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APPENDIX
Mathematical Program Source Code using GAMS Software
(RETROFIT DESIGNED H.E.N)

1. Stage model of Retrofit H.E.N. of Example 1 with EMAT = 7.7 °C

```
SETS
    I  hot streams /I1,I2/
    J  cold streams /J1,J2,J3 /
    K  Stage no. /K1,K2,K3,K4/;
PARAMETER TINI(I) /I1 = 165,I2 = 240/
       TINJ(J) /J1 = 125,J2 = 61,J3 = 70/
       TOUTI(I)/I1 = 95, I2 = 65/
       TOUTJ(J)/J1 =220,J2 = 192,J3 = 185/
       FI(I)  /I1 = 148 ,I2 = 86.4/
       FJ(J)  / J1 = 139 ,J2 = 54.6,J3 = 62 /
       OMEGA  /1000000/
       TAL    /1000000/
       EMAT   /7.7/;
VARIABLES
    dt(I,J,K)  Approach temperature
    dtcu(I)    Approach temperature between cold utility and hot stream
    dthu(J)    Approach temperature between hot utility and cold stream
    q(I,J,K)   heat exchanged between hot I and cold J
    qcu(I)     heat exchanged between cold utility and hot I
    qhu(J)     heat exchanged between hot utility and cold J
    ti(I,K)    temp of hot stream i at hot end of stage k
    tj(J,K)    temp of cold stream j at hot end of stage k
    z(I,J,K)   exchanger matching between hot I and cold J at stage k
    zcu(I)     cold utility matching with hot I
    zhu(J)     hot utility matching with cold J
    ZZ         total energy
    dtt(I,J,K) actual temperature;
POSITIVE VARIABLE dt(I,J,K),dtcu(I),dthu(J),q(I,J,K),qcu(I),qhu(J),ti(I,K),tj(J,K);
BINARY VARIABLES zcu(I),zhu(J),z(I,J,K);


EQUATIONS
    MINU          objective function minimize utilities
    HOTI(I)       heat balance in hot streams I
    COLDJ(J)      heat balance in cold stream J
    HOTK1(I)      heat balance of hot  at stage K1
    HOTK2(I)      heat balance of hot  at stage K2
    HOTK3(I)      heat balance of hot  at stage K3
    COLDK1(J)     heat balance of cold  at stage K1
    COLDK2(J)     heat balance of cold  at stage K2
    COLDK3(J)     heat balance of cold  at stage K3
    TINHOT(I)     hot temp in
    TINCOLD(J)    cold temp in
    FEHOTK1(I)    feasibility of  hot temp   at stage K1
    FEHOTK2(I)    feasibility of  hot temp   at stage K2
    FEHOTK3(I)    feasibility of  hot temp   at stage K3
    FECOLDK1(J)   feasibility of  cold temp  at stage K1
    FECOLDK2(J)   feasibility of  cold temp  at stage K2
    FECOLDK3(J)   feasibility of  cold temp  at stage K3
    FEHOTOUT(I)   feasibility of  hot temp out
    FECOLDOUT(J)  feasibility of  cold temp out
    HOTU(I)       hot utility load
    COLDU(J)      cold utility load
    LogicK1(I,J)  Logical constraint at stage k1
    LogicK2(I,J)  Logical constraint at stage k2
    LogicK3(I,J)  Logical constraint at stage k3
    LogicHOT(J)   Logical constraint hot  utility
    LogicCOLD(I)  Logical constraint cold utility
    ApproK1(I,J)  approach temp at stage k1
    AApproK1(I,J) the other approach temp at stage k1
    ApproK2(I,J)  approach temp at stage k2
    AApproK2(I,J) the other approach temp at stage k2
    ApproK3(I,J)  approach temp at stage k3
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      AApproK3(I,J)      the other approach temp at stage k3
      EMATdt1(I,J,K)     EMAT constraint
      CONSTRAINT1        constraint no.1
      CONSTRAINT2        constraint no.2
      CONSTRAINT3        constraint no.3
      CONSTRAINT4        constraint no.4
      HOTNOSPLITTING1K1  constraint of no splitting
      HOTNOSPLITTING2K1  constraint of no splitting
      HOTNOSPLITTING1K2  constraint of no splitting
      HOTNOSPLITTING2K2  constraint of no splitting
      HOTNOSPLITTING1K3  constraint of no splitting
      HOTNOSPLITTING2K3  constraint of no splitting
      COLDNOSPLITTING1K1  constraint of no splitting
      COLDNOSPLITTING2K1  constraint of no splitting
      COLDNOSPLITTING3K1  constraint of no splitting
      COLDNOSPLITTING1K2  constraint of no splitting
      COLDNOSPLITTING2K2  constraint of no splitting
      COLDNOSPLITTING3K2  constraint of no splitting
      COLDNOSPLITTING1K3  constraint of no splitting
      COLDNOSPLITTING2K3  constraint of no splitting
      COLDNOSPLITTING3K3  constraint of no splitting
      APPROACHTEMPK1(I,J) actual approac temperature at k1
      APPROACHTEMPK2(I,J) actual approac temperature at k2
      APPROACHTEMPK3(I,J) actual approac temperature at k3
      APPROACHTEMPK4(I,J) actual approac temperature at k4;
MINU      ZZ  =E= 10*SUM(I,qcu(I)) + 10*SUM(J,qhu(J))
           +10*SUM((I,J,K),z(I,J,K))
           +10*SUM(I,zcu(I))+ 10*SUM(J,zhu(J));
HOTI(I)   .. (TINI(I)-TOUTI(I))*FI(I)=E= SUM((J,K),q(I,J,K))+qcu(I);
COLDJ(J)  .. (TOUTJ(J)-TINJ(J))*FJ(J)=E= SUM((I,K),q(I,J,K))+qhu(J);
HOTK1(I)  .. (ti(I,'K1')-ti(I,'K2'))*FI(I)=E= SUM(J,q(I,J,'K1'));
HOTK2(I)  .. (ti(I,'K2')-ti(I,'K3'))*FI(I)=E= SUM(J,q(I,J,'K2'));
HOTK3(I)  .. (ti(I,'K3')-ti(I,'K4'))*FI(I)=E= SUM(J,q(I,J,'K3'));
COLDK1(J) .. (tj(J,'K1')-tj(J,'K2'))*FJ(J)=E= SUM(I,q(I,J,'K1'));
COLDK2(J) .. (tj(J,'K2')-tj(J,'K3'))*FJ(J)=E= SUM(I,q(I,J,'K2'));
COLDK3(J) .. (tj(J,'K3')-tj(J,'K4'))*FJ(J)=E= SUM(I,q(I,J,'K3'));
TINHOT(I) .. TINI(I) =E= ti(I,'K1');
TINCOLD(J) .. TINJ(J) =E= tj(J,'K4');
FEHOTK1(I) .. ti(I,'K1') =G= ti(I,'K2');
FEHOTK2(I) .. ti(I,'K2') =G= ti(I,'K3');
FEHOTK3(I) .. ti(I,'K3') =G= ti(I,'K4');
FECOLDK1(J).. tj(J,'K1') =G= tj(J,'K2');
FECOLDK2(J).. tj(J,'K2') =G= tj(J,'K3');
FECOLDK3(J).. tj(J,'K3') =G= tj(J,'K4');
FEHOTOUT(I) .. TOUTI(I) =L= ti(I,'K4');
FECOLDOUT(J).. TOUTJ(J) =G= tj(J,'K1');
HOTU(I) .. (ti(I,'K4')-TOUTI(I))*FI(I) =E= qcu(I);
COLDU(J) .. (TOUTJ(J)-tj(j,'K1'))*FJ(J) =E= qhu(J);
LogicK1(I,J).. q(I,J,'K1')-OMEGA*z(I,J,'K1') =L= 0;
LogicK2(I,J).. q(I,J,'K2')-OMEGA*z(I,J,'K2') =L= 0;
