SWAN SYSTEMS ENGINEERING

Pressure and flow regulation in water sample conditioning systems for water steam cycles

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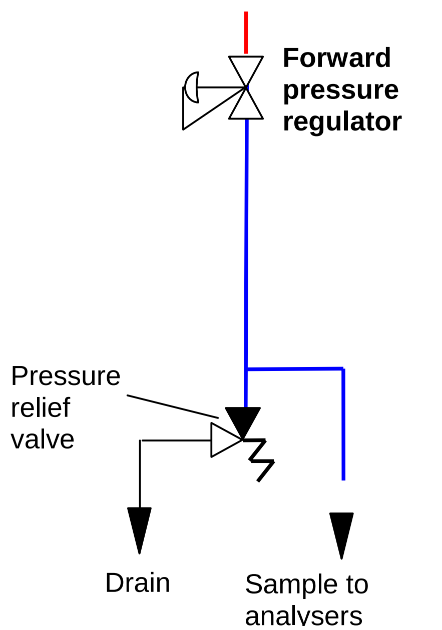
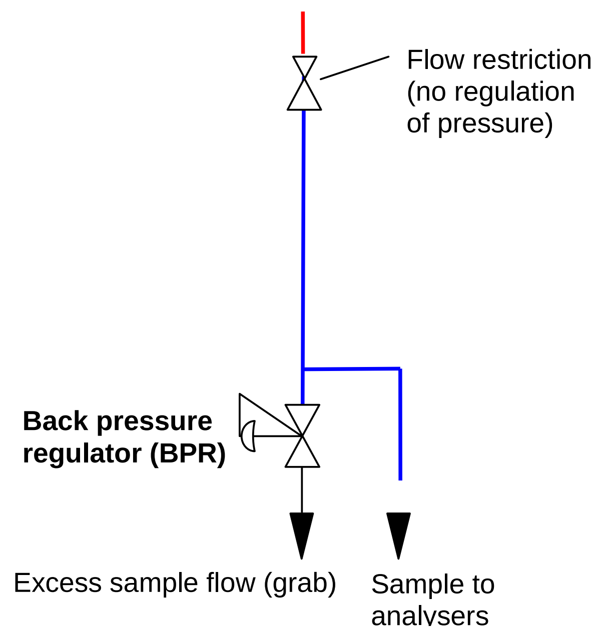
Introduction

This paper addresses questions related to the regulation of sample flow and pressure for online water analytics in water steam cycles. It describes the 2 most common design principles and includes considerations about the hydraulic behaviour in part-load or sliding pressure operation of systems using backpressure regulation.

Pressure and flow regulation

Online analysers require stable sample flow conditions in order to work reliably. Stable sample flow through an analyser can only be ensured by maintaining a stable inlet pressure upstream of the analyser. This pressure needs to be actively regulated as it is constantly influenced by process pressure fluctuations and variations in sample flow rate (e.g. grab sampling operations, switching on/off of analysers sharing same line). There are two main design philosophies for pressure regulation in water sampling applications:

	Forward pressure regulation	**Flow restriction combined with backward pressure regulation (SWAN philosophy)**
Descri-ption	Pressure and flow are controlled with a single device placed upstream of the distribution point to the analysers. A pressure relief valve is required in case of failure of the pressure regulation.	Flow and pressure control are split: flow is restricted with a needle valve (usually not an actively regulating element) and pressure is regulated with a back-pressure regulator (BPR) placed downstream of the distribution point to analysers. Pressure is regulated by discharging excess sample flow through the BPR.
Typical set-up (simplified) Full line pressure Regulated pressure		
	Forward pressure regulation	**Flow restriction combined with backward pressure regulation (SWAN philosophy)**
Working principle of the pressure regulating component	There are different types of forward pressure regulators. They all **regulate pressure at the OUTLET**. Mechanical regulators work with a small regulating needle (red) held in equilibrium between two springs, a small one on the high pressure side and a large one on the low pressure side. The pressure at the outlet regulates if further flow is allowed to pass (outlet pressure below set-point) or if the valve closes (outlet pressure is above setpoint).	The back pressure **regulates the pressure on the INLET side** (in the sketch below this are connections 1 and 3). The working principle is similar to a pressure relief valve. Pressure works against a membrane pre-loaded with a spring. Higher pressure will cause valve to open further, allowing more excess sample flow, which causes pressure to drop again.

