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APPENDICES

Appendix A Composite Curve Analysis Data

Example 1: This example involves a process with one hot process stream (I1), two cold process stream (J1-J2), one hot, and one cold utilities.

Table A1 Data for example 1.

Stream	TIN(°C)	TOUT(°C)	F(kW/°C)	h (kW/m^2-°C)	Cost ($/kW-yr)
I1	167	77	22	2	-
J1	76	157	20	2	-
J2	47	95	7.5	0.67	-
HU	227	227	-	1	120
CU	27	47	-	1	20

EMAT = 1°C, Exchanger cost ($) = 6,600 + 670(Area)$^{0.83}$

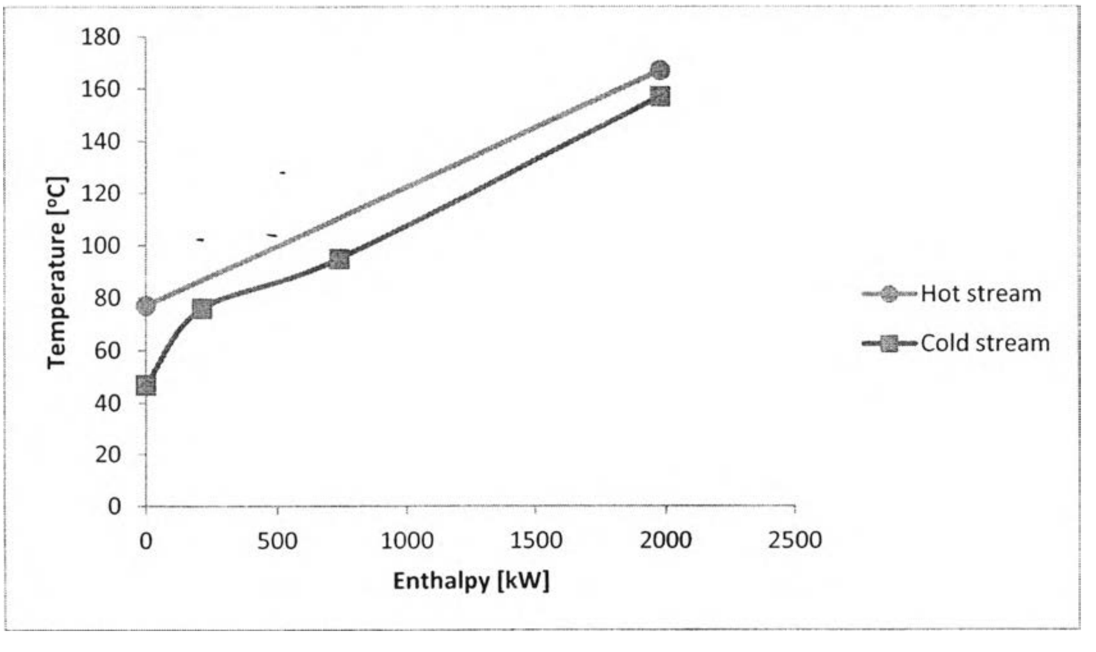

Figure A1 Composite curve of example 1.

Table A2 Composite curve analysis for example 1.

Hot Steam			dH	Q	Cold Stream				dH	Q
		I1	kW	kW			J1	J2	kW	kW
Temp. [°C]	FCp	22		[Up]	Temp. [°C]	FCp	20	7.5		[Down]
	dT					dT				
167				1980	157					1980
77	90	1980	1980	0	95	62	1240		1240	740
					76	19	380	142.5	522.5	217.5
					47	29		217.5	217.5	0
			1980						1762.5	

From figure A1:

Minimum cold utility = 0 kW, Maximum cold utility = 1980 kW

Minimum hot utility = 0 kW, Maximum hot utility = 1762.5 kW

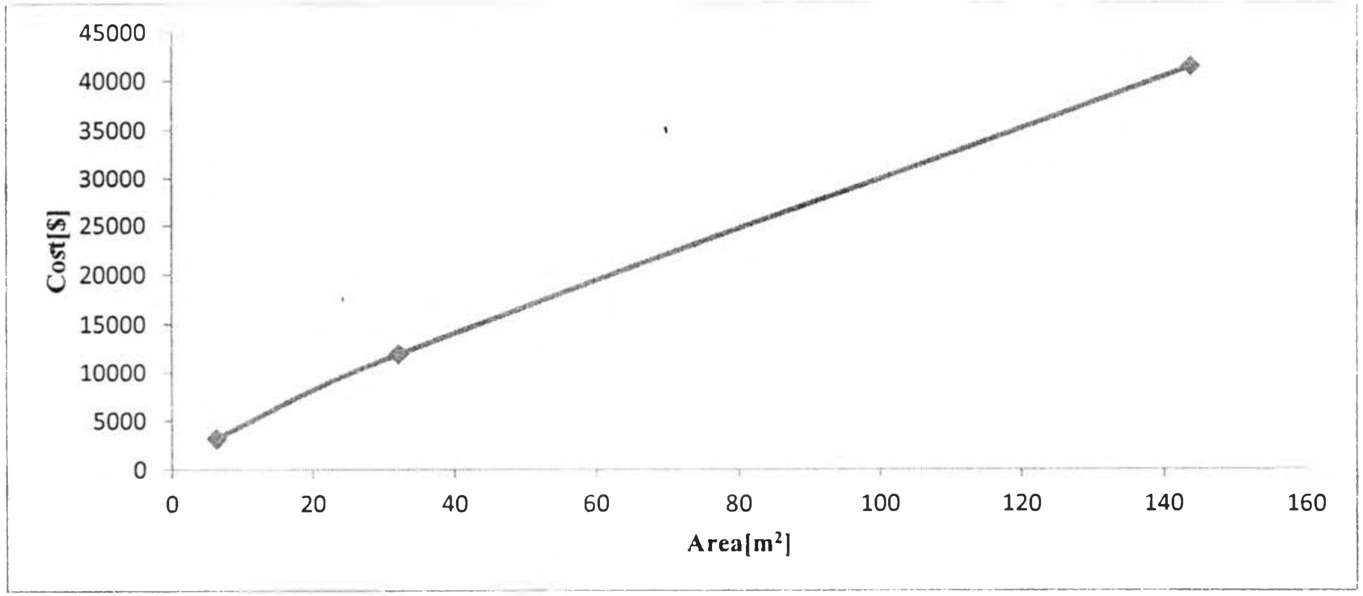

Figure A2 Trend of heat exchanger cost per area of example 1.

Table A3 Analysis cost for example 1.

Utility cost				Area cost		Fixed cost		TAC
Cost/kW	Hot (kW)	Cost/kW	Cold (kW)	Cost/m^2	Total area (m^2)	Cost/unit	No. of unit	$
120	0	20	0	309.9	182.5	6600	3	76,327

Example 2: This example involves a process with three hot process stream (I1-I3), two cold process stream (J1-J2), one hot, and one cold utilities.

Table A4 Data for example 2.

Stream	TIN(°C)	TOUT(°C)	F(kW/°C)	h (kW/m^2-°C)	Cost ($/kW-yr)
I1	155	30	8	2	-
I2	80	40	15	2	-
I3	200	40	15	2	-
J1	20	160	20	2	-
J2	20	100	15	2	-
HU	220	220	-	2	120
CU	20	30	-	2	20

EMAT = 1°C, Exchanger cost ($) = 6,000 + 660(Area)$^{0.85}$

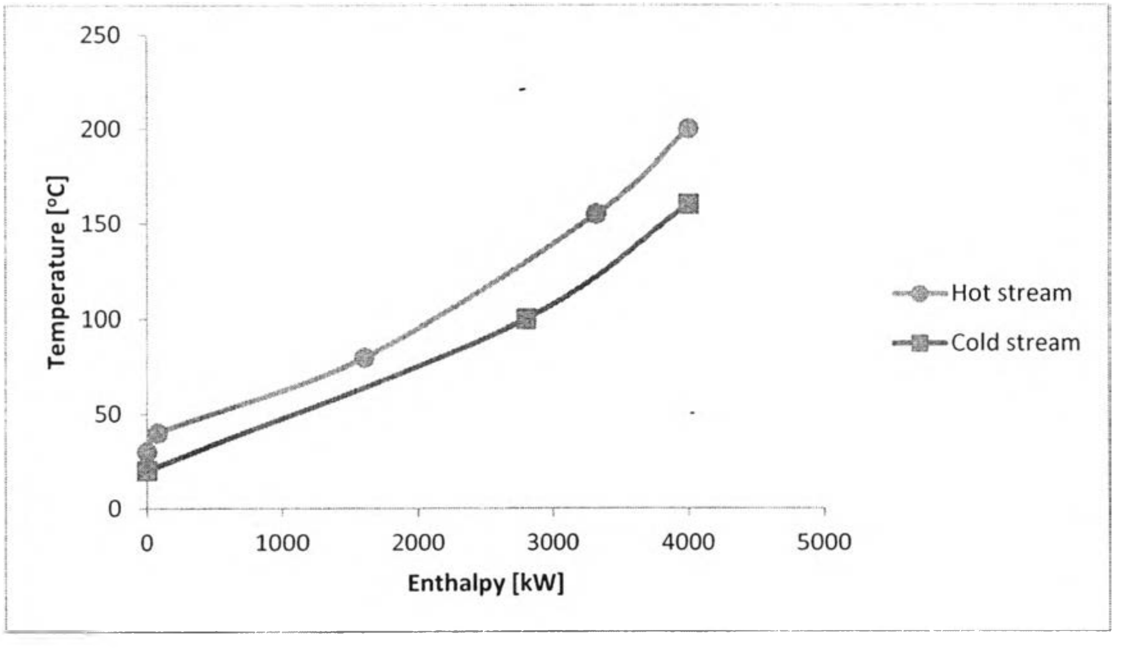

Figure A3 Composite curve of example 2.

Table A5 Composite curve analysis for example 2.

Hot Steam					dH	Q	Cold Stream				dH	Q
		I1	I2	I3	kW	kW			J1	J2	kW	kW
Temp.	FCp	8	15	15		[Up]	Temp.	FCp	20	15		[Down]
[°C]	dT						[°C]	dT				
200						4000	160					4000
155	45			675	675	3325	100	60	1200		1200	2800
80	75	600		1125	1725	1600	20	80	1600	1200	2800	0
40	40	320	600	600	1520	80						
30	10	80			80	0						
					4000						4000	

From figure A3:

Minimum cold utility = 0 kW, Maximum cold utility = 4000 kW

Minimum hot utility = 0 kW, Maximum hot utility = 4000 kW

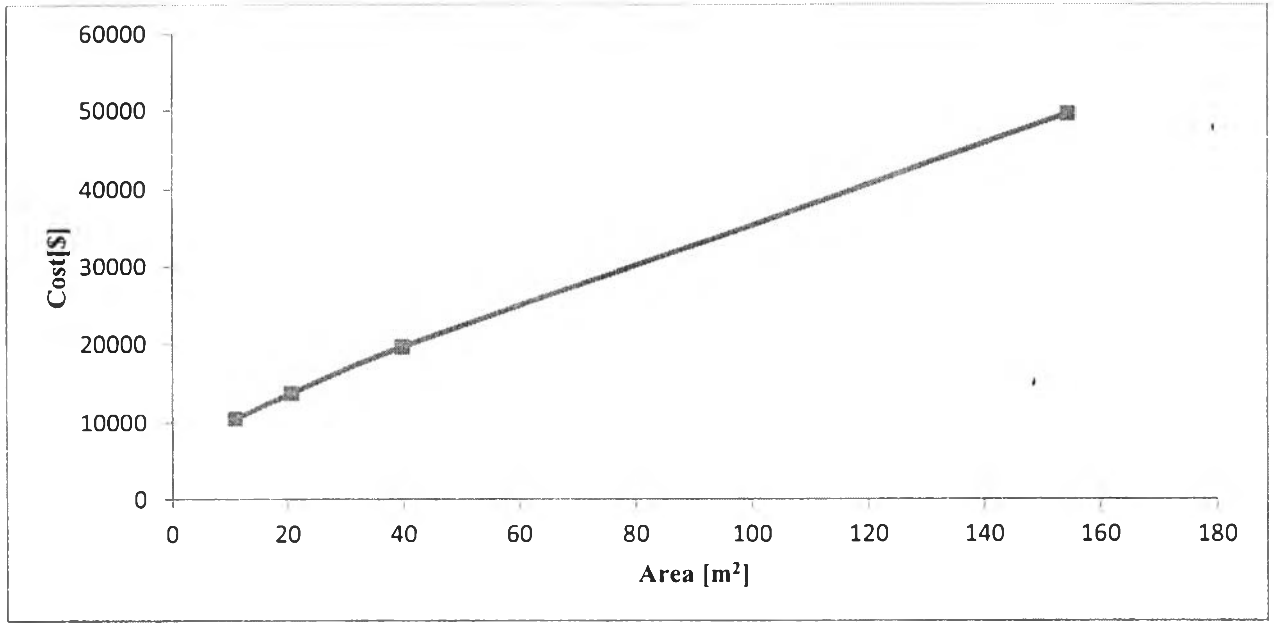

Figure A4 Trend of heat exchanger cost per area of example 2.