LogicK3(I,J).. q(I,J,'K3')-OMEGA*z(I,J,'K3') =L= 0;
LogicHOT(J) .. qhu(J)-OMEGA*zhu(J) =L= 0;
LogicCOLD(I).. qcu(I)-OMEGA*zcu(I) =L= 0;
ApproK1(I,J) .. dt(I,J,'K1') =L= (ti(I,'K1')-tj(J,'K1'))+TAL*(1-z(I,J,'K1'));
AApproK1(I,J) . dt(I,J,'K2') =L= (ti(I,'K2')-tj(J,'K2'))+TAL*(1-z(I,J,'K1'));
ApproK2(I,J) .. dt(I,J,'K2') =L= (ti(I,'K2')-tj(J,'K2'))+TAL*(1-z(I,J,'K2'));
AApproK2(I,J).. dt(I,J,'K3') =L= (ti(I,'K3')-tj(J,'K3'))+TAL*(1-z(I,J,'K2'));
ApproK3(I,J) .. dt(I,J,'K3') =L= (ti(I,'K3')-tj(J,'K3'))+TAL*(1-z(I,J,'K3'));
AApproK3(I,J).. dt(I,J,'K4') =L= (ti(I,'K4')-tj(J,'K4'))+TAL*(1-z(I,J,'K3'));
EMATdt1(I,J,K) .. dt(I,J,K)  =G= EMAT;
CONSTRAINT1  .. sum(K,z('I2','J1',K))=G=1;
CONSTRAINT2  .. sum(K,z('I1','J1',K))=G=1;
CONSTRAINT3  .. sum(K,z('I2','J2',K))=G=1;
CONSTRAINT4  .. sum(K,z('I1','J3',K))=G=1;
HOTNOSPLITTING1K1 .. sum(J,z('I1',J,'K1')) =L= 1;
HOTNOSPLITTING2K1 .. sum(J,z('I2',J,'K1')) =L= 1;
HOTNOSPLITTING1K2 .. sum(J,z('I1',J,'K2')) =L= 1;
HOTNOSPLITTING2K2 .. sum(J,z('I2',J,'K2')) =L= 1;
HOTNOSPLITTING1K3 .. sum(J,z('I1',J,'K3')) =L= 1;
HOTNOSPLITTING2K3 .. sum(J,z('I2',J,'K3')) =L= 1;
COLDNOSPLITTING1K1.. sum(I,z(I,'J1','K1')) =L= 1;
```

```
COLDNOSPLITTING2K1.. sum(I,z(I,'J2','K1')) =L= 1;
COLDNOSPLITTING3K1.. sum(I,z(I,'J3','K1')) =L= 1;
COLDNOSPLITTING1K2.. sum(I,z(I,'J1','K2')) =L= 1;
COLDNOSPLITTING2K2.. sum(I,z(I,'J2','K2')) =L= 1;
COLDNOSPLITTING3K2.. sum(I,z(I,'J3','K2')) =L= 1;
COLDNOSPLITTING1K3.. sum(I,z(I,'J1','K3')) =L= 1;
COLDNOSPLITTING2K3.. sum(I,z(I,'J2','K3')) =L= 1;
COLDNOSPLITTING3K3.. sum(I,z(I,'J3','K3')) =L= 1;
APPROACHTEMPK1(I,J) .. dtt(I,J,'K1') =E= ti(I,'K1')-tj(J,'K1');
APPROACHTEMPK2(I,J) .. dtt(I,J,'K2') =E= ti(I,'K2')-tj(J,'K2');
APPROACHTEMPK3(I,J) .. dtt(I,J,'K3') =E= ti(I,'K3')-tj(J,'K3');
APPROACHTEMPK4(I,J) .. dtt(I,J,'K4') =E= ti(I,'K4')-tj(J,'K4');
MODEL TSHIP /ALL/ ;
SOLVE TSHIP USING MIP MINIMIZING ZZ;
DISPLAY z.L,zcu.L,zhu.L,ZZ.L,q.L,qcu.L,qhu.L,ti.L,tj.L;
```

Result of stage model of Retrofit H.E.N. of Example 1 with EMAT = 7.7 °C

```
GAMS Rev 136 MS Windows                04/05/10 13:58:32 Page 6
G e n e r a l   A l g e b r a i c   M o d e l i n g   S y s t e m
E x e c u t i o n
----   190 VARIABLE z.L  exchanger matching between hot I and cold J at stage k
          K1        K2        K3
I1.J1              1.000
I1.J2                        1.000
I1.J3     1.000
I2.J1     1.000
I2.J2              1.000
I2.J3                        1.000
----   190 VARIABLE zcu.L  cold utility matching with hot I
I1 1.000,   I2 1.000
----   190 VARIABLE zhu.L  hot utility matching with cold J
J1 1.000,   J2 1.000,   J3 1.000
----   190 VARIABLE ZZ.L              =   117732.395  total energy
----   190 VARIABLE q.L  heat exchanged between hot I and cold J
          K1        K2        K3
I1.J1              3144.305
I1.J2                        3569.507
I1.J3  1432.507
I2.J1  7316.274
I2.J2              1159.994
I2.J3                        3980.093
----   190 VARIABLE qcu.L  heat exchanged between cold utility and hot I
I1 2213.681,   I2 2663.639
----   190 VARIABLE qhu.L  heat exchanged between hot utility and cold J
J1 2744.421,   J2 2423.099,   J3 1717.400
----   190 VARIABLE ti.L  temp of hot stream i at hot end of stage k
        K1        K2        K3        K4
I1   165.000   155.321   134.076   109.957
I2   240.000   155.321   141.895    95.829
----   190 VARIABLE tj.L  temp of cold stream j at hot end of stage k
        K1        K2        K3        K4
J1   200.256   147.621   125.000   125.000
J2   147.621   147.621   126.376    61.000
J3   157.300   134.195   134.195    70.000
EXECUTION TIME    =    0.000 SECONDS   1.5 Mb    WIN212-136
USER: The Petroleum and Petrochemical College      G030915:1142AP-WIN
```

2. Stage model of Retrofit H.E.N. of Example 2 with EMAT = 10 °C

```
SETS
    I  hot streams /I1,I2,I3/
    J  cold streams /J1,J2,J3/
    K  Stage no. /K1,K2,K3,K4/;
PARAMETER TINI(I) /I1 = 500,I2 = 450,I3 = 400/
       TINJ(J) /J1 = 300,J2 = 340,J3 = 340/
       TOUTI(I)/I1 = 350,I2 = 350,I3 = 320/
       TOUTJ(J)/J1 = 480,J2 = 420,J3 = 400/
       FI(I)  /I1 = 10 ,I2 = 12 ,I3 = 8 /
       FJ(J)  /J1 = 9  ,J2 = 10 ,J3 = 8 /
```

```
     OMEGA  /1000000/
     TAL    /1000000/
     EMAT   /10/;
VARIABLES
    dt(I,J,K)  Approach temperature
    dtcu(I)   Approach temperature between cold utility and hot stream
    dthu(J)   Approach temperature between hot utility and cold stream
    q(I,J,K)  heat exchanged between hot I and cold J
    qcu(I)    heat exchanged between cold utility and hot I
    qhu(J)    heat exchanged between hot utility and cold J
    ti(I,K)   temp of hot stream i at hot end of stage k
    tj(J,K)   temp of cold stream j at hot end of stage k
    z(I,J,K)  exchanger matching between hot I and cold J at stage k
    zcu(I)    cold utility matching with hot I
    zhu(J)    hot utility matching with cold J
    ZZ        total energy
    dtt(I,J,K) actual temperature;
POSITIVE VARIABLE dt(I,J,K),dtcu(I),dthu(J),q(I,J,K),qcu(I),qhu(J),ti(I,K),tj(J,K);
BINARY VARIABLES  zcu(I),zhu(J),z(I,J,K);
EQUATIONS
    MINU              objective function minimize utilities
    HOTI(I)           heat balance in hot streams I
    COLDJ(J)            heat balance in cold stream J
    HOTK1(I)            heat balance of hot  at stage K1
    HOTK2(I)            heat balance of hot  at stage K2
    HOTK3(I)            heat balance of hot  at stage K3
    COLDK1(J)             heat balance of cold  at stage K1
    COLDK2(J)             heat balance of cold  at stage K2
    COLDK3(J)             heat balance of cold  at stage K3
