Analysis of the thermo-fluid dynamics of a paint shop's hot water distribution network

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This article describes an analysis of the performance of a hot water distribution piping network consisting of a main boiler and various utilities inside an automotive paint shop based in France. The simulation is performed using Flownex, a CFD (computational fluid dynamics) software with concentrated parameters.

A paint shop is powered by several energy sources (hot and cold water, natural gas, electricity, and compressed air) that serve to drive the applications of surface treatments to the car body from the pre-treatment phases to the actual painting. The energy is delivered to different components (process tanks, air supply units, oven heating units) via a complex network of pipes. This study focuses on the hot water distribution system (Fig. 1).

Using a dedicated tool like Flownex offers several advantages:

- It reduces the need for assumptions and interpretation by operators;
- It enables the building of a simple and efficient model to analyse the performance of complex systems;
- It allows boundary conditions to be modified and gives immediate feedback on results.

The main objectives of the analysis are to:

- Verify the calculations of the global pressure drop that were made during the design phase of the system;
- Calculate the temperature distribution within the circuit and the global return temperature;
- Define an initial state of the system conditions (to regulate the valves and pumps).

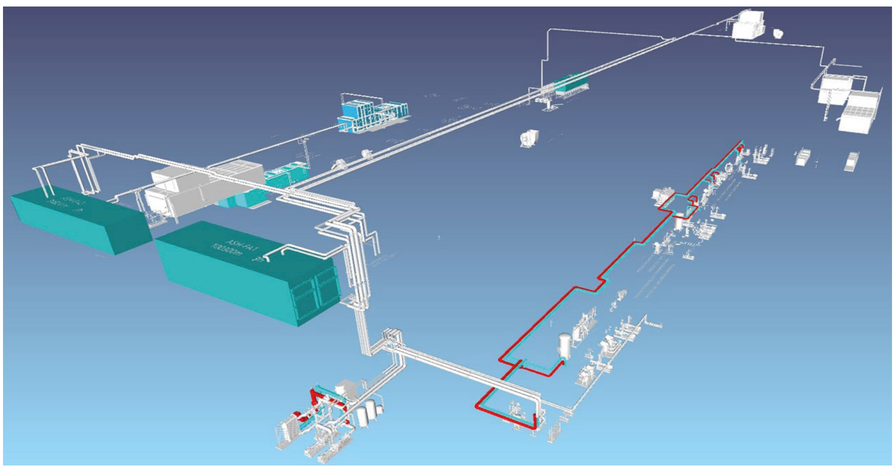

Fig. 1. Hot water distribution network.

System description

The piping network starts from the main boiler and connects eleven utilities by means of a closed ring (Fig. 2). The main distribution pipe first passes through and feeds the hot pre-treatment stages (three utilities) and then divides into two parallel branches that have five and three air supply units respectively. At the end of the circuit the water flow is divided again: part of it is led to the boiler; the rest passes through a heat exchanger to recover heat from an incinerator.

The boiler for this project was supplied by the customer. The water is provided at fixed temperature conditions. The utilities and other components of the circuit, on the other hand, are controlled by a thermoregulation skid with a three-way valve that allows the flow rate to be varied according to the heat required (Fig. 3).

Boundary conditions and simulation scenarios

Flownex makes it possible to recreate the actual distribution network using predefined