Table A6 Analysis cost for example 2.

Utility cost				Area cost		Fixed cost		TAC
Cost/kW	Hot (kW)	Cost/kW	Cold (kW)	Cost/m^2	Total area (m^2)	Cost/unit	No. of unit	$
120	0	20	0	328.93	217.8	6000	4	95,643

Example 3: This example involves a process with two hot process stream (I1-I2), four cold process stream (J1-J4), one hot, and one cold utilities.

Table A7 Data for example 3.

Stream	TIN(°C)	TOUT(°C)	F(kW/°C)	h (kW/m^2-°C)	Cost ($/kW-yr)
I1	180	75	30	2	-
I2	240	60	40	2	-
J1	40	230	20	1.5	-
J2	120	260	15	1.5	-
J3	40	130	25	2	
J4	80	190	20	2	-
HU	325	325	-	1	120
CU	25	25	-	2	20

EMAT = 1°C, Exchanger cost ($) = 8,000 + 50(Area)$^{0.75}$

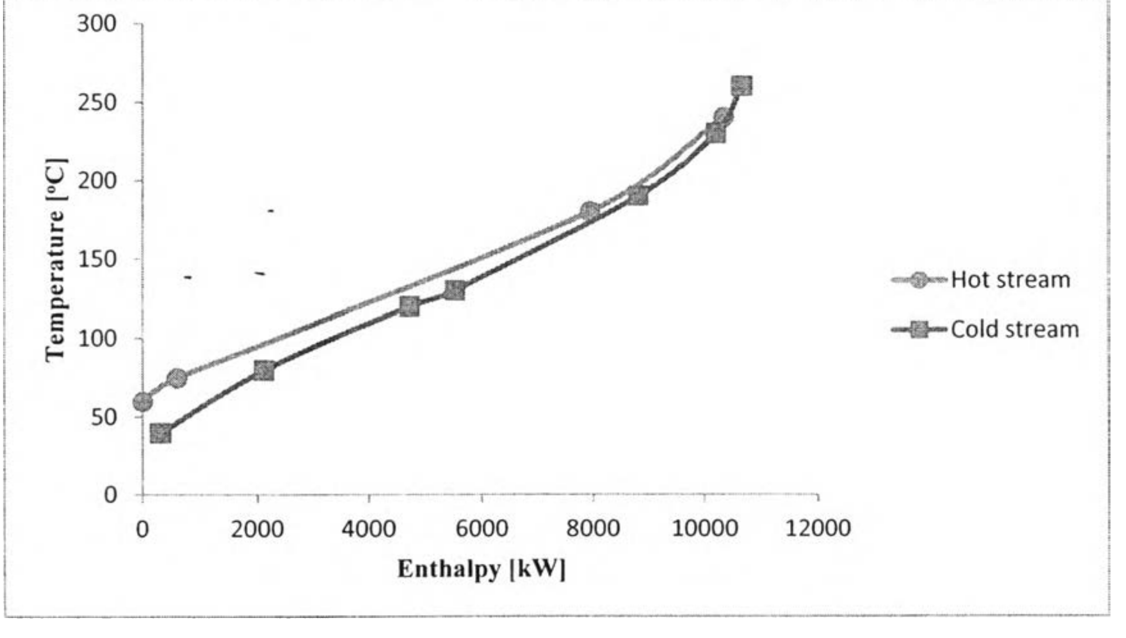

Figure A5 Composite curve of example 3.

Table A8 Composite curve analysis for example 2.

Hot Steam				dH	Q	Cold Stream						dH	Q
Temp. [°C]		I1	I2	kW	kW	Temp. [°C]		J1	J2	J3	J4	kW	kW
	FCp	30	40		[Up]		FCp	20	15	25	20		[Down]
	dT						dT						
240					10350	260							10665
180	60		2400	2400	7950	230	30		450			450	10215
75	105	3150	4200	7350	600	190	40	800	600			1400	8815
60	15		600	600	0	130	60	1200	900		1200	3300	5515
						120	10	200	150	250	200	800	4715
						80	40	800		1000	800	2600	2115
						40	40	800		1000		1800	315
				10350								10350	

From figure A5:

Minimum cold utility = 315 kW, Maximum cold utility = 10350 kW

Minimum hot utility = 315 kW, Maximum hot utility = 10350 kW

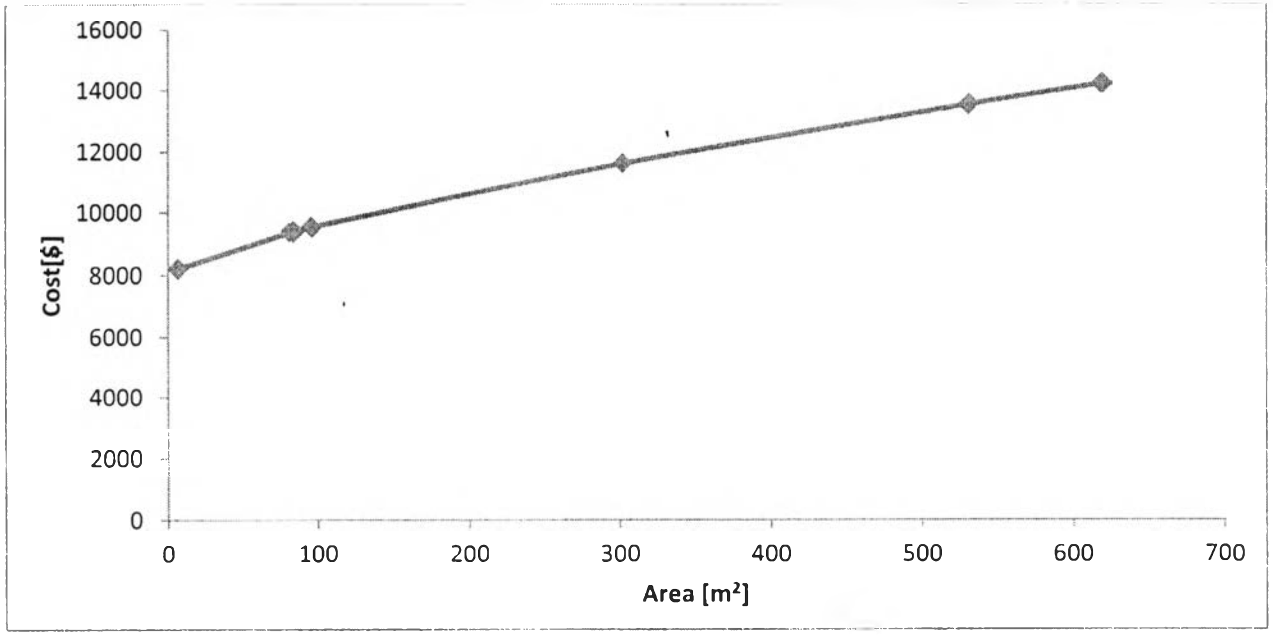

Figure A6 Trend of heat exchanger cost per area of example 3.

Table A9 Analysis cost for example 3.

Utility cost				Area cost		Fixed cost		TAC
Cost/kW	Hot (kW)	Cost/kW	Cold (kW)	Cost/m^2	Total area (m^2)	Cost/unit	No. of unit	$
120	0	20	0	11.61	1728.4	8000	8	128,169

Example 4: This example involves a process with five hot process stream (I1-I5), one cold process stream (J1), one hot, and one cold utilities.

Table A10 Data for example 4.

Stream	TIN(°C)	TOUT(°C)	F(kW/°C)	h (kW/m^2-°C)	Cost ($/kW-yr)
I1	227	47	6	2	-
J1	207	107	4	2	-
J2	187	87	6	2	-
J3	107	87	20	2	-
J4	107	47	12	2	
J5	17	387	18	2	-
HU	427	427	-	2	140
CU	27	47	-	2	10

EMAT = 5°C, Exchanger cost ($) = 1200(Area)$^{0.6}$

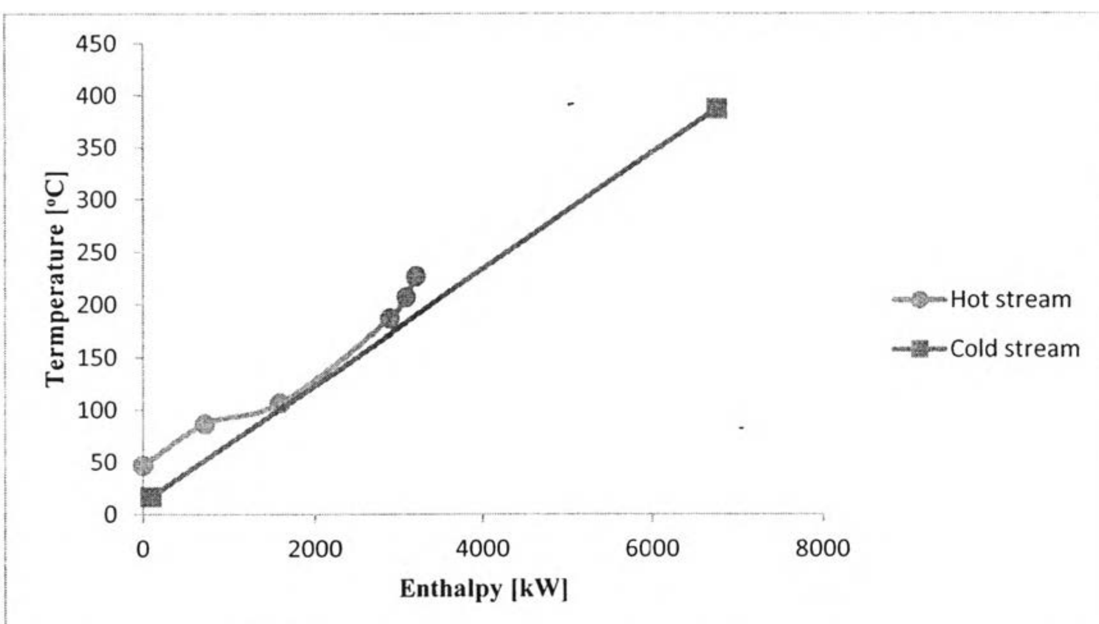

Figure A7 Composite curve of example 4.

Table A11 Composite curve analysis for example 4.

Hot Steam							dH	Q	Cold Stream			dH	Q
Temp. [°C]		I1	I2	I3	I4	I5	kW	kW	Temp. [°C]		J1	kW	kW
	FCp	6	4	6	20	12		[Up]		FCp	18		[Down]
	dT									dT			
227								3200	387				6750
207	20	120					120	3080	17	370	6660	6660	90
187	20	120	80				200	2880					
107	80	480	320	480			1280	1600					
87	20	120		120	400	240	880	720					
47	40	240				480	720	0					
							3200					6660	

From figure A7:

Minimum cold utility = 90 kW, Maximum cold utility = 3200 kW

Minimum hot utility = 3550 kW, Maximum hot utility = 6660 kW

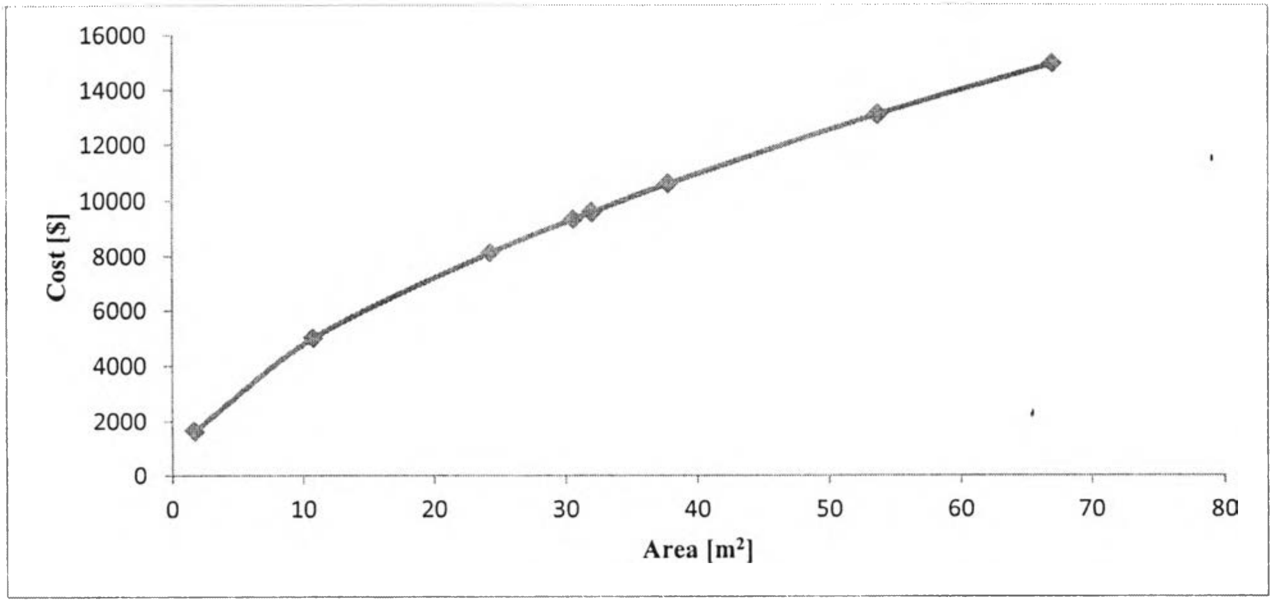

Figure A8 Trend of heat exchanger cost per area of example 4.