<table>
<tr>
<td>Illustration of the pressure regulating component</td>
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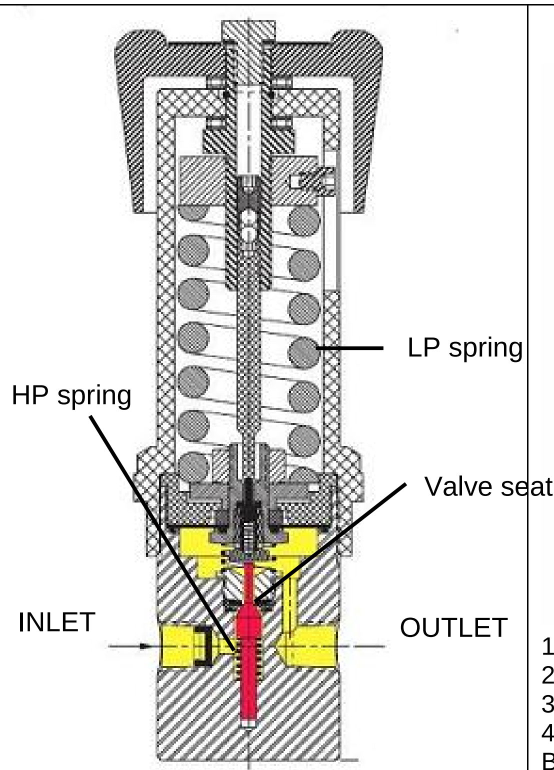

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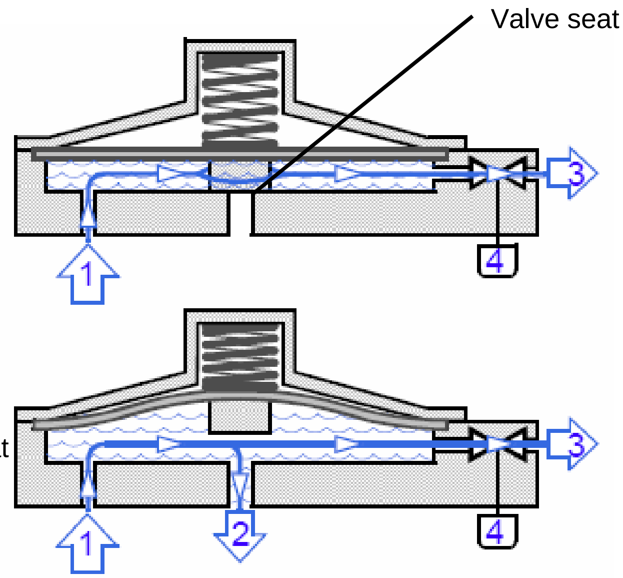

1 sample inlet
2 excess sample flow
3 distribution to analysers
4 distribution valve to analysers (integrated in SWAN BPR)
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</table>

	Forward pressure regulation (FPR)	Flow restriction combined with backward pressure regulation (BPR) (SWAN philosophy)
Advantages	• Regulates OUTLET pressure over a large INLET pressure range without excess sample flow	• Splitting flow restriction and pressure regulation follows the design principle of separating functions for simpler and safer system design • BPR has no small moving parts exposed to sample flow -> less maintenance • Swan BPR with low pre-set pressure of 0.5 bar has a large valve section -> allows evacuation of particles in flow • BPR is a reliable safety device against high pressure: it OPENS further in case of pressure rise – unlike with FPR, tight sealing is NOT required
Disadvantages	• Commercially available mechanical FPR are sensitive to clogging by particles (narrow flow paths, small moving parts exposed to flow). • Italian sampling component manufacturers have developed custom FPR for high pressure lines with a variable capillary (with pneumatic regulation). These components are specific to the Italian market and are not commercially available. • In “no flow” or “very low flow” conditions, reliable pressure regulation is not guaranteed: FPR CLOSES when OUTLET pressure rises. Leak free shut-off is crucial for proper operation. Smallest leaks at the valve seat will lead to pressure build up at outlet. A pressure relief valve is therefore required (= additional component operating only in critical situation)	• BPR requires excess sample flow in order to regulate pressure • **Note:** this excess flow is in the range of 20-30l/h. In combination with SWAN instruments, total sample flow on a single line is in the range of 40-60l/h