    TINHOT(I)           hot temp in
    TINCOLD(J)            cold temp in
    FEHOTK1(I)            feasibility of  hot temp   at stage K1
    FEHOTK2(I)            feasibility of  hot temp   at stage K2
    FEHOTK3(I)            feasibility of  hot temp   at stage K3
    FECOLDK1(J)             feasibility of  cold temp  at stage K1
    FECOLDK2(J)             feasibility of  cold temp  at stage K2
    FECOLDK3(J)             feasibility of  cold temp  at stage K3
    FEHOTOUT(I)             feasibility of  hot temp out
    FECOLDOUT(J)              feasibility of  cold temp out
    HOTU(I)             hot utility load
    COLDU(J)              cold utility load
    LogicK1(I,J)        Logical constraint at stage k1
    LogicK2(I,J)        Logical constraint at stage k2
    LogicK3(I,J)        Logical constraint at stage k3
    LogicHOT(J)           Logical constraint hot  utility
    LogicCOLD(I)            Logical constraint cold utility
    ApproK1(I,J)        approach temp at stage k1
    AApproK1(I,J)         the other approach temp at stage k1
    ApproK2(I,J)        approach temp at stage k2
    AApproK2(I,J)         the other approach temp at stage k2
    ApproK3(I,J)        approach temp at stage k3
    AApproK3(I,J)         the other approach temp at stage k3
    EMATdt1(I,J,K)        EMAT constraint
    CONSTRAINT1             constraint no.1
    CONSTRAINT2             constraint no.2
    CONSTRAINT3             constraint no 3
    CONSTRAINT4             constraint no.4
    HOTNOSPLITTING1K1   constraint of no splitting
    HOTNOSPLITTING2K1   constraint of no splitting
    HOTNOSPLITTING1K2   constraint of no splitting
    HOTNOSPLITTING2K2   constraint of no splitting
    HOTNOSPLITTING1K3   constraint of no splitting
    HOTNOSPLITTING2K3   constraint of no splitting
    COLDNOSPLITTING1K1  constraint of no splitting
    COLDNOSPLITTING2K1  constraint of no splitting
    COLDNOSPLITTING3K1  constraint of no splitting
    COLDNOSPLITTING1K2  constraint of no splitting
    COLDNOSPLITTING2K2  constraint of no splitting
    COLDNOSPLITTING3K2  constraint of no splitting
    COLDNOSPLITTING1K3  constraint of no splitting
    COLDNOSPLITTING2K3  constraint of no splitting
```

```
COLDNOSPLITTING3K3  constraint of no splitting
APPROACHTEMPK1(I,J) actual approac temperature at k1
APPROACHTEMPK2(I,J) actual approac temperature at k2
APPROACHTEMPK3(I,J) actual approac temperature at k3
APPROACHTEMPK4(I,J) actual approac temperature at k4;
MINU      .. ZZ  =E= 10*SUM(I,qcu(I)) + 10*SUM(J,qhu(J))+10*SUM((I,J,K),z(I,J,K))+10*SUM(I,zcu(I))+
10*SUM(J,zhu(J));
HOTI(I)   .. (TINI(I)-TOUTI(I))*FI(I)=E= SUM((J,K),q(I,J,K))+qcu(I);
COLDJ(J)  .. (TOUTJ(J)-TINJ(J))*FJ(J)=E= SUM((I,K),q(I,J,K))+qhu(J);
HOTK1(I)  .. (ti(I,'K1')-ti(I,'K2'))*FI(I)=E= SUM(J,q(I,J,'K1'));
HOTK2(I)  .. (ti(I,'K2')-ti(I,'K3'))*FI(I)=E= SUM(J,q(I,J,'K2'));
HOTK3(I)  .. (ti(I,'K3')-ti(I,'K4'))*FI(I)=E= SUM(J,q(I,J,'K3'));
COLDK1(J) .. (tj(J,'K1')-tj(J,'K2'))*FJ(J)=E= SUM(I,q(I,J,'K1'));
COLDK2(J) .. (tj(J,'K2')-tj(J,'K3'))*FJ(J)=E= SUM(I,q(I,J,'K2'));
COLDK3(J) .. (tj(J,'K3')-tj(J,'K4'))*FJ(J)=E= SUM(I,q(I,J,'K3'));
TINHOT(I) .. TINI(I) =E= ti(I,'K1');
TINCOLD(J) .. TINJ(J) =E= tj(J,'K4');
FEHOTK1(I) .. ti(I,'K1') =G= ti(I,'K2');
FEHOTK2(I) .. ti(I,'K2') =G= ti(I,'K3');
FEHOTK3(I) .. ti(I,'K3') =G= ti(I,'K4');
FECOLDK1(J).. tj(J,'K1') =G= tj(J,'K2');
FECOLDK2(J).. tj(J,'K2') =G= tj(J,'K3');
FECOLDK3(J).. tj(J,'K3') =G= tj(J,'K4');
FEHOTOUT(I) .. TOUTI(I) =L= ti(I,'K4');
FECOLDOUT(J).. TOUTJ(J) =G= tj(J,'K1');
HOTU(I)  .. (ti(I,'K4')-TOUTI(I))*FI(I) =E= qcu(I);
COLDU(J) .. (TOUTJ(J)-tj(j,'K1'))*FJ(J) =E= qhu(J);
LogicK1(I,J).. q(I,J,'K1')-OMEGA*z(I,J,'K1') =L= 0;
LogicK2(I,J).. q(I,J,'K2')-OMEGA*z(I,J,'K2') =L= 0;
LogicK3(I,J).. q(I,J,'K3')-OMEGA*z(I,J,'K3') =L= 0;
LogicHOT(J) .. qhu(J)-OMEGA*zhu(J) =L= 0;
LogicCOLD(I).. qcu(I)-OMEGA*zcu(I) =L= 0;
ApproK1(I,J) .. dt(I,J,'K1') =L= (ti(I,'K1')-tj(J,'K1'))+TAL*(1-z(I,J,'K1'));
AApproK1(I,J).. dt(I,J,'K2') =L= (ti(I,'K2')-tj(J,'K2'))+TAL*(1-z(I,J,'K1'));
ApproK2(I,J) .. dt(I,J,'K2') =L= (ti(I,'K2')-tj(J,'K2'))+TAL*(1-z(I,J,'K2'));
AApproK2(I,J).. dt(I,J,'K3') =L= (ti(I,'K3')-tj(J,'K3'))+TAL*(1-z(I,J,'K2'));
ApproK3(I,J) .. dt(I,J,'K3') =L= (ti(I,'K3')-tj(J,'K3'))+TAL*(1-z(I,J,'K3'));
AApproK3(I,J).. dt(I,J,'K4') =L= (ti(I,'K4')-tj(J,'K4'))+TAL*(1-z(I,J,'K3'));
EMATdt1(I,J,K) .. dt(I,J,K)  =G= EMAT;
CONSTRAINT1  .. sum(K,z('I1','J2',K))=G=1;
CONSTRAINT2  .. sum(K,z('I1','J3',K))=G=1;
CONSTRAINT3  .. sum(K,z('I2','J1',K))=G=1;
CONSTRAINT4  .. sum(K,z('I3','J1',K))=G=1;
HOTNOSPLITTING1K1 .. sum(J,z('I1',J,'K1')) =L= 1;
HOTNOSPLITTING2K1 .. sum(J,z('I2',J,'K1')) =L= 1;
HOTNOSPLITTING1K2 .. sum(J,z('I1',J,'K2')) =L= 1;
HOTNOSPLITTING2K2 .. sum(J,z('I2',J,'K2')) =L= 1;
HOTNOSPLITTING1K3 .. sum(J,z('I1',J,'K3')) =L= 1;
HOTNOSPLITTING2K3 .. sum(J,z('I2',J,'K3')) =L= 1;
COLDNOSPLITTING1K1 .. sum(I,z(I,'J1','K1')) =L= 1;
COLDNOSPLITTING2K1.. sum(I,z(I,'J2','K1')) =L= 1;
COLDNOSPLITTING3K1.. sum(I,z(I,'J3','K1')) =L= 1;
COLDNOSPLITTING1K2.. sum(I,z(I,'J1','K2')) =L= 1;
COLDNOSPLITTING2K2.. sum(I,z(I,'J2','K2')) =L= 1;
COLDNOSPLITTING3K2.. sum(I,z(I,'J3','K2')) =L= 1;
COLDNOSPLITTING1K3 .. sum(I,z(I,'J1','K3')) =L= 1;
COLDNOSPLITTING2K3 .. sum(I,z(I,'J2','K3')) =L= 1;
COLDNOSPLITTING3K3 .. sum(I,z(I,'J3','K3')) =L= 1;
APPROACHTEMPK1(I,J) .. dtt(I,J,'K1') =E= ti(I,'K1')-tj(J,'K1');
APPROACHTEMPK2(I,J) .. dtt(I,J,'K2') =E= ti(I,'K2')-tj(J,'K2');
APPROACHTEMPK3(I,J) .. dtt(I,J,'K3') =E= ti(I,'K3')-tj(J,'K3');
APPROACHTEMPK4(I,J) .. dtt(I,J,'K4') =E= ti(I,'K4')-tj(J,'K4');
MODEL TSHIP /ALL/ ;
