Matlab program computes thermal efficiency of fired heater

Hassan Al-Haj Ibrahim / *Mourhaf* Al-Qassimi

Abstract

Two basic methods are normally employed for the calculation and estimation of the thermal efficiency of fired heaters, viz. the direct and the indirect methods, where the net calorific value is used in the former and the gross calorific value is used in the latter. Two Matlab programmes based on these methods were written and applied for the calculation of the thermal efficiency of a crude oil heater. The results are presented in the form of Sankey diagrams.

Keywords

Fired heater · thermal efficiency

Hassan Al-Haj Ibrahim

Department of Chemical Engineering, Al-Baath University, P.O.Box 2468, Homs,, Syria
e-mail: hasahi@scs-net.org

Mourhaf Al-Qassimi

Department of Chemical Engineering, Al-Baath University, P.O.Box 2468, Homs,, Syria
e-mail: morhafqasimi@baath.shern.net

1 Introduction

The thermal efficiency of fired heaters is an important performance factor, particularly in view of the current trend of rising fuel costs. The successful design and operation of a fired heater must aim at the highest possible thermal efficiency with due regard to other performance and pollution considerations. On operating fired heaters, thermal efficiency is one of the most significant parameters that must be closely monitored by plant personnel.

Furnace thermal efficiency [1] is usually defined as the percent ratio of the total heat absorbed in a furnace to the total heat input, where the heat absorbed is calculated from the difference between the heat input and heat losses comprising both stack heat losses and radiation heat losses. The total heat input is the sum of the calorific value of the fuel (gross or net) and the sensible heat of all incoming streams including the combustion air, fuel and atomization steam (if used). The usual European practice is to calculate the thermal efficiency using the net or lower calorific value, while in the U.S.A. the calculation is mostly based on the gross or higher calorific value.

$$\text{Efficiency} = 100 \times \frac{\text{(Total heat input - Stack heat losses - Radiation heat loss)}}{\text{Total heat input}}$$

Radiation heat losses through furnace walls depend on the material composing the insulating refractory lining and its thickness. However, for an economically optimum insulating lining these losses are low. For furnaces of 10 MW or more, they range from 2 to 5% of the lower heating value. Radiation heat losses depend also on the size of the furnace, where greater heat losses are to be expected in small furnaces as the ratio between the walls area and the volume of the radiation section decreases with furnace size increase.

Heat losses are for the most part due to the hot flue gases discharged through the stack. They are a function of the flue gas flow rate and temperature. The flue gas flow rate increases with excess air, so the furnace should operate with the least possible excess air while ensuring at the same time complete combustion of the fuel. Operation with too little excess air may lead to unburned fuel losses that may be greater than the efficiency gained

by reducing the excess air. Incomplete combustion is undesirable not only on account of calorific value loss, but also because of fouling problems often associated with the unburnt fuel.

Flue gas temperature, on the other hand, is the main factor in furnace heat losses, and the thermal efficiency may be greatly improved if the flue gases are cooled before being discharged from the chimney. In order to cool the flue gases, a cold fluid must be available that needs to be heated. Flue gas cooling is limited, however, by corrosion problems caused by sulphuric acid condensation due to the presence of sulphur compounds in the fuels burned [2]. If the flue gases are cooled, excess air will no longer have any importance since all the heat transferred to the excess air will be recovered from it. If the fluid to be heated is at a temperature that is too high to give a sufficiently low flue gas temperature, i.e. a satisfactory thermal efficiency, either one of these two solutions may be used: (1) Steam production, which does not reduce fuel consumption, but is advantageous if the steam can be exploited, (2) Recycling the flue gas and utilizing its heat for preheating the combustion air. Preheating the combustion air allows a thermal efficiency of approximately 90% of the net calorific value, but this requires an air blower.

1.1 Methods for efficiency calculation

There are two main methods for determining efficiency: the input-output or direct method [2, 3] and the heat-loss or indirect method [4, 6]. In the input-output method, which is based on the ratio of useful output (heat absorbed by the heated fluid) to the heat input (i.e. fuel), accurate measurements of quantities of fuel, steam, air, fuel calorific value and flue-gas analysis are required. This is quite an elaborate procedure, where a couple of days may be required to stabilize the unit and ensure reliable readings.

The amounts of heat per unit U of fuel (weight (kg) or volume (m^3)) are as follows:

Heat In:
Fuel : NCV = Nett calorific value of fuel   kJ/U

H_{fuel} = sensible heat of fuel,   kJ/U

= $Cp_{fuel} \times (t_{fuel}-15)$

Combustion air: H_{air} = sensible heat of air   kJ/U

= $Cp_{air} \times (t_{comb}-15)$

Fuel atomization fluid (for liquid fuel when applicable):

H_{fluid} = sensible heat of atomization fluid   kJ/U

= $Cp_{fluid} \times (t_{fluid}-15)$

Therefore, the total heat input is the sum of the fuel NCV and the sensible heat of air, fuel and fuel atomization fluid (for liquid fuel when applicable). Namely:

Q_{input} = $m_{fuel} \times NCV + m_{fuel} \times H_{fuel} + m_{air} \times H_{air} + m_{fluid} \times H_{fluid}$

Heat Out:
Heat duty = heat absorbed by the heated fluid = Q_u kJ

Flue gases: The sensible heat of flue gases is determined from a summation of the enthalpy values for flue gases produced /unit of fuel, a step which would require the calculation of the flue gas components /unit of fuel.

