Maximising the Efficiency and $\Delta T$ in Water Distribution Systems

Tony Khoury Arabian Controls
Umesh Nair Pettinaroli Middle East
Martin Lowe - M Lowe Consulting

QATAR November 2018
• Introduction of Pettinaroli support Personnel
• History of Pettinaroli the last 80 years
• Pettinaroli support,
  • Technical support, Seminars, CPD’s,
  • Technical committees
  • Testing
• Types of PICV, Axial, Rotary, Equal Percentage/Linear
• Dynamic Curve
• Control Curve
• Delta T Syndrome
• Materials PICV valve manufactured from
• Flushing By-pass and Assemblies
Local & Technical support team

Tony Khoury
General Manager
Arabian Controls

Giorgio Simonotti
Pettinaroli
Commercial Manager Middle East

Umesh Nair
Pettinaroli Middle East local Technical & Area Manager
Controls Engineer Siemens Dubai Controls Engineer

Martin Lowe
Water Distribution Consultant
Technical Director Marflow Hydronics
Design Engineer M733 Hattersley
Product Manager Hattersley
Technical Manager T&A
An Italian company founded in 1938
1938  Year of foundation
1940  II World War
1945  Reopening
1954  The American dream
1970  Second generation
1975  BSI certification
1988  50 Years Anniversary
1990  Internationalization
80 years of history

1998 60 years anniversary

2001 Giuseppe passes away

2003 Foreign logistic centers

2008 Mario passes away

2009 Pettinaroli EvoPICV

2013 Pettinaroli Museum

2018 80 years of experience
Today Fratelli Pettinaroli is a group including 9 companies:

- Two manufacturing companies located in Italy.
- Five logistic centers abroad.
- Two offices abroad.

265 people of working and selling force.
Presence of our products in the market through private labels only.

Markets served by dealers and partners with national exclusivity.

Markets served by our sister companies and logistic centers.

Headquarters.
Pettinaroli Factory Support
More than 30 Approvals worldwide with 20 international bodies

Unique valve code
Valve Testing at Pettinaroli

Contaminated water test Rig

Valve Testing
Pettinaroli supports European Standard for PICV

**PI Curve DN20 Vnom 980l/h**

### Specified values

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Unit</th>
<th>Value</th>
<th>Has preset values</th>
<th>Number preset values &gt;= 10</th>
<th>Clear scale preset</th>
<th>Test points</th>
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### Measurement

#### Pressure Increasing curve

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<th>Pressure</th>
<th>Flow measured</th>
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#### Pressure Decreasing curve

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<tr>
<td>75</td>
<td>735</td>
<td>90</td>
</tr>
</tbody>
</table>

### Values for calculation

- **Vset (l/h)**: 735
- **Veff max 2.5 (l/h)**: 756 measured increasing curve (sector 2.5mindp to max dp)
- **Veff min 2.5 (l/h)**: 684 measured increasing curve (sector 2.5mindp to max dp)
- **V eff (l/h)**: 684 measured decreasing curve
- **Veff max (l/h)**: 756 measured increasing curve (sector mindp to max dp)
- **Veff min (l/h)**: 650 measured increasing curve (sector mindp to max dp)
- **V hyst max (l/h)**: 60 measured increasing curve (sector 2.5mindp to max dp)

### Calculated values

<table>
<thead>
<tr>
<th>Points</th>
<th>Features max</th>
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<tbody>
<tr>
<td>15</td>
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</table>
Types of PICV, Axial, Rotary, Equal Percentage/Linear

- Three Types of PICV
- Equal Percentage Axial ½”- 1 ¼” DZR and 2” to 12” SG Iron
  - Full Stroke
- Rotary ½” to 1 ¼” DZR and 1 ½” to 2” SG Iron
  - Reduced Stroke
- Linear Axial ½”- 3/4” DZR and 2” to 12” SG Iron
  - Reduced Stroke
PICV Type 1

A Combined DPCV, control valve, flow regulation

1) DPCV valve P1 – P3
2) Two Port Control valve
3) Pre-settable maximum flow rate

- Authority calculation
- Complex pipeline
- Need for commissioning
- High running cost
- Low ΔT Syndrome
PICV Type 2

A Combined DPCV, control valve, flow regulation

1) DPCV valve P1 – P3
2) Two Port Control valve & Adjustable Flow

- Authority calculation
- Complex pipeline
- Need for commissioning
- High running cost
- Low ΔT Syndrome
PICV Type 3

Pressure Differential Sensor

FCU

FCU

FCU

Chiller

VFD-Pump

\[ \Delta P \]

A Combined DPCV, control valve, flow regulation

1) DPCV valve P1 – P2
2) Two Port Control valve & Adjustable Flow
3) Linear Characteristic
4) Dirt Resistance

- Authority calculation
- Complex pipeline
- Need for commissioning
- High running cost
- Low \( \Delta T \) Syndrome
PICV
Features, Balancing & Testing
What is a PICV?

