Efficiency Estimation of Olefin Furnaces in Order to Provide Methods for Increasing the Efficiency

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Abstract: Despite the growing trend in the petrochemical industry in the country, the industry has faced challenges and accomplishments. One of the most important challenges in the petrochemical industry is energy management in the refinery. Fajr Jam refinery is designed to refine part of sour gas produced from Phase 6 of South Pars gas field in Iran and the nominal capacity of gas refining at this site, to determine the factors affecting energy consumption in the ophthalmic furnaces, 104 and 109 kilns were selected and the following were monitored scientifically: monitoring of furnace wall temperature with thermography, furnace feed analysis, steak gas analysis and energy efficiency of furnaces. The results of this study showed that in the furnace 104, the design efficiency and real efficiency was 92.98 and 84.67, respectively and for the furnace 109, the design efficiency and real efficiency was 94.98 and 71.18, respectively. As a result, the amount of energy loss is high and should save energy consumption in these furnaces and improve efficiency; replacement of refractory refractories is also a replacement of insulation.

Keywords: Cracking, Energy Dissipation, Furnace Efficiency, Optimization, Steak, Thermography

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1 INTRODUCTION

The upward trend in energy prices in the late twentieth century has created ways to optimize energy and save energy and reduce fuel consumption. The volatility and especially the rising oil price that has been controlling the energy market since early the eighteenth century created the process of optimizing energy and reforming industrial processes to reduce cost of production in industrialized countries, and this process was transferred to industrialized countries with delay. At the same time, the wave of environmental production has also evolved, providing different environmental solutions for industries and new constraints. Direct effects of energy optimization for applied industries are more than indirect effects observing environmental factors; therefore these solutions are more welcome from the industry owners because of environmental factors [1].
Technical energy audits play important roles in identifying and prioritizing energy conservation opportunities for energy systems. Even without those opportunities, technical assessments pave the way to perceive current working conditions of energy systems, their efficiencies and potentials for saving. Process heating systems, furnaces, are among the most energy intensive systems in petrochemical industry and therefore of import to work accordingly [2]. The efficiency of furnaces has important effect on fuel consumption and pollution. In the previous works some methods for efficiency estimation and increasing the efficiency are presented [3, 4]
To find energy conservation opportunities for furnaces, the first law of thermodynamics in form of mass and energy balance shall be established for the system, required and real energy consumptions should be calculated, energy efficiencies and losses shall be identified, operational and design data should be compared and best practices may be considered. Jam Petrochemical Company is a plant in south of Iran, with the range of polymer products and therefore, an important olefin unit with ten olefin furnaces. It is imperative to explain the cracking process in these olefin furnaces in the following sections [5].

1.1. Cracking Process

As Wikipedia puts it, "cracking is the process whereby complex organic molecules such as kerogens or long chain hydrocarbons are broken down into simpler molecules such as light hydrocarbons, by the breaking of carbon-carbon bonds in the precursors." In a cracking process several, not only one, reactions take place, where hydrocarbon binds break randomly to form a mixture of smaller hydrocarbons, some of them with a carbon double bind. There are several types of cracking used in petrochemical industry (Brown et all 1998). Thermal cracking at the presence of water vapor, to control the temperature and pressure, is the one used in furnaces. In this process water vapor, dilution steam, does not participate in the reaction and only acts as a diluent for the feed, though, it performs two main tasks in mitigating the intensity of coke formation in the radiation section tubes and lowering the partial pressure of hydrocarbons throughout the process [4].

1.2. Cracking Furnaces:

Cracking furnaces transfer combustion heat to reacting effluent in a controlled manner. The dominant heat transfer modes in furnaces are radiation and convection from the combustion products to the tubes, coils, carrying reacting composition. In combustion chamber, fuel reacts with oxygen in air to provide the desired amount of heat for the reaction to take place. The released heat is transferred to the reacting effluent through the tubes that are carrying them in a manner that the mixture of steam and hydrocarbons being heated continuously. Therefore, combustion gases cause the thermal cracking of hydrocarbons in coils located in radiation zone or fire box. Also, in convection section, the flue gas passing the tubes preheats the feed and dilution steam before they enter into the radiation zone for reaction to take place. Also, the boiler feed water will be superheated in the convection section and afterwards, with swapping heat with products out of the combustion chamber [6]. On ophthalmic kilns research has been carried out in the phase of inspection of furnaces in dealing with companies that are only limited to measuring the wall temperature of the furnaces. However, in the present study, the temperature of the furnaces is lost and the efficiency of the furnace is determined .
Sabunchi et. al. [7] studied the effect of hot charge on energy consumption and steel refineries capacity using thermal simulation. In this study, the drop in the temperature of the ingot in the environment was modeled after its exiting from the casting. Then, using a mathematical model prepared from a real grating simulator that simulates the exchange of radiation and displacement in the furnace, the effect of charging temperature on the ingot of the furnace is examined for specific energy consumption and furnace capacity. Also the simulation of the radiation inside the furnace is done using a uniform area method [8]. In the present work for the first time the thermodynamical efficiency of Olefin furnaces of the Jam Petrochemical Company is estimated and the methods for increasing the efficiency are presented.

