0
2	2152	3141	0	46.480182	4606	0	0	0	0	0	0	0	1.1	0	0
3	216	6772	0	0.281779	6615	0	0	0	0	0	0	0	1.1	5.73788E-09	0
4	287	5500	0	0.098963	6359	0	0	0	0	0	0	0	1.1	4.75676E-09	0
5	175	3473	0	0.070623	662	0	0	0	0	0	0	0	1.1	2.91834E-09	0
6	8032	503	0	0.245856	6615	0	0	0	0	0	0	0	1.1	0	0
7	6959	1792	0	25.982215	536	0	0	0	0	0	0	0	1.1	9.55863E-10	0

(Fig.2.2 Table Pipe,WDNetXL)

2.1.2) Pressure control

As previously mentioned, the common methods to control and to contain the hydraulic losses are:

- control of the "piezometric surface" in the distribution network,
- leaks location
- rehabilitation and remediation of deteriorated pipeline.

Control of pressures in the hydraulic network, assuming proper of values is an important tool to reduce leakages. The pressure control strategies are mainly based on the introduction and regulation of control valves in a distributed way in the network, in order to reduce service pressures to the lowest values that allow the complete satisfaction of the consumers' demands.

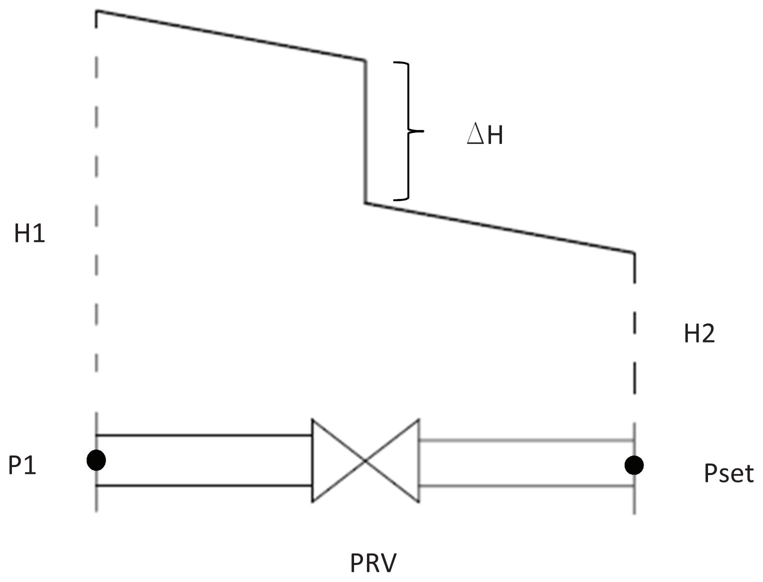
The network is designed to guarantee the service also during the periods with the minimums values of pressure corresponding to maximum water demand. In the other hours, the pipes are subject to pressure greater than necessary.

PRVs are usually installed at the inlet of a District Meter Area (DMA), so as to reduce pressure level and consequently water losses across the district. At critical nodes the pressure head should be monitored and kept greater than the minimum value required to fully satisfy the nodal demand. Such nodes can be identified by means of pressure measurements or numerical models, whereas the minimum pressure to be ensured is assessed based on the network characteristics (e.g., building elevation, pipe characteristics, user requirements, etc.). Since PRVs dissipate excess head, pressure regulation can be coupled with hydropower generation by means of turbines or Pumps As Turbines (PATs).

The aim of any pressure control strategy should be that of minimize the piezometric heads but satisfying the pressure at the customers connections in any moment. It exists a particular pressure level named target pressure level (Sterling e Bargiela, 1984) that it consisted to have in each node only the pressure needed for that correspondent demand. Obviously, we can have this optimal level only in few nodes of the net and, in general, the pressure will be greater in the other nodes.

There are many methods to reduce the pressure level such as reduce pump head system destructuralization in zones with same pressure, insertion of regulating valves etc. In particular we can use the valves when we must consider the daily pattern variability of the demand. The implementation of this pressure control system can lead to important losses reduction as an example following the procedure outlined in (Miyaoka, 1984; Germanopoulos e Jowitt, 1989) based on the determination of the valves optimal localization and then in the determination of the optimal regulation of the same valves.

A normal PRV is a particular device that fix an assigned pressure in the downstream node (Pset).:



(Fig.2.3 PRV scheme)

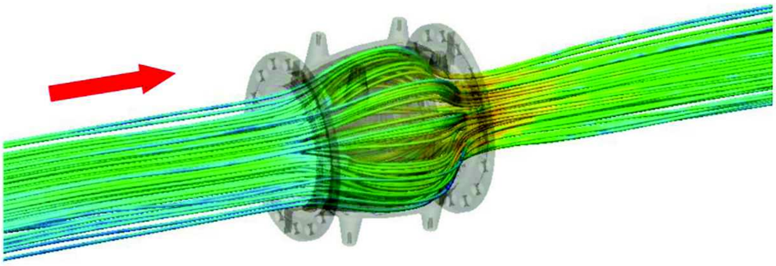
∆H is the pressure that the valve dissipates to allow reaching the Pset.

The goal of this thesis is to understand if it is possible and convenient to install a PAT To convert ∆H in power and don't waste it.

The main problem of normal PRVs is that being static devices or with a degree of fixed opening, the Pset reached will never really be the desired value but when the conditions in the network vary, it will also be very different at certain times of the day. Because of the head losses within the WDN (water distribution network), static regulation of the PRV is unable to minimize water losses, unless the monitored node is located just downstream of the valve. Head losses may vary according to space and time distribution of water demand. Consequently, the set point pressure of the PRV has to account for the head loss between the valve and the monitored node (Germanopoulos, 1995), which results in excess pressure during night hours and, generally, far from peak hours.

Since the condition inside the network change continuously, dynamic and real-time network pressure regulation could clearly help reduce leakage by adjusting the system to the time and space varying operational conditions. A simple and effective way to achieve such regulation is by real-time control (RTC) techniques (Schütze et al. 2004), which have been extensively adopted in the field of urban drainage systems during the last decades (Schilling 1994). Valve settings can be adjusted in real time according to time varying pressures at network nodes; in particular, at each time step, specific probes acquire distributed pressure measurements in the network; acquired data are then transferred to logic controllers which evaluate the valve settings to guide system pressures to the desired set-point values.

A possible valve for pressure control are the spindle valves (Fig.2.4). The spindle valves are mainly designed to regulate the flow or pressure of water in a pipeline. This adjustment takes place by means of the axial displacement of a cylindrical shutter driven by a crank-link-crank mechanism. The obturator, whose seal is in an area protected by the flow, closes following the direction of flow and moves in a suitably profiled compensated pressure chamber. These characteristics give the valve a smooth, stable and vibration-free operation in all operating conditions. The flow of water is channelled into a circular crown-shaped passage that progressively decreases from the inlet section to the seal seat, directing the flow of liquid to the centre of the pipe downstream of the seat. This particular design allows the cavitation to be removed from the walls of the pipeline.



(Fig.2.4 Spindle valve)

2.2) Energy recovery

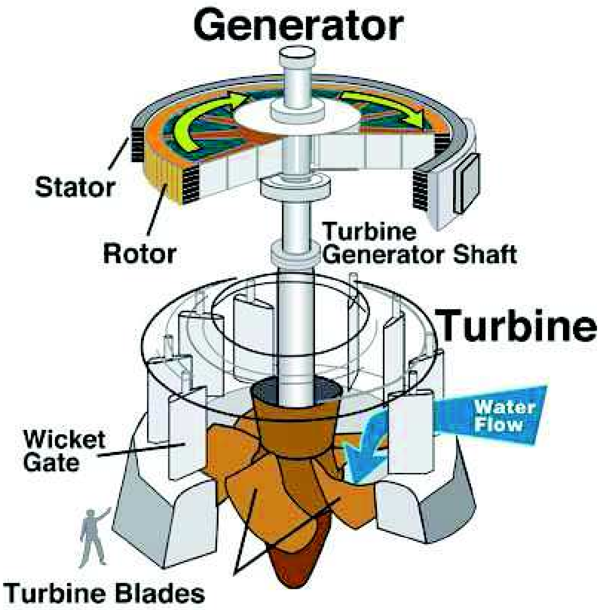
2.2.1) PATs and turbines

Nowadays, the world energy requirements depend for over 80% on non-renewable sources that, in addition to the problem linked to regeneration, have the disadvantage of introducing into the atmosphere such as CO2 (anhydride) carbon) that contributes to the progressive warming of the planet for the so-called greenhouse effect.

Non-renewable energy sources are represented by fossil fuels originating from the transformation of organic matter (coal, oil and natural gas) and minerals for the production of nuclear energy (uranium and plutonium).

The energies coming from sources that regenerate at the speed with which they are consumed (so they can be considered inexhaustible on the scale of human time), in general they are called renewable. The latter is spreading thanks to their minimal environmental impact.

The production of hydroelectric energy is based on the transformation of the potential energy, possessed by a certain mass of water at a given altitude, in kinetic; this kinetic energy is eventually transformed into electrical energy by means of an alternator coupled to a turbine:



(Fig. 2.5 Turbine scheme)

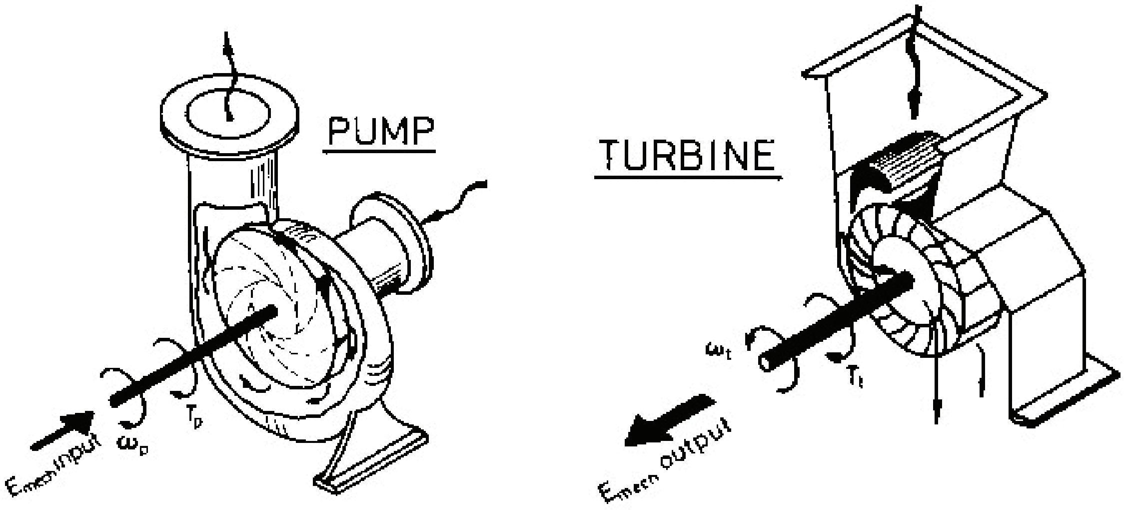
The power of a hydroelectric plant represents the electrical energy produced by the turbine referred to the time unit. The net power can be expressed by the formula

$$P = h^{*} g^{*} Q^{*} H$$

(Eq.2.9)

where *P* [kW] is power, *h* is global efficiency of the turbine-alternator group, *g* is specific weight of water (*9,806 kN/*m^3*),* *Q* [m^3/h] flow rate H[m] water pressure available to the machine.

For energy production, it is possible to use classic turbines or pumps used as turbines (PAT) as in our case. The term PAT identifies a pump that works in reverse mode and hence such as a turbine. The operation of a PAT is obtained by feeding the pump from the delivery flange and unloading the turbinated flow from the suction flange so as to behave in a similar way to that of a turbine:

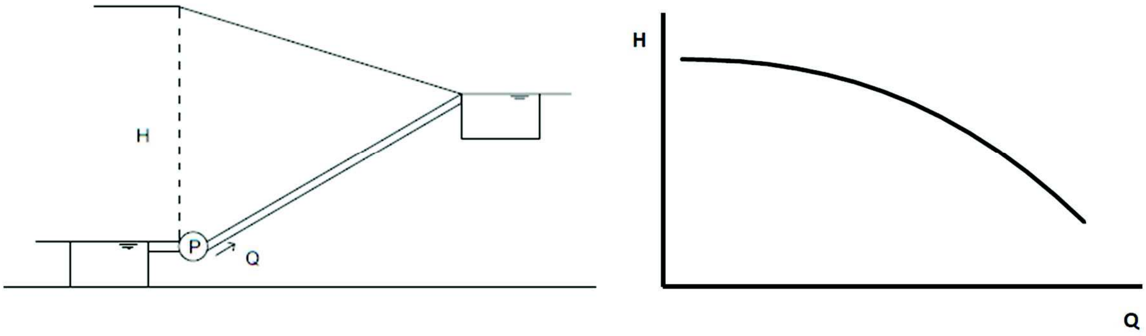


(Fig. 2.6 Difference between pump and PAT)

The pump impeller is not designed to operate in the opposite direction; for this reason, a PAT can be less efficient than a well-designed turbine. The main defect of a PAT consists in the fact that, due to the lack of a flow control device, it is required that the flow rate is fairly constant. Despite this, there are also considerable advantages that lead to the use of these devices:

- the investment costs of the PATs may be 50% lower than those of a comparable turbine
- the absence of a flow control device, usually perceived as a disadvantage, is at the same time an advantage, since, in this way, the construction of the pump is simpler and more durable over time, since its use is required for a wide range of applications (irrigation, industry, water supply)
- standard pumps are readily available (with short delivery times)
- manufacturers and their representatives operate worldwide. In addition, spare parts are readily available, as the major pump manufacturers offer services even after sale in almost all over the world
- no special equipment and special skills are required for Maintenance

The operation of a rotating hydraulic machine depends essentially on the speed of rotation and the flow rate that flows through the machine. The pumps transfer power to the current, raising the piezometric height. The pump operating conditions are described by the characteristic curve, which links the pressure head H to the flowing flow Q:



(Fig. 2.7 Characteristic curve of the pump)

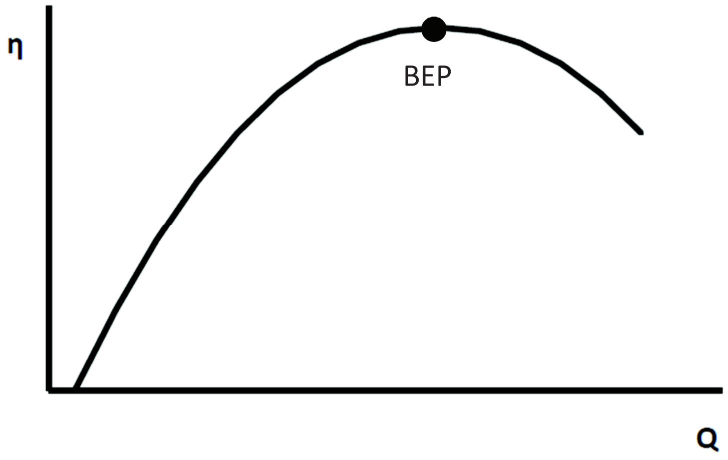
The ratio between the power transferred to the flow and the power supplied to the impeller constitutes the hydraulic efficiency of the pump

$$\eta = g * H * Q / P$$

(Eq.2.10)

Where *Q* is the circulating flow rate, *P* the power transferred from the engine to the impeller, *H* the head*, γ* the specific water weight.

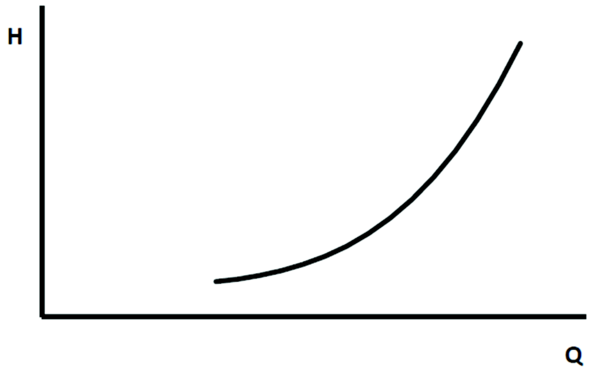
The efficiency is not constant throughout the flow range, but the curve that describes the trend reaches a maximum at a specific value (Best efficiency Point):



(Fig.2.8 Characteristic curve η*-Q)*

By reversing the direction of rotation of the impeller and the direction of the flow flows, the turbomachinery can operate as a turbine. The water flow transfers part of its power to the impeller through a lowering of the piezometric head. The impeller, in turn, connected to a generator, makes it possible to produce electricity.

The characteristic curve that describes the head drop generated by the turbine (H_t) as a function of the flow (Q_t) is the following



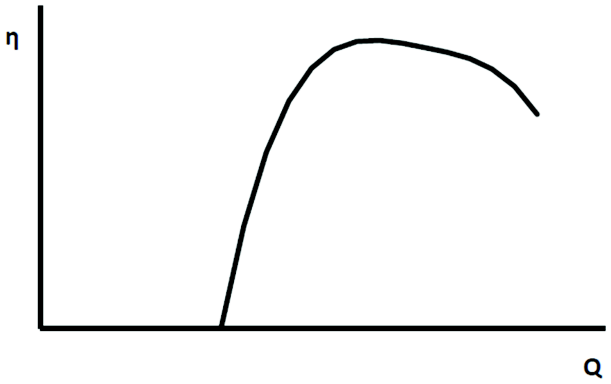
(Fig. 2.9 Characteristic curve H-Q PAT)

The efficiency for turbine operation is defined inversely

$$\eta = {P}/{g} * H * Q$$

(Eq.2.11)

The efficiency of a turbine also varies with the flow rate and its performance is described qualitatively by graphs below

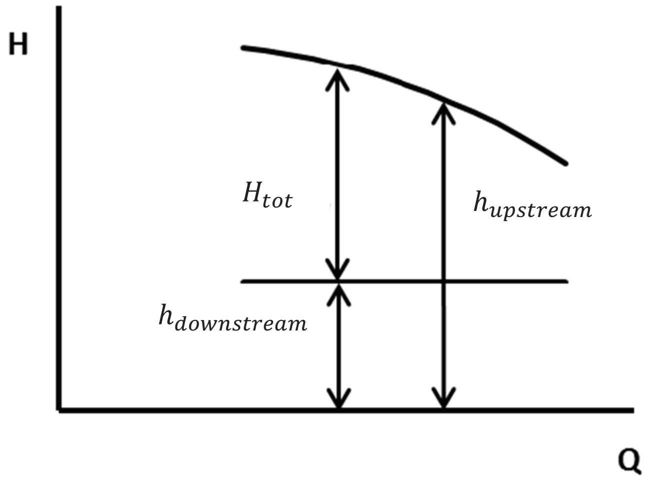


(Fig.2.10)

The determination of the prevalence and efficiency curves is the main design problem of a hydroelectric plant with PAT as show later.

The pumps are generally supplied with an asynchronous electric motor, which in the case of reverse operation works as a current generator. Without going into the details, the asynchronous generators only work if they are connected to the electrical network, which provides an excitation current that generates two magnetic fields (stator and rotor) that rotate the machine: if to the rotor sufficient mechanical energy is provided to create an hypersynchronism between the rotor magnetic field and the stator magnetic field which results in an electrical energy production. About asynchronous engines, also for this type of generator the rotation speed depends only on the frequency of the network and the number of poles, while it is independent of the supplied mechanical power and the electric power generated. The performance curves of this kind of machines, therefore, are characterized by a fixed rotation speed, which corresponds to that imposed by the frequency of the electric network.

The water pipeline network conditions can vary in time at daily, weekly or yearly scale. Ip.) An automatic pressure regulation valve placed inside a water network fix the pressure value downstream whatever the value of the pressure upstream of the valve. The values of flow and pressure upstream of the valve are generally arranged around a decreasing monotonic curve. The difference between the piezometric elevation (h) upstream and the value set downstream represents the useful head drop (H) which can be converted into energy by inserting a PAT.