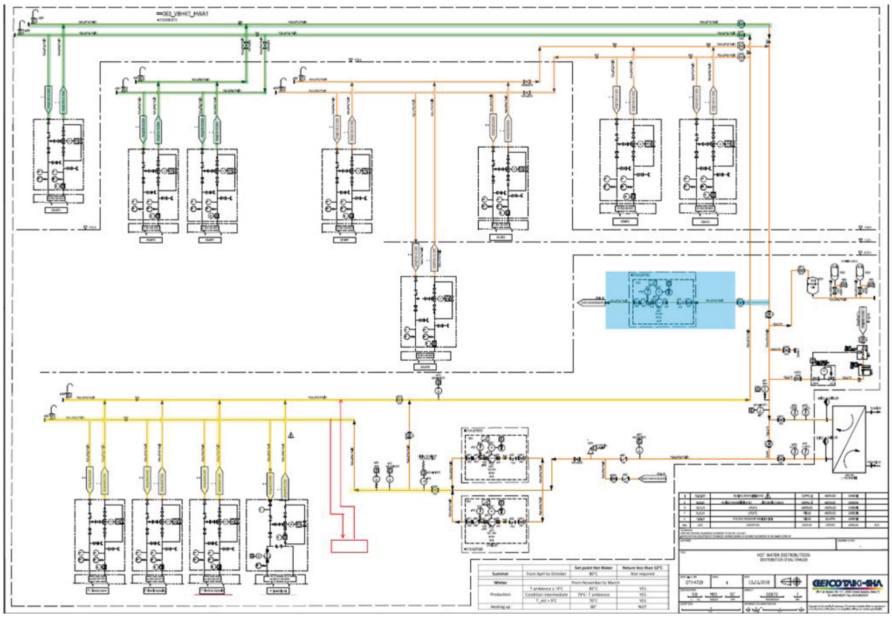

Fig. 2. Piping and instrumentation diagram.

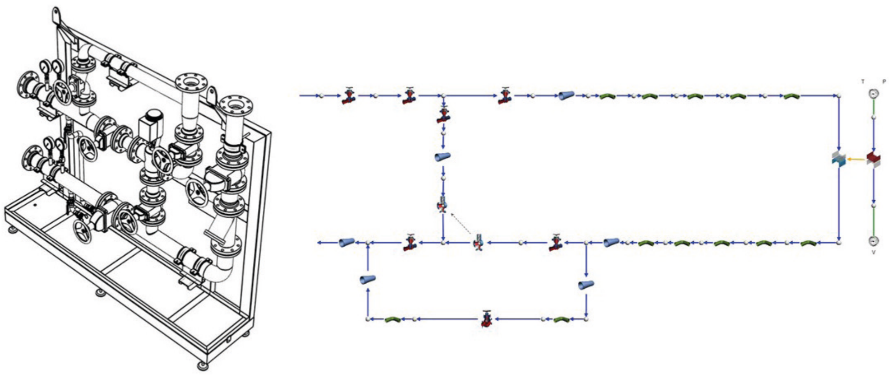

Fig. 3. The thermoregulation skid (left) and its model in Flownex (right).

components and customized elements. The behaviour of each component is modelled through different geometry and performance parameters.

The one-dimensional modelling of concentrated parameters reduces the number of inputs required without sacrificing the fidelity of the simulation model.

Most of the information can be found in the manufacturer's data sheets for each component. The operating curves of the valves and pumps can be specified using dedicated tables in the software database if they are not available in the integrated library (Fig. 4).
To define the heat exchangers, it is necessary to set the geometric and performance characteristics and the boundary conditions of the process side (second side). The operating conditions of the exchangers are not constant over time:

- Fresh-air supply units must offer variable heat output depending on the conditions of the external environment, which are not constant;
- Pre-treatment utilities have very different thermal requirements during start-up (heating of the tanks) and when operating at full capacity.

In the system being studied these variations are sufficiently slow to allow the phenomenon to be approached from a steady state. Since the parameters are so easily edited operation can be tested in three main simulation scenarios:

- The start-up phase;
- Operation at full load in summer conditions;
- Operation at full load in winter conditions.

The complete list of parameters is shown in Table 1.

Results

The temperature and pressure distributions for steady-state operation in summer conditions are shown in Figs. 5 and 6.

To balance the flow rates on both branches of the air supply units and achieve the desired flow rates, it was necessary to adjust the regulation valve to impose an adequate pressure drop. Regulating the valve increases the pressure drop across the entire circuit with a consequent variation in the pump behaviour. This results in a decrease in the total flow rate within the pipe network while maintaining an acceptable value for each user (Fig. 7).

