Componentwise Thermodynamic Analysis of Thermal Power Plant by Designed Software

Ankur Geete
Mechanical Engineering Department, S. D. Bansal College of Technology, Indore, Madhya Pradesh, India
Email: ankur_geete@yahoo.co.in

***Abstract*—This research work is based on 120MW thermal power plant which has five major components. The components are–steam turbine, condenser, feed water heaters and boiler. Each component is having its own importance and it effects the performance of power plant. In this research work component wise thermodynamic/exergy analysis is done. For analysis, more general software is designed. By this software, thermodynamic/exergy analysis is performed at different inlet pressure conditions of steam and identified conditions at which the performance of the plant is best. This software also helps to develop correction factor curves for power and heat rate at different inlet pressure conditions.**

***Index Terms*—software, exergy analysis, net power, heat rate and Inlet pressure**

I. Introduction

Layout of 120MW thermal power plant [1] is shown in Fig. 1.

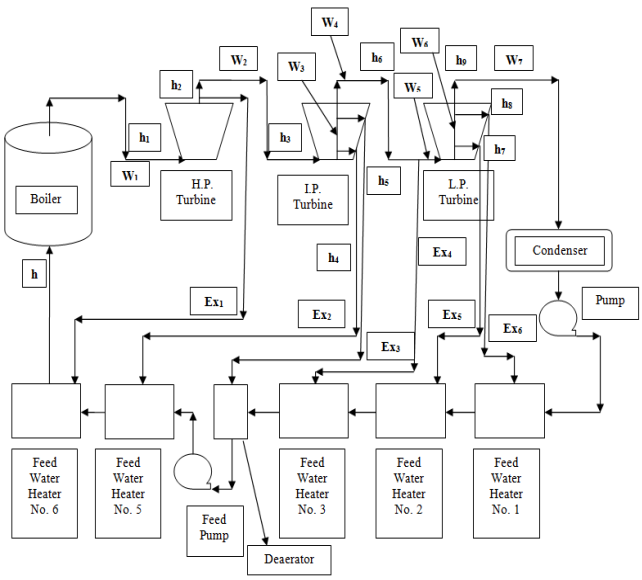

Figure 1. Block diagram of 120MW thermal power plant

In this thermal power plant, high pressure and temperature (125.10 bar and 537.78 ℃) steam is generated and then enters into HP turbine. In HP turbine steam is expanded and some amount of steam is extracted for feed water heating process for heater number 6. After that, steam is reheated and then enters into IP turbine. In IP turbine, steam is expanded and some amount of steam is extracted from two extraction points for feed water heater number 5 and deaerator respectively. After expansion in IP turbine, steam is again extracted for feed water heater 3. Then finally steam enters into LP turbine where it is expanded and steam is again extracted from two extraction points for feed water heater number 2 and feed water heater number 1 respectively. Then wet steam is condensed and converted into water in condenser. After heating in different feed water heaters, water enters again into the boiler with the help of feed water pump [1]. Some important terms which are used during analysis of power plant–**(1) Correction factor**–it is the ratio of designed output to actual output. Example–correction factor for power is the ratio of designed power to actual power output (net power) [1]. **(2) Flow function**-it shows the relation between mass flow rate, specific volume and inlet pressure. It is used by plant engineers to calculate different mass flow rates at different inlet pressure conditions [1]. **(3) Net power**–it is the actual power which will be achieved at particular condition. And generally, it is rate of doing work [1]. **(4) Heat rate**–it is the ratio of total heat addition in the boiler to net power. This term is used to analyze the performance of the power plant [2]. **(5) Exergy or available energy**-it can be defined as energy which is available or it can also be defined as the maximum useful work output from a system [3]. **(6) Anergy or unavailable energy**-during the operation some amount of energy is rejected into the surrounding and this energy cannot be converted into work; this is called unavailable energy [3]. In the literature surveyed, the use of correction factor at off design conditions has not been reported. The present work is taken up to generate correction factor curves. And for this, software is developed for 120MW thermal power plant which can be used for all thermal power plant of any capacity. The curves of correction factors and the software help to obtain a quick information about the off design performance of the plant at any value of the inlet pressure.

