FluidFlow
Steam & Condensate Recovery System Design
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1 Introduction

The principal role of a steam system is to surrender its latent heat energy and re-condense back to water. Hot water is formed as the steam condenses and generally collects along the bottom of the pipelines and low points in the system. This condensate must be drained from the main steam lines in order to ensure the plant operates effectively, efficiently and safely. It is also of critical importance that this fluid is removed on plant “start-up” as, when the steam leaves the boiler plant and comes into contact with the cooler surfaces of the pipework, development of condensate can be particularly heavy. The condensate can build up along the length of pipework eventually forming a slug which can be carried along the pipe at high velocities. This slug will then be brought to an abrupt halt at junctions or fittings causing a shock wave which must be absorbed by the pipework. If there is a substantial amount of liquid in the slug or if the slug has travelled at high velocity, this can cause failure or rupture of fittings in the plant leading to poor reliability, increased system “down-time” and higher maintenance costs than necessary. It is therefore essential that pipework is installed “laid to falls” in accordance with current good practice design codes and condensate removed at key system locations.

Although the condensate must be drained away it is much too valuable a commodity to simply drain and discharge to waste as it is essentially purified/distilled hot water which will likely warrant chemical treatment. From an economic viewpoint, it is much more cost effective to re-heat the hot condensate back to steam than it is to heat fresh and potentially untreated make-up water entering the system. By re-using this hot fluid, the costs associated with make-up water, chemical water treatment and expended energy to heat the water to steam can be minimised. As a general rule of thumb, condensate can account for as much as 16% of the energy that is used to produce steam. With ever increasing energy costs, careful consideration must therefore be given to the design of condensate recovery systems.

Steam traps should therefore be fitted to the steam system at appropriate locations and each connected to a proprietary condensate piping system which will channel all the fluid back to the main boiler plant feed tank.

FluidFlow is used successfully by engineers to design both steam and condensate recovery systems. Using the software enables the designer to fully evaluate the performance of the plant and identify improvement and energy optimisation opportunities. It also allows you to determine the vapor quality of the steam throughout your system.

This document will focus on condensate recovery systems.

Condensate Pipe Sizing

Sizing of condensate lines is calculated differently from sizing other fluids transferred in pipes. Although condensate is hot water, it can exist as two phases, i.e. water and vapor (flash steam). If we were to size condensate lines as though they were simply transporting hot water, the pipework would be undersized resulting excessive
backpressure in the system leading to operational issues. Note, condensate that is free of flash steam may be pumped and sized as liquid only (single phase fluid).

It is generally considered that, condensate pipe velocities (liquid and flash steam) must be lower than 4500 feet per minute to prevent system waterhammer and other damaging effects. If the condensate is in liquid form only, it is recommended that piping velocities are lower than 7 feet per second (2.13 m/s).

One of the key advantages of FluidFlow is that, the software will automatically determine the fluid phase and suggest an economic pipe size and velocity for each individual pipe section which the engineer can consider. Pipelines can also be automatically sized based on a design velocity or design pressure gradient. This gives the designer full flexibility in relation to the selected pipe sizing criteria to be used.

The unique features within FluidFlow allow engineers to automatically size pipes, pumps, control valves orifice plates and a range of other equipment items. This in turn helps speed up the design process saving you time and resources. Users have reported saving up to 40% time and capital expenditure per project by switching from other competitor software products to FluidFlow. Do you have a steam/condensate system to design or need to accelerate the design process? Contact our team for a discussion. Further information is available at: www.fluidflowinfo.com.

This document will focus on the development of steam and condensate recovery system models and how FluidFlow has been used successfully to help engineers develop efficient system designs.

FluidFlow is developed by Flite Software NI Ltd, an ISO9001:2008 registered company.
2 Upgrade of Existing Steam Distribution System.

2.1 System Description

This is a sample case of a project in Rotterdam where the client needed to expand their existing plant by adding two new facilities. For this, steam was needed to establish reaction conditions and the condensate had to be returned to the condensate return vessel. The client already experienced some issues with high pressures in the existing condensate system which would also be considered as part of the project.