(Fig. 2.11)

In a system of energy recovery in a water pipeline network, it is necessary to choose the machine that allows to optimize the overall efficiency and to pursue this goal it is necessary to know the characteristics of the machines.

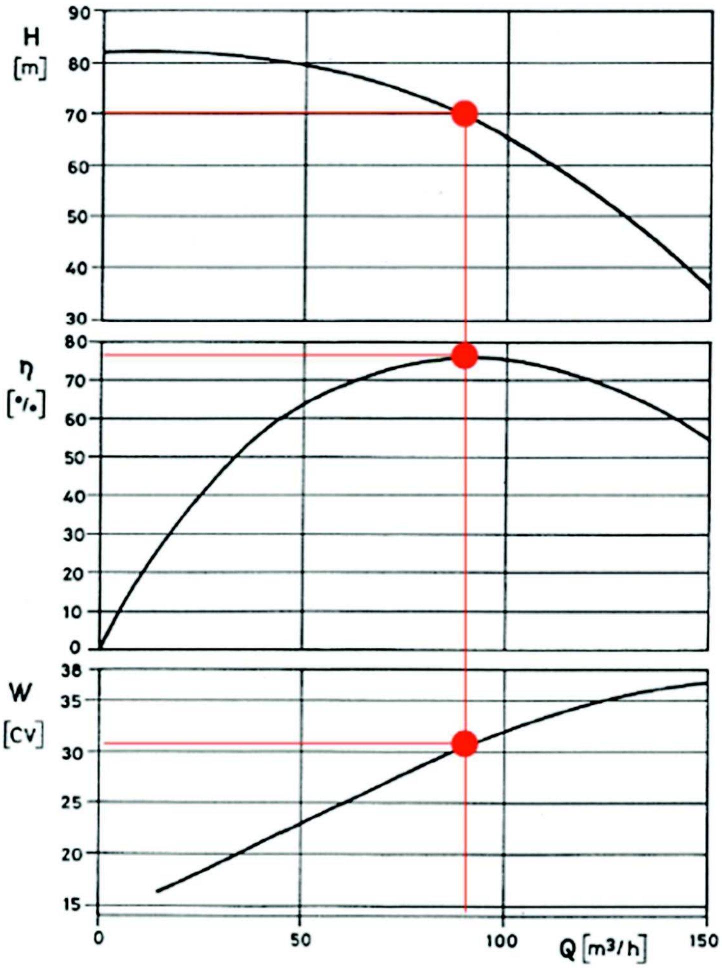
The Pumps are characterized by two main physical quantities

- Head: energy for unit of mass that the pump can supply to the liquid
- Flow: volume that crosses the section in a certain time

The curve represents the hydraulic features about the machine. We can have three kinds of graphs (Fig.2.12):

- H-Q
- Efficiency n- Q
- Power W- Q

the point with higher efficiency is called Best Efficiency Point (BEP)



(Fig. 2.12 Best Efficiency Point)

If for the pumps it is easy to obtain these data from the manufacturer, for the reverse mode (PAT) it doesn’t. In the chapter 3 we will see how this can be done.

2.2.2) PATs in water distribution systems

PATs are suitable for applications where pressures are reduced by PRV. The power generated can be used by the water distribution manager for internal purposes or can be delivered to the public network. Thanks to the low investment cost, PATs repay shortly time.

There are various ways to install a PAT, depending on the needs.

- If the system is operated at a constant speed, the right PAT is selected for a given flow rate and head. For different operating conditions, additional pressure reduction or by-pass elements will be provided. The PAT system is technically simple, easy to manage and above all, extremely cheap.
- Variable speeds allow the operator to fully utilize the existing energy potential. In this case a frequency variator is used to properly energy.
- A last alternative adoptable relative to the flow rates in the network are the PATs in parallel. Parallel operation is an excellent mode to fully exploit the energy potential, in particular, as the flow varies. It is about dividing the total flow between the different PATs operating in parallel at fixed speed.

For the planning, the first operative problem has to be understood is how to find the characteristic curves of the PATs starting from those of the pumps. Pugliese (2016) proposed three equations

$$\frac{H_t}{H_{tb}} = 1.0283\left(\frac{Q_t}{Q_{tb}}\right)^2 - 0.5468\left(\frac{Q_t}{Q_{tb}}\right) + 0.5314$$

(Eq.2.12)

$$\frac{P_t}{P_{tb}} = 4.000^{-3}\frac{Q_t}{Q_{tb}}^{3} + 1.386\frac{Q_t}{Q_{tb}}^{2} - 0.390\frac{Q_t}{Q_{tb}}$$

(Eq.2.13)

$$\frac{n_t}{n_{tb}} = \frac{4 * 10^{-3}(\frac{Q_t}{Q_{tb}})^3 + 1.386(\frac{Q_t}{Q_{tb}})^2 - 0.390(\frac{Q_t}{Q_{tb}})}{1.0283(\frac{Q_t}{Q_{tb}})^3 - 0.5468(\frac{Q_t}{Q_{tb}})^2 + 0.5314(\frac{Q_t}{Q_{tb}})}$$

(Eq.2.14)

Where *Q* is the flow within the system, P_{tb},Q_{tb} , H_{tb}, *h*tb are power, flow, head and efficiency in the BEP and ht, H_t, Q_t e P_t are the unknowns values.

To use the equations, we have to know the BEP values of the PATs but usually only the values corresponding to the direct, pump, mode are available. To do this Pugliese et al. reviewed some formulas. We used that of Yang et al.

$$\frac{Q_{tb}}{Q_{pb}} = \frac{1.2}{{n_p}^{0.55}}$$

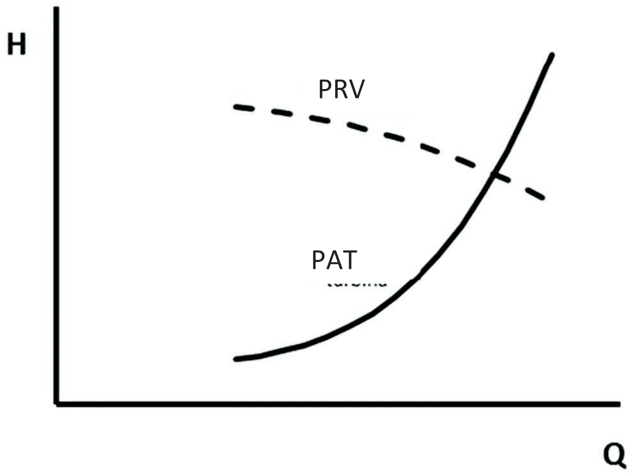
(Eq.2.15)

$$\frac{H_{tb}}{H_{pb}} = \frac{1.2}{{n_p}^{1.1}}$$

(Eq.2.16)

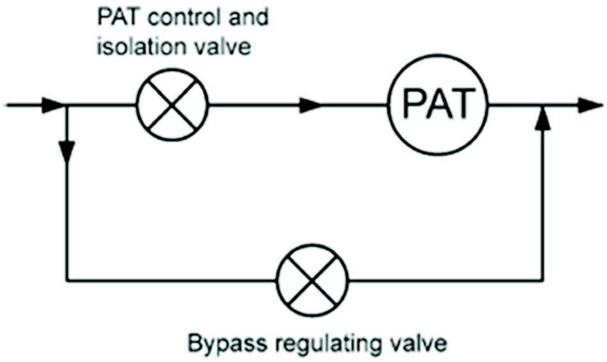
Where Q_{pb} and H_{pb} are the pressure and flow in the BEP in normal mode (pump), hp is the efficiency in normal mode.

Considering in the same (H,Q) plane both the PRV operating condition in time (24h) and the PAT characteristic curve, a completely different behaviour is obtained. This means that PAT and PRV have completely different working conditions:



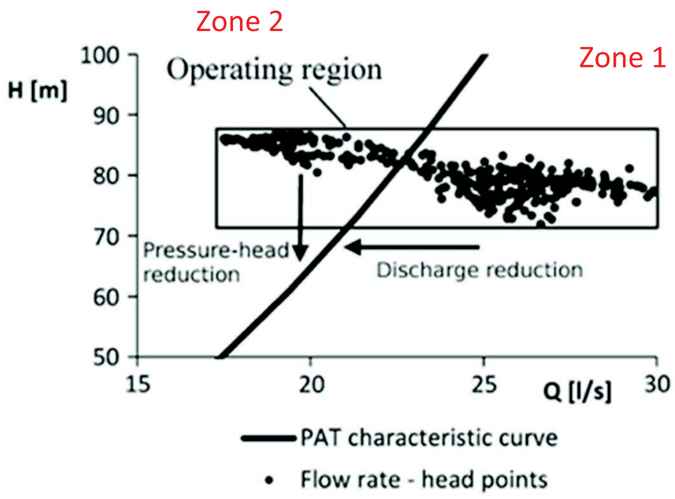
(Fig.2.13 PAT vs PRV)

To substitute the PRV with a PAT maintaining the same functioning conditions, along the first branch, the PAT is arranged in series with a regulative valve that allows to dissipate the head excess (Fig.2.18). On the other branch, in parallel to the PAT, a second valve is installed that allows the excess flow to be bypassed if the needs of the network require



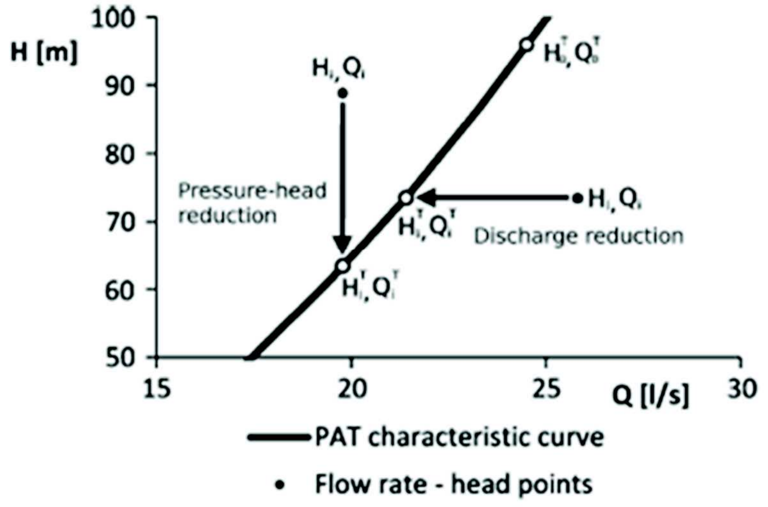
(Fig.2.14 Parallel-series system to install a PAT)

This scheme guarantees that the head losses are the same of the PRV for the given flows and that the turbine rotation per second allows the energy production without an inverter. As a drawback, this scheme does not allow to recover all of the head losses and flows. To explain this the operating points of the PRVs are drawn in the graph and they are compared with the PAT curve:



(Fig.2.15 Operative points vs PAT curve)

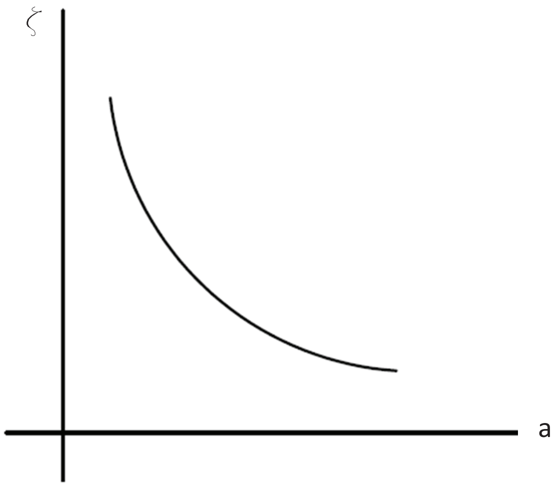
If the available head fall is greater than the convertible amount of the turbine (zone 2 Fig.2.15), the series valve dissipates the head excess. Vice versa, if the flow required by the network is in excess with respect to the PAT curve (zone 1 Fig.2.15), the second valve opens to allow part of the water flow to be bypassed:



(Fig. 2.16)

Doing this obviously means installing an automatic system that detecting pressure and flow data from the system, adjusts the two valves accordingly. Clearly behind the valve management system there are hydraulic logics that allow the operator to operate the system and in particular we see how to understand theoretically what is the degree of openings that the valves must have on the basis of the inputs of the system itself.

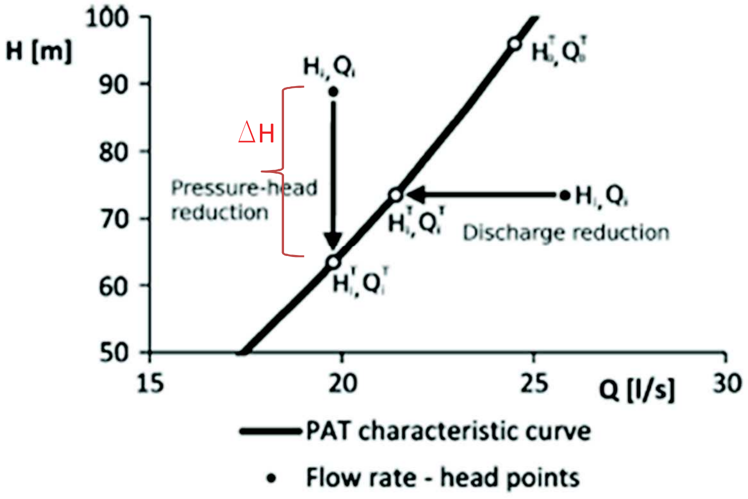
Usually the valves are characterized by characteristic curves like those shown in Fig. 2.17 and are supplied by the manufacturer of the device.



(Fig.2.17 PRV curve)

Where $\zeta=\Delta H/(V^2/2g)$ is the head loss coefficient and a is the degree of openings.

Thanks to this operating curve it is possible to evaluate the opening degrees that characterize the operation we are looking for. We can divide the study into two parts: the study of the valve in series and that of the valve in parallel. The valve in series is the one in charge of dissipating too much pressure. In this case, for the calculation of ζ, all the data are known. ΔH is the difference of the pressure in the network and the one that wants the Pat according to its characteristic curve



(Fig.2.18 ⊿H valve)

Once the coefficient has been found, entering the graph (Fig.2.18) it is easy to find the degree of opening directly.

The valve parallel is responsible for the disposal of excessive flow rates. In this case the operation of parallel pipes must be studied. The quantity of water flowing in the two trunks depends on the length *L*, the roughness *C* and the diameter *D* of the pipe.

In particular, in order to obtain the coefficient ζ of the valve, a system must be set which keeps the characteristics of the two parallel branches:

$$\Delta H_1 = \zeta_1 \frac{Q_1^2}{2 * g * A_1^2} \qquad \Delta H_2 = \zeta_2 \frac{Q_2^2}{2 * g * A_2^2} + \Delta pump$$

$$Q = Q_1 + Q_2$$

(Eq.2.17)

found the coefficient we go back to the degree of openness again thanks to the graph (Fig.2.17).

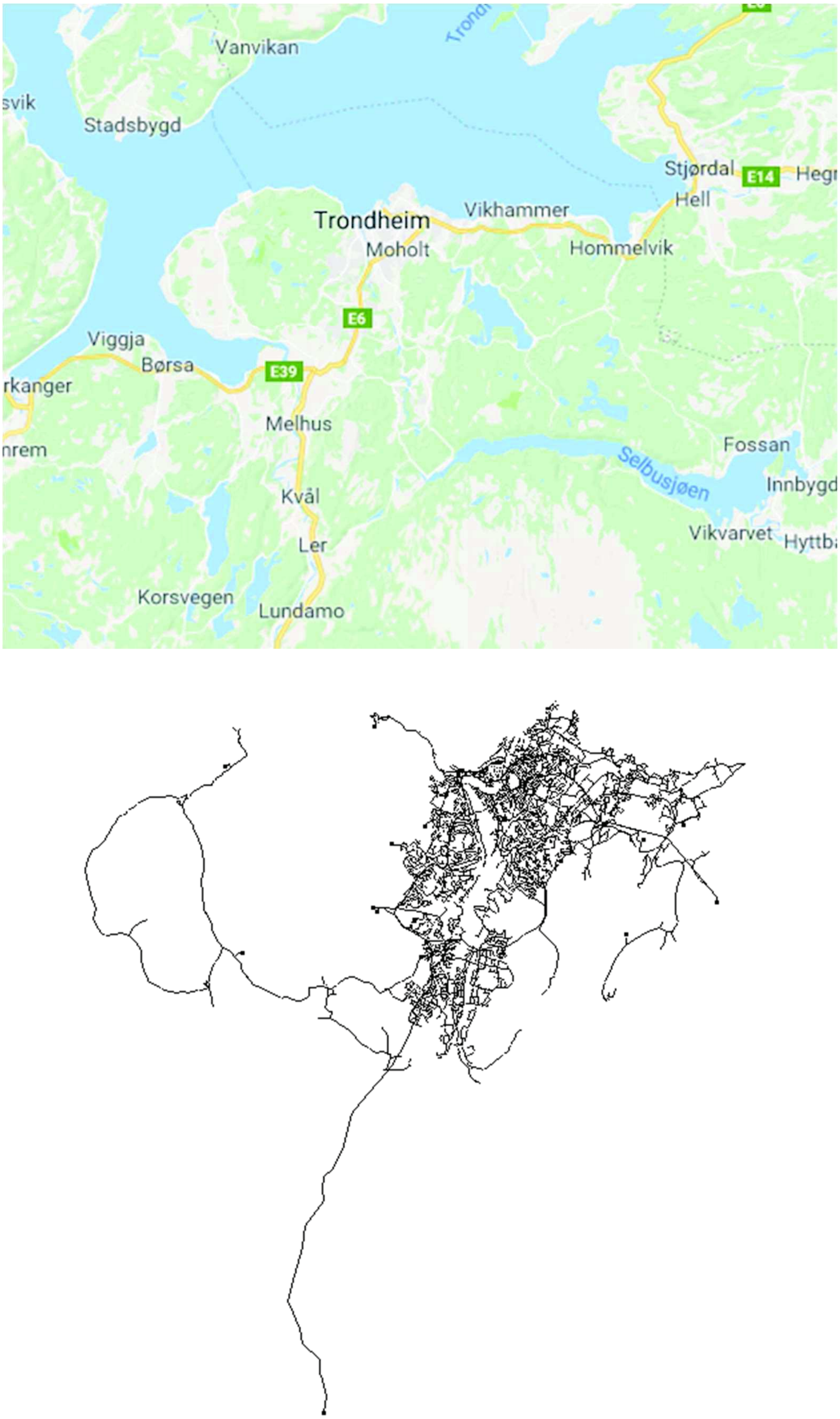
it is important to note that with regard to the pressure drops of the two tubes, the PAT and the various singularities such as the 90 degree curves must also be taken into account.

3) CASE STUDY

3.1) The model of the network

The network considered for the shown case study (Fig.3) supplies Trondheim, a municipality and a city in Norway. Located in the county of Sør-Trøndelag, it is also the administrative capital. With 187,353 inhabitants it is the third city of the country and is the northernmost of the large Norwegian cities. The approximately 30,000 students attending the city's university, the Norwegian University of Science and Technology (NTNU), must be added to the number of inhabitants. The city is located on the shore of the Trondheim fjord.

The Municipality of Trondheim has made available for the study the model of the managed network, for a total length of pipelines of 814 km. Non-protected spheroidal cast iron (52%) is the dominant material; then gray cast iron (27%) and a fair amount of PVC pipes (10%) appear. The average length of the sections of conduct is 84 m and the average age is 19 years. The network mostly supplied by gravity, has 60 pumps (only 20 working) used to deliver water to peripheral districts, and 17 tanks, both at variable or constant level. Pressure regulation is managed by 102 PRVs.



(Fig.3 Hydraulic network of Trondheim)

The average piezometric height in the network is about 70 m, with maxima around 150 m. The main reason for high pressures in the network is the variation in pipe elevation and the need to reduce the number of necessary pumping stations. In fact, an excessive pressure reduction in district, implies an increase through pumping in the downstream district. By keeping the pressures high, water can be delivered across hill, ridges, etc.