II. Methodology for Software

In this research work first of all flow function has been calculated for designed condition and then different mass flow rates have been calculated with the help of flow function at different inlet pressure and specific volume of

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generated steam. Then with different leakages and different extraction quantities, net power or exergy or available energy has been calculated. And then finally correction factor for power has been found. At designed condenser back pressure, exergy or available energy for condenser has been calculated. Then exergy or available energy has been calculated for all feed water heaters with the help of extracted quantity and latent heat transformation. Then exergy or available energy has been calculated for boiler at generated steam pressure and temperature. Then finally heat rate has been calculated and then finally correction factor for heat rate has been found. All the above calculation has been done by software and software has been designed based on visual basic 6.0 language [4, 5]. Coding for the software is given in appendix 1. These are the following steps which have been followed to operate software as in Fig. 2-Fig. 6.

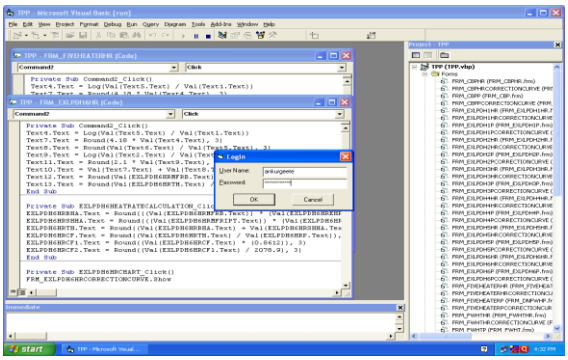

Figure 2. Enter user name and pass word to run the program

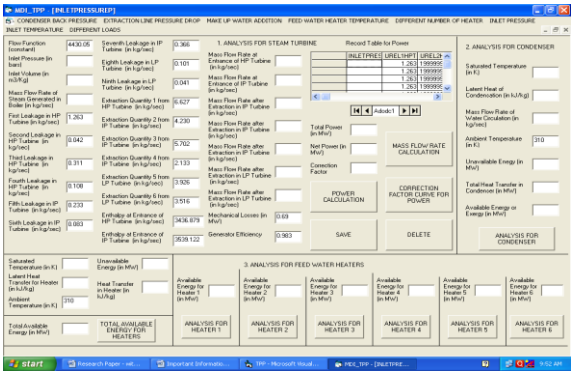

Figure 3. First inlet pressure form open to analyze steam turbine, condenser and feed water heaters

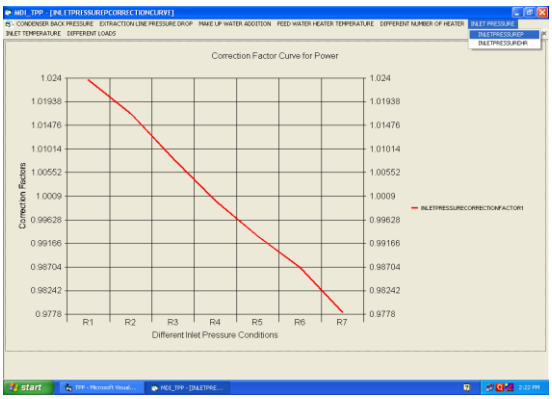

Figure 4. Correction factor curve for power for different inlet pressure conditions

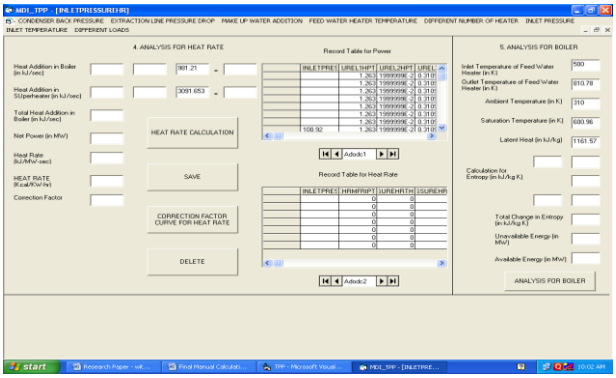

Figure 5. Second inlet pressure form open to analyze heat rate and boiler

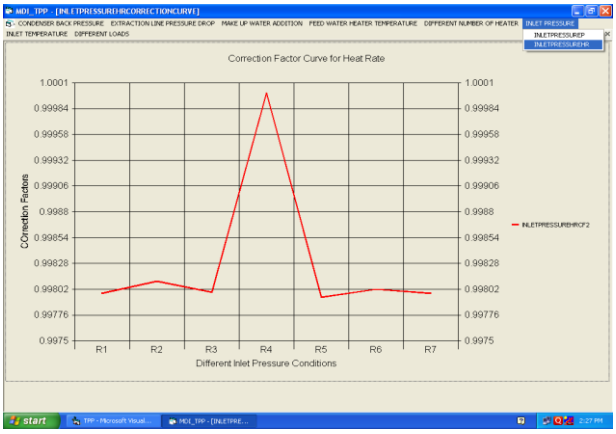

Figure 6. Correction factor curve for heat rate for different inlet pressure conditions

