APPENDIX 1

TAGUCHI METHODS AND DESIGN OF EXPERIMENTATION

Characteristic Values				
Orifice [mm]		**D4**	**D6**	**D8**
Recirculation %	5%	44	38	47
	10%	46	40	52
	15%	34	36	44

Mean value in the data = 42.33

Modified data:

Characteristic Values				
Orifice [mm]		**D4**	**D6**	**D8**
Recirculation %	5%	44	38	47
	10%	46	40	52
	15%	34	36	44

We now find the sum of squares for the above table

Orifice [mm]		D4	D6	D8	Row Total Rj	Rj^2
Recirculation %	5%	1.67	-4.33	4.67	2.01	4.0401
	10%	3.67	-2.33	9.67	11.01	121.2201
	15%	-8.33	-6.33	1.67	-12.99	168.7401

Column Total Cj	-2.99	-12.99	16.01	0.03
Cj^2	8.9401	168.7401	256.3201	0.0009

Null Hypothesis:

The data is homogeneous with respect to modifications

Number of data, N = 9

Step 1: Grand Total, T = 0.03

Step 2: Correction Factor, $\text{CF} = \frac{\text{T}^2}{\text{N}} = 0.0001$

Step 3: Sum of Squares of individual observation

Orifice [mm]		D4	D6	D8	Row Total Rj
Recirculation %	5%	2.7889	18.7489	21.8089	43.3467
	10%	13.4689	5.4289	93.5089	112.4067
	15%	69.3889	40.0689	2.7889	112.2467
				SS	268.0001

Sum of squares of individual observations, SS = 268.0001

Step 4: Total Sum of Squares, TSS = SS – CF = 268

Step 5: Sum of squares of columns (%EGR), SSC =

$$\frac{1}{4}\left(\sum C_j^{\,2} - CF\right) = 108.5$$

Degrees of Freedom, dfc = 2
(= No. of columns – 1)

Step 6: Sum of squares of rows (Orifice), SSR =

$$\frac{1}{4}\left(\sum R_j^{\,2} - CF\right) = 73.49998$$

Degrees of Freedom, dfc = 2
(= No. of rows – 1)

Step 7: Residual sum of squares of E, SSE = Residual =
TSS-(SSC+SSR) = 86.00005

Step 8: Degrees of Freedom, df = dfc (dfr) = 2 x 2 = 4

ANOVA TABLE						
Source of Variation	**Sum of squares**	**Degrees of Freedom**	**Mean squares**	**F - Ratio**	**F_{TAB} (0.05,2,4)**	
between % EGR	SSC	dfc =c -1	MSC = SSC/dfc	Fc = MSC/MSE	6.94	ok
	108.5	2	54.24999	2.523254		
between Orifice	SSR	dfr = r - 1	MSR = SSR/dfr	Fr = MSR/MSE		
	73.49998	2	36.74999	1.709301	6.94	ok
Residual	SSE	d f= (dfr)(dfc)	MSE = SSE/df	-		
	86.00005	4	21.50001			

Conclusion:

$F_{TAB} > F_R$, hence NULL Hypothesis is accepted for rows.

$F_{TAB} > F_C$, hence NULL Hypothesis is accepted for columns.

APPENDIX 2

MODEL CALCULATIONS

Brake Power:

Torque, T = 9 Nm

Speed, N = 4500 rpm

Brake Power, BP $= \frac{2\,\pi\,N\,T}{60000} \quad = 4.241\ kW$

Total Fuel Consumption:

Fuel Volume, f_c = 10 cc

Fuel density, ρ = 0.83 kg/m^3

Time taken for fuel consumption, t = 32 sec

Total Fuel Consumption, $\mathrm{TFC} = \frac{3600\ \rho\ \mathrm{fc}}{1000\ \mathrm{t}} = 0.93375\ \ \mathrm{kg/hr}$

Specific Fuel Consumption, $\mathrm{SFC} = \frac{1000\ \ \mathrm{TFC}}{\mathrm{BP}} = 220.16\ \ \mathrm{g/kWh}$

Brake Thermal Efficiency:

Calorific Value of the Fuel, CV = 43000 kJ/kg

Brake Thermal Efficiency. $\mathrm{BTE} = 100 * \frac{3600\ \ \mathrm{BP}}{\mathrm{TFC\ (CV)}} = 38\ \%$

Conversion of Emissions:

Grey cells are input cells

Emission of Carbon Monoxide

Conversion from ppm to % volume

1	ppm	=	0.0001	% vol

	2000	ppm		0.2	% vol

Conversion from % volume to ppm

	1	% Vol	=	10000	ppm
Input here	0.2	% Vol	=	2000	ppm

Avogadro's law of mass and volume

22.4	nm^3	=	1	kg mol	
22.4	lit	=	1	g mol	at 101.325 kPa (normal pressure) and (273+C) K;

$$1\ ppm = \frac{0.08205\ (T)}{M}\ mg/nm^3$$

The answer in mg/nm3

$$1\ mg/nm^3 = \frac{M}{0.08205\ (T)}\ ppm$$

The answer in ppm

T = 450 K Mol. wt. M = 28

ppm	mg/nm^3
1	0.7583452

A/F ratio	EA % point	Exh.Density	
14	0.1	0.457	kg/m^3

Emission in g/kg fuel	51.1095	g/kg fuel
Specific Fuel Consumption =	200	g/kWh
Emission in g/kWh =	10.221	g/kWh
Distance covered per litre of fuel =	60	km/lit
Fuel Density in kg/m3	0.77	kg/lit
Distance covered per kWh =	15.584	km/kWh
Emission in g/km	0.6559	g/km

Emission of Carbon Dioxide

Conversion from ppm to % volume

1	ppm	=	0.0001	% vol
110000	ppm	=	11	% vol

Conversion from % volume to ppm

	1	% vol	=	10000	ppm
Input here	11	% vol	=	110000	ppm

Avogadro's law of mass and volume

22.4	nm^3	=	1	kg mol	
22.4	lit	=	1	g mol	at 101.325 kPa (normal pressure) and (273+C) K;

$$1\ ppm = \frac{0.08205\ (T)}{M}\ mg/nm^3$$

$$1\ mg/nm^3 = \frac{M}{0.08205\ (T)}\ ppm$$

T = 450 K   Mol. wt. M = 44

ppm	mg/nm^3
1	1.1916853

A/F ratio	EA % point	Exh. Density	
14	0.1	0.457	kg/m^3

Emission in mg/kg fuel	4417.32	g/kg fuel
Specific Fuel Consumption =	200	g/kWh
Emission in g/kWh =	883.464	g/kWh
Distance covered per litre of fuel =	60	km/lit
Fuel Density in kg/m3	0.77	kg/lit
Distance covered per kWh =	15.5844	km/kWh
Emission in g/km	56.6889	g/km

Emission of Nitrogen Oxides

Conversion from ppm to % volume

	1	ppm	=	0.0001	% vol
Input here	400	ppm	=	0.04	% vol

Conversion from % volume to ppm

1	% vol	=	10000	ppm
0.04	% vol	=	400	ppm

Avogadro's law of mass and volume

22.4	nm^3	=	1	kg mol

22.4	lit	=	1	g mol	at 101.325 kPa (normal pressure) and (273+C) K;

$$1\ ppm = \frac{0.08205\ (T)}{M}\ mg/nm^3$$

$$1\ mg/nm^3 = \frac{M}{0.08205\ (T)}\ ppm$$

T =	450	K	Mol. wt. M = 46
ppm		mg/nm^3	
1		1.2458528	

A/F ratio	EA % point	Exh. Density		
14	0.1	0.457	kg/m^3	
Emission in mg/kg fuel			16.7931	g/kg fuel
Specific Fuel Consumption =			200	g/kWh
Emission in g/kWh =			3.35862	g/kWh
Distance covered per litre of fuel =			60	km/lit
Fuel Density in kg/m3			0.77	kg/lit
Distance covered per kWh =			15.5844	km/kWh
Emission in g/km			0.21551	g/km

Emission of Hydrocarbon

Conversion from ppm to % volume

	1	ppm	=	0.0001	% vol
Input here	500	ppm	=	0.05	% vol

Conversion from % volume to ppm

	1	% vol	=	10000	ppm
Input here	0.05	% vol	=	500	ppm

Avogadro’s law of mass and volume

22.4	nm^3	=	1	kg mol	
22.4	lit	=	1	g mol	at 101.325 kPa (normal pressure) and (273+C) K;

$$1\ ppm = \frac{0.08205\ (T)}{M}\ mg/nm^3$$

$$1\ mg/nm^3 = \frac{M}{0.08205\ (T)}\ ppm$$

T =	450	K	Mol. wt. M = 17	
ppm		mg/nm^3		
1		0.4604239		
A/F ratio	EA % point		Exh. Density	
14	0.1		0.457	kg/m^3
Emission in mg/kg fuel			7.7576	g/kg fuel
Specific Fuel Consumption =			200	g/kWh
Emission in g/kWh =			1.5515	g/kWh
Distance covered per litre of fuel =			60	km/lit
Fuel Density in kg/m3			0.77	kg/lit
Distance covered per kWh =			15.584	km/kWh
Emission in g/km			0.0995	g/km

$M/(0.08205T)]*ppm*((A/F)*EA+1)/\rho_{ex}$; Emission is mg/kg fuel

If SFC is x g/kWhr; then Mass flow of exhaust is

$(x/1000)*[M/(0.08205T)]*ppm*((A/F)*EA+1)/\rho_{ex}$; Emission is mg/kWhr

APPENDIX 3

ERROR ANALYSIS AND UNCERTAINTY IN MEASUREMENTS

All the measurements of physical quantities are subjected to uncertainties. Uncertainty study is important to verify the precision of the experiments. In order to have sensible limits of uncertainty for a computed value, error analysis is carried out as follows.