$H_{fluegases}$ = Sensible heat of flue gases   kJ/U

= $Cp_{fluegases} \times (t_g-15)$

The flue gases are: CO_2, H_2O, SO_2, N_2 and excess O_2.

$m_{fluegases} = m_{CO_2} + m_{H_2O} + m_{N_2} + m_{O_2} + m_{SO_2}$

= $m_{fuel} + m_{air} + m_{atomizationfluid}$ (for liquid fuel applicable)

$Q_{fluegases}$ = $m_{fluegases} \times H_{fluegases}$ = $m_{fluegasses} \times Cp_{fluegases} \times (t_g- 15)$

$H_{unburnt}$ = calorific value of unburnt fuel (if any)   kJ/U

Losses through fired heater walls ,Q_{losses}

The radiation heat losses, Q_{losses}/kg of fuel is determined by multiplying the NCV by radiation loss expressed as a percentage. Generally this loss is between 2 and 5%.

Q_{losses} = percentage (2-5%) $\times m_{fuel} \times NCV$.

In general, the total heat output is the sum of the sensible heat of flue gases and the losses through fired heater walls.

Q_{output} = $Q_{fluegases} + Q_{losses}$

The useful energy or heat absorbed Q_u by the heated fluid can be written as:

$Q_u = Q_{input} - (Q_{fluegases} + Q_{losses})$

$Q_u = m_{fuel} \times NCV + m_{fuel} \times H_{fuel} + m_{air} \times H_{air} + m_{fluid} \times H_{fluid} - (m_{fluegases} \times Cp_{fluegases} \times (t_g- 15) + $ percentage (2-5%) $\times m_{fuel} \times NCV)$.

Therefore, the thermal efficiency of fired heater can be written as:

$$E = \frac{Q_u}{Q_{input}} \times 100 = \frac{Q_{input} - Q_{output}}{Q_{input}} \times 100$$

The molar Heats at constant pressure for air and flue gases are given in Table 1 [7]:

Tab. 1. Molar heats at constant pressure for air and flue gases:

Gas	Molar heat (kJ / kmol .deg.)	Temperature Range
Air	$33.915 + 1.214 \times 10^{-3} \times T$	50-1500 K
CO_2	$43.2936 + 0.01147 \times T - 818558.5/T^2$	273-1200 K
N_2	$27.2155 + 4.187 \times 10^{-3} \times T$	300-3000 K
O_2	$34.63 + 1.0802 \times 10^{-3} \times T - 785900/T^2$	300-5000 K
SO_2	$32.24 + 0.0222 \times T - 3.475 \times 10^{-6} \times T^2$	300-2500 K
$H_2O_{(g)}$	$34.42 + 6.281 \times 10^{-4} \times T + 5.611 \times 10^{-6} \times T^2$	300-2500 K

The main advantages of the direct method can be summarized in four points, namely:

1 It is a quick and easy method for assessing the efficiency of fired eaters.

2 It requires few parameters for computation.

3 It needs few instruments for monitoring

4 It makes it easy to compare evaporation ratios with benchmark figures.

Its disadvantages on the other hand are that there is no break-down of losses by individual streams, and no clues are provided as to why the efficiency of the system is lower.

1.2 The Indirect Method for determining the fired heater efficiency

The indirect method, also called the heat loss method, is based largely upon the direct method in the sense that all inputs are calculated, and from this certain percentages of losses occur in combustion, radiation, flue gas etc, which can be subtracted from the total of 100%. With this method it is possible to gain insight where the losses in efficiency occur and then be able to reduce these losses to increase the efficiency .The efficiency can be calculated by subtracting the heat loss fractions from 100 as follows:

The ASME Power Test Code heat method is used to determine the losses, the features of which are [5]:

Efficiency is computed on both GCV and NCV basis.

Effect of relative humidity is considered.

Heat loss can be inputted if known

Unaccounted-for losses also can be inputted.

Up to 19 constituents can be handled if gaseous fuel is used.

Only the fuel analysis need be inputted, the calorific values and flue gas analysis are computed.

If the duty by the fluid is given, the total fuel, air and flue gas quantities are obtained.

Various losses are itemized on GCV basis.

The data required for the calculation of fired heater efficiency using the indirect method are:

Ultimate analysis of fuel (H, O ,S ,C, N), moisture content and ash content.