2 Main key features

- Start Up
  - Dynamic curve
- Flow Limitation
  - BSRIA BST No 1 (4.3)

- Control curve
  - Equal percentage
- Linear
  - BSRIA BST No 1 (4.2)
BALANCING

Energy Generated

Energy Distributed

Energy Supplied
BSRIA Test Rig Bracknell England

Report

EVOPICV tests

Report 53957/1
March 2010

Carried out for: Marflow Hydronics Ltd
Britannia House
Austin Way
Hamstead Industrial Estate
Hamstead
Birmingham
B42 1DU

On behalf of: Fratelli Pettinaroli S.p.A.
Via Planelli, 38
28017 San Maurizio d'Opaglio
Novara
Italy

More BSRIA Testing 2018 to BST No 1
4.3 FLOW LIMITATION (PRESSURE INDEPENDENCE)
This test indicates any hysteresis in the PICV flow rate performance as differential pressure rises and falls across its full range. The system shall be used to raise the differential pressure from the minimum to maximum setting of each PICV, and from the maximum back to minimum at two flow pre-settings of 30% and 100%. No actuator will normally be fitted for this test (unless requested by the manufacturer). Tests will then be conducted over the range 0-400-0 kPa for three valves and 0-600-0 kPa for two valves based on information received.

4.2 CONTROL CHARACTERISTIC TEST
The purpose of this test is to analyse the flow characteristics of the valve with an actuator in full operation. The valve’s flow rate shall be initially set to the maximum rated flow pre-setting position. The system shall be used to provide a constant differential pressure which shall be maintained during the test. A stepped signal shall be used to drive the valve from fully open to fully closed and back to fully open in suitable increments. No less than 20 increments shall be used in each direction with suitable timed allowed to settle at each increment. The stepped signal will be raised in 0.2V increments from 0.2V to 5V, and 0.5V increments from 5V to 10V. The step signal will then be decreased in 0.5V increments from 10V to 5V, and in 0.2V increments from 5V to 0.2V.

The test will be carried out at 1 bar differential pressure setting. The characteristic will be repeated at 75%, 50% and 30% pre-setting.
Start-Up Pressure

- Lower the start-up lesser the pumping cost
- Measurement of actual pressure drop across the valve
- Uniform range of start-up throughout the range
Figure 8  Flow Limitation Test - PICV 91L - 1/2" @ 100% 30% setting

Flow Limitation Test - PICV 91L - 1/2"

- **Flow rate (l/s)**
  - Setting 100%
  - Setting 30%

- **Pressure Difference (kPa)**

Graph showing the flow rate in liters per second (l/s) against the pressure difference in kilopascals (kPa) for two settings: 100% and 30%.
Pressure Measurement

Valve 1 Start Up PICV 25 Kpa
Index Circuit Ensure 25 kPa Measured across Valve
Valve 2 Start Up PICV 35 Kpa
Index Circuit Ensure 35 kPa Measured across Valve
Example of Start-Up Pressure ‘What it means’

Index circuit
Differential pressure as closest as possible to start-up.
Lower the start-up = lower the pump head.
Valve 1 Start Up = 25 kPa
Valve 2 Start Up = 35 kPa
10 kPa difference

Pump electrical power: \( P_e = \frac{G \cdot \Delta p}{\eta_e} \)

1

\[
\begin{align*}
G &= 1 \text{ m3/s} \\
\Delta p &= 355 \text{ kPa} \\
\eta_e &= 0.4 \\
P_e &= 887.5 \text{ kW}
\end{align*}
\]

2

\[
\begin{align*}
G &= 1 \text{ m3/s} \\
\Delta p &= 365 \text{ kPa} \\
\eta_e &= 0.4 \\
P_e &= 912.5 \text{ kW}
\end{align*}
\]

\( \Delta P_e = 25 \text{ kW} \)

To provide 10 kPa more at index circuit, pump head must increase 10 kPa at least.
Case study in Oman:

Difference of hydraulic power due to higher start-up at the index: $0.973 \text{ m}^3/\text{s} \times 12 \text{ kPa} = 11.68 \text{ kW}$ if we assume a global efficiency of 0.4 $\text{Pel} = \frac{11.68}{0.4} = 29.2 \text{ kW}$.