Let 'R' be the computed result function of the self-determining considered variables x_1, x_2, x_3, ...x_n as per the relation

$$R = R\,(x_1, x_2, x_3, \ldots\ldots, x_n)$$

and let error limits for the calculated variables (parameters) be

$$x_1 \pm \omega n_1, x_2 \pm \omega n_2, x_3 \pm \omega n_3, \ldots\ldots, x_n \pm \omega n_n,$$

and the error limits for the compound answer be $R \pm \omega R,$

In order to get the pragmatic error limits for the computed result, the principle of root- mean square method for the error by Holaman (1973) is used.

$$\omega\, R = \left[\left(\frac{\partial R}{\partial x_1}\omega x_1\right)^2 + \left(\frac{\partial R}{\partial x_2}\omega x_2\right)^2 + \cdots . \left(\frac{\partial R}{\partial x_n}\omega x_n\right)^2\right]^{\frac{1}{2}}$$

Using the equation, the uncertainty in the computed variable values such as brake power, brake thermal efficiency, and fuel flow measurements are evaluated. The calculated values such as speed, fuel time, torque are expected from their respective uncertainties based on Gaussian distribution. The uncertainties in the calculated parameters are for fuel time (ϖ t) and fuel volume (ϖ t) are taken as ± 0.2 s and ± 0.1 s respectively

Sample calculations are given below:

Brake Power (BP)

Fuel volume, f_c = 10 cc; Brake Power, BP = 2.1563 kW; Time taken = 40 s;

Fuel density, ρ = 0.83; Uncertainty in time measurement, $\omega_t = 0.2\ s$

Calorific value of the fuel, CV = 43000 kJ/kg

Uncertainty in brake power measurement, $\omega_{BP} = 0.002$ kW

Total Fuel Consumption (TFC)

$$\mathrm{TFC} = \frac{(3600)\ (\rho)f_c}{(1000)t} = 0.747\ \ \mathrm{kg/hr}$$

Total Fuel Consumption is a function of time.

TFC = f(t)

$$\frac{\partial \mathrm{TFC}}{\partial \mathrm{t}} = -\frac{(3600)\ (\rho)f_c}{(1000)\mathrm{t}^2} = -0.018675\ \mathrm{kg/hr}$$

$$\omega_{\mathrm{TFC}} = \sqrt{\left[\frac{\partial \mathrm{TFC}}{\partial \mathrm{t}}(\omega_t)\right]^2} = 0.003735\ \mathrm{kg/hr.}$$

The uncertainty in the total fuel consumption from equation is 0.003735 kg/hr and the limits of uncertainty are 0.747 $\pm$ 0.003735 kg/hr

Brake Thermal Efficiency (η)

Brake Power, BP = 2.1563 kW

Total Fuel Consumption, TFC = 0.747 kg/hr

Calorific value of the fuel, CV = 43000 kJ/kg

$$\eta = \frac{(3600)\mathrm{BP}(100)}{(\mathrm{TFC})(\mathrm{CV})}$$

Brake Thermal Efficiency is a function of brake power and total fuel consumption.

$$\eta = f(BP, TFC)$$

$$\eta = \frac{(3600)BP(100)}{(TFC)(CV)} = 24.1669\ \%$$

$$\frac{\partial\eta}{\partial BP} = \frac{\partial}{\partial BP}\left[\frac{(3600)BP(100)}{(TFC)(43000)}\right] = \frac{(3600)(100)}{(TFC)(43000)} = 11.207$$

$$\frac{\partial\eta}{\partial TFC} = \frac{\partial}{\partial TFC}\left[\frac{(3600)BP(100)}{(TFC)(43000)}\right] = \frac{(3600)BP(100)}{(TFC)^2(43000)} = 32.352$$

$$\omega_\eta = \sqrt{\left[\frac{\partial\eta}{\partial BP}\,\omega_{BP}\right]^2 + \left[\frac{\partial\eta}{\partial TFC}\,\omega_{TFC}\right]^2} =$$

$$\sqrt{[-11.207(0.002)]^2} + [-32.352(0.003735)]^2 = 0.123\ \%$$

Hence the uncertainty in the brake thermal efficiency will be ± 0.123 % and the limits of uncertainty are 24.1669 $\pm$ 0.123 %

24.1669 + 0.123 = 24.2899 % and 24.1669 – 0.123 = 24.0439 %

APPENDIX 4

TECHNICAL SPECIFICATIONS

1. EXHAUST GAS ANALYZER – SPECIFICATIONS

S.No.	Measurement	Range	Accuracy	Resolution
1	Oxygen	0 – 22 %	$<$ 2 % Vol $\pm$ 0.1 % Vol $>$ 2 % Vol $\pm$ 5 % Vol	0.01 % Vol
2	Carbon Dioxide	0 -20 %	$<$ 10 % Vol $\pm$ 0.5 % Vol $>$ 10 % Vol $\pm$ 5 % Vol	0.1 % Vol
3	Carbon Monoxide	0 – 10 %	$<$ 0.6 % Vol $\pm$ 0.03 % Vol $>$ 0.6 % Vol $\pm$ 5 % Vol	0.01 % Vol
4	Hydrocarbon	0 – 20000 ppm	$<$ 200 ppm: $\pm$ 10 ppm $>$ 200 ppm: $\pm$ 5 %	1 ppm for < 2000 ppm 10 ppm for > 2000 ppm
5	Nitrogen Oxide	0 – 5000 ppm	$< 500\ ppm$ $\pm 50\ ppm$	1 ppm

2. EDDY CURRENT DYNAMOMETER SPECIFICATIONS

Type	:	Eddy current
Rated Power	:	20 kW
Maximum torque	:	37 Nm
Maximum Speed	:	15000 rpm
Rotate Inertia	:	0.00921 kg-m^2
Max. water consumption	:	0.86 m^3/h
Full load Current	:	2.8 A
Weight	:	180 kg
Accuracy	:	$\pm$ 0.2 % FSR
Sensitivity	:	$\pm$ 0.1 % FSR
Error limit of measuring speed	:	$\pm$ 1 rpm

3. HEAT EXCHANGER SPECIFICATIONS

Type	:	Tube in Tube
Tube material	:	Steel
Heat Exchanger Effectiveness	:	0.35
Cooling Medium	:	Water
Heating Medium	:	Exhaust Gas

1. BYPASS VALVE SPECIFICATIONS

Model	:	AKL 25
Material	:	Steel
Maximum Pressure	:	20 bar
Maximum Temperature	:	600 ^{0}C

