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APPLICATION OF A COMPUTER PROGRAM TO EVALUATE THE PERFORMANCE OF PROCESS FURNACES, PIPE SEGMENT BY PIPE SEGMENT, BASED ON A REAL CASE OF CRUDE OIL HEATING FOR ATMOSPHERIC DISTILLATION.

APPLICATION OF COMPUTING PROGRAM FOR EVALUATING PROCESS FURNACES PERFORMANCE, SEGMENT BY SEGMENT OF PIPELINE, BASED ON A REAL CASE OF CRUDE OIL HEATING SERVICE TO ATMOSPHERIC DISTILLATION.

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Summary

Process furnaces are critical operating units of petroleum and chemical facilities in general, whose service is to provide combustion heat to process streams. The evaluation of the performance of this equipment, based on real data, is an essential activity for their diagnosis and operational improvement. The standard evaluation methodology consists of implementing resources such as API 560 to evaluate heat absorption and thermal efficiency from fire side data. The developed computer program is used to evaluate the performance of the tube coil furnace segment by segment, based on the same data and, load and equipment data. It is a proprietary development coded in Fortran 95. An outline of the program applied to crude oil heating service for atmospheric distillation, main equations, and evaluation of a real furnace are presented. The comparison of the program with real data showed deviations in the order of 1% for the flue gas temperature in the radiant arc, absorbed heat and thermal efficiency, and 4% for the crude oil outlet temperature. The evaluation of the convective bench showed a 50%

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reduction with respect to design in fin efficiencies, which raises as a possible explanation the damage of extended surface or smaller surface than specified in design. The program shows potential for evaluating the design of the radiation section of process furnaces, based on the comparison of the temperature in the radiant arc.

Keywords: Process furnaces; performance evaluation; computer program; thermal efficiency; API 560 standard.

Abstract

Process furnaces are critical operating units of petroleum and chemical facilities in general, whose service is to provide heat of combustion to process streams. The performance evaluation of these units, based on real data, is an essential activity for the diagnosis and operational improvement of them. The standard evaluation methodology consists of implementing resources such as the API Standard 560, to evaluate heat absorption and thermal efficiency from fire side data. The computing program developed is used to evaluate the performance of the furnace, segment by segment of pipe, based on the same data as standard evaluation, and data from the feed load and equipment. It is a proprietary development encoded in Fortran 95. A scheme of the program applied to crude oil heating to atmospheric distillation, main equations, and performance evaluation of a real furnace is presented. The comparison of the program with real data yielded deviations of the order of 1% for the temperature of the combustion gases in the radiant arc, absorbed heat and thermal efficiency, and 4% for the crude oil outlet temperature. The evaluation of the convective bank showed a 50% reduction with respect to the design in fin efficiencies, which raises as a possible explanation the damage of extended surfaces or surface smaller than that specified in the design. The program shows potential to evaluate the design of the radiation section of process furnaces, based on the temperature of combustion gases in the radiant arc.

Key words: Process furnaces; performance evaluation; computing program; thermal efficiency; API Standard 560.

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CONTENIDO

Introduction

Furnaces used in the oil and petrochemical industry are critical combustion equipment used for the thermal treatment of process streams. Combustion occurs by reacting gaseous and/or liquid fuel with oxygen in the air, producing flame and heat.

Two types of furnaces are used. Process furnaces, which provide heat to heat streams that are processed in downstream equipment. Pyrolysis furnaces, which provide heat for a chemical reaction to take place inside the furnace tubes.

The operation of this equipment must be carried out through strict controls and trained personnel, in order to provide optimum service to the load, in terms of capacity, fuel use, care of personnel, equipment and the environment.

Modern oil refineries must have instrumentation and controls systems to monitor, operate, control and protect this combustion equipment. These systems vary in scope depending on the resources available. On the one hand, there are facilities with high resources, where combustion and process control is rigorous and is supported by physical-chemical analysis in line or at least on a shift basis. On the other hand, there are facilities with poor instrumentation and very sporadic sample analysis.

In any of the cases described above, it is advantageous to have computer tools, of varying complexity, to support plant operations and decision making.