Percentage of oxygen or CO_2 in flue gas.

Flue gas temperature.

Ambient temperature and humidity of air in kg/kg of dry air

GCV of fuel

Percentage of combustible in ash (in case of solid fuels)

GCV of ash (in case of solid fuels)

A detailed procedure for calculating fired heater efficiency using the indirect method is given below [4,5, 6].

Step 1: Calculate the theoretical air requirement :

Theoretical air requirement

= [(11.43×C)+{34.5×(H_2-O_2/8)}+(4.32×S)]/100 kg/kg of fuel

Step 2: Calculate the percentage excess air supplied (EA) :

$$EA = \frac{O_2 \times 100}{(21 - O_2\%)}$$

Step 3: Calculate actual mass of air supplied /kg of fuel (AAS)

AAS = (1+EA/100)×theoretical air

Step 4: Estimate all heat losses:

The following equations are used to determine the losses in a fired heater after combustion calculations are performed.

1 Dry gas loss, L_1=100×M_{dg}×0.96×(t_g-t_a)/GCV %endenumerate Where: M_{dg}= mass of dry products of combustion/kg of fuel)+(mass of N_2 in fuel on 1 kg basis)+(mass of N_2 in actual mass of air supplied)

2 Percentage heat loss due to evaporation of moisture present in fuel.

L_2=100×M_{moist}×(2445.21+1.88×(tg-ta)/GCV

1 Loss due to moisture formed due to combustion of H_2.
L_3=100×9×H_2×(2445.21+1.88×(t_g- t_a)/GCV

Where 9×H_2 for fuel oil. For gases it must be calculated

1 Loss due to moisture in air supplied.
L_4=100×1.88×humidity factor ×AAS× (t_g-t_a)/GCV

2 Unburned fuel loss, L_5: This is a figure based on experience, excess air used, type of furnace, burner design, unit size, etc. Poor design or combustion results in a lot of unburned fuel, especially coal, to go along with ash to the bottom of the heater or to be carried away with flue gases. This is normally nil for oil and gaseous fuels, but for coals it varies from 0.25 to 1.0%. However, field data from similar units give good guidance.

3 Loss due to radiation, L_6: Since it is impossible to prevent any insulated surface from radiating energy to a lower-temperature source such as ambient air, some losses are inevitable. Heater surfaces, although insulated, are 15 to 25 ^{o}C above ambient temperature. ABMA has published a chart that gives the radiation losses [5].

4 Unmeasured losses, L_7: Each manufacturer must take care of certain normally unmeasured losses. CO formation leads to some losses, though low. Ash in the ash pit and flue gases is heated to the temperature at the pit and the stack temperature respectively by the energy in the fuel, which is a loss.

If CO is formed instead of CO_2, it is a loss of 24,656 kJ/kg. This is the difference between the heat of reactions of : C + O_2 → CO_2 and C + $^1/_2$ O_2 → CO. Loss due to CO formation L_6 is given by:

$$L_7 = \frac{CO}{CO + CO_2} 5 \times 10,160 \times C$$

The thermal efficiency can be calculated by substracting the heat loss fractions from 100 as follows:

Efficiency of furnace (fired heater) E =100-(L1+L2+L3+L4+L5+L6+L7)

The main advantage of the indirect method is that a complete mass and energy balance can be obtained for each individual stream, which makes it easier to identify options to improve fired heater efficiency. Its disadvantages include the time consumed and the laboratory facilities required for analysis.

The Sankey Diagram and its Use[9, 10]:

Sankey diagrams summarise all the energy transfers taking place in a process. The thicker the line or arrow, the greater the amount of energy involved.

Sankey diagrams are widely used in technology where material and energy balances have to be visualized. The flow rates and quantitative relations of a process can thus be visually created. The end result is thorough understanding of all the process steps and their interrelationship. Sankey diagrams have proven to be an outstanding tool in environmental technology projects for analyzing material and energy related problems.

The sankey diagram is a very useful tool for representing an entire input and output energy flow in any energy equipment or system such as boilers, fired heaters and furnaces after carrying out energy balance calculation.

The first consideration for the preparation of the diagram is to determine its basis. Typically a basis is selected as the flow rate of the quantity under consideration, such as the fuel input. Later, the flow streams are drawn where two parallel lines whose distance apart is proportional to the flow rate represent a stream.

Application of the above described methods:

Using computer programmes greatly simplify the procedure for the computations involved in both methods for thermal efficiency calculation. Some computer programmes are available in the literature [8], written in Basic, but no programmes exist in other more advanced computer languages. In this paper, two programs written in Matlab [11] are given for the calculation of heater efficiency based on the two methods available for its calculation, the direct and the indirect methods. The first program (Appendix 1), based on the indirect method, may be used to calculate all heat losses and the thermal efficiency for all types of fuel. The second programme (Appendix 2) is based on the direct method and may be used to calculate complete energy balance for all types of fuel also.