APPENDIX 5

EXCEL PROGRAMME

```
Option Explicit
Sub PopulateSheets()
Dim shMaster As String, gMaster As String
Dim i As Long, j As Long, k As Long, l As Long
Dim mData As String, mDataDes1 As String, mDataDes2 As String, cData As String,
cDataDes1 As String
Dim dData As String, dDataDes1 As String, pData As String, pDataDes1 As String
Dim CurRow As Long, Dec As Long
shMaster = "Master"
gMaster = "GraphTemplate"
CurRow = 2
Application.ScreenUpdating = False
Call Delete
' For each of the 12 factors
For i = 2 To 14
mData = Sheets(shMaster).Cells(i, 2).Value
mDataDes1 = Sheets(shMaster).Cells(i, 3).Value
mDataDes2 = Sheets(shMaster).Cells(i, 4).Value
Dec = Sheets(shMaster).Cells(i, 1).Value
' For dimensions
' For uncooled and then cooled
For j = 8 To 9
cData = Sheets(shMaster).Cells(j, 6).Value
```

```
cDataDes1 = Sheets(shMaster).Cells(j, 7).Value

For k = 2 To 4

dData = Sheets(shMaster).Cells(k, 6).Value

dDataDes1 = Sheets(shMaster).Cells(k, 7).Value

' Copy graph sheet

Sheets(gMaster).Copy After:=Sheets(Sheets.Count)

' Fill Cells D4, F5, G5, H5, M4  and rename the sheet

ActiveSheet.Cells(4, 4).Value = mData

ActiveSheet.Cells(5, 6).Value = dData & Sheets(shMaster).Cells(5, 6).Value & " E2"
& cData

ActiveSheet.Cells(5, 7).Value = dData & Sheets(shMaster).Cells(6, 6).Value & " E2"
& cData

ActiveSheet.Cells(5, 8).Value = dData & Sheets(shMaster).Cells(7, 6).Value & " E2"
& cData

ActiveSheet.Cells(4, 13).Value = dData

ActiveSheet.Name = mData & dData & " E2" & cData

Call SetDec(Dec)

ActiveSheet.ChartObjects("Chart 1").Activate

ActiveChart.Axes(xlValue).MaximumScale = Cells(7, 14).Value

ActiveChart.Axes(xlValue).MinimumScale = Cells(6, 14).Value

' Create hyperlink in master sheet

' Sheets(shMaster).Cells(CurRow, 9).Value = mData & dData & " E2" & cData

Sheets(shMaster).Cells(CurRow, 9).Hyperlinks.Add
Anchor:=Sheets(shMaster).Cells(CurRow, 9), Address:="", SubAddress:= _

"'" & mData & dData & " E2" & cData & "'!A1", TextToDisplay:=mData & dData & "
E2" & cData

Sheets(shMaster).Cells(CurRow, 10).Value = Sheets(mData & dData & " E2" &
cData).Cells(3, 3).Value
```

```
CurRow = CurRow + 1
Next k
Next j
' For Percentage
' For uncooled and then cooled
For j = 8 To 9
cData = Sheets(shMaster).Cells(j, 6).Value
cDataDes1 = Sheets(shMaster).Cells(j, 7).Value
For k = 5 To 7
pData = Sheets(shMaster).Cells(k, 6).Value
pDataDes1 = Sheets(shMaster).Cells(k, 7).Value
' Copy graph sheet
Sheets(gMaster).Copy After:=Sheets(Sheets.Count)
' Fill Cells D4, F5, G5, H5, M4 and rename the sheet
ActiveSheet.Cells(4, 4).Value = mData
ActiveSheet.Cells(5, 6).Value = Sheets(shMaster).Cells(2, 6).Value & pData & " E2"
& cData
ActiveSheet.Cells(5, 7).Value = Sheets(shMaster).Cells(3, 6).Value & pData & " E2"
& cData
ActiveSheet.Cells(5, 8).Value = Sheets(shMaster).Cells(4, 6).Value & pData & " E2"
& cData
ActiveSheet.Cells(4, 13).Value = pData
ActiveSheet.Name = mData & pData & " E2" & cData
Call SetDec(Dec)
ActiveSheet.ChartObjects("Chart 1").Activate
ActiveChart.Axes(xlValue).MaximumScale = Cells(7, 14).Value
ActiveChart.Axes(xlValue).MinimumScale = Cells(6, 14).Value
```

```
' Create Hyperlink in master sheet

' Sheets(shMaster).Cells(CurRow, 9).Value = mData & pData & " E2" & cData

Sheets(shMaster).Cells(CurRow, 9).Cells(CurRow, 9).Hyperlinks.Add
Anchor:=Sheets(shMaster).Cells(CurRow, 9), Address:="", SubAddress:= _

    "'" & mData & pData & " E2" & cData & "'!A1", TextToDisplay:=mData &
pData & " E2" & cData

Sheets(shMaster).Cells(CurRow, 10).Value = Sheets(mData & pData & " E2" &
cData).Cells(3, 3).Value

CurRow = CurRow + 1

Next k

Next j

Next i

Application.ScreenUpdating = True

MsgBox "Completed"

End Sub

Function Delete()

Dim sh As Worksheet

Application.EnableEvents = False

Application.DisplayAlerts = False

For Each sh In ActiveWorkbook.Worksheets

If sh.Name <> "Master" And sh.Name <> "Base" And sh.Name <> "GraphTemplate"
Then

sh.Delete

End If

Next

Application.EnableEvents = True

Application.DisplayAlerts = True
```

```
End Function
Function SetDec(Dec As Long)
Select Case Dec
Case 6
Range("D6:H12").NumberFormat = _
   "_ * #,##0.000000_ ;_ * -#,##0.000000_ ;_ * ""-""??_ ;_ @_ "
 Case 5
 Range("D6:H12").NumberFormat = _
        "_ * #,##0.00000_ ;_ * -#,##0.00000_ ;_ * ""-""??_ ;_ @_ "
Case 4
Range("D6:H12").NumberFormat = _
        "_ * #,##0.0000_ ;_ * -#,##0.0000_ ;_ * ""-""??_ ;_ @_ "
 Case 3
Range("D6:H12").NumberFormat = "_ * #,##0.000_ ;_ * -#,##0.000_ ;_ * ""-""??_ ;_
@_ "
Case 2
Range("D6:H12").NumberFormat = "_(* #,##0.00_);_(* (#,##0.00);_(* ""-
""??_);_(@_)"
Case 1
Range("D6:H12").NumberFormat = "_ * #,##0.0_ ;_ * -#,##0.0_ ;_ * ""-""??_ ;_ @_ "
Case Else
Range("D6:H12").NumberFormat = "_ * #,##0_ ;_ * -#,##0_ ;_ * ""-""??_ ;_ @_ "
End Select
End Function
```