If the load is half of the max one along the year, if the system works all the year long (8760 hr) and the pump head decreases 40% due to lower flow rate, energy waste for higher start-up is: $E = (29.2 \times 0.6) \times 8760 \text{ h/y} \times 0.5 = 76.738 \text{ kWh/y} = 76.7 \text{ MWh/y}$
Accessibility of pre-setting

- Verification of the actual setting becomes easy
- Can be modified without removing actuator
- Inspecting the valve max flow rate available
Stroke of the valve

- **Stroke plays an important role in the control ability**
- **Higher the stroke the better the control**
- **Actuators cannot cope with the stroke & EQM**

1. **Once preset the valve, the available stroke for controlling the room temperature could be very small.**
2. **Equal-percentage characteristic is lost.**

- i.e.: 900 l/h max, presetting 80%; stroke max 2.25 mm
- 720 l/h
  - Available stroke: 1.8 mm
Control Curve and Delta T
PICV Control Curve

- Coil Curve
- Valve Curve
  - On/Off
  - Linear
  - Equal Percentage
- Valve Stroke
  - Full Stroke
  - Reduced Stroke
The designer combines the valve flow characteristic with the coil performance curve (heating or cooling) to ensure the proper heat transfer characteristic. (Figure 17). For a typical hydronic heating or cooling coil, the coil output (Figure 17A) increases rapidly and begins to slow as it nears the design point. Mating this coil output with its mirror image in flow percentage (i.e., the equal percentage flow characteristic) as shown in Figure 17B results in a linear coil output (Figure 17C).

The three flow patterns are obtained by imposing a constant pressure drop across the modulating valve, but in actual conditions, the pressure drop across the valve varies between a maximum (when it is controlling) and a minimum (when the valve is near full open). The ratio of these two pressure drops is known as authority. Figures 18 and 19 show how linear and equal-percentage valve flow characteristic are distorted as the control valve authority is reduced because of a reduction in valve pressure drop. The quick-opening characteristic, not shown, is distorted to the point that it approaches two-position or on/off control. The selection of the control valve pressure drop directly affects the valve authority and should be at least 25 to 50% of the branch pressure drop (i.e., the pressure drop from the branch connection from the supply main to return main, including the piping, fittings, coil, balancing device, and control valve). The location of the control valve in the system results in unique pressure drop selections for each control valve. A higher valve pressure drop allows a smaller valve size and better control, but also higher friction energy losses.
Valve Characteristic

Control Valve Flow Characteristics

Based on the characteristics of the valve, three distinct flow conditions are possible (Figure 16):

- **Quick Opening.** When started from the closed position, a quick-opening valve allows a considerable amount of flow through a small opening of the valve. As the valve moves toward the full open position, the rate at which the flow is increased is reduced in a nonlinear fashion. This characteristic is used in two-position or on/off applications, because it is very difficult to position the stem accurately enough for low and medium flows in modulating applications.

- **Linear.** Linear valves produce equal flow increments per equal increments of the valve moving towards the full open position. This characteristic is used on steam coil terminals, bypass applications, and sometimes in the bypass port of three-way valves.

- **Equal Percentage.** This type of valve produces an exponential flow increase as the valve moves from the closed to the open position. The term equal percentage means that for equal increments of the valve opening, the flow increases by an equal percentage. For example, in Figure 16, if the valve is moved from 50 to 70% of full stroke, the percentage of full flow changes from 10 to 25%, an increase of 150%. Then, if the valve is moved from 80 to 100% of full stroke, the percentage of full flow changes from 40 to...
What Control Characteristic is Preferred?

Control curve

- **Power Output**

Control Signal (%) vs. Heat Output (%)

- Black line represents the preferred control characteristic.
6.2.1 91L - PICV ½” FXF 600 L/H

Figure 34, Figure 35, Figure 36 and Figure 37 show the test results for the control characteristic tests accordingly.