Two examples are given below in order to illustrate the use of the programmes.

Example 1

Liquid fuel is fired with 40% excess air in a fired heater .Ambient temperature $=15°C$, exit gas temperature $= 446°C$ and relative humidity is 40%

Heater name: Crude oil heater Type : Horizontal, box-type.

Service: Heating of crude oil in an atmospheric distillation unit.

Fuel : Fuel oil.

Ultimate analysis of fuel oil is (by weight): 83% C, 10% H, 5% S, 1% N and 1% O.

Flow rate of fuel (kg/h) :12000

Sp. gr. of fuel at 15°C/ 15°C : 0.969

Temperature on burner inlet ° C: 100~120°C

Tab. 2. Data for example 1

Nett Calorific Value of fuel,	kJ/kg	38520.4
flow rate of fuel,m1	kg/h	12000
specific heat of fuel,	kJ/kg.K	1.7
flow rate of steam, m2,	kg	4200
Enthalpy of steam,	kJ/g	2777
Mass of flue gas, m3,	kg	239165.73
Mass of Wet air,	kg	222965.572
percentage of excess air	%	0.4
humidity of air, kg of water vapor/kg of wet air		0.4
molar fraction of water is equivalent to humidity of air		.015
Mass fraction of CO_2,XCO_2		.1527
Mass fraction of H_2O,XH_2O		.0715
Mass fraction of O_2,XO_2		.062
Mass fraction of N_2,XN_2		.709
Mass fraction of SO_2,XSO_2		$.502 \cdot 10^{-2}$
temperature of combustion air	˚C	40
temperature of fuel	˚C	25
flue gas temperature	˚C	446

Tab. 3. Results for example 1

Heat value of fuel	4.62e+008	kJ/h
sensible heat of fuel	2.04e+005	kJ/h
sensible heat of wet air	6.60e+006	kJ/h
sensible heat of steam	1.17e+007	kJ/h
Energy Input	4.81e+008	kJ/h
Sensible Heat of Combustion gases	1.03e+008	kJ/h
Heat Losses	2.31e+007	kJ/h
Useful Energy	3.55e+008	kJ/h
thermal efficiency	73.81	%

NCV (kJ/kg) : 38456

Flow rate of air (kg/h) : 222965.572

Humidity of air : 40 kg of water /kg of air

Excess air % : 40%

Superheated steam for atomization of fuel oil at 8.5 bar and 190° C, flow rate: 4200 kg/h

Flue gas temperature : 446˚C

Running the program. In the RUN mode, the screen asks for the selection of the type of fuel used in the heater. To select fuel oil, INPUT (a =1) for the selection of fuel oil and INPUT (a=2) for selecting fuel gas.

For fuel oil, the screen asks for data as shown in Table 1. The results are shown in Table 2.

For fuel gas, the screen asks for data as shown in Table 3 .The results are shown in Table 4.

Example 2

Fuel gas is fired with 25% excess air in a fired heater. Ambient temperature =15˚C , exit gas temperature =446˚C and relative humidity is 40%
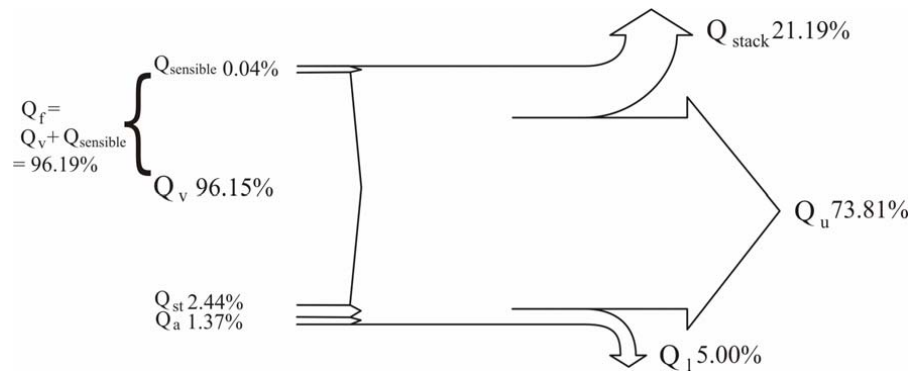
Heater name: Crude oil heater.

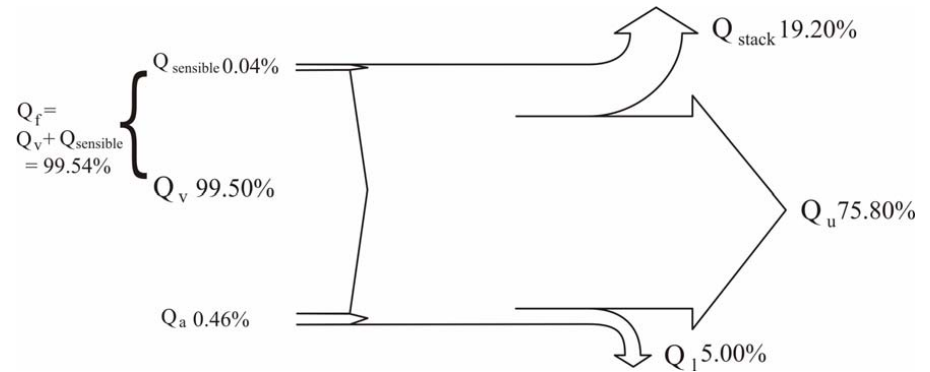Type: Horizontal, box-type .