APPENDIX 6

MATLAB PROGRAMME

% Brake Thermal Efficiencies observed are given as y variable below

%

```
BP = [2.09     2.51   2.93   3.35   3.77   4.19   4.61];
S2 =[27.0,     30.2,  31.9,  32.8,  33.5,  34.0,  34.3];
S4=[33.0,      36.4,  38.7,  40.0,  40.9,  41.6,  42.0];
D4P5C=[30      33.6   36.4   37.8   38.7   39.4   39.7];
D6P5C=[32      34.2   37.7   38.8   39.5   40     40.5];
D8P5C=[30.8    34     36.5   38     39     39.7   40];
D4P5H = [      29.2,  32,    34.7,  36,    36.8,  37.5,  37.8];
D6P5H = [      30,    33.1,  35.2,  36.6,  37.4,  38.1,  38.5];
D8P5H = [      28.7,  32,    34.2,  35.5,  36.3,  37.0,  37.3];
D4P10H = [     30.1,  34.1,  36.1,  37.3,  38.1,  38.7,  39.1];
D6P10H = [     30.7,  34.8,  36.9,  38.1,  38.9,  39.5,  39.9];
D8P10H = [     29.5,  33.2,  35.1,  36.2,  36.9,  37.5,  37.9];
D4P10C = [     31.4,  35.8,  37.9,  39.2,  40.1,  40.7,  41.1];
D6P10C = [     31.7,  36.0,   38.2, 39.5,  40.4,  41.1,  41.5];
D8P10C = [     31.1,  35.3,  37.5,  38.7,  39.6,  40.2,  40.6];
D4P15H = [     28.7,  32.2,  34.2,  35.4,  36.2,  36.8,  37.1];
D6P15H = [     29.4,  32.3,  34.4,  35.6,  36.4,  37.1,  37.3];
D8P15H = [     28.2,  31.9,  33.8,  34.9,  35.6,  36.2,  36.6];
D4P15C = [     30.7,  34.1,  36.3,  37.6,  38.4,  39.1,  39.4];
D6P15C = [     31.0,  34.3,   36.6, 37.9,  38.7,  39.4,  39.7];
D8P15C = [     30.1,  33.9,  36.0,  37.3,  38.1,  38.8,  39.2];
% Fix the size of varying variables
% D4P5COpt = zeros(1,3);D4P10COpt = zeros(1,3);D4P15COpt = zeros(1,3);
% D6P5COpt = zeros(1,3);D6P10COpt = zeros(1,3);D6P15COpt = zeros(1,3);
% D8P5COpt = zeros(1,3);D8P10COpt = zeros(1,3);D8P15COpt = zeros(1,3);
% D4P5HOpt = zeros(1,3);D4P10HOpt = zeros(1,3);D4P15HOpt = zeros(1,3);
% D6P5HOpt = zeros(1,3);D6P10HOpt = zeros(1,3);D6P15HOpt = zeros(1,3);
% D8P5HOpt = zeros(1,3);D8P10HOpt = zeros(1,3);D8P15HOpt = zeros(1,3);
% % prompt = 'What is the Characteristic BTE,MF,SFC,CO,CO2,NO2,CHC? ';
%prompt = 'What is the Fig. No 1to 7 to 7? ';
%figNo = input(prompt);
xlbl = "Brake Power [kW] ";ylbl = "Brake Thermal Efficiency %";
x1 = (2:0.1:5)';
[S2PC,zc1,S2Opt] = polycurve(BP,S2);
```

```
yref2S = S2Opt(1,2);xref2S = S2Opt(1,1);
yOpt = S2Opt(1,2);

delRes = DelRes(yref2S,yOpt);
S2Opt1 = [S2Opt,delRes];model = '2S';
fprintf('Comparison of Brake Thermal Efficiencies at optimum Brake Power points \n');
fprintf('Model          BP         BTE        %%improved    Remarks\n');
fprintf('%-10s    %-6.3f     %-6.3f    %-6.3f    \n',model,S2Opt1);
[S4PC,zc2,S4Opt] = polycurve(BP,S4);
% Note polyval(S2PC) is correct because we want increment over % 2S chVal
xref4S = S4Opt(1,1);yref4S = polyval(S2PC,xref4S);
yOpt = S4Opt(1,2);
delRes = DelRes(yref2S,yOpt);
S4Opt1 = [S4Opt,delRes];model = '4S';
fprintf('%-10s    %-6.3f     %-6.3f    %-6.3f    \n',model,S4Opt1);
for i = 1:7
   figNo = i;
switch figNo
    case 1
[D4P5HPC,zc3,D4P5HOpt] = polycurve(BP,D4P5H);
yOpt = D4P5HOpt(1,2);
delRes = DelRes(yref2S,yOpt);
 D4P5HOpt1 = [D4P5HOpt,delRes];model = '2SD4P5UC';
% fprintf('D4P5HOpt BP %-6.3f  BTE %% %-6.3f Improvement %% %-6.3f over %% %-6.3f
\n',D4P5HOpt1,yref2S);
% fprintf('Model    BP     BTE     %%improved   Remarks');
fprintf('%-10s    %-6.3f     %-6.3f    %-6.3f    \n',model,D4P5HOpt1);
[D6P5HPC, zc4,D6P5HOpt] = polycurve(BP,D6P5H);
yOpt = D6P5HOpt(1,2);
delRes = DelRes(yref2S,yOpt);
D6P5HOpt1 = [D6P5HOpt,delRes];model = '2SD6P5UC';
% fprintf('D6P5HOpt BP %-6.3f  BTE %% %-6.3f Improvement %% %-6.3f over %% %-6.3f
\n',D6P5HOpt1,yref2S);
% fprintf('Model    BP     BTE     %%improved   Remarks');
fprintf('%-10s    %-6.3f     %-6.3f    %-6.3f    \n',model,D6P5HOpt1);
[D8P5HPC, zc5,D8P5HOpt]= polycurve(BP,D8P5H);
yOpt = D8P5HOpt(1,2);
delRes = DelRes(yref2S,yOpt);
D8P5HOpt1 = [D8P5HOpt,delRes];model = '2SD8P5UC';
% fprintf('D8P5HOpt BP %-6.3f BTE %% %-6.3f Improvement %% %-6.3f over %% %-6.3f
\n',D8P5HOpt1,yref2S);
% fprintf('Model    BP     BTE     %%improved   Remarks');
fprintf('%-10s    %-6.3f     %-6.3f    %-6.3f    \n',model,D8P5HOpt1);
figure;
hold on;
plot(x1,zc1,'r--',x1,zc2,'r-',x1,zc3,'b--',x1,zc4,'k-',x1,zc5,'b-',...
    'LineWidth',1);
% plot(x1,zc1,'r-',x1,zc2,'b:',x1,zc3,'k-',x1,zc4,'c-',x1,zc5,'g-');
title('5 % Uncooled Exhaust Gas Recirculation','FontSize',13,'FontWeight','bold','Color','k');
legend('2S','4S', '2SD4P5UC', '2SD6P5UC', '2SD8P5UC', 'Location','southeast');
```

```
xlabel(xlbl,'FontSize',13,'FontWeight','bold','Color','k');
ylabel(ylbl,'FontSize',13,'FontWeight','bold','Color','k');
xlim ([2 5]),ylim auto;
s = "Fig_4_1_BTE.fig";
saveas(gcf,s);
hold off;
case 2
[D4P5CPC,zc3,D4P5COpt] = polycurve(BP,D4P5C);
yOpt = D4P5COpt(1,2);
delRes = DelRes(yref2S,yOpt);
D4P5COpt1 = [D4P5COpt,delRes];model = '2SD4P5C';
% fprintf('D4P5COpt BP %-6.3f  BTE %% %-6.3f Improvement %% %-6.3f over %% %-6.3f
\n',D4P5COpt1,yref2S);
% fprintf('Model    BP     BTE     %%improved   Remarks');
fprintf('%-10s    %-6.3f     %-6.3f    %-6.3f    \n',model,D4P5COpt1);

[D6P5CPC, zc4,D6P5COpt] = polycurve(BP,D6P5C);
yOpt = D6P5COpt(1,2);
delRes = DelRes(yref2S,yOpt);
D6P5COpt1 = [D6P5COpt,delRes];model = '2SD6P5C';
% fprintf('D6P5COpt BP %-6.3f  BTE %% %-6.3f Improvement %% %-6.3f over %% %-6.3f
\n',D6P5COpt1,yref2S);
% fprintf('Model    BP     BTE     %%improved   Remarks');
fprintf('%-10s    %-6.3f     %-6.3f    %-6.3f    \n',model,D6P5COpt1);
[D8P5CPC, zc5,D8P5COpt]= polycurve(BP,D8P5C);
yOpt = D8P5COpt(1,2);
delRes = DelRes(yref2S,yOpt);
D8P5COpt1 = [D8P5COpt,delRes];model = '2SD8P5C';
% fprintf('D8P5COpt BP %-6.3f  BTE %% %-6.3f Improvement %% %-6.3f over %% %-6.3f
\n',D8P5COpt1,yref2S);
% fprintf('Model    BP     BTE     %%improved   Remarks');
fprintf('%-10s    %-6.3f     %-6.3f    %-6.3f    \n',model,D8P5COpt1);
figure;
% plot(BP,S2,'ko',BP,S4,'k+','MarkerSize',4);
hold on;
% plot(d11,d12,'k-o',d11,d13,'k-x',d11,d14,'k:*',d11,d15,'k-.d',...
%    d11,d16,'k--x','MarkerSize',4);
plot(x1,zc1,'r--',x1,zc2,'r-',x1,zc3,'b--',x1,zc4,'k-',x1,zc5,'b-',...
    'LineWidth',1);
title('5 % Cooled Exhaust Gas Recirculation','FontSize',13,'FontWeight','bold','Color','k');
legend('2S','4S', '2SD4P5C', '2SD6P5C', '2SD8P5C', 'Location','southeast');
xlabel(xlbl,'FontSize',13,'FontWeight','bold','Color','k');
ylabel(ylbl,'FontSize',13,'FontWeight','bold','Color','k');
xlim ([2 5]),ylim auto;
s = "Fig_4_2_BTE.fig";
saveas(gcf,s);
hold off;
case 3
[D4P10HPC,zc3,D4P10HOpt] = polycurve(BP,D4P10H);
yOpt = D4P10HOpt(1,2);
delRes = DelRes(yref2S,yOpt);
```

```
 D4P10HOpt1 = [D4P10HOpt,delRes];model = '2SD4P10UC';
fprintf('%-10s    %-6.3f     %-6.3f    %-6.3f    \n',model,D4P10HOpt1);
[D6P10HPC, zc4,D6P10HOpt] = polycurve(BP,D6P10H);
yOpt = D6P10HOpt(1,2);
delRes = DelRes(yref2S,yOpt);
 D6P10HOpt1 = [D6P10HOpt,delRes];model = '2SD6P10UC';
 fprintf('%-10s    %-6.3f     %-6.3f    %-6.3f    \n',model,D6P10HOpt1);
[D8P10HPC, zc5,D8P10HOpt]= polycurve(BP,D8P10H);
yOpt = D8P10HOpt(1,2);
delRes = DelRes(yref2S,yOpt);
D8P10HOpt1 = [D8P10HOpt,delRes];model = '2SD8P10UC';
fprintf('%-10s    %-6.3f     %-6.3f    %-6.3f    \n',model,D8P10HOpt1);
 figure;
% plot(BP,S2,'ko',BP,S4,'k+','MarkerSize',4);
hold on;
% plot(x1,zc1,'r-',x1,zc2,'b:',x1,zc3,'k-',x1,zc4,'c-',x1,zc5,'g-');
plot(x1,zc1,'r--',x1,zc2,'r-',x1,zc3,'b--',x1,zc4,'k-',x1,zc5,'b-',...
    'LineWidth',1);
title('10 % Uncooled Exhaust Gas
Recirculation','FontSize',13,'FontWeight','bold','Color','k');
legend('2S','4S', '2SD4P10UC', '2SD6P10UC', '2SD8P10UC', 'Location','southeast');
xlabel(xlbl,'FontSize',13,'FontWeight','bold','Color','k');
ylabel(ylbl,'FontSize',13,'FontWeight','bold','Color','k');
xlim ([2 5]),ylim auto;
s = "Fig_4_3_BTE.fig";
saveas(gcf,s);
hold off;

case 4

[D4P10CPC,zc3,D4P10COpt] = polycurve(BP,D4P10C);
yOpt = D4P10COpt(1,2);
delRes = DelRes(yref2S,yOpt);
 D4P10COpt1 = [D4P10COpt,delRes];model = '2SD4P10C';
fprintf('%-10s    %-6.3f     %-6.3f    %-6.3f    \n',model,D4P10COpt1);
[D6P10CPC, zc4,D6P10COpt]= polycurve(BP,D6P10C);
yOpt = D6P10COpt(1,2);
delRes = DelRes(yref2S,yOpt);
 D6P10COpt1 = [D6P10COpt,delRes];model = '2SD6P10C';
fprintf('%-10s    %-6.3f     %-6.3f    %-6.3f    \n',model,D6P10COpt1);
 xrefD6P10C = D6P10COpt(1,1);yrefD6P10C = polyval(S2PC,xrefD6P10C);
[D8P10CPC, zc5,D8P10COpt]= polycurve(BP,D8P10C);
yOpt = D8P10COpt(1,2);
delRes = DelRes(yref2S,yOpt);
D8P10COpt1 = [D8P10COpt,delRes];model = '2SD8P10C';
fprintf('%-10s    %-6.3f     %-6.3f    %-6.3f    \n',model,D8P10COpt1);
figure;
% plot(BP,S2,'ko',BP,S4,'k+','MarkerSize',4);
hold on;
% plot(x1,zc1,'r-',x1,zc2,'b:',x1,zc3,'k-',x1,zc4,'c-',x1,zc5,'g-');
plot(x1,zc1,'r--',x1,zc2,'r-',x1,zc3,'b--',x1,zc4,'k-',x1,zc5,'b-',...
```

```
    'LineWidth',1);
title('10 % Cooled Exhaust Gas Recirculation','FontSize',13,'FontWeight','bold','Color','k');
legend('2S','4S', '2SD4P10C', '2SD6P10C', '2SD8P10C','Location','southeast');
xlabel(xlbl,'FontSize',12,'FontWeight','bold','Color','k');
ylabel(ylbl,'FontSize',12,'FontWeight','bold','Color','k');
xlim ([2 5]),ylim auto;
s = "Fig_4_4_BTE.fig";
saveas(gcf,s);
hold off;
case 5
[D4P15HPC,zc3,D4P15HOpt] = polycurve(BP,D4P15H);
yOpt = D4P15HOpt(1,2);
delRes = DelRes(yref2S,yOpt);
D4P15HOpt1 = [D4P15HOpt,delRes];model = '2SD4P15UC';
fprintf('%-10s    %-6.3f     %-6.3f    %-6.3f    \n',model,D4P15HOpt1);
[D6P15HPC, zc4,D6P15HOpt] = polycurve(BP,D6P15H);
yOpt = D6P15HOpt(1,2);
delRes = DelRes(yref2S,yOpt);
D6P15HOpt1 = [D6P15HOpt,delRes];model = '2SD6P15UC';
fprintf('%-10s    %-6.3f     %-6.3f    %-6.3f    \n',model,D6P15HOpt1);
[D8P15HPC, zc5,D8P15HOpt]= polycurve(BP,D8P15H);
yOpt = D8P15HOpt(1,2);
delRes = DelRes(yref2S,yOpt);
D8P15HOpt1 = [D8P15HOpt,delRes];model = '2SD8P15UC';
fprintf('%-10s    %-6.3f     %-6.3f    %-6.3f    \n',model,D8P15HOpt1);
figure;
% plot(BP,S2,'ko',BP,S4,'k+','MarkerSize',4);
hold on;
% plot(x1,zc1,'r-',x1,zc2,'b:',x1,zc3,'k-',x1,zc4,'c-',x1,zc5,'g-');
plot(x1,zc1,'r--',x1,zc2,'r-',x1,zc3,'b--',x1,zc4,'k-',x1,zc5,'b-',...
    'LineWidth',1);
title('15 % Uncooled Exhaust Gas
Recirculation','FontSize',13,'FontWeight','bold','Color','k');
legend('2S','4S', '2SD4P15UC', '2SD6P15UC', '2SD8P15UC', 'Location','southeast');
xlabel(xlbl,'FontSize',13,'FontWeight','bold','Color','k');
ylabel(ylbl,'FontSize',13,'FontWeight','bold','Color','k');
xlim ([2 5]),ylim auto;
s = "Fig_4_5_BTE.fig";
saveas(gcf,s);
hold off;
case 6
[D4P15CPC,zc3,D4P15COpt] = polycurve(BP,D4P15C);
yOpt = D4P15COpt(1,2);
delRes = DelRes(yref2S,yOpt);
 D4P15COpt1 = [D4P15COpt,delRes];model = '2SD4P15C';
fprintf('%-10s    %-6.3f     %-6.3f    %-6.3f    \n',model,D4P15COpt1);

[D6P15CPC, zc4,D6P15COpt] = polycurve(BP,D6P15C);
yOpt = D6P15COpt(1,2);
delRes = DelRes(yref2S,yOpt);
D6P15COpt1 = [D6P15COpt,delRes];model = '2SD6P15C';
```

```
fprintf('%-10s    %-6.3f     %-6.3f    %-6.3f    \n',model,D6P15COpt1);

[D8P15CPC, zc5,D8P15COpt]= polycurve(BP,D8P15C);
yOpt = D8P15COpt(1,2);
delRes = DelRes(yref2S,yOpt);
D8P15COpt1 = [D8P15COpt,delRes];model = '2SD8P15C';
fprintf('%-10s    %-6.3f     %-6.3f    %-6.3f    \n',model,D8P15COpt1);
figure;
% plot(BP,S2,'ko',BP,S4,'k+','MarkerSize',4);
hold on;
% plot(x1,zc1,'r--',x1,zc2,'r:',x1,zc3,'b--',x1,zc4,'k-',x1,zc5,'b:');
plot(x1,zc1,'r--',x1,zc2,'r-',x1,zc3,'b--',x1,zc4,'k-',x1,zc5,'b-',...
    'LineWidth',1);
title('15 % Cooled Exhaust Gas Recirculation','FontSize',13,'FontWeight','bold','Color','k');
legend('2S','4S', '2SD4P15C', '2SD6P15C', '2SD8P15C', 'Location','southeast');
xlabel(xlbl,'FontSize',13,'FontWeight','bold','Color','k');
ylabel(ylbl,'FontSize',13,'FontWeight','bold','Color','k');
xlim ([2 5]),ylim auto;
s = "Fig_4_6_BTE.fig";
saveas(gcf,s);
% hold off;
case 7
temp1 = D4P10C; temp2 = D6P10C; temp3 = D8P10C;
[D6P5CPC,zc3,D6P5COpt] = polycurve(BP,D6P5C);
[D6P10CPC, zc4,D6P10COpt] = polycurve(BP,D6P10C);
[D6P15CPC, zc5,D6P15COpt]= polycurve(BP,D6P15C);
figure;hold on;
% plot(x1,zc1,'r--',x1,zc2,'r-',x1,zc3,'b--',x1,zc4,'k-',x1,zc5,'b-');
plot(x1,zc1,'r--',x1,zc2,'r-',x1,zc3,'b--',x1,zc4,'k-',x1,zc5,'b-',...
    'LineWidth',1);
title('Cooled Exhaust Gas Recirculation - 6 mm
Orifice','FontSize',13,'FontWeight','bold','Color','k');
legend('2S','4S','2SD6P5C', '2SD6P10C', '2SD6P15C','Location','southeast');
% xlabel(xlbl,'FontSize',8);
xlabel(xlbl,'FontSize',13,'FontWeight','bold','Color','k');
ylabel(ylbl,'FontSize',13,'FontWeight','bold','Color','k');
xlim ([2 5]),ylim auto;
s = "Fig_4_7_BTE.fig";
saveas(gcf,s);
hold off;
    otherwise
end
end
```

```
Comparison of Brake Thermal Efficiencies at optimum Brake Power points
Model          BP         BTE       %improved    Remarks
2S            4.287      34.192     0.000
4S            4.398      41.841     22.370
```

```
2SD4P5UC      4.393     37.701    10.260
2SD6P5UC      4.445     38.345    12.150
2SD8P5UC      4.366     37.185    8.750
2SD4P5C       4.318     39.616    15.860
2SD6P5C       4.359     40.354    18.020
2SD8P5C       4.417     39.907    16.710
2SD4P10UC     4.283     38.958    13.940
2SD6P10UC     4.267     39.768    16.310
2SD8P10UC     4.292     37.745    10.390
2SD4P10C      4.265     40.975    19.840
2SD6P10C      4.297     41.350    20.940
2SD8P10C      4.272     40.470    18.360
2SD4P15UC     4.314     36.996    8.200
2SD6P15UC     4.394     37.224    8.870
2SD8P15UC     4.292     36.445    6.590
2SD4P15C      4.353     39.286    14.900
2SD6P15C      4.358     39.589    15.780
2SD8P15C      4.338     39.037    14.170
```