2 METHODS AND MATERIALS

Design analysis different elements of furnaces are assessed based on design data. The elements identified with energy perspective are, holistically, consistent with process perspective. Also, measurement requirements for data extraction are selected. The energy and mass balance for liquid and gas feed furnaces is demonstrated and efficiency is derived. Comparison between these results and manufacturers design data is carried out to outline a mathematical approach to be used in following chapters for evaluating working conditions.

2.1. Elements Identification and Performance

Jam olefin plant consists of ten furnaces. The phase and the composition of the feed determine the type of the furnace. The furnace can take liquid feed, gas feed and some accept both liquid and gas feeds. The analysis in this chapter includes both liquid feed and gas feed furnaces based on the design data on reactants and products compositions and properties. To conduct the assessment, different sections and elements of the furnaces were identified. From energy perspective, cracking furnaces consist of three sections of convection, radiation and exchangers.

2.2. Convection Section

In this section, combustion products exchange heat with the feed, dilution steam and boiler feed water before leaving the stack. In the first and second preheaters called Feed Preheater-I (FPH-I), the feed temperature increases. Also, the dilution steam in an exchanger called Dilution Steam Super Heater (DSSH) will be superheated. Then both streams mixed up together to be heated again in two exchangers called HTC-I and HTC-II before leaving the in convection section, temperature of boiler feed water increases in Economizer, HPSSH-I and HPSSH-II. In the convection section, temperature of boiler feed water increases in Economizer, HPSSH-I and HPSSH-II.

2.3. Fire Box

When the mixture of hydrocarbons and dilution steam reaches to the desired temperature in the convection section, embarks into the radiation coils in the fire box. Thermal cracking takes place along the radiation coils in the fire box where heat from the combustion of the fuel is being transferred to the reactants; radiation is the dominant heat transfer mode.

2.4. Exchangers

The product leaving the fire box has a high temperature (more than 800 degrees centigrade) and therefore considerable amount of energy. For the efficient use of this energy and also to cool down the product, there are exchangers called TLE with thermal duties of 30 to 32 Mega Watts for both types of furnaces to transfer heat from the product to steam. The following illustration represents three sections of the furnaces (“Fig. 1”).

As it is mentioned earlier, the heat released from the fuel is being used to heat up the dilution steam and reactants, then for cracking inside the fire box and also production of very high pressure steam (VHP). While, the second law of thermodynamics assures us of inevitable losses, the first law assists us to find them. In the following section, cycles and streams will be evaluated and measurement points will be identified [2].

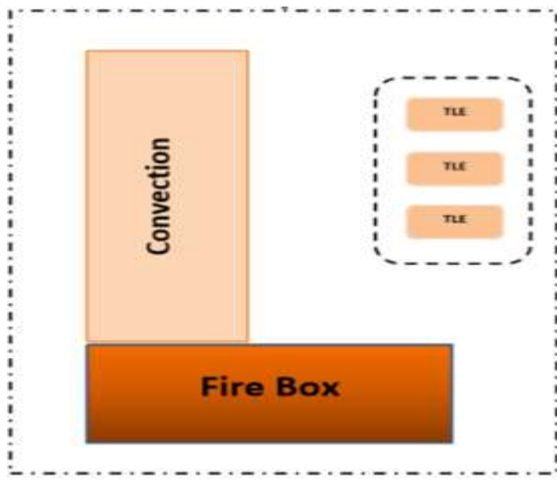

Fig. 1 Different sections of the furnace from energy perspective.

3 CYCLE ANALYSIS AND IDENTIFYING MEASUREMENT POINTS

To identify measurement requirements in working condition and to perform balance and other energy relevant calculations, the material streams and corresponding processes are studied. Three energy media flowing through the furnace are identified and will be studied from their entrance at the control volume to their departure from the boundary. Also, at the end of this section there is a table that summarizes the measurement tags on distributed control system [1].

3.1. The Stream of Feed and Product

At first, the feed enters into the preheating sections of the furnace (FPH-I) and then mixes with the dilution steam that is leaving the DSSH exchanger. Then this mixture passes through two exchangers of HTC-I and HTC-II, before departure to the radiation section. In the radiation section, (firebox) reaction takes place and the products leave the firebox to exchangers to offer heat to the steam stream. The difference between enthalpies of feed and dilution steam at the entrance and enthalpy of reactants at the outgoing boundary can be determined with acceptable accuracy and precision by knowledge of temperature, pressure, mass flow rate and composition of the media at each boundary; this is another step forward to close the energy and mass balance [8].

3.2. The Stream of Fuel and Flue Gas

Every furnace in Jam olefin unit is equipped with eighty burners. They are arranged in two sets of bottom and side configurations. The fuel combustion provides the required amount of heat in the firebox for the reaction to sustain. Then the combustion products (flue gases) move to the convection section to transfer heat to the preheating exchangers of feed, dilution steam and boiler feed water. The fuel mostly consists of hydrogen and methane and therefore the combustion products include carbon dioxide, water, nitrogen and oxygen in case of proper combustion. The mass flow rates of fuel and air are important quantities to determine the energy input and output of this stream into the convection sections. Knowledge of excess oxygen with consideration of combustion reaction provides the way to calculate the mass flow rate of air and flue gas [6].