For this study the Municipality provided data on consumption and losses, estimated around 32%; in this regard, however, it should be noted that the reliability of data on users is limited by the absence of water meters for most costumers (a typical problem of Norwegian cities is that they do not have devices to measure water consumption in their homes).

The network is divided in 55 sub districts (or "pressure zones") each one with a flow meter that measures how much water enter by the inlet pipe.

To evaluate the leakage level, a simplified procedure has been used. Assuming that one person uses 160 l/ab*g and knowing how many people there are in the zone. we can calculate the supplied total volume. Subtracting this value by the total entered volume we found the losses and then we can divide it over time (24h) in constant way.

Subtracting hour by hour the estimated volume of losses from the total volume of water introduced in the system, the demand pattern can be established.

This procedure introduces two main problems. The first one is the rough estimate of the 160 l/ab*g as a daily demand. The second one, the most important, is that in this way the losses don't depend on the pressure inside the pipe. With respect to this starting situation, as a first step in this thesis the water network model has been improved and the pressure dependence of the water losses has been implemented by means of a leak parameters calibration.

The network scheme given by the municipality was exported from Mike Urban and hence as a first step it was implemented in EPANET. Unfortunately, in EPANET there aren't the variable speed pumps. So we changed them into the combination of a normal pump and a PRV.

The spatial distribution of the losses was defined by calibrating a leak model associated to the nodes. Zone by zone (55 pressure zones) the mean pressure $P_{mean,i}$, the leakages flow q_i and the number of the nodes n_i were known. Using these information, the emitter coefficient β was calculated:

$$\beta_i = \frac{q_i / P_{mean,i}^{\alpha}}{n_i}$$

(Eq.3)

Exponent α_k (k represent the pipes) depends mainly on material representing the deformation response of the leaking holes under pressure. In technical literature the exponent α is reported to vary around values 1.0÷1.2 for a wide range of pipe materials. Considering all the uncertainties surrounding the hydraulic modelling, the exponent α_k can be roughly assumed to be the same for the whole network (i.e. α_k=α). Coefficient β represents the propensity to leak of the single pipe and might vary within a wider range of variability depending on material, diameter, age and installation conditions.

Zona	Pmedia	q	α	β tot	n	β
1	75.24648	6.88	1.1	0.059354	139	0.000427
2	46.14733	3.25	1.1	0.048009	13	0.003693
3	52.96927	11.10762	1.1	0.140992	127	0.00111
4	1	0	1.1	0	1	0
5	1	0	1.1	0	1	0
6	56.31442	9.58	1.1	0.11368	14	0.00812
7	1	0	1.1	0	1	0
8	1	0	1.1	0	1	0
9	63.72064	0.9	1.1	0.009323	27	0.000345
10	54.80971	2.869413	1.1	0.035079	125	0.000281
11	74.2297	0.01	1.1	8.76E-05	5	1.75E-05
12	72.22888	2.312393	1.1	0.020868	304	6.86E-05
13	58.40536	0.5	1.1	0.0057	9	0.000633
14	77.19717	18.97255	1.1	0.159134	584	0.000272
15	63.43768	1.399716	1.1	0.01457	139	0.000105
16	72.22916	7.1317	1.1	0.064359	252	0.000255
17	68.20424	13.54	1.1	0.130145	342	0.000381
18	76.20248	8.98	1.1	0.076403	203	0.000376
19	76.60258	28.08968	1.1	0.237618	560	0.000424
20	66.62745	19.11623	1.1	0.188531	564	0.000334
21	72.80592	7.52	1.1	0.067272	221	0.000304
22	1	0	1.1	0	1	0
23	63.80244	1.6	1.1	0.01655	210	7.88E-05
24	69.85707	0.59	1.1	0.005524	9	0.000614
25	78.68861	6.94	1.1	0.056998	204	0.000279
26	87.85817	3.9675	1.1	0.028864	23	0.001255
27	68.68575	8.065994	1.1	0.076932	336	0.000229
28	78.5129	9.239956	1.1	0.076074	474	0.00016
29	67.5623	4.17146	1.1	0.040515	450	9E-05
30	1	0	1.1	0	1	0
31	68.34868	3.67	1.1	0.035194	52	0.000677
32	1	0	1.1	0	1	0
33	71.53771	0.24	1.1	0.002189	12	0.000182
34	1	0	1.1	0	1	0
35	1	0	1.1	0	1	0
36	65.18009	2.96	1.1	0.029906	116	0.000258
37	70.03989	0.71	1.1	0.006628	40	0.000166
38	72.69168	4.65	1.1	0.04167	173	0.000241
39	1	0	1.1	0	1	0
40	1	0	1.1	0	1	0
41	73.25381	7.33	1.1	0.065131	229	0.000284
42	1	0	1.1	0	1	0
43	69.50567	2.17	1.1	0.020429	8	0.002554
44	64.18876	2.51868	1.1	0.02588	354	7.31E-05
45	1	0	1.1	0	1	0
46	1	0	1.1	0	1	0
47	69.50012	1.930303	1.1	0.018174	196	9.27E-05
48	68.89221	8.49	1.1	0.080709	228	0.000354
49	92	0.49	1.1	0.003389	1	0.003389
50	62.97878	0.774327	1.1	0.008125	273	2.98E-05
51	1	0	1.1	0	1	0
52	1	0	1.1	0	1	0
53	1	0	1.1	0	1	0
54	59.58301	2.93	1.1	0.032676	282	0.000116
55	1	0	1.1	0	1	0

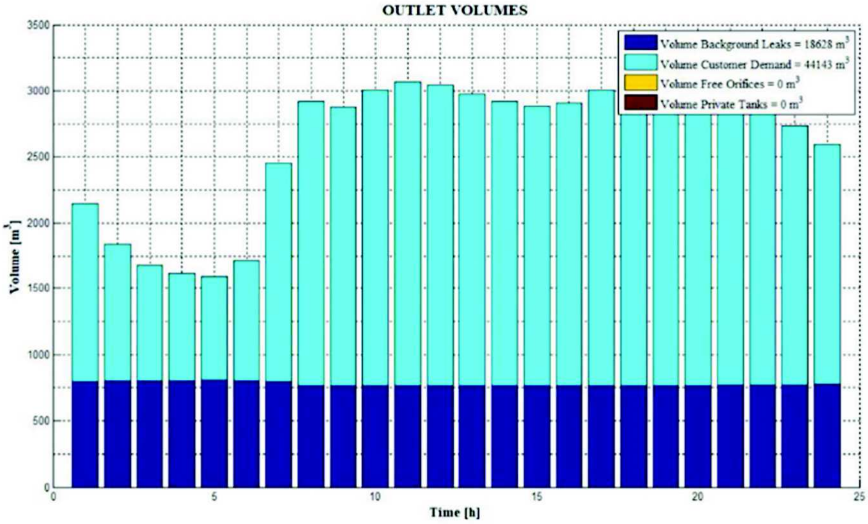
(Tab. 3 α and β of the 55 zones)

In Table 3, the 55 zones are listed. Pmedia (m) is the mean pressure during the day, q (l/s) is the leakage flow rate, a is the first emitter coefficient, btot is the second coefficient calculated for the zone, n is the number of nodes in the zone and b is the second emitter coefficient of the nodes in the zone. In the zones with β = 0 and Pmedia = 1 means that no loss has been assigned to the nodes.

From the table 1, it is evident that zone 19 is characterized by the highest percentage of losses and is also the one with the highest number of nodes. This can be logical due to the fact that statistically an area with more elements has a higher percentage of losses.

The implementation of the above-mentioned formulae and parameters in the network model allows the modelling of a pressure dependent leakage or a “pressure driven” analysis.

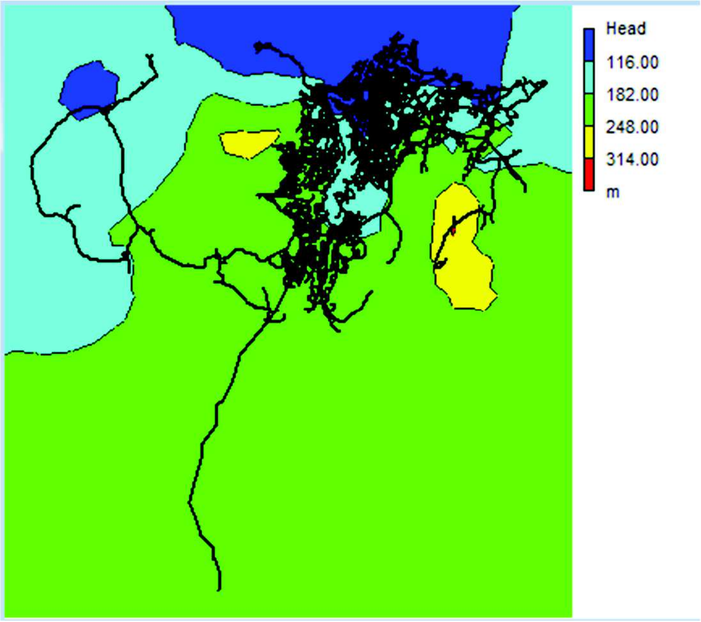
In order to compare results, the network was also uploaded on WDNetXL. Doing this was not easy in fact, uploading the file, WDNetXL reported many generic errors. The main problem was that the nodes with Pset target pressure were not assigned to the right PRV valve (the one placed in the tube converging to the node) but to a random one in the network. The way to fix the problem was to search in the map the node with Pest, control the true name upstream valve and correct in the program. By pressure-driven analysis in WDNetXL we can find the graphics that explain the losses trend:



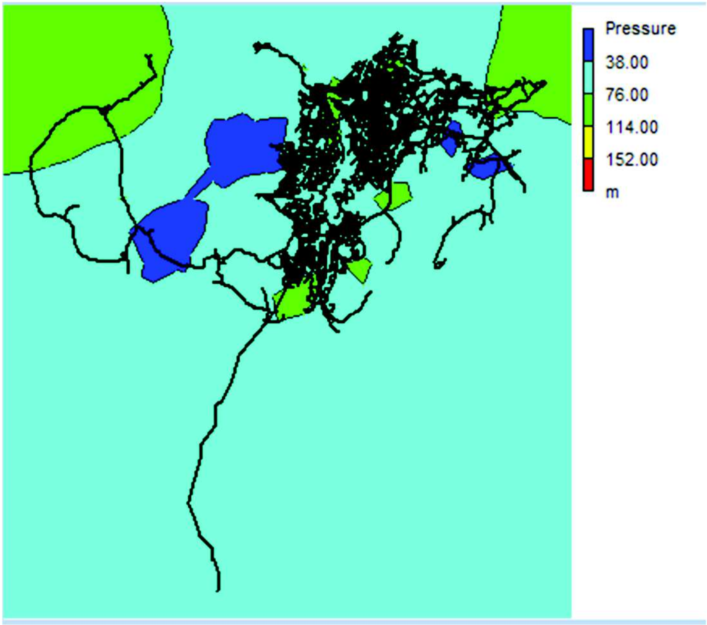
(Fig. 3.1 Pressure driven analysis graph produced by WDNetXL)

One the model was adjusted and verified, was decided to continue with the EPANET model implementation.

Due to the network high pressure, differences between the improved pressure driven model and the original demand driven model of the network are negligible. Figs.3.2 shows the trends of pressures, heads and flow.



(Fig. 3.2 a Head graph produced by EPANET)



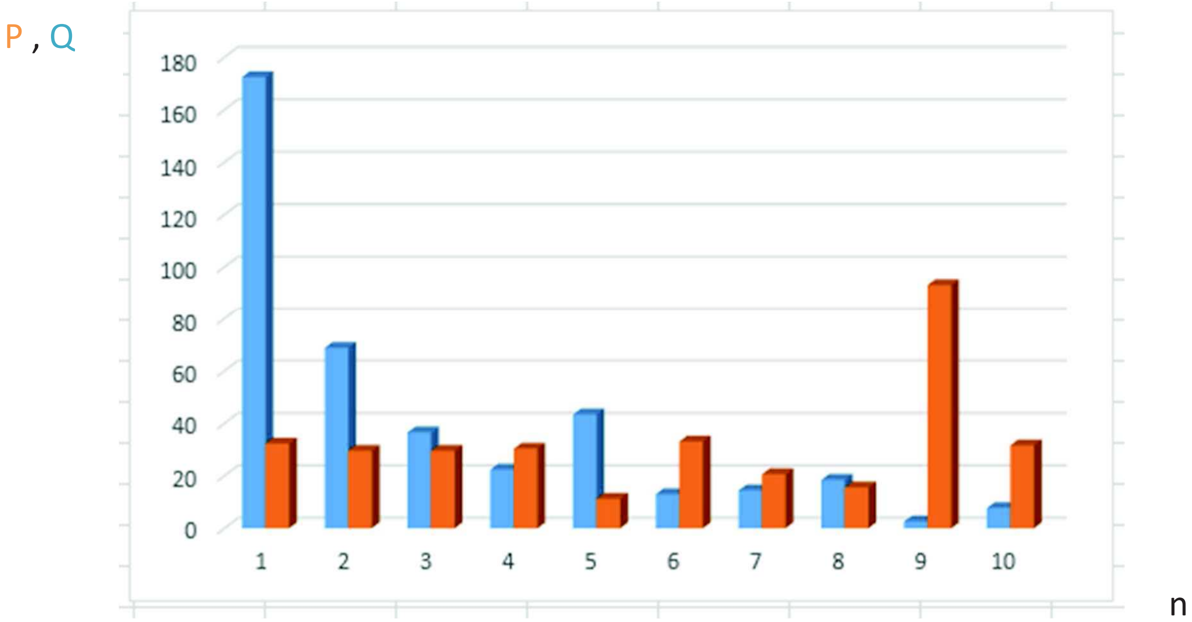
(Fig. 3.2 b Pressure graph produced by EPANET)

3.2) Pressure control by valves

As mentioned previously, the aim is to produce energy but keeping the initial conditions of the system. We want to replace standard valves with valve-PAT series-parallel system to reduce the same pressure but convert it into energy. Maintaining the same conditions is important above all from the operational point of view because in doing so we are sure of the functioning of the system without having to model the PAT in the software.

The producibility is linked to the flow and pressure dissipated but also to the actual operating conditions of the PAT (characteristic curve). At this point the first important step is to understand which valve is the best candidate to be replaced by a PAT by creating a ranking with a rough estimate of the producibility.

Flow and dissipated pressure dissipated by the valve have been considered with a PAT efficiency of 0.6. Based on this preliminary analysis, apparently only three valves would justify the investment (considering that only the cost of the machine and valve is around 15,000 euros):



(Fig. 3.3 Pressure and flow for the first 10 valves of the rough ranking)

pipe1	118		pipe2	328896		pipe3	328899
l/s	m		l/s	m		l/s	m
135.27	32.21808		41.09	28.84659		22.21	28.84441
117.01	32.6971		36.65	28.74892		19.99	28.74833
102.1	32.94477		33.81	28.71938		18.6	28.71914
94.73	33.07107		32.37	28.70038		17.89	28.70028
92.97	33.13877		35.06	28.68899		19.31	28.68893
100.04	33.11775		60.55	28.72744		32.69	28.72723
146.01	32.65159		84.41	29.12		44.74	29.1166
182.19	32.11914		86.89	30.04161		45.71	29.99909
198.98	32.05239		87.97	30.29768		46.12	30.22704
206.3	31.9335		87.58	30.50602		46.04	30.41527
210.88	31.87683		87.15	30.47213		45.88	30.39469
212.26	31.8864		86.15	30.41237		45.54	30.3415
211.55	31.93461		85.79	30.27547		45.4	30.22095
210.62	31.97237		84.21	30.22161		44.6	30.17073
208.18	32.03435		81.48	30.02929		43.17	29.98728
203.59	32.08407		81.12	29.90156		43.12	29.86607
201.41	32.07009		79.38	29.86249		42.17	29.83223
198.96	32.0812		79.84	29.80849		42.44	29.77822
198.6	32.0812		77.81	29.80849		41.45	29.77822
195.77	32.13013		74.22	29.7187		39.55	29.69478
189.97	32.21916		70.31	29.58255		37.45	29.56281
182.57	32.31765		66.9	29.48384		35.59	29.46546
175.48	32.39441		61.89	29.40736		32.96	29.38902
165.78	32.50898		50.16	29.28583		26.86	29.27054

(Tab.3.1 P-Q values for the first 3 valves)

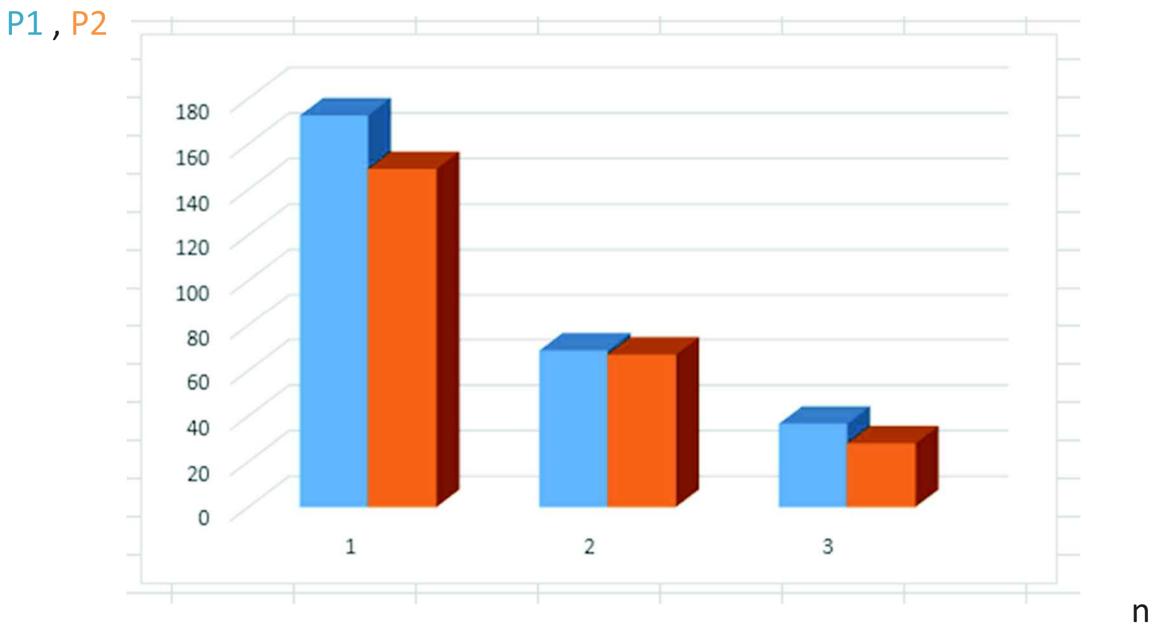
In the graph (Fig.3.3) the pressures and flow rates in the first 10 valves are give manage to make a comparison. Table 3.1 shows the numerical values for the first three valves, which can produce enough energy to justify the installation. In order the theoretical earning for the first three valves is 43000€, 29000€, 16000€.

Given the high pressure and flows, the best theoretical producibility of around 43000 euro yearly is reached on the valve 118.

