FLOWNEX®
SIMULATION ENVIRONMENT

# FIRED HEATER PROCESS GAS

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## OIL & GAS INDUSTRY

## CHALLENGE:

The client needed to know:

- The gas and metal temperature profiles in the coils,
- The maximum metal temperature gradients,
- And the maximum cooling rate when the burner is accidentally shutdown and process gas is left on.

## BENEFITS:

The benefits of using Flownex® for the simulation were:

- Heat conduction was simulated in 2D, radial conduction (through the pipe wall) and axial conduction (along the pipe in the flow direction).
- The thermal capacitance (or ability of a material to store and release heat during transient events) was calculated for each pipe segment by Flownex®.
- The coils piping data could be obtained from the built-in pipe schedule tables.
- Flownex® Actions was used to set up the transient on-off operation of both cycles of the duty mode, as well as the emergency shutdown of the burner.
- These sets of Actions can be saved as a scenario, which can be re-called at any time during further simulations.
- The Actions feature was also used to input the varying profile of the inlet temperature in the second duty cycle during the transient simulations.
- The temperature profiles can be displayed graphically in Flownex® for easier interpretation of results.
- The different modes of heat transfer, conduction and convection, could be modeled separately by combining different Flownex® elements. Flownex® also has generic heat transfer component models that can do this discretization automatically.
- Material properties can be obtained from the built-in material library, and can also be user-defined.

## SOLUTION:

The exact operating conditions of all cycles could be pre-programmed as a scenario by using Flownex® Actions and saved. They could then be re-called for simulation at any point. In transient simulation of the problem, the full effect of the piping material thermal capacitance was taken into account for more accurate results. Temperature profiles could be automatically generated by using graphs within Flownex®, which reduces the amount of post-processing. The findings enabled the client company to perform thermal fatigue and stress analysis on the heater coil.

Through use of Flownex®, the team was able to determine if the design met the required specifications, and also realised significant improvements to the previous industrial washing machine system.

"Flownex® enabled the prediction of the 2-D transient temperature gradients which were so crucial to this project. I am not aware of any other tool with which I could have obtained the required results in such a short time span. Part of the success must undoubtedly be attributed to the prompt and high level support provided by Flownex® International almost daily in answering all my questions and offering suggestions throughout this very technically challenging simulation. The support fee has been paid for with this one project!"

*Hannes van der Walt*

*Senior Thermal & Process Engineer*

# FIRED HEATER FOR PROCESS GAS

## INTRODUCTION

A client in the petrochemical industry sought help with regards to a fired heater employed on a plant. The client wished to perform thermal fatigue and stress analysis on the heater, especially during transient operating conditions such as start-up and on-off cyclic operations, where the possibility for large temperature gradients exists. The heater is used to heat process gas and its layout can be seen in Figure 1 below.

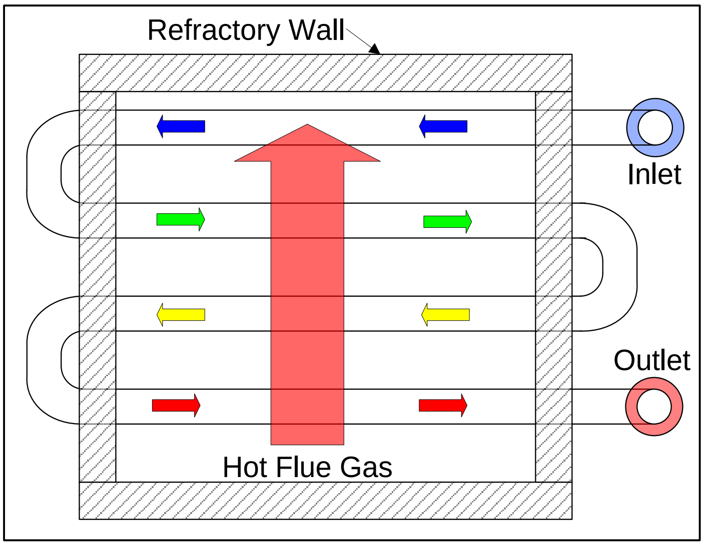


Figure 1: Simplified layout of the fired heater.

**FIRED HEATER:** A furnace which burn fuels such as oil or gas and is used to heat a variety of process media, including gas, liquids and multi-phase liquids.

**FLUE GAS:** Gas that exits to the atmosphere via a flue, which is a pipe or channel for conveying exhaust gas from a fire place, oven or furnace.

The current spray system has poor coverage of the struts. Impact force from the sprayed water is also low due to poor nozzle choice.