3.3. The Stream of Boiler Feed Water and Steam

One of the important tasks of olefin furnaces is to produce very high-pressure steam (VHPS). Boiler feed water receives heat to produce the required amount of steam in a desirable temperature and pressure in the Economizer, HPSSH-I and HPSSH-II in the convection section and TLE exchangers. The temperature, pressure and mass flow rate of input boiler feed water and output steam are enough to calculate the enthalpy difference of the input and output fluids and therefore the portion of fuel energy that is absorbed in the steam flow [2].
With the identification of energy medium and assessment of the properties that are necessary to be known to carry out the energy calculation for that medium, the measurement requirements and therefore their tags on the distributed control system can be demonstrated [9].

3.3. Tags on Distributed Control System

Distributed control system provides an opportunity to read the quantities that should be used to carry out energy calculations. These readings correspond to the tag numbers of the system sensors. The “Table 1” represents these tag numbers.

4 ENERGY AND MASS BALANCE FOR GAS AND LIQUID FEED FURNACES

To establish the energy and mass balance the furnace is considered to be a control volume. Then, energy efficiency and losses can be derived for each section of the furnace. Energy tags on DCs are presented in “Table 1”. “Fig. 2” shows the input and output fluid flows for a gas feed furnace.
The following formula describes the mass balance where the input mass is equal to the outgoing mass:

Table 1 Energy Tags on DCS

	Measured Quantity	Furnace 104	Furnace 109
1	Fuel Flow Rate 1	FIC-038	FIC-038
2	Fuel Flow Rate 2	FIC-036	FIC-036
3	Feed Flow Rate 1	FIC -002A	FIC -004A
4	Feed Flow Rate 2	FIC -002B	FIC -004B
5	Dilution Steam 1	FIC-006A	FIC-006A
6	Dilution Steam 2	FIC-006B	FIC-006B
7	Feed Temperature	400TI -056	200TI -049
8	Feed Pressure	400PC -01	400PC -01
9	Temperature of Feed to Radiation 1	TI-012	TI-012
10	Temperature of Feed to Radiation 2	TI-013	TI-013
11	Pressure of Feed to Radiation 1	PI-012	PI-012
12	Pressure of Feed to Radiation 2	PI-013	PI-013
13	Temperature of Products from Radiation	TIC -017	TIC -017
14	Pressure of Products from Radiation	PI -016	PI -016
15	Temperature of Products after Heat Swap	TI -022	TIC -025B
16	Pressure of Products after Heat Swap	PI -024	200PIC-005
17	Boiler Feed Water Flow Rate 1	FIC-033	FIC-033
18	Boiler Feed Water Flow Rate 2	FIC -030	FIC -030
19	Boiler Feed Water Temperature	900TI-006	900TI-006
20	Boiler Feed Water Pressure	Drum Pressure	Drum Pressure
21	Steam Flow Rate	FI -032	FI -032
22	Steam Temperature	TIC -032	TIC -032
23	Steam Pressure	PIC -032	PIC -032

$$Mass_{Input} = Mass_{Output} \tag{1}$$

The mass of gas feed with the mass of dilution steam is equal to the mass of products.

$$Mass_{Gas\ Feed} + Mass_{Diltion\ Steam} = Mass_{Products} \tag{2}$$

The mass of boiler feed water with boiler feed water injection is equal to the mass of steam and blowdown:

$$Mass_{BFW} = Mass_{VHP} \tag{3}$$

Where, Mass BFW is boiler feed water mass flow rates, respectively, in kg/hr and Mass VHP is steam mass flow rates, respectively, in kg/hr.

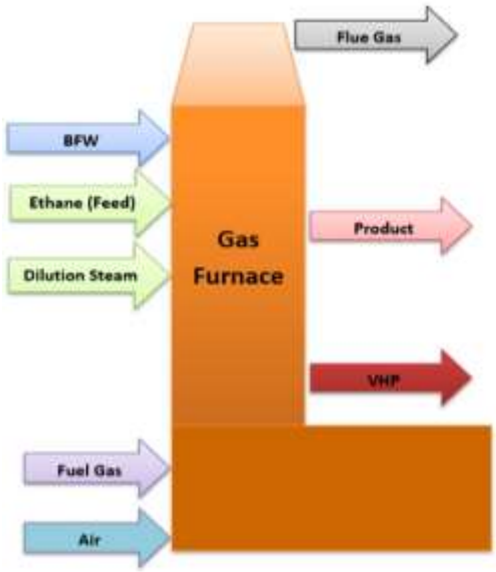

Fig. 2 Streams for a gas feed furnace.

The mass of fuel gas and the mass of air are equal to the mass of flue gas:

$$Mass_{Fuel\ Gas} + Mass_{Air} = Mss_{Flue\ Gas} \quad (4)$$

The quantity of these mass flow rates for the gas feed furnace are represented in "Table 2", where these quantities are derived from the design documents:
The following figure shows the input and output flows for a liquid feed furnace "Fig. 3".