Figure 34 Control Characteristic Tests - 100% Setting

Flow 100 % set value vs volts at 100kPa
Controlling the $\Delta T$
What is ∆T Syndrome

Design mass Flow rate is calculated from the equation below =

Required Power (kW) = mass flow Kg/s x Heat Capacity of water KJ/Kg x (ΔT)°C

Heat Capacity of water 4.189

ΔT changes 6° (UK) 9° Middle East Measured in absolute units

Power required calculated from Thermal Load on individual rooms in kW

Symbols Metric and Imperial

Power kW = Q \text{ BTU’s}

Mass Flow rate = \dot{m} \text{ kg/s (one Litre of water = 1 Kg GPM (USA)}}

Temperature = ΔT° C Degrees \text{ Fahrenheit °F}

Heat Capacity of water = Cp KJ/kg K
ΔT Syndrome is When the difference between Flow temperature and return temperature reduce

Flow 44°F

Return 56°F Design

Return 54°F Lower
3000 (25%) Linear
3000 (43%) EQP
Delta T Syndrome

2 ways the system will try to deal with ΔT Syndrome

Chiller Solution
Maintains the ΔT
Lower supply temperature
More Compressor Power

Heat Exchanger Solution
ΔT is Lower
Flow rate increases
More pump power
ΔT Effects on Chiller
Delta T

Chiller:

- Being power output the same, delta T between evaporator and cold water must be the same.

- If the coming water is colder (light green line), the evaporator (especially overheating) must be colder: so pressure must be lower!

- Lower evaporating pressure (dark red line) means higher compression rate: more energy must be used!
What is ΔT Syndrome

Water enter the chiller at a lower supply temperature (10 instead of 12) and therefore a lower ΔT (5 instead of 7), than designed but with the same 'Power Output' requirement.

Equation Balance \( kW = \text{mass flow rate} \times \text{Cp} \times (\Delta T \text{ this is now lower}) \)

Two scenario's
If the flow rate remains the same. Then to achieve the same power output the supply temperature must also drop below the design value. If supply was 5 then it must drop to 3? to main the same power output. To supply a lower output temperature in the Chiller the compressors have to work harder using more electricity. Hence the Green Line on the graph.

\[ KW \text{ Constant} = \text{mass flow rate constant} \times \text{Cp constant} \times (\Delta T \text{ Constant new return 10-3 = 7 instead of Design 12-5 = 7}) \]

Result Lower supply water temperature of 3 degrees.

\[ 700 \text{ kW} = 23.86 \text{ l/s} \times 4.189 \times (7) \text{ Supply now at 3} \]

If ΔT keeps getting lower the Chiller will freeze up?
Data
- Chiller load #1 = 90%
- Chiller load #2 = 0%
- Flow rate = 77.9 m³/h
- Chiller $\Delta T = 7^\circ C$

Design:
- 1.400 kW CHW
- $7^\circ C \Delta T$ Design

Flow rate 77.9 m³/h
Thermal power: \( P = G \cdot c_p \cdot \Delta T \)

**Data**
- Chiller load #1 = 45\%
- Chiller load #2 = 45\%
- Flow rate = 90.3 m\(^3\)/h
- Chiller \( \Delta T = 6^\circ \)C

**Flow rate increase 16\%**

*It needs to start the second pump and chiller to meet the higher flow rate demand, NOT THERMAL POWER!*

**Design:**
- 1.400 kW CHW
- 7°C\( \Delta T \) Design

If colder water comes from end users, being equal the thermal power, it needs to increase the flow rate. That's what happens in district cooling in middle east: if you don't meet the \( \Delta T \), you must pay a huge fee.
API3
Endress+Hauser

DHCC/AP-13

T cold  4.5 °C
T warm  11.7 °C
ΔT      7.2 °C

S/N: M7042C043BC
ΔT Effects on District Cooling
Heat Exchange Thermal power: \( Q = \dot{m} \cdot c_p \cdot \Delta T \)

District Cooling
Out 10.98° C

District Cooling
In 4°C

Delta T 6.98°C

Building Cooling
In 12°C

Building Cooling
Out 5° C
Heat Exchange Selected for Design Conditions

**Heat Exchanger: B649 H+HTx318**

### Side 1: Inner circuit
- **DUTY REQUIREMENTS**
  - Heat load kW: 700.0
  - Inlet temperature °C: 12.00
  - Outlet temperature °C: 10.88
  - Flow rate l/s: 23.88
  - Thermal length m: 6.925