Comparison at optimum performance point of 2S

Comparing 2S and D4P5H performance at the optimum point of 2S

```
fprintf('Comparison of performance wrt optimum point of two-stroke base configuration\n');
fprintf('Model        BP (kW)   BTE(base)(%%)    BTE(model)(%%)   (%%) improved\n');
%
xref2S = 4.287; yref2S = polyval(S2PC,xref2S);
xref = xref2S;yref = yref2S;
% 2S
c2 = S2PC;c0 = '2S';
comparing(c0,xref,yref,c2);
%4s
c2 = S4PC;c0 = '4S';
comparing(c0,xref,yref,c2);

% D4P5H
c2 = D4P5HPC;c0 = 'D4P5UC';
comparing(c0,xref,yref,c2);
% D6P5H
c2 = D6P5HPC;c0 = 'D6P5UC';
comparing(c0,xref,yref,c2);
% D8P5H
c2 = D8P5HPC;c0 = 'D8P5UC';
comparing(c0,xref,yref,c2);
% D4P5C
c2 = D4P5CPC;c0 = 'D4P5C';
comparing(c0,xref,yref,c2);
% D6P5C
c2 = D6P5CPC;c0 = 'D6P5C';
comparing(c0,xref,yref,c2);
% D8P5C
c2 = D8P5CPC;c0 = 'D8P5C';
```

```
comparing(c0,xref,yref,c2);

% D4P10H
c2 = D4P10HPC;c0 = 'D4P10UC';
comparing(c0,xref,yref,c2);
% D6P10H
c2 = D6P10HPC;c0 = 'D6P10UC';
comparing(c0,xref,yref,c2);
% D8P10H
c2 = D8P10HPC;c0 = 'D8P10UC';
comparing(c0,xref,yref,c2);

% D4P10C
c2 = D4P10CPC;c0 = 'D4P10C';
comparing(c0,xref,yref,c2);
% D6P10C
c2 = D6P10CPC;c0 = 'D6P10C';
comparing(c0,xref,yref,c2);
% D8P10C
c2 = D8P10CPC;c0 = 'D8P10C';
comparing(c0,xref,yref,c2);

% D4P15H
c2 = D4P15HPC;c0 = 'D4P15UC';
comparing(c0,xref,yref,c2);
% D6P15H
c2 = D6P15HPC;c0 = 'D6P15UC';
comparing(c0,xref,yref,c2);
% D8P15H
c2 = D8P15HPC;c0 = 'D8P15UC';
comparing(c0,xref,yref,c2);

% D4P15C
c2 = D4P15CPC;c0 = 'D4P15C';
comparing(c0,xref,yref,c2);
% D6P15C
c2 = D6P15CPC;c0 = 'D6P15C';
comparing(c0,xref,yref,c2);
%D8P15C
c2 = D8P15CPC;c0 = 'D8P15C';
comparing(c0,xref,yref,c2);
```

```
Comparison of performance wrt optimum point of two-stroke base configuration
Model         BP (kW)   BTE(base)(%)    BTE(model)(%)   (%) improved
2S2S           4.287       34.192         34.192            0.000
2S4S           4.287       34.192         41.821            22.313
2SD4P5UC       4.287       34.192         37.683            10.211
2SD6P5UC       4.287       34.192         38.309            12.040
2SD8P5UC       4.287       34.192         37.175            8.724
2SD4P5C        4.287       34.192         39.615            15.860
2SD6P5C        4.287       34.192         40.345            17.996
```

```
2SD8P5C        4.287       34.192       39.879           16.632
2SD4P10UC      4.287       34.192       38.958           13.939
2SD6P10UC      4.287       34.192       39.767           16.305
2SD8P10UC      4.287       34.192       37.745           10.392
2SD4P10C       4.287       34.192       40.974           19.835
2SD6P10C       4.287       34.192       41.350           20.935
2SD8P10C       4.287       34.192       40.469           18.359
2SD4P15UC      4.287       34.192       36.995           8.197
2SD6P15UC      4.287       34.192       37.208           8.820
2SD8P15UC      4.287       34.192       36.445           6.590
2SD4P15C       4.287       34.192       39.279           14.877
2SD6P15C       4.287       34.192       39.580           15.759
2SD8P15C       4.287       34.192       39.033           14.157
```

