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Graduation Project Submitted in Partial Full Filament for the Degree of BSc (honor degree) in Petroleum Engineering

About:

Evaluation of furnace efficiency

تقيم كفاءة فرن الاحتراق

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ABSTRACT

Furnaces and fired heaters provide the energy associated with running hydrocarbon processes and chemical plants. In this project the suitable and best way to gain high efficiency of the furnace has been determined by manipulating the parameters that affect in efficiency of the furnace (excess air, pre-heating, stack temperature, and the effect of the presence of the nitrogen to the furnace efficiency). Aspen exchanger design and rating V8.8 (EDR) was used to design fired heater and using the results in aspen HYSYS V8.8 todetermine the effect of these parameters consequently obtaining the best effective way for high efficiency which represent in reducing the percent of nitrogen.

This project also includes controlling and monitoring three major parameters: (Fuel gas/ fuel oil pressure, Excess air and Furnace draft fan), and using excel sheets for estimating the Cost of the furnace.

التجريد

توفر الافران والسخانات معظم الطاقة المرتبطة بالعمليات الهيدروكربونية والصناعات الكيميائية هذه الدراسة تحدد الطريقة المناسبة للحصول على اعلى كفاءة للافران من خلال التعامل مع العوامل التي تؤثر على كفاءة الفرن: (الهواء الزائد, التسخين المسبق, درجة حرارة المدخنة, وتأثير نسبة النتروجين علي كفاءة الفرن). وتم استخدام “Aspen exchanger design and rating v8.8” لتصميم فرن الاحتراق واستخدمت النتائج في “aspen HYSYS V8.8” لتحديد تاثير هذه العوامل وبالتالي الحصول على أفضل طريقة تؤدي الى أعلى كفاءة والتي تمثل تقليل نسبة النيتروجين

ويشتمل هذا المشروع ايضا على التحكم ومراقبة ثلاث عوامل رئيسية: (ضغط الوقود بنوعيه غازي وسائل, الهواء الفائض ومرواح للسحب) , الى جانب استخدام “excel sheets” لتقدير تكلفة الفرن

Keywords:

Furnace

Efficiency

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) come into contact with an ignition source and release heat and light. Furnaces use this principle to provide heat. Complete combustion occurs when reactants are ignited in the correct proportions. Incomplete combustion occurs in a fired furnace when not enough oxygen exists to completely convert all of the fuel to water and carbon dioxide [2].

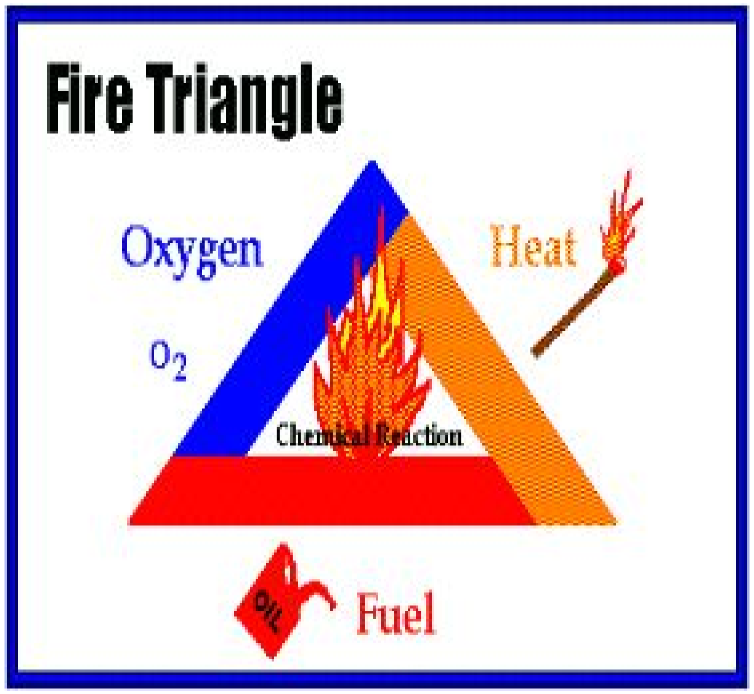


Figure (2-1): Fire triangle

2.1.1 Flame: -

Is ‘the visible part of an exothermic reaction between fuel and oxygen’. Flame is characterized by:

I. The emission of light.
II. The prevalence of temperatures higher than 1100℃.
III. Oxidation of carbon, hydrogen and Sulphur.
IV. The continuation of the initiated reaction.

Figure (2-2): Effect of fuel component in the flame

2.1.2 Heat transfer means:-

Conduction:-

The transfer of thermal energy from the more energetic particles of a medium to the adjacent less energetic ones. It was stated that conduction can take place in liquids and gases as well as solids provided that there is no bulk motion involved [4].

Convection:-

Heat transfer by convection is attributable to macroscopic motion of a fluid and is thus confined to liquids and gases. Convection was considered only insofar as it related to the boundary conditions imposed on a conduction problem [14].

Radiation:-

or Mj/kg are traditionally used to quantify maximum amount of heat that can be generated by combustion with air at standard condition (STP) ($25C^{\circ}$and $101.3kpa$). The amount of heat release from combustion of the fuel will depend on the phase of water in the product. If water is in gas phase in the product, the value of total heat denoted as the lower heating value (LHV).

2.2 Furnace: -

2.2.1 About furnace: -

Furnace is A process heater is a direct-fired heat exchanger that uses the hot gases of combustion to raise the temperature of a feed flowing through coils of tubes aligned throughout the furnace. Depending on the use, these are also called furnaces or fired heaters. Or (it is device used to heat up chemical or chemical mixture, fired haters transfer heat generated by the combustion of natural gas, ethane, propane or fuel gas).

Fired heaters transfer heat directly from a flame to a process fluid that usually flows through a set of tubes. Process heaters are used throughout the hydrocarbon and chemical processing industries in places such as refineries, gas plants, petrochemicals, chemicals and synthetics, olefins, ammonia and fertilizer plants. Some plants may have only two or three heaters while larger plants can have more than fifty [5].

Unit operation that require furnace: -

-crude distillation unit (CDU)

-fluidized catalytic cracking unit (FCC)

Figure (2-3): parts of furnace

2.2.3 Types of Furnace: -

Furnaces can be classified by several features:(type of draft, number of fireboxes, number of passes.)