- **PLATE HEAT EXCHANGER**
  - Total heat transfer area m²: 207
  - Heat flux W/m²: 1.38
  - Mean temperature difference K: 1.01
  - O.H.T.C. (available/required) W/m²°C: 3320/3360
  - Pressure drop - total kPa: 52.1
    - In ports kPa: 0.964
    - Out ports kPa: 0.981
  - Port diameter mm: 150/150 (up/down)
  - Number of channels per pass: 60/40HT
  - Number of plates: 318

### Side 2: Outer circuit
- **DUTY REQUIREMENTS**
  - Heat load kW: 12.00
  - Inlet temperature °C: 10.88
  - Outlet temperature °C: 12.00

- **PHYSICAL PROPERTIES**
  - Reference temperature °C: 7.46
  - Dynamic viscosity µP: 1.41
  - Dynamic viscosity - wall µP: 1.37
  - Density kg/m³: 999.9
  - Heat capacity kJ/kg°C: 4.184
  - Thermal conductivity W/m°C: 0.5703
  - Minimum wall temperature difference °C: 4.47
  - Maximum wall temperature °C: 11.48
  - Film coefficient W/m²°C: 7970
  - Average wall temperature °C: 7.97
  - Channel velocity m/s: 0.157
  - Shear stress Pa: 45.2

*Excluding pressure drop in connections.*
Temperature drops from 10.98 to 9.41
= 1.57°C
= 3.6°F
3.6 °F x 7%
= 25% payback
Increased pumping Flow and Pressure
District Cooling

Heat exchanger (District Cooling) cannot work lower than the design supply water temperature of 5 degree's but the same power is required then the flow must increase (if allowed) to compensate for the smaller Delta T.

\[ 700 \text{ kW} = 25.84 \text{ l/s (increased)} \times 4.189 \times (\text{Delta T of 5 decreased}) \]
Materials of Construction
PICV Valve and assembly Materials and jointing

- Stress Corrosion Cracking SCC
  - Stressed brass fractures (Chilled Water Systems)
- Materials
  - Brass Bar and Forgings
  - DZR Brass Bar and Forgings
  - Heat Treated after Machining
- Jointing
  - Female parts always use Forgings
  - Male Parts made from Bar
  - Assemblies constructed using Parallel Threads
  - ‘O’ Ring seals
  - Part Glue joints
Failures due to Stress Corrosion

- Material under constant pressure
- Male Tapered Thread screwed into a Female thread
- Material already stress from machining process
- Extra stress and the present of Ammonia
- Chilled water

Result = Component cracks leaks
Different Brass Materials for different locations
- Brass European,
- Brass Asia,
- Claiming the same EN number but different

- Dezincification-resistant Brass
  - Part of the manufacturing process is to ‘heat treat after machining’
  - Heat treating reduces the stress by changing the grain structure
- Always use forgings for female parts stronger grain structure
Type of Brass used

- Valves with CW602N Body material are DZR Brass
- Valves with CW617N body material are simple Forged Brass
  - CW602N Brass, which contains the appropriate corrosion inhibitors, is annealed at high temperatures and then cooled at a controlled rate. This allows for the best alloy structure against dezincification.
Kits
PICV Valve and assembly Materials and jointing

- **Jointing**
  - Female parts always use Forgings
  - Male Parts made from Forging but Bar is fine
  - Assemblies constructed using Parallel Threads
  - ‘O’ Ring seals
  - Part Glue joints
PICV Valve and assembly Materials and jointing

**Advantages**
Connecting kit for terminal units
Reduced on-site labour time
Factory tested for minimum leakage risk
100% made in Italy with patented technology
Flexible and bespoken configuration (automatic, manual balancing)
No flushing thru control valve (100% safe). Very Important in case of any PICV’s
Customized Insulation (Class 1 fire rated)
ASTM fire rated hoses
No Dielectric union required
The complete range
Balancing mode

Flushing mode
Large size PICV

2" up to 10"

Ductile iron body

Special multi/function actuator
Pettinaroli – Pressure Independent Control Valves Range

**Threaded**

½" - 150 l/h to 2" - 18000 l/h
(0.041 – 5 l/s)
(0.66 – 79 GPM)

**Flanged**

2" - 20000 l/h to 10" - 500000 l/h
(5.55 – 138.89 l/s)
(88 – 2200 GPM)
Thank You!

Probably the best PICV in the world