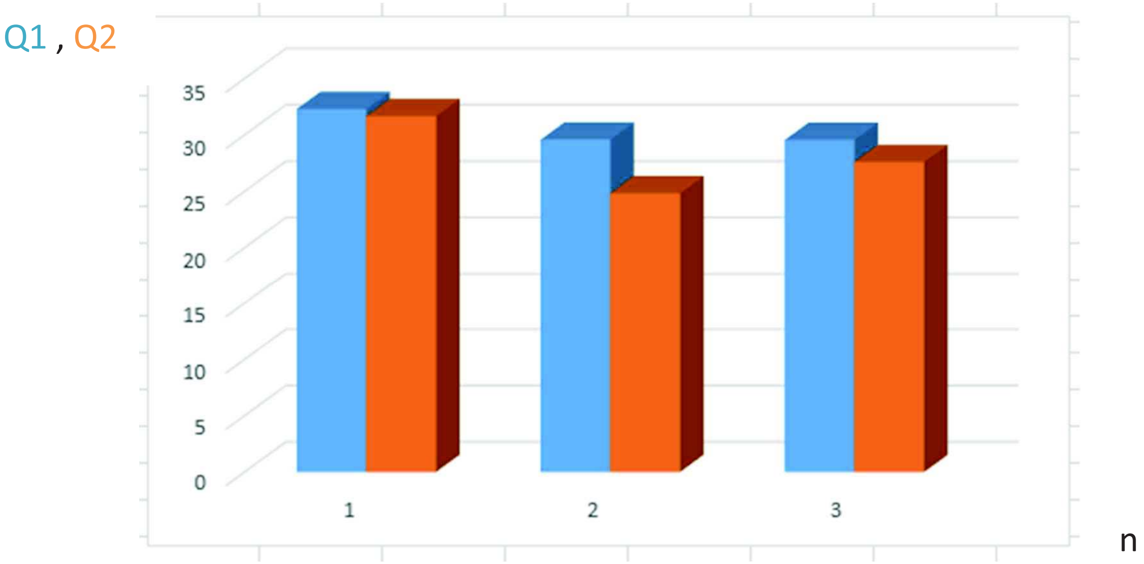
Chosen the first valves that guarantee a certain theoretical producibility, it remains to choose the right PAT and to construct the characteristic curve, to calculate the real producibility according to the procedure reported in *paragraph 2.2.2.*

3.3) Energy recovery by PATs

So, once the PAT has been chosen and the characteristic curve is determined by Eq.2.12, the true possible production can be calculate (Tab.3.2):



(Fig. 3.4 a Initial pressure P1 vs final pressure P2)



(Fig. 3.4 b Initial flow Q1 vs final flow Q2)

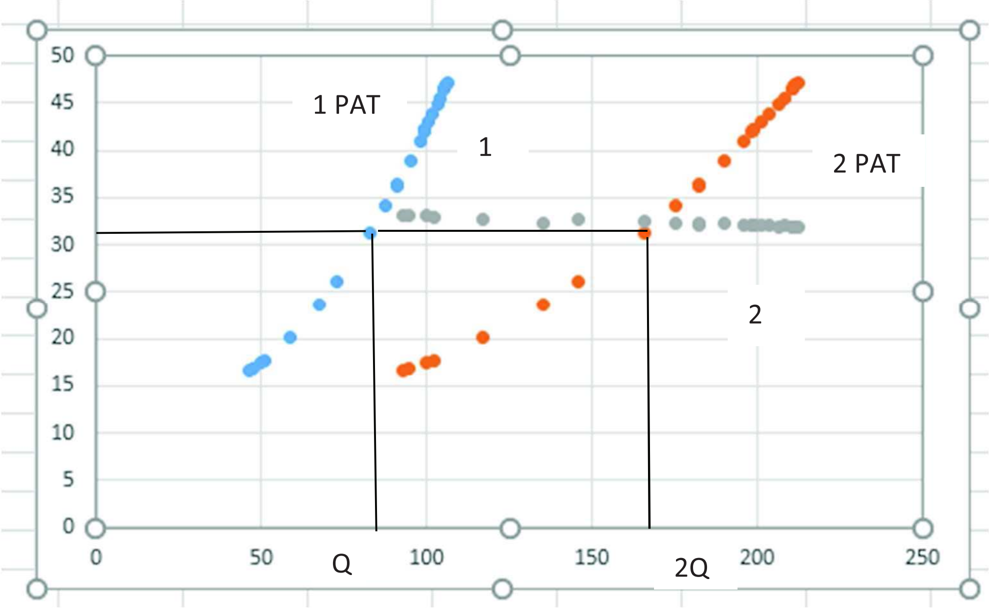
Q	H	Kw		Q	H	Kw		Q	H	Kw
135.27	23.61517	22.77572		41.09	15.44793	2.820957		22.21	21.70686	2.803951
85.29313	32.6971	20.0234		36.65	14.7279	1.906462		19.99	20.08339	2.073636
85.70521	32.94477	20.25355		33.81	14.36397	1.399071		18.6	19.22135	1.667333
85.87212	33.07107	20.36286		32.37	14.20824	1.164914		17.89	18.82692	1.474935
86.02946	33.13877	20.43432		35.06	14.51486	1.614941		19.31	19.64681	1.869966
85.99547	33.11775	20.41494		60.55	20.77734	8.575367		32.69	28.72723	6.527841
146.01	26.068	27.53022		79.04649	29.12	16.68259		29.48038	29.1166	5.890909
168.6639	32.11914	38.97533		80.73927	30.04161	17.55226		30.17606	29.99909	6.243085
168.4397	32.05239	38.85141		81.20371	30.29768	17.79377		30.35321	30.22704	6.334018
168.0059	31.9335	38.62416		81.57151	30.50602	17.9886		30.49543	30.41527	6.408289
167.8131	31.87683	38.51858		81.50933	30.47213	17.95642		30.47879	30.39469	6.399895
167.8464	31.8864	38.53655		81.39928	30.41237	17.89963		30.43626	30.3415	6.378327
168.011	31.93461	38.62649		81.15383	30.27547	17.77091		30.34367	30.22095	6.330412
168.1397	31.97237	38.69691		81.05402	30.22161	17.71967		30.30068	30.17073	6.309389
168.3506	32.03435	38.81245		80.6652	30.02929	17.53043		30.15308	29.98728	6.234999
168.5865	32.08407	38.91795		80.47403	29.90156	17.41814		30.05911	29.86607	6.1868
168.5181	32.07009	38.88789		79.38	29.3038	16.83908		30.02945	29.83223	6.172514
168.537	32.0812	38.90498		79.84	29.55356	17.08281		29.98832	29.77822	6.15125
168.5347	32.0812	38.90455		77.81	28.46624	16.0353		29.98538	29.77822	6.150528
168.6864	32.13013	38.99298		74.22	26.63763	14.316		29.91664	29.69478	6.116426
169.0744	32.21916	39.17538		70.31	24.78308	12.62044		29.81124	29.56281	6.06337
169.3356	32.31765	39.34512		66.9	23.28234	11.28327		29.74374	29.46546	6.02681
169.6648	32.39441	39.50148		61.89	21.27458	9.539016		32.96	29.38902	6.733847

(Tab.3.2 Values new pairs P-Q, first 3 valves)

In Figs 3.4 and Table 3.2, the real amount of pressure and flow, (in orange) that the system uses (according to the PAT curve) can be evaluated.

From the results, we can see that the first valve is characterized by a very high flow. For this reason, two pumps in parallel are also considered.

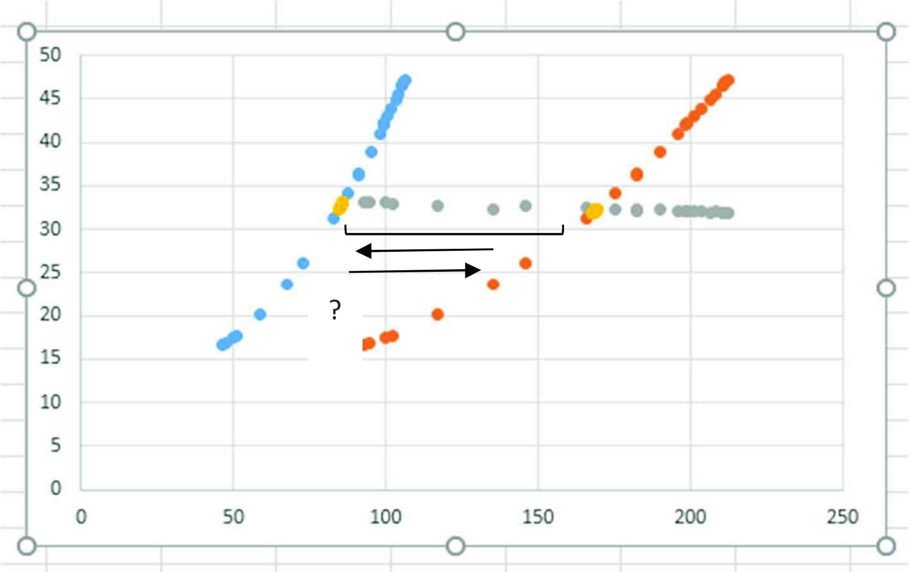
This arrangement allows to work with higher flow with respect to the single PAT and in particular with a double flow with the same head and efficiency (BEP=$2Q_{tb}$) :



(Fig. 3.5 Characteristic curve parallel PAT, system 1)

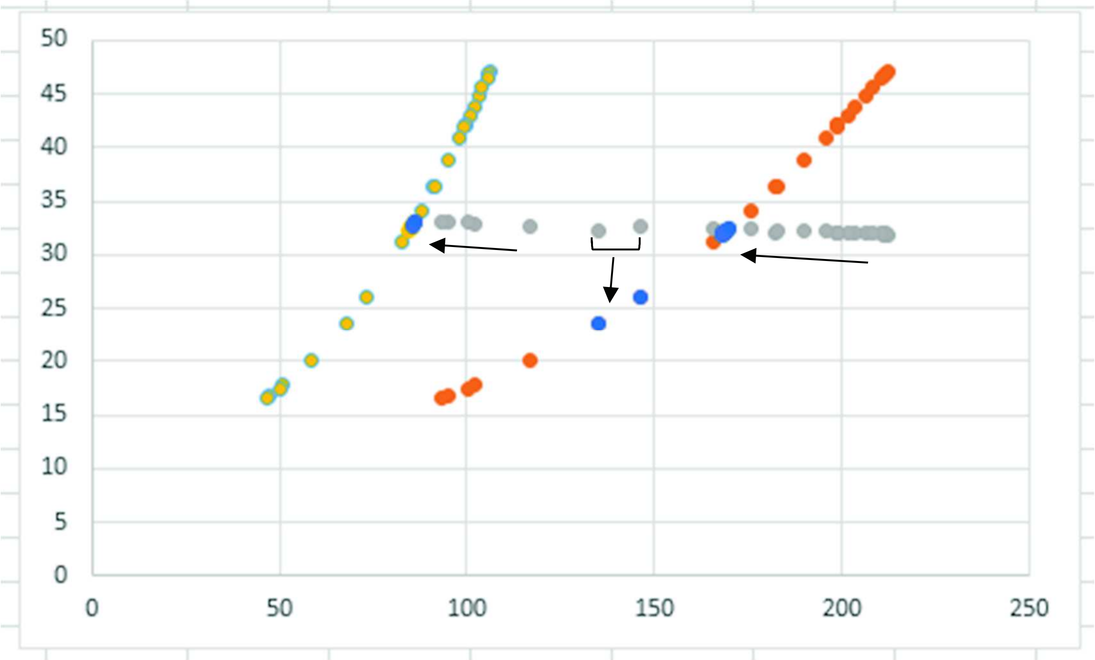
Running the pumps in parallel means bringing all the operating points back into the orange curve (Fig.3.5).

At this point, it is interesting to understand if it is convenient to always use pumps in parallel or there are conditions in which it is convenient to use a single pump (blue curve). To study this, we need to think about the points of the intermediate zone to the two curves and understand which curve to bring them back to:



(Fig. 3.6)

The point-to-point producibility is compared with the operating couples H, Q obtained from the single curve (blue) and the double curve (orange) Fig(3.6).



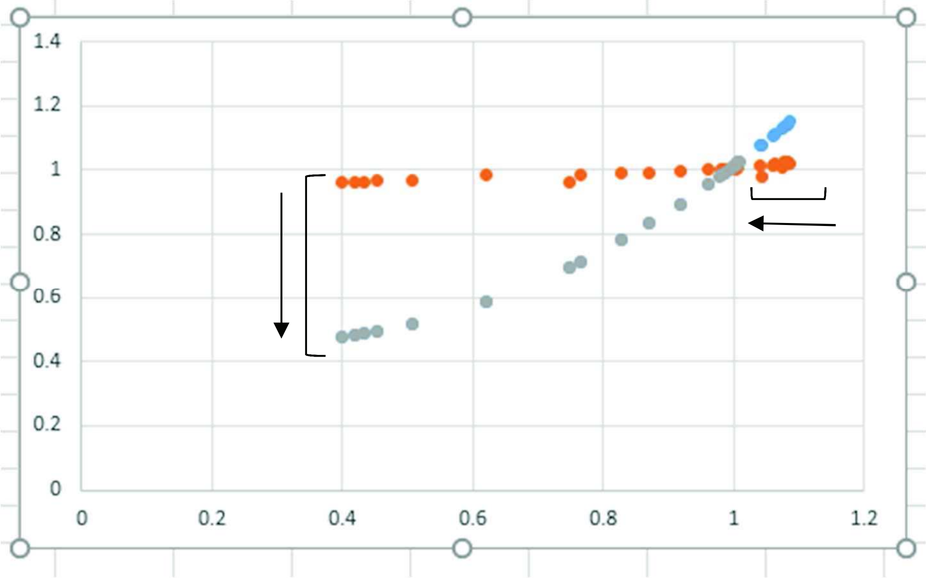
(Fig. 3.7 Final operation graph system 1)

curva singola				curva doppia				funzionamento ottimale risultante				
Q	H	Kw		Q	H	Kw		Q	H	Kw		
84.48584	32.21808	19.57721		135.27	23.61517	22.77572		135.27	23.61517	22.77572		parallelo
85.29313	32.6971	20.0234		117.01	20.06434	15.68914		85.29313	32.6971	20.0234		singola
85.70521	32.94477	20.25355		102.1	17.74345	10.83304		85.70521	32.94477	20.25355		singola
85.87212	33.07107	20.36286		94.73	16.78831	8.741353		85.87212	33.07107	20.36286		singola
86.02946	33.13877	20.43432		92.97	16.57902	8.27204		86.02946	33.13877	20.43432		singola
85.99547	33.11775	20.41494		100.04	17.46368	10.22783		85.99547	33.11775	20.41494		singola
85.20408	32.65159	19.97861		146.01	26.068	27.53022		146.01	26.068	27.53022		parallelo
..	..	..		168.6639	32.11914	38.97533		168.6639	32.11914	38.97533		parallelo
..	..	..		168.4397	32.05239	38.85141		168.4397	32.05239	38.85141		parallelo
..	..	..		168.0059	31.9335	38.62416		168.0059	31.9335	38.62416		parallelo
..	..	..		167.8131	31.87683	38.51858		167.8131	31.87683	38.51858		parallelo
..	..	..		167.8464	31.8864	38.53655		167.8464	31.8864	38.53655		parallelo
..	..	..		168.011	31.93461	38.62649		168.011	31.93461	38.62649		parallelo
..	..	..		168.1397	31.97237	38.69691		168.1397	31.97237	38.69691		parallelo
..	..	..		168.3506	32.03435	38.81245		168.3506	32.03435	38.81245		parallelo
..	..	..		168.5865	32.08407	38.91795		168.5865	32.08407	38.91795		parallelo
..	..	..		168.5181	32.07009	38.88789		168.5181	32.07009	38.88789		parallelo
..	..	..		168.537	32.0812	38.90498		168.537	32.0812	38.90498		parallelo
..	..	..		168.5347	32.0812	38.90455		168.5347	32.0812	38.90455		parallelo
..	..	..		168.6864	32.13013	38.99298		168.6864	32.13013	38.99298		parallelo
..	..	..		169.0744	32.21916	39.17538		169.0744	32.21916	39.17538		parallelo
..	..	..		169.3356	32.31765	39.34512		169.3356	32.31765	39.34512		parallelo
..	..	..		169.6648	32.39441	39.50148		169.6648	32.39441	39.50148		parallelo
85.00027	32.50898	19.85264		170.0005	32.50898	39.70528		170.0005	32.50898	39.70528		parallelo

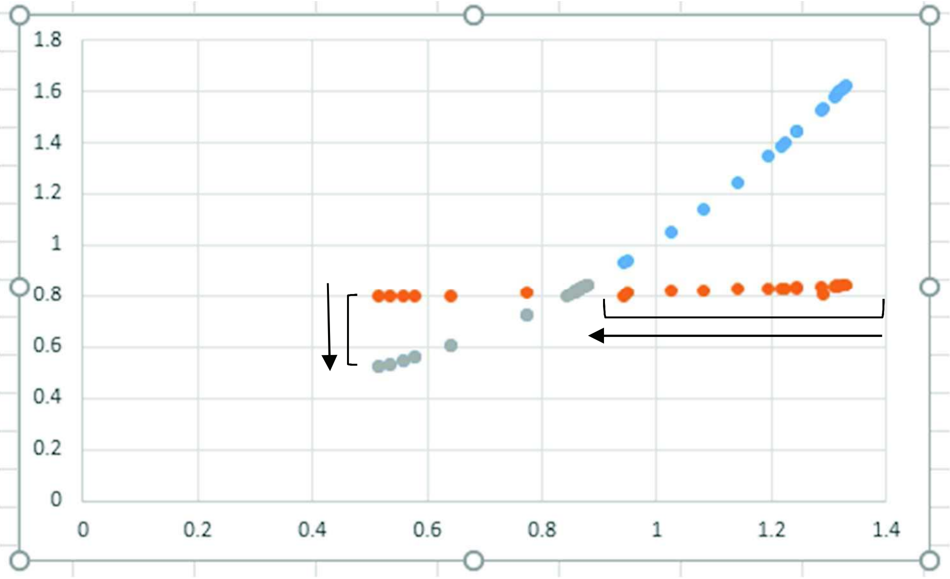
(Tab.3.3 Final values system 1)

In the table 3.3 and Fig.3.7, It is possible to see that for 5 hours (yellow) of the day it is convenient to work a single PAT to achieve an additional benefit of about 3000 € for a total income of about 44000€.

For the other 2 selected positions (valve 328896 and 328899) it was not necessary to evaluate pat in parallel as the flow rates were smaller. The procedure followed was the same as getting



(Fig. 3.8, PAT 2)



(Fig.3.9, PAT 3)

PAT 2				PAT 3		
Q	H	Kw		Q	H	Kw
41.09	15.44793	2.820957		22.21	21.70686	2.803951
36.65	14.7279	1.906462		19.99	20.08339	2.073636
33.81	14.36397	1.399071		18.6	19.22135	1.667333
32.37	14.20824	1.164914		17.89	18.82692	1.474935
35.06	14.51486	1.614941		19.31	19.64681	1.869966
60.55	20.77734	8.575367		32.69	28.72723	6.527841
79.04649	29.12	16.68259		29.48038	29.1166	5.890909
80.73927	30.04161	17.55226		30.17606	29.99909	6.243085
81.20371	30.29768	17.79377		30.35321	30.22704	6.334018
81.57151	30.50602	17.9886		30.49543	30.41527	6.408289
81.50933	30.47213	17.95642		30.47879	30.39469	6.399895
81.39928	30.41237	17.89963		30.43626	30.3415	6.378327
81.15383	30.27547	17.77091		30.34367	30.22095	6.330412
81.05402	30.22161	17.71967		30.30068	30.17073	6.309389
80.6652	30.02929	17.53043		30.15308	29.98728	6.234999
80.47403	29.90156	17.41814		30.05911	29.86607	6.1868
79.38	29.3038	16.83908		30.02945	29.83223	6.172514
79.84	29.55356	17.08281		29.98832	29.77822	6.15125
77.81	28.46624	16.0353		29.98538	29.77822	6.150528
74.22	26.63763	14.316		29.91664	29.69478	6.116426
70.31	24.78308	12.62044		29.81124	29.56281	6.06337
66.9	23.28234	11.28327		29.74374	29.46546	6.02681
61.89	21.27458	9.539016		32.96	29.38902	6.733847
50.16	17.49147	6.357515		26.86	26.09063	4.658353

(Tab.3.4 New values PAT 2 and 3)

The real annual gain for PAT 2 and 3 is respectively 16000€ and 7000€.

It is important to say that to calculate the real producibility the real efficiency hour by hour has been calculated by Eq.2.14.