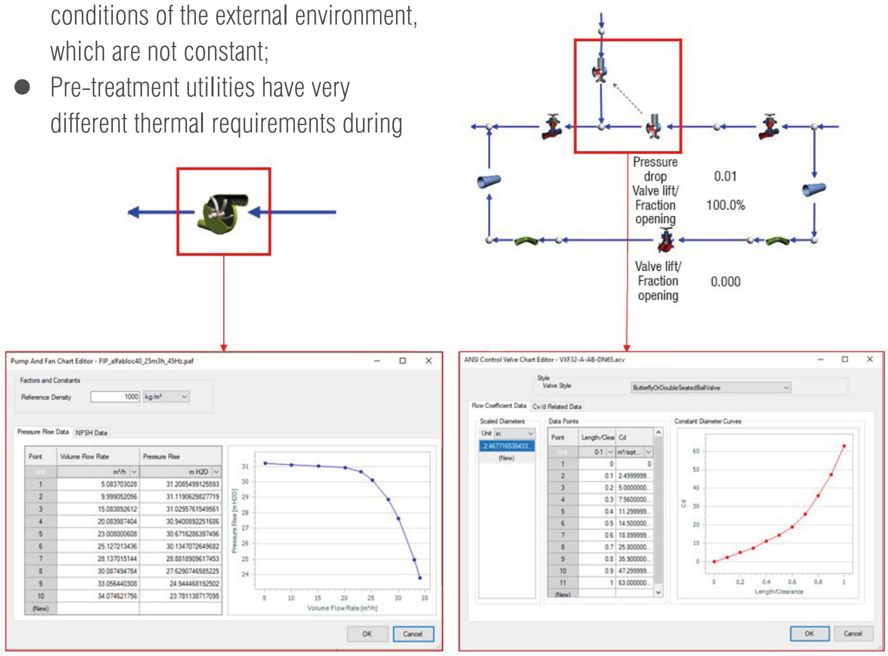

Fig. 4. Pump and valve curves.

Component	Boundary Conditions
Piping	Length
	Diameter
	Roughness
	Curve
	Fittings
	Elevation
Valve	Type
	Diameter
	Pressure drop curve
Pump	Hydraulic efficiency
	Flow rate vs head curve
Heat Exchanger	Type
	Pressure-loss coefficient
	Heat-transfer coefficient

Table 1. Boundary conditions.

The overall pressure drop and the resulting flow rate are in line with the project requirements and confirm the calculations made during the design of the plant components. The contractual temperature constraint on the return line was verified under critical operating conditions (summer).

Conclusions

Traditional spreadsheets cannot manage the whole system and lead to excessive approximations and greater possibilities of error. Flownex enabled the complete system to be studied under various operating conditions using a one-dimensional model with concentrated parameters. The analysis conducted made it possible to calculate:

- The global pressure drop across the system, validating the calculations of the design phase;
- The regulation levels for the system's pumps and valves to obtain the desired flow rate;
- The overall return temperature in critical conditions.

Flownex software can easily manage the complexity typical of engineering plants and will also be used in other areas of the automotive paint shop.

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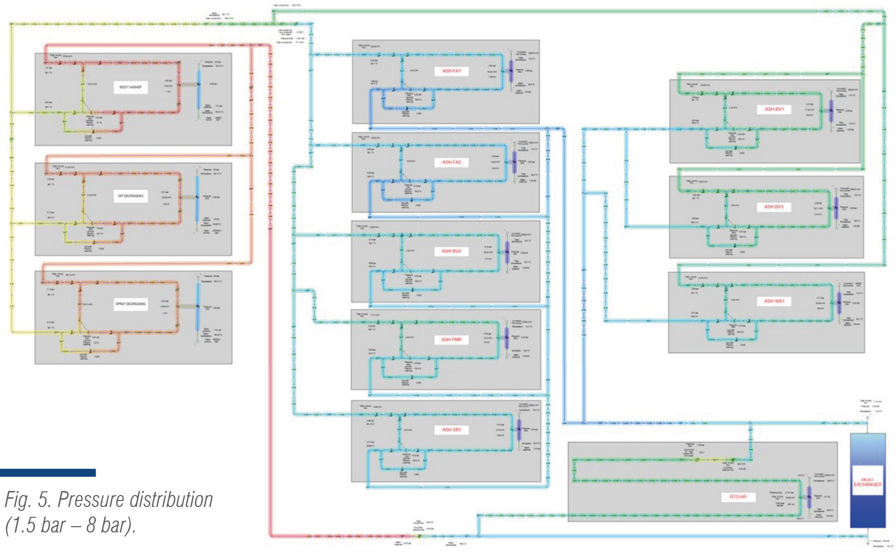

Fig. 5. Pressure distribution (1.5 bar – 8 bar).