## CHALLENGES

The client needed to know:

- The gas and metal temperature profiles in the coils,
- The maximum metal temperature gradients,
- And the maximum cooling rate when the burner is accidentally shutdown and process gas is left on.

Flownex® enabled the prediction of the 2-D transient temperature gradients which were so crucial to this project. I am not aware of any other tool with which I could have obtained the required results in such a short time span. Part of the success must undoubtedly be attributed to the prompt and high level support provided by Flownex® International almost daily in answering all my questions and offering suggestions throughout this very technically challenging simulation. The support fee has been paid for with this one project!

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## BACKGROUND

The fired heater has two operation modes, a standby mode and a duty mode. Standby mode is employed at the start-up and during the on-off cyclic operation of the heater in normal operation. In standby mode, there is no flow of process gas; however, the heater is on low fire.

The duty mode has two cycles. In the first cycle, gas is heated by the heater which is at high fire. Process gas enters the heater at 20 °C flowing at a fixed flow rate of 3 kg/s and exits at high temperature at the outlet. The heater alternates between the duty and standby modes every hour and a half. This on-off operation of the first cycle occurs frequently over the design life of the heater.

The second cycle occurs a fifth less frequently than the first cycle over the same period. In this cycle the gas flows constantly at 3 kg/s, but the gas inlet temperature is varied.

The worst case accidental cooling in the coil would occur when the burner is shut down whilst the combustion and flue gas recirculation fans remain operational and the process gas continues to flow through the coils. Cold gas would flow into the hot coil pipes that are no longer being heated by the heater. Consequently, the coil pipes will cool down at a rate much larger than intended for normal shutdown (where only natural convection would operate to slowly cool down the external coil surfaces).

Given the extreme operation environment of the heater and the cyclic nature of operation, it was imperative to the client to accurately determine temperature gradients. This would enable them to perform thermal fatigue and stress analysis, which can be catastrophic if not monitored.

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It was determined from temperature measurements that the inlet coil at the top in Figure 1 experiences the most extreme temperature variations. The inlet coil at the top was thus selected for simulation in Flownex® SE.

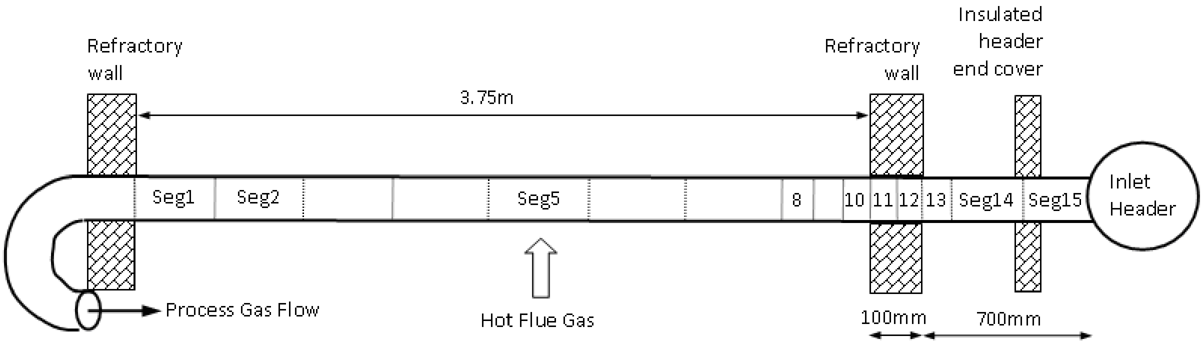


*Figure 2: The segment approach to develop the Flownex® model.*

The inlet coil was divided into 15 segments to develop the Flownex® model as shown in Figure 2. Segments closer to the inlet heater and through the refractory wall into the header cover box which is filled with hot flue gas were cut thinner as that is where the cold entry gas is first exposed to high temperatures and hence the largest gradients are expected. Such a discretised approach is necessary to accurately determine the temperature profiles.

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## SOLUTION

Transient events similar to cycles of plant operation (as shown in Figure 4) as well as accidental shutdown of the burner were simulated in the Flownex® model below.