Service: Heating of crude oil for distillation.

Fuel: Natural gas .

Fig. 1. Sankey diagram for the energy balance of a fired heater, where fuel oil is used.

$Q_f =$
$Q_v + Q_{sensible}$
$= 96.19\%$

$Q_{sensible}\ 0.04\%$

$Q_v\ 96.15\%$

$Q_{st}\ 2.44\%$
$Q_a\ 1.37\%$

$Q_{stack}\ 21.19\%$

$Q_u\ 73.81\%$

$Q_l\ 5.00\%$

Fig. 2. Sankey diagram for the energy balance of a fired heater, where fuel gas is used

$Q_f =$
$Q_v + Q_{sensible}$
$= 99.54\%$

$Q_{sensible}\ 0.04\%$

$Q_v\ 99.50\%$

$Q_a\ 0.46\%$

$Q_{stack}\ 19.20\%$

$Q_u\ 75.80\%$

$Q_l\ 5.00\%$

Tab. 4. Data for example 2

Nett calorific value of fuel, kJ/Kmol	927844.41
Molar heat of gas fuel, kJ/Kmol.K	39.26
Molar flow rate of gas fuel Kmol/h	120
Molar flow rate of entering air to fired heater, Kmol/h	1589.014
Molar flow rate of combustion gases exiting from stack, Kmol/h	1720.9
percentage of excess air	.25
humidity of air, kg of water vapor/kg of wet air	0.4
molar fraction of water is equivalent to humidity of air =:	.015
Molar fraction of CO_2, XCO_2=	.08234
Molar fraction of H_2O, XH_2O=	.15968
Molar fraction of O_2, XO_2=	.0382
Molar fraction of N_2, XN=	.7197
Molar fraction of SO_2, XSO_2	6.276×10^{-5}
temperature of combustion air	25
temperature of burner fuel	25
flue gas temperature	446

Combustion of fuel : 80.43 % CH_4 , 9.02 % C_2H_6 , 4.54 % C_3H_8 , 0.20 % iso-C_4H_{10} , 0.32 % n-C_4H_{10} , 0.04 % iso-C_5H_{12} , 0.04 % n-C_5H_{12} , 3.61 % CO_2 and 1.73 % N_2

NCV(kJ / kmol) : 927844.41

Excess air% : 25%

Temperature on burner inlet : 100∼120°C

Flue gas temperature : 446°C

For both types of fuel, the energy balance for the entire system is summarized in Sankey diagrams (Fig. 1 for fuel oil and Fig. 2 for gas oil). The values are shown as percentages of the total energy released by the combustion of the fuel in the furnace.

Tab. 5. Results for example 2

Heat value of fuel	1.11e+008	kJ/h
Sensible Heat of fuel	3.93e+002	kJ/h
Sensible Heat of air	5.39e+005	kJ/h
Sensible Heat of Combustion gases	2.15e+007	kJ/h
Heat Losses	5.57e+006	kJ/h
Energy Output	2.71e+007	kJ/h
Useful Energy	8.48e+007	kJ/h
thermal efficiency = 75.78	%	

2 Conclusions

This paper presents a review of the methods used in the calculation of the thermal efficiency to predict fired heater efficiency.

The paper is divided into two parts. The first part concentrates on a description of thermal efficiency methods, with special attention given to the direct method, and how to prepare a Sankey diagram in order to determine energy balance (input and output heat) for fired heaters, the thermal efficiency is then calculated .

The second part deals with the indirect method for calculating the thermal efficiency of fired heaters, for which a basic program was previously written and published [8]. In this paper a Matlab programme is written for both the direct and the indirect methods. Nowadays, programming by Matlab is widely used in all scientific fields and in engineering sciences in particular.

However, the use of the direct method to calculate the thermal efficiency is to be preferred due to its many advantages. It also requires no laboratory facilities or analysis. Furthermore, the time required for the computations involved is much less than that for the indirect method.