(1) Step 1 – Enter 'username' and 'password' to open the program. **(2) Step 2** – Select 'Inlet Pressure' as a parameter and click on 'INLETPRESSUREP' then inlet pressure form open. **(3) Step 3** - Enter value in the 'blank text' (inlet pressure and specific volume) for first inlet pressure condition and then click on 'MAS FLOW RATE CALCULATION' to calculate mass flow rate of steam. Then enter different extraction quantities in the blank text and click on 'POWER CALCULATION' to calculate net power and correction factor. **(4) Step 4** – Enter values of 'Saturated Temperature' and 'Latent Heat of Condensation' and then click on 'ANALYSIS FOR CONDENSER' to calculate mass flow rate of water circulation, exergy and anergy for condenser. **(5) Step 5** – Enter values of 'Saturated Temperature' and 'Latent Heat Transfer' for heater 1,2,3,4,5 and 6. And then click on 'ANALYSIS FOR HEATER 1', 'ANALYSIS FOR HEATER 2', 'ANALYSIS FOR HEATER 3', 'ANALYSIS FOR HEATER 4', 'ANALYSIS FOR HEATER 5' and 'ANALYSIS FOR HEATER 6' respectively to calculate exergy for all feed water heaters. **(6) Step 6** – Click on 'TOTAL AVAILABLE ENERGY OF HEATERS'. **(7) Step 7** – Click on 'SAVE'. **(8) Step 8** – Repeat above steps by entering values for different inlet pressure conditions. **(9) Step 9** – Click on 'CORRECTION FACTOR CURVE FOR POWER' to generate correction factor curve for power for different inlet pressure conditions. **(10) Step 10** – Select 'INLETPRESSUREHR' for heat rate calculation from

first page of the program. And then INLETPRESSUREHR form open. **(11) Step 11** – Select values for blank texts from 'Record Table for Power' and then click on 'HEAT RATE CALCULATION' to calculate heat rate and correction factor. **(12) Step 12** – Enter values of 'Inlet Temperature', 'Outlet Temperature', 'Saturated Temperature' and 'Latent Heat Transfer' and then click on 'ANALYSIS FOR BOILER' to calculate exergy and anergy for boiler. And then click on 'SAVE' to save calculated values in 'Record Table for Heat Rate'. **(13) Step 13** - Repeat above steps by selecting values for different inlet pressure conditions from 'Record Table for Power'. Calculate and save all values in 'Record Table for Heat Rate'. **(14) Step 14** – Click on 'CORRECTION FACTOR CURVE FOR HEAT RATE' to generate correction factor curve for heat rate. Thus with the help of software, correction factor curves for different inlet pressure conditions are generated. And component wise analysis of thermal power plant is also done by software as in Figs 2-6. Software is designed on the basis of mathematical formulas, which are [6-8]-

- Exergy Outlet Analysis For Boiler -

$dS = \{(C_{pw})\ \ln[T_2/T_1] + \text{Latent Heat}/\ T_2 + (C_{ps})\ \ln[T_3/T_2]\}$ (1)

$U.E. = T_0 ds$ (2)

$A.E. = Q - T_0 ds$ (3)

- Exergy Outlet Analysis For Steam Turbines [9]
- Flow Function Calculation

$FF = W/\sqrt{(P/v)}$ kg ^{7}bar m ^{3}hr (4)

Mass Flow Rate Calculation

$4430.051 = W / \sqrt{(P/v)}$

Mass Flow Rate Calculation for Different Stages of HP, IP and LP Turbines

$W_1 = (W' - L_1 - L_2 - L_3 - L_4)$ (5)

$W_2 = (W_1 + L_1 - L_5 - L_6 - Ex_1)$ (6)

$W_3 = (W_2 - Ex_2 - L_7 - L_8)$ (7)

$W_4 = (W_3 - Ex_3)$ (8)