PAT 1	PAT 2	PAT 3
0.726793	0.453024	0.592865
0.73189	0.360035	0.526518
0.731204	0.293664	0.475397
0.730919	0.258191	0.44639
0.730647	0.323491	0.502447
0.730706	0.694832	0.708585
0.737311	0.738789	0.699584
0.73339	0.737659	0.703007
0.733555	0.737248	0.703737
0.73387	0.736893	0.704282
0.734007	0.736955	0.70422
0.733984	0.737062	0.704059
0.733866	0.737294	0.703699
0.733774	0.737385	0.703526
0.73362	0.737721	0.702908
0.733447	0.737875	0.702494
0.733497	0.737929	0.70236
0.733484	0.738006	0.702172
0.733485	0.737976	0.702158
0.733373	0.738135	0.701836
0.733081	0.7383	0.701325
0.732882	0.738437	0.700987
0.732626	0.738504	0.708634
0.732362	0.738643	0.677599

(Tab.3.5 Efficiency)

Obviously next to BEP, the efficiency is greater. As it is easy to imagine, the choice of the appropriate PAT is fundamental. This means to have a wide range of pumps with the relevant BEP values to make a comparison.

3.4) Preliminary economic analysis

In this section the costs necessary for the systems are evaluated.

Based on the diagram of Figure (2.14), prices of valves and PATs are taken into consideration with related works for the implementation, maintenance and design. For simplicity, we call PAT 1, PAT2, PAT 3 in order the machines needed for valve 1, 2 and 3, respectively. Each system consists of two valves and a pump; in order to reduce costs, it is possible to take advantage of the valve that already exists on site, thus having the need to acquire only the second one.

The items that contribute to the definition of costs are described below in details considering both activities and materials involved (Garlaschelli et al. 2010) :

- *Refinement of the Order.* It is a phase in which the Company, which has acquired the order of design, must resume all the studies made at the time of submission of the offer. In fact, since the offer was presented to the customer at the time it is acquired, the order can also take several months; we need to go and re-establish the details in detail sizing that had been done and understanding if mistakes were made. In theory, design is a phase that should precede supply. This phase, however, is at the expense of the company that makes the proposal; if a customer asks that he presents himself an offer for a hydroelectric plant, the project costs must be borne, even in the case of an important plant. Only later, if you take the order, then the customer will pay also the draft drawn up at the time of the offer, but if the order is given to another company, then the project is forgotten without receiving any reimbursement for expenses incurred during the offer phase.
- *Basic Engineering.* Phase in which the sizing of the machine is carried out and proceed with the start of the commercial activities of suppliers in basic engineering recover the topographic drawings and surveys of the site where the Turbine will be installed: for example, the distance from the point of connection with the network is evaluated, we check that I data collected are correct, measurements are taken and the morphology of the terrain is observed. With all this information is possible to sketch a plant design. This phase of design aims to provide an overall idea of the plant; in fact, at the end of

basic engineering, you will know what type of bolts will need to be bought to fix them foundations, or what type of wardrobe will need to be purchased to contain the equipment, or even what stainless steel pieces will need to be constructed and with what weight, etc. At the end of this phase it is also possible to establish how much power will be produced, a value that is already known in the offer phase, but that in basic engineering is put in detail.

- *Construction of Carpentry Memories*. At this stage the company, which received the order from the customer to proceed with the design, entrust the work to third parties. It is not, therefore, a phase that takes place within the company contacted directly by the customer, but it is a process that will be completed by other suppliers. In this case, the time taken for completing this phase does not take the meaning of days of work, but of days of waiting, because it is necessary to wait for the execution to be concluded by other operators.
- *Re-examination of the Order*. After organizing the work and sending the suppliers to the request of the indispensable components for the design, we spend a short time for carry out a review of the contract, in order to assess whether the work has started in organized way and without errors.
- *Electrical Panel Engineering*. The connection to the electrical network.
- *Purchase of the pump.*
- *Purchase of the PRV.*
- *Purchase of the pipes for the by-pass.*
- *painting of carpentry*
- *Preparation of the electrical panel*
- *Preparation of the Generator*
- *Preparation of Commercial Materials.* With "commercial materials" we mean all the tools needed in the various phases, including possible contingencies.
- *Transmission Preparation*
- *Pre-assembly.* This phase is done in the workshop to verify that the machine works. It is a test
- *Dismantling*. After the test carried out during the "Pre-assembly" phase, the machine is disassembled and prepared for delivery to the client

- *Touch Up.* This is a relatively quick phase, and consists in solving the problems that they can have the purely aesthetic aspect of the machine, born during the procedure design. It is a phase that is not always necessary.
- *Transportation in the Central.* Delivery to the customer with payment of the carrier.
- *Annual management and maintenance fees*. Based on experience with similar facilities to those studied, we assume an incidence equal to 1% of the total investment

Two economical scenarios are considered to evaluate the sustainability of the investments.

- In the first scenario, we assume the selling price of the KWh

- cost of 1 Kwh in the first 15 years: 0.22 €
- cost of 1 kWh from 16° years: 0.06 €

- In the second scenario, we assume a constant cost of 0.06 €/Kwh.

The difference between the two scenarios are due to the possibility that some incentives can be obtained due to local national rules.

Costs and the expenditure are considered with reference to the present and to Italy 5 years is calculated. Table 3.7 shows the gain attributable to the first 5 years of activity in Scenario 1, table 3.8 in scenario 2.

	euro	euro	euro
Refinement of the Order	500	500	500
Basic Engineering	2200	2200	1300
Electrical Panel Engineering	3000	3000	2100
Construction of Carpentry Memories	4400	4400	2640
Re-examination of the Order	800	800	800
Purchase of the pump.	4500	2200	1250
Purchase of the PRV.	10500	7500	7500
Purchase of the pipes for the by-pass.	1000	1000	1000
Painting of carpentry	800	800	800
Preparation of the electrical panel	10000	5000	2000
Preparation of the Generator	500	500	250
Preparation of Commercial Materials	1500	1500	1500
Transmission Preparation	200	200	200
Pre-assembly	800	800	800
Dismantling	800	800	800
Touch Up	100	100	100
Transportation in the Central	500	500	500
	tot.	tot.	tot.
	42100	31800	24040
costumer price (36 % more)	57256	43248	32694.4
Management and maintenance fees (5 anni)	4500	2300	1800
	tot. 5 anni	tot. 5 anni	tot. 5 anni
	61756	45548	34494.4

(Tab 3.6 costs)

	Kwh giorno	euro annui	euro in 5 years
PAT1	813.772497	64450.782	322253.9089
PAT2	297.867562	23591.111	117955.5546
PAT3	127.206883	10074.785	50373.9255

(Tab.3.7 benefits scenario 1)

	Kwh giorno	euro annui	euro in 5 years
PAT1	813.7724972	17577.48594	87887.4297
PAT2	297.8675621	6433.93934	32169.6967
PAT3	127.2068826	2747.668663	13738.34332

(Tab.3.8 benefits scenario 2)

On the basis of the calculated values it is possible to obtain the following overall profits (for first 5 years):

	Scenario 1:	*Scenario 2:*
PAT1	*322.253-61.756* = ***260.497 €***	*87887-61.756* = ***+26.131***
PAT2	*117.955-45.548* = ***72.407 €***	*32.169-45.558* = ***-13.389***
PAT3	*50.373-34494* = ***15.879 €***	*13.738-34.494* = ***-20.756***

As it is easy to see the PAT system reduced cost combined with the high flow rates and pressures of the hydraulic network allow to repay quickly the investment in *scenario 1*, in the first year, leading to large profits in the following years.

In scenario 2 it is possible to see that, in the absence of incentives, it is not possible to cover expenses in the first 5 years for the PATs 2 and 3 but respectively in 8 and 14 years.

4) CONCLUSION

4.1) Discussion of results

The enormous advantage of the PATs is due the reduced costs compared to turbines. This aspect can be seen in the economic evaluations where the investment is practically repaid in the first year of activity in scenario 1, where incentives are considered. In scenario 2, the cost are repaid in 1, 8, 14 years for the PATs 1, 2, 3 respectively. Obviously, it must be specified that the Trondheim water network is a particular case being mainly gravity and having very high pressures.

An important consideration must be made on the final gains. The system 1 made up of two parallel PATs leads to an astounding result due to the perfect choice of the machine and the combination of two machines to manage the great differences in flow over time. For systems 2 and 3 the gains are much lower than those expected from the preliminary ranking. This can be due to the inaccurate choice of the pump. In Table (3.5) we can see how the efficiencies are very low for different hours of the day. This means that the system flow and pressure values are far from the machine BEP, which in turn does not work with maximum efficiency.

4.2) Short summary and main conclusions

The activities of this thesis can be divided into two phases. As a first step, the Trondheim network was modelled in the EPANET and WDNetXL software. In order to do this, the coefficients alpha and beta of the emitters have been calculated; to take into account the pressure-leakage dependence (pressure driven analysis). The second phase concerned the energy productiveness; in fact, the ideal positions for the turbines was identified, the characteristic curves of the PATs have been studied along with their installation and actual functioning conditions. Being ground not fully explored there have been few works taken as a reference and this has led to the need to invest time in the study and understanding of the hydraulic behaviour of the PATs. Once the PATs have been selected and the characteristic curve built, the actual operation of the system has been evaluated and the 24 Q-P pairs useful for calculating the final power have been found. In conclusion, the costs of initial investment and maintenance were compared with the gain due to the sale of energy to derive the profit.

Ultimately, at the end of this thesis, we can conclude that the PAT system for energy production can lead to large profits with low initial investments for the Trondheim WDS. This leads also to the general consideration that in the water distribution networks PATs can be a valid alternative to classic turbines.

5) BIBLIOGRAFY

1. Perdikou et al., "Integrated Use of Space, Geophysical and Hyperspectral Technologies Intended for Monitoring Water Leakages in Water Supply Networks", 2014

2. Germanopoulos and Jowitt (1989), Leakage reduction by excessive pressure minimization in a water supply network, Proc. Inst of Civil Engr., (87)2, pp.195-214.

3. Derakhshan S, Nourbakhsh A (2007) Experimental study of characteristic curves of centrifugal pumps working as turbines in different specific speeds. Exp Therm Fluid Sci 32:800–807

4. Carravetta et al.,2012 Energy Production in Water Distribution Networks: A PAT Design Strategy, Water Resour Manage (2012) 26:3947–3959

5. Artina, S., Naldi, G., Marchi, A., Bragalli, G., Lenzi, C., and Liserra, T. (2008). "Dal controllo della pressione al recupero energetico nei sistemi di distribuzione idrica." 31° Convegno Nazionale di Idraulica e Costruzioni Idrauliche (CD-ROM), Morlacchi Editore, Perugia, Italy, 1–10 (in Italian).

6. Khadam, M. A., Shammas, N. K., and Feraiheedi, Al Y. (1991). "Water losses from municipal utilities and their impacts." Water Int., 16(4), 254–261

7. Lambert, 2001 Lambert, A. O. (2001). "What do we know about pressure-leakage relationships in distribution systems?" Proc. IWA Conf., System Approach to Leakage Control and Water Distribution Systems Management, IWA Publishing, London.

8. V. Milano, 2006. "Dipendenza delle perdite di una tubazione dalla pressione di esercizio." L'Acqua 4, 47–54 (in Italian).

9. Todini, E., Pilati, S., "A Gradient Method for the Analysis of Pipe Networks,"International Conference on Computer Applications for Water Supply and Distribution 1987, Leicester Polytechnic, U.K., 8-10 September, 1987

10. Salgado, R., Todini, E., & O'Connell, P.E. 1988. "Extending the gradient method to include pressure regulating valves in pipe networks". Proc. Inter. Symposium on Computer Modeling of Water Distribution Systems , University of Kentucky, May 12-13.

11. Hamam and Brameller 1971, "Hybrid method for the solution of piping networks", Proc. IEE, Vol. 113, No. 11, pp. 1607-1612.

12. Osiadacz, A.J. 1987. Simulation and Analysis of Gas Networks. E. & F.N. Spon, London.

13. Giustolisi et al., 2008 “Pressure-driven demand and leakage simulation for water distribution networks.” J. Hydraul. Eng., 134(5), 626–635

14. Sterling e Bargiela, 1984 Leakage reduction by optimised control of valves in water networks, Volume: 6 issues: 6, page(s): 293-298

15. Miyaoka, 1984, Optimal control of water distribution systems by network flow theory IEEE Transactions on Automatic Control (Volume: 29, Issue: 4, Apr 1984)

16. Germanopoulos, 1995, Valve Control Regulation for Reducing Leakage, Water Science and Technology Library book series (WSTL, volume 14)

17. Schütze et al. 2004, Real time control of urban wastewater systems—where do we stand today, Volume 299, Issues 3–4, 1 December 2004, Pages 335-348

18. Schilling 1994; Deterministic modelling of integrated urban drainage systems, Published February 2002, 45 (3) 81-94;

19. Garlaschelli et al., 2010, Centrifugal pump as standard used as a prime mover for micro-hydroelectric plant at the discharge of the waste water purifier. Master Thesis, Milano.

6) APPENDIX

A1) Appendix 1: estimate of the power in the valves.

The table shows an estimate of the power that can be produced in the valves. The values in the 24 hours and the relative average value are shown.

	t=1	t=2	t=3	t=4	t=5	t=6	t=7	t=8	t=9	t=10	t=11	t=12	t=13	t=14	t=15	t=16	t=17	t=18	t=19	t=20	t=21	t=22	t=23	t=24	
pipe	Kw	Kw	Kw	Kw	Kw	Kw	Kw	Kw	Kw	Kw	Kw	Kw	Kw	Kw	Kw	Kw	Kw	Kw	Kw	Kw	Kw	Kw	Kw	Kw	average
9996	1E-07	8E-08	8E-08	0	9E-08	1E-07	2E-07	2E-07	2E-07	7E-05	2E-04	3E-04	0	6E-04	0.0008	0.0009	9E-04	9E-04	1E-03	9E-04	1E-03	0.001	0.001	8E-04	0.00046
9905	0.2447	0.219	0.208	0.21	0.23	0.419	0.5	0.441	0.452	0.463	0.46	0.441	0.42	0.415	0.43	0.4745	0.497	0.5	0.5	0.482	0.463	0.456	0.426	0.319	0.40284
9918	0.1604	0.144	0.133	0.13	0.146	0.311	0.363	0.324	0.335	0.341	0.338	0.325	0.31	0.312	0.3244	0.3564	0.365	0.37	0.37	0.355	0.345	0.343	0.32	0.245	0.2944
9919	0.4278	0.357	0.332	0.33	0.411	0.759	0.871	0.855	0.92	0.953	0.949	0.938	0.92	0.909	0.9545	1.0176	1.038	1.013	1.016	0.998	0.951	0.9	0.825	0.593	0.80177
9930	0.2188	0.194	0.186	0.19	0.211	0.353	0.416	0.361	0.376	0.385	0.379	0.366	0.35	0.348	0.3633	0.4042	0.419	0.42	0.423	0.405	0.389	0.385	0.356	0.263	0.34026
9914	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
9958	0.0471	0.056	0.056	0.07	0.108	0.136	0.131	0.13	0.137	0.143	0.131	0.114	0.1	0.105	0.1228	0.1371	0.148	0.152	0.149	0.135	0.127	0.116	0.08	0.045	0.11137
9908	0.0981	0.086	0.077	0.08	0.088	0.153	0.179	0.168	0.184	0.19	0.189	0.185	0.18	0.18	0.1852	0.1964	0.199	0.196	0.196	0.189	0.183	0.173	0.167	0.129	0.16033
9952	0.202	0.169	0.158	0.16	0.192	0.355	0.406	0.398	0.429	0.443	0.443	0.437	0.43	0.423	0.444	0.4762	0.484	0.472	0.475	0.466	0.443	0.417	0.385	0.278	0.37422
9965	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
9928	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
9971	0.2275	0.205	0.197	0.19	0.213	0.353	0.408	0.387	0.401	0.407	0.399	0.382	0.37	0.378	0.3878	0.4207	0.431	0.429	0.429	0.417	0.4	0.389	0.369	0.289	0.35365
9961	0.4592	0.396	0.368	0.38	0.474	0.828	0.925	0.911	0.983	1.015	1.008	0.985	0.96	0.964	1.0196	1.0933	1.118	1.091	1.091	1.061	1.016	0.955	0.859	0.617	0.85748
9985	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
9942	0.0088	0.009	0.009	0.01	0.009	0.015	0.017	0.017	0.018	0.018	0.018	0.015	0.01	0.015	0.0149	0.0179	0.018	0.018	0.018	0.018	0.018	0.018	0.015	0.012	0.01486
9944	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
9987	0.2764	0.246	0.235	0.23	0.258	0.436	0.502	0.474	0.491	0.497	0.489	0.47	0.46	0.462	0.4777	0.5159	0.527	0.522	0.525	0.51	0.488	0.478	0.452	0.353	0.43233
9937	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
9964	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
9923	0.0618	0.056	0.054	0.05	0.06	0.096	0.112	0.105	0.109	0.109	0.106	0.104	0.1	0.102	0.1052	0.114	0.116	0.116	0.116	0.113	0.107	0.105	0.099	0.078	0.0957
9984	0.0295	0.033	0.036	0.04	0.063	0.08	0.076	0.078	0.082	0.085	0.079	0.068	0.06	0.06	0.072	0.0806	0.089	0.091	0.088	0.079	0.074	0.068	0.048	0.027	0.06594
9946	0.0582	0.058	0.058	0.06	0.061	0.068	0.07	0.069	0.071	0.071	0.071	0.071	0.07	0.072	0.0718	0.0719	0.072	0.072	0.072	0.072	0.07	0.069	0.068	0.065	0.06798
9926	0.212	0.252	0.262	0.29	0.451	0.59	0.56	0.565	0.6	0.616	0.57	0.486	0.43	0.448	0.5208	0.5989	0.652	0.671	0.653	0.588	0.545	0.492	0.343	0.202	0.48323
9951	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
9920	0.4788	0.42	0.404	0.4	0.443	0.709	0.981	0.991	1.036	1.075	1.065	1.05	1.04	1.018	0.9654	0.9599	0.942	0.928	0.909	0.877	0.836	0.799	0.762	0.6	0.82018
9953	1.125	0.971	0.938	0.93	1.022	1.314	1.42	1.397	1.424	1.44	1.437	1.426	1.42	1.416	1.4163	1.4372	1.443	1.436	1.435	1.418	1.399	1.383	1.366	1.273	1.32039
9941	0.6004	0.531	0.517	0.51	0.567	0.91	1.203	1.164	1.224	1.258	1.237	1.222	1.21	1.192	1.1401	1.1462	1.128	1.109	1.09	1.056	1.013	0.976	0.936	0.74	0.98666
9986	1.641	1.807	1.896	1.94	1.977	2.085	1.869	1.62	1.596	1.564	1.547	1.543	1.56	1.543	1.555	1.5739	1.587	1.593	1.582	1.586	1.604	1.642	1.659	1.653	1.67626
9997	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
9939	0.6434	0.479	0.386	0.34	0.423	1.204	1.751	2.385	2.491	2.52	2.512	2.49	2.5	2.392	2.2903	2.216	2.186	2.193	2.131	2.045	1.967	1.889	1.763	1.275	1.76977
9924	0.092	0.085	0.083	0.08	0.09	0.127	0.135	0.122	0.128	0.13	0.127	0.123	0.12	0.121	0.1273	0.1358	0.139	0.139	0.139	0.136	0.131	0.129	0.123	0.103	0.11958
9945	0.3331	0.294	0.276	0.27	0.279	0.431	0.599	0.714	0.727	0.731	0.73	0.722	0.71	0.695	0.6819	0.6964	0.702	0.71	0.696	0.674	0.65	0.63	0.598	0.476	0.58437
9968	0	0	0	0	0	0.349	0.691	0.594	0.672	0.719	0.708	0.668	0.63	0.625	0.6437	0.7302	0.766	0.75	0.75	0.695	0.63	0.564	0.51	0.188	0.49516
9949	0.5352	0.258	0.127	0.06	0.038	0.087	0.98	5.373	5.595	5.278	5.207	4.906	4.89	4.779	4.6935	4.5188	4.458	4.466	4.261	4.133	3.979	3.681	3.355	2.547	3.25875
9963	0.9495	0.864	0.844	0.83	0.901	1.318	1.717	1.665	1.748	1.799	1.777	1.763	1.75	1.745	1.6648	1.6537	1.622	1.6	1.567	1.527	1.472	1.433	1.374	1.13	1.44675
9933	0.131	0.122	0.118	0.12	0.128	0.187	0.201	0.181	0.187	0.189	0.186	0.181	0.18	0.177	0.186	0.1989	0.204	0.205	0.203	0.2	0.193	0.192	0.18	0.148	0.1747
9980	2.4922	2.223	2.172	2.12	2.32	3.525	4.78	4.509	4.838	5.049	4.964	4.923	4.92	4.976	4.6599	4.6084	4.531	4.45	4.321	4.201	4.033	3.947	3.75	3.035	3.97311
9922	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
9948	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
9957	0	0	0	0	0	0	0.053	0.021	0.466	0.84	0.746	0.653	0.72	0.588	0.3441	0.2348	0.395	0.517	0.319	0.047	0	0	0	0	0.24754
9910	0.0135	0.003	0.003	0	0.007	0.051	0.071	0.05	0.054	0.057	0.054	0.047	0.04	0.044	0.048	0.065	0.075	0.074	0.078	0.078	0.068	0.061	0.058	0.038	0.04778
9972	6.9767	6.202	5.715	5.47	5.92	10.24	14.47	15.36	15.69	15.73	15.63	15.42	15.3	14.98	14.402	14.277	13.95	14.01	13.65	12.98	12.24	11.61	10.71	8.646	12.0655
9973	3.7708	3.383	3.144	3.02	3.261	5.528	7.668	8.071	8.206	8.242	8.208	8.133	8.08	7.92	7.6197	7.5801	7.405	7.439	7.265	6.913	6.517	6.173	5.702	4.628	6.41129
9931	0.2849	0.246	0.229	0.22	0.241	0.425	0.596	0.522	0.551	0.547	0.538	0.513	0.5	0.495	0.5105	0.5446	0.559	0.558	0.556	0.542	0.521	0.513	0.492	0.371	0.46158