Comparison at optimum performance point of 4S

Comparing 2S and D4P5H performance at the optimum point of 4S

```
fprintf('Comparison of performance wrt optimum point of four-stroke engine\n');
fprintf('Model        BP (kW)   BTE(base)(%%)    BTE(model)(%%)   (%%) improved\n');
xref = xref4S;yref = yref4S;
% 2S
c2 = S2PC;c0 = '2S';
comparing(c0,xref,yref,c2);
%4s
c2 = S4PC;c0 = '4S';
comparing(c0,xref,yref,c2);
% D4P5H
c2 = D4P5HPC;c0 = 'D4P5UC';
comparing(c0,xref,yref,c2);
% D6P5H
c2 = D6P5HPC;c0 = 'D6P5UC';
comparing(c0,xref,yref,c2);
% D8P5H
c2 = D8P5HPC;c0 = 'D8P5UC';
comparing(c0,xref,yref,c2);
% D4P5C
c2 = D4P5CPC;c0 = 'D4P5C';
comparing(c0,xref,yref,c2);
% D6P5C
c2 = D6P5CPC;c0 = 'D6P5C';
comparing(c0,xref,yref,c2);
% D8P5C
c2 = D8P5CPC;c0 = 'D8P5C';
comparing(c0,xref,yref,c2);

% D4P10H
c2 = D4P10HPC;c0 = 'D4P10UC';
comparing(c0,xref,yref,c2);
% D6P10H
c2 = D6P10HPC;c0 = 'D6P10UC';
comparing(c0,xref,yref,c2);
```

```
% D8P10H
c2 = D8P10HPC;c0 = 'D8P10UC';
comparing(c0,xref,yref,c2);

% D4P10C
c2 = D4P10CPC;c0 = 'D4P10C';
comparing(c0,xref,yref,c2);
% D6P10C
c2 = D6P10CPC;c0 = 'D6P10C';
comparing(c0,xref,yref,c2);
% D8P10C
c2 = D8P10CPC;c0 = 'D8P10C';
comparing(c0,xref,yref,c2);

% D4P15H
c2 = D4P15HPC;c0 = 'D4P15UC';
comparing(c0,xref,yref,c2);
% D6P15H
c2 = D6P15HPC;c0 = 'D6P15UC';
comparing(c0,xref,yref,c2);
% D8P15H
c2 = D8P15HPC;c0 = 'D8P15UC';
comparing(c0,xref,yref,c2);

% D4P15C
c2 = D4P15CPC;c0 = 'D4P15C';
comparing(c0,xref,yref,c2);
% D6P15C
c2 = D6P15CPC;c0 = 'D6P15C';
comparing(c0,xref,yref,c2);
%D8P15C
c2 = D8P15CPC;c0 = 'D8P15C';
comparing(c0,xref,yref,c2);
```

```
Comparison of performance wrt optimum point of four-stroke engine
Model        BP (kW)   BTE(base)(%)    BTE(model)(%)   (%) improved
2S2S          4.398       34.175         34.175            0.000
2S4S          4.398       34.175         41.841            22.433
2SD4P5UC      4.398       34.175         37.701            10.318
2SD6P5UC      4.398       34.175         38.342            12.193
2SD8P5UC      4.398       34.175         37.183            8.803
2SD4P5C       4.398       34.175         39.604            15.887
2SD6P5C       4.398       34.175         40.351            18.073
2SD8P5C       4.398       34.175         39.906            16.771
2SD4P10UC     4.398       34.175         38.935            13.928
2SD6P10UC     4.398       34.175         39.737            16.275
2SD8P10UC     4.398       34.175         37.727            10.396
2SD4P10C      4.398       34.175         40.941            19.800
2SD6P10C      4.398       34.175         41.331            20.941
2SD8P10C      4.398       34.175         40.440            18.334
2SD4P15UC     4.398       34.175         36.984            8.222
```

```
2SD6P15UC      4.398       34.175       37.224            8.923
2SD8P15UC      4.398       34.175       36.427            6.592
2SD4P15C       4.398       34.175       39.282            14.946
2SD6P15C       4.398       34.175       39.586            15.834
2SD8P15C       4.398       34.175       39.031            14.210
```

