Tubular Furnaces Performances Study Using UniSim FPH Simulator

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The paper is presenting and analyzing the Unisim FPH simulator used for simulate the tubular furnaces. The paper is structured in for parts. First part is dedicated to describe and comment the principal commands utilized on the simulators configuration. The geometric and operating data utilized were from a Catalytic Reforming unit. The next two parts present the simulation results and importing of the heated stream's properties (gasoline). The last part presents the comparison between the results obtained with Unisim FPH simulator and the result obtained during classic calculation with formulas from literature. The results have revealed both common and different features of the two mathematical models.

Keywords: furnace, Unisim Design, Unisim FPH, catalytic reforming

The great majority of operations in refining and petrochemical industries use temperature as one of the main operating variables. Therefore, it is crucial to known if the heating equipment works properly, in order to minimize the expenses, which is a very important variable nowadays.

The most important equipment for producing and transfer of heat is the tubular furnace. Establishing the operating parameters and the furnace's performances could be realized based on mathematical models for combustion and heat transfer and using of some calculating programs. In principal for an engineer are two available solutions:

First solution consists in creating of a mathematical model of the tubular furnace and elaborating of a calculation program for numerical solving of the model. In this category are included some international [1, 2] and national [3-5] paper works. In the latest researches presented are being treated separately the two sections of the tubular furnace. The convection section is being assimilated to a system with concentrated parameters. The mathematical model contains two thermal balance equations associated to those two material streams: flue gases and hated stream [4]. The expressions utilized in thermal balance are derived from Newton's law. A difficult issue is related to adapting of mathematical model to specific of the furnace and at the particularities of the heated stream. The simulation of the convective section allowed establishing of the static characteristics which are linear.

The modeling of the radiation section has been widely presented in [3], where the tubular furnace radiation section contains two subsystems: combustion subsystem and heat transfer subsystem. The combustion model is based on the material balance equations associated to the burning of the Hydrogen and Carbons contained in the fuel, these equations exist in literature.

An interesting study of incomplete burning in different operating conditions of the tubular furnace is made in the mentioned paper. The mathematical model of the thermic transfer is based on the Lobo-Evans model. The model makes part from category of the models which consider the perfect mixture of the flue gases. Solving of the mathematical model allows establishing of the static characteristics of the radiation section. From these features we can highlight the *Output temperature – the amount of air coefficient* characteristic, there is a characteristic with extreme point [6].

The second solution is based on the specialized simulators developed on solving the heat transfer equipment. Among them we can mention the following simulators: Aspen Fired Heater produced by Aspentech [7], HeaterSim [8], Fired Process Heater Modeler (UniSim FPH) produced by Honeywell [9]. There is relatively little scientific information about these simulators, for example [10], but should be mentioned the tendency of using them in academic field [11].

On this purpose, the authors have been studied UniSim FPH, realizing a guide for using this simulator, this paper work having didactical and scientific use.

General presentation of UniSim FPH

UniSim FPH is a simulation program developed to calculate convection and radiation sections performances in an industrial furnace. The simulator disposes of two options that any user can choose depending on the subject of the research:

FIXED-Performance Simulations – This option can be used when the performances of a furnace needs to be tested. It is used to see if the furnace works properly. Input data are furnace geometry, feed composition etc. and the program calculate temperatures, heat transfer, pressure drops etc.

CALCULATE-Burner Rate Mode – In this case, UniSim FPH calculates the necessary fuel flow in order to bring the outer feed to demanded parameters. This option is very useful nowadays where the fuel consumption needs to minimized. This facility is used especially when a new radiation section needs to be created.

The Unisim FPH can simulate furnaces which have is convection section up to 9 bundles of horizontal tubes, with or without fins. Each bundle can be fed with different technological stream. A typical scheme associated to the tubular furnace is presented in figure 1.