9925	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
9992	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
9993	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
9994	0.168	0.2	0.16	0.16	0.17	0.23	0.25	0.247	0.26	0.26	0.26	0.262	0.259	0.257	0.26	0.276	0.28	0.274	0.275	0.271	0.265	0.26	0.243	0.206	0.238
9977	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
9935	0.162	0.1	0.12	0.12	0.13	0.254	0.38	0.337	0.35	0.35	0.35	0.33	0.317	0.314	0.33	0.35	0.36	0.362	0.362	0.351	0.335	0.33	0.313	0.226	0.29
9970	0	0	0	0	0	0	0	1.051	2.59	2.9	2.58	1.856	1.403	0	0	0	0	0	0	0	0	0	0	0	0.516
9911	0.072	0.1	0.07	0.07	0.07	0.087	0.1	0.092	0.1	0.1	0.1	0.098	0.094	0.094	0.1	0.102	0.11	0.108	0.107	0.112	0.107	0.11	0.101	0.084	0.094
9915	0.065	0.1	0.05	0.05	0.07	0.132	0.15	0.145	0.15	0.15	0.14	0.139	0.139	0.143	0.15	0.171	0.18	0.183	0.189	0.171	0.162	0.15	0.132	0.09	0.132
9989	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
9897	4.582	16	22.2	25.9	0	0	0	0	0	0	1.51	20.12	44.32	41.62	39.2	0	21.4	45.66	42.52	39.54	37.16	35.3	50.63	46.29	22.23
9916	0.072	0.1	0.06	0.06	0.07	0.146	0.16	0.159	0.16	0.16	0.16	0.151	0.151	0.154	0.17	0.185	0.19	0.195	0.202	0.183	0.172	0.16	0.14	0.096	0.142
9936	0.12	0.1	0.11	0.11	0.13	0.226	0.28	0.273	0.28	0.29	0.29	0.288	0.286	0.286	0.29	0.299	0.3	0.295	0.285	0.264	0.244	0.23	0.213	0.158	0.236
9932	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
9954	0.558	0.5	0.49	0.52	0.61	1.073	1.31	1.263	1.32	1.35	1.34	1.326	1.316	1.321	1.35	1.373	1.37	1.347	1.301	1.214	1.127	1.07	0.994	0.737	1.09
9927	0.303	0.3	0.26	0.28	0.33	0.593	0.75	0.733	0.77	0.79	0.78	0.775	0.768	0.77	0.79	0.803	0.8	0.789	0.76	0.705	0.648	0.61	0.564	0.41	0.626
9966	0.274	0.2	0.24	0.24	0.26	0.47	0.55	0.482	0.5	0.51	0.5	0.488	0.471	0.47	0.49	0.537	0.55	0.556	0.556	0.536	0.517	0.51	0.481	0.367	0.45
9913	0.02	0	0.01	0.01	0.01	0.025	0.04	0.029	0.03	0.03	0.03	0.034	0.029	0.029	0.03	0.034	0.04	0.039	0.039	0.034	0.034	0.03	0.03	0.025	0.03
9974	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
9982	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
9981	0.255	0.2	0.22	0.24	0.27	0.487	0.6	0.586	0.61	0.63	0.62	0.616	0.613	0.613	0.63	0.639	0.64	0.627	0.605	0.564	0.52	0.49	0.456	0.337	0.504
9960	1.64	1.6	1.6	1.63	0.29	0.402	0.42	0.401	0.43	0.42	0.41	0.4	0.397	0.408	0.43	0.431	0.43	0.434	0.434	0.421	0.405	0.4	0.376	1.884	0.669
9959	0	0	0	0	0.31	0.425	0.44	0.422	0.45	0.44	0.43	0.421	0.418	0.428	0.45	0.451	0.46	0.454	0.454	0.441	0.425	0.42	0.399	0	0.339
9921	0	0	0	0	0.13	0.186	0.2	0.187	0.2	0.2	0.19	0.187	0.187	0.19	0.2	0.2	0.2	0.2	0.2	0.193	0.187	0.19	0.173	0	0.15
9906	0.01	0	0.01	0.01	0.01	0.012	0.01	0.012	0.01	0.01	0.01	0.013	0.013	0.013	0.01	0.013	0.01	0.013	0.013	0.013	0.013	0.01	0.012	0.011	0.012
9978	0.019	0	0.02	0.02	0.02	0.025	0.03	0.025	0.03	0.03	0.03	0.028	0.028	0.028	0.03	0.031	0.03	0.031	0.031	0.028	0.028	0.03	0.025	0.022	0.026
9983	0.034	0	0.03	0.03	0.04	0.051	0.05	0.051	0.05	0.05	0.05	0.051	0.051	0.051	0.05	0.051	0.05	0.05	0.05	0.05	0.051	0.05	0.045	0.039	0.047
9979	0.038	0	0.04	0.04	0.04	0.045	0.04	0.045	0.04	0.04	0.04	0.045	0.045	0.045	0.04	0.045	0.04	0.045	0.045	0.045	0.045	0.04	0.041	0.038	0.043
9969	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
9947	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
9934	0.143	0.1	0.14	0.14	0.14	0.167	0.17	0.174	0.18	0.18	0.18	0.175	0.173	0.173	0.18	0.181	0.18	0.182	0.182	0.177	0.175	0.17	0.166	0.152	0.168
9950	0.715	0.7	0.71	0.71	0.72	0.83	0.86	0.872	0.9	1.42	1.42	1.397	1.394	1.398	1.41	1.428	1.44	1.432	1.427	1.409	1.401	1.38	1.36	1.29	1.167
9976	0.532	0.5	0.52	0.52	0.53	0.603	0.63	0.638	0.66	0.66	0.66	0.643	0.638	0.64	0.65	0.661	0.67	0.669	0.667	0.653	0.645	0.63	0.614	0.569	0.618
9929	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
9940	1.024	1	1.02	1.02	1.05	1.245	1.29	1.321	1.38	1.56	1.56	1.524	1.52	1.528	1.55	1.588	1.61	1.601	1.59	1.563	1.55	1.52	1.474	1.353	1.393
9962	0.173	0.2	0.17	0.17	0.17	0.212	0.22	0.229	0.24	0.24	0.24	0.233	0.229	0.229	0.23	0.244	0.25	0.247	0.244	0.236	0.233	0.23	0.215	0.191	0.218
9956	0.287	0.3	0.28	0.28	0.29	0.345	0.36	0.371	0.39	0.39	0.38	0.375	0.37	0.37	0.38	0.387	0.4	0.395	0.391	0.381	0.377	0.36	0.35	0.314	0.354
9938	0.418	0.4	0.42	0.42	0.43	0.534	0.56	0.577	0.61	0.6	0.6	0.58	0.577	0.579	0.59	0.612	0.63	0.623	0.613	0.6	0.588	0.57	0.547	0.477	0.548
9955	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
9943	0.202	0.2	0.2	0.2	0.2	0.255	0.27	0.277	0.29	0.29	0.29	0.281	0.276	0.279	0.28	0.295	0.3	0.299	0.296	0.286	0.281	0.27	0.261	0.227	0.263
9909	0.247	0.2	0.24	0.24	0.25	0.28	0.3	0.297	0.31	0.3	0.3	0.289	0.286	0.286	0.3	0.309	0.31	0.305	0.299	0.292	0.286	0.28	0.273	0.249	0.281
9975	0.035	0	0.03	0.03	0.03	0.047	0.05	0.043	0.04	0.05	0.05	0.046	0.042	0.042	0.04	0.046	0.05	0.052	0.056	0.054	0.054	0.05	0.049	0.041	0.044
9917	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
9900	1.483	1.2	1.12	1.06	1.2	2.235	3.16	2.877	3	3.03	3.05	2.955	2.851	2.827	2.88	3.067	3.16	3.194	3.148	3.049	2.942	2.86	2.729	2.034	2.547
9991	0	0	0	0	0.46	0.668	0.7	0.663	0.71	0.7	0.69	0.662	0.659	0.68	0.71	0.723	0.73	0.725	0.725	0.699	0.67	0.66	0.621	0	0.536
9998	1.042	1	1	1	1.03	1.378	1.49	1.563	1.67	1.67	1.65	1.589	1.565	1.57	1.6	1.676	1.73	1.724	1.702	1.641	1.6	1.53	1.449	1.217	1.462
9999	0.071	0.1	0.06	0.06	0.06	0.138	0.18	0.177	0.19	0.19	0.19	0.196	0.194	0.179	0.17	0.174	0.16	0.166	0.164	0.154	0.141	0.12	0.114	0.089	0.142
9990	0	0	0	0	0.58	0.813	0.85	0.806	0.86	0.85	0.83	0.808	0.805	0.826	0.86	0.872	0.88	0.875	0.875	0.845	0.816	0.81	0.761	0	0.651
9904	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
9988	0.118	0.1	0.1	0.1	0.1	0.194	0.21	0.199	0.21	0.21	0.21	0.212	0.208	0.204	0.23	0.245	0.25	0.259	0.251	0.246	0.234	0.21	0.195	0.144	0.194
9901	0.511	0.5	0.49	0.49	0.52	0.69	0.69	0.612	0.63	0.64	0.64	0.627	0.618	0.629	0.65	0.701	0.73	0.727	0.732	0.718	0.709	0.72	0.675	0.576	0.634
9899	0.01	0	0.01	0.01	0.01	0.014	0.02	0.016	0.02	0.02	0.02	0.017	0.016	0.017	0.02	0.018	0.02	0.018	0.018	0.017	0.017	0.02	0.015	0.012	0.015
9902	0.019	0	0.02	0.02	0.02	0.023	0.02	0.022	0.02	0.02	0.02	0.023	0.022	0.023	0.02	0.023	0.02	0.023	0.023	0.023	0.023	0.02	0.022	0.02	0.022
9967	0.133	0.2	0.16	0.18	0.27	0.359	0.34	0.342	0.36	0.38	0.35	0.293	0.258	0.269	0.31	0.364	0.4	0.407	0.399	0.357	0.33	0.3	0.209	0.127	0.294
9903	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
10001	0.142	0.1	0.13	0.14	0.14	0.183	0.19	0.175	0.18	0.18	0.18	0.176	0.172	0.173	0.18	0.187	0.19	0.19	0.19	0.187	0.183	0.18	0.174	0.15	0.171
9898	25.65	23	19.8	18.4	18.1	19.5	28.1	34.44	37.5	38.8	39.6	39.84	39.76	39.64	39.3	38.45	38	37.57	37.5	37.02	36.03	34.7	33.46	31.72	32.73
10002	0.915	0.9	0.91	0.88	0.31	0.398	0.48	0.499	0.57	0.57	0.59	0.825	1.126	1.09	1.07	0.582	0.84	1.142	1.101	1.06	1.024	1	1.181	1.083	0.841
10003	0.905	0.9	0.9	0.87	0.31	0.393	0.48	0.493	0.56	0.57	0.59	0.816	1.113	1.077	1.05	0.575	0.83	1.129	1.088	1.048	1.012	0.99	1.167	1.071	0.832
9995	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
9907	0.002	0	0	0	0	0.002	0	0.002	0	0	0	0.002	0.002	0.002	0	0.002	0	0.002	0.002	0.002	0.002	0	0.002	0.002	0.002
10000	0.696	0.7	0.73	0.73	0.77	0.963	0.89	1.696	1.73	1.75	1.73	1.755	1.749	1.728	1.71	1.709	1.71	1.717	1.702	1.681	1.671	1.65	1.598	1.409	1.425
10004	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

A2) Appendix 2: flow in the valves.

The table shows the flow in the valves. The values in the 24 hours and the relative average value are shown.

	t=1	t=2	t=3	t=4	t=5	t=6	t=7	t=8	t=9	t=10	t=11	t=12	t=13	t=14	t=15	t=16	t=17	t=18	t=19	t=20	t=21	t=22	t=23	t=24	
pipe	Q (l/s)	Q (l/s)	Q (l/s)	Q (l/s)	Q (l/s)	Q (l/s)	Q (l/s)	Q (l/s)	Q (l/s)	Q (l/s)	Q (l/s	Q (l/s)	Q (l/s	Q (l/s)	Q (l/s)	Q (l/s)	Q (l/s)	Q (l/s)	Q (l/s)	Q (l/s)	Q (l/s)	Q (l/s)	Q (l/s)	Q (l/s)	averag
9996	0.15	0.14	0.15	0.15	0.16	0.2	0.2	0.2	0.21	0.21	0.21	0.2	0.19	0.18	0.19	0.21	0.21	0.21	0.22	0.21	0.22	0.28	0.25	0.17	0.197
9905	0.66	0.59	0.56	0.56	0.62	1.13	1.35	1.19	1.22	1.25	1.24	1.19	1.13	1.12	1.16	1.28	1.34	1.35	1.35	1.3	1.25	1.23	1.15	0.86	1.087
9918	0.55	0.49	0.45	0.43	0.49	1.05	1.25	1.12	1.15	1.17	1.16	1.11	1.06	1.05	1.09	1.2	1.24	1.26	1.26	1.21	1.17	1.16	1.08	0.82	1.001
9919	1.45	1.2	1.11	1.11	1.36	2.51	2.89	2.84	3.05	3.16	3.15	3.11	3.05	3.01	3.16	3.37	3.44	3.36	3.37	3.31	3.15	2.98	2.73	1.96	2.66
9930	0.75	0.66	0.63	0.65	0.71	1.19	1.43	1.25	1.29	1.32	1.3	1.25	1.19	1.17	1.22	1.36	1.42	1.43	1.44	1.38	1.32	1.3	1.2	0.88	1.156
9914	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
9958	0.16	0.19	0.19	0.22	0.36	0.46	0.45	0.45	0.47	0.49	0.45	0.39	0.34	0.35	0.41	0.46	0.5	0.52	0.51	0.46	0.43	0.39	0.27	0.15	0.378
9908	0.41	0.35	0.31	0.31	0.35	0.61	0.74	0.71	0.77	0.8	0.8	0.78	0.75	0.75	0.77	0.82	0.84	0.83	0.83	0.8	0.77	0.72	0.69	0.53	0.668
9952	0.69	0.57	0.53	0.53	0.64	1.18	1.36	1.34	1.44	1.49	1.49	1.47	1.44	1.42	1.49	1.6	1.63	1.59	1.6	1.57	1.49	1.4	1.29	0.93	1.258
9965	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
9928	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
9971	0.77	0.69	0.66	0.65	0.71	1.18	1.38	1.31	1.35	1.37	1.34	1.28	1.24	1.25	1.28	1.39	1.43	1.43	1.43	1.39	1.33	1.29	1.22	0.95	1.18
9961	1.28	1.1	1.02	1.04	1.31	2.3	2.6	2.56	2.75	2.84	2.82	2.74	2.66	2.64	2.79	3	3.09	3.03	3.03	2.95	2.81	2.63	2.36	1.68	2.376
9985	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
9942	0.03	0.03	0.03	0.03	0.03	0.05	0.06	0.06	0.06	0.06	0.06	0.05	0.05	0.05	0.05	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.05	0.04	0.05
9944	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
9987	0.94	0.83	0.79	0.77	0.86	1.46	1.71	1.62	1.67	1.69	1.66	1.59	1.54	1.54	1.59	1.72	1.77	1.76	1.77	1.72	1.64	1.6	1.51	1.17	1.455
9937	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
9964	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
9923	0.21	0.19	0.18	0.18	0.2	0.32	0.38	0.36	0.37	0.37	0.36	0.35	0.34	0.34	0.35	0.38	0.39	0.39	0.39	0.38	0.36	0.35	0.33	0.26	0.322
9984	0.1	0.11	0.12	0.13	0.21	0.27	0.26	0.27	0.28	0.29	0.27	0.23	0.2	0.2	0.24	0.27	0.3	0.31	0.3	0.27	0.25	0.23	0.16	0.09	0.223
9946	0.38	0.37	0.37	0.37	0.38	0.42	0.44	0.44	0.45	0.45	0.45	0.45	0.45	0.45	0.45	0.45	0.45	0.45	0.45	0.45	0.44	0.43	0.42	0.4	0.428
9926	0.72	0.85	0.88	0.98	1.51	1.99	1.93	1.95	2.06	2.12	1.96	1.66	1.44	1.5	1.74	2.01	2.21	2.29	2.23	2.01	1.85	1.66	1.15	0.67	1.64
9951	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
9920	3.26	2.86	2.75	2.72	3.01	4.82	6.68	6.76	7.07	7.34	7.27	7.17	7.08	6.95	6.59	6.55	6.43	6.33	6.2	5.98	5.7	5.45	5.19	4.09	5.594
9953	9.73	8.24	7.84	7.7	8.37	10.7	11.6	11.43	11.62	11.75	11.7	11.62	11.5	11.51	11.5	11.67	11.73	11.68	11.67	11.53	11.37	11.22	11.07	10.3	10.8
9941	3.51	3.06	2.95	2.91	3.22	5.2	7.13	7.17	7.5	7.78	7.71	7.6	7.49	7.36	7.03	7.03	6.94	6.83	6.71	6.47	6.17	5.9	5.62	4.42	5.988
9986	16.62	16.28	16.13	16.07	16.16	17.28	19.11	19.62	19.89	20.01	20	19.97	20	19.72	19.47	19.26	19.18	19.19	19.06	18.85	18.67	18.48	18.2	17.3	18.52
9997	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
9939	6.34	4.22	3.22	2.76	3.39	9.79	17.41	19.2	20.16	20.56	20.6	20.41	20.5	19.54	18.64	17.89	17.59	17.62	17.12	16.35	15.64	14.88	13.8	9.85	14.48
9924	0.4	0.37	0.36	0.36	0.39	0.55	0.59	0.54	0.56	0.57	0.56	0.54	0.53	0.53	0.56	0.6	0.62	0.62	0.62	0.61	0.59	0.58	0.55	0.46	0.528
9945	2.28	1.99	1.86	1.79	1.87	2.9	4.12	4.17	4.22	4.24	4.25	4.2	4.15	4.05	3.99	4.07	4.1	4.14	4.06	3.93	3.8	3.7	3.53	2.83	3.51
9968	0	0	0	0	0	2.73	5.39	4.64	5.23	5.6	5.51	5.19	4.9	4.85	4.99	5.66	5.94	5.82	5.82	5.39	4.89	4.37	3.95	1.45	3.847
9949	27.43	24.01	21.69	20.72	21.27	32.21	51.92	58.67	62.22	59.6	58.6	55.01	54.3	52.85	51.24	48.91	48.12	48.04	45.84	44.2	42.7	41.54	39.24	32.82	43.47
9963	4.96	4.43	4.29	4.22	4.56	6.69	9.02	9.17	9.59	9.96	9.9	9.79	9.69	9.59	9.12	9.02	8.89	8.77	8.59	8.32	7.97	7.7	7.34	6	7.816
9933	0.57	0.53	0.51	0.51	0.55	0.81	0.88	0.8	0.82	0.83	0.82	0.8	0.78	0.78	0.82	0.88	0.91	0.92	0.91	0.9	0.87	0.86	0.81	0.66	0.772
9980	13.39	11.62	11.21	10.9	11.89	18.15	25.9	26.09	27.87	29.51	29.4	29.01	28.8	28.97	27.07	26.5	26.13	25.65	24.91	23.99	22.82	22.08	20.82	16.67	22.47
9922	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
9948	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
9957	0	0	0	0	0	0	0.2	0.08	1.76	3.16	2.79	2.44	2.67	2.19	1.28	0.88	1.49	1.96	1.21	0.18	0	0	0	0	0.929
9910	0.04	0.01	0.01	0.01	0.02	0.15	0.21	0.15	0.16	0.17	0.16	0.14	0.13	0.13	0.14	0.19	0.22	0.22	0.23	0.23	0.2	0.18	0.17	0.11	0.141
9972	41.09	36.65	33.81	32.37	35.06	60.55	84.41	86.89	87.97	87.58	87.2	86.15	85.8	84.21	81.48	81.12	79.38	79.84	77.81	74.22	70.31	66.9	61.89	50.16	68.87
9973	22.21	19.99	18.6	17.89	19.31	32.69	44.74	45.71	46.12	46.04	45.9	45.54	45.4	44.6	43.17	43.12	42.17	42.44	41.45	39.55	37.45	35.59	32.96	26.86	36.65
9931	1.2	1.01	0.93	0.9	0.97	1.71	2.49	2.33	2.42	2.42	2.38	2.26	2.17	2.14	2.2	2.36	2.46	2.48	2.47	2.41	2.3	2.24	2.14	1.6	2