This paper presents results of a computer program for the performance evaluation of oil refinery process furnaces (Perfetti, J. C., 2020). Based on the application of the program for heating service for crude oil distillation, a description of the program and calculation bases is made, and its usefulness with a real equipment is illustrated.

Process furnace

The process furnace or direct fired heater is a heat exchanger that provides combustion heat to fluid streams (feed load), which circulate through tubes contained within an internally insulated metal enclosure or casing.

The tubes are connected in series, one after the other, forming a tube coil that runs from the furnace inlet to the furnace outlet. The tube coils are arranged in paired arrangements. A two-pass furnace has two coils.

The furnace evaluated in this work is similar to the one shown in Fig. 1. This figure, available on the Internet, adapted from a PDVSA process design manual (PDVSA-MDP, 1995), is a schematic of a vertical cylindrical furnace with a horizontal convection section.

Vertical cylindrical furnaces are widely used in the oil and petrochemical industry for thermal outputs of up to 1.50 x 10^8 Btu/h. Thermal efficiency is the total heat absorbed ("heat duty") by all process streams.

Fig. 1 describes the furnace sections and illustrates the location of the operating variable indicators on the fire side. For simplicity, TI is shown instead of temperature indicator. The process side operating variable indicators are understood to be located on the furnace inlet and outlet piping.

Fig. 1 illustrates the location of the following indicators:

- Oxygen % indicator, which measures the residual oxygen content of the flue gas, % v/v on a dry basis. It is located in the convection section.
- TI radiant arc, which measures the flue gas temperature at the exit of the radiation section of the furnace. This temperature indicator is also known as "Bridgewall Temperature".

The radiation section, also known as the combustion chamber or furnace hearth, is the structure that surrounds the radiant tubes and burners.

- The tube skin TI, which measures the temperature on the external surface of the tube. This temperature is measured in several radiating tubes in order to obtain an average value.
- TI outlet convective bench, which measures the temperature of the flue gases at the outlet of the convection section of the furnace.

The feed charge (crude oil) is distributed according to the furnace passes, and enters through the convection section. The furnace evaluated in this work has two passes and burns gas. The charge then passes through the protection section, is diverted out of the furnace through the transition pipe, enters the radiation section, and finally exits the furnace from the last pipe of that section.

On the fire side, the combustion air stream and the gas stream enter the furnace hearth through the burners. In the evaluated furnace, the air enters by natural draft. In the burners the streams are mixed, reacting Oxygen and fuels producing flame and hot combustion gases, which transfer heat to the fluid that circulates through the coil tubes that are arranged in the radiation section of the furnace (as many coils as furnace passages).