$W_5 = (W_4 - Ex_4)$ (9)

$W_6 = (W_5 - Ex_5 - L_9)$ (10)

$W_7 = (W_6 - Ex_6)$ (11)

Total Power Calculation

$P = \text{HP Turbine } \{W_1 (h_1 - h_2)\} + \text{IP Turbine } \{[W_2 (h_3 - h_4)] + [W_3 (h_4 - h_5)] + [W_4 (h_5 - h_6)]\} + \text{LP Turbine } \{[W_5 (h_6 - h_7)] + [W_6 (h_7 - h_8)] + [W_7 (h_8 - h_9)]\}$ (12)

Exergy Outlet or Net Power Calculation

Exergy outlet or P_{net} = Generator Efficiency (Power – Mechanical Losses), (13)

- Exergy Outlet Analysis For Condenser [10-12]

(m_s) (h_{fg}, Enthalpy drop in condenser) = (m_w) (C_{pw}) $(T_{out} - T_{in})$ (14)

Change in entropy for Condenser (dS) = (Enthalpy drop in condenser / Saturated temperature) (15)

Unavailable energy = T_0(dS), Change in entropy (16)

Heat transfer (Q) = (m_s) (h_{fg}) (17)

$A.E. = Q - T_0 ds$ (18)

- Exergy Outlet Analysis For Feed Water Heaters [10-12] –

$dS = h_{fg}/T_{sat}$ = (Latent heat transfer in heater)/(Saturated temperature) (19)

For heater, Unavailable Energy (U.E.) = (Ex_i) $(T_0 dS_i)$(20)

And Q = (Ex_i) (h_{fgi}, for heater) (21)

Total Available Energy or Exergy outlet = (Exergy outlet for Heater 1)+(Exergy outlet for Heater 2)+(Exergy outlet for Heater 3)+(Exergy outlet for Heater 4)+(Exergy outlet for Heater 5)+(Exergy outlet for Heater 6) (22)

- Heat Rate Calculation [10-12] -

Heat rate = (Total heat addition in boiler) / (Net power)(23)

$HR = (Q_1 + Q_2)/ P_{net}$ kJ/MW-sec (24)

$Q_1 = W' (h_1 - h)$, (Heat addition in Boiler) (25)

$Q_2 = W_2 (h_3 - h')$ (Heat addition in Super heater) (26)

All the predicted leakages and extraction quantities were taken for 120MW thermal power plant [7-8].

III. Results

In these research work, software has been developed to generate correction factor curves for power and heat rate as shown in Fig. 4 and in Fig. 6 respectively. Component wise analysis has also been done for different inlet pressure conditions (between 122.16 bar–128.04 bar) and results have been obtained which indicate that the maximum exergy or available energy for steam turbine, condenser, feed water heater 1 (LP heater), feed water heater 2 (LP heater), feed water heater 3 (LP heater), feed water heater 4 (deaerator), feed water heater 5 (HP heater) and feed water heater 6 (HP heater) can be achieved at 128.04 bar pressure. All the results with different conditions are tabulated in Table I.

TABLE I. Power and Heat Rate for Different Inlet Pressure Conditions from the Software

Sr. No	Pressure (in bar)	Mass Flow Rate (in kg/sec)	Power (in MW)	Correc -tion Factor for power	Correc-tion Factor for heat rate
1	122.16	98.67	117.23	1.0236	0.9979
2	123.14	99.32	117.97	1.0171	0.9981
3	124.12	100.25	119.01	1.0082	0.9979
4	125.10	100.92	120.00	1.0000	1.0000
5	126.08	101.86	120.82	0.9931	0.9979
6	127.06	102.53	121.58	0.9869	0.9980
7	128.04	103.50	122.67	0.9782	0.9979

IV. Conclusions

More general software has been developed which can be used for different inlet pressure values and also can be used for all thermal power plant. Software can be used if –(1) inlet pressure and specific volume of generated steam vary, (2) leakage quantities and extraction quantities vary, (3) mechanical losses and generator efficiency vary, (4) saturated temperature and latent heat transfer for condenser vary and (5) saturated temperature and latent heat transfer for all feed water heaters vary.

Work can be concluded as-(1) when inlet pressure increases the correction factor for power decreases. It means that when inlet pressure increases then plant output increases, (2) maximum heat rate can be achieved at 125.10 bar inlet pressure which is designed condition and (3) If inlet pressure increases then exergy or available energy for each component increases.