Nomenclatures:

AAS	Actual mass of air supplied
Cp air	Molar heat of air (kJ/kmol.deg.).
Cp_{CO2}	Molar heat of carbon dioxide (kJ/kmol.deg.).
Cp_{fuel}	Molar heat of fuel (kJ/kmol.deg.)
Cp_{H2O}	Molar heat of (H_2O) in gas phase (kJ/ kmol .deg.).
Cp_{O2}	Molar heat of oxygen (kJ/kmol.deg.).
Cp_{SO2}	Molar heat of sulphur dioxide (kJ/kmol.deg.)
CO', CO_2', O_2', N_2'	% carbon monoxide, carbon dioxide, oxygen, and nitrogen in flue gas by volume (without the prime, they stand for the gas)
E	Thermal efficiency %.
GCV	Higher heating Value or gross calorie value (kJ/kg).
H_{air}	Sensible heat of air
H_{fluid}	Sensible heat of atomization fluid
H_{fuel}	Sensible heat of fuel
$H_{fluegases}$	Sensible heat of flue gases
Humidity factor	Moisture in air
L1	Dry gas loss %
L2	Loss due to moisture in fuel %
L3	Loss due to combustion
L4	Loss due to moisture in air supplied
L5	Unburned fuel loss %
L6	Loss due to radiation
L7	Unmeasured losses %
M moist	% moisture in 1 kg fuel
M_{dg}	Dry flue gases produced (Mass of dry flue gas in kg /kg of fuel)
NCV	Lower heating value or net calorie value (kJ/kg) .
$Q_{fluegases}$	Calculated stack heat losses (kJ/h)
Q_{losses}	Assumed radiation heat loss (kJ/h)
Q_u	Heat duty or useful heat (kJ/h)
t_a	Ambient temperature (^oC) .
$t_{comb.}$	Combustion air temperature (^oC)
t_{fuel}	Fuel temperature (^oC) .
t_g	Flue gas temperature (^oC) .

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Appendix 1: The indirect method programme for determining the thermal efficiency for fired heaters

```
function indirectmethod=indirectefficiency
% The indirect Method for determining the
thermal efficiency of fired heat
% Input :
% The required data for calculation of fired
heater efficiency...
% by using the direct method are :
% Ultimate analysis of fuel (H, O, C, S),
moisture content and ash content
% Percentage of Oxygen or CO2 in flue gas
% Flue gas temperature tf in C
% Ambient temperature ta in C
% Humidity of air in kg/kg of dry air
% Gross calorific value of fuel in kJ/kg (GCV)
% Mass of dry flue gas in kg/kg of fuel
% Output :
% L1 percentage heat losses due to dry flue gas
% L2 Heat loss to evaporation of water formed
...
% due to H2 in fuel
% L3 Heat loss due to moisture present in air
% L4 Percentage heat loss due to evaporation of
moisture present if fuel
% moisture present if fuel
% L5 Percentage heat loss due to radiation and
other unaccounted loss ...
```

```matlab
% for a fired heater, These losses are between
2% and 5%
% Thermal efficiency of fired heater
tf=input('Flue gas temperature in C,tf=:');
ta=input('Ambient temperature in C,ta=:');
GCV=input('Gross Calorific Value of fuel,
kJ/kg=:');
H=input('percentage of H in fuel by weight,
H=');
C=input('percentage of C in fuel by weight,
C=');
O=input('percentage of O in fuel by weight,
O=');
S=input('percentage of H in fuel by weight,
S=');
M=input('moisture content in 1 kg of fuel,
M=:');
mfuel=input('mass of fuel supplied, (mfuel)=:');
h=input('humidity of air, h=:');
% calculate the theoretical air requirement
air=((11.43*C) + (34.5*(H-O/8)) + (4.32*S))/100
% calculate the % excess air supplied (EA)
EA=O*100/(21-O)
% calculate actual mass of air supplied /kg of
fuel (AAS)
AAS=(1+EA/100)*air
% calculate mass of dry flue gas in kg /kg of
fuel
% m(total of lue gas)=mass of actual air
supplied(ASS) + ...
% mass of fuel supplied (mfuel)
m=AAS + mfuel
% Output :
% Estimate all heat losses
% percentage heat losses due to dry flue gas
L1=m*0.96*(tf-ta)*100/GCV;
fprintf('percentage heat losses due to dry flue
gas %10.2e kJ/h\n',L1)
% Heat loss to evaporation of water formed due
to H2 in fuel
L2=0.09*H*(2445.2+1.884*(tf-ta))*100/GCV;
fprintf('Heat loss due to evaporation of water
formed due to H2 in fuel %10.2e kJ/h\n',L2)
% Heat loss due to moisture present in air
L3=AAS*h*1.9*(tf-ta)*100/GCV ;
fprintf('Heat loss due to moisture in air %10.2e
kJ/h\n',L3)
% Percentage heat loss due to evaporation of
moisture present in fuel
L4=M*(2445.21+1.8842*(tf-ta))*100/GCV;
fprintf('Heat loss to evaporation of water
formed due evaporation of moisture present in
fuel %10.2e kJ/h\n',L4)
```

```matlab
% Percentage heat loss due to radiation and
other unaccounted loss ...
% for a fired heater, these losses are between
2% and 5%
L5=5;
fprintf('Heat losses due to radiation and other
unaccounted loss %10.2e kJ/h\n',L5)
% calculate thermal efficiency by indirect
method
E=100 - (L1+L2+L3+L4+L5);
fprintf('thermal efficiency %8.2f %%\n',E)
```