1-Draft: -

Furnace draft can be natural, forced, induced, or balanced. In a natural-draft furnace, buoyancy forces induce draft as the hot air rises through the stack and creates a negative pressure inside the firebox. Forced-draft furnaces use a fan to push fresh air to burners for combustion Forced draft is used in furnaces that preheat the combustion air to reduce fuel requirements. In an induced-draft furnace, a fan located below the stack pulls air up through the firebox and out the stack. Balanced-draft furnaces require two fans: one inducing flow out the stack and one providing positive pressure to the burners [2].

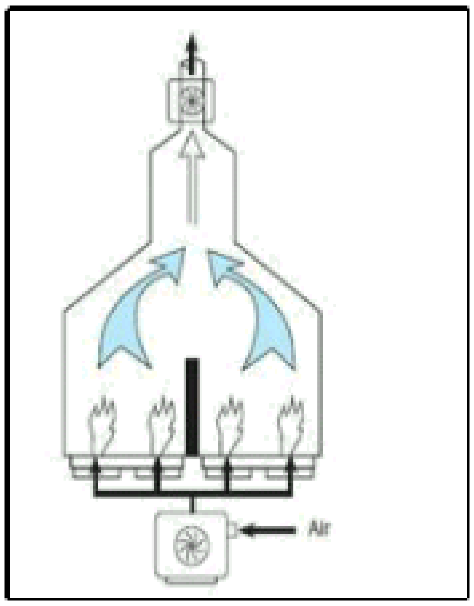
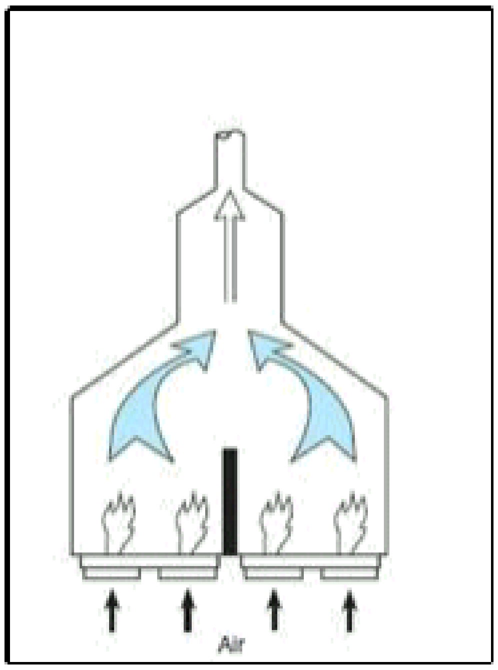


Figure (2-4): Induced draft furnace

Figure (2-5): Balanced draft furnace



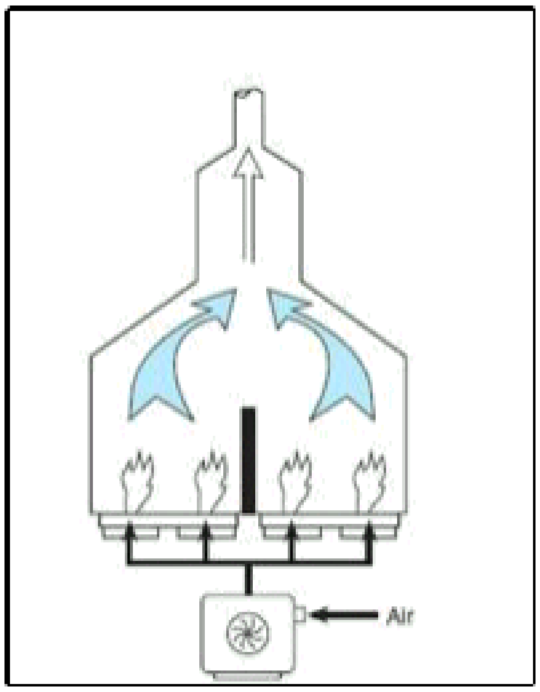


Figure (2-6): Natural draft furnace

Figure (2-7): Forced draft furnace

Draft System: -

There is another way to determine total efficiency: by subtracting all losses from a value of 100%.

In this calculation, the following losses are taken into account: -

I. Stack losses.
II. Radiation losses.
III. Residual losses.

2.2.6.1 Excess air:-

The terms excess air and excess oxygen are commonly used to define combustion.They can be used synonymously but have different units of measurements.The percentage of excess air is the amount of air above the stoichiometric requirement for complete combustion. The excess oxygen is the amount of oxygen in the incoming air not used during combustion and is related to percentage excess air. For example, 15% excess air equals 3% oxygen while firing natural gas.In theory, to have the most efficient combustion in any combustion process, the quantity of fuel and air would be in a perfect ratio to provide perfect combustion with no unused fuel or air. This type of theoretical perfect combustion is called stoichiometric combustion. In practice, however, for safety and maintenance needs, additional air beyond the theoretical “perfect ratio” needs to be added to the combustion process— this is referred to as “excess air.”.With boiler combustion, if some excess air is not added to the combustion process, unburned fuel, soot, smoke, and carbon monoxide exhaust will create additional emissions and surface fouling. From a safety standpoint,