Table 2 Design data on gas feed furnaces

Gas Feed Furnace			
Stream	Mass Input (kg/hr)	Stream	Mass Output (kg/hr)
Ethane (Feed)	40047	Product	52061(40047+12014)
Dilution steam	12014		
BFW+(BFW-Inj)	60166+1295=61461	VHP+(Blow down)	60281+1180=61461
Fuel Gas	5430	Flue Gas	123571(5430+118141)
Air	118141		

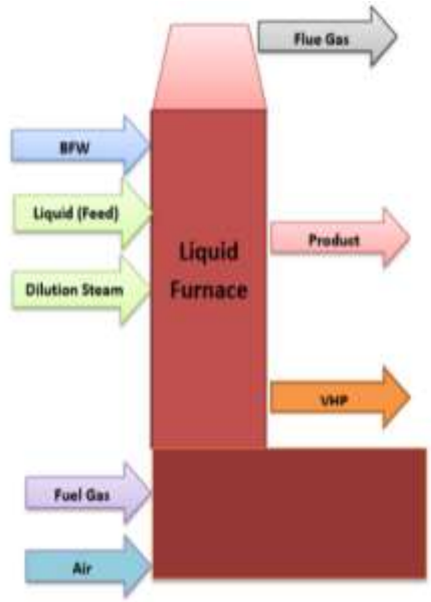

Fig. 3 Streams for a liquid feed furnace.

Consequently, the following formula represents the mass balance, where the input mass is equal to the outgoing mass:

$$Mass_{Input} = Mass_{Output} \quad (5)$$

The mass of liquid feed with the mass of dilution steam is equal to the mass of products.

$$Mass_{Liquid\ Feed} + Mass_{Diltion\ Steam} = Mass_{Products} \quad (6)$$

The mass of boiler feed water with boiler feed water injection is equal to the mass of steam and blowdown:

$$Mass_{BFW} = Mass_{VHP} \quad (7)$$

The mass of fuel gas and the mass of air are equal to the mass of flue gas:

$$Mass_{Fuel\ Gas} + Mass_{Air} = Mss_{Flue\ Gas} \quad (8)$$

Values of the above quantities extracted from the design data for a liquid feed furnace are shown in "Table 3".

Table 3 Design data on liquid feed furnaces

Liquid Feed Furnace			
Stream	Mass Input (kg/hr)	Stream	Mass Output (kg/hr)
Liquid (Feed)	49913	Product	74870(49913+24957)
Dilution steam	24957		
BFW+(BFW-Inj)	63749+1885=65634	VHP+(B low down)	64383+1250=65633
Fuel Gas	6117	Flue Gas	139221(6117+133104)
Air	133104		

Also, the following chart visualizes the energy balance for each furnace “Fig. 4”.

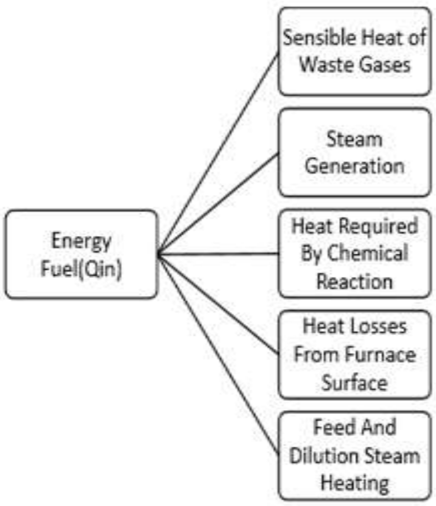

Fig. 4 Energy balance illustration.

Consequently, the following formula represents the mass balance, where the input mass is equal to the outgoing mass:

$$Energy_{In} = Energy_{Out} \tag{9}$$

The fuel gas energy is equal to the fuel gas mass multiplied in lower heating value of the fuel:

$$Q_{Fuel\ Gas} = Mass_{Fuel\ Gas} * LHV_{Fuel\ Gas} \tag{10}$$

Where, Q Fuel Gas is Fuel Gas Energy and LHV Fuel Gas is the lower heating value of each component of the fuel gas, respectively, in MJ/kg. The energy for steam is equal to the enthalpy difference between steam and boiler feed water:

$$Q_{Steam\ Generation} = Entahalpy_{VHP} - Entahalpy_{BFW} \tag{11}$$

Where, Q Steam Generation is the Energy for Steam, respectively, in MJ/kg. The energy for reaction is equal to the enthalpy difference of reactants and products:

$$Q_{Reaction} = Q_{Products} - Q_{Reactants} \tag{12}$$

Where, Q reaction is the reaction energy, Q Products is energy products and Q reactants is energy reactants, respectively, in MJ/kg. The energy loss from the stack is equal to the flue gas flow multiplied in specific heat multiplied in temperature difference of the stack and ambient:

$$Q_{Flue\ Gas\ Loos} = Mass_{Flue\ Gas} * cp * (T_{Steack} - T_{Ambient}) \tag{13}$$

Where, cp is Specific heat capacity.

The energy loss from the surface is equal to the energy loss from convection and radiation:

$$Q_{Surface\ Loss} = Mass_{Surface\ Convection} + Mass_{Surface\ Radiation} \tag{14}$$

The energy for feed preheating is equal to the feed flow multiplied in enthalpy difference at convection section outlet and inlet.

$$Q_{Feed\ Preheat} = Mass_{Feed} * Entahalpy\ Difference_{Feed} \tag{15}$$

The energy for dilution steam preheating is equal to the dilution steam flow multiplied in enthalpy difference at convection outlet and inlet.

$$Q_{Diltion\ Steam\ Preheat} = Mass_{Diltion\ Steam} * Entahalpy\ Difference_{Diltion\ Steam} \tag{16}$$

“Table 4” shows the values for the above quantities. The next section demonstrates the overall efficiency for each furnace plus the efficiency for each section of the furnaces at design condition based on the derived energy and mass balance in this section.

