Martina Brajković, Antonia Gregov, Tamara Graić, Hrvoje Šoprek, Igor Posarić

ISSN 0350-350X
GOMABN 53, 1, 62-71
Stručni rad / Professional paper

PROCESS FURNACES IMPROVEMENT IN RIJEKA AND SISAK REFINERY

Abstract
Process heaters along with boilers are the biggest producers of thermal energy in refinery. Their efficient operation and management is of great importance in order to achieve cost savings and lower environmental impact. Process heaters in old Rijeka Refinery (RR) and Sisak Refinery (SR) units are operating at efficiencies that can be improved and just a few of them are partly in line with BAT (Best Available Techniques) and IPPC (Integrated Pollution Prevention and Control) directive. Therefore in RR and SR an Engineering Study is being performed in order to improve process heaters. The purpose of the Study is to determine the ways and methods which will enable the compliance with emission limit values according to Croatian and EU environmental regulations and to improve heaters efficiency in order to attain savings in energy. The Study will include the evaluation of current condition and operation of heaters and provide necessary data as well as propose methods for improving efficiency. The goal is to achieve efficiencies of more than 80 % for every process heater so is in line with that investigation of possibilities in accordance with good engineering practice will be carried out and solutions for different levels of efficiency improvements will be proposed. In this work the possibilities for improvement in process heater efficiency based on decrease in fuel consumption; decrease in flue gas temperatures and emissions, as well as on optimization of heaters operation and on increasing of efficiency and reliability of heaters will be presented.

UNAPREĐENJE PROCESNIH PEĆI U RAFINERIJAMA NAFTE RIJEKA I SISAK

Sažetak
Procesne peći su uz generatore pare najveći proizvođači toplinske energije u rafineriji. Od velike je važnosti njihov učinkovit rad i upravljanje, kako bi se ostvarile ekonomske uštede i smanjio utjecaj na okoliš. Procesne peći starih postrojenja u Rafineriji nafte Rijeka (RNR) i Rafineriji nafte Sisak (RNS) rade s toplinskom

učinkovitosti koja se može poboljšati te su samo neke od njih djelomično u skladu s BAT (eng. Best Available Technique) konceptom i IPPC (eng. Integrated Pollution Prevention and Control) direktivom. Stoga je u RNR i RNS u svrhu unapređenja procesnih peći pokrenuta Inženjerska studija. Svrha studije je utvrditi načine i modifikacije pomoću kojih će se zadovoljiti granične vrijednosti emisija u skladu s hrvatskim i EU regulativama te poboljšati učinkovitost peći s ciljem postizanja energetskih ušteda. U okviru studije provest će se analiza trenutačnog stanja i rada peći te će biti definirani potrebni podaci i predložene metode poboljšanja učinkovitosti. Cilj je za sve procesne peći postići učinkovitost veću od 80 %, te će se u skladu s tim istražiti mogućnosti unapređenja s obzirom na dobru inženjersku praksu i predložiti rješenja za različite razine učinkovitosti peći.

U ovom radu će biti prikazane mogućnosti unapređenja procesnih peći na temelju smanjenja potrošnje goriva, smanjenja temperatura i emisija dimnih plinova, optimizacije rada peći te povećanja učinkovitosti i pouzdanosti peći.

1. Introduction

In most refineries and petrochemical industries thermal energy required by the process is supplied by direct-fired heaters in which the energy produced by combustion is directly transmitted to the process fluid which flow in a tubular coil or a bundle [1]. Process heaters are one of the biggest producers of thermal energy in one process unit and they are very complex systems by thermodynamically point of view and need to be modernized in line with more advanced technologies and capable to meet different operational conditions and other requirements which influence on their reliability and efficiency.