Figure (2-8): Excess air and efficiency relationship

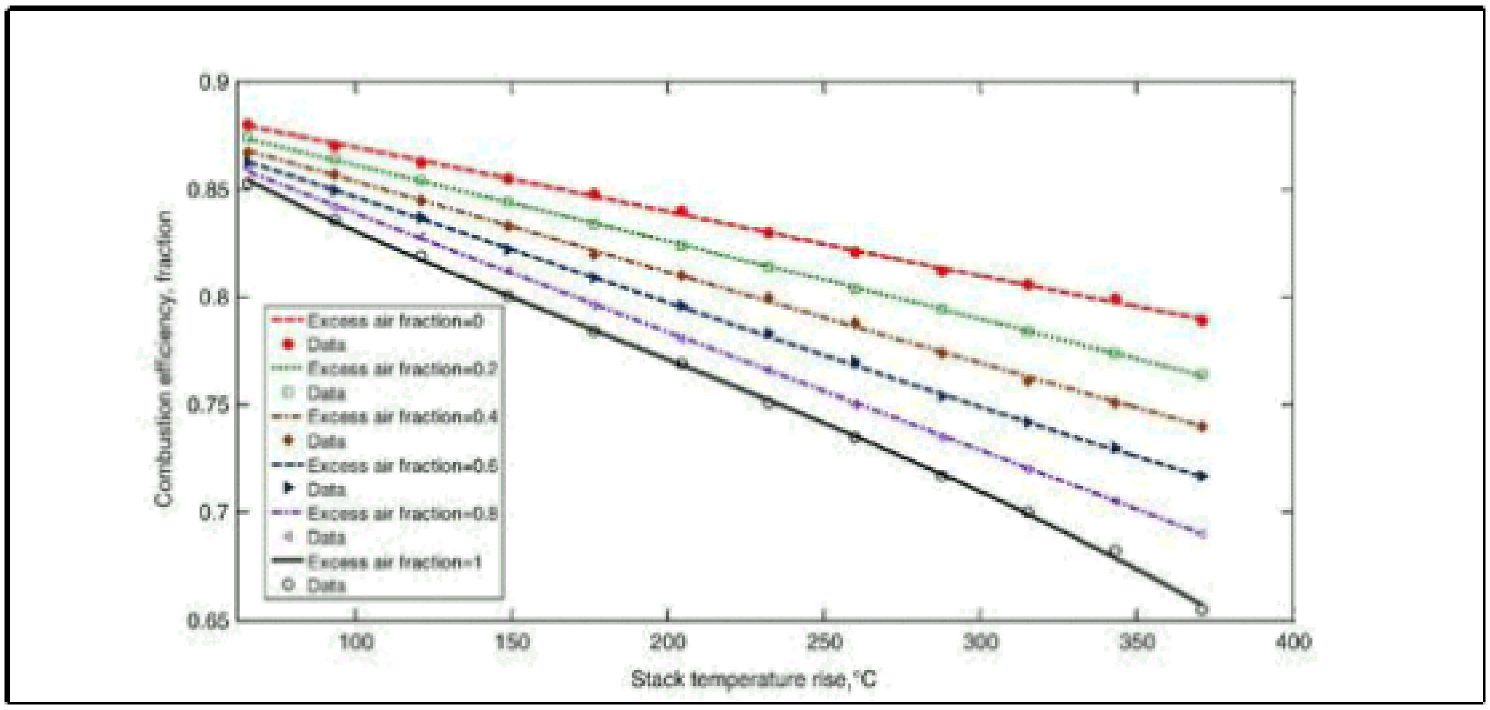


Figure (2-9): Combustion efficiency as function of excess air and stack temperature.

Figure (2-9) Developed predictive tools performance for estimating combustion efficiency as a function of excess air fraction and stack temperature rise in (the more stack temperature rise the more efficiency decrease as well as the more excess air rise the more efficiency decrease) [8].

Figure (2-10): Excess air in relation with flue gas

Figure (2-10)shows the predicted excess air fraction as a function of flue gas oxygen fraction

The effect of excess air on the efficiency of the furnace is obtained from equation:

$$heater\ efficiency = \frac{Q}{Q+L} \quad (2.1)$$

Q: Absorbed heat flux by all tubes and walls.

L: Lost heat flux at the boiler outlet.

It is apparent that supplying excess air up to 18% provides better situation for combustion, and improves the efficiency. increasing excess air beyond 18% reduces the flame temperature, and the furnace efficiency. In addition, increasing the excess air results in more CO_2 and H_2O levels, both having high emitting power.

Furthermore, too much excess air can cause corrosion in metallic components exposed to combustion gases. The optimum amount of excess air for combustion is about 15– 20%. as shown in figure (2-11).

Figure (2-11): Effect of excess air on volumetric average temperature and efficiency of the furnace.

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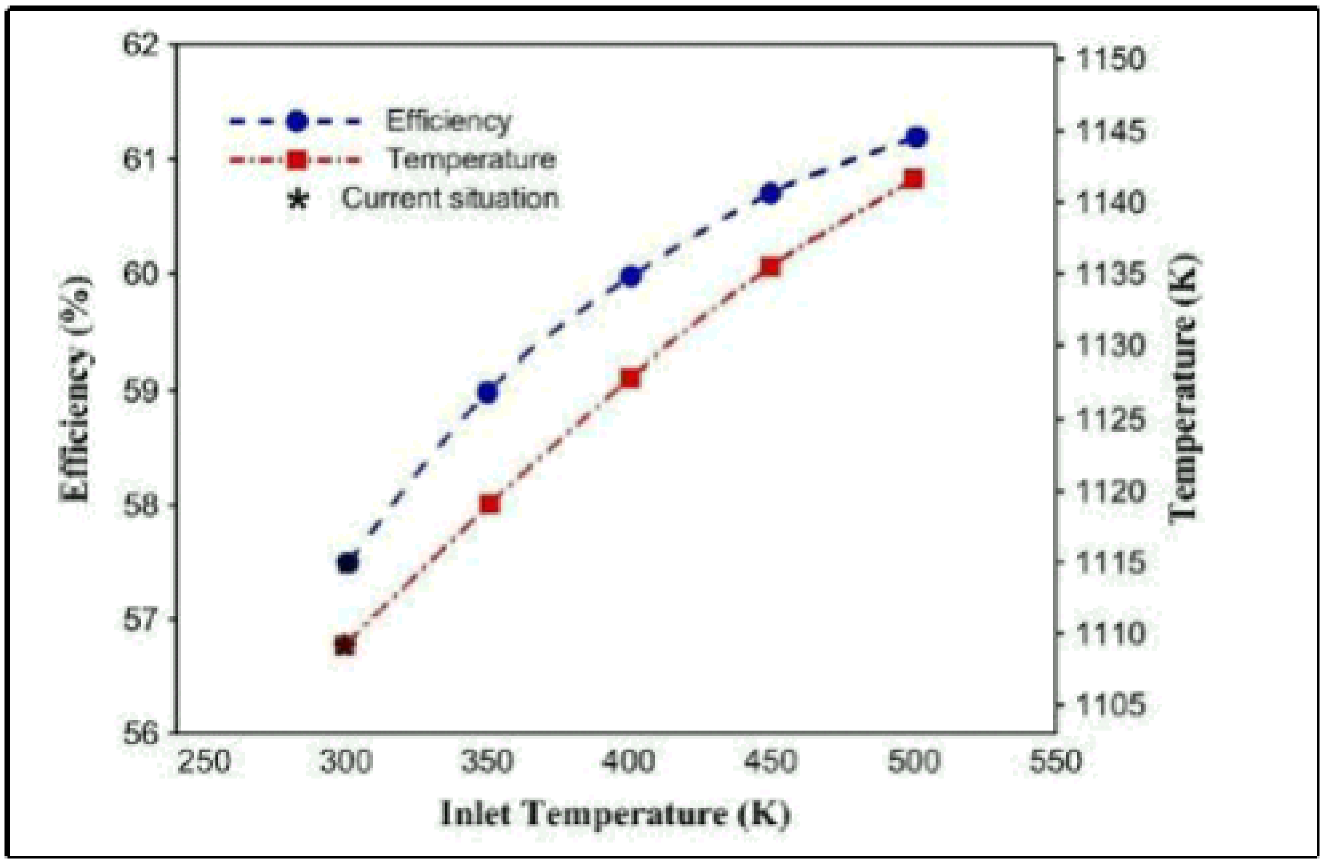


Figure (2-12) Effect of preheating on the volumetric average temperature and efficiency of the furnace.

consumption, and less O_2 emission from the outlet [9].