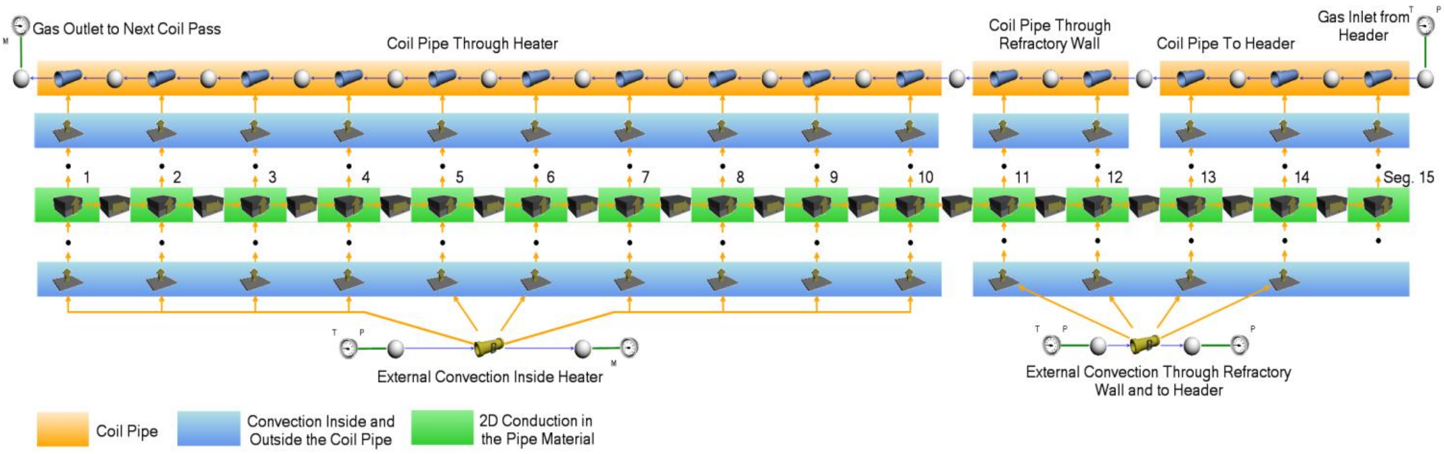


Figure 3: The Flownex® model used for analysis.

**The benefits of using Flownex® for the simulation were:**

- Heat conduction was simulated in 2D, radial conduction (through the pipe wall) and axial conduction (along the pipe in the flow direction).
- The thermal capacitance (or ability of a material to store and release heat during transient events) was calculated for each pipe segment by Flownex®.
- The coils piping data could be obtained from the built-in pipe schedule tables.
- Flownex® Actions was used to set up the transient on-off operation of both cycles of the duty mode, as well as the emergency shutdown of the burner.
- These sets of Actions can be saved as a scenario, which can be re-called at any time during further simulations.

- The Actions feature was also used to input the varying profile of the inlet temperature in the second duty cycle during the transient simulations.
- The temperature profiles can be displayed graphically in Flownex® for easier interpretation of results.
- The different modes of heat transfer, conduction and convection, could be modelled separately by combining different Flownex® elements. Flownex® also has generic heat transfer component models that can do this discretisation automatically.
- Material properties can be obtained from the built-in material library, and can also be user-defined.

The temperature profiles can be displayed graphically in Flownex® for easier interpretation of results

## RESULTS

Temperature gradients occur in two forms; spatial temperature gradient, $\partial T/\partial x$ and transient temperature gradient, $\partial T/\partial t$. The areas found to be prone to extreme temperature gradients and the magnitudes of the gradients are shown in Table 1 below.

| Case | Mode | Segment(s) | ΔT | $\partial T/\partial x$ | $\partial T/\partial t$ |
|---|---|---|---|---|---|
| Units | | | [°C] | [°C/mm] | [°C/s] |
| 1st Cycle | Heating | 10 & 11 | 105 | 2.06 | |
| | Cooling | 10 & 11 | -90 | -1.77 | |
| | Cooling | 13 | -80 | | -1.60 |
| 2nd Cycle | Cooling | 10 & 11 | -80 | -1.57 | |
| | Heating | 15 | 75 | | 0.47 |
| Rapid Cooling | Cooling | 1 | -50 | | -1.20 |

Table 1: Maximum temperature gradients for each cycle.

It is shown in Figure 4 that the sections of the coil directly exposed to the heater flue gas (segments 1 to 10) rise rapidly during duty mode. Segment 11 and 12 represents the coil sections within the refractory wall as the coil passes through the refractory wall to the header. These coil section temperatures rise considerably slower as they are only subjected to a much lower level of convection and radiation. Consequently they do not reach steady state within the duration of the cycle. Segment 13 represents the first section outside of the refractory wall but still within the insulated header end cover. It is shown that the temperature in this section rises even slower.

The highest spatial temperature gradients are in segments 10 and 11 during the heating and cooling of the first cycle, as highlighted in the table. Segment 13 experiences the steepest transient temperature gradient, which is during cooling of the first cycle. The tube wall temperature would drop by approximately 1.6 °C every second.