Heater design varies depending on its function, heating duty, type of fuel and method of introducing combustion air. Regarding to their function, heaters can be classified by heat duty it means heat transfer on process fluid on the following: *heaters which preheated fluid without any change in their physical state and in which only sensible heat is transmitted to the liquid or gaseous feed* (heaters in catalytic reforming units or hydrotreatment units, "hot oil" heaters, steam super heaters independent from steam cracker heaters when the steam generated in the transfer line heat exchangers is not superheated in the convection zone); *heaters which preheated fluid with partial evaporation* (mostly there are heaters in atmospheric and vacuum distillation units and in these heaters the feed receives latent heat to reach the degree of vaporization required) and *heaters which preheated fluid with chemical reaction* (as chemical reactors and these heaters are used in thermal cracking as visbreaking and coking unit, steam cracking (ethylene production unit) and in catalytic processes as steam reforming (hydrogen production unit)) [2]. Regarding to method for supply of heat energy - fuel combustion (gas or liquid), electricity (ex. hot oil heater) and induction (heaters mostly used in metal industry). By arrangement heaters can be vertical and horizontal and by the type can be box, cylindrical, cabin or terrace wall heaters. Last heaters classification is by air supply, it means by air draft to burners; naturally, forced, induced and balanced drafted heater.

Two main parameters influence on air draft to burners (stack height and flue gas exit temperature) and the difference between types of air draft to burners is in number of fans and its performances.

Almost, every process heater contains two sections (zones): radiant and convection. Tubes located in radiant section receive direct heat from the burners. Convection section is responsible for feed preheating, steam dilution and flue gases preheating. In refineries different variants of process heaters are used, depending of their geometry and specific technological requirements. Process heaters in refineries are usually rectangular (cabin) or cylindrical performance with more specialized designed burners which can be located on the heater bottom or on the heater walls. Vertical (cylindrical) type of heater can contain one (radiant) or two (radiant and convection) sections depending on its purpose and heater duty. Burners are mostly located in the heater bottom. Vertical (cylindrical) heater is geometrically characterized by axis and vertical symmetry and there are two possible cases of burners numbers: case of one (1) burner which is located in heater axis (very rarely) and case of more burners which are located around the heater axis (usually due to better heating). Size of radiant section can be different depending on its duty, with diameter between the 1.5 and 13 m and height from 2.5 to 25 m [3]. The biggest heater duty is usually ~ 70,000 t/hr which include ~ 7 t/hr fuel combustion.

In Rijeka Refinery, from 14 process heaters that are within the scope of Engineering Study of process heaters efficiency improving, 10 are cylindrical type. In Sisak Refinery, from 15 heaters that are within the scope of Engineering Study of process heaters efficiency improving, 11 are cylindrical type.

The main difference between process heaters of cylindrical and rectangular (cabin) form is in their geometry and burners arrangement. Horizontal (cabin) heaters usually have both (radiant and convection) sections and bigger heater duty, but also depending on heater purpose. Radiant section is usually tight ~ 6 m and high from 10 to 15 m, but length depends on duty and number of necessary burners (can be long to 40 m) [4]. Sometimes, length of heater decreased with division of cells inside of radiant section (ex. two parallel cells with common convection section above).

Horizontal (cabin) heater is geometrically characterized by burners arrangement and there are two possible cases of burners arrangement: bottom burner arrangement, where the burners are in one row or divided in more rows and sidewalls burner arrangement, where the burners are located on the heater walls.

In Rijeka Refinery, from 14 heaters that are within the scope of Engineering Study of process heaters efficiency improving, there are four (4) heaters cabin type and two of them have bottom burner arrangement and another two sidewalls burner arrangement. In Sisak Refinery from 15 heaters that are within the scope of Engineering Study of process heaters efficiency improving, four (4) heaters are cabin type and two of them have bottom burner arrangement, and another two have sidewalls burner arrangement as in Rijeka Refinery.