Appendix 2 : The direct method programme for determining the thermal efficiency for fired heaters

```matlab
function directmethod=directeficiency
% The direct Method for determining the thermal
efficiency
% Input :The data required for calculation of
fired heater efficiency ...
% using the direct method are:
% Temperature of fuel tf
% Flow rate of fuel
% Temperature of combustion air ta
% percentage of exsess air
% Humidity of air
% Flue gas temperature tg
% Net Calorific Value (NCV)of fuel
% output:
% Thermal Efficiency
char('if you use liquid fuel then let
s(select)=1 or if you use gas fuel then
s(select)=2')
a=input('if you use liquid fuel then let
[a=(select)=1] or of you use gas fuel then
[a=(select)=2]')
if a==1
NCV=input('Nett Calorific Value of fuel,
kJ/kg=:');
m1=input('flow rate of fuel, m1=kg/h:');
Cpf=input('specific heat of fuel,=kJ/kg.K:');
m2=input('flow rate of steam, m2, kg=:');
Hs=input('Enthalpy of steam, kJ/g=:');
m3=input('Mass of flue gas, m3, kg=:');
mairwet=input('Mass of Wet air, kg=');
airper=input('percentage of excess air=:');
hum=input('humidity of air, kg of water vapor/kg
of wet air=:');
Xh=input('molar fraction of water is equivalent
to humidity of air =:');
% Input :Composition of flue gas
xc=input('Mass fraction of CO2,Xco2=');
xh=input('Mass fraction of H2O,XH2O=');
xo=input('Mass fraction of O2,Xo2=');
```

```matlab
xn=input('Mass fraction of N2,XN=');
xs=input('Mass fraction of SO2,Xso2=');
td=15; % Datum temperature
ta=input('temperature of combustion air, C=:');
tf=input('temperature of fuel, C=:');
tg=input('flue gas temperature, C=:');
% Energy balance of furnace
% Energy input
Qv=m1*NCV; % heating value of fuel
fprintf('Heat value of fuel is %10.2e
kJ/h\n',Qv)
Qseniseble=m1*Cpf*(tf-15); % Sensible heat of
fuel
fprintf('sensible heat of fuel is %10.2e
kJ/h\n',Qseniseble)
Qf=Qseniseble + Qv;
% Calculation of Molecular weight of wet air
Mwair=(1-Xh)*28.84 + Xh*18;
Mair=mairwet/Mwair; % Molar mass of wet air
Cpa=33.915 + 1.214*10^(-3)*(ta + 15)/2 ; % Molar
heat of dry air
% Molar heat of water as humidity in air
Cphum = 34.42 + 6.281*10^(-4) * (ta+15)/2 +
5.6106 * 10^(-6) * ((ta+15)/2)^2 ;
Ha=((1-Xh)*Cpa+Xh*Cphum) *(ta-15); % Enthalpy of
wet air
Qa=Mair*Ha;
fprintf('sensible heat of wet air is %10.2e
kJ/h\n',Qa)
% Sensible of steam at 8.5 bar and 190 C
Qs=m2*Hs;
fprintf('sensible heat of steam %10.2e
kJ/h\n',Qs)
Qin=Qf + Qa + Qs;
fprintf('Energy Input is %10.2e kJ/h\n',Qin)
% Energy output
% Molar heat of CO2
Cpco2=43.2936 + 0.0115*(tg+15)/2 -
818558.5/((tg+15)/2)^2;
Nco2=xc*m3/44;
% Sensible heat of carbon dioxide
HCO2=Nco2*Cpco2*(tg-15);
% Molar heat of O2
Cpo2=34.627 + 1.0802*10^(-3)*(tg+15)/2 -
785900/((tg+15)/2)^2 ;
No2=xo*m3/32;
% Sensible heat of excess O2
HO2=No2*Cpo2*(tg-15);
% Molar heat of N2
Cpn2=27.2155 + 4.187*10^(-3) * (tg+15)/2 ;
NN2=xn*m3/28;
% sensible heat of N2
HN2=NN2*Cpn2*(tg-td);
% Molar heat of H2O
Cph2o=34.417 + 6.281*10^(-4)*(tg+15)/2 -
5.611*10^(-6) * ((tg+15)/2)^2 ;
NH2O=xh*m3/18;
% Sensible heat of H2O
HH2O=NH2O*Cph2o*(tg-15);
% Molar heat of SO2
Cpso2=32.24 + 0.0222*(tg+15)/2 -
3.475*10*10^(-6) * ((tg+15)/2)^2 ;
Nso2=xs*m3/64;
% Sensible hear of SO2
HSO2=Nso2*Cpso2*(tg-15);
Qstack=HCO2 + HO2 + HN2 + HH2O + HSO2;