SOLVE TSHIP USING MIP MINIMIZING ZZ;
DISPLAY z.L,zcu.L,zhu.L,ZZ.L,q.L,qcu.L,qhu.L,ti.L,tj.L;
```

Result of stage model of Retrofit H.E.N. of Example 2 with EMAT = 10 °C

```
GAMS Rev 136  MS Windows                04/05/10 14:09:28 Page 6
General Algebraic Modeling System
```

```
Execution
----   190 VARIABLE z.L  exchanger matching between hot I and cold J at stage k
          K1        K2        K3
I1.J1     1.000
I1.J2                         1.000
I1.J3               1.000
I2.J1               1.000
I3.J1                         1.000
I3.J3                         1.000
----   190 VARIABLE zcu.L  cold utility matching with hot I
I2 1.000,  I3 1.000
----   190 VARIABLE zhu.L  hot utility matching with cold J
            ( ALL      0.000 )
----   190 VARIABLE ZZ.L              =     4480.000  total energy
----   190 VARIABLE q.L  heat exchanged between hot I and cold J
          K1        K2        K3
I1.J1   620.000
I1.J2                       800.000
I1.J3              80.000
I2.J1            1000.000
I3.J3                       400.000
----   190 VARIABLE qcu.L  heat exchanged between cold utility and hot I
I2 200.000,  I3 240.000
----   190 VARIABLE qhu.L  heat exchanged between hot utility and cold J
            ( ALL      0.000 )
----   190 VARIABLE ti.L  temp of hot stream i at hot end of stage k
        K1        K2        K3        K4
I1   500.000   438.000   430.000   350.000
I2   450.000   450.000   366.667   366.667
I3   400.000   400.000   400.000   350.000
----   190 VARIABLE tj.L  temp of cold stream j at hot end of stage k
        K1        K2        K3        K4
J1   480.000   411.111   300.000   300.000
J2   420.000   420.000   420.000   340.000
J3   400.000   400.000   390.000   340.000
EXECUTION TIME      =      0.000 SECONDS   1.5 Mb    WIN212-136
USER: The Petroleum and Petrochemical College       G030915:1142AP-WIN
```

3. Stage model of Retrofit H.E.N. of Example 3 with EMAT = 10 °C

```
SETS
    I   hot streams /I1,I2,I3,I4/
    J   cold streams /J1,J2,J3,J4,J5/
    K   Stage no. /K1,K2,K3,K4,K5,K6/;
PARAMETER TINI(I) /I1 = 327,I2 = 220,I3 = 220,I4 = 160/
        TINJ(J) /J1 = 100,J2 = 35,J3 = 80,J4 = 60,J5 = 140/
        TOUTI(I)/I1 = 30,I2 = 160,I3 = 60,I4 = 45/
        TOUTJ(J)/J1 = 300,J2 = 164,J3 = 125,J4 = 170,J5 = 300/
        FI(I)  /I1 = 100 ,I2 = 160 ,I3 = 60,I4 = 200  /
        FJ(J)  /J1 = 100  ,J2 = 70 ,J3 = 175,J4 = 60,J5 = 200  /
        HI(I)  /I1 = 0.8 ,I2 = 0.5 ,I3 = 2,I4 = 0.4  /
        HJ(J)  /J1 = 5  ,J2 = 1 ,J3 = 0.5,J4 = 0.2,J5 = 0.8  /
        OMEGA  /1000000/
        TAL    /1000000/
        EMAT   /10/;
VARIABLES
     dt(I,J,K)  Approach temperature
     dtcu(I)    Approach temperature between cold utility and hot stream
     dthu(J)    Approach temperature between hot utility and cold stream
     q(I,J,K)   heat exchanged between hot I and cold J
     qcu(I)     heat exchanged between cold utility and hot I
     qhu(J)     heat exchanged between hot utility and cold J
     ti(I,K)    temp of hot stream i at hot end of stage k
     tj(J,K)    temp of cold stream j at hot end of stage k
     z(I,J,K)   exchanger matching between hot I and cold J at stage k
     zcu(I)     cold utility matching with hot I
     zhu(J)     hot utility matching with cold J
     ZZ         total energy
     dtt(I,J,K) actual temperature;
POSITIVE VARIABLE dt(I,J,K),dtcu(I),dthu(J),q(I,J,K),qcu(I),qhu(J),ti(I,K),tj(J,K);
BINARY VARIABLES  zcu(I),zhu(J),z(I,J,K);
```

```
EQUATIONS
    MINU            objective function minimize utilities
    HOTI(I)         heat balance in hot streams I
    COLDJ(J)          heat balance in cold stream J
    HOTK1(I)          heat balance of hot  at stage K1
    HOTK2(I)          heat balance of hot  at stage K2
    HOTK3(I)          heat balance of hot  at stage K3
    HOTK4(I)          heat balance of hot  at stage K4
    HOTK5(I)          heat balance of hot  at stage K5
    COLDK1(J)          heat balance of cold  at stage K1
    COLDK2(J)          heat balance of cold  at stage K2
    COLDK3(J)          heat balance of cold  at stage K3
    COLDK4(J)          heat balance of cold  at stage K4
    COLDK5(J)          heat balance of cold  at stage K5
    TINHOT(I)          hot temp in
    TINCOLD(J)          cold temp in
    FEHOTK1(I)          feasibility of  hot temp   at stage K1
    FEHOTK2(I)          feasibility of  hot temp   at stage K2
    FEHOTK3(I)          feasibility of  hot temp   at stage K3
    FEHOTK4(I)          feasibility of  hot temp   at stage K4
    FEHOTK5(I)          feasibility of  hot temp   at stage K5
    FECOLDK1(J)          feasibility of  cold temp  at stage K1
    FECOLDK2(J)          feasibility of  cold temp  at stage K2
    FECOLDK3(J)          feasibility of  cold temp  at stage K3
    FECOLDK4(J)          feasibility of  cold temp  at stage K4
    FECOLDK5(J)          feasibility of  cold temp  at stage K5
    FEHOTOUT(I)          feasibility of  hot temp out
    FECOLDOUT(J)          feasibility of  cold temp out
    HOTU(I)          hot utility load
    COLDU(J)          cold utility load
    LogicK1(I,J)      Logical constraint at stage k1
    LogicK2(I,J)      Logical constraint at stage k2
    LogicK3(I,J)      Logical constraint at stage k3
    LogicK4(I,J)      Logical constraint at stage k4
    LogicK5(I,J)      Logical constraint at stage k5
    LogicHOT(J)          Logical constraint hot  utility
    LogicCOLD(I)          Logical constraint cold utility
    ApproK1(I,J)      approach temp at stage k1
    AApproK1(I,J)      the other approach temp at stage k1
    ApproK2(I,J)      approach temp at stage k2