The existing plant consists of one 8” main 10 barg condensate header running over the main pipe rack at an elevation of approximate 6 meters. The steam consumers in the different facilities return the condensate via sub-branches to the main header. The condensate producers are situated at different elevations throughout the different plants, between 0 and 15 meters. The amount of condensate returned to the header had been estimated by the client for each of the existing facilities. During winter, over 5 ton/h of 10 barg steam is used for winterization, which is divided over the different condensate producers. The total flow in the main header is approximate 17.5 ton/h.

The pressure in condensate return vessel is taken as the steam saturation pressure at a temperature of 145 °C, taken from live plant data, equalling 4.2 bara or 3.2 barg. The entrance nozzle is situated at an elevation of 13.9 meters.

**Facility 1:** In the proposed upgraded system, the first facility will use 35 barg steam which will be reduced to 14 barg (saturated). This steam is then used for heating of the reactor and then enters a flash vessel at 10 barg, producing 4 barg steam. The remaining condensate is pumped via a condensate collection vessel to the 10 barg condensate header. The amount of used 14 barg steam is approx. 10 ton/h.

In addition to this, 2 ton/h of 10 barg steam is estimated to be used for heating and utilities.

**Facility 2:** Steam consumption of approximate 450 kg/h has been calculated with a peak of 1.5 ton/h. Also this project makes use of a pumped system and as such, it was considered that there would not be any flashed steam in the condensate pipeline connected to the main header.

An overview of the model as developed in FluidFlow is shown in Figure 2.1.

![Figure 2.1: System Distribution Plant.](image-url)
2.2 Application of FluidFlow to the Project

The amount of flashed steam in the pipe was the most important factor to be considered when sizing the condensate return headers. The amount of flashing depends on the temperature of the returned condensate, the pressure of this condensate and the pressure in the condensate header. The higher the pressure in the condensate header, the less flashing will occur, however if the pressure was to rise too much, it would not be possible for some of the facilities to return their condensate to the header.

Flashing condensate was treated by the engineer as a two-phase medium in FluidFlow. The heat losses from the pipelines could not be ignored as it is an old plant and the insulation of the condensate header was of minimal thickness. FluidFlow software has the option to perform two-phase pressure drop and heat loss calculations for networks, whereas otherwise, separate calculations have to be carried out manually or in spreadsheets. This means it would become tedious and difficult to control the design calculations and a lot of time and effort would be spent on creating the model and cross-checking with separate spreadsheet heat loss data.

2.3 Engineers Comments

Building the network in FluidFlow was easy and fast. The interface visualizes the connections of the facilities to the header and the specifications (pressure, temperature and quality) can be managed.

For the specification of condensate/steam, we asked for assistance from the FluidFlow service team. They have been very helpful in explaining how FluidFlow needs to be specified with the right settings to model a condensate/steam mixture. Within the same day we had an answer which helped us further in performing the calculations. As a result, we have been able to help our client in selecting the right sizes for the new pipelines from the two new facilities to the header.

Secondly we have been able to give advice on the slight rise of pressure in the header system and which adjustments in the older parts of the plant have to be made in order to compensate for the higher pressure in the header and sub-headers, such as reselection of the type and resizing of the steam traps, the use of flash drums and a pumped condensate system and enlargement of the inlet nozzle of the condensate collecton vessel.
3 Steam Utility Plant.

3.1 System Description

At the Chemelot site in Geleen (the Netherlands), EdeA distributes and produces utilities for a total of 58 factories on site. These utilities comprise of fluids (process water, demineralized water, drinking water), gases (compressed and dehydrated air, natural/process gas) and superheated steam at pressures between 140, 79, 42, 26, 18 and 3 bar at various temperatures.

Some utilities are produced on the site and others are distributed over a system of 500 km pipelines in total.

3.2 Challenges facing engineers at EdeA

In order to manage the steam quality over the 750 hectares site, we purchased FluidFlow to calculate the various process parameters (pressures, temperatures) within the steam grid. As superheated steam may condense when the heat loss is too much, we also purchased the two phase module which makes it possible to calculate water/steam mixtures. As we need to rely on the results we generate, we also have a support contract in place with Flite Software NI LTD - the developers of the program.

3.3 Application of FluidFlow to the Project

The main purpose we have for using FluidFlow is to optimize the steam flow in the existing grid but also to do calculations in “What if” type cases to prevent condensation due to low steam flow speeds. This condensation of course may cause water hammer in the steam grid which can result in damage to the system with possible casualties. The program has been used successfully by EdeA to retrospectively identify this phenomenon within the existing grid after operational problems had been experienced.