The steps of use UniSim FPH include:

-Start up – beginning of the program;

-Firebox Model – choosing of the mathematical model;

-Firebox Geometry – user defines geometrical details of the radiation section;

-Firebox Processes – radiation input streams;

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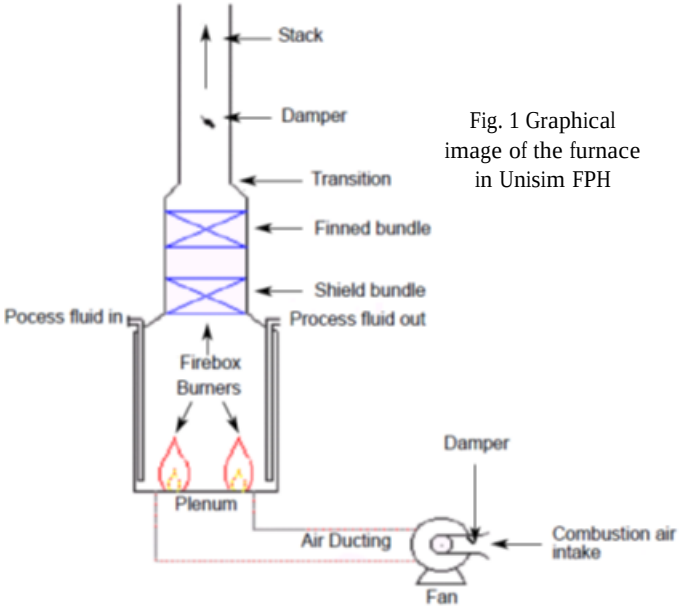


Fig. 1 Graphical image of the furnace in Unisim FPH

-Tube Bank Geometry – user defines geometrical details of the convection section;
-Tube Bank Processes – convection input streams;
-Combustion – the calculus of the burn gas distribution;
-Draught Calculation;
-Physical Properties of heated streams.

The simulator configuration

The configuration of the simulator may be presented and analyzed just for a real furnace. The case study presents the most important aspects of performance simulation of a furnace from Catalytic Reforming Unit [14]. Since endothermal reactions are dominant in Catalytic Reforming reaction, the multiple reactors are arranged in a series with a reheating furnace to maintain the reaction rate for reforming reaction.

In figure 2 is presented a section of tubular furnace that is heating the gasoline entering in Catalytic reforming unit, and steam generator in convection section.

Below will presented the most important issues in simulator configuration, detailing the configuration menus of the simulator.

Start Up menu contain next specifications:
- Furnace configuration: paralellipipedical radiation section provided with tubes;
- Number of Process Streams: 3 (the effluent stream consisting of gasoline and recirculating gases, sub-cooled water and boiling point water);
- Number of Tubes Banks: 2 (2 tube banks in radiation section).

Firebox Model. The mathematical model of the radiation section is considered well stirred; the distribution of the heating zones inside the furnace shall be done automatically by the program. That means that is considered constant temperature in the radiation section.

Firebox Geometry
- Cabin Firebox Layout: Paralellipipedical with *U* tubes;
- Number of Fireboxes: 1;
- Firebox Length: 6.817 m;
- Firebox Width: 5.183 m;
- Firebox Height: 13.12 m.

- No. of Tubes in a Path: 2;
- No. of Paths in a Firebox Tube Line: 24;
- Orientation of Main Tubes: Vertical tubes;

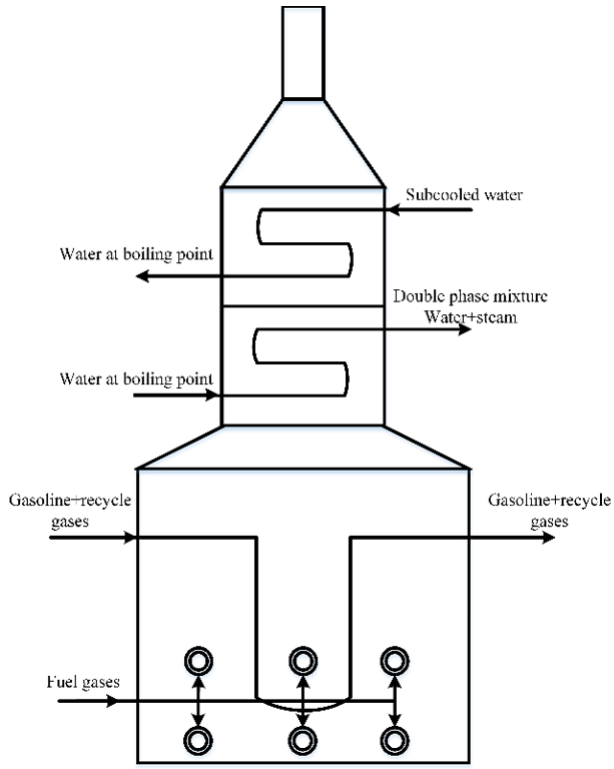


Fig. 2 The structure of the Furnace from Catalytic Reforming Unit

- Height from floor to first tube: 0.365 m

- Tube Outside Diameter: 91 mm;
- Tube Wall Thickness: 8 mm;
- Tube Separation: 3048 mm.