    AApproK2(I,J)      the other approach temp at stage k2
    ApproK3(I,J)      approach temp at stage k3
    AApproK3(I,J)      the other approach temp at stage k3
    ApproK4(I,J)      approach temp at stage k4
    AApproK4(I,J)      the other approach temp at stage k4
    ApproK5(I,J)      approach temp at stage k5
    AApproK5(I,J)      the other approach temp at stage k5
    EMATdt1(I,J,K)      EMAT constraint
    CONSTRAINT1          constraint no.1
    CONSTRAINT2          constraint no.2
    CONSTRAINT3          constraint no.3
    CONSTRAINT4          constraint no.4
    CONSTRAINT5          constraint no.5
    HOTNOSPLITTING1K1   constraint of no splitting
    HOTNOSPLITTING2K1   constraint of no splitting
    HOTNOSPLITTING3K1   constraint of no splitting
    HOTNOSPLITTING4K1   constraint of no splitting
    HOTNOSPLITTING1K2   constraint of no splitting
    HOTNOSPLITTING2K2   constraint of no splitting
    HOTNOSPLITTING3K2   constraint of no splitting
    HOTNOSPLITTING4K2   constraint of no splitting
    HOTNOSPLITTING1K3   constraint of no splitting
    HOTNOSPLITTING2K3   constraint of no splitting
    HOTNOSPLITTING3K3   constraint of no splitting
    HOTNOSPLITTING4K3   constraint of no splitting
    HOTNOSPLITTING1K4   constraint of no splitting
    HOTNOSPLITTING2K4   constraint of no splitting
    HOTNOSPLITTING3K4   constraint of no splitting
    HOTNOSPLITTING4K4   constraint of no splitting
    HOTNOSPLITTING1K5   constraint of no splitting
    HOTNOSPLITTING2K5   constraint of no splitting
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```
    HOTNOSPLITTING3K5   constraint of no splitting
    HOTNOSPLITTING4K5   constraint of no splitting
    COLDNOSPLITTING1K1  constraint of no splitting
    COLDNOSPLITTING2K1  constraint of no splitting
    COLDNOSPLITTING3K1  constraint of no splitting
    COLDNOSPLITTING4K1  constraint of no splitting
    COLDNOSPLITTING5K1  constraint of no splitting
    COLDNOSPLITTING1K2  constraint of no splitting
    COLDNOSPLITTING2K2  constraint of no splitting
    COLDNOSPLITTING3K2  constraint of no splitting
    COLDNOSPLITTING4K2  constraint of no splitting
    COLDNOSPLITTING5K2  constraint of no splitting
    COLDNOSPLITTING1K3  constraint of no splitting
    COLDNOSPLITTING2K3  constraint of no splitting
    COLDNOSPLITTING3K3  constraint of no splitting
    COLDNOSPLITTING4K3  constraint of no splitting
    COLDNOSPLITTING5K3  constraint of no splitting
    COLDNOSPLITTING1K4  constraint of no splitting
    COLDNOSPLITTING2K4  constraint of no splitting
    COLDNOSPLITTING3K4  constraint of no splitting
    COLDNOSPLITTING4K4  constraint of no splitting
    COLDNOSPLITTING5K4  constraint of no splitting
    COLDNOSPLITTING1K5  constraint of no splitting
    COLDNOSPLITTING2K5  constraint of no splitting
    COLDNOSPLITTING3K5  constraint of no splitting
    COLDNOSPLITTING4K5  constraint of no splitting
    COLDNOSPLITTING5K5  constraint of no splitting
    APPROACHTEMPK1(I,J) actual approac temperature at k1
    APPROACHTEMPK2(I,J) actual approac temperature at k2
    APPROACHTEMPK3(I,J) actual approac temperature at k3
    APPROACHTEMPK4(I,J) actual approac temperature at k4
    APPROACHTEMPK5(I,J) actual approac temperature at k5
    APPROACHTEMPK6(I,J) actual approac temperature at k6;
MINU      .. ZZ =E= 10*SUM(I,qcu(I)) + 10*SUM(J,qhu(J))+10*SUM((I,J,K),z(I,J,K))+10*SUM(I,zcu(I))+
10*SUM(J,zhu(J));
HOTI(I)   .. (TINI(I)-TOUTI(I))*FI(I)=E= SUM((J,K),q(I,J,K))+qcu(I);
COLDJ(J)  .. (TOUTJ(J)-TINJ(J))*FJ(J)=E= SUM((I,K),q(I,J,K))+qhu(J);
HOTK1(I)  .. (ti(I,'K1')-ti(I,'K2'))*FI(I)=E= SUM(J,q(I,J,'K1'));
HOTK2(I)  .. (ti(I,'K2')-ti(I,'K3'))*FI(I)=E= SUM(J,q(I,J,'K2'));
HOTK3(I)  .. (ti(I,'K3')-ti(I,'K4'))*FI(I)=E= SUM(J,q(I,J,'K3'));
HOTK4(I)  .. (ti(I,'K4')-ti(I,'K5'))*FI(I)=E= SUM(J,q(I,J,'K4'));
HOTK5(I)  .. (ti(I,'K5')-ti(I,'K6'))*FI(I)=E= SUM(J,q(I,J,'K5'));
COLDK1(J) .. (tj(J,'K1')-tj(J,'K2'))*FJ(J)=E= SUM(I,q(I,J,'K1'));
COLDK2(J) .. (tj(J,'K2')-tj(J,'K3'))*FJ(J)=E= SUM(I,q(I,J,'K2'));
COLDK3(J) .. (tj(J,'K3')-tj(J,'K4'))*FJ(J)=E= SUM(I,q(I,J,'K3'));
COLDK4(J) .. (tj(J,'K4')-tj(J,'K5'))*FJ(J)=E= SUM(I,q(I,J,'K4'));
COLDK5(J) .. (tj(J,'K5')-tj(J,'K6'))*FJ(J)=E= SUM(I,q(I,J,'K5'));
TINHOT(I) .. TINI(I) =E= ti(I,'K1');
TINCOLD(J) .. TINJ(J) =E= tj(J,'K6');
FEHOTK1(I) .. ti(I,'K1') =G= ti(I,'K2');
FEHOTK2(I) .. ti(I,'K2') =G= ti(I,'K3');
FEHOTK3(I) .. ti(I,'K3') =G= ti(I,'K4');
FEHOTK4(I) .. ti(I,'K4') =G= ti(I,'K5');
FEHOTK5(I) .. ti(I,'K5') =G= ti(I,'K6');
FECOLDK1(J).. tj(J,'K1') =G= tj(J,'K2');
FECOLDK2(J).. tj(J,'K2') =G= tj(J,'K3');
FECOLDK3(J).. tj(J,'K3') =G= tj(J,'K4');
FECOLDK4(J).. tj(J,'K4') =G= tj(J,'K5');
FECOLDK5(J).. tj(J,'K5') =G= tj(J,'K6');
FEHOTOUT(I) .. TOUTI(I) =L= ti(I,'K6');
FECOLDOUT(J).. TOUTJ(J) =G= tj(J,'K1');
HOTU(I)  .. (ti(I,'K6')-TOUTI(I))*FI(I) =E= qcu(I);
COLDU(J) .. (TOUTJ(J)-tj(j,'K1'))*FJ(J) =E= qhu(J);
LogicK1(I,J).. q(I,J,'K1')-OMEGA*z(I,J,'K1') =L= 0;
LogicK2(I,J).. q(I,J,'K2')-OMEGA*z(I,J,'K2') =L= 0;
LogicK3(I,J).. q(I,J,'K3')-OMEGA*z(I,J,'K3') =L= 0;
LogicK4(I,J).. q(I,J,'K4')-OMEGA*z(I,J,'K4') =L= 0;
LogicK5(I,J).. q(I,J,'K5')-OMEGA*z(I,J,'K5') =L= 0;
LogicHOT(J) .. qhu(J)-OMEGA*zhu(J) =L= 0;
LogicCOLD(I).. qcu(I)-OMEGA*zcu(I) =L= 0;
ApproK1(I,J) .. dt(I,J,'K1') =L= (ti(I,'K1')-tj(J,'K1'))+TAL*(1-z(I,J,'K1'));
```

```
AApproK1(I,J).. dt(I,J,'K2') =L= (ti(I,'K2')-tj(J,'K2'))+TAL*(1-z(I,J,'K1'));
ApproK2(I,J) .. dt(I,J,'K2') =L= (ti(I,'K2')-tj(J,'K2'))+TAL*(1-z(I,J,'K2'));
AApproK2(I,J).. dt(I,J,'K3') =L= (ti(I,'K3')-tj(J,'K3'))+TAL*(1-z(I,J,'K2'));