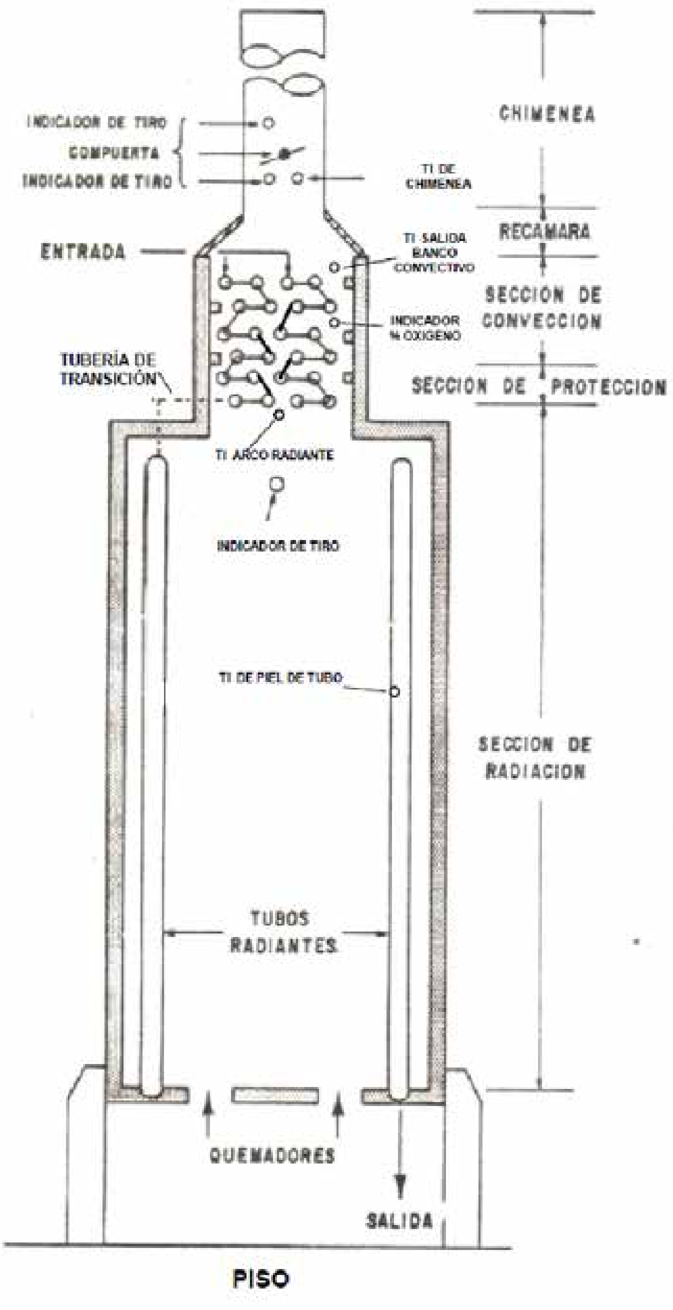

Fig. 1. Diagram of vertical furnace with horizontal convection section (PDVSA-MDP, 1995).

The gases continue their path and transfer heat by convection to the fluid circulating through the tubes that form the convective bank. After which, the combustion gases leave the furnace through the chimney.

Depending on the configuration of the furnace, part of the convective bench may be exposed to thermal radiation from the furnace hearth, which is the case of the furnace evaluated. The convective bench is formed by the rows of horizontal tubes that make up the protection and convection sections.

The tubes of each of the two coils through which the crude oil circulates are aligned vertically forming a circle contained in the furnace hearth.

The first two rows of tubes following the furnace hearth constitute the protection section (smooth tubes). The following rows of the bench, six in the case evaluated, constitute the convection section, which is formed by tubes with extended surface; fins in the case evaluated.

Rows of finned tubes are used to compensate for the relatively poor convective heat transfer coefficients.

Standard evaluation of thermal performance of furnaces

The standard evaluation of the thermal performance of furnaces in the oil and chemical industry in general (oil refineries, petrochemical complexes, natural gas processing plants, etc.) is based on references such as API 560, which applies to general purpose process furnaces such as those used in oil refineries (American Petroleum Institute, 2001).

Fig. 2 represents the simplified flow diagram of a computer program for the evaluation of furnaces based on the above mentioned standard applied to Gas. This program functions as a subroutine of the computer program of this work (Fig. 3). The label “Input” includes the operational variables to be recorded for the evaluation, while “Output” refers to the calculated variables. Fig. 2 and Fig. 3 include a set of variables that facilitate the monitoring of the computer program.

Gas flow is specified in plant at standard conditions of pressure and temperature. Fuel composition is specified in % molar.

The resolution of the fire side mass balance is described in detail in API 560. The reference condition is atmospheric pressure and 60ºF.

The heat released Qlib (Btu/h) is obtained from:

$$Qlib = Fcomb \cdot PCI \quad (1)$$

Where, Fcomb (lb/h) is the fuel flow rate; and PCI (Btu/lb) is the lower heat output, which can be calculated using a standard (American Society for Testing and Materials, 2003).

Entrance

Fuel flow, fuel composition.
Residual oxygen in flue gas or excess air.
Flue gas temperature:
Output of the radiation section Tg.
Tgsal convection section output.

↓

Output

Air flow, flue gas flow/composition.
Heat released Qlib, heat absorbed in the radiation section Qsrad, heat absorbed by convection in the convective bank Qconv, stack losses Qch, wall losses Qp.
Thermal efficiency .