Norms regarding sample pressure and flow regulation in sampling systems

Internationally recognised technical norms and directives do not provide specific guidance about design principles for regulating flow and pressure for online water analysis systems. An exception to this is the recently updated ASME performance test code "**ASME PTC 19.11-2008 - steam and water sampling conditioning and analysis**". The relevant extracts are shown below:

5-4.2 Pressure Reducers

Pressure reducers shall be located downstream of the primary sample cooler so that the liquid is sub-cooled before pressure reduction. For samples equal to or greater than 500 psig (3 447 kPa), the pressure reducer should be a rod-in-tube type orifice (variable or fixed) or a capillary tube. Variable rod-in-tube devices are recommended since they provide for varying the pressure drop and, therefore, the flow and are cleanable in-place. Also, this method of pressure reduction eliminates the possibility of sample bias due to the potential dissociation of water into hydrogen and oxygen that can occur across throttling valves when sampling at high pressures. [4]

Forepressure regulators are not recommended for large pressure reductions because of susceptibility to erosion, water dissociation, and wire drawing of the stem or seat. For samples less than 500 psig (3 447 kPa), the pressure reducer should be a needle valve or forepressure regulator. A needle valve is preferred since it will not oscillate with small pressure variations.

5-4.3 Pressure Regulators

Pressure and flow regulation for on-line analysis is essential for proper instrument performance and repeatability. This is achieved by establishing a constant pressure zone where the sample line feeds the analyzer branch lines. Because of the relationship of pressure and flow, this constant pressure zone ensures that each analyzer fed from this zone gets a constant flow rate independent of actions taken in the other branch lines, while maintaining constant flow in the main sample line. This is necessary for a representative sample (see Section 4). To achieve this constant pressure zone in conjunction with the upstream pressure reducer, a back pressure regulator (fixed or variable) is required. A head cup will provide the required constant pressure zone but is not recommended for sample pressure control upstream of the analyzers (see subsection 5-2).

NOTE: A forepressure regulator without a backpressure regulator or head cup is not recommended. A forepressure regulator alone cannot provide a constant sample line flow. Flow changes in the branch lines below the regulator result in the forepressure regulator closing or opening to maintain the analyzer inlet pressure thereby changing the main sample line flow. The sample ceases to be representative. Use of a backpressure regulator is the highly preferred method to achieve the constant pressure zone.

Basics of 1D-hydrodynamics for water (non-viscous flow)

For liquid flows through a pipe with a series of fixed obstacles (example: pipe bends, flow restrictions, manual valves in fixed position), the relation between flow and pressure follows the following relation:

$$K_v = Q\sqrt{\frac{\rho}{\Delta p}}$$

Where **Kv** is the flow coefficient (a constant for the system considered), **Q** is the flow in m3/h, ρ the density in kg/l, **ΔP** the pressure difference in bar between entry and exit of the system.

The Kv value is typically indicated in the datasheets of valves and corresponds to the water flow (in m^3/h) that would establish through this valve in a given position with a pressure difference of 1 bar across the valve and a water temperature of 5 - 30 °C. The American equivalent is the Cv value (gal/min @ 1 psi ΔP). Due to the different units Cv = Kv x 1.16.

In other words, for a system consisting of a pipe with fixed obstacles (Kv is constant), the flow through the system will increase proportionally to the square root pressure ratio:

$$\frac{Q1}{Q2} = \sqrt{\frac{\Delta p1}{\Delta p2}}$$

For example if at 25bar inlet pressure an 0 bar outlet, the flow through a needle valve in fixed position is 10l/h, at 100bar inlet pressure (pressure x4), the sample flow will be 20l/h (factor x2).