Comparison at optimum performance point of D6P10C

Comparing 2S and D4P5H performance at the optimum point of 2SD6P10C

```
fprintf('Comparison of performance wrt optimum point of 2SD6P10C configuration\n');
fprintf('Model        BP (kW)   BTE(base)(%%)    BTE(model)(%%)   (%%) improved\n');
xref = xrefD6P10C;yref = yrefD6P10C;
% 2S
c2 = S2PC;c0 = '2S';
comparing(c0,xref,yref,c2);
%4s
c2 = S4PC;c0 = '4S';
comparing(c0,xref,yref,c2);
% D4P5H
c2 = D4P5HPC;c0 = 'D4P5UC';
comparing(c0,xref,yref,c2);
% D6P5H
c2 = D6P5HPC;c0 = 'D6P5UC';
comparing(c0,xref,yref,c2);
% D8P5H
c2 = D8P5HPC;c0 = 'D8P5UC';
comparing(c0,xref,yref,c2);
% D4P5C
c2 = D4P5CPC;c0 = 'D4P5C';
comparing(c0,xref,yref,c2);
% D6P5C
c2 = D6P5CPC;c0 = 'D6P5C';
comparing(c0,xref,yref,c2);
% D8P5C
c2 = D8P5CPC;c0 = 'D8P5C';
comparing(c0,xref,yref,c2);

% D4P10H
c2 = D4P10HPC;c0 = 'D4P10UC';
comparing(c0,xref,yref,c2);
% D6P10H
c2 = D6P10HPC;c0 = 'D6P10UC';
comparing(c0,xref,yref,c2);
% D8P10H
c2 = D8P10HPC;c0 = 'D8P10UC';
comparing(c0,xref,yref,c2);

% D4P10C
c2 = D4P10CPC;c0 = 'D4P10C';
comparing(c0,xref,yref,c2);
% D6P10C
```

```
c2 = D6P10CPC;c0 = 'D6P10C';
comparing(c0,xref,yref,c2);
% D8P10C
c2 = D8P10CPC;c0 = 'D8P10C';
comparing(c0,xref,yref,c2);

% D4P15H
c2 = D4P15HPC;c0 = 'D4P15UC';
comparing(c0,xref,yref,c2);
% D6P15H
c2 = D6P15HPC;c0 = 'D6P15UC';
comparing(c0,xref,yref,c2);
% D8P15H
c2 = D8P15HPC;c0 = 'D8P15UC';
comparing(c0,xref,yref,c2);

% D4P15C
c2 = D4P15CPC;c0 = 'D4P15C';
comparing(c0,xref,yref,c2);
% D6P15C
c2 = D6P15CPC;c0 = 'D6P15C';
comparing(c0,xref,yref,c2);
%D8P15C
c2 = D8P15CPC;c0 = 'D8P15C';
comparing(c0,xref,yref,c2);

fprintf('Equations of curves\n');
fprintf('2S Eff =  %-6.3f  x^2+ %-6.3f x+  %-6.3f\n',S2PC);
fprintf('4S Eff =  %-6.3f  x^2+ %-6.3f x+  %-6.3f\n',S4PC);
fprintf('2SD4P5UCPC   Eff =  %-6.3f  x^2+ %-6.3f x+  %-6.3f\n',D4P5HPC);
fprintf('2SD6P5UCPC  Eff =  %-6.3f  x^2+ %-6.3f x+  %-6.3f\n',D6P5HPC);
fprintf('2SD8P5UCPC  Eff =  %-6.3f  x^2+ %-6.3f x+  %-6.3f\n',D8P5HPC);
fprintf('2SD4P5CPC  Eff =  %-6.3f  x^2+ %-6.3f x+  %-6.3f\n',D4P5CPC);
fprintf('2SD6P5CPC  Eff =  %-6.3f  x^2+ %-6.3f x+  %-6.3f\n',D6P5CPC);
fprintf('2SD8P5CPC  Eff =  %-6.3f  x^2+ %-6.3f x+  %-6.3f\n',D8P5CPC);

fprintf('2SD4P10UCPC  Eff =  %-6.3f  x^2+ %-6.3f x+  %-6.3f\n',D4P10HPC);
fprintf('2SD6P10UCPC  Eff =  %-6.3f  x^2+ %-6.3f x+  %-6.3f\n',D6P10HPC);
fprintf('2SD8P10UCPC  Eff =  %-6.3f  x^2+ %-6.3f x+  %-6.3f\n',D8P10HPC);
fprintf('2SD4P10CPC  Eff =  %-6.3f  x^2+ %-6.3f x+  %-6.3f\n',D4P10CPC);
fprintf('2SD6P10CPC  Eff =  %-6.3f  x^2+ %-6.3f x+  %-6.3f\n',D6P10CPC);
fprintf('2SD8P10CPC  Eff =  %-6.3f  x^2+ %-6.3f x+  %-6.3f\n',D8P10CPC);

fprintf('2SD4P15UC  Eff =  %-6.3f  x^2+ %-6.3f x+  %-6.3f\n',D4P15HPC);
fprintf('2SD6P15UC  Eff =  %-6.3f  x^2+ %-6.3f x+  %-6.3f\n',D6P15HPC);
fprintf('2SD8P15UC  Eff =  %-6.3f  x^2+ %-6.3f x+  %-6.3f\n',D8P15HPC);
fprintf('2SD4P15C  Eff =  %-6.3f  x^2+ %-6.3f x+  %-6.3f\n',D4P15CPC);
fprintf('2SD6P15C  Eff =  %-6.3f  x^2+ %-6.3f x+  %-6.3f\n',D6P15CPC);
fprintf('2SD8P15C  Eff =  %-6.3f  x^2+ %-6.3f x+  %-6.3f\n',D8P15CPC);

function [S2PC, zc,zOpt] = polycurve(BP,S2)
```

```
% Error calculation and comparison
x1=(2:0.1:5)';
S2PC = polyfit(BP,S2,2);
zc = polyval(S2PC,x1);
xOpt = -S2PC(2)/(2*S2PC(1));
yOpt = polyval(S2PC,xOpt);
zOpt = [xOpt,yOpt];
% [S2PC, zc];
end

function [delres] = DelRes(yref,yOpt)
delres = round((100*(yOpt-yref)/yref),2);
end

function [z]= comparing(model, xref, yref, c2PC)
model = strcat('2S',model);
y1 = yref;
y2 = polyval(c2PC,xref);
perImp = 100*(y2-y1)/y1;
% perImp is percentage improvement increase or decrease in chVal
z = [xref,yref,y2,perImp];

% fprintf('%-10s BP %-6.3f  BTE %% %-6.3f Improvement %% %-6.3f over %% %-6.3f  \n',model,z);
fprintf('%-10s    %-6.3f      %-6.3f        %-6.3f            %-6.3f\n',model,z);
end
```

```
Comparison of performance wrt optimum point of 2SD6P10C configuration
Model        BP (kW)   BTE(base)(%)    BTE(model)(%)   (%) improved
2S2S          4.297       34.192        34.192           0.000
2S4S          4.297       34.192        41.825           22.324
2SD4P5UC      4.297       34.192        37.686           10.221
2SD6P5UC      4.297       34.192        38.313           12.053
2SD8P5UC      4.297       34.192        37.177           8.732
2SD4P5C       4.297       34.192        39.616           15.863
2SD6P5C       4.297       34.192        40.348           18.004
2SD8P5C       4.297       34.192        39.883           16.645
2SD4P10UC     4.297       34.192        38.957           13.938
2SD6P10UC     4.297       34.192        39.766           16.303
2SD8P10UC     4.297       34.192        37.745           10.393
2SD4P10C      4.297       34.192        40.973           19.833
2SD6P10C      4.297       34.192        41.350           20.936
2SD8P10C      4.297       34.192        40.469           18.357
2SD4P15UC     4.297       34.192        36.996           8.200
2SD6P15UC     4.297       34.192        37.211           8.829
2SD8P15UC     4.297       34.192        36.445           6.591
2SD4P15C      4.297       34.192        39.281           14.883
2SD6P15C      4.297       34.192        39.583           15.766
2SD8P15C      4.297       34.192        39.034           14.162
Equations of curves
2S Eff =  -1.410  x^2+ 12.095 x+  8.264
4S Eff =  -1.606  x^2+ 14.129 x+  10.770
```

```
2SD4P5UCPC   Eff =  -1.586  x^2+ 13.934 x+  7.097
2SD6P5UCPC  Eff =  -1.464  x^2+ 13.018 x+  9.416
2SD8P5UCPC  Eff =  -1.586  x^2+ 13.849 x+  6.953
2SD4P5CPC  Eff =  -1.890  x^2+ 16.317 x+  4.392
2SD6P5CPC  Eff =  -1.640  x^2+ 14.295 x+  9.200
2SD8P5CPC  Eff =  -1.653  x^2+ 14.607 x+  7.646
2SD4P10UCPC  Eff =  -1.741  x^2+ 14.914 x+  7.021
2SD6P10UCPC  Eff =  -1.809  x^2+ 15.434 x+  6.840
2SD8P10UCPC  Eff =  -1.606  x^2+ 13.789 x+  8.152
2SD4P10CPC  Eff =  -1.910  x^2+ 16.291 x+  6.235
2SD6P10CPC  Eff =  -1.876  x^2+ 16.125 x+  6.704
2SD8P10CPC  Eff =  -1.863  x^2+ 15.915 x+  6.474
2SD4P15UC  Eff =  -1.606  x^2+ 13.857 x+  7.110
2SD6P15UC  Eff =  -1.437  x^2+ 12.633 x+  9.469
2SD8P15UC  Eff =  -1.606  x^2+ 13.789 x+  6.852
2SD4P15C  Eff =  -1.620  x^2+ 14.100 x+  8.598
2SD6P15C  Eff =  -1.620  x^2+ 14.117 x+  8.827
2SD8P15C  Eff =  -1.687  x^2+ 14.637 x+  7.289
```

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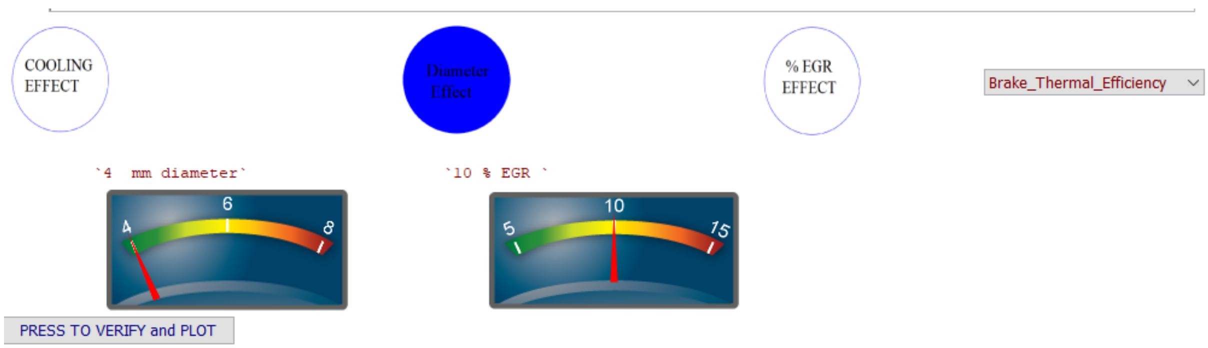
APPENDIX 7