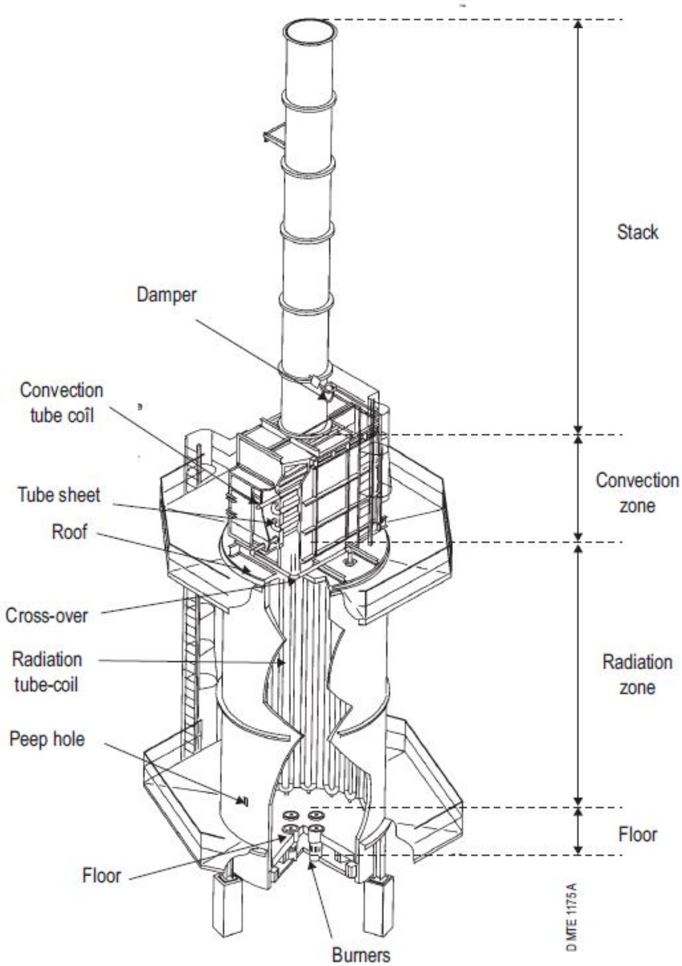

Figure 1: Example of vertical (cylindrical) process heater

Heaters, different type and inside arrangement have different efficiency which is based on the fact that amount of heat released at the burners by combustion is not totally transferred to the process fluid, and heat losses occur and they have two (2) main causes: losses through the heater casing (Q_{casing}) due to imperfections in the refractory material used to insulate the heater (by „high" duty heaters, Q_{casing} is 1-2 % of Q_{fired}) and losses through the flue gases ($Q_{flue\ gas}$) which released to atmosphere with relatively large amount of heat equivalent to 5-20 % of the heat fired.