Fig. 2. Computer program flowchart for the evaluation of furnaces based on API Standard 560

The heat absorbed in the radiation section, Qsrad (Btu/h), is obtained from the following heat balance on the fire side:

$$Qsrad = Qlib + Qa - Qp - Qg \quad (2)$$

Where, Qa (Btu/h) is the enthalpy flux of the combustion air; Qp (Btu/h) is the heat lost through the walls (2% of Qlib is the design factor of the evaluated case); Qg (Btu/lb) is the enthalpy flux of the flue gases that are cooled to the radiant arc temperature Tg (ºF).

The total heat absorbed or thermal efficiency of the furnace, Qabs (Btu/h), is obtained from:

$$Qabs = Qlib + Qa - Qp - Qgsal \quad (3)$$

Where, Qgsal (Btu/h), is the enthalpy flux of the flue gas leaving the convection section to the stack at Tgsal (ºF).

Thus the heat absorbed by convection in the convective bank, Qconv (Btu/h), is given by:

$$Qconv= Qg - Qgsal \quad (4)$$

The thermal efficiency η (%) is given by:

$$\eta = Qabs/Qlib \cdot 100 \quad (5)$$

In the case of furnaces without combustion air preheating as in the case evaluated, Qa is negligible, and the thermal efficiency corresponds in practice to the fuel efficiency.

The usefulness of the results obtained based on the API 560 standard is its use to evaluate the thermal performance of oil refinery furnaces in general. For diagnosis and quantification of operational improvements.

Computer program for segment-by-segment evaluation of coil furnaces

The primary objective of the computer program developed is to serve as a tool to support the operation, good performance and operational improvements of process furnaces, through a more accurate and detailed diagnosis than the one performed based on the standard evaluation. The program is self-developed and is coded in the Fortran 95 programming language.

Fig. 3 represents the simplified flow chart of the program. It uses fuel data and flue gas side data, as in the case of the standard evaluation. As for the feed load, it uses data from the operating conditions (furnace inlet variables, pressure profile) and physical property curves that the program uses as subroutines. The physical property curves can be obtained by running instantaneous liquid/vapor separation models using process simulators such as PRO/II (Schneider Electric SimSci, 2018).

As for the equipment, the computer program uses the following data:

- Heat transfer surfaces: configuration aspects in the radiation section and in the convective bank, and specification of piping and extended surfaces.
- Refractory surfaces: surface areas of the sections involved.
- Convective bank openings.
- Heat transfer factors. In this work this includes: internal pipe fouling factors and factors associated with the convection section (adjustment factors). The latter are used when the heat absorbed in the convection section is clearly lower than expected, based on design data and fouling factors consistent with the operation.

The program evaluates the heat transfer problem in the radiation and convection sections, with the protection section in common. The solution is obtained when both problems converge to the radiant arc temperature, and to the load temperature at the inlet of the radiation section.

The temperature profile of the crude oil along the tube coil is obtained from the resolution of enthalpy balances per furnace section and per coil segment. In parallel, the program solves the respective heat transfer equation by furnace section and by coil segment.

The flue gas temperature in the radiant arc is a variable recorded in the plant. The program calculates this variable by evaluating the heat absorbed in the radiation section, Qsrad, by complying with the following relationship:

$$Qsrad = Q^{rad}\,srad + Q^{conv}\,srad \quad (6)$$

Where, Q^{rad} srad, Q^{conv} srad, are respectively, heat absorbed by radiation in the radiation section, and heat absorbed by convection in the radiation section.