Analysis of flow conditions in systems using back-pressure regulation

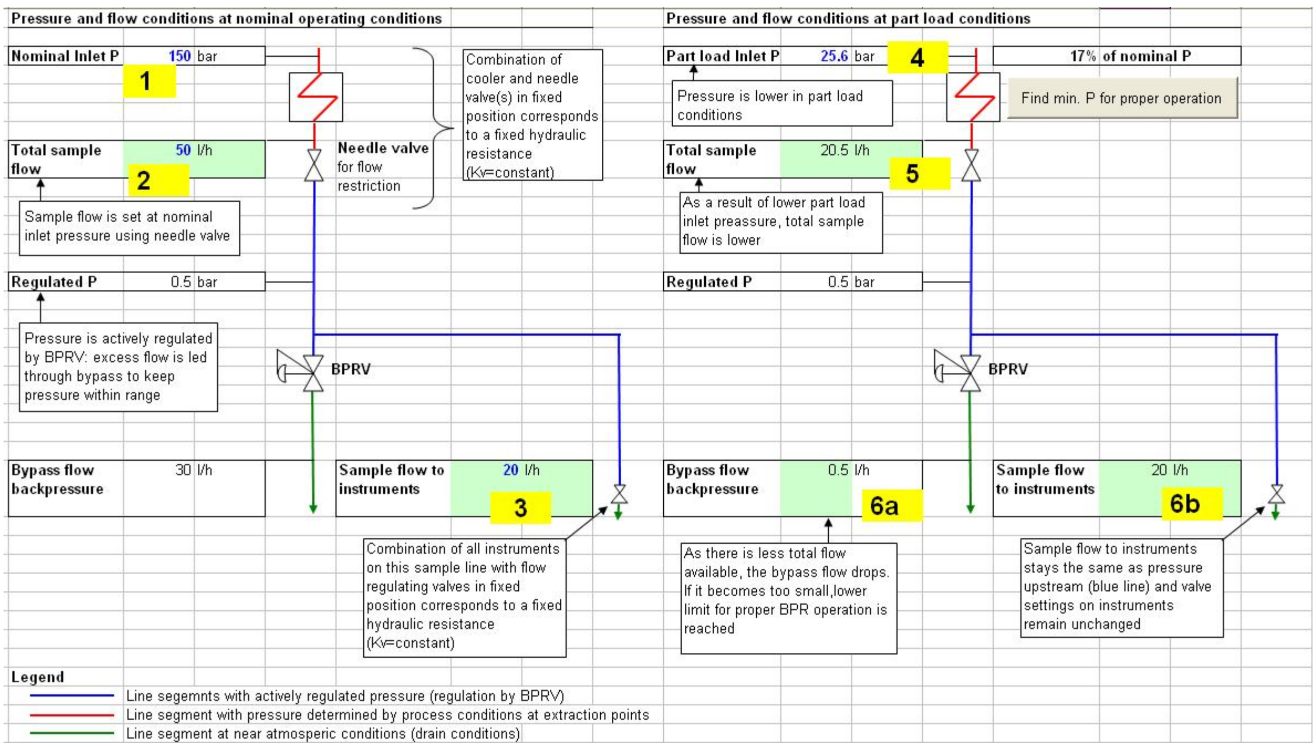
With the above considerations, we can analyse the flow conditions in a sampling system that uses back-pressure regulation. Again, in the set up with backpressure regulator, the regulation of flow and pressure is split:

- Total sample flow is set at nominal pressure using a needle valve (no active flow regulation afterwards, simply a fixed hydraulic resistance upstream).
- Back-pressure regulator actively regulates feed pressure to instruments (in our case to 0.5bar), by letting excess sample drain to bypass. The inlet pressure can vary over a broad span; as long as there is some excess flow on the BPRV bypass, the instruments run with the same individual sample flows than at full load inlet pressure.

At this point it is important to consider the following boundary conditions:

- Sample flow is normally set to values of 45-55l/h in order to achieve sufficient sample velocity in sample tubing.
- With the combination of 1) a constant feed pressure (as provided by the backpressure) and 2) a flow monitoring on each instrument (as per default on all SWAN monitors) it is possible to run online instruments reliably with much lower sample flow rates that commonly found in specifications of sampling systems. As a result the total sample flow required by the instruments only is typically only 20-25l/h.
- The difference between total sample flow rate (45-55l/h) and sample flow effectively required by the instruments of this line (20-25l/h) is available as bypass flow for the backpressure regulator.

The diagram below shows an example calculation for typical feedwater line conditions



Left side = FULL LOAD CONDITIONS

Given inlet pressure 1, of 150bar a total sample flow of 50l/h 2 of 50l/h is set by adjusting the needle valve after the cooler. The backpressure BPRV maintains a constant backpressure of 0.5bar, letting a sample flow 3 of 20l/h flow to the instruments and 30l/h down the bypass.