The second cycle causes high temperature gradients at segments 10 and 11 when cooling down and at segment 15 when heating up. The transient temperature gradient becomes large at segment 1 in case of rapid cooling, when the burner is accidentally shut-down.

The results show that in general segment 10 ~ 15 will have the highest temperature gradients, both spatial and transient. This is the area where the cool inlet process gas is first exposed to the high temperatures of the furnace. These segments will thus be of prime interest in stress and thermal analysis.

Figure 4 shows temperature profiles of the heating and cooling process of the first cycle. Note the temperature difference of 105 °C between segments 13 and 14 during heating, as well as a 90 °C difference between segments 10 and 11 during cooling. The point of maximum heating gradient is indicated, which is between segment 10 and 11.

The simulations in Flownex® could be completed in minutes once the model was fully set-up.

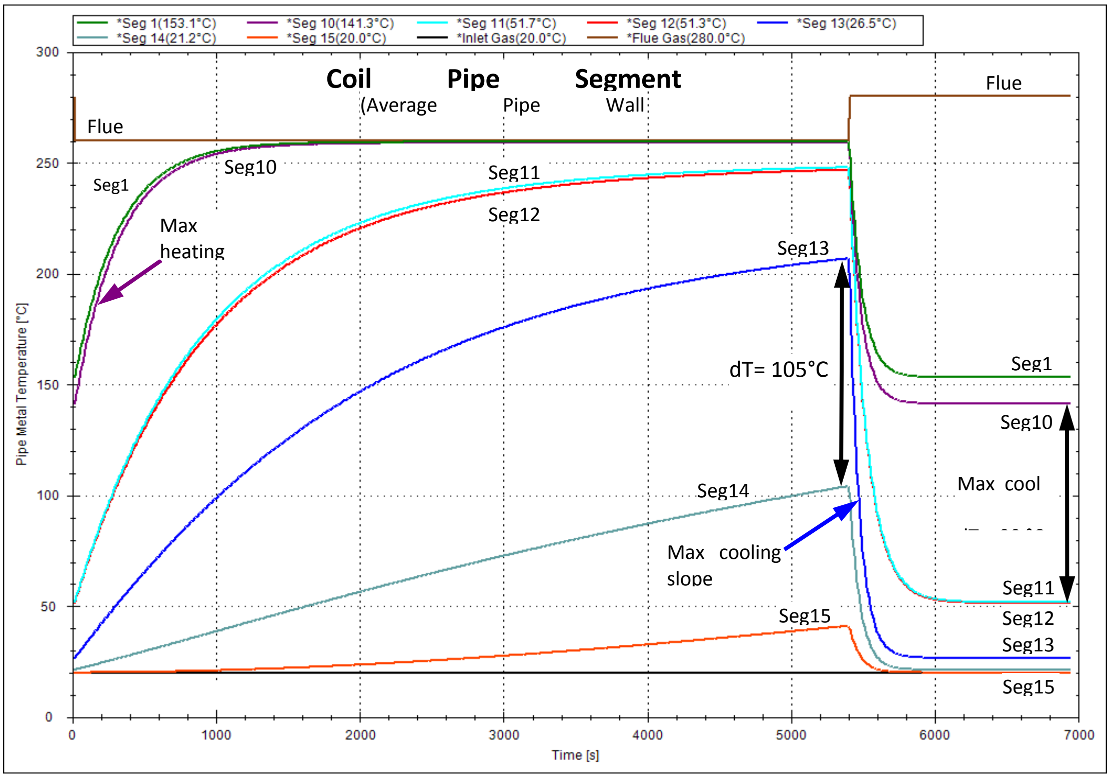


Figure 4: Results of the first cycle in duty mode. The graph is produced using Flownex®.

## SUMMARY

Cyclic operation of a fired heater in the process industry was simulated in Flownex®. The use of Flownex® allowed for the problem to be discretised into smaller segments for more accurate simulations, yet the model remained compact and light. CFD simulation of the problem, which can be very time consuming, was avoided as the results from Flownex® provided sufficient detail on heat transfer across the pipe wall. The simulations in Flownex® could be completed in minutes once the model was fully set-up. The setting up of the model, once the user is familiar with Flownex®, would require approximately one workday.

The exact operating conditions of all cycles could be pre-programmed as a scenario by using Flownex® Actions and saved. They could then be re-called for simulation at any point. In transient simulation of the problem, the full effect of the piping material thermal capacitance was taken into account for more accurate results. Temperature profiles could be automatically generated by using graphs within Flownex®, which reduces the amount of post-processing. The findings enabled the client company to perform thermal fatigue and stress analysis on the heater coil.



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