ApproK3(I,J) .. dt(I,J,'K3') =L= (ti(I,'K3')-tj(J,'K3'))+TAL*(1-z(I,J,'K3'));
AApproK3(I,J).. dt(I,J,'K4') =L= (ti(I,'K4')-tj(J,'K4'))+TAL*(1-z(I,J,'K3'));
ApproK4(I,J) .. dt(I,J,'K4') =L= (ti(I,'K4')-tj(J,'K4'))+TAL*(1-z(I,J,'K4'));
AApproK4(I,J).. dt(I,J,'K5') =L= (ti(I,'K5')-tj(J,'K5'))+TAL*(1-z(I,J,'K4'));
ApproK5(I,J) .. dt(I,J,'K5') =L= (ti(I,'K5')-tj(J,'K5'))+TAL*(1-z(I,J,'K5'));
AApproK5(I,J).. dt(I,J,'K6') =L= (ti(I,'K6')-tj(J,'K6'))+TAL*(1-z(I,J,'K5'));
EMATdt1(I,J,K) .. dt(I,J,K)  =G= EMAT;
CONSTRAINT1 .. sum(K,z('I1','J1',K)) =G= 1;
CONSTRAINT2 .. sum(K,z('I2','J5',K)) =G= 1;
CONSTRAINT3 .. sum(K,z('I4','J3',K)) =G= 1;
CONSTRAINT4 .. sum(K,z('I3','J4',K)) =G= 1;
CONSTRAINT5 .. sum(K,z('I1','J2',K)) =G= 1;
HOTNOSPLITTING1K1 .. sum(J,z('I1',J,'K1')) =L= 1;
HOTNOSPLITTING2K1 .. sum(J,z('I2',J,'K1')) =L= 1;
HOTNOSPLITTING3K1 .. sum(J,z('I3',J,'K1')) =L= 1;
HOTNOSPLITTING4K1 .. sum(J,z('I4',J,'K1')) =L= 1;
HOTNOSPLITTING1K2 .. sum(J,z('I1',J,'K2')) =L= 1;
HOTNOSPLITTING2K2 .. sum(J,z('I2',J,'K2')) =L= 1;
HOTNOSPLITTING3K2 .. sum(J,z('I3',J,'K2')) =L= 1;
HOTNOSPLITTING4K2 .. sum(J,z('I4',J,'K2')) =L= 1;
HOTNOSPLITTING1K3 .. sum(J,z('I1',J,'K3')) =L= 1;
HOTNOSPLITTING2K3 .. sum(J,z('I2',J,'K3')) =L= 1;
HOTNOSPLITTING3K3 .. sum(J,z('I3',J,'K3')) =L= 1;
HOTNOSPLITTING4K3 .. sum(J,z('I4',J,'K3')) =L= 1;
HOTNOSPLITTING1K4 .. sum(J,z('I1',J,'K4')) =L= 1;
HOTNOSPLITTING2K4 .. sum(J,z('I2',J,'K4')) =L= 1;
HOTNOSPLITTING3K4    sum(J,z('I3',J,'K4')) =L= 1;
HOTNOSPLITTING4K4 .. sum(J,z('I4',J,'K4')) =L= 1;
HOTNOSPLITTING1K5 .. sum(J,z('I1',J,'K5')) =L= 1;
HOTNOSPLITTING2K5 .. sum(J,z('I2',J,'K5')) =L= 1;
HOTNOSPLITTING3K5 .. sum(J,z('I3',J,'K5')) =L= 1;
HOTNOSPLITTING4K5 .. sum(J,z('I4',J,'K5')) =L= 1;
COLDNOSPLITTING1K1.. sum(I,z(I,'J1','K1')) =L= 1;
COLDNOSPLITTING2K1.. sum(I,z(I,'J2','K1')) =L= 1;
COLDNOSPLITTING3K1.. sum(I,z(I,'J3','K1')) =L= 1;
COLDNOSPLITTING4K1.. sum(I,z(I,'J4','K1')) =L= 1;
COLDNOSPLITTING5K1.. sum(I,z(I,'J5','K1')) =L= 1;
COLDNOSPLITTING1K2.. sum(I,z(I,'J1','K2')) =L= 1;
COLDNOSPLITTING2K2.. sum(I,z(I,'J2','K2')) =L= 1;
COLDNOSPLITTING3K2.. sum(I,z(I,'J3','K2')) =L= 1;
COLDNOSPLITTING4K2.. sum(I,z(I,'J4','K2')) =L= 1;
COLDNOSPLITTING5K2.. sum(I,z(I,'J5','K2')) =L= 1;
COLDNOSPLITTING1K3.. sum(I,z(I,'J1','K3')) =L= 1;
COLDNOSPLITTING2K3.. sum(I,z(I,'J2','K3')) =L= 1;
COLDNOSPLITTING3K3.. sum(I,z(I,'J3','K3')) =L= 1;
COLDNOSPLITTING4K3.. sum(I,z(I,'J4','K3')) =L= 1;
COLDNOSPLITTING5K3.. sum(I,z(I,'J5','K3')) =L= 1;
COLDNOSPLITTING1K4.. sum(I,z(I,'J1','K4')) =L= 1;
COLDNOSPLITTING2K4.. sum(I,z(I,'J2','K4')) =L= 1;
COLDNOSPLITTING3K4.. sum(I,z(I,'J3','K4')) =L= 1;
COLDNOSPLITTING4K4.. sum(I,z(I,'J4','K4')) =L= 1;
COLDNOSPLITTING5K4.. sum(I,z(I,'J5','K4')) =L= 1;
COLDNOSPLITTING1K5.. sum(I,z(I,'J1','K5')) =L= 1;
COLDNOSPLITTING2K5.. sum(I,z(I,'J2','K5')) =L= 1;
COLDNOSPLITTING3K5.. sum(I,z(I,'J3','K5')) =L= 1;
COLDNOSPLITTING4K5.. sum(I,z(I,'J4','K5')) =L= 1;
COLDNOSPLITTING5K5.. sum(I,z(I,'J5','K5')) =L= 1;
APPROACHTEMPK1(I,J) .. dtt(I,J,'K1') =E= ti(I,'K1')-tj(J,'K1');
APPROACHTEMPK2(I,J) .. dtt(I,J,'K2') =E= ti(I,'K2')-tj(J,'K2');
APPROACHTEMPK3(I,J) .. dtt(I,J,'K3') =E= ti(I,'K3')-tj(J,'K3');
APPROACHTEMPK4(I,J) .. dtt(I,J,'K4') =E= ti(I,'K4')-tj(J,'K4');
APPROACHTEMPK5(I,J) .. dtt(I,J,'K5') =E= ti(I,'K5')-tj(J,'K5');
APPROACHTEMPK6(I,J) .. dtt(I,J,'K6') =E= ti(I,'K6')-tj(J,'K6');
MODEL TSHIP /ALL/ ;
SOLVE TSHIP USING MIP MINIMIZING ZZ;
DISPLAY z.L,zcu.L,zhu.L,ZZ.L,q.L,qcu.L,qhu.L,ti.L,tj.L;
```

Result of stage model of Retrofit H.E.N. of Example 3 with EMAT = 10 °C

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GAMS Rev 136  MS Windows                    04/05/10 14:25:35 Page 6
General Algebraic Modeling System
Execution
----   286 VARIABLE z.L  exchanger matching between hot I and cold J at stage k
          K1       K2       K3       K4       K5
I1.J1             1.000
I1.J2                               1.000
I1.J5    1.000
I2.J5             1.000
I3.J1    1.000
I3.J2             1.000
I3.J4                      1.000
I4.J2                               1.000
I4.J3                                        1.000
I4.J5                      1.000
----   286 VARIABLE zcu.L  cold utility matching with hot I
I1 1.000,   I3 1.000,   I4 1.000
----   286 VARIABLE zhu.L  hot utility matching with cold J
J1 1.000,   J5 1.000
----   286 VARIABLE ZZ.L              =  323700.000  total energy
----   286 VARIABLE q.L  heat exchanged between hot I and cold J
          K1        K2        K3        K4        K5
I1.J1          9800.000
I1.J2                                   4350.000
I1.J5  11900.000
I2.J5          9600.000
I3.J1    720.000
I3.J2          1680.000
I3.J4                    6600.000
I4.J2                              3000.000
I4.J3                                   7875.000
I4.J5                    2000.000
----   286 VARIABLE qcu.L  heat exchanged between cold utility and hot I
I1  3650.000,   I3  600.000,   I4 10125.000
----   286 VARIABLE qhu.L  heat exchanged between hot utility and cold J
J1 9480.000,   J5 8500.000
----   286 VARIABLE ti.L  temp of hot stream i at hot end of stage k
        K1         K2         K3         K4         K5         K6
I1   327.000    208.000    110.000    110.000    110.000     66.500
I2   220.000    220.000    160.000    160.000    160.000    160.000
I3   220.000    208.000    180.000     70.000     70.000     70.000
I4   160.000    160.000    160.000    150.000    135.000     95.625
----   286 VARIABLE tj.L  temp of cold stream j at hot end of stage k
        K1         K2         K3         K4         K5         K6