Table A12 Analysis cost for example 4.

Utility cost				Area cost		Fixed cost		TAC
Cost/kW	Hot (kW)	Cost/kW	Cold (kW)	Cost/m^2	Total area (m^2)	Cost/unit	No. of unit	$
140	315	10	315	250.96	257.9	953.82	8	571,657

Example 5: This example involves a process with eleven hot process stream (I1-I5), two cold process stream (J1-J2), one hot, and one cold utilities.

Table A13 Data for example 5.

Stream	TIN(°C)	TOUT(°C)	F(kW/°C)	h (kW/m^2-°C)	Cost ($/kW-yr)
I1	140.2	39.5	382.3	2	-
I2	248.8	110	115.2	2	-
I3	170.1	60	121.6	2	-
I4	277	121.9	90.1	2	-
I5	250.6	90	471.2	2	-
I6	210	163	424.3	2	-
I7	303.6	270.2	840.7	2	-
I8	360	115	140.8	2	-
I9	117.7	50	441.9	2	-
I10	178.6	108.9	170.4	2	-
I11	359.6	280	87.3	2	-
J1	30	130	720	2	-
J2	130	350	1051	2	-
HU	25	25	-	2	2.78
CU	370	370	-	2	27.78

EMAT = 10°C,

Table A14 Composite curve analysis of hot stream for example 5.

Hot Steam													dH	Q
		I1	I2	I3	I4	I5	I6	I7	I8	I9	I10	I11	kW	kW
Temp.	FCp	382.3	115.2	121.6	90.1	471.2	424.3	840.7	140.8	441.9	170.4	87.3		[Up]
[°C]	dT													
360														288911.5
359.6	0.4								56.3				56.3	288855.2
303.6	56								7884.8			4888.8	12773.6	276081.6
280	23.6							19840	3322.9			2060.3	25223.7	250857.9
277	3							2522	4722.4				2944.5	247913.4
270.2	6.8				612.7			5716.8	957.4				7286.9	240626.6
250.6	19.6				1766				2759.7				4525.6	236100.9
248.8	1.8				162.2	848.2			253.4				1263.8	234837.1
210	38.8		4469.8		3459.9	18283			5463				31711.2	203125.9
178.6	31.4		3617.3		2829.1	14796	13323		4421.1				38986.2	164139.7
170.1	8.5		979.2		765.8	4005.2	3606		1196.8		1448.4		1002	15213.7
163	7.1		817.9	863.4	639.7	3345.5	3012.5		999.7		1208.8		10888.6	141249.1
140.2	22.8		817.9	2772.5	2054.3	10743			3210.2		3885.1		25292	115957.1
121.9	18.3	6996.1	2626.6	2225.3	1648.8	8623			2576.6		3118.3		27296	88660.8
117.7	4.2	1605.7	2108.2	510.7		1979			591.4		715.7		5886	82774.5
115	2.7	1032.2	483.8	328.3		1272			380.2	1193.1	460.1		4977.2	77797.3

Table A15 Composite curve analysis of hot stream for example 5 (continue).

		Hot Steam											dH	Q
Temp. [°C]		I1	I2	I3	I4	I5	I6	I7	I8	I9	I10	I11	kW	kW
	FCp	382.3	115.2	121.6	90.1	471.2	424.3	840.7	140.8	441.9	170.4	87.3		[Up]
	dT													
110	5	1911.5	311	608		2356				2209.5	852		8513	69284.3
108.9	1.1	420.5	576	133.8		518				486.1	187.4		1873	67411.4
90	18.9	7225.5	126.7	2298.2		8905.7				8351.9			26781.3	40630.1
60	30	11469		3648						13257			28374	12256.1
50	10	3823								4419			8242	4014.1
39.5	10.5	4014.1											4014.1	0
													288911.5	

Table A16 Composite curve analysis of cold stream for example 5.

Cold Steam				dH	Q
		I1	I2	kW	kW
Temp.	FCp	720	1051		[Down]
[°C]	dT				
350					353220
130	220		231220	231220	122000
30	100	72000		72000	50000
				303220	

From figure A9:

Minimum cold utility = 50000 kW, Maximum cold utility = 288911.5 kW

Minimum hot utility = 64308 kW, Maximum hot utility = 303220 kW

Table A17 Analysis cost for example 5.

Utility cost				Area cost		Fixed cost		TAC
Cost/kW	Hot (kW)	Cost/kW	Cold (kW)	Cost/m^2	Total area (m^2)	Cost/unit	No. of unit	$
27.78	108,114.45	2.78	93,679.28	271.2	6,296.7	127,129	14	571,657

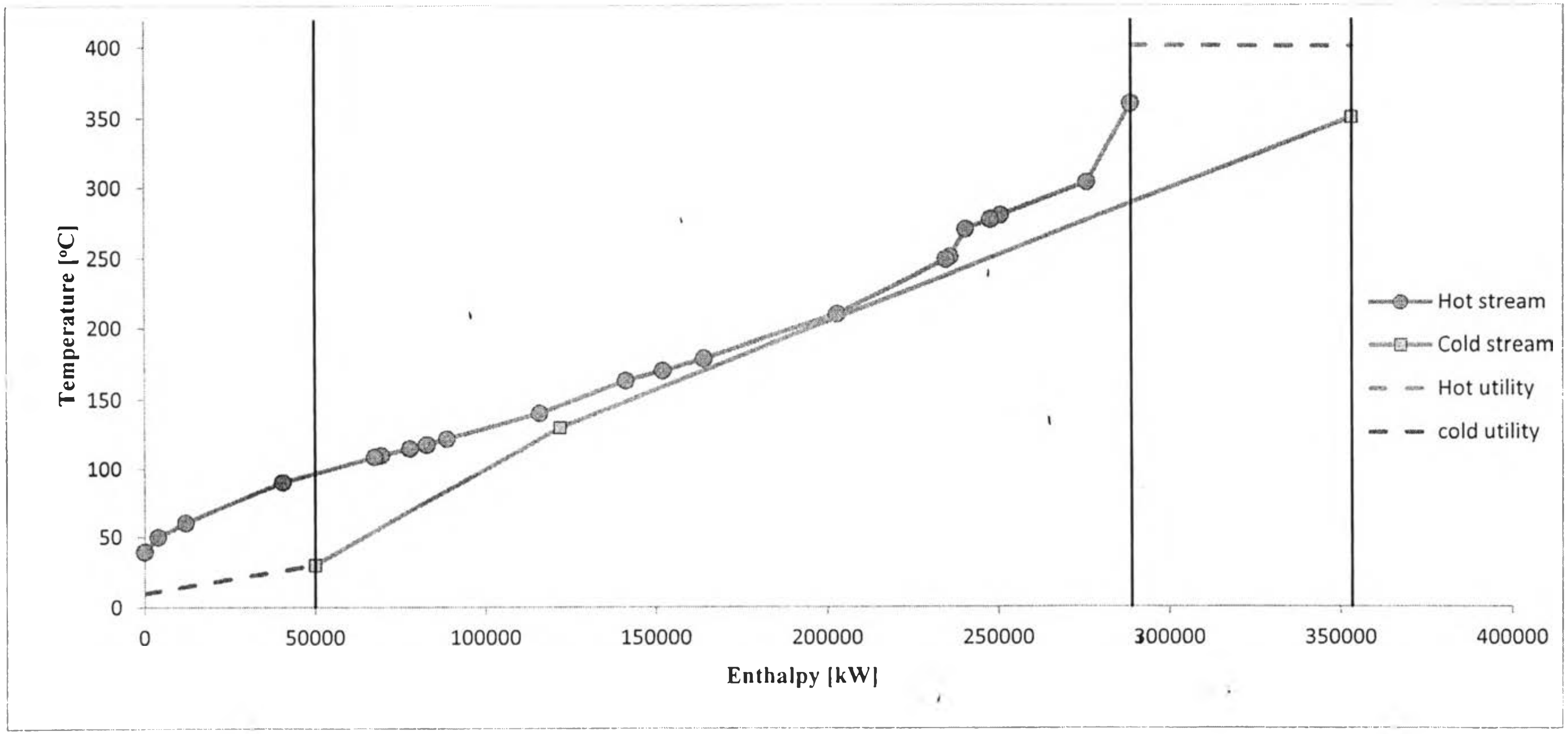

Figure A9 Composite curve of example 5.

Appendix B Programming Model for Grass-Roots Design

```
SETS
     I        Hot streams  / I1 /
     J        Cold streams  / J1*J2 /
     MK       Major-stage location     / MKF,MK2*MK4,MKL /
     K        Sub-stage location       / KF,K2*K5,KL /
     Bh       Split Hot stream location     / Bh1,Bh2 /
     Bc       Split Cold stream location    / Bc1,Bc2 /
;

SCALARS

     HULimit   The minimum heat utility require    / 0 /
     HUMAX     The maximum heat utility require    / 1762.5 /

     CULimit   The minimum cold utility require    / 0 /
     CUMAX     The maximum cold utility require    / 1980 /

     EMAT      exchanger minimum approach temperature   /1/
     DTMIN     utility minimum approach temperature     /1/

     CAP       area cost of process-process  /309.74/
     CAC       area cost of cold utility     /309.74/
     CAH       area cost of hot utility      /309.74/

     CCU       unit cost for cold utility    /20/
     CHU       unit cost for hot utility     /120/
     CF        fixed charge for exchangers   /6600/
     EAC       exponent for area cost        /1/

     MinT      Minimum temp. of the process  / 47 /
     MaxT      Maximum temp. of the process  / 167 /

     XT        Number of iteration / 2 /
;
```

PARAMETERS

TINH(I) inlet temperature of hot stream

/ I1 167 /

TINC(J) inlet temperature of cold stream

/ J1 76

J2 47 /

TOUTH(I) outlet temperature of hot stream

/ I1 77 /

TOUTC(J) outlet temperature of cold stream

/ J1 157

J2 95 /

FH(I) heat capacity of hot stream

/ I1 22 /

FC(J) heat capacity of cold stream

/ J1 20

J2 7.5 /

hH(I) heat capacity of hot stream

/ I1 2 /

hC(J) heat capacity of cold stream

/ J1 2

J2 0.67 /

* Heat capacity Branch Flow..

fhbP(I,MK,Bh) Heat capacity flow of branch Bh cold on I at stage MK

fcbP(J,MK,Bc) Heat capacity flow of branch Bc cold on J at stage MK

* Overall heat exchange..

U Overall heat transfer coefficient when match IJ

Uc Overall heat transfer coefficient of cold utility at I

Uh Overall heat transfer coefficient of hot utility at J

* Upper bound..

QUP(I,J,MK,Bh,Bc,K) Upper bound of heat exchange

QLO(I,J,MK,Bh,Bc,K) Lower bound of heat exchange

* Binary parameter of Heat Location...

ZP(I,J,MK,Bh,Bc,K) Binary parameter of HE for Process-Process

ZcuP(I) Binary parameter of HE for Cold Utility

ZhuP(J)	Binary parameter of HE for Hot Utility

* For Logical constraints...

OMEGA	upper bound for heat exchange
GAMMA	upper bound for temperature difference
GAMh	Upper bound of I stream for temperature difference
GAMc	Upper bound of J stream for temperature difference
HCT	Heat content of I stream
CCT	Heat content of J stream

* Loop control...

X	Iteration Countor
CX	Iteration Countor
MK_Loop	Iteration of MK
K_Loop	Iteration of K
I_Loop	Iteration of I
J_Loop	Iteration of J
Bc_Loop	Iteration of branch J
Bh_Loop	Iteration of branch I
INH_Loop	Iteration loop control of heat interval
Dinter	Delta heat exchange of each interval

* Upper bound of Total annual cost... ...

TACup	Upper bound of Total Annual Cost

;

VARIABLES

* Objective variables...

UTC	Total Utility Cost
NUC	Total Number of Unit Cost
ARC	Total Area Cost
TAC1	Total number of units
TAC2	Total Utility requires
TAC3	Total annoul+Utility cost
TAC4	Total annoul+Utility cost
TAC5	Total annoul+Utility cost
TAC6	Total annoul+Utility cost

* Temperature...

TH(I,MK)	Temperature of hot stream I at location K
Thb(I,MK,Bh,K)	Temperature of hot stream I at location K in stage MK
TC(J,MK)	Temperature of cold stream J at location MK
Tcb(J,MK,Bc,K)	Temperature of cold stream J at location K in stage MK

* Heat Stage Intermedia variable...

QHM(MK,I)	Heat of hot stream I at Stage MK
QH(MK,I,Bh)	Heat of hot stream I is branch stream Bh at Stage MK
Ha(MK)	Heat of hot stream I in Stage MK region
qHK(I,MK,Bh,K)	Heat sub-stage K of stream I
QCM(MK,J)	Heat of cold stream J at stage MK
QC(MK,J,Bc)	Heat of cold stream J is branch stream at Stage MK
Ca(MK)	Heat of cold stream J in stage MK region
qCK(MK,J,Bc,K)	Heat sub-stage K of stream J

* Multiple of Temperature & Heat capacity flow.................................