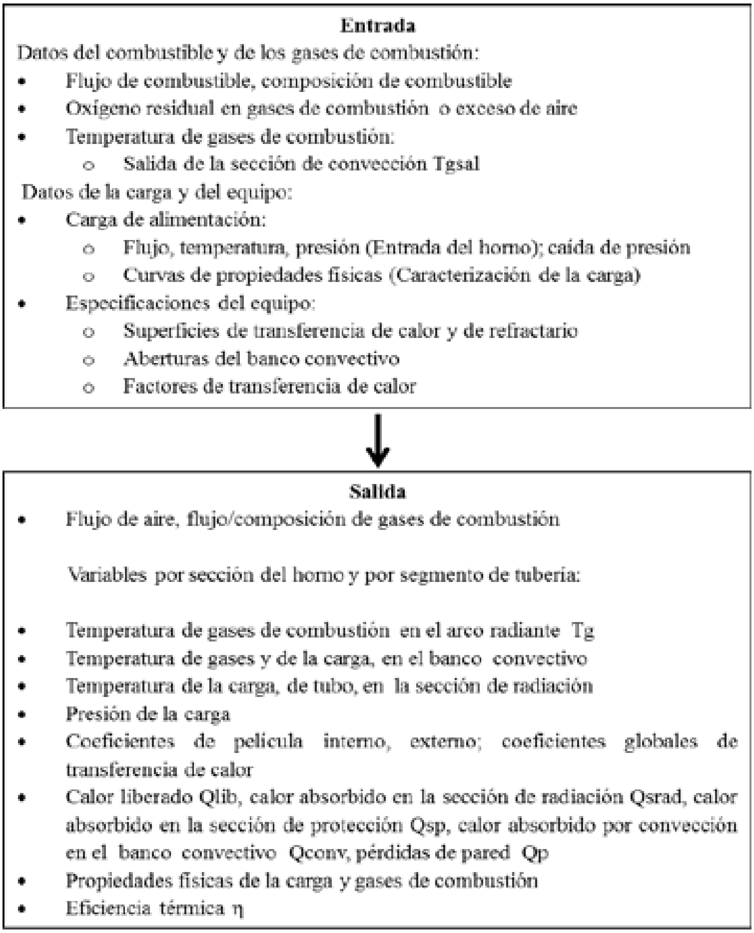

Fig. 3. Flow chart of computer program to evaluate process furnaces, pipe segment by pipe segment.

The protection section of the evaluated furnace is directly exposed to radiation from the furnace hearth, so that Qsrad includes heat absorbed by radiation in the protection section.

For the evaluation of the terms of eq. (6) the Lobo and Evans Method is used, which uses a Stefan-Boltzmann type equation with a total exchange factor *F*, and a convective heat equation, respectively. This method is explained in detail in “Heat Transfer Processes” (Kern, D. Q., 1973).

When the convection section is not directly exposed to radiation from the radiation section, Q^{rad} srad is given by:

$$Q^{rad}\,srad = \alpha \cdot Acp \cdot F \cdot \sigma\,[(Tg)^4 - (Ts)\,]^4 \quad (7)$$

Where: σ, is the Stefan-Boltzmann constant, $\sigma = 0.1713 \times 10^{-8}$ Btu/h-ft^2 -ºR; Ts is the average tube skin temperature in the radiation section, ºR; α·Acp, is the effective cold surface area of the radiation section, ft^2 .

The furnace evaluated in this work has a protection section at the bottom of the convective bench, so the effective cold surface of the protection section, Acpsp, must be added. This surface can be obtained from the openings of the convective bench or from the flat surface of the protection tubes.

So Q^{rad} srad for the evaluated case is given by:

$$Q^{rad}\,srad = (\alpha \cdot Acp + Acpsp)\,F \cdot \sigma\,[(Tg)^4 - (Ts)\,]^4 \quad (8)$$

The heat absorbed by convection in the radiation section is obtained from:

$$Q^{conv}\,srad = 2Acp \cdot h \cdot (Tg - Ts) \quad (9)$$

Where h is the flue gas film coefficient; h=2 Btu/h-ft^2 -ºF is an accepted reference value.

The heat absorbed by radiation in the furnace, Q^{rad} srad, conveniently breaks down as:

$$Q^{rad}\,srad = Q^{rad}\,hogar + Q^{rad}\,sp \quad (10)$$

With:

$$Q^{rad}\,sp = Fsp \cdot Q^{rad}\,home \quad (11)$$

Where, Q^{rad} hearth, Q^{rad} sp, are respectively, heat absorbed by radiation in the furnace hearth, and heat absorbed by radiation in the protection section.

Fsp, is a design factor to estimate the heat radiated from the furnace hearth to the protection tubes. This factor is defined in a PDVSA process design manual that is not available on the Internet, so it is not specified here (PDVSA-PD, 1986).