APPENDIX

A. *Coding for Analysis for Steam Turbine, Condenser and Feed Water Heaters*

```
Private Sub Form_Load()
Call CONNECTION
End Sub
Private Sub INLETPRESSUREMASSFLOWRATECALCULATE_Click()
INLETPRESSUREMFRB.Text = Round((Sqr(Val(INLETPRESSURE.Text) / Val(INLETVOLUME.Text))) * (INLETPRESSUREFLOWFUNCTION.Text / 3600), 2)
End Sub
Private Sub INLETPRESSUREPCHART_Click()
FRM_INLETPRESSUREPCORRECTIONCURVE.Show
End Sub
Private Sub INLETPRESSUREPDELETE_Click()
On Error GoTo XX
Dim TXT As Control
Set RS = New ADODB.Recordset
CMD = "SELECT* FROM INLETPRESSUREP"
RS.Open CMD, CN, adOpenDynamic, adLockPessimistic
CN.Execute ("delete from INLETPRESSUREP")
RS.Update
MsgBox "DELETE SUCCESSFULL"
Exit Sub
XX:
MsgBox Err.Description, vbCritical, "ERROR..."
Exit Sub
End Sub
Private Sub INLETPRESSUREPOWERCALCULATION_Click()
Dim a, b, c, d, e, f, g, h, i, j, k As Single
INLETPRESSUREW1.Text = Val(INLETPRESSUREMFRB.Text) - Val(INLETPRESSUREL1HPT.Text) - Round(Val(INLETPRESSUREL2HPT.Text), 3) - Val(INLETPRESSUREL3HPT.Text) - Val(INLETPRESSUREL4HPT.Text)
INLETPRESSUREW2.Text = Val(INLETPRESSUREW1.Text) + Val(INLETPRESSUREL1HPT.Text) - Val(INLETPRESSUREL5IPT.Text) - Val(INLETPRESSUREL6IPT.Text) - Val(INLETPRESSUREEXQ1HPT.Text)
INLETPRESSUREW3.Text = Val(INLETPRESSUREW2.Text) - Val(INLETPRESSUREEXQ2IPT.Text) - Val(INLETPRESSUREL7IPT.Text) - Val(INLETPRESSUREL8LPT.Text)
INLETPRESSUREW4.Text = Val(INLETPRESSUREW3.Text) - Val(INLETPRESSUREEXQ3IPT.Text)
INLETPRESSUREW5.Text = Val(INLETPRESSUREW4.Text) - Val(INLETPRESSUREEXQ4IPT.Text)
INLETPRESSUREW6.Text = Val(INLETPRESSUREW5.Text) - Val(INLETPRESSUREEXQ5LPT.Text) - Val(INLETPRESSUREL9LPT.Text)
INLETPRESSUREW7.Text = Val(INLETPRESSUREW6.Text) - Val(INLETPRESSUREEXQ6LPT.Text)
a = Val(INLETPRESSUREW1.Text) * (0.1016 * Val(INLETPRESSUREEHP.Text))
b = Val(INLETPRESSUREW2.Text) * (Val(INLETPRESSUREEIP.Text) - 3387.304)
c = Val(INLETPRESSUREW3.Text) * 186.762
d = Val(INLETPRESSUREW4.Text) * 281.983
e = Val(INLETPRESSUREW5.Text) * 90.831
f = Val(INLETPRESSUREW6.Text) * 173.01
g = Val(INLETPRESSUREW7.Text) * 179.785
INLETPRESSUREPOWER.Text = Round(((a + b + c + d + e + f + g) / 1000), 3)
j = Val(INLETPRESSUREPOWER.Text) - Val(INLETPRESSUREMECHLOSSES.Text)