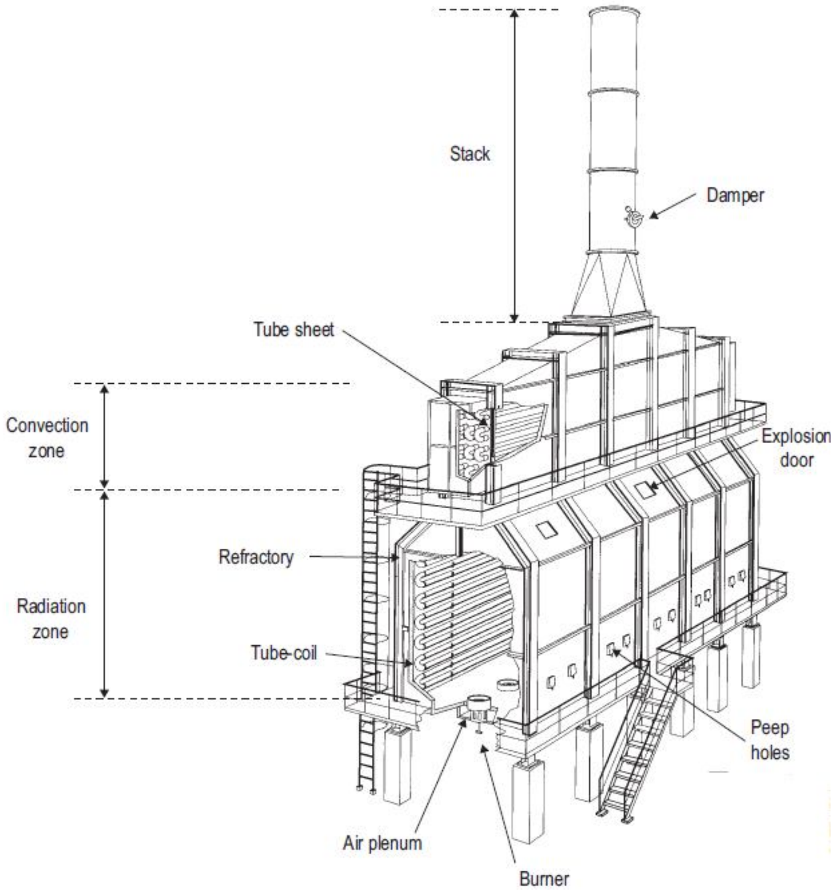

Figure 2: Example of horizontal (cabin) process heater

So, heat balance of the heater [5]:

$$Q_{entered} = Q_{absorbed} + Q_{flue\ gas} + Q_{casing} \quad (1)$$

Heater efficiency, η (eta) can be defined than as ratio of heat absorbed by the process fluid and heat supplied to the heater by combustion (Q_{fired}) [6].

$$\text{Efficiency (\%)} = \eta = (Q_{absorbed} / Q_{entered}) \times 100 \quad (2)$$

Another way of expressing the heat absorbed, by means of the heat balance, is as following:

$$Q_{absorbed} = Q_{entered} - Q_{flue\ gas} - Q_{casing} \quad (3)$$

Efficiency is than expressed on the following way:

$$\text{Efficiency (\%)} = \eta = (Q_{entered} - Q_{flue\ gas} - Q_{casing}) / Q_{entered} \times 100 \quad (4)$$

The efficiency expression is:

$$\text{Efficiency (\%)} = \eta = (100\ \% - \%\ \text{flue gas losses} - \%\ \text{casing losses}) \quad (5)$$

There are few parameters which are related to heater efficiency; *combustion excess air*, *flue gas temperature* and *fuel*. *Combustion excess air* increases the flue gases and decreases the heater efficiency (combustion with excess air results in oxygen in the flue gases, and the greater the excess air the higher the oxygen concentration). So, is necessary to find optimal amount of excess air because it improves heat transfer and achieve maximal heater efficiency with less flue gas emissions and lower flue gas temperature, less fuel consumption, lower pressure drop in firebox, stronger draft in heater and better utilization of heater firebox. But, percentage of losses through the flue gases due to excess air can be calculated as following:

% losses through the flue gases due to excess air = (oxygen content in flue gas, % / 2) (6)

Flue gas temperature - higher temperature of flue gases means more emissions, lower energy recuperation and less heater efficiency. Decreasing of flue gas temperature is the most efficient way to increase heater efficiency, because decreasing temperature for 20 °C is equivalent to increasing efficiency for 1 %. Percentage of losses through the flue gases due to its temperature can be calculated as following:

% losses through the flue gases due to flue gas temp. = (flue gas temperature,°C / 20) (7)

So, losses through the casing can be evaluated to 2 %. Lower flue gas temperature and less excess air achieve higher heater efficiency. *Type and quantity of fuel* have influence on heater efficiency, because gas fuel has more advantages than liquid fuel in view of burners type, and emissions. Decreasing of fuel consumption will decrease flue gas emissions and also increase heater efficiency.

In order to improve heaters energy efficiency, in 2010 was performed an EBRD Energy Study which recommendations were related to methods of efficiency improving and initiated projects with same purpose in both refineries. Now, the projects are ongoing and performed as Engineering Study from experienced professional company. Engineering Study of process heaters efficiency improving has to be prepared on way that satisfy the emission limit values according to environmental regulations, improve heater efficiency and energy savings. Regarding the Study purpose, it has to be focused on the following items: *decreasing of fuel consumption* and *flue gas emissions*, *optimization of heaters operation* and *increasing efficiency* and *reliability of process heaters*. So, for that purposes it has to evaluate current condition and operation of total 29 process heaters (14 in Rijeka Refinery and 15 in Sisak Refinery) and give necessary data and consider possibilities for efficiency improving. It will allow it by evaluation of current condition and operation of heaters in both refineries and by investigation of all possible alternatives which will be base for proposing two or three adequate technical solutions for efficiency improving for different levels (ranges) of efficiency. But, intention is that every process heater has efficiency more than 80 % and also usage of gas fuels in the future, so the Study has to consider investigation of alternatives and propose equipment related to efficiency improving in this direction. Results of Engineering Study will be base for future projects related to heaters efficiency improving, but for getting results is needed to follow the methodology below.

