FLOWNEX®

SIMULATION ENVIRONMENT

CASE STUDY

FIRED HEATER DESIGN

This case study demonstrates the implementation of an API 560 fired heater compound component in Flownex. It also shows how Flownex® has been used during the process design and preliminary sizing of a typical API 560 fired heater, combustion air fan and the associated ducting. Results are compared with other commercial software.

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Challenge:

The main challenge in this cases study is the application of Flownex® to:

- design the process by performing a heat and mass balance,
- size the fired heater and determine typical tube wall and flue gas temperatures,
- size the combustion air fan,
- determine the required ducting and piping sizes, and,
- analyze the combustion process, specifically the flue gas emissions.

Benefits:

By creating a fired heater compound component, a Flownex® model can be developed which is able to model both the fluid flow, combustion and heat transfer processes. This combined capability is not commonly available in other design tools.

Solution:

Flownex® could effectively be used during the design and sizing of the fired heater, combustion air fan and the associated ducting.

"To remain competitive in a globalised competitive environment, engineering companies have to perform the same tasks in a quicker, more efficient manner – they have to work smarter, not harder. In the case of sizing packages such as a fired heater during the quotation stage when there is never enough time, Flownex has proven to be an invaluable tool. It allows us to complete a very comprehensive sizing analysis within a few hours. I am not aware of any other tool that can do this to the level of detail done in this case study."

Hannes van der Walt
Principal Thermal Engineer
Gasco Pty Ltd

Introduction

The design of a fired heater (or similar) package typically starts with a heat and mass balance. This first step is necessary to determine the process parameters which determine most of the sizing of the package. A fired heater package heat and mass balance includes the modelling of the combustion process and the modelling of the heat transfer and fluid flow processes. Modelling the combustion process typically involves the specification of the fuel gas composition, the combustion air composition, the air-fuel ratio and the fuel flow rate. The heat transfer from the fired heater combustion process into the process fluid may be specified in terms of an overall heater thermal efficiency. Typical heat and mass balance calculations do not provide estimations of the physical size of the heater or even the ducting and other components such as combustion air fans, neither do they enable the calculation of system pressure losses or heat losses. They are also incapable of providing insight into tube wall and process fluid film temperatures which are very important in the oil and gas industry. Flownex® enables the user to perform all these tasks easily and quickly in a single calculation.

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Model

The main purpose of this exercise is to size a fired heater (typically an API 560 design) and its associated combustion air fan and ducting. In order to perform this task efficiently, a Flownex® model has been developed which is able to model the combustion, fluid flow and heat transfer processes. As such the model relies on a fired heater compound component and a few scripts to handle fuel and flue gas analyses. Required data inputs are indicated by blue rectangles in Figure 1. The fired heater compound component input and result fields are shown in Figure 2 and Figure 3 respectively.

Typically, the client would specify the following heater requirements:

- The required heater duty (to the process fluid).
- Process fluid composition and flow rate.
- Process fluid required inlet and outlet temperatures.
- A required, or at least a desired heater efficiency.
- Maximum allowable flue gas temperatures (if specified).
- Maximum allowable tube wall temperatures and/or process fluid film temperatures.
- Allowable process coil API erosional velocities, mass velocities or ρV^2-values.
- Process coil fouling factors.
- Fuel gas composition.
- Ambient conditions.

The required heater data specification is as follows:

- Estimate the heater efficiency based on previous experience, or if the efficiency is stated by the client, specify this as the *Required Efficiency (HHV)*. Typical fired heater HHV efficiencies range from 75% to 80%.
- Add estimates for the *Heater Flue Pressure Drop* and *Process Pressure Drop*. A typical flue side pressure drop is 50 kPa to 60 kPa. The model may be used to estimate the process side pressure drop by specifying the expected number of return bends in the coils and a return bend loss coefficient. These may be updated at a later stage when the actual heater pressure drop has been determined via dedicated heater design software.
- Specify the heater configuration; Counter Flow or Parallel Flow. Most fired heaters are counter flow. In parallel flow designs the process fluid inlet would be at the radiant section and the outlet at the top of the convection section. They are typically used in situations where corrosion may be a problem at the top-most convection tubes. This occurs when the top convection tube temperatures would be too close to the water or SOx acid gas dew point temperatures in counter flow configuration and therefore a risk of tube corrosion exists.
- Specify the *Design Heat Flux*. Adjust the *Design Heat Flux* to obtain larger or smaller coil areas. This parameter may also be used to obtain comfortable tube wall temperatures. This value may rely on previous experience and also depends on the type of process fluid. For fluids where local hot spots may cause degradation, such as oils, this value would be lower than others, such as air, where no such degradation occurs. From practical experience, the following are approximate guidelines:
    - For water heating, a maximum of 36 kW/m^2 should be used.
    - For oils with temperatures below 150°C, a maximum flux of 23 kW/m^2 is recommended.
    - For oils with temperatures between 150°C and 250°C, a maximum flux of 21 kW/m^2 is recommended.
    - For oils with temperatures above 250°C, a maximum flux of 19 kW/m^2 is recommended.
    - For natural gases and other gases such as air the heat flux may be set higher, however a safe margin between the calculated tube wall temperature and the maximum design temperature for the project at hand should exist.
- Since this model does not perform detailed radiation or even convection calculations, but simply applies average heat fluxes over a coil area, peak fluxes and temperatures cannot be calculated. However, a Peak Heat Flux Factor is used to artificially increase the maximum temperature values to obtain an estimate of potential maximum tube wall temperatures. Therefore, a minimum value of 1 causes no peak temperatures. From experience, peak wall temperatures are about 5% to 10% higher than averaged maximum temperatures.
- If the heater is to feature both a radiant section as well as a convection section, such as API 560 Type C or Type E heaters, an estimate for the duty split between the radiant and convection sections is specified. This is achieved by specifying the *Radiant Duty Fraction*. This value is also used to control the *Radiant Chamber Exit Temperature* which cannot be too high, else the convection section will experience excessive temperatures, especially the tube fins. Typical bridge wall temperatures of 1000°C or lower should be obtained. From practical experience, radiant sections transfer between 50% and 60% of the heat. Therefore start the first iteration with a radiant duty fraction of 55%.
- The radiant section is sized based on the burner (or burners) flame size and layout. The flame dimensions are specified in terms of a *Flame Length* and a *Flame Diameter* for a single burner. Burner flame dimensions are available from the burner manufacturer for a specific duty rating. When multiple burners are used, the burners are arranged around a *Burner Circle* of which the *Diameter* must be specified. This diameter is zero for a single burner. Furthermore, a clearance must exist between the flame edge and the coil wall. These are typically 0.4m to 0.6m. These

parameters will be used to determine the radiant section coil PCD.

- To estimate the required radiant section height, a *Radiant Chamber Height to Width Ratio* is specified. API 560 recommends a maximum value of 2.75 and a minimum of 1.5. For horizontally oriented heaters, API 560 recommends a range of H/W ratios for both maxima and minima depending on the heater duty. A ratio of 2.5 may be a good starting value. Another related factor specified by API 560 is a maximum volumetric heat release of 165 kW/m^3 for gas fired heaters. Ensure that this limit is not exceeded with the selected geometry.
- The process fluid is selected as well as the coil materials.
- Coil inside and outside fouling factors may be specified. Fouling factors have a significant influence on tube wall temperatures.
- The coil geometry is specified in terms of the diameter, thickness and the number of parallel flow paths which essentially "duplicates" the coil into parallel flowing coils. Start by specifying a coil size and number of parallel flow paths that feels right from experience. After the first solution is obtained, the coil size and/or number of parallel flow paths may be adjusted depending on velocity and pressure drop considerations.
- Lastly, in the case of a convection section being present, a fin geometry may be specified. The model does not have the functionality to specify shock tubes - bare tubes without fins, usually the first 3 rows in the convection section. Since the model simply determines the required bare tube area from the specified *Design Heat Flux*, the specification of fins has no influence on the calculated required convection coil length. The only purpose of specifying the fin geometry is for the model to estimate likely fin tip temperatures and to calculate an equivalent average convection coefficient which only serves as a reality check. Typical convection coefficients range between 10 and 30 $W/m^2.K$. According to API 560, fin lengths should not exceed 25.4mm and the minimum fin thickness is recommended to be 1.3mm. From practical experience, fin lengths may include 10mm, 12.5mm, 20mm and 25.4mm whilst the fin thickness may be either 1.3mm or 1.5mm. Fin densities should remain below approximately 200 fins/m according to API 560.