9925	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
9992	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
9993	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
9994	1.35	1.26	1.23	1.23	1.32	1.75	1.9	1.88	1.96	2	1.99	1.98	1.96	1.94	2	2.08	2.1	2.07	2.08	2.05	2	1.93	1.83	1.55	1.81
9977	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
9935	0.74	0.6	0.54	0.52	0.57	1.12	1.71	1.59	1.65	1.65	1.63	1.54	1.47	1.45	1.5	1.62	1.69	1.7	1.7	1.65	1.57	1.52	1.45	1.04	1.343
9970	0	0	0	0	0	0	0	2.93	7.24	8.11	7.21	5.19	3.92	0	0	0	0	0	0	0	0	0	0	0	1.442
9911	0.45	0.43	0.43	0.42	0.44	0.53	0.62	0.57	0.6	0.62	0.64	0.61	0.58	0.58	0.61	0.63	0.65	0.67	0.66	0.69	0.66	0.66	0.62	0.51	0.578
9915	0.37	0.32	0.3	0.29	0.38	0.75	0.84	0.82	0.83	0.84	0.82	0.79	0.79	0.81	0.86	0.97	1.02	1.04	1.07	0.97	0.92	0.84	0.75	0.51	0.746
9989	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
9897	478	432.1	389.8	351	0	0	0	0	0	0	14.43	189.3	410.99	381.35	356	0	195.3	417.71	389	362.4	339	319.98	455.2	411.7	245.5
9916	0.42	0.36	0.34	0.33	0.43	0.85	0.95	0.93	0.94	0.95	0.93	0.89	0.89	0.91	0.98	1.1	1.16	1.17	1.21	1.1	1.04	0.95	0.85	0.58	0.844
9936	0.61	0.54	0.54	0.56	0.64	1.13	1.41	1.39	1.45	1.5	1.49	1.47	1.46	1.46	1.49	1.52	1.52	1.5	1.45	1.34	1.24	1.16	1.08	0.8	1.198
9932	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
9954	2.87	2.44	2.45	2.64	3.06	5.41	6.79	6.71	7.01	7.22	7.17	7.1	7.03	7.05	7.2	7.34	7.32	7.22	6.97	6.47	5.96	5.59	5.19	3.82	5.751
9927	2.07	1.76	1.76	1.9	2.22	4.04	5.11	5.05	5.28	5.45	5.4	5.35	5.3	5.31	5.43	5.54	5.52	5.45	5.25	4.86	4.46	4.18	3.87	2.81	4.307
9966	1.27	1.14	1.08	1.07	1.18	2.13	2.53	2.25	2.31	2.36	2.33	2.24	2.14	2.12	2.19	2.42	2.51	2.54	2.54	2.45	2.35	2.33	2.17	1.64	2.054
9913	0.04	0.03	0.03	0.03	0.03	0.05	0.08	0.06	0.07	0.07	0.07	0.07	0.06	0.06	0.07	0.07	0.08	0.08	0.08	0.07	0.07	0.07	0.06	0.05	0.06
9974	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
9982	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
9981	1.13	0.97	0.97	1.04	1.2	2.13	2.67	2.64	2.76	2.84	2.82	2.79	2.77	2.77	2.83	2.89	2.88	2.84	2.74	2.55	2.34	2.2	2.04	1.5	2.263
9960	4.78	4.51	4.62	4.71	0.83	1.16	1.23	1.18	1.26	1.24	1.22	1.18	1.17	1.2	1.26	1.27	1.28	1.28	1.28	1.24	1.19	1.18	1.1	5.5	1.953
9959	0	0	0	0	0.89	1.23	1.29	1.24	1.32	1.3	1.28	1.24	1.23	1.26	1.32	1.33	1.35	1.34	1.34	1.3	1.25	1.24	1.17	0	0.997
9921	0	0	0	0	0.38	0.54	0.57	0.55	0.58	0.58	0.56	0.55	0.55	0.56	0.59	0.59	0.6	0.59	0.59	0.57	0.55	0.55	0.51	0	0.44
9906	0.09	0.08	0.08	0.08	0.09	0.11	0.11	0.11	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.11	0.1	0.11
9978	0.07	0.07	0.07	0.07	0.07	0.09	0.1	0.09	0.1	0.1	0.1	0.1	0.1	0.1	0.11	0.11	0.11	0.11	0.11	0.1	0.1	0.09	0.09	0.08	0.093
9983	0.06	0.06	0.06	0.06	0.07	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.08	0.07	0.083
9979	0.11	0.11	0.11	0.11	0.11	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.12	0.11	0.125
9969	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
9947	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
9934	0.56	0.54	0.55	0.55	0.55	0.65	0.67	0.69	0.72	0.72	0.71	0.7	0.69	0.69	0.7	0.72	0.74	0.73	0.73	0.71	0.7	0.68	0.66	0.6	0.665
9950	2.81	2.74	2.75	2.76	2.8	3.24	3.39	3.47	3.61	5.7	5.68	5.6	5.57	5.58	5.61	5.71	5.78	5.76	5.74	5.66	5.61	5.53	5.42	5.12	4.652
9976	2.01	1.97	1.98	1.98	2.01	2.28	2.37	2.41	2.5	2.49	2.48	2.43	2.41	2.42	2.44	2.5	2.54	2.53	2.52	2.47	2.44	2.39	2.32	2.15	2.335
9929	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
9940	10.8	10.48	10.56	10.56	10.75	12.76	13.41	13.78	14.41	16.41	16.33	15.96	15.83	15.87	16	16.48	16.79	16.71	16.6	16.25	16	15.66	15.16	13.85	14.48
9962	0.49	0.47	0.48	0.48	0.49	0.6	0.63	0.65	0.68	0.68	0.68	0.66	0.65	0.65	0.66	0.69	0.7	0.7	0.69	0.67	0.66	0.64	0.61	0.54	0.619
9956	0.64	0.63	0.63	0.63	0.64	0.77	0.81	0.83	0.87	0.87	0.86	0.84	0.83	0.83	0.85	0.87	0.89	0.89	0.88	0.86	0.85	0.82	0.79	0.71	0.795
9938	0.88	0.85	0.86	0.86	0.88	1.1	1.17	1.21	1.28	1.27	1.26	1.22	1.21	1.21	1.23	1.28	1.32	1.31	1.29	1.26	1.23	1.19	1.14	0.99	1.146
9955	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
9943	0.77	0.74	0.75	0.75	0.77	0.97	1.03	1.06	1.13	1.12	1.11	1.08	1.06	1.07	1.08	1.13	1.16	1.15	1.14	1.1	1.08	1.05	1	0.87	1.007
9909	0.81	0.79	0.78	0.78	0.82	0.92	0.98	0.98	1.01	1	0.98	0.96	0.95	0.95	0.99	1.03	1.03	1.02	1	0.98	0.96	0.94	0.92	0.84	0.934
9975	0.17	0.15	0.15	0.15	0.15	0.23	0.25	0.21	0.22	0.23	0.23	0.23	0.21	0.21	0.22	0.23	0.25	0.26	0.28	0.27	0.27	0.25	0.25	0.21	0.22
9917	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
9900	7.61	6.23	5.64	5.33	6.01	11.22	16.06	14.84	15.48	15.68	15.84	15.33	14.77	14.63	14.9	15.82	16.31	16.48	16.24	15.71	15.1	14.68	13.96	10.37	13.09
9991	0	0	0	0	1.32	1.93	2.04	1.95	2.1	2.06	2.02	1.95	1.94	2	2.1	2.13	2.15	2.14	2.14	2.06	1.97	1.95	1.82	0	1.574
9998	1.91	1.81	1.84	1.84	1.89	2.53	2.73	2.85	3.05	3.03	3	2.89	2.85	2.86	2.91	3.05	3.15	3.13	3.09	2.98	2.91	2.79	2.64	2.22	2.665
9999	0.73	0.64	0.61	0.58	0.66	1.42	1.89	1.91	2.01	2.11	2.11	2.13	2.11	1.95	1.85	1.87	1.76	1.78	1.76	1.65	1.5	1.32	1.2	0.93	1.52
9990	0	0	0	0	1.68	2.35	2.48	2.37	2.53	2.5	2.45	2.38	2.37	2.43	2.54	2.57	2.59	2.58	2.58	2.49	2.4	2.38	2.23	0	1.913
9904	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
9988	0.59	0.54	0.5	0.49	0.51	0.97	1.03	1	1.07	1.08	1.08	1.07	1.05	1.03	1.14	1.24	1.29	1.32	1.28	1.26	1.2	1.09	1	0.74	0.982
9901	1.08	1.04	1.02	1.02	1.08	1.43	1.44	1.29	1.33	1.34	1.34	1.32	1.3	1.32	1.37	1.47	1.53	1.53	1.54	1.51	1.49	1.5	1.41	1.2	1.329
9899	0.1	0.1	0.1	0.1	0.1	0.14	0.16	0.16	0.18	0.18	0.17	0.17	0.16	0.17	0.17	0.18	0.18	0.18	0.18	0.17	0.17	0.16	0.15	0.12	0.152
9902	0.36	0.34	0.34	0.34	0.35	0.41	0.44	0.43	0.44	0.45	0.45	0.45	0.44	0.44	0.45	0.46	0.47	0.46	0.46	0.46	0.45	0.44	0.43	0.38	0.423
9967	0.45	0.53	0.54	0.6	0.91	1.21	1.17	1.18	1.25	1.29	1.19	1	0.87	0.9	1.05	1.22	1.34	1.39	1.36	1.22	1.12	1	0.7	0.42	0.996
9903	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
10001	0.71	0.68	0.66	0.67	0.7	0.91	0.96	0.9	0.91	0.92	0.91	0.9	0.88	0.88	0.91	0.96	0.99	0.99	0.99	0.98	0.96	0.95	0.91	0.78	0.875
9898	135	117	102.1	94.73	92.97	100	146	182.2	199	206.3	210.88	212.3	211.55	210.62	208	203.6	201.4	198.96	198.6	195.8	190	182.57	175.5	165.78	172.6
10002	397	357.9	326.3	301.7	104	130.5	169.8	187.9	212.3	218.3	227.06	313.2	422.29	405.21	392	213.2	310.5	420.56	405.4	388.5	371	355.58	416.4	375.69	309.2
10003	392	353.8	322.5	298.3	102.8	129	167.8	185.7	209.8	215.8	224.44	309.6	417.43	400.54	388	210.7	306.9	415.71	400.8	384	366	351.48	411.6	371.36	305.7
9995	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
9907	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
10000	7	6.45	6.18	5.99	6.25	7.92	9.05	9.64	9.85	10.06	9.98	10.14	10.06	9.94	9.79	9.7	9.66	9.7	9.61	9.45	9.37	9.32	9.03	8.06	8.842
10004	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

A3) Appendix 3: pressure in the valves.

The table shows the pressure in the valves. The values in the 24 hours and the relative average value are shown.

	t1	t2	t3	t4	t5	t6	t7	t8	t9	t10	t11	t12	t13	t14	t15	t16	t17	t18	t19	t20	t21	t22	t23	t24	
pipe	deltaH	deltaH	deltaH	deltaH	deltaH	deltaH	deltaH	deltaH	deltaH	deltaH	deltaH	deltaH	deltaH	deltaH	deltaH	deltaH	deltaH	deltaH	deltaH	deltaH	deltaH	deltaH	deltaH	deltaH	averag
9996	1E-04	1E-04	9E-05	1E-04	1E-04	1E-04	2E-04	2E-04	2E-04	0.06	0.171	0.29	0.42	0.55	0.671	0.759	0.746	0.739	0.739	0.738	0.745	0.749	0.744	0.762	0.37
9905	62.99	62.99	62.99	62.99	62.99	62.99	62.98	62.98	62.98	62.98	62.98	62.98	62.98	62.98	62.98	62.98	62.98	62.98	62.98	62.98	62.98	62.98	62.98	62.98	62.98
9918	49.53	50	50.23	50.42	50.55	50.39	49.39	49.08	49.48	49.47	49.5	49.74	50.12	50.45	50.56	50.46	50.08	49.86	49.86	49.82	50.03	50.23	50.35	50.76	50.01
9919	50.12	50.53	50.85	51.09	51.28	51.38	51.23	51.17	51.23	51.21	51.21	51.23	51.26	51.29	51.32	51.3	51.26	51.24	51.24	51.25	51.27	51.31	51.36	51.42	51.17
9930	49.56	50.02	50.24	50.44	50.57	50.41	49.42	49.13	49.52	49.51	49.54	49.78	50.15	50.48	50.59	50.5	50.12	49.9	49.9	49.86	50.08	50.27	50.39	50.79	50.05
9914	72.63	73.6	74.16	74.56	74.8	74.72	73.09	72.27	72.64	72.21	72.05	72.15	72.44	72.73	72.82	72.65	72.27	72.08	72.08	72.15	72.38	72.71	73.11	73.36	72.9
9958	50.03	50.36	50.5	50.67	50.76	50.35	49.33	49.25	49.51	49.42	49.43	49.79	50.37	50.8	50.87	50.64	50.14	49.78	49.78	49.74	50.11	50.4	50.64	51.29	50.16
9908	40.65	41.62	42.19	42.59	42.82	42.74	41.12	40.31	40.68	40.25	40.09	40.19	40.48	40.77	40.86	40.69	40.31	40.12	40.12	40.2	40.42	40.75	41.14	41.4	40.94
9952	49.74	50.27	50.63	50.89	51.08	51.13	50.7	50.52	50.6	50.51	50.47	50.5	50.54	50.6	50.63	50.57	50.44	50.4	50.4	50.44	50.48	50.58	50.69	50.83	50.57
9965	9.739	9.892	9.955	9.978	9.975	9.892	9.502	9.355	9.375	9.284	9.235	9.245	9.276	9.312	9.325	9.252	9.147	9.107	9.107	9.137	9.175	9.249	9.333	9.453	9.429
9928	98.43	98.57	98.67	98.73	98.76	98.69	98.2	97.93	34.8	98.05	97.96	97.97	97.99	98.02	97.98	97.85	97.58	97.41	97.41	97.26	97.26	97.31	97.32	97.42	95.32
9971	50.19	50.5	50.68	50.86	50.98	50.87	50.28	50.2	50.46	50.48	50.54	50.76	51.09	51.37	51.47	51.42	51.15	50.99	50.99	50.96	51.13	51.27	51.36	51.69	50.9
9961	60.96	61.18	61.29	61.44	61.53	61.19	60.45	60.47	60.71	60.69	60.73	61.08	61.63	62.03	62.09	61.92	61.49	61.17	61.17	61.11	61.45	61.68	61.87	62.41	61.32
9985	66.92	67.03	94.69	94.75	94.78	94.72	94.31	94.08	94.26	94.17	94.1	94.1	94.12	94.13	94.1	66.42	93.75	93.6	93.6	93.46	65.89	93.49	65.92	93.57	88.33
9942	49.6	50.05	50.27	50.46	50.59	50.44	49.48	49.2	49.58	49.57	49.61	49.84	50.22	50.54	50.65	50.56	50.19	49.98	49.98	49.94	50.15	50.34	50.46	50.85	50.11
9944	0.175	0.133	0.11	0.095	0.089	0.093	0.182	0.265	0.251	0.244	0.239	0.241	0.237	0.239	0.244	0.247	0.249	0.25	0.25	0.251	0.252	0.238	0.229	0.208	0.209
9987	49.96	50.36	50.57	50.76	50.89	50.75	49.9	49.67	49.98	49.97	50.02	50.26	50.63	50.94	51.04	50.96	50.61	50.41	50.41	50.39	50.59	50.78	50.9	51.28	50.5
9937	26.03	26.51	26.86	27.15	27.38	27.43	26.91	26.76	26.87	26.8	26.79	26.88	26.96	27.09	27.18	27.21	27.2	27.2	27.2	27.23	27.28	27.38	27.49	27.64	27.06
9964	83.23	81.46	80.52	80.12	79.99	80.16	83.42	85.32	85.97	86.33	86.53	86.75	86.95	87.23	87.07	86.7	86.24	86.01	86.01	85.8	85.69	85.36	85.09	84.72	84.7
9923	49.96	50.36	50.57	50.76	50.89	50.75	49.9	49.67	49.98	49.97	50.02	50.26	50.63	50.94	51.04	50.96	50.61	50.41	50.41	50.39	50.59	50.78	50.9	51.28	50.5
9984	50.15	50.47	50.62	50.78	50.87	50.46	49.43	49.35	49.61	49.52	49.52	49.89	50.47	50.9	50.97	50.74	50.23	49.87	49.87	49.83	50.21	50.49	50.75	51.39	50.27
9946	26.01	26.49	26.85	27.14	27.37	27.42	26.87	26.72	26.82	26.74	26.73	26.82	26.9	27.03	27.12	27.15	27.13	27.14	27.14	27.17	27.22	27.33	27.44	27.6	27.01
9926	50.03	50.35	50.5	50.67	50.75	50.34	49.31	49.23	49.49	49.4	49.4	49.77	50.35	50.79	50.85	50.62	50.11	49.75	49.75	49.71	50.09	50.38	50.63	51.28	50.15
9951	50.07	50.07	50.07	50.07	50.07	50.07	50.02	65.13	65.41	65.52	65.56	65.54	65.56	65.54	65.45	65.36	65.28	65.26	65.26	65.21	65.01	64.39	63.95	62.87	60.7
9920	24.96	24.97	24.98	24.98	24.98	24.98	24.94	24.9	24.9	24.89	24.88	24.88	24.88	24.89	24.89	24.9	24.9	24.9	24.9	24.91	24.91	24.92	24.93	24.94	24.92
9953	19.64	20.02	20.32	20.56	20.75	20.87	20.8	20.77	20.83	20.83	20.83	20.85	20.88	20.91	20.92	20.92	20.9	20.89	20.89	20.89	20.91	20.94	20.96	21	20.75
9941	29.06	29.5	29.77	29.87	29.91	29.73	28.68	27.58	27.72	27.47	27.26	27.31	27.42	27.51	27.55	27.7	27.6	27.6	27.6	27.74	27.91	28.11	28.28	28.46	28.22
9986	16.77	18.86	19.97	20.54	20.78	20.5	16.62	14.03	13.64	13.28	13.13	13.13	13.28	13.29	13.57	13.88	14.05	14.1	14.1	14.29	14.6	15.1	15.49	16.24	15.55
9997	59.53	59.94	60.14	60.2	60.24	60.14	59.27	58.28	58.29	58.04	57.8	57.83	57.9	57.94	57.94	58.22	58.29	58.34	58.34	58.52	58.65	58.84	58.95	59.14	58.78
9939	17.24	19.28	20.37	20.93	21.17	20.9	17.09	21.11	20.99	20.82	20.71	20.72	20.79	20.8	20.88	21.04	21.12	21.14	21.14	21.25	21.37	21.57	21.7	21.98	20.67
9924	39.09	39.22	39.33	39.39	39.42	39.35	38.81	38.52	38.77	38.66	38.57	38.59	38.62	38.65	38.61	38.46	38.18	37.99	37.99	37.85	37.85	37.91	37.92	38.04	38.57
9945	24.82	25.09	25.23	25.31	25.33	25.27	24.71	29.11	29.25	29.27	29.19	29.22	29.18	29.17	29.04	29.07	29.08	29.12	29.12	29.13	29.06	28.92	28.8	28.58	27.92
9968	20.62	20.99	21.17	21.34	21.5	21.73	21.78	21.76	21.82	21.83	21.83	21.85	21.88	21.9	21.92	21.92	21.9	21.89	21.89	21.89	21.91	21.93	21.95	21.99	21.72
9949	3.315	1.824	0.994	0.508	0.301	0.46	3.206	15.56	15.28	15.05	15.09	15.15	15.3	15.36	15.56	15.7	15.74	15.79	15.79	15.89	15.83	15.06	14.53	13.18	11.27
9963	32.52	33.13	33.41	33.51	33.57	33.46	32.34	30.85	30.97	30.69	30.5	30.6	30.77	30.91	31.01	31.15	31	31	31	31.17	31.38	31.62	31.8	32.01	31.68
9933	39.04	39.19	39.3	39.36	39.39	39.32	38.74	38.44	38.7	38.59	38.5	38.52	38.55	38.58	38.55	38.39	38.1	37.91	37.91	37.76	37.76	37.83	37.85	37.98	38.51
9980	31.62	32.5	32.92	33.07	33.16	33	31.36	29.36	29.49	29.07	28.73	28.83	29.04	29.18	29.25	29.54	29.46	29.47	29.47	29.75	30.03	30.37	30.6	30.93	30.42
9922	81.93	82.88	83.31	83.47	0	83.39	81.61	79.51	79.77	79.36	79.08	79.22	79.47	79.65	0	79.89	79.66	79.58	79.58	79.83	80.13	80.47	80.7	81.04	73.9
9948	44.55	44.04	43.91	43.99	44.1	44.4	46.06	48.08	48.17	48.61	48.99	48.93	48.78	48.66	48.56	48.17	48.13	48.02	48.02	47.67	47.41	47.07	46.85	46.55	46.99
9957	44.14	44.11	44.11	44.17	44.22	44.36	44.83	44.73	45.01	45.15	45.44	45.44	45.56	45.64	45.67	45.33	45.07	44.83	44.83	44.53	44.45	44.46	44.41	44.37	44.79
9910	57.21	57.67	57.9	58.09	58.22	58.07	57.08	56.76	57.18	57.16	57.19	57.43	57.81	58.14	58.26	58.16	57.76	57.52	57.52	57.48	57.69	57.91	58.03	58.44	57.69
9972	28.85	28.75	28.72	28.7	28.69	28.73	29.12	30.04	30.3	30.51	30.47	30.41	30.28	30.22	30.03	29.9	29.86	29.81	29.81	29.72	29.58	29.48	29.41	29.29	29.61
9973	28.84	28.75	28.72	28.7	28.69	28.73	29.12	30	30.23	30.42	30.39	30.34	30.22	30.17	29.99	29.87	29.83	29.78	29.78	29.69	29.56	29.47	29.39	29.27	29.58
9931	40.34	41.4	41.88	42.12	42.26	42.21	40.66	38.07	38.7	38.4	38.4	38.56	38.99	39.3	39.42	39.21	38.63	38.26	38.26	38.21	38.46	38.87	39.09	39.44	39.55