The enthalpy flux of the crude oil from the furnace inlet to the inlet of the radiation section is:

$$Fc\cdot(hceh - hce) = Qconv + Q^{rad}\, sp \quad (12)$$

Where, Fc (lb/h), is the mass flow of crude oil, and hceh, hce, are respectively, specific enthalpy at the inlet of the radiation section, and at the inlet of the furnace.

The heat transfer equation , Q, is given in generic form by:

$$Q = A\, U_{oo}\, \Delta T \quad (13)$$

Where, A_o is the transfer area of the corresponding total external pipe surface, including the extended surface if the pipe is lined with the same; U_o , is the overall heat transfer coefficient based on the corresponding total external pipe surface, Btu/h-ft^2 -ºF; ΔT, is the overall temperature difference associated with the corresponding U_o coefficient.

U_o can be calculated from the following equation from the "Heat Transmission" section in (Perry, R. H; Green, D. W, 1984)

$$1/U_o = 1/h_o + R_{do} + xA_o/(kA_{prom}) + (1/h_i)A/A_{oi} + R\, A/A_{\,di\,oi} \quad (14)$$

Where, A_i , A_{prom} , are respectively, pipe internal surface transfer area, and transfer area based on mean pipe diameter; h_o , h_i , respectively, film coefficient of flue gas, and crude oil; x, is pipe wall thickness; k, is pipe thermal conductivity; R_{do} , R_{di} , respectively, pipe external fouling factor, pipe internal fouling factor, h-ft^2 -ºF/Btu. R_{do} is null for gas flaring.

For the radiation section, the heat absorbed is calculated tube by tube. For the convection section and the protection section, the absorbed heat is calculated row by row of tubes of the convective bank.

To calculate the film coefficient of the crude oil in the tubes of the radiation section, h_i , the work of (Chen, J. C., 1966) is used.

The work of (Sieder and Tate, 1936) is used to calculate the film coefficient of the crude oil in the convective bank tubes, h_i.

To calculate the film coefficient of the flue gases through the tubes of the convective bank (smooth tubes, tubes with extended surface), h_o , correlations as a function of temperature and flow regime of the flue gases are used. These are not available on the Internet and are not published here (PDVSA-PD, 1986).

For tubes with extended surface, A_o is replaced by the effective surface A_{oe} , which is defined as:

$$A_{oe} = A_{uf} + A_f \ \Omega \quad (15)$$

Where, A_{uf} is the exposed surface area of smooth tube, A_f is the net extended surface area, and Ω is the fin efficiency.

Eq. (15) is explained in the section on "Heat Transmission" in (Perry, R. H; Green, D. W, 1984).

The fin efficiency Ω is used as a heat transfer factor to adjust the effective surface area A_{oe} , if necessary (see Fig. 3).

Results

In this paper, process conditions of a real equipment are described in order to illustrate the application of the computer program as a performance evaluation tool. Specifications of heat transfer surfaces and other specific design data are not included.

Table 1 compares the computer program with design data of a crude oil heating furnace for atmospheric distillation (Meneven, 1977).

The furnace heats 40,000 BPD of 38.4 °API crude oil from 297 to 570 ºF, going from 182 to 25 psia. The equipment burns 1,200 Btu/ft gas^3 standard higher heat output (HHP) at 20% excess air, releasing heat at a rate of 129.3 x 10^6 Btu/h (based on PCI). Flue gases exit the furnace at 500ºF.

It is observed that the program compares very well in general with design, with relative deviations in the range of 0.4%, except for the radiant arc temperature Tg, where the program exceeds the design value by more than 16%. This last result is discussed further below, taking advantage of the comparison of the program with real plant data.

It should be noted that fouling factors were selected (internal only because gas is burned), since they are not specified in the design. The program used 0.006 h-ft -^{2}ºF⁄Btu for the radiation section tubes, and 0.001 h-ft.^{2}-ºF⁄Btu for the convective bank tubes. This selection is consistent with heating services in petroleum refineries (Perry, R. H; Green, D. W, 1984).

Table 1.
Comparison of computer program and design data of a crude oil heating furnace for distillation (Meneven, 1977).