k = j * Val(INLETPRESSUREGENERATOREFFICIENCY.Text)
INLETPRESSURENETPOWER.Text = Round((k), 3)
INLETPRESSURECORRECTIONFACTOR1.Text = Round((Val(INLETPRESSURENETPOWER.Text) / 120), 3)
End Sub
Private Sub INLETPRESSUREPSAVE_Click()
On Error GoTo XX
Dim TXT As Control
Set RS = New ADODB.Recordset
CMD = "SELECT* FROM INLETPRESSUREP"
RS.Open CMD, CN, adOpenDynamic, adLockPessimistic
RS.AddNew Array("INLETPRESSUREMFRB", "INLETPRESSUREL1HPT", "INLETPRESSUREL2HPT", "INLETPRESSUREL3HPT", "INLETPRESSUREL4HPT", "INLETPRESSUREL5IPT", "INLETPRESSUREL6IPT", "INLETPRESSUREL7IPT", "INLETPRESSUREL8LPT", "INLETPRESSUREL9LPT", "INLETPRESSUREEXQ1HPT", "INLETPRESSUREEXQ2IPT", "INLETPRESSUREEXQ3IPT", "INLETPRESSUREEXQ4IPT", "INLETPRESSUREEXQ5LPT", "INLETPRESSUREEXQ6LPT", "INLETPRESSUREEHP", "INLETPRESSUREEIP", "INLETPRESSUREPOWER",
```

```
"INLETPRESSURENETPOWER",
"INLETPRESSURECORRECTIONFACTOR1",
"INLETPRESSUREW1",  "INLETPRESSUREW2",
"INLETPRESSUREW3",  "INLETPRESSUREW4",
"INLETPRESSUREW5",  "INLETPRESSUREW6",
"INLETPRESSUREW7"), _
Array(INLETPRESSUREMFRB.Text,
Val(INLETPRESSUREL1HPT.Text),
Round(Val(INLETPRESSUREL2HPT.Text),  3),
Val(INLETPRESSUREL3HPT.Text),
Val(INLETPRESSUREL4HPT.Text),
Val(INLETPRESSUREL5IPT.Text),
Val(INLETPRESSUREL6IPT.Text),
Val(INLETPRESSUREL7IPT.Text),
Val(INLETPRESSUREL8LPT.Text),
Val(INLETPRESSUREL9LPT.Text),
Val(INLETPRESSUREEXQ1HPT.Text),
Val(INLETPRESSUREEXQ2IPT.Text),
Val(INLETPRESSUREEXQ3IPT.Text),
Val(INLETPRESSUREEXQ4IPT.Text),
Val(INLETPRESSUREEXQ5LPT.Text),
Val(INLETPRESSUREEXQ6LPT.Text),
Val(INLETPRESSUREEHP.Text),
Val(INLETPRESSUREEIP.Text),
Val(INLETPRESSUREPOWER.Text),
Val(INLETPRESSURENETPOWER.Text),
Val(INLETPRESSURECORRECTIONFACTOR1.Text),
Val(INLETPRESSUREW1.Text),
Val(INLETPRESSUREW2.Text),
Val(INLETPRESSUREW3.Text),
Val(INLETPRESSUREW4.Text),
Val(INLETPRESSUREW5.Text),
Val(INLETPRESSUREW6.Text),
Val(INLETPRESSUREW7.Text))
RS.Update
INLETPRESSUREMFRB.Text = ""
INLETPRESSUREEXQ1HPT.Text = ""
INLETPRESSUREEXQ2IPT.Text = ""
INLETPRESSUREEXQ3IPT.Text = ""
INLETPRESSUREEXQ4IPT.Text = ""
INLETPRESSUREEXQ5LPT.Text = ""
INLETPRESSUREEXQ6LPT.Text = ""
INLETPRESSUREEHP.Text = ""
MsgBox "SAVE SUCCESSFULL"
Exit Sub
XX:
MsgBox Err.Description, vbCritical, "ERROR..."
Exit Sub
End Sub
```