The heater, combustion air fan and ducting are then sized by following the steps below:

- Having specified a required or desired heater thermal efficiency, adjust the *Fuel Gas Flow Rate* to obtain the required *Heat to Process* (Duty) to achieve the required process fluid outlet temperature.
- Adjust the *Excess Air % (Wet)* to obtain the required *Adiabatic Flame Temperature* (theoretical maximum combustion temperature) and therefore indirectly the *Flue Temperature* into the convection section and into the stack. These temperatures depend on the combination of fuel flow rate, excess air percentage and the heater efficiency. Furthermore, the excess air also directly influences the O_2 and CO concentrations in the flue gas. API 560 recommends 15% excess air for forced draft heaters and 20% excess air for natural draft heaters.
- Adjust the *Radiant Duty Fraction* if required, however this is a major unknown as the model does not really perform any radiation heat transfer calculations. Therefore aim to use the values suggested above.
- Adjust the coil geometry to satisfy velocity, mass velocity or ρV^2-value requirements. Both the coil diameter and the number of parallel coils may be altered to achieve desired flow velocities. From practical experience, aim for velocities between 3 m/s and 4 m/s for liquids such as water. For more viscous liquids, the velocities may be significantly lower and the pressure drop may be the governing factor. For gases, aim for velocities of approximately 15 m/s.
- Adjust the *Design Heat Flux*. Again, when the process fluid is temperature sensitive, aim to use the values suggested above.
- Inspect the velocities in the air, fuel and flue piping and ducting and adjust their sizes to obtain comfortable velocities.

The combustion air fan flow rate is automatically set by the required combustion air flow rate calculated in the combustion calculations. The fan element then calculates the required duty point to satisfy the flow and pressure requirements.

SOLUTION

The model calculates the following:

- The combustion system performance. These include:
  - The calculated heat to process to achieve the required process fluid temperature increase;
  - Required burner heat release (HHV and LHV);
  - The heater thermal efficiency (HHV and LHV);
  - Combustion temperature;
  - Radiant chamber flue gas exit temperature;
- The heater geometry as follows:
  - The required coil lengths for both the radiant and convection sections;
  - The required coil areas for both the radiant and convection sections;
  - The radiant section chamber PCD and height;
- The flue gas flow results:
  - Flue gas mass flow and average actual volume flow;
  - Flue gas average density;
  - Flue gas side pressure drop;
- The process fluid results:
  - Process fluid mass flow;
  - Process fluid inlet and outlet temperatures for both the radiant and convection sections;
  - Process fluid inlet pressure and pressure drop;
  - Process fluid inlet and outlet velocities for both the radiant and convection coils;
  - API 14E erosional velocity, the mass velocity and the ρV^2-value for both the radiant and convection coils
- The heat transfer results:
  - Heat transfer to each coil;
  - Average heat flux to each coil;
  - Radiant section volumetric heat release;
  - Convection section average convection coefficient;
  - Convection section estimated maximum fin tip temperature;
  - Coil inside and outside surface temperatures (minimum, maximum and average).
- the required fuel flow rate;
- the required air flow rate;
- The required combustion fan pressure rise and flow rate;
- Pressure drops for the various components;
- Duct and pipe velocities – check for duct and pipe sizing;

- Flue gas properties; of particular interest may be the oxygen content, the CO content, the SO2 content and the dew point temperatures.

CASE STUDY

As an example, a natural gas fired heater package is to be designed to heat 73.6 kg/s of water flow from 155°C to 175°C. Perform a quick 15 minute heater package sizing and compare the results with a detailed final heater design done on a third-party fired-heater software such as HTRI or FRNC.