Raising the fuel temperature causes the fuel density to decrease. If the fuel flow rate is maintained unchanged, the fuel flow velocity must be increased. The higher speed for fuel exiting the burner nozzle shortens the time for the fuel to reach the burning point so that the flame volume is reduced. when the fuel temperature is gradually raised from $95C^{\circ}$ to $130C^{\circ}$, on-site results obtained with a currently operated full-scale furnace show that the raised fuel temperature causes the temperature of the furnace convection zone to increase from $674C^{\circ}$ to $695C^{\circ}$, furnace pressure to rise from -6.8 mmH_2O to - 4.3 mmH_2O, O_2 concentration in the flue gas to drop from 3.2 vol.% to 2.0 vol.%.. Additionally, when the hot gas flow in the furnace is under higher temperature, the time for the fuel to reach the burning point becomes shorter so that less fuel is consumed. If the fuel temperature is increased from $95C^{\circ}$ to $130C^{\circ}$, the fuel consumption is reduced by 85 $m3/h$ [10].

(3.1)

2- Indirect method: -

$$e=\frac{(LHV+Ha+Hf)-Qs-Qr}{(LHV+Ha+Hf)}*100\% \quad (3.2)$$

e= Net thermal efficiency.

LHV=Lower heating value of fuel (BTU/LB).

H_a=Heat input in form of sensible heat of air (BTU/LB).

H_f=Heat input in form of sensible heat of fuel (BTU/LB).

Q_s=Heat stack losses(BTU/LB).

Q_r=Radiation heat losses (BTU/ LB).

This research focus on indirect method as a source of high accuracy because all loses (stack losses, radiation losses) are taken into account.

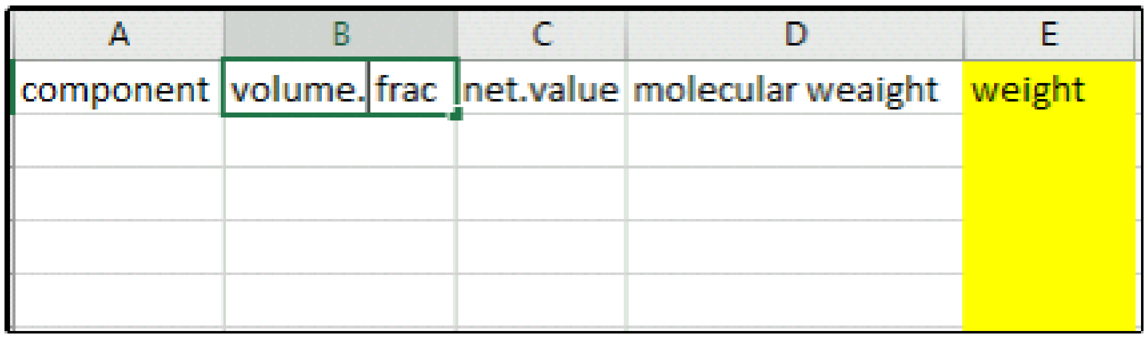
To determine the efficiency of DCU furnace you must have some information about the fuel used to supply heat to the furnace. This information includes (volume

Figure (3-1): Component given data

3.2.1 Steps of data preparation: -

Firstly, the weight for each component must be determined.

$$Weight = (volume\ fraction * molecular\ weight).$$



A	B	C	D	E
component	volume.frac	net.value	molecular weaight	weight

Figure (3-2): Weight calculation

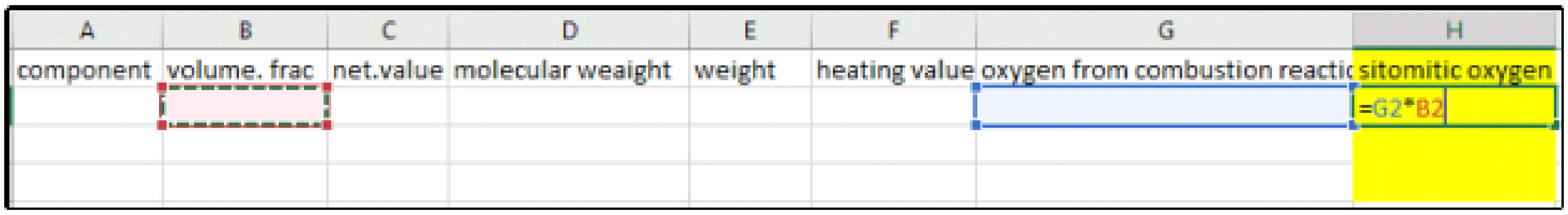
The next step is to determine the heating value for each component.

$$Heating\ value = (net.\ heating\ value * weight).$$

Figure (3-3): Heating value calculation

After that the Stoichiometric oxygen of each component must be calculated.

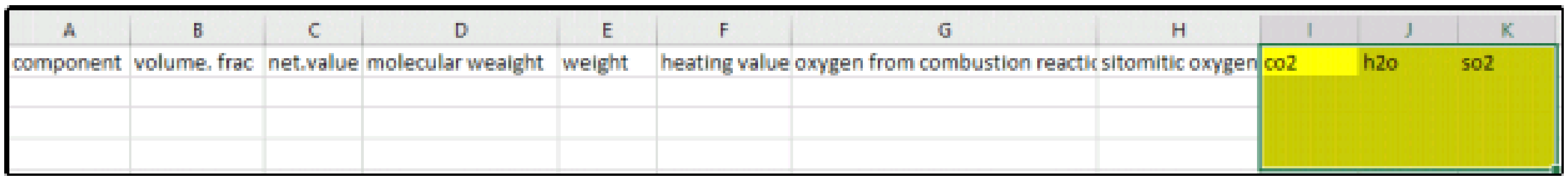
Stoichiometric oxygen = (*oxygen from combustion reaction *volume fraction*).



A	B	C	D	E	F	G	H
component	volume. frac	net.value	molecular weaight	weight	heating value	oxygen from combustion reactic	sitomitic oxygen
							=G2*B2

Figure (3-4): Stoichiometric oxygen calculation

Finally the amount of (CO_2, H_2O, SO_2)has been calculated, by the same procedures followed to calculate Stoichiometric oxygen above.