Variable	Unit	Design	Program	Relative deviation (%)
Home tube skin temperature	ºF	610	603	1,1
Flue gas temperature in the radiant arc	ºF	1.310	1.525	16,4
Temperature of the crude oil at the furnace exit (exit of the last pipe)	ºF	570	565	0,9
Temperature of the raw meal at the furnace hearth entrance	ºF	-	432	
Vaporized mass fraction at the furnace exit	%	58,0	57,7	0,5
Film coefficient of the crude oil in the furnace hearth	Btu/hft^2 ºF	1.092	1.054	3,5
Film coefficient of crude oil in convective section	Btu/hft^2 ºF	370	354	4,3
Heat absorbed by crude oil	10 Btu/h^6	112,0	111,5[(a)]	0,4
Furnace efficiency	%	86,6	86,2[(a)]	0,5

Note:

(a): Heat absorbed is estimated based on the implementation of the API 560 standard for furnace evaluation. Wall losses by design are estimated at 2% of the heat released.

Table 2 compares the computer program with data from an in-plant capacity test, which was an effort to establish whether the furnace could operate at design conditions. The test was of great interest, since it was performed after a burner change, with which there were high expectations of getting the kiln to operate at design conditions (Jimenez, D., 1984).

The test ran for one shift at steady state conditions at 37,000 BPD of 39.8 °API crude oil, from 338 to 540 ºF, going from 215 to 30 psia, burning 93,005 ft^3 /h of 1,221 Btu/ft^3 standard gas (PCS), at 27.9 % excess air. The flue gas temperature was set at 697ºF.

Table 2 shows that the program compares very well with the records and results of the event, with relative deviations in the range of 0.44.4%. The radiant arc temperature calculated by the program is 1.2% higher than the value recorded in the test. The same internal fouling factors were used as were used for the design comparison.

The absorbed heat test results are those obtained based on the implementation of API 560 (flue gas side heat balance).

On the other hand, the absorbed heat results of the computer program correspond to the totalization of the respective section, calculated by means of the respective heat transfer model through the pipe.

The same curves used for the comparison with design were used to estimate the physical properties of the crude oil.

Table 2.
Comparison of the computer program and a plant test of the crude distillation furnace evaluated in this work (Jiménez, D.,1984).

Variable	Unit	Test	Program	Relative deviation (%)
Flue gas temperature in the radiant arc	ºF	1.410	1.427	1,2
Raw meal temperature at kiln exit	ºF	540	564	4,4
Temperature of the raw meal at the furnace hearth inlet.	ºF		433	
Heat released (based on PCI)	10^6 Btu/h	103,1(b)	103,1(a)	-
Heat absorbed by crude oil	10^6 Btu/h	82,2 (a)	81,9	0,4
Absorbed heat radiation section	10^6 Btu/h	58,6 (a)	58,2	1,5
Heat absorbed by convection in the convection bank	10^6 Btu/h	23,6 (a)	23,7	0,4
Thermal efficiency (based on PCI)	%	79,7 (a)	79,4	0,4

Notes:

(a): Calculated based on the method used in refineries, corresponding to the implementation based on API 560 or equivalent.

(b): Heat released is the same in both cases since the same estimated gas composition was assumed.

Table 3 describes some results of the computer program for the plant test case, row by row of convective bench tubes.

Table 3 shows the temperature of the crude oil at the exit of the last tube of each row of tubes of the convective bench, from the 1st row of the convective bench to the bottom of the bench, where it reaches 433 ºF. The latter corresponds to the furnace hearth entry temperature indicated in Table 2.

This table also shows the flue gas temperature, from before the 1st row of the convective bank at 774ºF to before the 8th row at 1,427ºF. The latter corresponds to the flue gas temperature in the radiant arc shown in Table 2.

Also, Table 3 shows the convective heat absorbed by the tubes of the convective bench row by row, up to a total of 23.7 x 10^6 Btu/h. This value corresponds to the convective heat absorbed in the plant test furnace shown in Table 2.

Regarding the fin efficiency Ω shown in Table 3, it should be noted that the value in each row is a reference value calculated based on extended surface design data. That value of fin efficiency Ω is not used by the program to evaluate the effective surface area A_{oe} of the convective bank.

Table 3.
Results of the computer program applied to the crude distillation furnace test case, row by row of convective bench tubes.