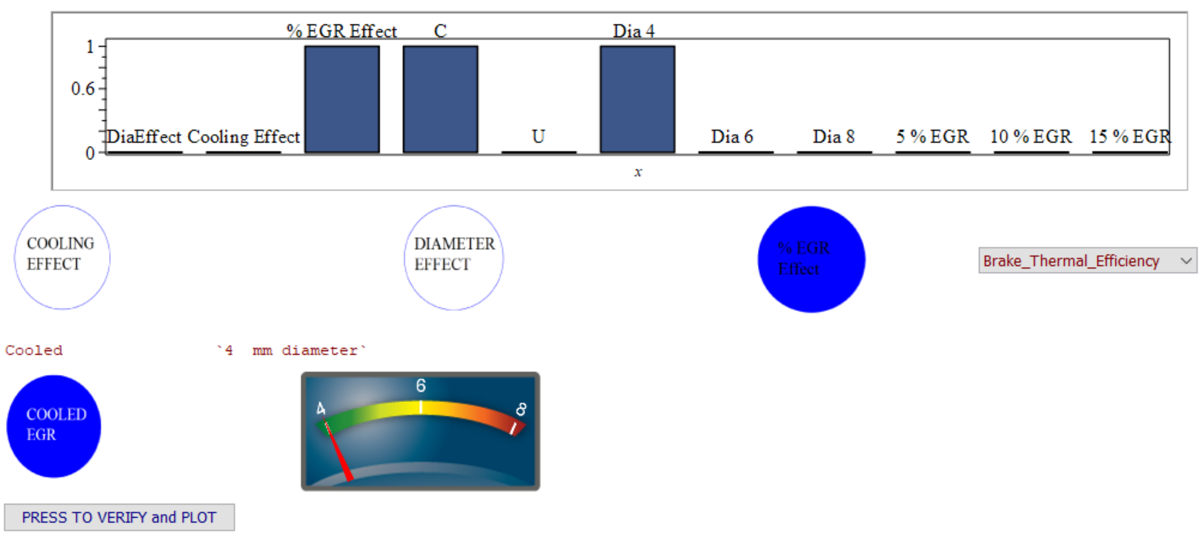
MAPLE PROGRAMME

restart :

```
Have Patience Wait For some time even if Maple Shows Ready!! Select Options First.
For EACH selections TWO further options pop out.
Select Characterisc Data from ComboBox popout menu.Data table will cahnge to give you the
experimental data for that characteristic from various experiments.
Only 3 columns will be present to confirm your options. Press to verify and Plot for the current
option.
Press to generate for all options for this characteristic.
Play as you like for all characteristics!

This report gives an experimental analysis on the improvement of a Two-Stroke Engine with orifice
suction and Cooled Exhaust Gas Recirculation (EGR).
Objective; To match the performance of a 4 Stroke Gasoline Engine with EGR modifications.

This document can be modified by any one for their experimental study.
The data are plotted, curve fitted, optimum points obtained and report generated for selected one or
all options and characteristics.
OPTIONS:
2SD4P5U : 2 Stroke 4 mm Orifice 5 % EGR UNCOOLED;
2SD4P10U: 2 Stroke 4 mm Orifice 10 % EGR UNCOOLED
2SD4P15U: 2 Stroke 4 mm Orifice 15 % EGR UNCOOLED

2SD6P5U : 2 Stroke 6 mm Orifice 5 % EGR UNCOOLED
2SD6P10U: 2 Stroke 6 mm Orifice 10 % EGR UNCOOLED
2SD6P15U: 2 Stroke 6 mm Orifice 15 % EGR UNCOOLED

2SD8P5U : 2 Stroke 8 mm Orifice 5 % EGR UNCOOLED
2SD8P10U: 2 Stroke 8 mm Orifice 10 % EGR UNCOOLED
2SD8P15U: 2 Stroke 8 mm Orifice 15 % EGR UNCOOLED
-------------------------------------------------
2SD4P5C : 2 Stroke 4 mm Orifice 5 % EGR COOLED;
2SD4P10C: 2 Stroke 4 mm Orifice 10 % EGR COOLED
2SD4P15C: 2 Stroke 4 mm Orifice 15 % EGR COOLED

2SD6P5C : 2 Stroke 6 mm Orifice 5 % EGR COOLED
2SD6P10C: 2 Stroke 6 mm Orifice 10 % EGR COOLED
2SD6P15C: 2 Stroke 6 mm Orifice 15 % EGR COOLED

2SD8P5C : 2 Stroke 8 mm Orifice 5 % EGR COOLED
2SD8P10C: 2 Stroke 8 mm Orifice 10 % EGR COOLED
2SD8P15C: 2 Stroke 8 mm Orifice 15 % EGR COOLED
```

	2SD4P...	2SD6P...	2SD8P...	2SD4P...	2SD6P...	2SD8P...	2SD4P5C	2SD6P5C	2SD8P5C	2SD4P...	2SD6P...	2SD8P...	2SD4P...	2SD6P...	2SD8P...
1	30.100	30.700	29.500	28.700	29.400	28.200	30.000	32.000	30.800	31.400	31.700	31.100	30.700	31.000	30.100
2	34.100	34.800	33.200	32.200	32.300	31.900	33.600	34.200	34.000	35.800	36.000	35.300	34.100	34.300	33.900
3	36.100	36.900	35.100	34.200	34.400	33.800	36.400	37.700	36.500	37.900	38.200	37.500	36.300	36.600	36.000
4	37.300	38.100	36.200	35.400	35.600	34.900	37.800	38.800	38.000	39.200	39.500	38.700	37.600	37.900	37.300
5	38.100	38.900	36.900	36.200	36.400	35.600	38.700	39.500	39.000	40.100	40.400	39.600	38.400	38.700	38.100
6	38.700	39.500	37.500	36.800	37.100	36.200	39.400	40.000	39.700	40.700	41.100	40.200	39.100	39.400	38.800
7	39.100	39.900	37.900	37.100	37.300	36.600	39.700	40.500	40.000	41.100	41.500	40.600	39.400	39.700	39.200


COOLING EFFECT
Diameter Effect
% EGR EFFECT
Brake_Thermal_Efficiency
`4 mm diameter`
`10 % EGR `
4
6
8
5
10
15
PRESS TO VERIFY and PLOT


% EGR Effect
C
Dia 4
1
0.6
0
DiaEffect
Cooling Effect
U
Dia 6
Dia 8
5 % EGR
10 % EGR
15 % EGR
x
COOLING EFFECT
DIAMETER EFFECT
% EGR Effect
Brake_Thermal_Efficiency
Cooled
`4 mm diameter`
COOLED EGR
4
6
8
PRESS TO VERIFY and PLOT

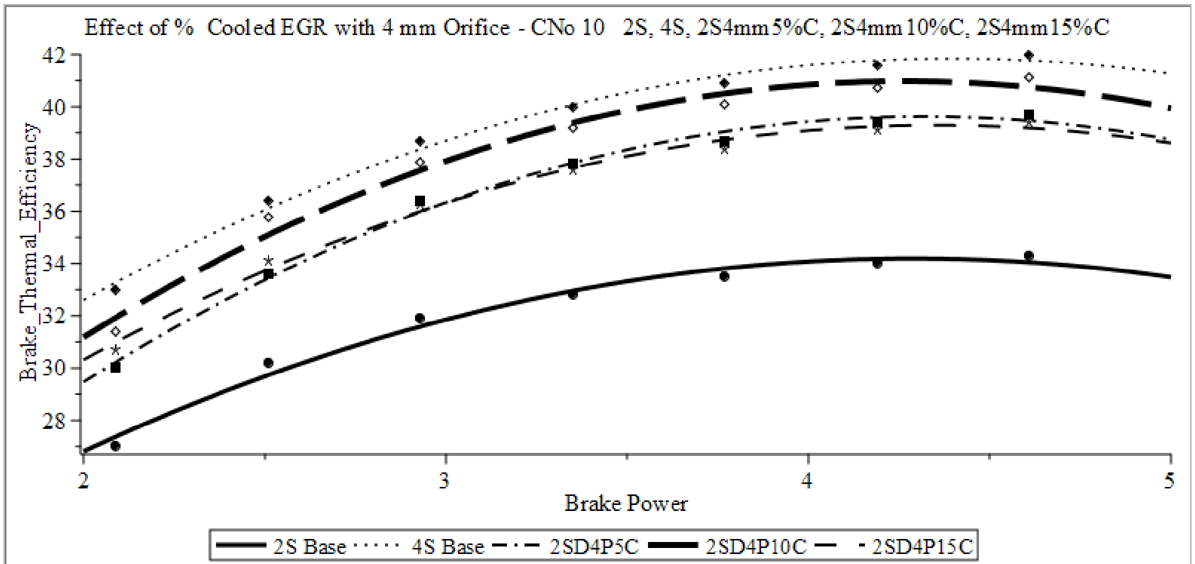


Fig. 10 Cooled 4 mm Orifice

Clear print area

Press To Print printrea

Effect of % Cooled EGR with 4 mm Orifice - CNo 10
Brake_Thermal_E 2S, 4S, 2S4mm5%C, 2S4mm10%C, 2S4mm15%C

Engine	Brake Power	Brake_Thermal_Efficiency	
2S Base	4.29	34.2	%
4S Base	4.4	41.8	%
2SD4P5C	4.32	39.6	%
2SD4P10C	4.26	41	%

Press To Generate all Reports for this Characteristic

Report on Effect of Cooling at 4 mm Orifice and 5% EGR - CNo 1
Brake_Thermal_Efficiency 2S, 4S, 2S4mm5%C, 2S4mm10%C, 2S4mm15%C

Engine	Brake Power	Brake_Thermal_Efficiency
2S Base	4.29 kW	34.2 %
4S Base	4.4 kW	41.8 %
2SD4P5U	4.39 kW	37.7 %
2SD4P5C	4.32 kW	39.6 %

Report on Effect of Cooling at 6 mm Orifice and 5% EGR - CNo 2
Brake_Thermal_Efficiency 2S, 4S, 2S4mm5%C, 2S4mm10%C, 2S4mm15%C

Engine	Brake Power	Brake_Thermal_Efficiency
2S Base	4.29 kW	34.2 %
4S Base	4.4 kW	41.8 %
2SD6P5U	4.44 kW	38.3 %
2SD6P5C	4.36 kW	40.4 %

Report on Effect of Diameter with uncooled 10 % EGR - CNo 17
Brake_Thermal_Efficiency 2S, 4S, 2S4mm5%C, 2S4mm10%C, 2S4mm15%C

Engine	Brake Power	Brake_Thermal_Efficiency
2S Base	4.29 kW	34.2 %
4S Base	4.4 kW	41.8 %
2SD4P10U	4.28 kW	39 %
2SD6P10U	4.27 kW	39.8 %
2SD8P10U	4.29 kW	37.7 %

Report on Effect of Diameter with Cooled 10 % EGR - CNo 20
Brake_Thermal_Efficiency 2S, 4S, 2S4mm5%C, 2S4mm10%C, 2S4mm15%C

Engine	Brake Power	Brake_Thermal_Efficiency
2S Base	4.29 kW	34.2 %
4S Base	4.4 kW	41.8 %
2SD4P10C	4.26 kW	41 %
2SD6P10C	4.3 kW	41.4 %
2SD8P10C	4.27 kW	40.5 %

Report on Effect of Diameter with Cooled 15 % EGR - CNo 21
Brake_Thermal_Efficiency 2S, 4S, 2S4mm5%C, 2S4mm10%C, 2S4mm15%C

Engine	Brake Power	Brake_Thermal_Efficiency
2S Base	4.29 kW	34.2 %
4S Base	4.4 kW	41.8 %
2SD4P15C	4.35 kW	39.3 %
2SD6P15C	4.36 kW	39.6 %
2SD8P15C	4.34 kW	39 %