Right side = PART LOAD CONDITIONS

If the inlet pressure 4 drops in part load conditions to 25.6bar (17% of the nominal inlet pressure), total sample flow 5 drops to 20.5l/h, which splits into 20l/h to the instruments (6b, same as 3) and a minimum flow of 0.5l/h (6a) on the BPRV bypass.

Conclusions

Sample conditioning systems using backpressure regulators in combination with a fixed flow restriction are able to supply constant sample flow to instruments over a broad pressure range, typically from 15 to 100% of operating pressure, provided that:

- The value of the backpressure is low (1.5bar or less)
- The instrumentation used on the sample line is able to work with low flow, which means each instrument has a flow regulating valve and a flow monitoring device.

This pressure range is sufficient to ensure proper operation of instruments in power plants operating in part load conditions (sliding pressure).

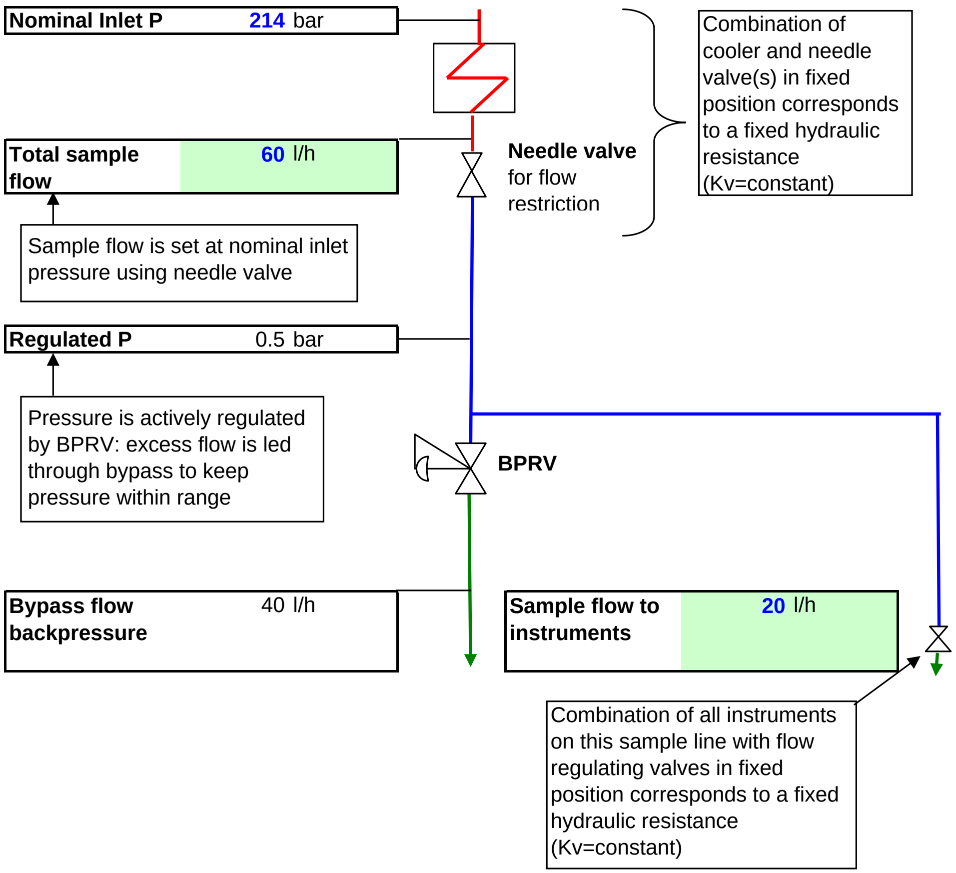
Sample pressure regulation with backpressure regulator is common practice in Europe and in the USA and is even described in detail in an ASME performance test code as recommended practice.

During start-ups from unpressurised conditions, the main concern in the first phase of the start-up (effective pressure below 20% of nominal line pressure) should be the flushing of sample lines properly before any sample is sent to instruments.