A	B	C	D	E	F	G	H	I	J	K
component	volume. frac	net.value	molecular weaight	weight	heating value	oxygen from combustion reactic	sitomitic oxygen	co2	h2o	so2

Figure(3-5):Amount of (CO_2, H_2O, SO_2) calculation

So the data finally being ready to calculate efficiency. After data preparation the main body of the research starts right now (determined furnace efficiency).

- Oxygen in flue gas is measured by oxygen analyzer then from figure below excess air has been estimated.

Figure (3-6): Relation between excess air % and oxygen% in flue gas

$$\text{-}Actual\ oxygen\ required = Stoichiometric\ oxygen + (excess\ air * Stoichiometric\ oxygen).$$

$$\text{-}\ Actual\ air\ required = actual\ oxygen\ required * (100/21).$$

- Estimate stack component ($CO_2, H_2O, SO_2, O_2, N_2$).

$$\text{-}Amount\ of\ CO_2\ \ in\ flue\ gas = (total\ formed + CO_2\ \ reported\ as\ fuel).$$

$$\text{-}Amount\ of\ \ H_2O\ in\ flue\ gas = (total\ formed + H_2O\ reported\ as\ fuel).$$

$$\text{-}Amount\ of\ SO_2\ in\ flue\ gas = (total\ formed + SO_2\ reported\ as\ fuel).$$

$$\text{-}Amount\ of\ O_2\ in\ flue\ gas = (actual\ O_2\ \ supplied - actual\ O_2\ \ used\ during\ combustion).$$

$$\text{-}Amount\ of\ N_2\ in\ flue\ gas = (79\%\ of\ moles\ of\ air + N_2\ reported\ as\ fuel).$$

-Temperature in the stack is measured and used to calculate enthalpy for stack component.

)

-First (LHV) was determined: -

$$LHV=\frac{\sum heating\ value}{\sum weight\ of\ component\ of\ fuel} \quad (3.3)$$

-Second stack losses were calculated: -

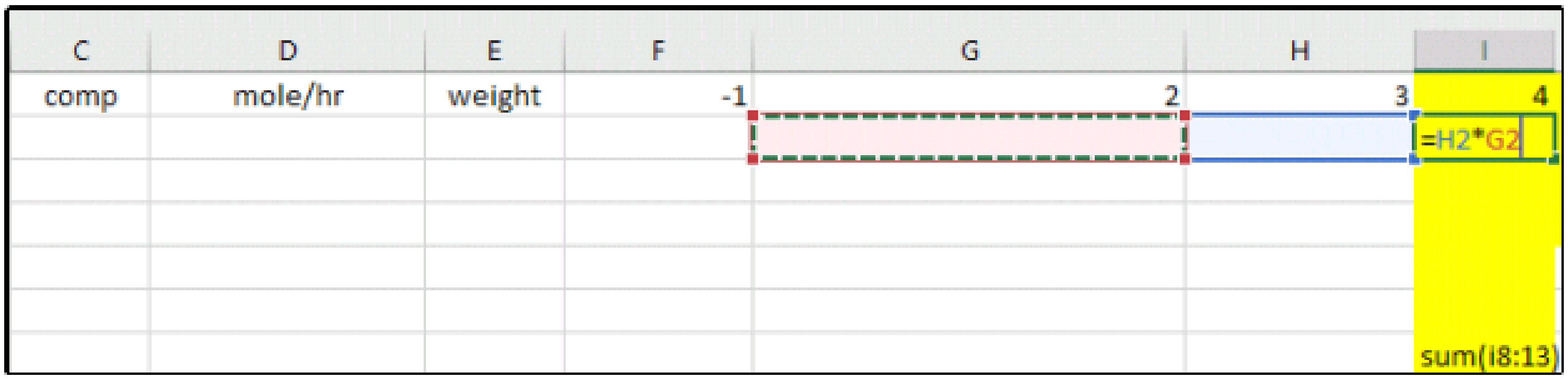
1- (*amount of stack component *molecular weight*).

2- (*result from* (1)/ *amount of fuel enter the furnace*).

3- *result from* (2) * *enthalpy for each stack component*).

4- *summation of all result in* (3).

These summation is equal to stack losses.



C	D	E	F	G	H	I
comp	mole/hr	weight	-1	2	3	4
						=H2*G2
						sum(i8:13)

Figure (3-7): Stack losses calculation

-Third radiation losses were calculated: -

The radiation heat losses were determined by multiplying heat input fuel (LHV)by the radiation losses expressed as percentage (radiation heat losses between 1 to 3 % from chemical and process design hand book).

Therefore, *radiation heat losses* = (1%+3%)/2=2% *of heat input*(*LHV*).

-Forth sensible heat correction for combustion of air (H_a) was calculated: -

$/\ lb\ of\ fuel * Cp_{air} * (T_t - T_d)$ (3.4)

T_t = combustion air temperature.

T_d = datum temperature (60°f).

-Fifth sensible heat correction for fuel (H_f) was calculated: -

$H_f = C_{Pfuel} * (Tt - Td)$ (3.5)

Finally calculating the efficiency of the furnace using indirect method for all data determined in the step before.

3.3 Stack temperature and excess air: -

After efficiency of furnace has been determined, the effect of stack temperature rise has been examined on furnace efficiency using excel sheet.

The temperature of stack has been changed then determined enthalpy of each component in flue gas component finally calculate furnace efficiency (follow the same procedure in 3.2). (11)