AH(I,MK,Bh,K)	Multiple of Temperature & Heat capacity flow of I
AC(J,MK,Bc,K)	Multiple of Temperature & Heat capacity flow of J

* Heat Capacity flow...

fhb(I,MK,Bh)	Heat capacity flow of branch Bh hot on I at stage MK
fcb(J,MK,Bc)	Heat capacity flow of branch Bc cold on J at stage MK

* Total Heat Exchange...

TOTALqex	Total heat exchange
TOTAL_HU	Total hot utility
TOTAL_CU	Total cold utility
TOTALarea	Total heat exchange area

;

BINARY VARIABLES

* Number of units...

Z(I,J,MK,Bh,Bc,K)	binary variable to denote existence of match IJ
Zcu(I)	binary variable to denote existence of cold utility with I
Zhu(J)	binary variable to denote existence of hot utility with J

```
* Flow control..................................................................
      hg(I,MK,Bh)         Binary variable to donate existence of hot branch stream I
      cg(J,MK,Bc)         Binary variable to donate existence of hot branch stream J

;

POSITIVE VARIABLES
* Temperature approach.........................................................
      dTHS(I,J,MK,Bh,Bc,K)      Hot side temperature different
      dTCS(I,J,MK,Bh,Bc,K)      Cold side temperature different
      dtcu(I)                   Temperature approach for match hot stream I and cold utility
      dthu(J)                   Temperature approach for match cold stream J and hot utility

* Area of HX....................................................................
      LMTD(I,J,MK,Bh,Bc,K)      Log temperature different between IJ at location MK substage K
of branch Km
      LMTDcu(I)                 Log temperature different of cold utility at stream I
      LMTDhu(J)                 Log temperature different of hot utility at stream J

      Ap(I,J,MK,Bh,Bc,K)        Area of process-process HX
      Acu(I)                    Area of cold utility at stream I
      Ahu(J)                    Area of hot utility at stream J

* Heat exchange.................................................................
      q(I,J,MK,Bh,Bc,K)         Heat exchanged between stream I and stream J
      qcu(I)                    Heat exchanged between hot stream I and cold utility
      qhu(J)                    Heat exchanged between cold stream J and hot utility

;

*******************************************************************************
* Bound Constrains.............................................................
*******************************************************************************
* Total heat exchange.........
            TOTALqex.lo = 0;
            TOTAL_HU.lo = 0;
            TOTAL_CU.lo = 0;

* Multiple of Temperature & Heat capacity flow..................................
```

```
        AH.lo(I,MK,Bh,K) = 0;
        AC.lo(J,MK,Bc,K) = 0;

I_Loop=1;
WHILE(I_Loop<=CARD(I),

        HCT(I)$(ord(I)=I_Loop)= FH(I)*(TINH(I)-TOUTH(I));
        GAMh(I)$(ord(I)=I_Loop) = TINH(I)-TOUTH(I);
* Hot Temperture..............
        TH.lo(I,MK)$(ord(I)=I_Loop) = TOUTH(I);
        TH.up(I,MK)$(ord(I)=I_Loop) = TINH(I);
        Thb.lo(I,MK,Bh,K)$(ord(I)=I_Loop) = MinT;
        Thb.up(I,MK,Bh,K)$(ord(I)=I_Loop) = MaxT;

* Heat capacity flow of Hot stream..........
        fhb.lo(I,MK,Bh)$(ord(I)=I_Loop) = 0;
        fhb.up(I,MK,Bh)$(ord(I)=I_Loop) = FH(I);

* Heat Constrain of hot stream..............
        qcu.lo(I)$(ord(I)=I_Loop) =0;
        qcu.up(I)$(ord(I)=I_Loop) =HCT(I);
        qHK.lo(I,MK,Bh,K)$(ord(I)=I_Loop) =0;
        qHK.up(I,MK,Bh,K)$(ord(I)=I_Loop) = HCT(I);
        QHM.lo(MK,I)$(ord(I)=I_Loop)  = 0;
        QHM.up(MK,I)$(ord(I)=I_Loop)  = HCT(I);
        QH.lo(MK,I,Bh)$(ord(I)=I_Loop)  = 0;
        QH.up(MK,I,Bh)$(ord(I)=I_Loop)  = HCT(I);
        Ha.lo(MK) = 0;
        Ha.up(MK) = CUMAX;
I_Loop = I_Loop+1; );

J_Loop=1;
WHILE(J_Loop<=CARD(J),

        CCT(J)$(ord(J)=J_Loop)=FC(J)*(TOUTC(J)-TINC(J));
        GAMc(J)$(ord(J)=J_Loop) = TOUTC(J)-TINC(J);
* Cold Temperature............
        TC.lo(J,MK)$(ord(J)=J_Loop) = TINC(J);
```

```
            TC.up(J,MK)$(ord(J)=J_Loop) = TOUTC(J);
            Tcb.lo(J,MK,Bc,K)$(ord(J)=J_Loop) = MinT;
            Tcb.up(J,MK,Bc,K)$(ord(J)=J_Loop) = MaxT;

* Heat capacity flow of Cold stream..........
            fcb.lo(J,MK,Bc)$(ord(J)=J_Loop) = 0;
            fcb.up(J,MK,Bc)$(ord(J)=J_Loop) = FC(J);

* Heat Constrain of cold stream..............
            qhu.lo(J)$(ord(J)=J_Loop)=0;
            qhu.up(J)$(ord(J)=J_Loop)=CCT(J);
            qCK.lo(MK,J,Bc,K)$(ord(J)=J_Loop)=0;
            qCK.up(MK,J,Bc,K)$(ord(J)=J_Loop)=CCT(J);
            QCM.lo(MK,J)$(ord(J)=J_Loop) = 0;
            QCM.UP(MK,J)$(ord(J)=J_Loop) = CCT(J);
            QC.lo(MK,J,Bc)$(ord(J)=J_Loop) = 0;
            QC.UP(MK,J,Bc)$(ord(J)=J_Loop) = CCT(J);
            Ca.lo(MK) = 0;
            Ca.UP(MK) = HUMAX;

J_Loop=J_Loop+1; );


*     U(I,J)=1;
*     Uc(I)=1;
*     Uh(J)=1;

      U(I,J)=hH(I)*hC(J)/(hH(I)+hC(J));
      Uc(I)=hH(I)*1/(hH(I)+1);
      Uh(J)=1*hC(J)/(1+hC(J));

      QUP(I,J,MK,Bh,Bc,K)=Min(HCT(I),CCT(J),Max(0,TINH(I)-TINC(J)-
EMAT)*min(FH(I),FC(J)));
      QLO(I,J,MK,Bh,Bc,K)=1*U(I,J)*EMAT;

      OMEGA(I,J) = min(HCT(I),CCT(J));
      GAMMA(I,J)  =  max(TINH(I)-TINC(J),TINH(I)-TOUTC(J),TOUTH(I)-TINC(J),TOUTH(I)-
TOUTC(J),
```

```
TINC(J)-TINH(I),TOUTC(J)-TINH(I),TINC(J)-TOUTH(I),TOUTC(J)-TOUTH(I));

*...........................................................................................................................................
*............................................ Assignment initial point of Branch Flow stream.......................................
*...........................................................................................................................................

* Hot stream..........................................................
fhbP('I1',MK,'Bh1')=19;
fhbP('I1',MK,'Bh2')=3;
fhbP('I1','MKL','Bh1')=22;
fhbP('I1','MKL','Bh2')=0;

* Cold stream.........................................................
fcbP('J1',MK,'Bc1')=15;
fcbP('J1',MK,'Bc2')=5;
fcbP('J1','MKL','Bc1')=20;
fcbP('J1','MKL','Bc2')=0;
*......................................
fcbP('J2',MK,'Bc1')=5.5;
fcbP('J2',MK,'Bc2')=2;
fcbP('J2','MKL','Bc1')=7.5;
fcbP('J2','MKL','Bc2')=0;

*************************************************************************************
EQUATIONS

* Heat constraint...............................................................
      A(I,J,MK,Bh,Bc)              Heat constraint at KL

* Overall heat balance.........................................................
      OHB_H(I)                     Overall heat balance for each hot stream
      OHB_C(J)                     Overall heat balance for each cold stream

* Heat Balance at each stage...................................................
      SHB_Ha(MK)                   Total heat of each hot stream I
*.............................................................................
      SHB_HC(MK)                   Heat Balance of Hot and Cold Zone
      SHB_QHM(MK,I)                Heat Balance of total branch I at stage MK
```

SHB_QH1(MK,I)	Total of branch hot stream at stage MK
SHB_QH2(MK,I,Bh)	Heat of branch hot stream at stage MK
SHB_QH3(MK,I.Bh,K)	Heat of branch K hot stream at stage MK
SHB_Ca(MK)	Total heat of each hot stream I
SHB_QCM(MK,J)	Heat Balance of total branch I at stage MK
SHB_QC1(MK,J)	Total of branch cold stream at stage MK
SHB_QC2(MK,J,Bc)	Heat of branch cold stream at stage MK
SHB_QC3(MK,J,Bc,K)	Heat of branch K cold stream at stage MK

* Heat balance of sub-stage K..

SHB_fqH(I,Bh,MK,K)	Heat balance of Sub-stage K at Hot stream
SHB_fqH1(I,Bh,MK,K)	Intermediate Variable equivalent of Hot I
SHB_fqC(J,Bc,MK,K)	Heat balance of Sub-stage K at Cold stream
SHB_fqC1(J,Bc.MK,K)	Intermediate Variable equivalent of Cold J
SHB_fqH2(I,Bh.MK,K)	Intermediate Variable equivalent of Hot I
SHB_fqC2(J,Bc,MK,K)	Intermediate Variable equivalent of Cold J

* Temperature and Heat capacity flow......[Variable]...........................

TFAH(I,MK,Bh,K)	Multiple of Temperature&Heat capacity flow of I
TFAC(J,MK,Bc,K)	Multiple of Temperature&Heat capacity flow of J

* Temperature and Heat capacity flow......[Parameter]..........................

TFAH_P(I,MK,Bh,K)	Multiple of Temperature&Heat capacity flow of I
TFAC_P(J,MK,Bc,K)	Multiple of Temperature&Heat capacity flow of J

* Assignment of Temperature..

ASITH(I)	Assignment of inlet temperature of hot stream I
ASITMH1(I,MK)	Assignment of inlet sub-stage temperature of I
ASITMH2(I,MK)	Assignment of outlet sub-stage temperature of I
ASITMH3(I,MK,Bh)	Assignment of inlet sub-stage temp of Hot I
ASITC(J)	Assignment of inlet temperature of J
ASITMC1(J,MK)	Assignment of inlet sub-stage temperature of J
ASITMC2(J,MK)	Assignment of outlet sub-stage temperature of J
ASITMC3(J,MK,Bc)	Assignment of inlet sub-stage temp of Cold J

.............................[Linear Equation Form]...........................

ASITMH1_P(I,MK,Bh)	Assignment of inlet sub-stage temperature of I
ASITMH2_P(I,MK)	Assignment of outlet sub-stage temperature of I
ASITMC1_P(J,MK)	Assignment of inlet sub-stage temperature of J

ASITMC2_P(J,MK,Bc) Assignment of outlet sub-stage temperature of J

*Feasibility of Temperature...

FOTH1(I,MK)	Feasibility of Hot Temperature I of Stage MK
FOTH2(I,MK,Bh,K)	Feasibility of Hot Temperature I of Sub-stage K
FOTH3(I)	Feasibility of Hot Temperature I
FOTH4(I,MK,Bh,K)	Feasibility of Hot Temperature branch stream I
FOTH5(I,MK,Bh,K)	Feasibility of Hot Temperature branch stream I
FOTC1(J,MK)	Feasibility of Cold Temperature J of Stage MK
FOTC2(J,MK,Bc,K)	Feasibility of Cold Temperature J of Sub-stage K
FOTC3(J)	Feasibility of Cold Temperature J
FOTC4(J,MK,Bc,K)	Feasibility of Hot Temperature branch stream J
FOTC5(J,MK,Bc,K)	Feasibility of Hot Temperature branch stream J

* Feasible of branch flow...

FOTfhb1(I,MK,Bh)	Lower bound of hot branch flow I
FOTfhb2(I,MK,Bh)	Upper bound of hot branch flow I
FOTfcb1(J,MK,Bc)	Lower bound of cold branch flow J
FOTfcb2(J,MK,Bc)	Upper bound of cold branch flow J

* Utility Load..

HULOAD(I)	Hot utility load
CULOAD(J)	Cold utility load

* Logical constraints of Heat Exchange and Utility.............................

LG_H(I,J,MK,Bh,Bc,K)	Count heat exchanger
LG_HU(I)	Count hot utiility
LG_CU(J)	Count cold utility

* Fix Logical constraints of Heat Exchange and Utility.........................

LGP_H(I,J,MK,Bh,Bc,K)	Count heat exchanger of ZP
LGP_HU(I)	Count hot utiility of ZhuP
LGP_CU(J)	Count cold utility of ZcuP

* Maximum Matching Constraints...