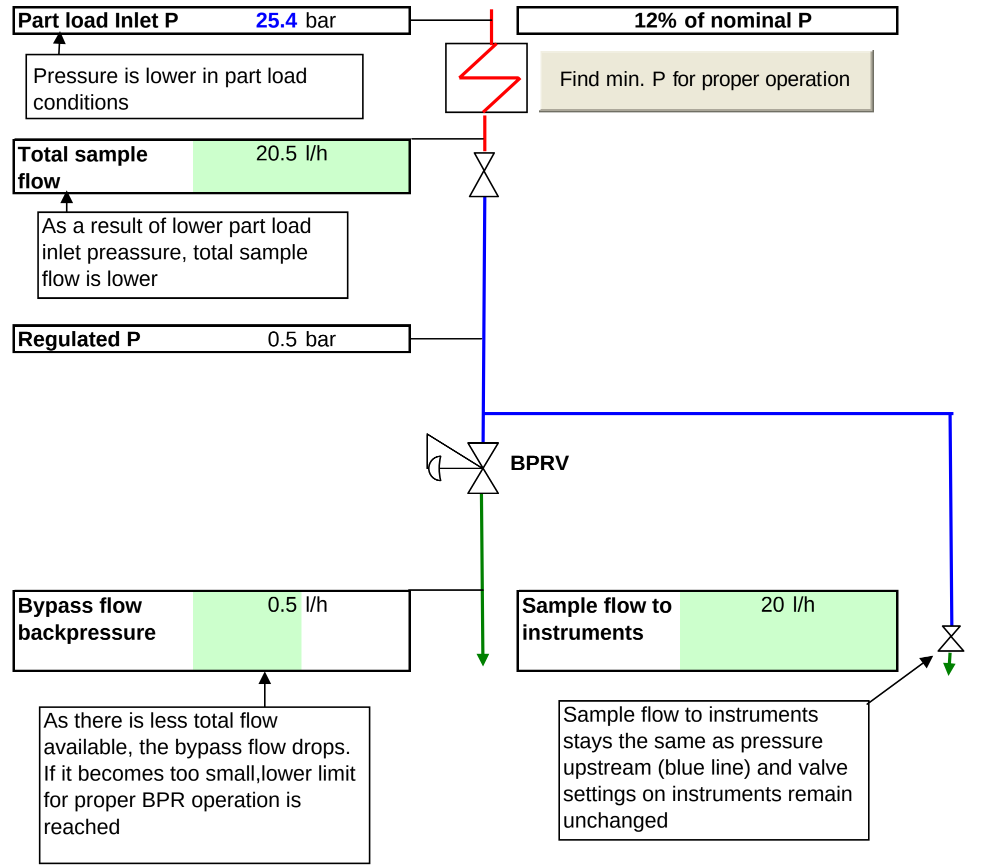
Simulation of pressure and flow conditions in sample conditioning system with BPRV