Table 4 Energy results at design condition for gas and liquid feed furnaces

Result	Gas Feed Furnace	Liquid Feed Furnace
Mass $_{Fuel\ Gas}$ (kg/hr)	5430	6117
LHV $_{Fuel\ Gas}$ (KJ/kg)	59949	59949
Q $_{Fuel\ Gas}$ (MJ/hr) (Input Energy)	325523	366708
Enthalpy $_{VHP}$ (KJ/kg)	3393.67	3393.67
Enthalpy $_{BFW}$ (KJ/kg)	477.86	477.86
Q $_{Steam\ generation}$ (MJ/hr)	178400	190516
Q2 $_{Reaction}$ (MJ/hr)	132835	154285
Mass $_{Flue\ Gas}$ (kg/hr)	123571	139221
Feed Pre Heating(MJ/hr)	81031	81031
Dilution Steam Pre Heating(MJ/hr)	13503	23504

5 ENERGY EFFICIENCY FOR GAS AND LIQUID FEED FURNACES

This section offers an approach to calculate the efficiency of each section of the furnace as well as overall efficiency of the gas and liquid feed furnaces. The overall efficiency of the furnace is the ratio between energy intake due to the reaction and steam generation to the energy input to the furnace.

This section offers an approach to calculate the efficiency of each section of the furnace as well as overall efficiency of the gas and liquid feed furnaces. The overall efficiency of the furnace is the ratio between energy intake due to the reaction and steam generation to the energy input to the furnace.

$$Overall\ \ Efficiency=\frac{Q_{1\ Reaction}+Q_{Steam\ Generation}}{Q_{Fuel}} \tag{17}$$

The energy input to the furnace is equal to the energy release of the fuel combustion in the firebox that is:

$$Q_{Fuel}=\sum Fuel\ \ \dot{m}_i LHV_i \tag{18}$$

Where, Q Fuel is the total energy released in the combustion process (MJ/hr), $\dot{m}\ i$ is the mass flow rate of each component of the fuel in kg/hr and $LHV\ i$ is the lower heating value of each component of the fuel in MJ/kg.

The reaction energy is the enthalpy difference of the components of reactant and product flows at the boundaries of the furnace, which are the input to the convection section and output from the exchangers. The reactants contain hydrocarbons and dilution steam. The products are the results of cracking reaction at the radiation section. The boundaries of the control volume are the input to the convection section and output of the exchangers.

$$Q_{1\ Reaction}=\sum{}_{Products}\ \dot{m}_i h_i - \sum{}_{Reactants}\ \dot{m}_i h_i \tag{19}$$

Where, $\dot{m}\ i$ is the mass flow rate of each component in kg/hr and hi is the enthalpy of each component of the products and reactant in MJ/kg at outlet (after the exchangers) and inlet (before the convection section) of the furnace, respectively. To calculate the enthalpy of each component, it is important to consider the reaction and therefore the challenges associated with the enthalpy calculations. Since, the reaction is taking place, the enthalpy of formation and the standard enthalpy should be involved in the calculations for each component (refer to the "chemical reaction" section in any standard thermodynamics textbook). The amount of heat used for steam generation is the enthalpy difference of boiler feed water and very high-pressure steam.

$$Q_{Steam\ Generation}=\dot{m}_{Steam}\ h_{Steam} - \dot{m}_{BFW}\ h_{BFW} \tag{20}$$

Where, $\dot{m}\ steam$ and $\dot{m}\ BFW$ are steam and boiler feed water mass flow rates, respectively, in kg/hr and $hsteam$ and $hBFW$ are steam and boiler feed water enthalpies, respectively, in MJ/kg. Inside the firebox, the method to calculate the reaction energy is similar to the calculation of reaction energy for the furnace, the only difference is the extent of the control volume and therefore boundary conditions. When the firebox is the control volume, the inlet flows are the ones from the convection section to the firebox and the outlet flows are the ones leaving the firebox at the temperature more than 800 degrees centigrade. In contrast to the case when the furnace is the control volume and the inlet flows enter the convection section and outlet flows leave the exchangers.

Therefore, for the fire box the reaction energy is the enthalpy difference between reactants and products both at higher temperatures compared to the case when the control volume is the whole furnace; it is called Q2 reaction:

$$Q_{2\ Reaction}=\sum{}_{Products}\ \dot{m}_i h_i - \sum{}_{Reactants}\ \dot{m}_i h_i \tag{21}$$

Where, $\dot{m}\ i$ is the mass flow rate of each component in kg/hr and hi is the enthalpy of each component of the products and reactants in MJ/kg at outlet (after the firebox) and inlet (after the convection section) of the firebox, respectively. The following table, "Table 5", represents the results for gas and liquid feed furnaces in design conditions:

Table 5 Efficiencies for gas and liquid feed furnaces at design condition

Gas Feed Furnace		Liquid Feed Furnace	
Q1 Reaction(MJ)	122997	Q1 Reaction(MJ)	149818.7
Q2 Reaction(MJ)	132836	Q2 Reaction(MJ)	154285
Q Steam Generation(MJ)	178401	Q Steam Generation(MJ)	190516
Q Fuel(MJ)	325523	Q Fuel(MJ)	366708
Overall Efficiency	92.59	Overall Efficiency	92.81
Absorbed Heat in Fire Box (MW)	37	Absorbed Heat in Fire Box (MW)	42.8

The significance of the above table is in the method of calculation and the consistency of its results with the design data. Only the absorbed heat in the firebox for the liquid feed furnace has a 2 percent deviation from the design data and for the gas, feed furnace there is a 3 percent deviation for the absorbed heat in the firebox.