MMC1(I,MK,Bh,K)	Limit of maximum matching stream I
MMC2(J,MK,Bc,K)	Limit of maximum matching stream J

* Mass Balance of each stage..

MBH(I,MK)	Mass balance of hot stream at stage MK
MBC(J,MK)	Mass balance of cold stream at stage MK

* Heat Exchange and Hot&Cold Utility Constraints...............................

CON_HU1	Total minimum of Hot Utility
CON_HU2	Total maximum of Hot Utility
CON_HU3(J)	Maximum of Hot Utility J
CON_HU4	Total Hot Utility
CON_CU1	Total minimum of Cold Utility
CON_CU2	Total maximum of Cold Utility
CON_CU3(I)	Maximum of Cold Utility I
CON_CU4	Total Cold Utility
CON_EXSE	Total Heat Exchange of process by guess
CON_EXFR	Total Heat Exchange of process by guess
CON_EX	Total Heat Exchange of process
CON_HEU(I,J,MK,Bh,Bc,K)	Upper bound of heat exchange
CON_HEL(I,J,MK,Bh,Bc,K)	Lower bound of heat exchange

* Total Number of heat exchange..

COUNTING	Total heat exchange
COUNTING_A	Total heat exchange area

* Approach temperature..

APPTEM_L1(I,J,MK,Bh,Bc,K)	Approach temperature at the left of stage K
APPTEM_R1(I,J,MK,Bh,Bc,K)	Approach temperature at the right of stage K
APPTEM_L2(I,J,MK,Bh,Bc,K)	Approach temperature at the left of stage K
APPTEM_R2(I,J,MK,Bh,Bc,K)	Approach temperature at the right of stage K
APPTEM_CU(I)	Approach temperature at HE of I
APPTEM_HU(J)	Approach temperature at HE of J
APPTECU(I)	Approach temperature of cold utility
APPTEHU(J)	Approach temperature of hot utility

* Approach temperature......[Z is Parameter]...................................

APPTEMP_L1(I,J,MK,Bh,Bc,K)	Approach temp at the left of stage K
APPTEMP_R1(I,J,MK,Bh.Bc,K)	Approach temp at the right of stage K
APPTEMP_CU(I)	Approach temperature at HE of I
APPTEMP_HU(J)	Approach temperature at HE of J

*Area calculations...

LMTHx(I,J,MK,Bh,Bc,K)	Limitaion minimum temperature of HX
LMTCU(I)	Limitaion minimum Tem of Cold utility
LMTHU(J)	Limitaion minimum Tem of Heat utility
LMTHc(I,J,MK,Bh,Bc,K)	Limitaion minimum temperature of HX
LMTCUc(I)	Limitaion minimum Tem of Cold utility
LMTHUc(J)	Limitaion minimum Tem of Heat utility
AreaP(I,J,MK,Bh,Bc,K)	Area of process-process HX
AreaC(I)	Area of cold utility
AreaH(J)	Area of hot utility

* Objective function..

UTILITY	Total Utility used
NoUNIT	Total number of HE Unit
TOAREA	Total Heat exchanger area
OBJFN1	Number of unit
OBJFN2	utility cost
OBJFN3	utility cost + fixed heat exchanger cost
OBJFN4	utility cost + fixed heat exchanger cost + Area
OBJFN5	utility cost + fixed heat exchanger cost + Area
OBJFN6	utility cost + fixed heat exchanger cost + Area
BrouTAC	

;

```
**************************************************************************************
*.......................................................................Equation.........................................................................*
**************************************************************************************
```

* Heat Constraints...