J1   205.200    198.000    100.000    100.000    100.000    100.000
J2   164.000    164.000    140.000    140.000     97.143     35.000
J3   125.000    125.000    125.000    125.000    125.000     80.000
J4   170.000    170.000    170.000     60.000     60.000     60.000
J5   257.500    198.000    150.000    140.000    140.000    140.000
EXECUTION TIME      =      0.016 SECONDS   1.5 Mb     WIN212-136
USER: The Petroleum and Petrochemical College       G030915:1142AP-WIN
```

4. Stage model of Retrofit H.E.N. of Example 4 with EMAT = 12.92 °C

```
SETS
    I  hot streams /I1,I2,I3,I4/
    J  cold streams /J1,J2,J3,J4,J5/
    K  Stage no. /K1,K2,K3,K4,K5,K6,K7/;
PARAMETER TINI(I) /I1 = 327,I2 = 220,I3 = 220,I4 = 160/
      TINJ(J) /J1 = 100,J2 = 35,J3 = 85,J4 = 60,J5 = 140/
      TOUTI(I)/I1 = 40,I2 = 160,I3 = 60,I4 = 45/
      TOUTJ(J)/J1 = 300,J2 = 164,J3 = 138,J4 = 170,J5 = 300/
      FI(I)  /I1 = 100 ,I2 = 160 ,I3 = 60,I4 = 400  /
      FJ(J)  /J1 = 100  ,J2 = 70 ,J3 = 350,J4 = 60,J5 = 200  /
      HI(I)  /I1 = 0.5 ,I2 = 0.4 ,I3 = 0.14,I4 = 0.3  /
      HJ(J)  /J1 = 0.35  ,J2 = 0.7 ,J3 = 0.5,J4 = 0.14,J5 = 0.6  /
      OMEGA   /1000000/
      TAL     /1000000/
```

```
    EMAT   /12.92/;
VARIABLES
    dt(I,J,K)  Approach temperature
    dtcu(I)    Approach temperature between cold utility and hot stream
    dthu(J)    Approach temperature between hot utility and cold stream
    q(I,J,K)   heat exchanged between hot I and cold J
    qcu(I)     heat exchanged between cold utility and hot I
    qhu(J)     heat exchanged between hot utility and cold J
    ti(I,K)    temp of hot stream i at hot end of stage k
    tj(J,K)    temp of cold stream j at hot end of stage k
    z(I,J,K)   exchanger matching between hot I and cold J at stage k
    zcu(I)     cold utility matching with hot I
    zhu(J)     hot utility matching with cold J
    ZZ         total energy
    dtt(I,J,K) actual temperature;
POSITIVE VARIABLE dt(I,J,K),dtcu(I),dthu(J),q(I,J,K),qcu(I),qhu(J),ti(I,K),tj(J,K);
BINARY VARIABLES  zcu(I),zhu(J),z(I,J,K);
EQUATIONS
    MINU            objective function minimize utilities
    HOTI(I)         heat balance in hot streams I
    COLDJ(J)        heat balance in cold stream J
    HOTK1(I)        heat balance of hot  at stage K1
    HOTK2(I)        heat balance of hot  at stage K2
    HOTK3(I)        heat balance of hot  at stage K3
    HOTK4(I)        heat balance of hot  at stage K4
    HOTK5(I)        heat balance of hot  at stage K5
    HOTK6(I)        heat balance of hot  at stage K6
    COLDK1(J)       heat balance of cold  at stage K1
    COLDK2(J)       heat balance of cold  at stage K2
    COLDK3(J)       heat balance of cold  at stage K3
    COLDK4(J)       heat balance of cold  at stage K4
    COLDK5(J)       heat balance of cold  at stage K5
    COLDK6(J)       heat balance of cold  at stage K6
    TINHOT(I)       hot temp in
    TINCOLD(J)      cold temp in
    FEHOTK1(I)      feasibility of  hot temp  at stage K1
    FEHOTK2(I)      feasibility of  hot temp  at stage K2
    FEHOTK3(I)      feasibility of  hot temp  at stage K3
    FEHOTK4(I)      feasibility of  hot temp  at stage K4
    FEHOTK5(I)      feasibility of  hot temp  at stage K5
    FEHOTK6(I)      feasibility of  hot temp  at stage K6
    FECOLDK1(J)     feasibility of  cold temp  at stage K1
    FECOLDK2(J)     feasibility of  cold temp  at stage K2
    FECOLDK3(J)     feasibility of  cold temp  at stage K3
    FECOLDK4(J)     feasibility of  cold temp  at stage K4
    FECOLDK5(J)     feasibility of  cold temp  at stage K5
    FECOLDK6(J)     feasibility of  cold temp  at stage K6
    FEHOTOUT(I)     feasibility of  hot temp out
    FECOLDOUT(J)    feasibility of  cold temp out
    HOTU(I)         hot utility load
    COLDU(J)        cold utility load
    LogicK1(I,J)    Logical constraint at stage k1
    LogicK2(I,J)    Logical constraint at stage k2
    LogicK3(I,J)    Logical constraint at stage k3
    LogicK4(I,J)    Logical constraint at stage k4
    LogicK5(I,J)    Logical constraint at stage k5
    LogicK6(I,J)    Logical constraint at stage k6
    LogicHOT(J)     Logical constraint hot  utility
    LogicCOLD(I)    Logical constraint cold utility
    ApproK1(I,J)    approach temp at stage k1
    AApproK1(I,J)   the other approach temp at stage k1
    ApproK2(I,J)    approach temp at stage k2
    AApproK2(I,J)   the other approach temp at stage k2
    ApproK3(I,J)    approach temp at stage k3
    AApproK3(I,J)   the other approach temp at stage k3
    ApproK4(I,J)    approach temp at stage k4
    AApproK4(I,J)   the other approach temp at stage k4
    ApproK5(I,J)    approach temp at stage k5
    AApproK5(I,J)   the other approach temp at stage k5
    ApproK6(I,J)    approach temp at stage k6
    AApproK6(I,J)   the other approach temp at stage k6
```

```
EMATdt1(I,J,K)    EMAT constraint
CONSTRAINT1       constraint no 1
CONSTRAINT2       constraint no 2
CONSTRAINT3       constraint no 3
CONSTRAINT4       constraint no 4
CONSTRAINT5       constraint no 5
CONSTRAINT6       constraint no 6
CONSTRAINT7       constraint no 7
HOTNOSPLITTING1K1  constraint of no splitting
HOTNOSPLITTING2K1  constraint of no splitting
HOTNOSPLITTING3K1  constraint of no splitting
HOTNOSPLITTING4K1  constraint of no splitting
HOTNOSPLITTING1K2  constraint of no splitting
HOTNOSPLITTING2K2  constraint of no splitting
HOTNOSPLITTING3K2  constraint of no splitting
HOTNOSPLITTING4K2  constraint of no splitting
HOTNOSPLITTING1K3  constraint of no splitting
HOTNOSPLITTING2K3  constraint of no splitting
HOTNOSPLITTING3K3  constraint of no splitting