Firebox Process – Firebox Process Stream
- Process Stream in Firebox: 1 (process fluid defined by number 1);
- Flow History: First entry (the first entry of the effluent is in the radiation section).

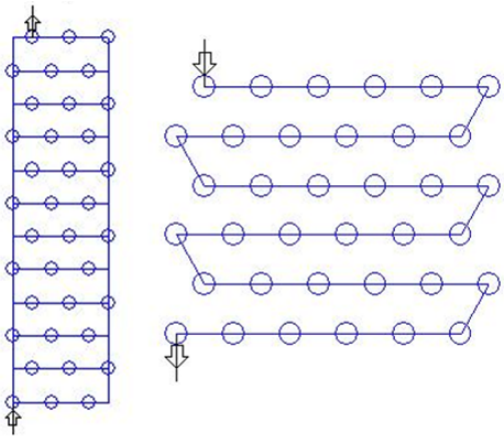
Tube Bank Geometry – Tube Bank Details
- Tube Type: High round fins;
- Tube Layout: triangle at 30°;
- Tube Pitch: 228.6 mm;
- Transverse Pitch: 228.6 mm;
- Longitudinal Pitch: 198 mm;
- Tube Length: 5.064 m.

After introduce characteristic data, the resulted scheme is presented in figure 3.

Combustion – Burner +Combustion
- Type of Burners: Natural Draught;
- Burner Location: floor;
- Number of Burners: 12;
- Burner Diameter: 0.6 m.

Observation. The burners in the case of simulated furnace are located on the sidewalls, sideways of the *U* tubes. The FPH simulator doesn't contain this option, and this is the reason why the authors have chosen to simulate the furnace using floor located burners , and instead of *U* tubes have chosen the sidewalls tubes. Despite the fact that geometry is a little different, have been secured the heating of the tubes using the floor burners.

Combustion - Fuel
-Fuel Type Identifier: Gaseous;
-Fuel Flowrate: 600 kg/h;
-Fuel Temperature: 20°C.



a) b)

Fig. 3. Scheme of strems circulation a) the stream no. 1; b) the stream no. 2

Combustion – Gaseous Fuel. FPH simulator allows using of gaseous fuels defined by types of chemical compounds. In figure 4 is presented the specification window of fuel composition, there contains usually Hydrocarbons, H_2 but also CO.

Combustion - Combustion products

The specifications are:

- Percent Oxygen in Flue Gases: 7.8 %;
- Percentage of Excess Air: 57%.

Calculation of the heated stream of gasoline properties

One of the important aspects of the UniSim FPH is the estimation and the importing of the physical properties of the streams which circulate inside the furnace. In this paper is presented the calculation mode of gasoline's properties processed in Catalytic Reforming Unit. The next stage described in the paper it is focused on importing physical properties of the heated streams, properties which depend with the temperature and the pressure inside the different parts of the furnace. The gasoline used has the next properties: density $d^{20}_{4} = 0.7583$ and the ASTM distillation curve there are presented in table 1.

Table 1

GASOLINE STREAM PROPERTIES

Vaporized volume [%]	Temperature [°C]	Vaporized volume [%]	Temperature [°C]
5	103	60	136
10	106	70	143
15	109	80	153
20	115	90	163
30	118	95	174
40	122	100	185
50	127		

The physical properties calculation of the gasoline has been done using Unisim Design and it is necessary to cover the next stages [12]:

- Choosing of the thermodynamic model;
- Defining distillation curve of the gasoline;
- Specify of the gasoline's density;
- Checking the properties resulted.

The thermodynamic model is Peng-Robinson and the specification of the steps b) and c) are presented in [12].

After covering of this steps regarding the operation of defining the pseudocompounds associated to blending, is being calculated the mixture of pseudocompounds which approximates the gasoline stream introduced in reforming furnace. In figure 5 is presented the comparison between the ASTM and experimental curves.