6 DATA EXTRACTION IN WORKING CONDITION

To calculate the efficiency and losses, mass and energy balance should be developed for the furnace as a control volume. In chapter two, furnace control volume and corresponding streams were identified. For each stream, the energy difference between inlet and outlet should be calculated. Knowledge of mass flow rates, temperature, pressure and material composition of the streams are needed to carry out the required calculations for energy and mass balance.

In the last section, the data requirement for each stream in energy calculations was identified based on the tag numbers on distributed control system (DCS). The tags on the distributed control system correspond to the quantities sought. Therefore, the sensors on the distributed control system measure the relevant values. In this section, those values that are the requirements in the mass and energy balance calculations at working conditions for ten olefin furnaces are extracted and reported.

The DCS data for each furnace was extracted simultaneously with oxygen data from the stack to consider the effect of load and fuel mass flow rate. As it will be explained, from the oxygen data and knowledge of fuel composition, one can calculate the combustion airflow rate and then flue gas flow rate for further analysis. Therefore, the losses through the stack will be quantified. The other major loss is due to the high skin temperatures.

The skin temperature is the function of temperature inside the furnace at different sections, refractory performance, and the convective heat transfer coefficient for furnace peripheral and air. It should be noted that unless the load of furnace drops very sharply, the furnace has to maintain its temperature for the reaction to take place and therefore mild changes of the load does not change the temperature inside the furnace and consequently the skin temperature is only the function of convective heat transfer coefficient for furnace and air.

6.1. Excess Oxygen

The value of excess oxygen has a twofold importance from energy perspective: a) the excess oxygen is the required quantity to measure airflow rate and consequently flue gas flow rate and b) controlling the excess oxygen is an important measure for improving energy performance. Therefore, the excess oxygen was measured by an oxygen analyzer, made by KIMO, for liquid feed and gas feed furnaces.

To calculate the air fuel ratio and consequently air flow rates, the fuel composition should be known. Then, the air fuel ratio will be calculated from the stoichiometric balance. When the air fuel ratio is known, the air flow rate is the product of the fuel mass flow rate and air fuel ratio. Finally, the flue gas flow rate is the sum of fuel and airflow rate.

The following formula depicts the parametric calculation for flow rates of air and flue gas:

$$aCH_4 + bH_2 + c(O_2 + 3.76N_2) = dCO_2 + eH_2O + fO_2 + gN_2 \tag{22}$$

Since a, b and the excess oxygen are known:

$$Excess\ \ Oxsygen = \frac{f}{d+e+f+g} \tag{23}$$

Also, from the stoichiometric balance:

$$a = d \tag{24}$$

$$4a + 2b = 2e \tag{25}$$

$$2c = 2d + e + 2f \tag{26}$$

Therefore, there are five equations for five unknowns. The air fuel ratio is calculated with the knowledge of c in the above equation and molecular weight of air, methane and hydrogen:

$$Air\ \ Fuel\ \ Ratio = \frac{c{*}4.76{*}28.97}{a{*}(12{+}4){+}b{*}2} \tag{27}$$

$$Air\ \ Flow\ \ Ratie = Air\ \ Fuel\ \ Ratie \; {*}Fuel\ \ Flow\ \ Ratie \tag{28}$$

$$Flue\ \ Gas\ \ Ratie = Air\ \ Flow\ \ Ratie \; {*}Fuel\ \ Flow\ \ Ratie \tag{29}$$

The following table, “Table 6”, represents the excess air, air fuel ratio (AFR) and airflow rate for olefin furnaces.

Table 6 Air quantities for furnace 104 and 109 in real condition Fuel, feed and product

Furnace 104		Furnace 109	
%Excess Oxygen	2.6	%Excess Oxygen	4.1
Air -Fuel Ratio(AF)	22.24	Air -Fuel Ratio(AF)	23.61
Air Flow(kg/hr)	123020	Air Flow(kg/hr)	140400

6.2. Fuel, Feed and Product

The quantities related to the fuel, reactant and product streams, that their tags on the DCS were identified earlier, were extracted from the system simultaneously with data extraction on oxygen that was reported earlier. These quantities of furnace streams are reported in “Table 7”.