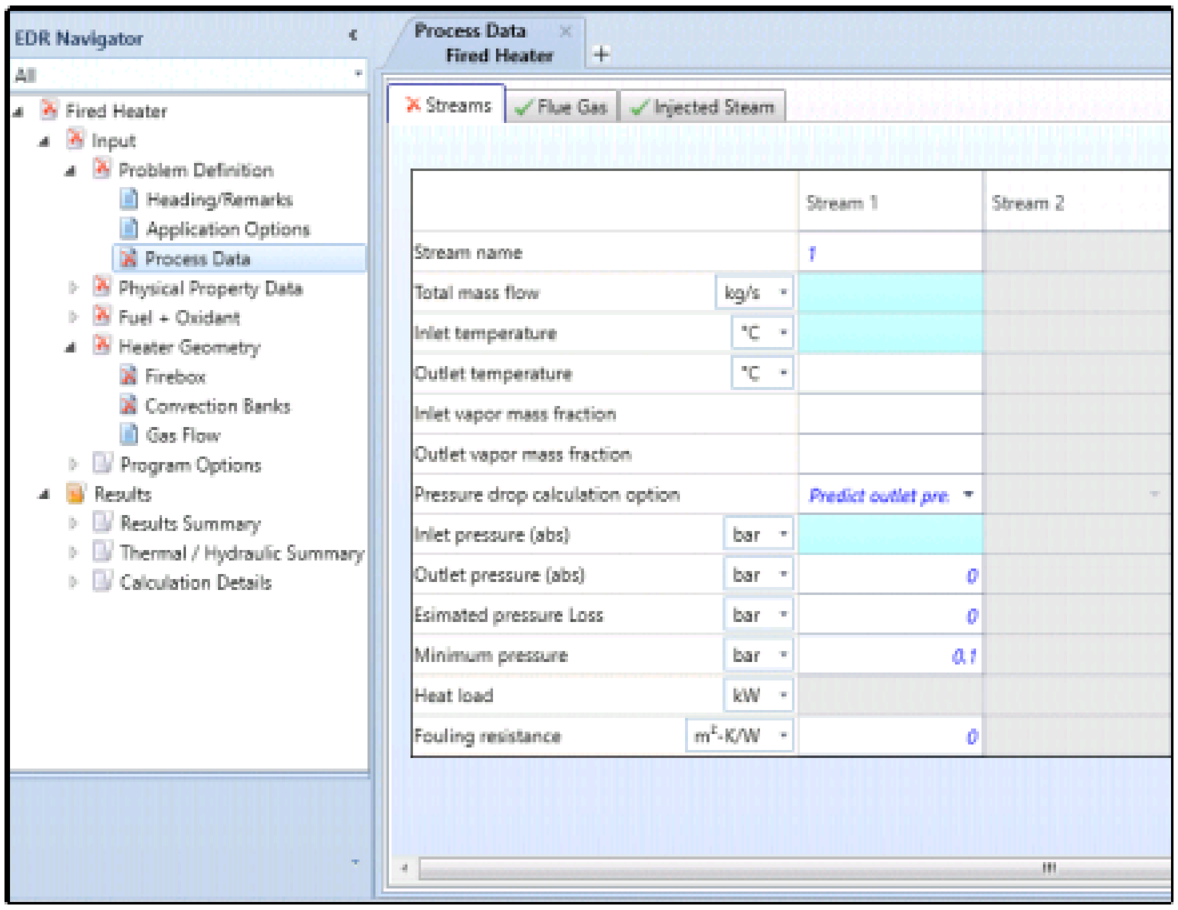
3.4 Aspen HYSYS Simulation: -

Aspen HYSYS is the market-leading process modeling solution that provide large economic benefits throughout the process engineering lifecycle. It brings the power of process simulation and optimization to your desktop, and delivers a unique combination of modeling technology and ease of use. Aspen HYSYS enables companies to bring new plants and design to market faster and optimize production for greater margins [12].

Aspen HYSYS benefits: -

1- Improve engineering design and operation.
2- Improve energy efficiency.
3- Reduce capital cost.

Figure (3-8): Headings/ Remarks data

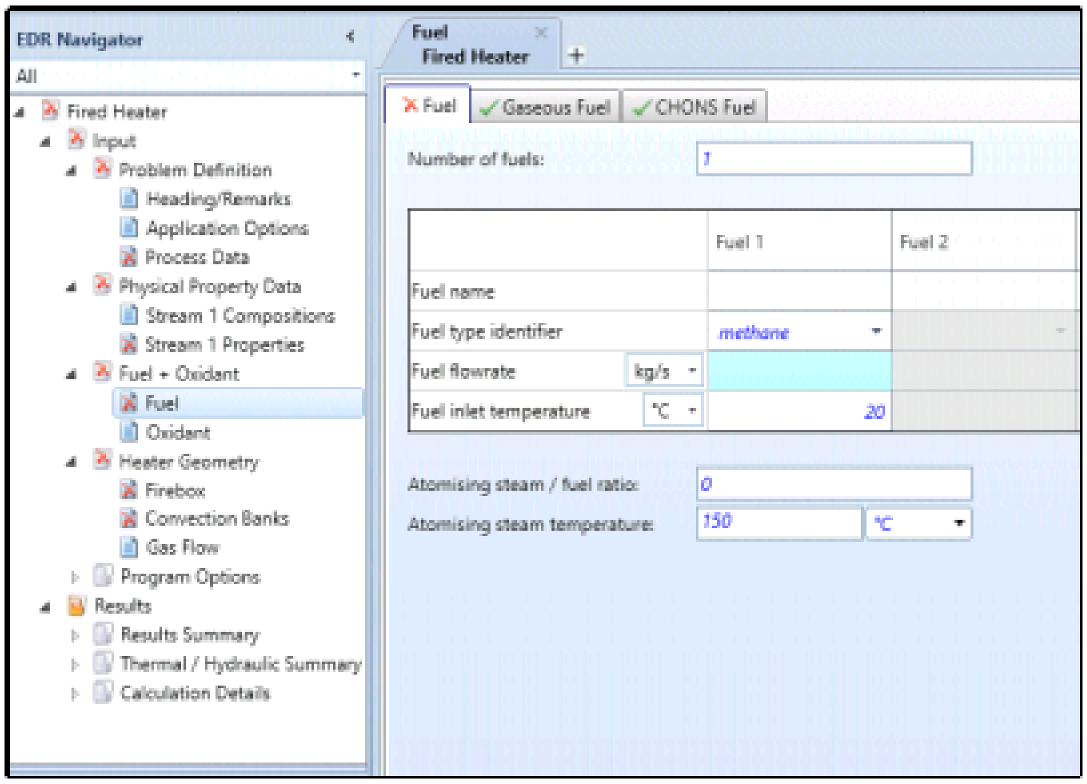


		Stream 1	Stream 2
Stream name		1	
Total mass flow	kg/s		
Inlet temperature	°C		
Outlet temperature	°C		
Inlet vapor mass fraction			
Outlet vapor mass fraction			
Pressure drop calculation option		Predict outlet pre	
Inlet pressure (abs)	bar		
Outlet pressure (abs)	bar	0	
Esimated pressure Loss	bar	0	
Minimum pressure	bar	0.1	
Heat load	kW		
Fouling resistance	m^2-K/W	0	

Figure (3-9): Process data

Figure (3-10): Stream 1 properties data

-After that fuel+ oxidant has been opened theses section contain two type of data the first one is the data about fuel used, this type contains three categories. the data of each category must be complete.