Data Specification

Typical fired heater properties when heating water are approximately as follows:

General Data		
Property	Unit	Value
Thermal efficiency (HHV)	%	80
Thermal efficiency (LHV)	%	88.2
Flue side pressure drop	Pa	60
Process side pressure drop	kPa	150
Design Heat Flux	kW/m^2	30
Peak Heat Flux Factor	%	5
Radiant chamber duty fraction	%	55
Fouling (outside)	$m^2.K.W$	0.0002
Maximum flue velocity	m/s	15
Maximum water velocity	m/s	4
Maximum tube wall temperature	°C	300
Maximum fin temperature	°C	350
Burner Circle	m	0
Flame-to-Wall Clearance	m	0.55
Radiant Chamber Height-to-Width	m/m	2.75
Fin Height	mm	20
Fin Thickness	mm	1.5
Fin Density	Fins/m	160
Burner Data		
Manufacturer	Fives North American	
Model	4384-18	
Fuel Supply Pressure	kPag	55
Air Supply Pressure	kPag	1.5
Max. Flame Length	m	4.3
Max Flame Diameter	m	1.01

RESULTS COMPARISON & DISCUSSION

The following results were obtained using the Flownex® model and are compared to results obtained from an actual detailed design done using HTRI:

Property	Unit	Flownex	HTRI
Thermal efficiency (HHV)	%	80	-
Thermal efficiency (LHV)	%	88.2	89.9
Heat to Process	kW	6401	6510
Heat release (HHV)	kW	8001	-
Heat release (LHV)	kW	7259	7211
Fuel gas flow rate	kg/hr	546	536
Combustion air flow rate	kg/hr	10676	10452
Flue gas flow rate	kg/hr	11222	10988
Adiabatic flame temperature	°C	1784	-
Radiant chamber duty fraction	%	55	55.9
Radiant chamber exit temperature	°C	992	972
Stack flue gas exit temperature	°C	266	224[Note 1]
Stack flue gas water dew point temperature	°C	59	-
Stack flue gas SOx acid dew point temperature	°C	138	-
Stack flue gas O_2 content	%	2.3	3.0
Flue side pressure drop	Pa	60	26
Process side pressure drop	kPa	285	253
Design Heat Flux	kW/m^2	30	-
Radiant coil average heat flux	kW/m^2	26.7	26.8
Convection coil average heat flux	kW/m^2	30	29.6
Convection coil average convection coefficient	$kW/m^2.K$	19.0	20.1
Required radiant coil length	m	367	367[Note 2]
Required convection coil length	m	267	270[Note 2]
Maximum flue velocity in ducting	m/s	11.6	-
Maximum water velocity	m/s	3.7	3.7
API 14E erosional velocity	m/s	6.1	-
Mass velocity	$kg/m^2.s$	3331	-
ρV^2	Pa	12347	-
Maximum radiant section tube wall temperature	°C	207	209
Average radiant section tube wall temperature	°C	179	-
Maximum convection section tube wall temperature	°C	197	200
Average convection section tube wall temperature	°C	170	-
Maximum fin temperature	°C	258	261
Convection section process inlet temperature	°C	155	155
Crossover process temperature	°C	164	164
Radiant section outlet process temperature	°C	175	175
Combustion air fan required pressure rise	kPa	10.2	-
Combustion air fan required hydraulic duty	kW	28.5	-

Note 1: Due to the higher efficiency of the final design using HTRI, the HTRI calculated stack flue gas temperature is slightly lower. Changing the Flownex® required efficiency to align with the HTRI results, a flue gas temperature within 10°C of the HTRI result is obtained.

Note 2: Note that the heater geometry was first determined using Flownex® and the HTRI model subsequently used this geometry.