B. Coding for Correction Factor Curve for Power -

```
Private Sub Form_Load()
Call CONNECTION
Set RS = New ADODB.Recordset
CMD = "SELECT INLETPRESSURECORRECTIONFACTOR1 FROM INLETPRESSUREP"
RS.Open CMD, CN, adOpenKeyset
RS.MoveFirst
With MSChart1
.ShowLegend = True
.EditCopy
.EditPaste
Set .DataSource = RS
End With
End Sub
```

C. Coding for Analysis for Boiler and Heat Rate –

```
Private Sub Form_Load()
Call CONNECTION
End Sub
Private Sub INLETPRESSUREHEATRATECALCULATION_Click()
INLETPRESSUREHRBHA.Text = Round(((Val(INLETPRESSUREHRMFRB.Text)) * (Val(INLETPRESSUREHREHP.Text) - Val(INLETPRESSUREHREB.Text))), 3)
INLETPRESSUREHRSHHA.Text = Round(((Val(INLETPRESSUREHRMFRIPT.Text)) * (Val(INLETPRESSUREHREIP.Text) - Val(INLETPRESSUREHRESH.Text))), 3)
INLETPRESSUREHRTH.Text = Round((Val(INLETPRESSUREHRBHA.Text) + Val(INLETPRESSUREHRSHHA.Text)), 3)
INLETPRESSUREHRCF.Text = Round((Val(INLETPRESSUREHRTH.Text) / Val(INLETPRESSUREHRP.Text)), 3)
INLETPRESSUREHRCF1.Text = Round((Val(INLETPRESSUREHRCF.Text) * (0.8612)), 3)
INLETPRESSUREHRCF2.Text = Round((Val(INLETPRESSUREHRCF1.Text) / 2078.9), 3)
End Sub
Private Sub INLETPRESSUREHRCHART_Click()
FRM_INLETPRESSUREHRCORRECTIONCURVE.Show
End Sub
Private Sub INLETPRESSUREHRDELETE_Click()
On Error GoTo XX
Dim TXT As Control
Set RS = New ADODB.Recordset
CMD = "SELECT* FROM INLETPRESSUREHR"
CMD = "SELECT* FROM INLETPRESSUREP"
RS.Open CMD, CN, adOpenDynamic, adLockPessimistic
CN.Execute ("delete from INLETPRESSUREHR")
CN.Execute ("delete from INLETPRESSUREP")
RS.Update
MsgBox "DELETE SUCCESSFULL"
Exit Sub
XX:
MsgBox Err.Description, vbCritical, "ERROR..."
Exit Sub
End Sub
Private Sub INLETPRESSUREHRSAVE_Click()
On Error GoTo XX
Dim TXT As Control
Set RS = New ADODB.Recordset
CMD = "SELECT * FROM INLETPRESSUREHR"
RS.Open CMD, CN, adOpenDynamic, adLockPessimistic
```

```
RS.AddNew Array("INLETPRESSUREHRMFRB", "INLETPRESSUREHRMFRIPT", "INLETPRESSUREHRTH", "INLETPRESSUREHRP", "INLETPRESSUREHRCF", "INLETPRESSUREHRCF1", "INLETPRESSUREHRCF2"), Array(INLETPRESSUREHRMFRB.Text, Val(INLETPRESSUREHRMFRIPT.Text), Val(INLETPRESSUREHRTH.Text), Val(INLETPRESSUREHRP.Text), Val(INLETPRESSUREHRCF.Text), Val(INLETPRESSUREHRCF1.Text), Val(INLETPRESSUREHRCF2.Text))
RS.Update
MsgBox "SAVE SUCCESSFULL"
Exit Sub
XX:
MsgBox Err.Description, vbCritical, "ERROR..."
Exit Sub
End Sub
Private Sub MSHFlexGrid1_Click()
INLETPRESSUREHRMFRB.Text = MSHFlexGrid1.TextMatrix(MSHFlexGrid1.Row, 1)
INLETPRESSUREHREHP.Text = MSHFlexGrid1.TextMatrix(MSHFlexGrid1.Row, 17)
INLETPRESSUREHRMFRIPT.Text = MSHFlexGrid1.TextMatrix(MSHFlexGrid1.Row, 20)
INLETPRESSUREHREIP.Text = MSHFlexGrid1.TextMatrix(MSHFlexGrid1.Row, 18)
INLETPRESSUREHRP.Text = MSHFlexGrid1.TextMatrix(MSHFlexGrid1.Row, 27)
End Sub
```

D. Coding for Correction Factor Curve for Heat Rate –

```
Private Sub Form_Load()
Call CONNECTION
Set RS = New ADODB.Recordset
CMD = "SELECT INLETPRESSUREHRCF2 FROM INLETPRESSUREHR"
RS.Open CMD, CN, adOpenKeyset
RS.MoveFirst
With MSChart1
.ShowLegend = True
.EditCopy
.EditPaste
Set .DataSource = RS
End With
End Sub
```

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Ankur Geete: He is working as Associated Professor, in Sushila Devi Bansal College of Technology, Indore. He has completed his Ph.D. in mechanical engineering. His research field was thermal power plant. He has published many research papers in international/national journals. He is guiding PG (M.Tech.) students.