Number of fuels: 1

		Fuel 1	Fuel 2
Fuel name			
Fuel type identifier		methane	
Fuel flowrate	kg/s		
Fuel inlet temperature	°C	20	

Atomising steam / fuel ratio: 0

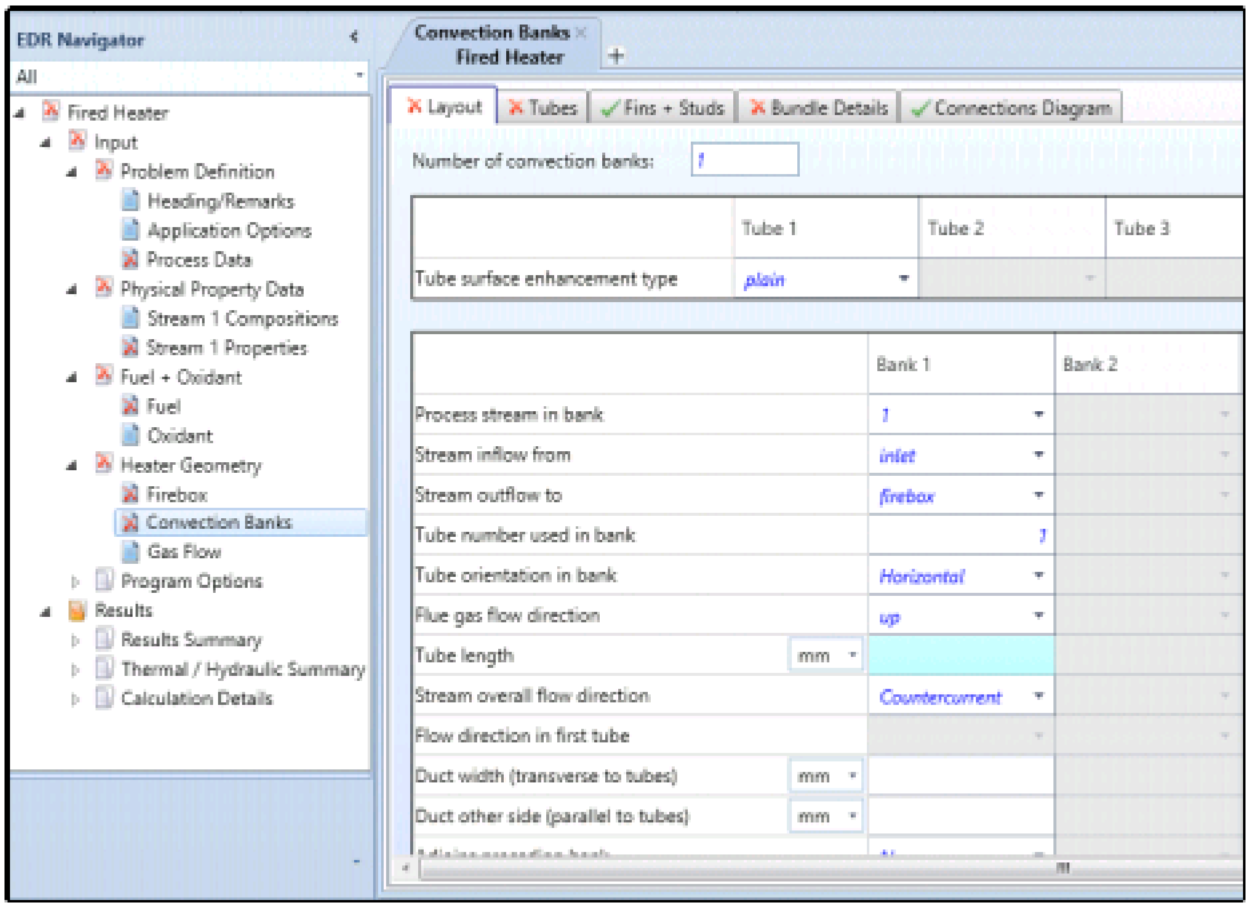
Atomising steam temperature: 150 °C

Figure (3-12): Oxidant data

The last section is heater geometry this section contains three type of data. the first data is firebox this data contains (layout, main tube rows, roof tube rows, tube details, gas offtake and firebox diagram) data of each one must be entered.

Figure (3-13): Firebox data

-The Second type of data is convection bank, this data contains (layout, tube, fins + studs, bundle detail, connection diagram).



Number of convection banks: 1

	Tube 1	Tube 2	Tube 3
Tube surface enhancement type	plain		

		Bank 1	Bank 2
Process stream in bank		1	
Stream inflow from		inlet	
Stream outflow to		firebox	
Tube number used in bank		1	
Tube orientation in bank		Horizontal	
Flue gas flow direction		up	
Tube length	mm		
Stream overall flow direction		Countercurrent	
Flow direction in first tube			
Duct width (transverse to tubes)	mm		
Duct other side (parallel to tubes)	mm		

Figure (3-15): Gas flow data

Then run the program if no error appear that mean the furnace design is completely successful. So the furnace design is end the simulation environment has been entered and the EDR furnace has been imported to show the effect of nitrogen to oxygen ratio in the thermal efficiency.

The air enter to furnace was separated into two stream. stream one for oxygen and stream two for nitrogen then the two stream enter mixture. Spread sheet has been added to calculate the furnace efficiency at different nitrogen to oxygen ratio. and the simulation environment shown below.

Figure (3-16): Process flow sheet

3.5 Cost Estimation: -

Cost estimation is required for any industrial process and determination of the necessary investment is an important part of plant design project.

Cost estimation include the determination of:

1- Fixed cost (Capital cost, Installation cost, Transportation).
2- Operation cost:

-Utilities (electricity, fuel gas, compress air).

-Operator Labor.

-Maintenance Labor.

-Depreciation.

(3.6)

$$\text{Installation Cost} = 0.4 * \text{capital cost} \quad (3.7)$$

$$\text{Transportation} = 0.05 * \text{capital cost} \quad (3.8)$$

3.5.1.2 Operation cost: -

$$\text{Depreciation} = (\text{capital cost} * 0.9) / \text{anticipated life} \quad (3.9)$$

$$\text{Est. Downtime hr} = \text{no. days} * 24\ \text{hr} \quad (3.10)$$

$$\text{Est. Operating hr} = \text{no. days} * 24\ \text{hr} \quad (3.11)$$

$$\text{Total Available Hours/ Year} = \text{est. downtime} + \text{est. operation} \quad (3.12)$$

$$\text{Operator Labor} = \text{hr/furn/yr} * \text{price of hr} * \text{no.operater} \quad (3.13)$$

$$\text{Maintenance Labor} = \text{hrs/furn/yr} * \text{price of hr} * \text{no.operater} \quad (3.14)$$