Row No.	Flue gas temperature before the row (ºF)	Crude oil temperature at the outlet of the last pipe in the row (ºF)	Film coefficient of the flue gas (Btu/hpie^{2}ºF)	Fin efficiency Ω	Heat absorbed by crude oil (Btu/h)
1	774	347	3,15	0,808	2.387.476
2	861	358	3,26	0,803	2.721.715
3	964	370	3,37	0,797	3.311.862
4	1080	385	3,50	0,790	3.741.672
5	1219	401	3,64	0,784	4.558.195
6	1.348	415	3,78	0,776	4.265.448
7	1.387	425	3,78		1.313.677
8	1.427	433	3,81		1.368.093

Discussion of results

In Table 1, the focus is on the deviation between program and design data in the flue gas temperature in the radiant arc, on the order of 16%.

The condition of the tubes is defined by the skin temperature, where the relative deviation between program and design is very close, in the order of 1%.

Since this deviation is practically negligible, it is then clear that the cause of the deviation in the flue gas temperature in the radiant arc by 16% could only be in the modeling of the heat transferred by the flue gas cloud to the tubes or inconsistency in the design data of 1,310 ºF.

In Table 2, attention is again focused on the flue gas temperature in the radiant arc, where a narrow difference of 1,427 versus 1,410 ºF, respectively (1.2%), is observed in the program compared to the plant case.

It is worth noting that the high temperature behavior of Tg with respect to the design temperature of 1,310ºF, was present in the plant at load conditions close to design since the unit was commissioned in 1977. At least as far as we have records for this work, this behavior was still present at the plant in 1986 (Torrez, T., 1986).

The very good correspondence in the radiant arc temperature between the computer program and the plant test, added to the historical behavior of this variable at conditions close to design, leads to deduce that the value specified in the design of 1,310 ºF is an underestimated value that does not correspond to what is expected.

Regarding the fin efficiency Ω shown in Table 3 (average value of 0.793), it should be noted that it contrasts with the value of 0.385 per row that had to be used as the adjustment parameter to obtain the heat absorbed by convection, Qconv, of 23.7 x 10^6 Btu/h indicated in Table 2.

The fact that the fin efficiency Ω of the actual case evaluated had to be reduced to practically half the value expected by engineering practices, leads to at least two possible reasons: (1) Actual extended surface much smaller than specified in design; (2) Deterioration of the extended surface (fins) to a significant degree.

This makes sense in the fact that the plant information available at the time indicated red-hot pipes in at least rows 5 and 6 of the convective bank (Lucena, R., 1982), without evidence of internal fouling that would justify it (Lucena, R., 1989). These rows are the two following the two protection rows.

The adjustment parameter used (Ω), allowed the flue gas temperature upstream of the bottom of the convective bank to be 1,427 °F, and the temperature of the crude oil at the furnace hearth inlet to be 433 °F.

Conclusions

- The software allows evaluating the performance of process furnaces from operational data, coil segment by coil segment. The tool calculates plant logging variables and engineering variables and parameters along the crude and flue gas path, expanding the capability to support operations.
- The program was used to compare with real data from a plant test, finding deviations on the order of 1% for the radiant arc temperature (1,427 ºF program vs. 1,410 ºF plant), and similar deviations for heat absorbed and efficiency, and on the order of 4% for the crude oil outlet temperature.
- The very good correspondence in the radiant arc temperature between the computer program and the plant test, added to the historical behavior of this variable at conditions close to design, leads to deduce that the value specified in the design of 1,310 ºF is an underestimated value.
- These evidences with the relation to the radiant arc temperature, serve to establish that the program shows potential for the evaluation of the design of the radiation section of process furnaces.
- In order to cool the flue gases as much as expected (1,427 to 697ºF), using appropriate fouling factors, the fin efficiency was used as a tuning parameter and was reduced by 50%. A possible explanation for this is the damage of extended surface area or surface area less than that specified in the design.
- This adjustment of the effective area of the convective bench offers an explanation of how to achieve the heat absorbed by convection in that part of the evaluated furnace, since the information given by the red-hot tube row plant, in severely stressed condition, was not due to internal fouling.

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