9925	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
9992	20.89	21.38	21.71	21.958	22.15	22.252	21.94	21.49	21.71	21.64	21.61	21.68	21.78	21.84	21.86	21.87	21.74	21.7	21.69	21.67	21.74	21.81	21.89	21.97	21.75
9993	20.89	21.38	21.71	21.958	22.15	22.252	21.94	21.49	21.71	21.64	21.61	21.68	21.78	21.84	21.86	21.87	21.74	21.7	21.69	21.67	21.74	21.81	21.89	21.97	21.75
9994	21.143	21.48	21.76	21.995	22.18	22.314	22.34	22.35	22.4	22.42	22.43	22.45	22.468	22.49	22.5	22.5	22.49	22.5	22.49	22.49	22.49	22.51	22.52	22.54	22.3
9977	33.335	33.53	33.68	33.774	33.82	33.819	33.75	33.96	33.61	33.59	33.56	33.61	33.555	33.48	33.51	33.62	33.8	33.9	33.94	34.01	34.04	34.06	34.09	34.1	33.76
9935	37.268	37.97	38.3	38.473	38.58	38.572	37.62	36.04	36.43	36.25	36.25	36.35	36.62	36.81	36.89	36.76	36.4	36.2	36.17	36.14	36.3	36.55	36.69	36.9	36.94
9970	61.125	61.44	61.6	61.69	61.74	61.726	61.36	60.92	60.88	60.78	60.74	60.76	60.802	60.83	60.89	60.94	60.92	60.9	60.94	60.98	61.05	61.13	61.19	61.28	61.11
9911	27.254	27.46	27.58	27.693	27.79	27.832	27.53	27.38	27.51	27.45	27.41	27.4	27.444	27.5	27.52	27.54	27.49	27.5	27.48	27.56	27.61	27.7	27.75	27.84	27.55
9915	29.99	29.99	30	29.997	30	29.995	29.98	29.97	29.98	29.97	29.97	29.98	29.977	29.98	29.98	29.97	29.97	30	29.96	29.96	29.96	29.97	29.97	29.98	29.98
9989	44.667	44.48	44.37	44.305	44.26	44.262	44.45	44.67	44.68	44.72	44.74	44.73	44.708	44.69	44.66	44.64	44.65	44.6	44.65	44.63	44.59	44.55	44.52	44.47	44.57
9897	1.6295	6.13	9.69	12.517	14.76	16.385	16.73	16.72	17.35	17.61	17.84	18.06	18.319	18.54	18.71	18.76	18.65	18.6	18.57	18.54	18.61	18.76	18.9	19.1	16.23
9916	29.295	29.28	29.26	29.235	29.21	29.182	29.1	29.03	28.97	28.91	28.85	28.79	28.735	28.68	28.62	28.55	28.46	28.4	28.38	28.22	28.16	28.1	28.05	28.01	28.73
9936	33.447	33.72	33.87	33.956	34.01	34.001	33.72	33.38	33.34	33.27	33.24	33.25	33.291	33.32	33.37	33.41	33.4	33.4	33.41	33.43	33.48	33.53	33.57	33.64	33.52
9932	91.668	91.71	91.72	91.718	91.71	91.699	91.58	91.48	91.49	91.46	91.45	91.45	91.456	91.46	91.46	91.45	91.44	91.4	91.44	91.47	91.51	91.55	91.57	91.6	91.54
9954	33.054	33.5	33.7	33.773	33.79	33.698	32.77	31.98	32.01	31.8	31.68	31.72	31.792	31.84	31.86	31.78	31.7	31.7	31.71	31.87	32.13	32.39	32.55	32.76	32.4
9927	24.897	24.94	24.96	24.96	24.95	24.936	24.79	24.66	24.67	24.64	24.62	24.62	24.629	24.64	24.64	24.62	24.6	24.6	24.61	24.64	24.69	24.74	24.77	24.81	24.73
9966	36.706	37.12	37.33	37.518	37.65	37.502	36.64	36.42	36.76	36.76	36.8	37.03	37.391	37.7	37.81	37.73	37.39	37.2	37.19	37.15	37.35	37.53	37.64	38.02	37.26
9913	83.19	83.39	83.53	83.629	83.72	83.742	83.51	83.37	83.45	83.41	83.41	83.44	83.479	83.53	83.55	83.52	83.45	83.4	83.43	83.49	83.52	83.58	83.66	83.77	83.51
9974	91.578	91.28	91.09	90.955	90.84	90.832	91.17	91.35	91.18	91.21	91.14	91.03	90.912	90.78	90.7	90.71	90.77	90.7	90.74	90.49	90.41	90.26	90.11	89.89	90.84
9982	38.27	38.61	38.78	38.85	38.88	38.819	38.19	37.68	37.71	37.56	37.49	37.52	37.577	37.61	37.62	37.57	37.51	37.5	37.51	37.59	37.75	37.9	38	38.14	37.94
9981	38.27	38.61	38.78	38.85	38.88	38.818	38.19	37.68	37.71	37.55	37.49	37.52	37.577	37.61	37.62	37.57	37.51	37.5	37.51	37.59	37.75	37.9	38	38.14	37.94
9960	58.304	58.63	58.8	58.866	58.89	58.841	58.25	57.77	57.8	57.65	57.59	57.62	57.669	57.7	57.71	57.67	57.61	57.6	57.61	57.69	57.83	57.97	58.07	58.2	58.01
9959	58.238	58.57	58.74	58.801	58.83	58.772	58.17	57.77	57.82	57.66	57.62	57.65	57.71	57.74	57.73	57.66	57.61	57.6	57.6	57.64	57.76	57.89	57.96	58.1	57.98
9921	57.932	58.25	58.47	58.583	58.66	58.631	58.16	57.8	57.84	57.68	57.63	57.66	57.716	57.74	57.74	57.67	57.61	57.6	57.6	57.6	57.67	57.74	57.77	57.85	57.9
9906	18.5	18.78	18.95	19.067	19.16	19.142	18.72	18.53	18.61	18.53	18.5	18.53	18.578	18.64	18.67	18.61	18.51	18.5	18.47	18.55	18.59	18.68	18.79	18.94	18.69
9978	47.271	47.51	47.67	47.778	47.87	47.864	47.52	47.32	47.41	47.34	47.34	47.38	47.436	47.49	47.51	47.45	47.35	47.3	47.3	47.39	47.42	47.5	47.6	47.74	47.49
9983	95.593	95.91	96.13	96.256	96.34	96.318	95.86	95.5	95.55	95.38	95.34	95.36	95.417	95.45	95.44	95.38	95.31	95.3	95.3	95.3	95.36	95.43	95.46	95.53	95.59
9979	58.471	58.77	59.01	59.152	59.25	59.232	58.8	58.47	58.51	58.35	58.3	58.31	58.369	58.4	58.39	58.33	58.26	58.2	58.24	58.23	58.29	58.35	58.37	58.43	58.52
9969	32.846	33.15	33.38	33.53	33.63	33.613	33.2	32.89	32.93	32.77	32.72	32.72	32.778	32.8	32.8	32.74	32.67	32.7	32.65	32.63	32.67	32.73	32.75	32.81	32.92
9947	45.53	45.47	45.45	45.459	45.46	45.469	45.59	45.63	45.66	45.7	45.69	45.69	45.665	45.66	45.66	45.67	45.7	45.7	45.72	45.71	45.68	45.67	45.64	45.61	45.62
9934	43.371	43.67	43.75	43.73	43.73	43.679	43.06	42.83	42.7	42.46	42.48	42.51	42.649	42.7	42.68	42.62	42.45	42.3	42.33	42.4	42.54	42.62	42.76	42.94	42.87
9950	43.216	43.5	43.59	43.566	43.56	43.515	42.91	42.7	42.57	42.35	42.37	42.4	42.528	42.57	42.56	42.5	42.34	42.2	42.23	42.3	42.42	42.5	42.63	42.8	42.74
9976	44.958	44.96	44.97	44.965	44.97	44.964	44.95	44.95	44.94	44.94	44.94	44.94	44.943	44.94	44.94	44.94	44.94	44.9	44.94	44.94	44.94	44.94	44.95	44.95	44.95
9929	91.335	91.3	91.27	91.229	91.19	91.154	91.1	91.05	91	90.95	90.9	90.85	90.802	90.76	90.71	90.66	90.6	90.6	90.55	90.45	90.4	90.36	90.31	90.27	90.82
9940	16.131	16.32	16.42	16.477	16.54	16.581	16.35	16.28	16.25	16.17	16.2	16.23	16.309	16.36	16.37	16.37	16.31	16.3	16.27	16.34	16.41	16.46	16.52	16.6	16.36
9962	59.98	59.98	59.98	59.985	59.98	59.984	59.98	59.97	59.97	59.97	59.97	59.97	59.971	59.97	59.97	59.97	59.97	60	59.97	59.97	59.97	59.97	59.97	59.97	59.97
9956	76.269	76.25	76.21	76.176	76.14	76.099	76.02	75.97	75.91	75.85	75.8	75.75	75.711	75.67	75.62	75.57	75.51	75.4	75.45	75.35	75.31	75.26	75.22	75.19	75.74
9938	80.789	81.59	82	82.185	82.41	82.499	81.36	80.99	80.88	80.52	80.63	80.75	81.074	81.25	81.29	81.24	80.98	80.8	80.78	80.92	81.15	81.3	81.57	81.94	81.28
9955	0.0013	0.001	9E-04	0.0009	9E-04	0.001	0.002	0.002	0.002	0.002	0.002	0.002	0.0021	0.002	0.002	0.002	0.002	0	0.003	0.002	0.002	0.002	0.002	0.002	0.002
9943	44.573	44.68	44.71	44.699	44.7	44.681	44.46	44.37	44.32	44.23	44.24	44.25	44.306	44.32	44.32	44.29	44.23	44.2	44.18	44.21	44.26	44.29	44.35	44.42	44.39
9909	51.883	51.83	51.78	51.735	51.69	51.63	51.55	51.48	51.41	51.34	51.27	51.2	51.139	51.07	51.01	50.94	50.86	50.8	50.79	50.64	50.57	50.5	50.44	50.37	51.16
9975	34.979	34.93	34.88	34.831	34.78	34.73	34.66	34.58	34.52	34.45	34.38	34.31	34.247	34.18	34.12	34.05	33.98	33.9	33.9	33.75	33.68	33.61	33.54	33.47	34.27
9917	74.887	73.62	72.92	72.502	72.28	72.394	74.62	87.08	87.23	87.27	87.23	87.13	87.076	86.98	86.86	86.73	86.63	86.5	86.54	86.35	86.07	85.26	84.68	83.34	82.59
9900	33.104	33.5	33.7	33.809	33.87	33.85	33.43	32.94	32.89	32.78	32.73	32.75	32.793	32.83	32.89	32.93	32.92	32.9	32.93	32.98	33.06	33.15	33.22	33.32	33.14
9991	58.235	58.56	58.73	58.799	58.83	58.77	58.17	57.77	57.82	57.66	57.62	57.65	57.709	57.74	57.73	57.66	57.61	57.6	57.6	57.64	57.76	57.89	57.96	58.09	57.98
9998	92.697	92.5	92.47	92.49	92.5	92.544	92.99	93.16	93.27	93.46	93.44	93.41	93.311	93.28	93.31	93.36	93.5	93.6	93.6	93.54	93.43	93.37	93.26	93.13	93.15
9999	16.418	16.52	16.56	16.582	16.59	16.556	16.16	15.77	15.72	15.64	15.59	15.59	15.606	15.63	15.74	15.81	15.81	15.9	15.88	15.89	15.97	16.06	16.16	16.23	16.01
9990	58.236	58.56	58.73	58.799	58.83	58.771	58.17	57.78	57.82	57.66	57.62	57.65	57.711	57.74	57.73	57.66	57.61	57.6	57.6	57.64	57.76	57.89	57.96	58.1	57.98
9904	42.739	43.18	43.36	43.465	43.54	43.56	42.87	41.3	41.9	41.79	41.89	42.01	42.335	42.56	42.62	42.4	41.94	41.6	41.59	41.44	41.49	41.68	41.75	41.9	42.29
9988	33.893	33.92	33.95	33.973	34	34.018	33.92	33.85	33.82	33.76	33.71	33.67	33.635	33.61	33.58	33.51	33.41	33.3	33.33	33.21	33.16	33.13	33.12	33.11	33.61
9901	80.351	81	81.42	81.721	81.95	81.953	80.98	80.65	80.83	80.65	80.59	80.67	80.792	80.95	81.07	80.98	80.79	80.7	80.73	80.8	80.89	81.08	81.29	81.58	81.02
9899	17.037	17.04	17.04	17.043	17.04	17.042	17.03	17.03	17.03	17.02	17.02	17.02	17.026	17.03	17.03	17.03	17.02	17	17.02	17.02	17.02	17.03	17.03	17.03	17.03
9902	8.7549	9.104	9.311	9.4386	9.528	9.4808	8.893	8.635	8.724	8.608	8.564	8.595	8.6469	8.717	8.754	8.672	8.528	8.48	8.484	8.567	8.619	8.739	8.881	9.078	8.825
9967	50.032	50.36	50.51	50.672	50.76	50.352	49.33	49.25	49.51	49.43	49.43	49.79	50.37	50.8	50.87	50.64	50.14	49.8	49.78	49.74	50.11	50.4	50.65	51.29	50.17
9903	40.836	41.68	42.08	42.291	42.42	42.404	41.23	39.26	39.75	39.52	39.53	39.65	39.979	40.22	40.31	40.15	39.71	39.4	39.42	39.39	39.58	39.89	40.06	40.33	40.38
10001	33.861	34.06	34.19	34.256	34.28	34.194	33.46	33.11	33.43	33.3	33.2	33.23	33.278	33.32	33.29	33.11	32.76	32.5	32.55	32.4	32.41	32.5	32.53	32.69	33.25
9898	32.218	32.7	32.94	33.071	33.14	33.118	32.65	32.12	32.05	31.93	31.88	31.89	31.935	31.97	32.03	32.08	32.07	32.1	32.08	32.13	32.22	32.32	32.39	32.51	32.31
10002	0.392	0.443	0.476	0.4972	0.513	0.5181	0.485	0.451	0.453	0.447	0.445	0.448	0.4529	0.457	0.461	0.464	0.461	0.46	0.461	0.464	0.469	0.476	0.482	0.49	0.465
10003	0.392	0.443	0.476	0.4972	0.513	0.5181	0.485	0.451	0.453	0.447	0.445	0.448	0.4529	0.457	0.461	0.464	0.461	0.46	0.461	0.464	0.469	0.476	0.482	0.49	0.465
9995	21.143	21.48	21.76	21.995	22.18	22.314	22.34	22.35	22.4	22.42	22.43	22.45	22.468	22.49	22.5	22.5	22.49	22.5	22.49	22.49	22.49	22.51	22.52	22.54	22.3
9907	38.595	38.59	38.59	38.595	38.59	38.595	38.59	38.59	38.59	38.59	38.59	38.59	38.595	38.59	38.59	38.59	38.59	38.6	38.59	38.59	38.59	38.59	38.59	38.59	38.59
10000	16.881	18.99	20.12	20.705	20.96	20.665	16.73	29.9	29.76	29.54	29.42	29.41	29.542	29.53	29.7	29.93	30.05	30.1	30.08	30.22	30.3	30.15	30.07	29.69	26.77
10004	16.882	19	20.12	20.705	20.96	20.665	16.73	29.9	29.76	29.54	29.42	29.41	29.542	29.53	29.7	29.93	30.05	30.1	30.08	30.22	30.3	30.15	30.07	29.69	26.77