With changes in the steam consumption pattern the program is also used to find possible optimizations within the existing steam grid by forcing flows (closing block valves) or changing the plant infrastructure.

By making these models as close to the reality as possible (e.g. lengths, diameters, valves, bends, insulation) the accuracy of the solution increased. As a result of this correctness of the models and the ability to relate the calculations to real values, we were able to point out a problem in our system from the calculations of FluidFlow.

The following two images provide an illustration of the models developed in FluidFlow at EdeA. Figure 3.1 provides an overview of a steam system sub-sector. This network is made up of 15,485.2 M of steel pipework ranging in diameter from 52.5 mm to 477.8 mm. The plant contains two known pressure inlets of steam at 15.8 barg and 260 °C and four fixed flow inputs of 25.4, 6.9, 4.2 and 22.2 kg/s all of which are defined as having an inlet temperature of 260 °C. The system then includes 36 outlet boundaries which have a variety of flow rates defined in a combination of units such as tonne/h and kg/s.
Figure 3.1: System Distribution Plant.

Figure 3.2 provides an overview of a steam system sub-section. This network is made up of 8,355 M of steel pipework ranging in diameter from 52.5 mm to 488.9 mm. The plant contains four known pressure inlets of steam at 2.5 barg and 165 °C and five fixed flow inputs of 0.02, 1.38, 1.6, 3.3, and 7.5 kg/s all of which are defined as having an inlet temperature of 165 °C. The system then includes 90 outlet boundaries which once again, have a variety of flow rates defined in a combination of units such as tonne/h and kg/s.
3.4 Engineers Comments

All in all the program has been used for years now (starting with version 2 and later upgrading to version 3) and our intention is to continue to do so as the program has proved itself in the past and continues to be developed by the team at Flite Software NI Ltd.
4 Superheated Steam Distribution Network

This is an example of a superheated steam distribution system consisting of over 700 individual pipes and fittings. Steam is generated in this system by central boiler plant which serves a number of remote demand points on the site. This system was modelled to assess the potential benefit of upgrading the piping thermal insulation and also identify the system limitations in terms of future expansion capabilities.

The system was originally partially insulated in 25mm mineral wool insulation which was in an advanced state of deterioration. Using the Engineering Consultancy at Flite Software NI Ltd, the customer wished to carry out an analysis of the heat transfer for the system for varying insulation thicknesses with the view to determining the most efficient thickness for the system. As the customer wished to replace the insulation for the entire system, it was critical that the optimum insulation thickness was identified to ensure maximum benefit from such a significant investment. The FluidFlow Dynamic Analysis Scripting Module was used to perform the real-time analysis of this system.

An overview of the system can be seen in Figure 4.1.

![Figure 4.1: System Distribution Plant.](image)

In completing the analysis, consideration was given to both the thermal conductivity of the varying thicknesses of mineral wool insulation and the capital cost of the material. As there was over 14.5 kM of large diameter pipework, it was essential that the optimum thickness be established so as to obtain maximum benefit from the capital investment.

From the analysis, it was clear that 76mm of Mineral Wool insulation was the optimum insulation thickness for this system, providing the maximum return on investment. The payback period for the investment was established as 0.4 years with a reduction in
waste energy of 32,645,804 kwh representing significant annual cost savings of $3,016,472.

This study also identified that fitting insulation with a thickness of 76mm yielded a reduction in annual CO2 emissions by 8,487 tons.

Figure 4.2 provides an overview of the spreadsheet output as generated by FluidFlow. Note, a full detailed assessment was completed for each insulation type and thickness with the view to establishing the optimum thickness and most cost effective means of upgrading the insulation.

**Figure 4.2: FluidFlow Spreadsheet Report.**

FluidFlow was also used to generate a detailed Bill of Materials for this project allowing the customer to quickly develop a materials procurement schedule.
5 Steam Condensate Recovery System

It is required to remove condensate from a steam system at three key locations. From analysis of the steam lines in FluidFlow, the pressure and temperature of the condensate at the collection points was established to be:

**Collection Point 1:** 360 kPa g @ 146°C.

**Collection Point 2:** 360 kPa g @ 146°C.

**Collection Point 3:** 386.8 kPa g @ 148°C.

A network of condensate pipework shall be connected to each collection point. However, the user wants to establish if there will be any useful flash steam which may be separated from the condensate line and used to supplement a low pressure heating application. Note, any flash steam developed in the system as a bi-product of the condensate may be put to useful work thus reducing the overall requirement from the main boiler plant to generate steam. This in turn further improves system efficiency.