Importing of the properties of the gasoline stream

Due to the fact that UniSim FPH importing mechanism is conditioned by the heated stream properties, which needs an heating equipment, (E101 heat exchanger), in Unisim Design simulator the user is going to introduce the

	Fuel 1	Fuel 2	Fuel 3	Fuel 4
Mass or Molar Compositions	Molar flows/f	default (mass	default (mass	default (mass
Methane	9,38			
Ethane	10,24			
Propane	12,74			
Butanes	12,06			
Pentanes	3,03			
Hexanes	0,03			
Cyclohexane	0			
Benzene	0			
Ethene	0			
Propene	0			
Butenes	0			
Pentenes	0			
Butadienes	0			
Acetylene	0			
Hydrogen	50,04			
Hydrogen sulphide	0			
Oxygen	0			
Nitrogen	2,48			
Argon	0			
Water vapour	0			
Carbon monoxide	0			
Carbon dioxide	0			
Sulphur dioxide	0			

Fig. 4. The composition of the gaseous fuel

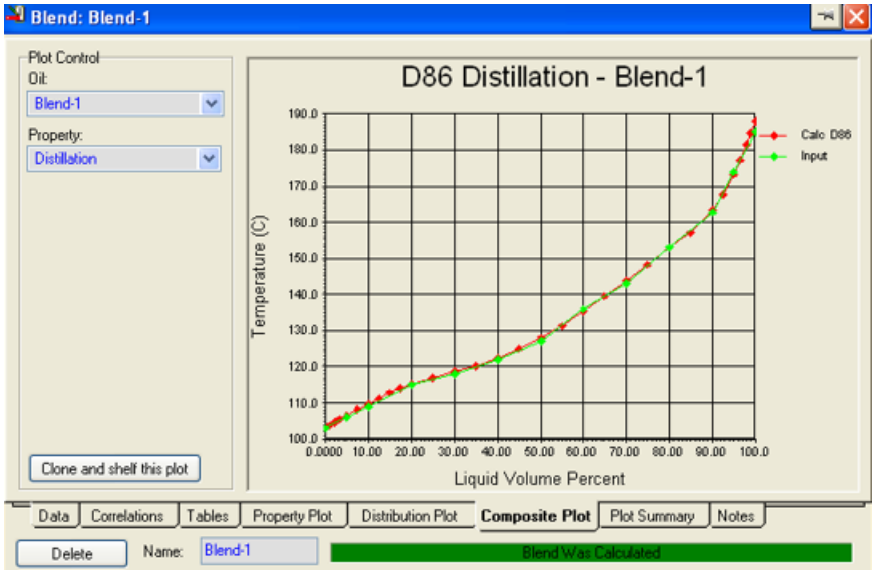


Fig. 5. Comparison of ASTM curves based on pseudocompounds and experimental curve