Table 7 Measured values for reactants, steam, products and fuel streams for furnace 104 and 109 in real condition

Measured Quantity	Furnace 104	Furnace 109
Fuel Flow Rate (kg/hr)	5530	5940
Feed Flow Rate (kg/hr)	40000	45000
Dilution Steam (kg/hr)	12000	25400
Feed Temperature	26°C	50°C
Feed Pressure	6.1bar	5.8bar
Temperature of Feed to Radiation	632°C	573°C
Pressure of Feed to Radiation	4.2bar	4bar
Temperature of Products from Radiation	844°C	847°C
Pressure of Products from Radiation	2.1 bar	2.05bar
Temperature of Products after Heat Swap	182°C	330°C
Pressure of Products after Heat Swap	0.7bar	0.7bar
Boiler Feed Water Flow Rate (kg/hr)	60000	50000
Boiler Feed Water Temperature	114°C	114°C
Boiler Feed Water Pressure	103.6bar	103.6bar
Steam Flow Rate(kg/h r)	60000	50000
Steam Temperature	488°C	482°C
Steam Pressure	103.6bar	103bar

Also, the composition of feed and products for both gas and liquid feed furnaces were received from the Jam petrochemical laboratory and are reported in “Tables 8-11”

Table 8 Feed composition for gas feed furnaces in real condition

Gas Furnaces – Feed Composition		
Input Substance(Feed)	Formula	0.018
Methane	CH4	0.975
Ethane	C2H6	0.007
Propane	C3H8	0
Ethylene	C2H4	0
Propylene	C3H6	0
Carbon Monoxide	CO	0
Carbon Dioxide	CO2	0
C3+ hydrocarbons	C3+	0
C4+ hydrocarbons	C4+	0
Total		1

Table 9 Product composition for gas feed furnace in real condition.

Gas Furnaces – Product Composition		
Output Substance(Product)	Formula	Mole Fraction
Hydrogen	H2	0.3372
Ethane	C2H6	0.2433
Propylene	C3H6	0.00597
Acetylene	C2H2	0.00245
Methane	CH4	0.06575
Ethylene	C2H4	0.33748
n –Butane	C 4H10	0.00078
Total		0.9938

Table 10 Feed composition for liquid feed furnaces in real condition

Liquid Furnaces– Feed Composition		
Input Substance(Feed)	Formula	Weight Fraction
Ethane	C2H6	0.006
Propane	C3H8	0.032
Isobutane	C4H10	0.078
n –Butane	C4H10	0.224
Neopentane	C5H12	0.004
Isopentane	C5H12	0.250
n -C5	C5H12	0.232
Cyclopentane	C6H10	0.008
n -C6	C6H14	0.040
Benzene	C6H6	0.019
n -C7	C7H16	0.002
CC5	C5H8	0.013
CC6	C5H8	0.006
MCC5	C6H12	0.011
2MC5	C6H14	0.051
3MC5	C6H14	0.024
Total		1

Table 11 Product composition for liquid feed furnace in real condition

Liquid Furnaces – Product Composition		
Output Substance(Product)	Formula	Weight Fraction
Hydrogen	H2	0.01
Ethane	C2H6	0.06
Propylene	C3H6	0.21
Acetylene	C2H2	0.01
Propane	C3H8	0.02
Propane	CH4	0.26
Ethylene	C2H4	0.36
C3H4's	C3H4	0.00
C5+	C5H12	0.00
Butadiene	C4H6	0.06
Butanes	C4H8	0.01
Butanes	C4H10	0.01
Benzene	C6H6	0.00
Toluene	C7H8	0.00
Xylenes	C8H10	0.00
C10+	C10H22	0.00
Total		1

Already, one has the required data to know the enthalpy change on every stream inside the furnace. That provides the required data to calculate the efficiency of each furnace and consequently losses which is the difference between input energy from the fuel and required energy for reaction and steam generation. Part of that loss is due to stack losses that the required information to calculate that portion is already known. The rest of the loss happens through the skin and surfaces.

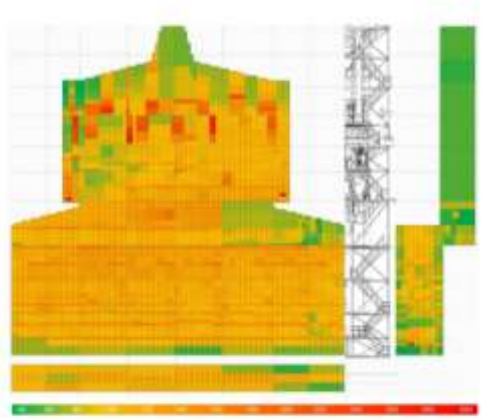

Fig. 5 Extracted temperature in degrees centigrade for furnace 104 in real condition.

6.3. Skin Temperature

In order to calculate the quantity of skin losses, the skin temperatures were recorded with an infrared thermometer, made by KIMO. Then, the measured quantities were transferred to the excel sheet in which every furnace was mapped on, with the scale of one cell for every 25 square centimeters; the dimensions of gas and liquid feed furnaces were transferred to the excel sheets in a way that every cell represents 25 square centimeters of the furnace peripheral. Figure 5 depicts the extracted temperature for furnace 104.

The reported temperature for furnace 104 and 109 was extracted during June when the wind is very strong. For other furnaces, the temperature was extracted during July and August in Asalouyeh, meaning it is not as windy as in May and June; wind affects the temperature on the furnaces' body.