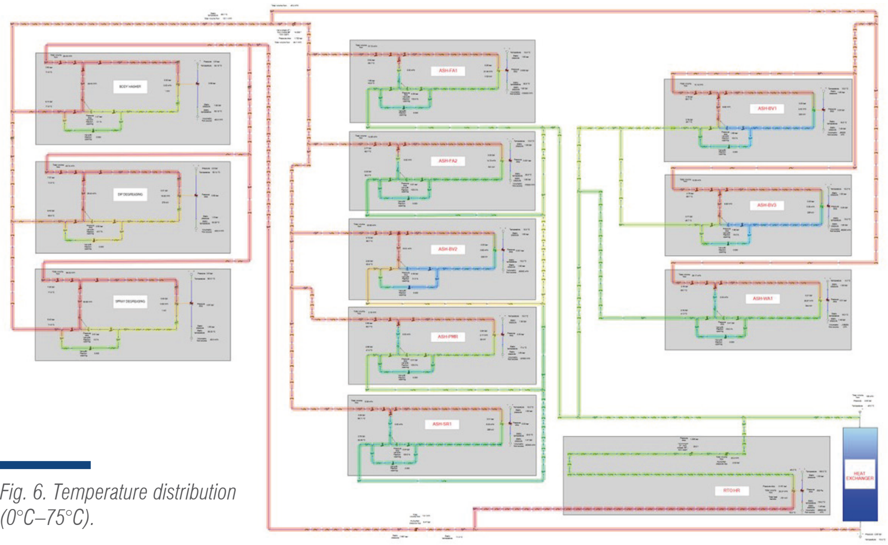

Fig. 6. Temperature distribution (0°C–75°C).

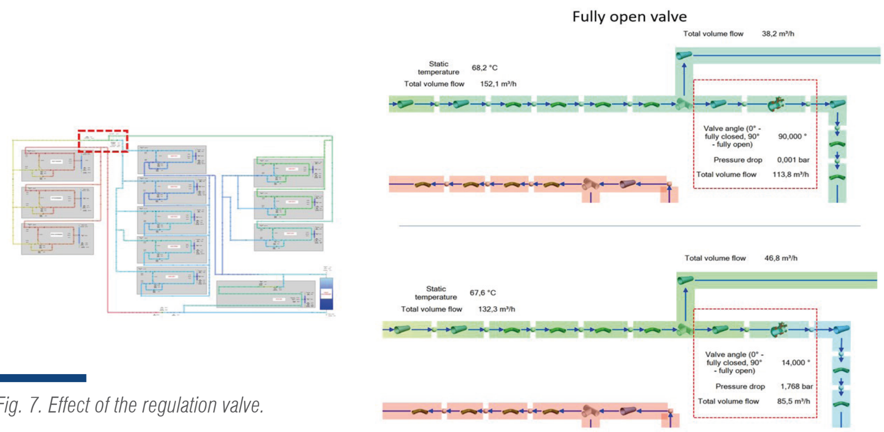

Fig. 7. Effect of the regulation valve.

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SimulHub is a business unit of GeicoTaikisha that plans, executes and analyses engineering simulations using highly professional software with the objective of predicting, preventing and optimising the behaviour of production equipment and products throughout the production process. Thanks to a young and highly experienced team of engineers, SimulHub offers computational fluid dynamics (CFD), discrete event (DES) and one-dimensional (1D) simulations accompanied with a valuable expertise that comes from a very competitive and innovative market such as the automotive industry. SimulHub places the customer at the centre of its existence, making it needs its own, creating tailor-made sustainable solutions.