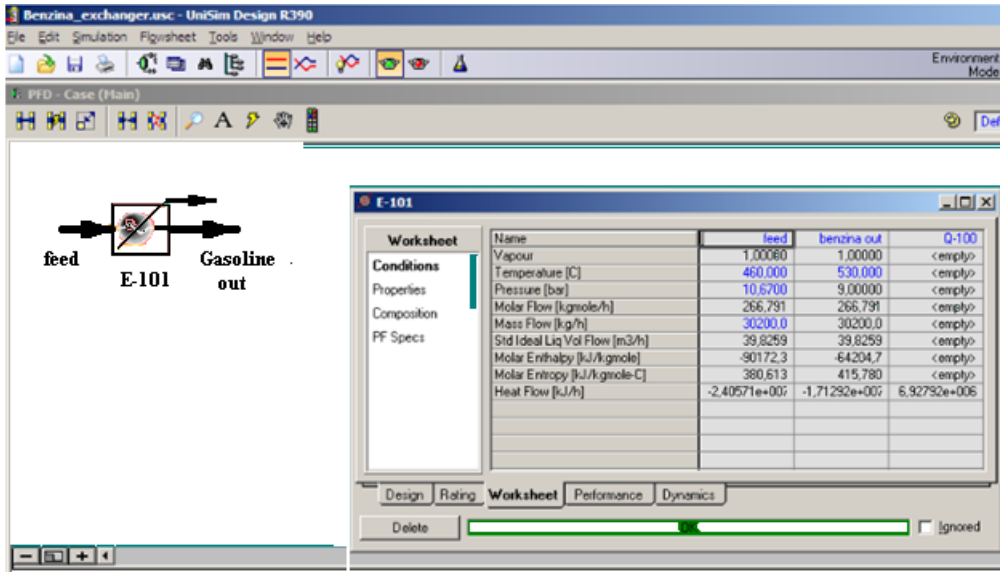


Fig. 6. Unisim Design – The simulation diagram with heat exchanger

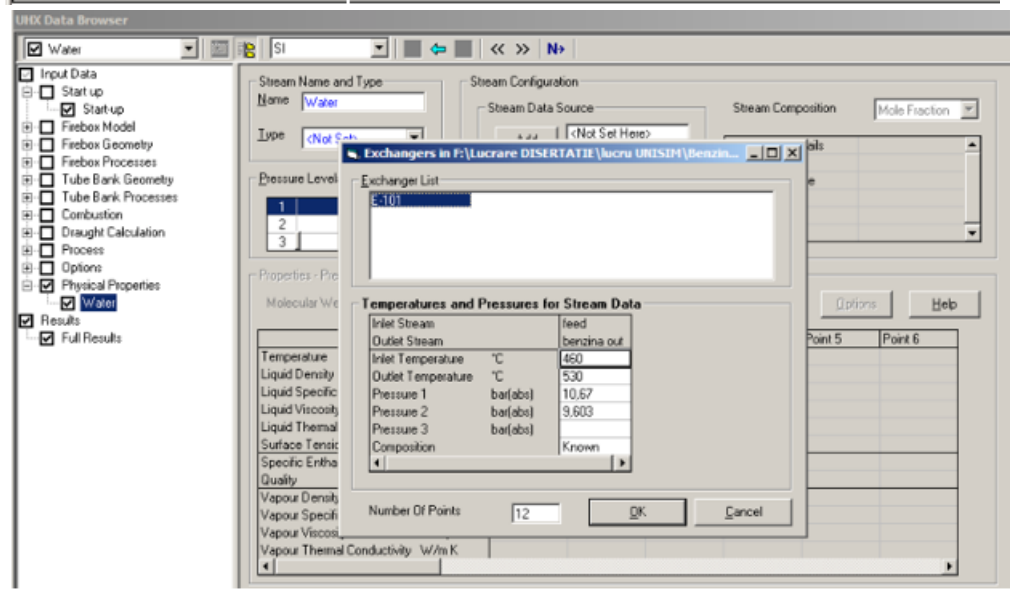


Fig. 7. Unisim FPH – selection of the heat exhanger to calculate the phisical properties

simulation diagram of a heat exchanger configured as below:

- The heated stream is *Feed*;
- The inlet temperature of the heated stream is the inferior limit of the temperature domain associated to the heated stream in tubular furnace (inlet temperature);
- The outlet temperature of the heated stream is the superior limit of the temperature domain associated to the heated stream in tubular furnace (outlet temperature);
- The inlet pressure of the heated stream is the inferior limit of the pressure domain associated to the heated stream in tubular furnace;
- the outlet pressure of the heated stream is the superior limit of the pressure domain associated to the heated stream in tubular furnace;
- the pressure drop on the heat exchanger should lead to the value associated to the inferior limit of the heated stream pressure domain.