Example for **HP feedwater**

Pressure and flow conditions at nominal operating conditions



Pressure and flow conditions at part load conditions



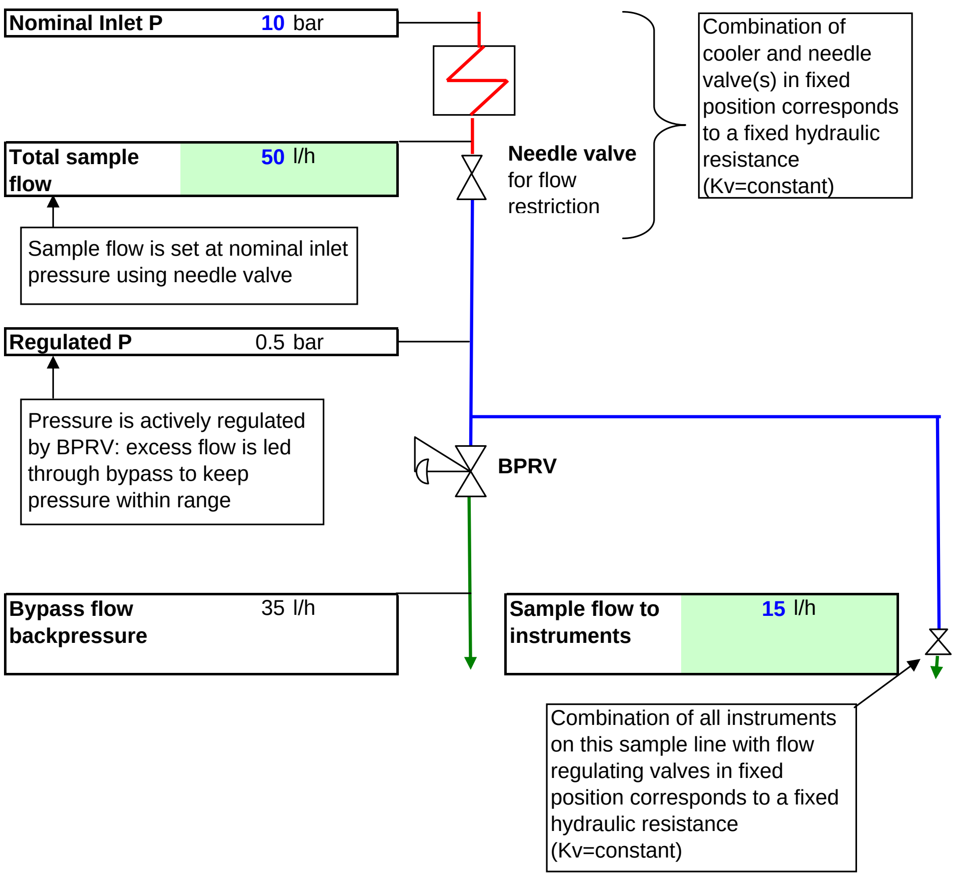
Legend

- Blue line: Line segemnts with actively regulated pressure (regulation by BPRV)
- Red line: Line segment with pressure determined by process conditions at extraction points
- Green line: Line segment at near atmosperic conditions (drain conditions)

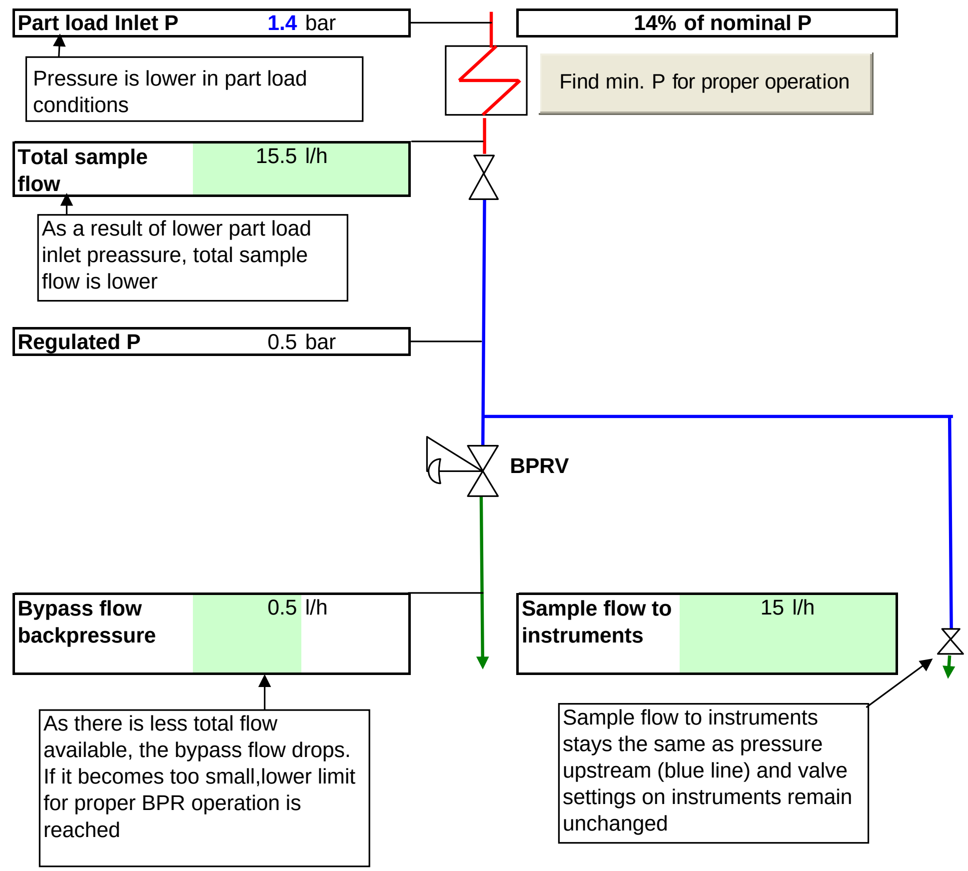
Simulation of pressure and flow conditions in sample conditioning system with BPRV

Example for **LP superheated steam**

Pressure and flow conditions at nominal operating conditions



Pressure and flow conditions at part load conditions



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