fprintf('Sensible Heat of Combustion gases is
%10.2e kJ/h\n',Qstack)
% Percentage heat losses due to radiation and
other unaccounted loss ...
% for a fired heater, These losses are between
2% and 5%
% Ql=percentage of heating value of fuel
Ql=0.05*m1*NCV;
fprintf('Heat Losses is %10.2e kJ/h\n',Ql)
Qout=Qstack + Ql;
% The useful energy or heat absorbed by heated
fluid
Qu=Qin - (Qstack + Ql);
fprintf('Useful Energy is %10.2e kJ/h\n',Qu)
% calculation of thermal efficiency
E=100*Qu/Qin;
fprintf('thermal efficiency %8.2f %%\n',E)
end
if a~=1
NCV=input('Nett calorific value of fuel,
kJ/Kmol=:');
Cpf=input('Molar heat of gas fuel,=kJ/Kmol.K:');
n1=input('Molar flow rate of gas fuel
Kmol/h=:');
n2=input('Molar flow rate of entering air to
fired heater, Kmol/h=:');
n3=input('Molar flow rate of combustion gases
exiting from stack,Kmol/h=:');
airper=input('percentage of excess air=:');
hum=input('humidity of air, kg of water vapor/kg
of wet air=:');
Xh=input('molar fraction of water is equivalent
to humidity of air =:');
% Input :Composition of flue gas
XCO2=input('Molar fraction of CO2,Xco2=');
XH2O=input('Molar fraction of H2O,XH2O=');
XO2=input('Molar fraction of O2,Xo2=');
XN2=input('Molar fraction of N2,XN=');
XSO2=input('Molar fraction of SO2,Xso2=');
td=15; % Datum temperature ©
```

```
ta=input('temperature of combustion air, c=:');
tf=input('temperature of burner fuel, c=:');
tg=input('flue gas temperature, c=:');
% Energy balance of furnace
% Energy input
Qv=n1*NCV ; % heating value of fuel
fprintf('Heat value of fuel is %10.2e
kJ/h\n',Qv)
Qsensible=Cpf*(tf-15); % Sensible heat of fuel
fprintf('Sensible Heat of fuel is %10.2e
kJ/h\n',Qsensible)
Qf=Qv + n1*Qsensible;
% Calculation of Molecular weight of wet air
Mwair=(1-Xh)*28.84 + Xh*18;
% Molar heat of dry air
Cpa=33.915 + 1.214*10^(-3)*(ta+15)/2;
% Molar heat of water as humidity in air
Cphum=34.42 + 6.281*10^(-4) *
(ta+15)/2+5.6106*10^(-6) * ((ta+15)/2)^2 ;
% Sensible heat of wet air
Ha=((1-Xh)*Cpa+Xh*Cphum)*(ta-15);
Qa=n2*Ha;
fprintf('Sensible Heat of air is %10.2e
kJ/h\n',Qa)
Qin=Qf + Qa;
% Energy output
% Molar heat of CO2
CpCO2=43.2936 + 0.0115*(tg+15)/2 -
818558.5/((tg+15)/2)^2;
QCO2=XCO2*n3*CpCO2*(tg-15);
% Molar heat of O2
CpO2=34.627 + 1.0802*10^(-3) * (tg+15)/2 -
785900/((tg+15)/2)^2 ;
QO2=XO2*n3*CpO2*(tg-15);
% Molar heat of N2
CpN2=27.2155 + 4.187*10^(-3)*(tg+15)/2 ;
QN2=XN2*n3*CpN2*(tg-15);
% Molar heat of H2O
CpH2O=34.417 + 6.281*10^(-4)*(tg+15)/2 -
5.611*10^(-6)*((tg+15)/2)^2 ;
QH2O=XH2O*n3*CpH2O*(tg-15);
% Molar heat of SO2
CpSO2=32.24 + 0.0222*(tg+15)/2 -
3.475*10^(-6)*((tg+15)/2)^2 ;
QSO2=XSO2*n3*CpSO2*(tg-15);
Qstack=QCO2 + QO2 + QN2 + QH2O + QSO2;
fprintf('Sensible Heat of Combustion gases is
%10.2e kJ/h\n',Qstack)
% Percentage heat losses due to radiation and
other unaccounted loss ...
% for a fired heater, These losses are between
2% and 5%
Ql=0.05*n1*NCV;
fprintf('Heat Losses is %10.2e kJ/h\n',Ql)
Qout=Qstack + Ql;
fprintf('Energy Output is %10.2e kJ/h\n',Qout)
% The useful energy or heat absorbed by heated
fluid
Qu=Qin - Qout;
fprintf('Usful Energy is %10.2e kJ/h\n',Qu)
% calculation of thermal efficiency
E=100*Qu/Qin;
fprintf('thermal efficiency %8.2f %%\n',E)
end
```