Utilities: -

$$\text{Electricity} = \text{full load KW} * \text{Price of KW} \quad (3.15)$$

$$\text{Fuel gas} = \text{lb/hr} * \text{price of lb} \quad (3.16)$$

$$\text{Comp air} = \text{lb/hr} * \text{price of lb} \quad (3.17)$$

$$\text{Annual Furnace Operating Cost} = \text{Depreciation} + \text{electricity annual cost} + \text{fuel gas annual cost} + \text{compressed air c}$$
$$(3.18)$$

$$\text{Total cost} = \text{operation cost} + \text{fixed cost} \quad (3.19)$$

	/ *hr*	Net heating value *BTU/ Lb*
Methane	49.67	21500
Hydrogen	9.48	51600
Ethane	19.57	20420
Ethylene	3.12	20290
Propane	5.11	19930
Propylene	3.09	19690
Butane	1.93	19670
Butylene	0.92	19420
Pentane	0.84	19500
Nitrogen	1.38	0
Carbone monoxide	2.44	4345
Carbone dioxide	2.43	0
Hydrogen sulfide	0.0036	6550
Total	99.9836	

	0.5
$CO + 0.5O_2 \rightarrow CO_2$	0.5
$CH_4 + 2O_2 \rightarrow CO_2 + 2H_2O$	2
$C_2H_6 + 3.5O_2 \rightarrow 2CO_2 + 3H_2O$	3.5
$C_2H_4 + 3O_2 \rightarrow 2CO_2 + 2H_2O$	2
$C_3H_8 + 5O_2 \rightarrow 3CO_2 + 4H_2O$	5
$C_3H_6 + 4.5O_2 \rightarrow 3CO_2 + 3H_2O$	4.5
$C_4H_{10} + 6.5O_2 \rightarrow 4CO_2 + 5H_2O$	6.5
$C_4H_8 + 6O_2 \rightarrow 4CO_2 + 4H_2O$	6
$C_5H_{12} + 8O_2 \rightarrow 5CO_2 + 6H_2O$	8
$C_6H_{14} + 9.5O_2 \rightarrow 6CO_2 + 7H_2O$	9.5
$S + O_2 \rightarrow SO_2$	1
$H_2S + 1.5O_2 \rightarrow SO_2 + H_2O$	1.5

- From these data the thermal efficiency of DCU furnace in Khartoum refinery = 86.43%.

4.1.1.2 Effect of stack temperature and excess air on thermal efficiency: -

The effect of stack temperature has been examined and excess air on thermal efficiency and the results were found as shown in figure below.

Figure (4-1): Effect of excess air and stack temperature on efficiency

Inlet temperature	270 C°
Out let temperature	320 C°
Inlet vapor mass fraction	3%
Out let vapor mass fraction	40%
Flue gas:-	
Inlet temperature to convection section	290 C°
Ambient temperature	33.1 C°
Injection steam:-	
Mass flow rate	360 kg/Hr
Pressure	2.5 Mpa
Temperature	420 C°
Firebox:-	
Fire heater type	Twin box

)	3070

Convection bank:-

Process stream in bank	2	2
Stream inflow form	Bank2	Inlet
Stream out flow	Firebox	Bank1
Tube No. used in bank	1	1
Tube alienation in bank	Horizontal	Horizontal
Flue gas flow direction	Up	Up
Duct width(mm)	1553	1553
Duct other side(mm)	1553	1553
Tube length(mm)	15700	15700

Gas flow:-

Stack diameter at bottom	3070
Stack diameter at top	2800

Table (4-4): Inlet stream parameter

Item	Unit	Design thermal load		
Calculated thermal load	Kw	4755	682	25754
Name		Crude	steam	Heater feed
Flow	*Kg/hr*	123010	9650	162294
Inlet pressure	*Mpa*	0.9	1.25	2.85
Outlet pressure	*Mpa*	0.57	1.15	0.65
Inlet temperature	C°	270	191	366
Outlet temperature	C°	320	300	500

4.1.2.1 Effect of preheated air on thermal efficiency: -

Figure (4-2): Effect of preheated air on efficiency

4.1.2.2 Effect of nitrogen to oxygen ratio in furnace thermal efficiency.

The effect of nitrogen to oxygen ratio has been examined in HYSYS simulation environment and the result shown in figure below.

Figure(4-3):Effect of N_2/O_2 ratio

4.1.3 Cost estimation results:

Table (4-5): Cost estimation data

Capital Cost	1301300 $
Est. Downtime day	30 *day*
Est. Operating day	335 *day*
Anticipated life	20 *year*
Throughput	162300 *ton*/*hr*
Electricity full load	20397000 *kw*
Electricity price	0.13 $/*kw hr*
Fuel gas full load	2280.7 *lb*/*hr*

Compressed air full load	39630.5 lb/hr
Compressed air price	0.003$/$lb$
Number of furnace operator labor hour per year	8760 hr
Price of hour for operator labor	1.3$/$hr$
Number of operator labor	67 man
Number of furnace maintenance labor hour per year	8760 hr
Price of hour for maintenance labor	1.6$
Number of maintenance labor	19 man

Figure (4-4): Cost estimation by excel sheet

4.2 Discussions: -

The furnace efficiency has been put under light in this research as one of the important facilities in the refinery and for the fact that its consume a huge amount of fuel so huge amount of cost. The efficiency of DCU furnace in Khartoum refinery has been calculated using indirect method.

The results show that furnace efficiency is 86.43%. which indicates the furnace

Figure (4-5): Conventional furnace control scheme

A number of modifications can be made to this scheme. A common variation is a control scheme where the individual pass outlet temperatures are controlled to ensure a uniform outlet temperature Fig (4-5).

This scheme works fine as long as the service is not fouling. With coking or fouling services, it does not work satisfactory because it tries to reduce the flow in the pass that is cooked and the situation becomes even worse. The pass tends to coke even more at reduced flow.

Fluid flowing through the tubes should have an adequate pressure drop in the fired heater to ensure good fluid distribution in a multiple- pass heater.

Firing Controls – Two major parameters that should be controlled and monitored are:

-Fuel gas/ fuel oil pressure.

-Furnace draft.

Fuel Pressure control – One of the simplest schemes for controlling fuel pressure is shown in Fig (4-5). The feed output temperature controller provides the set point for the burner fuel pressure controller.

Figure (4-6): Balance draft control scheme

Closing the stack damper reduces the furnace draft. To adjust excess air, the stack damper must be adjusted in conjunction with the air registers. A step-by-step procedure to adjust the draft and excess air in balance draft furnaces is shown in Fig (4-6).

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