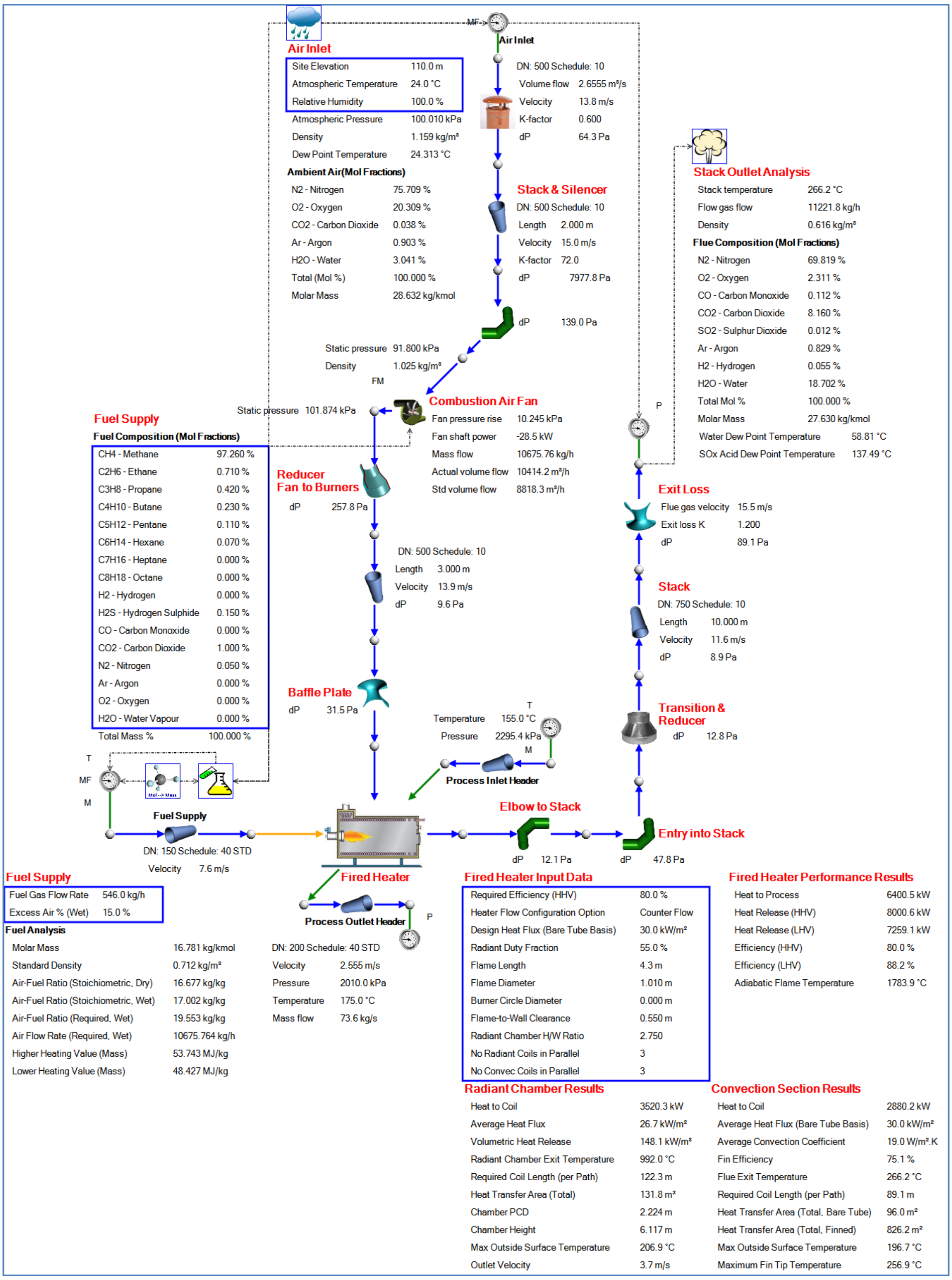

Figure 1: Flownex® Model.

Basic Fired Heater - 324 (Basic Fired Heater) Properties

Property	Value	Unit
Required Performance		
Required Efficiency (HHV)	80	%
Burner Required Fuel Pressure D…	55	kPa
Burner Required Air Pressure Drop	1.5	kPa
Heater Flue Pressure Drop	60	Pa
Process Pressure Drop Option	Estimate Pressure Drop	
Number of Radiant Section Retur…	16	
Number of Convection Section R…	19	
Return Bend Loss Coefficient	0.3	
Heat Transfer Limits		
Heater Flow Configuration Option	Counter Flow	
Design Heat Flux (Bare Tube Basis)	30	kW/m²
Peak Heat Flux Factor	1.05	
Radiant Duty Fraction	55	%
Radiant Chamber & Burner Flame Dimensions		
Flame Length	4.3	m
Flame Diameter	1.01	m
Burner Circle Diameter	0	m
Flame-to-Wall Clearance	0.55	m
Radiant Chamber Height to Widt…	2.75	
Heat Transfer Coils		
Fluids & Materials		
Process Fluid	H2O - Water| Liquids (Pure Fluids…	
Radiant Coil Material	Carbon Steel - Plain Carbon (Mn l…	
Convection Coil Material	Carbon Steel - Plain Carbon (Mn l…	
Fouling & Erosion		
Radiant Coil Inside Fouling Fa…	0	m².K/W
Radiant Coil Outside Fouling F…	0.00018	m².K/W
Convection Coil Inside Fouling…	0	m².K/W
Convection Coil Outside Foulin…	0.00018	m².K/W
API Erosional Velocity Constant	150	Sqrt(lbm/ft.s²)
Radiant Coil Geometry		
Geometry option	Specify schedule	
Database	DN: 100 Schedule: 40 STD	
Number in parallel	3	
Convection Coil Geometry		
Geometry option	Specify schedule	
Database	DN: 100 Schedule: 40 STD	
Number in parallel	3	
Fin Option	Finned	
Fin Height	20	mm
Fin Thickness	1.5	mm
Fin Density	160	fins/m