2. Methodology

The Study is usually performed due to elaboration of existing situation and proposing possible alternatives for improving. In this case, process heaters are the main points, especially heaters of obsolete design and low energetic efficiency which have to be reconstructed and modernized due to better reliability of their operation and extending of their life. So, reconstruction of process heaters can be performed due to; c*hange of operational conditions it means process parameters (temperature, pressure, flow)* which leads to changing of inside/outside temperature, increasing of flow rate and operational pressure and changing fuel; s*tricter safety rules* (obligation to modernizing start-up with less manual management); s*tricter environmental regulations (demands),* which leads to decreasing of CO_2, NO_X, SO_2 emissions and fuel consumption; *replacement of old materials (equipment) after inspection review; problems of equipment operation or maintenance as* acid condensation and corrosion, coils and/or passes vibrations and excessive coking.

Reconstruction of process heaters related to heater efficiency improving required certain modifications which have to be done on some heater and according to that there are few types of reconstruction as following: *replacement of existing burners with the new generation burners (Low-*NO_x*, Ultra Low-*NO_x *etc.), addition of a steam air preheater, air preheating system* and *convection section, modification of radiant section, convective section* and *process coils* and *addition of some instruments (equipment).*

Replacement of existing burners with the new generation burners (Low-NO_x, Ultra Low-NO_x etc.) has the following advantages: lower NO_x emissions, better heat distribution inside of radiant section, decreasing combustion problems (due to better mixing of fuel and air) and less problems with operation and maintenance. Replacement of burners also require modification of radiant section floor (construction and insulation) and modification of burners piping. Addition of a steam air preheater on some heater is necessary just when a flue gas air preheater already exists. This method has the following advantages: no more acid corrosion problems, slight increase of fuel efficiency and less operation and maintenance problems of flue gas air preheater / fans / cold flue gas duct and require some modifications on heater. By addition of a steam air preheater, air duct has to be reconfigured to insert a steam air preheater between the forced draft fans and the flue gas air preheater and LP steam piping has to be implemented. Addition of air preheating system can increase fuel efficiency and decrease fuel consumption and CO_2 emissions. Only disadvantage of this method is increasing of NO_x emissions.

By addition of air preheating system, is necessary to add foundations, to install fans (two forced + one induced draft fan), but in case of integrated air preheating system, there is no induced draft fan. It is also necessary to add airs and flue gas duct, to install one flue gas air preheater (integrated/at grade: cast or plate type) and one steam air preheater (depending on climatic data/fuel composition), to replace natural draft burners with the forced draft burners and to modify existing stack.

Addition of convection section is valid just for radiant heaters only and this method can increase fuel efficiency and decrease fuel consumption, CO_2 emissions and heat flux density in radiant section. By addition of convection section on heater, is necessary to modify radiant section roof (construction and insulation), to perform „reinforcement“ of heater structure (if is needed) and to modify flue gases exit (duct and/or stack). Modification of radiant section is valid for box type of heaters with horizontal tubes and with vertical tubes in case of multi-passes type. Modification of radiant section can influence on heater capacity. So, in case of modification of radiant section in terms of unchanged heater capacity, it can decrease heat flux density in radiant section and increase heater run length and decrease process fluid pressure drop in case of multi-passes heater type. Another case is modification of radiant section which increases heater capacity. By modification of radiant section is necessary to modify radiant section height (in case of horizontal tubes) or radiant section length (in case of vertical tubes), to perform „reinforcement“ of heater structure (if is needed) and to add tubes with coil site welding.