The design condition at the inlet to the heating plant shall be 15 kPa g at 100°C.

**Step 1: Determine Design Conditions.**

Firstly, based on the design inlet and outlet temperature and pressures provided, we can set our system boundary conditions and connect these points together based on the design pipe route as dictated by on site conditions. This will require pipe length and system elevation data to be defined in the model. As a first pass, we can leave the pipe diameters as default which is 2 Inch Schedule 40.

**Step 2: Develop the Model.**

Figure 5.1 provides an overview of the condensate collection system.
Step 3: Size Equipment.

When we calculate the model, we can review the fluid physical properties such as phase state, density, velocity etc and consider if pipe diameters require changing. The initial solution confirms that the fluid shall be in liquid phase in all branch pipes connected to inlets 1 & 2. However, although the fluid is in liquid phase at collection point 3, due to the pressure losses in the pipelines, some of the liquid evaporates and the fluid changes to two-phase downstream of the inlet. A quick check of the results reveals a very low vapor quality of 0.06%. The fluid is therefore predominantly liquid (99.94%).

Sizing condensate lines requires careful planning to control velocities of both the liquid and gases phases. It is generally recommended to increase the line sizes from the collection points in the steam system. This promotes flashing in the lines, thus develop useful heat steam.
The fluid velocities in this particular system have been reviewed in detail and as such, the lines have been sized at 6, 8, 10 & 12 inches. This produces fluid velocities in the region of 0.68 ft/s for liquid and 28.04 ft/s for the vapor phase. Careful consideration was also given to the vapor quality. In order to improve the vapor quality i.e. create flash steam, a number of valves were added in strategic locations and throttled to create further resistance. This has the effect of dropping further pressure in the lines and forcing further evaporation of the liquid producing higher quality vapor/steam for the lower pressure heating application.

**Step 4: Optimisation/Ageing Study**

Once the system has been modelled and the design targets achieved, we can take the model a step further by completing a time-based study on system performance. The FluidFlow Scripting Module allows engineers to simulate dynamic system analysis such as pipe scale build-up over time. This allows the designers to establish the effects on flow distribution and heat transfer due to the gradual build-up of the scale on the internal pipe surface. This allows the end-user to develop an effective maintenance action plan as part of the ongoing system operation. This will maximize system performance, efficiency and reduce system operating costs.

Using a typical scale build-up value of 0.07mm per annum (obtained from Idechik Handbook), a dynamic simulation of this system was completed to determine the number of years the plant will operate before we need to complete a shut-down and clean the pipes. Heat transfer considerations dictate that once the flow drops below 95% of its “clean” initial value the system will need cleaning. Figure 5.2 provides details of the program output. As we can see, the system flow drops below 95% of the design flow at a period of 6 years. It is at this point that the maintenance team should carry out a shut-down and clean/flush out and treat the plant.

![Figure 5.2: FluidFlow Scripting Ageing Study (Scale Build-up).](image-url)
6 Conclusion

FluidFlow is a powerful piping system modelling package and an ideal tool for addressing the complex issues that arise when designing steam systems.

The ability to model steam systems with flexibility and accuracy is fundamental to successful designs and FluidFlow has years of experience in this area. The software’s ability to determine vapor quality throughout the system as well as liquid and gas superficial velocities, helps the designer develop efficient plant designs.

FluidFlow can be used at any stage of a project and the effort put into maintaining an accurate model will also yield dividends when the plant is fully operational and undergoing process improvements and modifications to the piping systems.

If you have a specific design application and wish to use an intuitive user friendly program to speed up your design process, contact us at: support@fluidflowinfo.com.

Testimonial:

"Building the network in FluidFlow was easy and fast. The interface visualizes the connections of the facilities to the header and the specifications (pressure, temperature and quality) can managed.

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Sergei van Wijngaarden (Senior Engineer)"