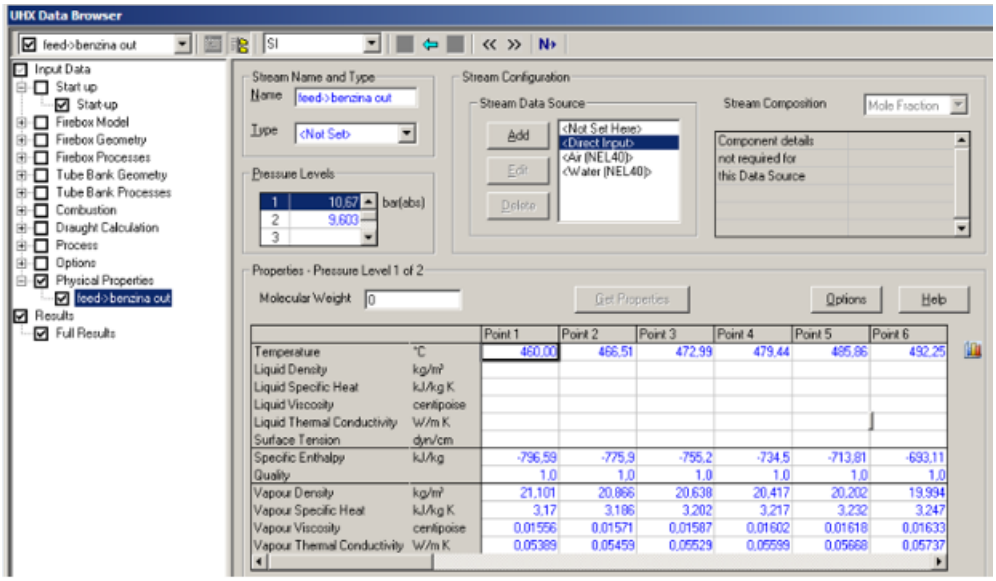


Fig. 8. Unisim FPH - Properties of the heated stream, imported from Unisim Design

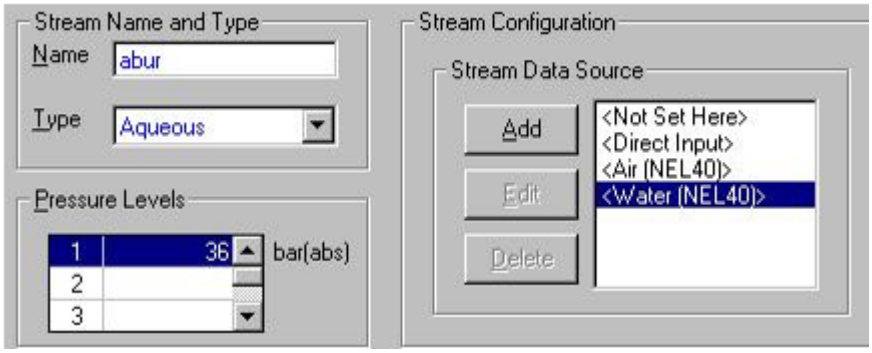


Fig. 9 The configuration of the Unisim FPH simulator for heated stream: water

In the figure 6 is presented the simulation diagram (Unisim Design) associated to the heat exchanger utilized to import the heated stream properties.

In the Unisim FPH environment it will be activated the *Import from Unisim Design*. At this moment the user is operating with two simulators: Unisim FPH (the simulating of tubular furnace) and Unisim Design (the simulation of the phase equilibrium associated to the *Feed* stream). After this action, the Unisim FPH program opens a dialog window with active heat exchangers from Unisim design, figure 7. Thus, the user may select in Unisim Design the heat exchanger in which will be calculated the physical properties of the heated stream.

In Unisim FPH, the user will define the parameters farther:

- the number of the points which will be taken for properties calculation =12;

- the temperature domain of the heated stream, domain defined by the inlet and outlet temperature of the heated stream for the E101 exchanger;

- the pressure domain of the heated stream, domain defined by the inlet pressure and the difference between inlet pressure and pressure drop associated with E101 heat exchanger.

After all these conditions have been fulfilled, the Unisim FPH will activate the calculation of the physical properties for each point, characterized by temperature and pressure by utilizing the structure of Feed stream and the thermodynamic model selected through Unisim Design. At the end of these calculations, Unisim FPH simulator will show the calculated properties of the heated stream in the number of points defined lately (fig. 8).

Defining of the properties for stream composed from known chemical compounds

The tubular furnace studied presents a second stream heated, water. The Unisim FPH has a thermodynamic database which allows the calculation of the pure components mixture. In figure 9 is presented the

Parameter	U.M.	Calculation method	
		Classical	UniSim FPH
Yield of the furnace	%	76.17	73.11
Inferior heat capacity of the fuel	kJ/kg	48532	48414
Combustion air flow	kg/h	15171	14835
Flue gases flow	kg/h	15771	15435
Heat developed	kW	8096	8069
Heat lost through walls	kW	787	602
Heat lost with flue gases	kW	1142	1559

Table 2
RESULT OBTAINED WITH UNISIM AND CLASSICAL CALCULATION

configuration mode of the simulator for the water compound.