Modification of convective section can be performed when the space is still available in convective section. Modification of convective section can also influence on heater capacity, it means that can be unchanged or changed, in terms of increasing. If the heater capacity remains unchanged, modification of convective section can increase fuel efficiency, decrease fuel consumption, CO_2 emissions and heat flux density in radiant section. By modification of convective section, is necessary to add tube rows or to perform complete replacement of existing coil, to perform „reinforcement“ of heater structure (if is needed) and to modify the coil inlets and crossover with coil site welding.

Modification of process coils can be performed on two ways; as modification the outside diameter of few tubes and as increasing of passes number. Modification of outside diameter of few tubes can allow lower pressure drop and be a possible solution of vibration problems in case of excessive fluid velocity. Increasing of passes number can also allow a lower pressure drop and increase the heater capacity. Addition of some particular instruments (equipment) on process heater can improve its operation. So, addition of flue gas pressure controller in radiant arch can enable bigger safety (pressure < atmospheric in radiant arch), less draft on the radiant floor, it means less air ingress inside of heater and less fuel consumption if burners operate under natural draft. Addition of combustion air flow measurement when burners operate under forced draft can also enable more safety (no combustion with a lack of air) and less fuel consumption.

Addition of process parameters measurers (devices) inside/outside and on the heater passes can enable better control and fixing of parameters (temperature, pressure, flow) and bigger reliability and safety. For performing the Study and proposing some of mentioned methods for efficiency improving, is necessary to provide technical documentation of those process heaters.

2.1. Engineering Study

For performance of the Study, there are provided the following data: heater and burners drawings and datasheets, P&ID's, PFD's, prints screens of heater streams, plot plans (where the available space around the heaters can be seen), the fuel data (composition and other characteristics), the feed data (composition, distillation curve as IBP, TBP (10%, 30%, 50%, 70%, 90%), FBP and other characteristics), the process design conditions and present operating conditions (inside, outside parameters and on heater passes), the emission values data per each heater and data of heaters maintenance and examinations. All data are needed for better understanding of heater structure, current state and operation mode. Process design conditions will be base for simulation and results of simulation will be compared with current operational process parameters. Also, results of simulation will indicate on which way some heater can be improved and according to that investigate possible modifications which will be studied and quantified in terms of cost. The Study has to contain the short description of the operational conditions observed on site, theoretical performances of the heater based on its present configuration and the present operating conditions, different possible modifications to improve the heater performances and the corresponding fuel consumption and fuel efficiency with cost estimation at +/- 30% of the different possible modifications. So, for every heater two or three possible alternatives for efficiency improving will be proposed. Expectations are in proposals of different methods for efficiency improving for different level (range) of efficiency. Proposed modifications will be reviewed and for each heater in every refinery one method as best technological and economical solution for efficiency improving will be chosen. Chosen methods for heaters efficiency improving have to be elaborated in terms of description, preliminary cost estimation and time schedule to be base for future detailed engineering.

3. Conclusion

Performing of Engineering Study for process heaters improvement is good way for determination of waste heat source and quality and propose recovery potential for different streams. Elaboration of current condition and operation of heaters will be also recommendation for their future operation management and maintenance.

Process heaters efficiency improving can be achieved in different ways meaning that different methods can be proposed for increasing their efficiency and reliability.

Technological modernization of process heaters in view of efficiency improving will ensure capability to meet currently and future emission regulations and operational demands.

Literature

[1-6] IFP training: Furnace construction and operating conditions; Furnace routine operation; Burner operation and control; Furnace firing procedure; Combustion - Fuels; Flue gas circulation draft, 2011.

Varga Z., Separation Processes, DS Development Academy, University of Pannonia, Hungary, 2013.

Heurtey Petrochem Company, Heaters Revamp, France, 2012.

Key words: process heaters, efficiency, improvement

Authors
Martina Brajković[1], Antonia Gregov[1], Tamara Graić[2], Hrvoje Šoprek[1], Igor Posarić[1]
[1]INA - Industrija nafte d.d., Sektor razvoja rafinerija i marketinga
[2]INA - Industrija nafte d.d., Sektor Rafinerije nafte Sisak
e-mail: martina.brajkovic@ina.hr

Received
7.10.2013.

Accepted
11.3.2014.