For instance, the side of the furnace 101 and 110, which are facing an open area show lower temperatures that the other sides of them. The lower temperature at different time of the year does not necessarily mean the heat loss is less since the coefficient of convective heat transfer increases significantly with the assistance of wind. Also, "Fig. 6" shows the measured temperatures on furnace 109 peripheral

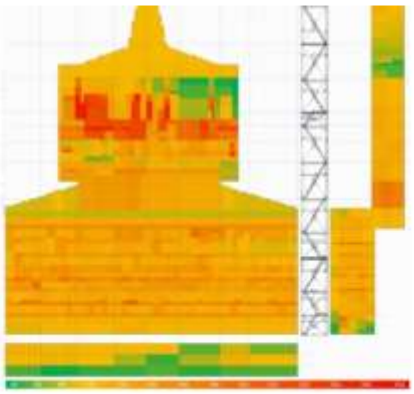

Fig. 6 Extracted temperature in degrees centigrade for furnace 109 in real condition.

Each stream inside the furnace was identified on Design Analysis chapter in this report. The enthalpy difference on each stream is calculated and presented in this chapter. Besides, the losses associated with the flue gas stream and furnace peripheral are calculated and reported.One can calculate the flue gas losses with the knowledge of flue gas flow rate, which is already known for all of the furnaces. Since the specific heat of flue gas at constant pressure is considered to be equal to the air itself, it is quite straightforward to calculate the stack losses.

Table 12 Energy results for furnace 106 to 110 in real condition

Result	Furnace104	Furnace109
$Q_{\text{Fuel Gas}}$ (MJ/hr) (Input Energy)	343485.6	368952
$Q_{\text{Steam generation}}$ (MJ/hr)	173914	144626.5
$Q1_{\text{Reaction}}$ (MJ/hr)	116910	117988.8
$Q2_{\text{Reaction}}$ (MJ/hr)	142844	136328
$Q_{\text{Flue Gas}}$ (MJ/hr)	19657.31	23792.5
$Q_{\text{Total Skin Loss}}$ (MJ/hr)	33003.64	23792.5

The peripheral losses are due to convection and radiation from the furnace body to the surroundings. Since the temperature of the skin is determined and recorded, it is also straightforward to calculate the losses from the furnace peripheral. Only one of the losses is enough to calculate the other, given the fact that the energy can only be dissipated through either the stack or the skin of the furnace. However, direct calculation of the losses is helpful to assess the accuracy of the data measured. The "Table 12", presents the amount of energy for the input, reaction, steam generation and losses for each furnace, based on the real furnace data. Following tables, "Tables 13-14", compare the results of energy balance under working condition for furnaces with design situations

Table 13 Comparison between energy results for gas feed furnaces with design condition

Furnace 104		
Results	Real Condition	Design
Q Steam Generation(MW)	48.31	49.23
Q Feed Heating(MW)	19.84	22.51
Q Dilution Steam Heating(MW)	3.22	3.75
Box Efficiency(MW)	41.59	43.91
Overall Efficiency(MW)	84.67	92.83

Table 14 Comparison between energy results for gas feed furnaces with design condition

Furnace 104		
Results	Real Condition	Design
Q Steam Generation(MW)	40.17	52.51
Q Feed Heating(MW)	24.21	26.94
Q Dilution Steam Heating(MW)	5.91	6.55
Box Efficiency(MW)	36.95	41.1
Overall Efficiency(MW)	71.18	94.98

8 CONCLUSION

The results of this study showed that in the furnace 104, the design efficiency and real efficiency was 92.98 and 84.67, respectively and for the furnace 109, the design efficiency and real efficiency was 94.98 and 71.18, respectively. Heat loss from exchangers surfaces, especially on top of the primary exchangers and on some sections of secondary and tertiary exchangers in gas feed furnaces, can affect the quality of steam and energy performance of the furnaces and therefore it is necessary to repair those insulations. As a result, the amount of energy loss is high and should reduce energy consumption in these furnaces and improve efficiency; replacement of refractory refractories is a replacement of insulation.

NOMENCLATURE

T	Temperature
H	Enthalpy
LHV	Lower Heating Value of each *Component* of the Fuel in MJ/kg.
$\dot{m}$	Mass Flow Rate of each Component of the Fuel in kg/hr
P	Pressure
T_{Steack}	Temperature Difference of the Stack
$T_{Ambient}$	Temperature Difference of the Ambient
BFW	Boiler Feed Water
VHP	Very High Pressure Steam
cp	Specific heat capacity.
$\dot{m}_{BFW}$	Boiler Feed Water Mass Flow Rates, Respectively, in kg/hr
$\dot{m}_{Steam}$	Steam Mass Flow Rates, Respectively, in kg/hr
h_{BFW}	Boiler Feed Water Enthalpies, Respectively, in MJ/kg.
h_{Steam}	Steam Enthalpies, Respectively, in MJ/kg.
$Q_{1\ Reaction}$	Reaction Energy
$Q_{2\ Reaction}$	Firebox the Reaction Energy
$Q_{Diltion\ Steam\ Preheat}$	Energy for Dilution Steam Preheating
$Q_{Flue\ Gas\ Loos}$	Energy Loss From the Stack
$Q_{Feed\ Preheat}$	Energy for Feed Preheating
$Q_{Steam\ Generation}$	Energy for Steam
$Q_{Fuel\ Gas}$	Fuel Gas Energy
$Q_{Surface\ Loss}$	Energy Loss From the Surface
Q_{Fuel}	Energy Input to the Furnace
$Q_{Products}$	Energy Products
$Q_{Reactants}$	Energy Reactants

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