The simulation of the furnace

The performances of the Catalytic Reforming furnace have been established using UniSim FPH software and using classically hand methods [13]. The results obtained through two methods of calculation are presented in table 2. The analysis of the results reported to Unisim FPH lead to the following conclusions (Unisim versus classical method):

- the yield calculated with Unism FPH is less than the yield obtain through classical calculation (4.1%);
- the flow of the combustion air generated from classical calculation is bigger than the one obtained using Unisim (2%);
- the heat lost through walls has different values (-30%);
- the heat loss from flue gases has different values (+26%);

All this differences are generated by different mathematical models utilized on the two cases. Not having industrial measures and taking into account the complexity of the mathematical models, we may estimate that the results obtained with Unisim are more accurate than the ones obtained based on classical relation.

Conclusions

In the paper was presented and analyzed Unisim FPH simulator for reforming furnace. There have been also described and commented the main commands used in the Unisim FPH simulator configuration. Geometric and operating data used came from a furnace in a catalytic reforming unit. Particular attention was given to the calculation and importing of the physical properties of flow heated stream (gasoline). Simulation of the furnace was accomplished by two pathways: the classical simulator Unisim FPH and an algorithm based on the relations in the literature. Comparative analysis of the results revealed both close values (yield, burning heat) but also significant differences (airflow rate, heat loss through walls and flue gases). The results obtained showed both common and differences mathematical models. Taking into account the common points of the two methods and also the differences generated by the simplification of the model based on classical relation, the authors consider validated the model associated to Unisim FPH simulator.

References

1.GUO SHU-CAI CHEM, Mathematical Model of Heat Transmission in the Radiant Section of Tubular Furnace, Journal for Chemical Industry and Engineering, Beijing, China, 2006.

2.SAPKAL P. N., BAVISKAR P. R., SABLE M. J., MAKASARE P. A., Optimization of Air Preheater Design for the Enhancement of Heat Transfer Coefficient, International Journal of Applied Research In Mechanical Engineering, Volume-1, Issue-2, 2011, 44-51.

3.PATRASCIOIU. C., MARINOIU. V., Sistem automat evoluat pentru cuptoarele tubulare din instalatia de distilare atmosferica si in vid a titeiului I. Modelarea matematica a combustiei si transferului termic, Rev. Chim. (Bucharest), **48**, no.4, 1997, p. 357

4.PATRASCIOIU C., The Modeling and Simulation of the Convection Section of the Atmospheric Distillation Plant Heaters, Rev Chim. (Bucharest), **67**, no. 8, 2016, p. 1599

5.PATRASCIOIU, C., NEGOITA, L., The Convection Heater Numerical Simulation, XII International Conference on Thermal and Fluids Engineering, Venice, Italy, International Science Index, Vol:8, No:4, 2014, 335-339.

6.DUMITRACHE I. (coordonator), Automatica, vol. 3, POPESCU D., PARASCHIV N., PATRASCIOIU C., Automatizări în industria chimica si petrochimica, Editura Academiei Romane, Bucuresti, 2016.

7.*** http://www.aspentech.com/products/aspen-firedheater.aspx

8.*** http://www.heatersim.com/

9.*** https://www.honeywellprocess.com/library/marketing/notes/UniSim_Design_Heat_Exchangers_PIN.pdf

10.*** MAHESH N. JETHVA, C. G. BHAGCHANDANI, Fired Heater Design and Simulation, International Journal of Engineering Trends and Technology, Volume4, Issue 2, 2013, 159-164.

11.*** https://blogs.mtu.edu/chem-eng-undergrad/page/4/

12.PATRASCIOIU, C., STAMATESCU, G., Petroleum Fractions Liquid – Vapor Equilibrium Simulation using Unisim Design, Rev. Chim. (Bucharest), **66**, no. 11, 2015, p. 1867

13.DOBRINESCU D., Procese de transfer termic si utilaje specifice, Editura Didactica si Pedagogica, Bucuresti, 1983.

14.ONUTU, I., Fabricarea combustibililor petrolieri ecologici. Scheme complexe de rafinarii, Editura UPG Ploiesti, 2001

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