A(I,J,MK,Bh,Bc) .. q(I,J,MK,Bh,Bc,'KL') =E= 0;

```
* Overall Energy balance......................................................
OHB_H(I) .. (TINH(I)-TOUTH(I))*FH(I) =E= SUM((MK,Bh,J,Bc,K)$((ORD(MK) NE CARD(MK))and(ORD(K) NE CARD(K))),q(I,J,MK,Bh,Bc,K))+qcu(I);
OHB_C(J) .. (TOUTC(J)-TINC(J))*FC(J) =E= SUM((MK,Bc,I,Bh,K)$((ORD(MK) NE CARD(MK))and(ORD(K) NE CARD(K))),q(I,J,MK,Bh,Bc,K))+qhu(J);

* Heat balance of each stage...................................................
SHB_HC(MK)$(ORD(MK) NE CARD(MK)) .. Ha(MK) =E= Ca(MK);

* Hot stream.......
SHB_Ha(MK)$(ORD(MK) NE CARD(MK)) .. Ha(MK) =E= SUM(I,QHM(MK,I));
SHB_QHM(MK,I)$(ORD(MK) NE CARD(MK)) .. (TH(I,MK)-TH(I,MK+1))*FH(I) =E= QHM(MK,I);
SHB_QH1(MK,I)$(ORD(MK) NE CARD(MK)) .. QHM(MK,I) =E= SUM(Bh,QH(MK,I,Bh));
SHB_QH2(MK,I,Bh)$(ORD(MK) NE CARD(MK)) .. QH(MK,I,Bh) =E= SUM(K$(ORD(K) NE CARD(K)),qHK(I,MK,Bh,K));

SHB_QH3(MK,I,Bh,K)$((ORD(MK) NE CARD(MK))and(ORD(K) NE CARD(K))) .. qHK(I,MK,Bh,K) =E= AH(I,MK,Bh,K)-AH(I,MK,Bh,K+1);

* Cold stream......
SHB_Ca(MK)$(ORD(MK) NE CARD(MK)) .. Ca(MK) =E= SUM(J,QCM(MK,J));
SHB_QCM(MK,J)$(ORD(MK) NE CARD(MK)) .. (TC(J,MK)-TC(J,MK+1))*FC(J) =E= QCM(MK,J);
SHB_QC1(MK,J)$(ORD(MK) NE CARD(MK)) .. QCM(MK,J) =E= SUM(Bc,QC(MK,J,Bc));
SHB_QC2(MK,J,Bc)$(ORD(MK) NE CARD(MK)) .. QC(MK,J,Bc) =E= SUM(K$(ORD(K) NE CARD(K)),qCK(MK,J,Bc,K));

SHB_QC3(MK,J,Bc,K)$((ORD(MK) NE CARD(MK))and(ORD(K) NE CARD(K))) .. qCK(MK,J,Bc,K) =E= AC(J,MK,Bc,K)-AC(J,MK,Bc,K+1);

* Heat balance of Sub-stage K..................................................
SHB_fqH(I,Bh,MK,K)$((ORD(MK) NE CARD(MK))and(ORD(K) NE CARD(K))) .. qHK(I,MK,Bh,K) =E= SUM((J,Bc),q(I,J,MK,Bh,Bc,K));
SHB_fqH1(I,Bh,MK,K)$((ORD(MK) NE CARD(MK))and(ORD(K) NE CARD(K))) .. (Thb(I,MK,Bh,K)-Thb(I,MK,Bh,K+1))*fhb(I,MK,Bh) =E= AH(I,MK,Bh,K)-AH(I,MK,Bh,K+1);
```

```
SHB_fqC(J,Bc,MK,K)$((ORD(MK) NE CARD(MK))and(ORD(K) NE CARD(K))) ..
qCK(MK,J,Bc,K) =E= SUM((I,Bh),q(I,J,MK,Bh,Bc,K));
SHB_fqC1(J,Bc,MK,K)$((ORD(MK) NE CARD(MK))and(ORD(K) NE
CARD(K))) ..(Tcb(J,MK,Bc,K)-Tcb(J,MK,Bc,K+1))*fcb(J,MK,Bc) =E= AC(J,MK,Bc,K)-
AC(J,MK,Bc,K+1);

SHB_fqH2(I,Bh,MK,K)$((ORD(MK) NE CARD(MK))and(ORD(K) NE CARD(K))) ..
(Thb(I,MK,Bh,K)-Thb(I,MK,Bh,K+1))*fhbP(I,MK,Bh) =E= AH(I,MK,Bh,K)-AH(I,MK,Bh,K+1);
SHB_fqC2(J,Bc,MK,K)$((ORD(MK) NE CARD(MK))and(ORD(K) NE
CARD(K))) ..(Tcb(J,MK,Bc,K)-Tcb(J,MK,Bc,K+1))*fcbP(J,MK,Bc) =E= AC(J,MK,Bc,K)-
AC(J,MK,Bc,K+1);

* Multiple of Temperature and Heat capacity flow.............[Variable].........
TFAH(I,MK,Bh,K)$((ORD(MK) NE CARD(MK))and(ORD(K) NE CARD(K))) .. AH(I,MK,Bh,K)
=E= Thb(I,MK,Bh,K)*fhb(I,MK,Bh);
TFAC(J,MK,Bc,K)$((ORD(MK) NE CARD(MK))and(ORD(K) NE CARD(K))) .. AC(J,MK,Bc,K)
=E= Tcb(J,MK,Bc,K)*fcb(J,MK,Bc);
* Multiple of Temperature and Heat capacity flow.............[Parameter]........
TFAH_P(I,MK,Bh,K)$((ORD(MK) NE CARD(MK))and(ORD(K) NE CARD(K))) ..
AH(I,MK,Bh,K) =E= Thb(I,MK,Bh,K)*fhbP(I,MK,Bh);
TFAC_p(J,MK,Bc,K)$((ORD(MK) NE CARD(MK))and(ORD(K) NE CARD(K))) ..
AC(J,MK,Bc,K) =E= Tcb(J,MK,Bc,K)*fcbP(J,MK,Bc);

* Heat&Cold utility.............................................................
HULOAD(I) .. (TH(I,'MKL')-TOUTH(I))*FH(I) =E= qcu(I);
CULOAD(J) .. (TOUTC(J)-TC(J,'MKF'))*FC(J) =E= qhu(J);

* Assighment of superstructure inlet Temperature................................
ASITH(I) .. TINH(I) =E= TH(I,'MKF');
ASITMH1(I,MK)$(ORD(MK) NE CARD(MK)) .. FH(I)*TH(I,MK) =E=
SUM(Bh,AH(I,MK,Bh,'KF'));
ASITMH2(I,MK)$(ORD(MK) NE CARD(MK)) .. FH(I)*TH(I,MK+1) =E=
SUM(Bh,AH(I,MK,Bh,'KL'));
ASITMH3(I,MK,Bh)$(ORD(MK) NE CARD(MK)) .. TH(I,MK) =E= Thb(I,MK,Bh,'KF');

ASITC(J) .. TINC(J) =E= TC(J,'MKL');
ASITMC1(J,MK)$(ORD(MK) NE CARD(MK)) .. FC(J)*TC(J,MK) =E=
SUM(Bc,AC(J,MK,Bc,'KF'));
```

```
ASITMC2(J,MK)$(ORD(MK) NE CARD(MK)) .. FC(J)*TC(J,MK+1) =E=
SUM(Bc,AC(J,MK,Bc,'KL'));
ASITMC3(J,MK,Bc)$(ORD(MK) NE CARD(MK)) .. TC(J,MK+1) =E= Tcb(J,MK,Bc,'KL');

*............................[Linear Equation Form]..........................*
ASITMH1_P(I,MK,Bh)$(ORD(MK) NE CARD(MK)) .. TH(I,MK) =E= Thb(I,MK,Bh,'KF');
ASITMH2_P(I,MK)$(ORD(MK) NE CARD(MK)) .. FH(I)*TH(I,MK+1) =E=
SUM(Bh,Thb(I,MK,Bh,'KL')*fhbP(I,MK,Bh));

ASITMC1_P(J,MK)$(ORD(MK) NE CARD(MK)) .. FC(J)*TC(J,MK) =E=
SUM(Bc,Tcb(J,MK,Bc,'KF')*fcbP(J,MK,Bc));
ASITMC2_P(J,MK,Bc)$(ORD(MK) NE CARD(MK)) .. TC(J,MK+1) =E= Tcb(J,MK,Bc,'KL');

* Feasibility of Temperature...................................................
FOTH1(I,MK)$(ORD(MK) NE CARD(MK)) .. TH(I,MK) =G= TH(I,MK+1);
FOTH2(I,MK,Bh,K)$((ORD(MK) NE CARD(MK))$(ORD(K) NE CARD(K))) .. Thb(I,MK,Bh,K)
=G= Thb(I,MK,Bh,K+1);
FOTH3(I) .. TOUTH(I) =L= TH(I,'MKL');

FOTH4(I,MK,Bh,K)$((ORD(MK) NE CARD(MK))$(ORD(K) NE CARD(K))) .. Thb(I,MK,Bh,K)
=L= MaxT;
FOTH5(I,MK,Bh,K)$((ORD(MK) NE CARD(MK))$(ORD(K) NE CARD(K))) .. Thb(I,MK,Bh,K)
=G= MinT;

FOTC1(J,MK)$(ORD(MK) NE CARD(MK)) .. TC(J,MK) =G= TC(J,MK+1);
FOTC2(J,MK,Bc,K)$((ORD(MK) NE CARD(MK))$(ORD(K) NE CARD(K))) .. Tcb(J,MK,Bc,K)
=G= Tcb(J,MK,Bc,K+1);
FOTC3(J) .. TOUTC(J) =G= TC(J,'MKF');

FOTC4(J,MK,Bc,K)$((ORD(MK) NE CARD(MK))$(ORD(K) NE CARD(K))) .. Tcb(J,MK,Bc,K)
=L= MaxT;
FOTC5(J,MK,Bc,K)$((ORD(MK) NE CARD(MK))$(ORD(K) NE CARD(K))) .. Tcb(J,MK,Bc,K)
=G= MinT;

* Feasible of branch flow......................................................
FOTfhb1(I,MK,Bh)$(ORD(MK) NE CARD(MK)) .. fhb(I,MK,Bh)=G=0;
FOTfhb2(I,MK,Bh)$(ORD(MK) NE CARD(MK)) .. fhb(I,MK,Bh)=L=FH(I);
```

```
FOTfcb1(J,MK,Bc)$(ORD(MK) NE CARD(MK)) .. fcb(J,MK,Bc)=G=0;
FOTfcb2(J,MK,Bc)$(ORD(MK) NE CARD(MK)) .. fcb(J,MK,Bc)=L=FC(J);

* Logical constraints of Heat Exchange and Utility.............................
LG_H(I,J,MK,Bh,Bc,K)$((ORD(MK) NE CARD(MK))and(ORD(K) NE CARD(K))) ..
q(I,J,MK,Bh,Bc,K)-OMEGA(I,J)*Z(I,J,MK,Bh,Bc,K) =L= 0;
LG_HU(I) .. qcu(I)-HCT(I)*Zcu(I) =L= 0;
LG_CU(J) .. qhu(J)-CCT(J)*Zhu(J) =L= 0;

* Fix Logical constraints of Heat Exchange and Utility..........................
LGP_H(I,J,MK,Bh,Bc,K)$((ORD(MK) NE CARD(MK))and(ORD(K) NE CARD(K))) ..
q(I,J,MK,Bh,Bc,K)-OMEGA(I,J)*ZP(I,J,MK,Bh.Bc,K) =L= 0;
LGP_HU(I) .. qcu(I)-HCT(I)*ZcuP(I) =L= 0;
LGP_CU(J) .. qhu(J)-CCT(J)*ZhuP(J) =L= 0;

* Maximum Matching Constraints.................................................
MMC1(I,MK,Bh,K)$((ORD(MK) NE CARD(MK))and(ORD(K) NE CARD(K)))..
SUM((J,Bc),Z(I,J,MK,Bh,Bc,K)) =L= 1;
MMC2(J,MK,Bc,K)$((ORD(MK) NE CARD(MK))and(ORD(K) NE CARD(K)))..
SUM((I,Bh),Z(I,J,MK,Bh,Bc,K)) =L= 1;

* Mass balance of each stage MK................................................
MBH(I,MK) .. FH(I) =E= SUM(Bh,fhb(I,MK,Bh));
MBC(J,MK) .. FC(J) =E= SUM(Bc,fcb(J,MK,Bc));

* Heat Exchange and Heat & Cold utility constraints............................
* Hot utility....
CON_HU1 .. SUM(J,qhu(J))=G= HULimit;
CON_HU2 .. SUM(J,qhu(J))=L= HUMAX;
CON_HU3(J) .. qhu(J) =L= Zhu(J)*CCT(J);
CON_HU4 .. TOTAL_HU =E= SUM(J,qhu(J));
* Cold utility....
CON_CU1 .. SUM(I,qcu(I))=G= CULimit;
CON_CU2 .. SUM(I,qcu(I))=L= CUMAX;
CON_CU3(I) .. qcu(I) =L= Zcu(I)*HCT(I);
CON_CU4 .. TOTAL_CU =E= SUM(I,qcu(I));
```

```
* Heat Exchange....
*.................................................................................................................................
* Importance Equations not both in this thesis and paper but needed
*.................................................................................................................................
CON_HEU(I,J,MK,Bh,Bc,K)$((ORD(MK) NE CARD(MK))$(ORD(K) NE CARD(K))) ..
q(I,J,MK,Bh,Bc,K)=L=Z(I,J,MK,Bh,Bc,K)*QUP(I,J,MK,Bh,Bc,K);
CON_HEL(I,J,MK,Bh,Bc,K)$((ORD(MK) NE CARD(MK))$(ORD(K) NE CARD(K))) ..
q(I,J,MK,Bh,Bc,K)=G=Z(I,J,MK,Bh,Bc,K)*QLO(I,J,MK,Bh,Bc,K);

* Counting total heat exchange.....
COUNTING .. TOTALqex =E=SUM((I,J,MK,Bh,Bc,K)$((ORD(MK) NE CARD(MK))and(ORD(K)
NE CARD(K))),q(I,J,MK,Bh,Bc,K));
COUNTING_A .. TOTALarea =E=SUM((I,J,MK,Bh,Bc,K)$((ORD(MK) NE
CARD(MK))and(ORD(K) NE CARD(K))),Ap(I,J,MK,Bh,Bc,K))+SUM(I,Acu(I))+SUM(J,Ahu(J));

* Calculation of approach temperature..........................................
APPTEM_L1(I,J,MK,Bh,Bc,K)$((ORD(MK) NE CARD(MK))and(ORD(K) NE CARD(K))) ..
dTHS(I,J,MK,Bh,Bc,K) =L= Thb(I,MK,Bh,K)-Tcb(J,MK,Bc,K)
                    +GAMMA(I,J)*(1-Z(I,J,MK,Bh,Bc,K));
APPTEM_R1(I,J,MK,Bh,Bc,K)$((ORD(MK) NE CARD(MK))and(ORD(K) NE CARD(K))) ..
dTCS(I,J,MK,Bh,Bc,K) =L= Thb(I,MK,Bh,K+1)-Tcb(J,MK,Bc,K+1)
                    +GAMMA(I,J)*(1-Z(I,J,MK,Bh,Bc,K));
APPTEM_L2(I,J,MK,Bh,Bc,K)$((ORD(MK) NE CARD(MK))and(ORD(K) NE CARD(K))) ..
dTHS(I,J,MK,Bh,Bc,K) =G= EMAT;
APPTEM_R2(I,J,MK,Bh,Bc,K)$((ORD(MK) NE CARD(MK))and(ORD(K) NE CARD(K))) ..
dTCS(I,J,MK,Bh,Bc,K) =G= EMAT;

APPTEM_CU(I) .. dtcu(I) =L= TH(I,'MKL')-TOUTH(I)+GAMh(I)*(1-Zcu(I));

APPTEM_HU(J) .. dthu(J) =L= TOUTC(J)- TC(J,'MKF')+GAMc(J)*(1-Zhu(J));

APPTECU(I) .. dtcu(I) =G= DTMIN;
APPTEHU(J) .. dthu(J) =G= DTMIN;

* Calculation of approach temperature...[Z is Parameter]........................
APPTEMP_L1(I,J,MK,Bh,Bc,K)$((ORD(MK) NE CARD(MK))and(ORD(K) NE CARD(K))) ..
dTHS(I,J,MK,Bh,Bc,K) =L= Thb(I,MK,Bh,K)-Tcb(J,MK,Bc,K)
                    +GAMMA(I,J)*(1-ZP(I,J,MK,Bh,Bc,K));
```

```
APPTEMP_R1(I,J,MK,Bh,Bc,K)$((ORD(MK) NE CARD(MK))and(ORD(K) NE CARD(K))) ..
dTCS(I,J,MK,Bh,Bc,K) =L= Thb(I,MK,Bh,K+1)-Tcb(J,MK,Bc,K+1)
                    +GAMMA(I,J)*(1-ZP(I,J,MK,Bh,Bc,K));
APPTEMP_CU(I) .. dtcu(I) =L= TH(I,'MKL')-TOUTH(I)+GAMh(I)*(1-ZcuP(I));

APPTEMP_HU(J) .. dthu(J) =L= TOUTC(J)- TC(J,'MKF')+GAMc(J)*(1-ZhuP(J));

* Area equations................................................................
LMTHx(I,J,MK,Bh,Bc,K)$((ORD(MK) NE CARD(MK))and(ORD(K) NE CARD(K))) ..
LMTD(I,J,MK,Bh,Bc,K) =E=

(((dTHS(I,J,MK,Bh,Bc,K)*dTCS(I,J,MK,Bh,Bc,K))*((dTHS(I,J,MK,Bh,Bc,K)+dTCS(I,J,MK,Bh,Bc,
K))/2)))**(1/3);

LMTCU(I) .. LMTDcu(I) =E= (((dtcu(I)*(TH(I,'MKL')-TOUTH(I))*(dtcu(I)+(TH(I,'MKL')-
TOUTH(I)))/2)))**(1/3);
LMTHU(J) .. LMTDhu(J) =E= (((dthu(J)*(TOUTC(J)- TC(J,'MKF'))*(dthu(J)+(TOUTC(J)-
TC(J,'MKF')))/2)))**(1/3);

LMTHc(I,J,MK,Bh,Bc,K)$((ORD(MK) NE CARD(MK))and(ORD(K) NE CARD(K))) ..
LMTD(I,J,MK,Bh,Bc,K) =L= 0.5*(dTHS(I,J,MK,Bh,Bc,K)+dTCS(I,J,MK,Bh,Bc,K));
LMTCUc(I) .. LMTDcu(I) =L= 0.5*(dtcu(I)+(TH(I,'MKL')-TOUTH(I)));
LMTHUc(J) .. LMTDhu(J) =L= 0.5*(dthu(J)+(TOUTC(J)- TC(J,'MKF')));

AreaP(I,J,MK,Bh,Bc,K)$((ORD(MK) NE CARD(MK))and(ORD(K) NE CARD(K))) ..
q(I,J,MK,Bh,Bc,K)-(Ap(I,J,MK,Bh,Bc,K)*U(I,J)*LMTD(I,J,MK,Bh,Bc,K)) =L= 0;
AreaC(I) .. qcu(I)-(Acu(I)*Uc(I)*LMTDcu(I)) =L= 0;
AreaH(J) .. qhu(J)-(Ahu(J)*Uh(J)*LMTDhu(J)) =L= 0;

* Objective function............................................................
UTILITY .. UTC =E= (CCU*SUM(I,qcu(I)))+ (CHU*SUM(J,qhu(J)));
NoUNIT .. NUC =E=
(CF*SUM((I,J,MK,Bh,Bc,K),Z(I,J,MK,Bh,Bc,K)))+(CF*SUM(I,Zcu(I)))+(CF*SUM(J,Zhu(J)));
TOAREA .. ARC =E=
(CAP*sum((I,J,MK,Bh,Bc,K),Ap(I,J.MK,Bh,Bc,K)))+(CAC*sum(I,Acu(I)))+(CAH*sum(J,Ahu(J)));

OBJFN1 .. TAC1 =E= NUC+UTC;
OBJFN2 .. TAC2 =E= UTC;
```

```
OBJFN3 .. TAC3 =E= NUC+UTC;
OBJFN4 .. TAC4 =E= (UTC + ARC);
OBJFN5 .. TAC5 =E= (UTC + NUC + ARC);
OBJFN6 .. TAC6 =E= (UTC + NUC + ARC);

BrouTAC .. TAC6 =L= TACup;

OPTION Ap:6:2:4;
OPTION q:6:2:4;
OPTION QH:3:2:1;
OPTION QC:3:2:1;
OPTION Thb:4:3:1;
OPTION Tcb:4:3:1;
OPTION Z:6:2:4;
OPTION ZP:6:2:4;
OPTION fhb:3:1:2;
OPTION fcb:3:1:2;
OPTION fhbP:3:1:2;
OPTION fcbP:3:1:2;
OPTION hg:3:1:2;
OPTION cg:3:1:2;

OPTION sysout = on;
OPTION iterlim = 1e+09;
OPTION reslim = 5e+06;


MODEL LINEAR1 "MILP model"
        / OHB_H,OHB_C,SHB_Ha,SHB_QHM,SHB_QH1,SHB_QH2,SHB_QH3,
         SHB_Ca,SHB_QCM,SHB_QC1,SHB_QC2,SHB_QC3,SHB_HC,
         SHB_fqH,SHB_fqH2,
         SHB_fqC,SHB_fqC2,
         TFAH_P,TFAC_P,
         ASITH,ASITMH1,ASITMH2,ASITMH3,
         ASITC,ASITMC1,ASITMC2,ASITMC3,
         FOTH1,FOTH2,FOTH3,FOTC1,FOTC2,FOTC3,HULOAD,CULOAD,
         LG_H,LG_HU,LG_CU,MMC1,MMC2,
         CON_HU1,CON_HU2,CON_HU3,CON_HU4,
```

CON_CU1,CON_CU2,CON_CU3,CON_CU4,
CON_EXSE,COUNTING,
APPTEM_L1,APPTEM_R1,APPTEM_L2,APPTEM_R2,APPTEM_CU,APPTEM_HU,
APPTECU,APPTEHU,
UTILITY,NoUNIT,OBJFN1 /