Figure 2: Fired Heater Inputs.

Basic Fired Heater - 324 (Basic Fired Heater) Properties

Property	Value	Unit
General		
Identifier	Basic Fired Heater - 324	
Combustion Performance		
Heat to Process	6400.46	kW
Heat Release (HHV)	8000.58	kW
Heat Release (LHV)	7259.09	kW
Efficiency (HHV)	80	%
Efficiency (LHV)	88.1717	%
Adiabatic Flame Temperature	1783.94	°C
Radiant Chamber Exit Temperature	992.044	°C
Flue Temperature	266.192	°C
Burner Calculated Fuel Pressure …	55	kPa
Burner Calculated Air Pressure D…	1.5	kPa
Geometry		
Radiant Section		
Required Coil Length (per Path)	122.337	m
Heat Transfer Area (Total)	131.787	m²
Chamber PCD	2.2243	m
Chamber Height	6.11683	m
Convection Section		
Required Coil Length (per Path)	89.1221	m
Heat Transfer Area (Total, Ba…	96.007	m²
Heat Transfer Area (Total, Fin…	826.181	m²
Flue Gas Flow		
Mass Flow	11221.8	kg/h
Volume Flow	8.44694	m³/s
Density (Average)	0.369028	kg/m³
Flue Pressure Drop	60.0006	Pa
Process Fluid Flow		
Mass Flow	265135	kg/h
Inlet Temperature	155	°C
Outlet Temperature	175.028	°C
Inlet Static Pressure	2295.17	kPa
Process Pressure Drop	284.966	kPa
Radiant Coil		
Inlet Temperature	164.053	°C
Outlet Temperature	175.028	°C
Inlet Velocity	3.66004	m/s
Outlet Velocity	3.70672	m/s
API 14E Erosional Velocity	6.10454	m/s
Mass Velocity	3331.09	kg/m².s
RhoV²	12347.4	Pa
Convection Coil		
Inlet Temperature	155.001	°C
Outlet Temperature	164.053	°C
Inlet Velocity	3.62421	m/s
Outlet Velocity	3.66004	m/s
API 14E Erosional Velocity	6.07035	m/s
Mass Velocity	3326.29	kg/m².s
RhoV²	12174.4	Pa
Heat Transfer		
Radiant Coil		
Heat to Coil	3520.26	kW
Average Heat Flux	26.7117	kW/m²
Volumetric Heat Release	148.106	kW/m³
Outside Surface		
Maximum Temperature	206.908	°C
Average Temperature	179.137	°C
Minimum Temperature	174.21	°C
Inside Surface		
Maximum Temperature	176.13	°C
Average Temperature	171.219	°C
Minimum Temperature	166.293	°C
Convection Coil		
Heat to Coil	2880.21	kW
Average Heat Flux (Bare Tub…	30	kW/m²
Average Convection Coefficient	18.9965	W/m².K
Fin Efficiency	75.0908	%
Outside Surface		
Maximum Temperature	196.749	°C
Average Temperature	170.326	°C
Minimum Temperature	166.269	°C
Maximum Fin Tip Temperature	256.911	°C
Inside Surface		
Maximum Temperature	165.505	°C
Average Temperature	161.458	°C
Minimum Temperature	157.401	°C

Figure 3: Fired Heater Results.

Summary

Using Flownex®, the design and sizing of the fired heater, combustion air fan and the associated piping and ducting could be performed within an hour. Furthermore, results such as process temperatures, tube wall temperatures, heat fluxes, flow velocities, pressure losses etc. could easily be obtained from the network. As an overall package sizing and design tool, Flownex® has proven to be far more efficient than other detailed design software.