LINEAR2 "MILP model"
/ OHB_H,OHB_C,SHB_Ha,SHB_QHM,SHB_QH1,SHB_QH2,SHB_QH3,
SHB_Ca,SHB_QCM,SHB_QC1,SHB_QC2,SHB_QC3,SHB_HC,
SHB_fqH,SHB_fqH2,
SHB_fqC,SHB_fqC2,
TFAH_P,TFAC_P,
ASITH,ASITMH1,ASITMH2,ASITMH3,
ASITC,ASITMC1,ASITMC2,ASITMC3,
FOTH1,FOTH2,FOTH3,FOTC1,FOTC2,FOTC3,HULOAD,CULOAD,
LG_H,LG_HU,LG_CU,MMC1,MMC2,
CON_HU1,CON_HU2,CON_HU3,CON_HU4,
CON_CU1,CON_CU2,CON_CU3,CON_CU4,
CON_EXFR,COUNTING,
APPTEM_L1,APPTEM_R1,APPTEM_L2,APPTEM_R2,APPTEM_CU,APPTEM_HU,
APPTECU,APPTEHU,
UTILITY,NoUNIT,OBJFN3 /

NONLINEAR1 "Flow(Variable)"
/ OHB_H,OHB_C,SHB_Ha,SHB_QHM,SHB_QH1,SHB_QH2,SHB_QH3,
SHB_Ca,SHB_QCM,SHB_QC1,SHB_QC2,SHB_QC3,SHB_HC,
SHB_fqH,SHB_fqH1,
SHB_fqC,SHB_fqC1,
TFAH,TFAC,
ASITH,ASITMH1,ASITMH2,ASITMH3,
ASITC,ASITMC1,ASITMC2,ASITMC3,
FOTfhb1,FOTfhb2,FOTfcb1,FOTfcb2,
FOTH1,FOTH2,FOTH3,FOTC1,FOTC2,FOTC3,HULOAD,CULOAD,
LGP_H,LGP_HU,LGP_CU,
MBH,MBC,
CON_HU1,CON_HU2,CON_HU4,
CON_CU1,CON_CU2,CON_CU4,
CON_EXSE,COUNTING,

```
        APPTEMP_L1,APPTEMP_R1,APPTEMP_CU,APPTEMP_HU,
        APPTEM_L2,APPTEM_R2,APPTECU,APPTEHU,
        UTILITY,OBJFN2   /

    NONLINEAR2 "Flow(Parameter)+Area"
       / OHB_H,OHB_C,SHB_Ha,SHB_QHM,SHB_QH1,SHB_QH2,SHB_QH3,
        SHB_Ca,SHB_QCM,SHB_QC1,SHB_QC2,SHB_QC3,SHB_HC,
        SHB_fqH,SHB_fqH1,
        SHB_fqC,SHB_fqC1,
        TFAH,TFAC,
        ASITH,ASITMH1,ASITMH2,ASITMH3,
        ASITC,ASITMC1,ASITMC2,ASITMC3,
        FOTfhb1,FOTfhb2,FOTfcb1,FOTfcb2,
        FOTH1,FOTH2,FOTH3,FOTC1,FOTC2,FOTC3,HULOAD,CULOAD,
        LGP_H,LGP_HU,LGP_CU,
        MBH,MBC,
        CON_HU1,CON_HU2,CON_HU4,
        CON_CU1,CON_CU2,CON_CU4,
        CON_EXFR,COUNTING,
        APPTEMP_L1,APPTEMP_R1,APPTEMP_CU,APPTEMP_HU,
        APPTEM_L2,APPTEM_R2,APPTECU,APPTEHU,
        LMTHx,LMTCU,LMTHU,LMTHc,LMTCUc,LMTHUc,AreaP,AreaC,AreaH,
        UTILITY,TOAREA,OBJFN4   /

    NONLINEAR3 "Flow(Varialbe)+Area"
       / OHB_H,OHB_C,SHB_Ha,SHB_QHM,SHB_QH1,SHB_QH2,SHB_QH3,
        SHB_Ca,SHB_QCM,SHB_QC1,SHB_QC2,SHB_QC3,SHB_HC,
        SHB_fqH,SHB_fqH1,
        SHB_fqC,SHB_fqC1,
        TFAH,TFAC,
        ASITH,ASITMH1,ASITMH2,ASITMH3,
        ASITC,ASITMC1,ASITMC2,ASITMC3,

*................Temperature Bound...........
        FOTH1,FOTH2,FOTH3,
        FOTC1,FOTC2,FOTC3,
*...........................................
        HULOAD,CULOAD,
```

```
        FOTfhb1,FOTfhb2,FOTfcb1,FOTfcb2,
        LG_H,LG_HU,LG_CU,MMC1,MMC2,MBH,MBC,
        CON_HU1,CON_HU2,CON_HU3,CON_HU4,
        CON_CU1,CON_CU2,CON_CU3,CON_CU4,
        CON_HEU,CON_HEL,
        CON_EX,COUNTING,COUNTING_A,
        APPTEM_L1,APPTEM_R1,APPTEM_L2,APPTEM_R2,APPTEM_CU,APPTEM_HU,
        APPTECU,APPTEHU,
        LMTHx,LMTCU,LMTHU,LMTHc,LMTCUc,LMTHUc,AreaP,AreaC,AreaH,
        UTILITY,NoUNIT,TOAREA,OBJFN5   /

    NONLINEAR4 "Flow(Varialbe)+Area"
       / OHB_H,OHB_C,SHB_Ha,SHB_QHM,SHB_QH1,SHB_QH2,SHB_QH3,
        SHB_Ca,SHB_QCM,SHB_QC1,SHB_QC2,SHB_QC3,SHB_HC,
        SHB_fqH,SHB_fqH1,
        SHB_fqC,SHB_fqC1,
        TFAH,TFAC,
        ASITH,ASITMH1,ASITMH2,ASITMH3,
        ASITC,ASITMC1,ASITMC2,ASITMC3,
*................Temperature Bound...........
*        FOTH1,FOTH2,FOTH3,FOTH4,FOTH5,
*        FOTC1,FOTC2,FOTC3,FOTC4,FOTC5,

        FOTH1,FOTH2,FOTH3,
        FOTC1,FOTC2,FOTC3,
*............................................
        HULOAD,CULOAD,
        FOTfhb1,FOTfhb2,FOTfcb1,FOTfcb2,
        CON_HU1,CON_HU2,CON_HU3,CON_HU4,
        CON_CU1,CON_CU2,CON_CU3,CON_CU4,
        CON_HEU,CON_HEL,
        CON_EX,COUNTING,COUNTING_A,
        APPTEM_L1,APPTEM_R1,APPTEM_L2,APPTEM_R2,APPTEM_CU,APPTEM_HU,
        APPTECU,APPTEHU,
        LMTHx,LMTCU,LMTHU,LMTHc,LMTCUc,LMTHUc,AreaP,AreaC,AreaH,
        UTILITY,NoUNIT,TOAREA,OBJFN6,BrouTAC   /

;
```

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**************************************************************************************
*.............................................................Initialization.................................................................
**************************************************************************************
PARAMETER
      AlinearP(I,J,MK,Bh,Bc,K)    Area of process-process HX for linear case
      AlinearC(I)                 Area of cold utility for linear case
      AlinearH(J)                 Area of hot utility for linear case

      QCUn(I)                     Cold utility for linear case
      QHUn(J)                     Hot utility for linear case
      QEXn(I,J,MK,Bh,Bc,K)        Heat exchange for linear case

      TCMlinear(J,MK)             Temperature of cold stream at location for linear case
      TClinear(J,MK,Bc,K)         Temperature of cold stream at substage for linear case
      THMlinear(I,MK)             Temperature of hot stream at location for linear case
      THlinear(I,MK,Bh,K)         Temperature of hot stream at substage for linear case

      dTHS_IN(I,J,MK,Bh,Bc,K)     Hot side approach temperature
      dTCS_IN(I,J,MK,Bh,Bc,K)     Cold side approach temperature
      dtcu_IN(I)                  Approach temperature of Cold utility
      dthu_IN(J)                  Approach temperature of Hot utility

      Zlinear(I,J,MK,Bh,Bc,K)     Existent HX
      ZCUlinear(I)                Existent cold utility of stream I
      ZHUlinear(J)                Existent hot utility of stream J
;
**************************************************************************************

x=1;

WHILE(x<=XT,

SOLVE LINEAR1 USING MIP MINIMIZING TAC1;
DISPLAY TH.l,Thb.l,TC.l,Tcb.l,q.l,qcu.l,qhu.l,Z.l,Zcu.l,Zhu.l,fhbP,fcbP,
      TOTALqex.l,TOTAL_HU.l,TOTAL_CU.l,TAC1.l;

* Initial Area..................................................................
```

```
AlinearP(I,J,MK,Bh,Bc,K) =
q.l(I,J,MK,Bh,Bc,K)/((U(I,J)*( (dTHS.l(I,J,MK,Bh,Bc,K)*dTCS.l(I,J,MK,Bh,Bc,K)*((dTHS.l(I,J,MK
,Bh,Bc,K)+dTCS.l(I,J,MK,Bh,Bc,K))/2))**(1/3) ))+1e-06);
AlinearC(I) = qcu.l(I)/ ((Uc(I)*((dtcu.l(I)*ABS(TH.l(I,'MKL')-
TOUTH(I))*(dtcu.l(I)+ABS(TH.l(I,'MKL')-TOUTH(I)))/2)**(1/3)))+1e-06);
AlinearH(J) = qhu.l(J)/((Uh(J)*((dthu.l(J)*ABS(TOUTC(J)-
TC.l(J,'MKF'))*(dthu.l(J)+ABS(TOUTC(J)- TC.l(J,'MKF')))/2)**(1/3)))+1e-06);

Ap.l(I,J,MK,Bh,Bc,K) = AlinearP(I,J,MK,Bh,Bc,K);
Acu.l(I) = AlinearC(I);
Ahu.l(J) = AlinearH(J);

Display Ap.l,Acu.l,Ahu.l;

* Inintial flow...............................................................
fhb.l(I,MK,Bh)=fhbP(I,MK,Bh);
fcb.l(J,MK,Bc)=fcbP(J,MK,Bc);

* Initial heat recovery & utility.............................................
QCUn(I) = qcu.l(I);
QHUn(J) = qhu.l(J);
QEXn(I,J,MK,Bh,Bc,K) = q.l(I,J,MK,Bh,Bc,K);

qcu.l(I) = QCUn(I);
qhu.l(J) = QHUn(J);
q.l(I,J,MK,Bh,Bc,K) = QEXn(I,J,MK,Bh,Bc,K);

* Initial temperature.........................................................
TCMlinear(J,MK) = TC.l(J,MK);
TClinear(J,MK,Bc,K) = Tcb.l(J,MK,Bc,K);
THMlinear(I,MK) = TH.l(I,MK);
THlinear(I,MK,Bh,K) = Thb.l(I,MK,Bh,K);

TC.l(J,MK) = TCMlinear(J,MK);
Tcb.l(J,MK,Bc,K) = TClinear(J,MK,Bc,K);
TH.l(I,MK) = THMlinear(I,MK);
Thb.l(I,MK,Bh,K) = THlinear(I,MK,Bh,K);
```

```
* Initial existen of HX.......................................................
Zlinear(I,J,MK,Bh,Bc,K) = Z.l(I,J,MK,Bh,Bc,K);
ZCUlinear(I) = Zcu.l(I);
ZHUlinear(J) = Zhu.l(J);

ZP(I,J,MK,Bh,Bc,K) = Zlinear(I,J,MK,Bh,Bc,K);
ZcuP(I) = ZCUlinear(I);
ZhuP(J) = ZHUlinear(J);

*********************************************************************************
NONLINEAR1.optfile = 1;
$onecho>dicopt.opt
MAXCYCLES 30
$offecho
*********************************************************************************

SOLVE NONLINEAR1 USING NLP MINIMIZING TAC2;
DISPLAY QH.l,QC.l,TH.l,Thb.l,TC.l,Tcb.l,q.l,qcu.l,qhu.l,ZP,ZcuP,ZhuP,fhb.l,fcb.l,
    TOTALqex.l,TOTAL_HU.l,TOTAL_CU.l,TAC1.l,TAC2.l;

* Initial Area..................................................................
AlinearP(I,J,MK,Bh,Bc,K) =
q.l(I,J,MK,Bh,Bc,K)/((U(I,J)*( (dTHS.l(I,J,MK,Bh,Bc,K)*dTCS.l(I,J,MK,Bh,Bc,K)*((dTHS.l(I,J,MK
,Bh,Bc,K)+dTCS.l(I,J,MK,Bh,Bc,K))/2))**(1/3) ))+1e-06);
AlinearC(I) = qcu.l(I)/ ((Uc(I)*((dtcu.l(I)*ABS(TH.l(I,'MKL')-
TOUTH(I))*(dtcu.l(I)+ABS(TH.l(I,'MKL')-TOUTH(I)))/2)**(1/3)))+1e-06);
AlinearH(J) = qhu.l(J)/((Uh(J)*((dthu.l(J)*ABS(TOUTC(J)-
TC.l(J,'MKF'))*(dthu.l(J)+ABS(TOUTC(J)- TC.l(J,'MKF')))/2)**(1/3)))+1e-06);

Ap.l(I,J,MK,Bh,Bc,K) = AlinearP(I,J,MK,Bh,Bc,K);
Acu.l(I) = AlinearC(I);
Ahu.l(J) = AlinearH(J);

Display Ap.l,Acu.l,Ahu.l;

* Inintial flow.................................................................
fhbP(I,MK,Bh)=fhb.l(I,MK,Bh);
fcbP(J,MK,Bc)=fcb.l(J,MK,Bc);
```

```
* Initial heat recovery & utility..............................................
QCUn(I) = qcu.l(I);
QHUn(J) = qhu.l(J);
QEXn(I,J,MK,Bh,Bc,K) = q.l(I,J,MK,Bh,Bc,K);

qcu.l(I) = QCUn(I);
qhu.l(J) = QHUn(J);
q.l(I,J,MK,Bh,Bc,K) = QEXn(I,J,MK,Bh,Bc,K);

* Initial temperature..........................................................
TCMlinear(J,MK) = TC.l(J,MK);
TClinear(J,MK,Bc,K) = Tcb.l(J,MK,Bc,K);
THMlinear(I,MK) = TH.l(I,MK);
THlinear(I,MK,Bh,K) = Thb.l(I,MK,Bh,K);

TC.l(J,MK) = TCMlinear(J,MK);
Tcb.l(J,MK,Bc,K) = TClinear(J,MK,Bc,K);
TH.l(I,MK) = THMlinear(I,MK);
Thb.l(I,MK,Bh,K) = THlinear(I,MK,Bh,K);

* Initial existen of HX........................................................
Zlinear(I,J,MK,Bh,Bc,K) = ZP(I,J,MK,Bh,Bc,K);
ZCUlinear(I) = ZcuP(I);
ZHUlinear(J) = ZhuP(J);

Z.l(I,J,MK,Bh,Bc,K) = Zlinear(I,J,MK,Bh,Bc,K);
Zcu.l(I) = ZCUlinear(I);
Zhu.l(J) = ZHUlinear(J);

SOLVE LINEAR2 USING MIP MINIMIZING TAC3;
DISPLAY QH.l,QC.l,TH.l,Thb.l,TC.l,Tcb.l,q.l,qcu.l,qhu.l,Z.l,Zcu.l,Zhu.l,fhbP,fcbP,
    TOTALqex.l,TOTAL_HU.l,TOTAL_CU.l,TAC1.l,TAC2.l,TAC3.l;


* Inintial flow................................................................
fhb.l(I,MK,Bh)=fhbP(I,MK,Bh);
fcb.l(J,MK,Bc)=fcbP(J,MK,Bc);
```

```
* Initial Area...............................................................
AlinearP(I,J,MK,Bh,Bc,K) =
q.l(I,J,MK,Bh,Bc,K)/((U(I,J)*( (dTHS.l(I,J,MK,Bh,Bc,K)*dTCS.l(I,J,MK,Bh,Bc,K)*((dTHS.l(I,J,MK
,Bh,Bc,K)+dTCS.l(I,J,MK,Bh,Bc,K))/2))**(1/3) ))+1e-06);
AlinearC(I) = qcu.l(I)/ ((Uc(I)*((dtcu.l(I)*ABS(TH.l(I,'MKL')-
TOUTH(I))*(dtcu.l(I)+ABS(TH.l(I,'MKL')-TOUTH(I)))/2)**(1/3)))+1e-06);
AlinearH(J) = qhu.l(J)/((Uh(J)*((dthu.l(J)*ABS(TOUTC(J)-
TC.l(J,'MKF'))*(dthu.l(J)+ABS(TOUTC(J)- TC.l(J,'MKF')))/2)**(1/3)))+1e-06);

Ap.l(I,J,MK,Bh,Bc,K) = AlinearP(I,J,MK,Bh,Bc,K);
Acu.l(I) = AlinearC(I);
Ahu.l(J) = AlinearH(J);

Display Ap.l,Acu.l,Ahu.l;

* Calculation of approach temperature..........................................
dTHS_IN(I,J,MK,Bh,Bc,K)=dTHS.l(I,J,MK,Bh,Bc,K);
dTCS_IN(I,J,MK,Bh,Bc,K)=dTCS.l(I,J,MK,Bh,Bc,K);
dtcu_IN(I)=dtcu.l(I);
dthu_IN(J)=dthu.l(J);

dTHS.l(I,J,MK,Bh,Bc,K)=dTHS_IN(I,J,MK,Bh,Bc,K);
dTCS.l(I,J,MK,Bh,Bc,K)=dTCS_IN(I,J,MK,Bh,Bc,K);
dtcu.l(I)=dtcu_IN(I);
dthu.l(J)=dthu_IN(J);

* Initial heat recovery & utility.............................................
QCUn(I) = qcu.l(I);
QHUn(J) = qhu.l(J);
QEXn(I,J,MK,Bh,Bc,K) = q.l(I,J,MK,Bh,Bc,K);

qcu.l(I) = QCUn(I);
qhu.l(J) = QHUn(J);
q.l(I,J,MK,Bh,Bc,K) = QEXn(I,J,MK,Bh,Bc,K);

* Initial temperature..........................................................
TCMlinear(J,MK) = TC.l(J,MK);
```

```
TClinear(J,MK,Bc,K) = Tcb.l(J,MK,Bc,K);
THMlinear(I,MK) = TH.l(I,MK);
THlinear(I,MK,Bh,K) = Thb.l(I,MK,Bh,K);

TC.l(J,MK) = TCMlinear(J,MK);
Tcb.l(J,MK,Bc,K) = TClinear(J,MK,Bc,K);
TH.l(I,MK) = THMlinear(I,MK);
Thb.l(I,MK,Bh,K) = THlinear(I,MK,Bh,K);

* Initial existen of HX......................................................
Zlinear(I,J,MK,Bh,Bc,K) = Z.l(I,J,MK,Bh,Bc,K);
ZCUlinear(I) = Zcu.l(I);
ZHUlinear(J) = Zhu.l(J);

ZP(I,J,MK,Bh,Bc,K) = Zlinear(I,J,MK,Bh,Bc,K);
ZcuP(I) = ZCUlinear(I);
ZhuP(J) = ZHUlinear(J);

**********************************************************************************
NONLINEAR2.optfile = 1;
$onecho>dicopt.opt
MAXCYCLES 30
mipoptfile cplex.opt 1
$offecho
**********************************************************************************
SOLVE NONLINEAR2 USING NLP MINIMIZING TAC4;
DISPLAY QH.l,QC.l,TH.l,Thb.l,TC.l,Tcb.l,Ap.l,Acu.l,Ahu.l,q.l,qcu.l,qhu.l,ZP,ZcuP,ZhuP,fhb.l,fcb.l,
      TOTALqex.l,TOTAL_HU.l,TOTAL_CU.l,TAC1.l,TAC2.l,TAC3.l,TAC4.l;

* Inintial flow..............................................................
fhb.l(I,MK,Bh)=fhbP(I,MK,Bh);
fcb.l(J,MK,Bc)=fcbP(J,MK,Bc);


* Initial Area...............................................................
AlinearP(I,J,MK,Bh,Bc,K) = Ap.l(I,J,MK,Bh,Bc,K);
AlinearC(I) = Acu.l(I);
AlinearH(J) = Ahu.l(J);
```

```
Ap.l(I,J,MK,Bh,Bc,K) = AlinearP(I,J,MK,Bh,Bc,K);
Acu.l(I) = AlinearC(I);
Ahu.l(J) = AlinearH(J);

* Calculation of approach temperature..........................................
dTHS_IN(I,J,MK,Bh,Bc,K)=dTHS.l(I,J,MK,Bh,Bc,K);
dTCS_IN(I,J,MK,Bh,Bc,K)=dTCS.l(I,J,MK,Bh,Bc,K);
dtcu_IN(I)=dtcu.l(I);
dthu_IN(J)=dthu.l(J);
dTHS.l(I,J,MK,Bh,Bc,K)=dTHS_IN(I,J,MK,Bh,Bc,K);
dTCS.l(I,J,MK,Bh,Bc,K)=dTCS_IN(I,J,MK,Bh,Bc,K);
dtcu.l(I)=dtcu_IN(I);
dthu.l(J)=dthu_IN(J);

* Initial heat recovery & utility..............................................
QCUn(I) = qcu.l(I);
QHUn(J) = qhu.l(J);
QEXn(I,J,MK,Bh,Bc,K) = q.l(I,J,MK,Bh,Bc,K);
qcu.l(I) = QCUn(I);
qhu.l(J) = QHUn(J);
q.l(I,J,MK,Bh,Bc,K) = QEXn(I,J,MK,Bh,Bc,K);

* Initial temperature..........................................................
TCMlinear(J,MK) = TC.l(J,MK);
TClinear(J,MK,Bc,K) = Tcb.l(J,MK,Bc,K);
THMlinear(I,MK) = TH.l(I,MK);
THlinear(I,MK,Bh,K) = Thb.l(I,MK,Bh,K);
TC.l(J,MK) = TCMlinear(J,MK);
Tcb.l(J,MK,Bc,K) = TClinear(J,MK,Bc,K);
TH.l(I,MK) = THMlinear(I,MK);
Thb.l(I,MK,Bh,K) = THlinear(I,MK,Bh,K);

* Initial existen of HX........................................................
Zlinear(I,J,MK,Bh,Bc,K) = Z.l(I,J,MK,Bh,Bc,K);
ZCUlinear(I) = Zcu.l(I);
ZHUlinear(J) = Zhu.l(J);

Z.l(I,J,MK,Bh,Bc,K) = Zlinear(I,J,MK,Bh,Bc,K);
```

```
Zcu.l(I) = ZCUlinear(I);
Zhu.l(J) = ZHUlinear(J);

If(x=1,

*************************************************************************************
NONLINEAR3.optfile = 1;
$onecho>dicopt.opt
MAXCYCLES 50
mipoptfile cplex.opt 1
$offecho
*************************************************************************************
SOLVE NONLINEAR3 USING MINLP MINIMIZING TAC5;
DISPLAY QH.l,QC.l,TH.l,Thb.l,TC.l,Tcb.l,Ap.l,Acu.l,Ahu.l,q.l,qcu.l,qhu.l,Z.l,Zcu.l,Zhu.l,fhb.l,fcb.l,

TOTALarea.l,TOTALqex.l,TOTAL_HU.l,TOTAL_CU.l,TAC1.l,TAC2.l,TAC3.l,TAC4.l,TAC5.l;

* Upper bound of Total annoul cost...........................................
TACup=TAC5.l;

* Inintial flow...............................................................
fhbP(I,MK,Bh)=fhb.l(I,MK,Bh);
fcbP(J,MK,Bc)=fcb.l(J,MK,Bc);

MK_Loop=1;
WHILE(MK_Loop<CARD(MK),

fhbP(I,MK,Bh)$(ord(MK)=MK_Loop and fhbP(I,MK,Bh)=0) = 0.05*FH(I);
fcbP(J,MK,Bc)$(ord(MK)=MK_Loop and fcbP(J,MK,Bc)=0) = 0.05*FC(J);

MK_Loop=MK_Loop+1; );




else
*************************************************************************************
NONLINEAR4.optfile = 1;
$onecho>dicopt.opt
```

```
MAXCYCLES 50
mipoptfile cplex.opt 1
$offecho
*******************************************************************************
SOLVE NONLINEAR4 USING MINLP MINIMIZING TAC6;
DISPLAY QH.l,QC.l,TH.l,Thb.l,TC.l,Tcb.l,Ap.l,Acu.l,Ahu.l,q.l,qcu.l,qhu.l,Z.l,Zcu.l,Zhu.l,fhb.l,fcb.l,

TOTALarea.l,TOTALqex.l,TOTAL_HU.l,TOTAL_CU.l,TAC1.l,TAC2.l,TAC3.l,TAC4.l,TAC5.l,TA
C6.l;

* Upper bound of Total annoul cost..............................................
TACup$(NONLINEAR4.modelstat<9 and NONLINEAR4.modelstat<>6 and
NONLINEAR4.modelstat<>4)=TAC6.l;

If(NONLINEAR4.modelstat=4 or NONLINEAR4.modelstat=6,
* Inintial flow.................................................................
fhbP(I,MK,Bh)=fhb.l(I,MK,Bh);
fcbP(J,MK,Bc)=fcb.l(J,MK,Bc);
);

*...............................................................................
* Importance Equations not both in this thesis and paper but needed
*...............................................................................
);

x=x+1; );
```

CURRICULUM VITAE

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2008–2012 Bachelor Degree of Chemical Engineering, Faculty of Engineering, Mahidol University, Bangkok, Thailand

Work Experience:

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	Company name:	The Gas Separation Plant, Rayong

Proceedings:

1. Jongsuwat, P.; Suriyapraphadilok, U.; and Bagajewicz, M.J. (2014, August 23-27) New Heat Exchanger Network Model Design. Proceedings of the 17th Conference on Process Integration, Modelling and Optimisation for Energy Saving and Pollution Reduction, Prague, Czech Republic.
2. Jongsuwat, P.; Suriyapraphadilok, U.; and Bagajewicz, M.J. (2014, April 22) Heat Integration of Crude Distillation Unit. Proceedings of the 5th Research Symposium on Petrochemical and Materials Technology and the 20th PPC Symposium on Petroleum, Petrochemicals, and Polymers, Bangkok, Thailand.