HOTNOSPLITTING4K3  constraint of no splitting
HOTNOSPLITTING1K4  constraint of no splitting
HOTNOSPLITTING2K4  constraint of no splitting
HOTNOSPLITTING3K4  constraint of no splitting
HOTNOSPLITTING4K4  constraint of no splitting
HOTNOSPLITTING1K5  constraint of no splitting
HOTNOSPLITTING2K5  constraint of no splitting
HOTNOSPLITTING3K5  constraint of no splitting
HOTNOSPLITTING4K5  constraint of no splitting
HOTNOSPLITTING1K6  constraint of no splitting
HOTNOSPLITTING2K6  constraint of no splitting
HOTNOSPLITTING3K6  constraint of no splitting
HOTNOSPLITTING4K6  constraint of no splitting
COLDNOSPLITTING1K1  constraint of no splitting
COLDNOSPLITTING2K1  constraint of no splitting
COLDNOSPLITTING3K1  constraint of no splitting
COLDNOSPLITTING4K1  constraint of no splitting
COLDNOSPLITTING5K1  constraint of no splitting
COLDNOSPLITTING1K2  constraint of no splitting
COLDNOSPLITTING2K2  constraint of no splitting
COLDNOSPLITTING3K2  constraint of no splitting
COLDNOSPLITTING4K2  constraint of no splitting
COLDNOSPLITTING5K2  constraint of no splitting
COLDNOSPLITTING1K3  constraint of no splitting
COLDNOSPLITTING2K3  constraint of no splitting
COLDNOSPLITTING3K3  constraint of no splitting
COLDNOSPLITTING4K3  constraint of no splitting
COLDNOSPLITTING5K3  constraint of no splitting
COLDNOSPLITTING1K4  constraint of no splitting
COLDNOSPLITTING2K4  constraint of no splitting
COLDNOSPLITTING3K4  constraint of no splitting
COLDNOSPLITTING4K4  constraint of no splitting
COLDNOSPLITTING5K4  constraint of no splitting
COLDNOSPLITTING1K5  constraint of no splitting
COLDNOSPLITTING2K5  constraint of no splitting
COLDNOSPLITTING3K5  constraint of no splitting
COLDNOSPLITTING4K5  constraint of no splitting
COLDNOSPLITTING5K5  constraint of no splitting
COLDNOSPLITTING1K6  constraint of no splitting
COLDNOSPLITTING2K6  constraint of no splitting
COLDNOSPLITTING3K6  constraint of no splitting
COLDNOSPLITTING4K6  constraint of no splitting
COLDNOSPLITTING5K6  constraint of no splitting
APPROACHTEMPK1(I,J) actual approac temperature at k1
APPROACHTEMPK2(I,J) actual approac temperature at k2
APPROACHTEMPK3(I,J) actual approac temperature at k3
APPROACHTEMPK4(I,J) actual approac temperature at k4
APPROACHTEMPK5(I,J) actual approac temperature at k5
APPROACHTEMPK6(I,J) actual approac temperature at k6
APPROACHTEMPK7(I,J) actual approac temperature at k7;
MINU      .. ZZ =E= 10*SUM(I,qcu(I)) + 10*SUM(J,qhu(J))+10*SUM((I,J,K),z(I,J,K))+10*SUM(I,zcu(I))+
10*SUM(J,zhu(J));
```

```
HOTI(I)    .. (TINI(I)-TOUTI(I))*FI(I)=E= SUM((J,K),q(I,J,K))+qcu(I);
COLDJ(J)   .. (TOUTJ(J)-TINJ(J))*FJ(J)=E= SUM((I,K),q(I,J,K))+qhu(J);
HOTK1(I)   .. (ti(I,'K1')-ti(I,'K2'))*FI(I)=E= SUM(J,q(I,J,'K1'));
HOTK2(I)   .. (ti(I,'K2')-ti(I,'K3'))*FI(I)=E= SUM(J,q(I,J,'K2'));
HOTK3(I)   .. (ti(I,'K3')-ti(I,'K4'))*FI(I)=E= SUM(J,q(I,J,'K3'));
HOTK4(I)   .. (ti(I,'K4')-ti(I,'K5'))*FI(I)=E= SUM(J,q(I,J,'K4'));
HOTK5(I)   .. (ti(I,'K5')-ti(I,'K6'))*FI(I)=E= SUM(J,q(I,J,'K5'));
HOTK6(I)   .. (ti(I,'K6')-ti(I,'K7'))*FI(I)=E= SUM(J,q(I,J,'K6'));
COLDK1(J)  .. (tj(J,'K1')-tj(J,'K2'))*FJ(J)=E= SUM(I,q(I,J,'K1'));
COLDK2(J)  .. (tj(J,'K2')-tj(J,'K3'))*FJ(J)=E= SUM(I,q(I,J,'K2'));
COLDK3(J)  .. (tj(J,'K3')-tj(J,'K4'))*FJ(J)=E= SUM(I,q(I,J,'K3'));
COLDK4(J)  .. (tj(J,'K4')-tj(J,'K5'))*FJ(J)=E= SUM(I,q(I,J,'K4'));
COLDK5(J)  .. (tj(J,'K5')-tj(J,'K6'))*FJ(J)=E= SUM(I,q(I,J,'K5'));
COLDK6(J)  .. (tj(J,'K6')-tj(J,'K7'))*FJ(J)=E= SUM(I,q(I,J,'K6'));
TINHOT(I) .. TINI(I) =E= ti(I,'K1');
TINCOLD(J) .. TINJ(J) =E= tj(J,'K7');
FEHOTK1(I) .. ti(I,'K1') =G= ti(I,'K2');
FEHOTK2(I) .. ti(I,'K2') =G= ti(I,'K3');
FEHOTK3(I) .. ti(I,'K3') =G= ti(I,'K4');
FEHOTK4(I) .. ti(I,'K4') =G= ti(I,'K5');
FEHOTK5(I) .. ti(I,'K5') =G= ti(I,'K6');
FEHOTK6(I) .. ti(I,'K6') =G= ti(I,'K7');
FECOLDK1(J).. tj(J,'K1') =G= tj(J,'K2');
FECOLDK2(J).. tj(J,'K2') =G= tj(J,'K3');
FECOLDK3(J).. tj(J,'K3') =G= tj(J,'K4');
FECOLDK4(J).. tj(J,'K4') =G= tj(J,'K5');
FECOLDK5(J).. tj(J,'K5') =G= tj(J,'K6');
FECOLDK6(J).. tj(J,'K6') =G= tj(J,'K7');
FEHOTOUT(I) .. TOUTI(I) =L= ti(I,'K7');
FECOLDOUT(J).. TOUTJ(J) =G= tj(J,'K1');
HOTU(I)  .. (ti(I,'K7')-TOUTI(I))*FI(I) =E= qcu(I);
COLDU(J) .. (TOUTJ(J)-tj(j,'K1'))*FJ(J) =E= qhu(J);
LogicK1(I,J).. q(I,J,'K1')-OMEGA*z(I,J,'K1') =L= 0;
LogicK2(I,J).. q(I,J,'K2')-OMEGA*z(I,J,'K2') =L= 0;
LogicK3(I,J).. q(I,J,'K3')-OMEGA*z(I,J,'K3') =L= 0;
LogicK4(I,J).. q(I,J,'K4')-OMEGA*z(I,J,'K4') =L= 0;
LogicK5(I,J).. q(I,J,'K5')-OMEGA*z(I,J,'K5') =L= 0;
LogicK6(I,J).. q(I,J,'K6')-OMEGA*z(I,J,'K6') =L= 0;
LogicHOT(J) .. qhu(J)-OMEGA*zhu(J) =L= 0;
LogicCOLD(I).. qcu(I)-OMEGA*zcu(I) =L= 0;
ApproK1(I,J) .. dt(I,J,'K1') =L= (ti(I,'K1')-tj(J,'K1'))+TAL*(1-z(I,J,'K1'));
AApproK1(I,J).. dt(I,J,'K2') =L= (ti(I,'K2')-tj(J,'K2'))+TAL*(1-z(I,J,'K1'));
ApproK2(I,J) .. dt(I,J,'K2') =L= (ti(I,'K2')-tj(J,'K2'))+TAL*(1-z(I,J,'K2'));
AApproK2(I,J).. dt(I,J,'K3') =L= (ti(I,'K3')-tj(J,'K3'))+TAL*(1-z(I,J,'K2'));
ApproK3(I,J) .. dt(I,J,'K3') =L= (ti(I,'K3')-tj(J,'K3'))+TAL*(1-z(I,J,'K3'));
AApproK3(I,J).. dt(I,J,'K4') =L= (ti(I,'K4')-tj(J,'K4'))+TAL*(1-z(I,J,'K3'));
ApproK4(I,J) .. dt(I,J,'K4') =L= (ti(I,'K4')-tj(J,'K4'))+TAL*(1-z(I,J,'K4'));
AApproK4(I,J).. dt(I,J,'K5') =L= (ti(I,'K5')-tj(J,'K5'))+TAL*(1-z(I,J,'K4'));
ApproK5(I,J) .. dt(I,J,'K5') =L= (ti(I,'K5')-tj(J,'K5'))+TAL*(1-z(I,J,'K5'));
AApproK5(I,J).. dt(I,J,'K6') =L= (ti(I,'K6')-tj(J,'K6'))+TAL*(1-z(I,J,'K5'));
ApproK6(I,J) .. dt(I,J,'K6') =L= (ti(I,'K6')-tj(J,'K6'))+TAL*(1-z(I,J,'K6'));
AApproK6(I,J).. dt(I,J,'K7') =L= (ti(I,'K7')-tj(J,'K7'))+TAL*(1-z(I,J,'K6'));
EMATdt1(I,J,K) .. dt(I,J,K)  =G= EMAT;
CONSTRAINT1  .. sum(K,z('I1','J4','K1')) =G= 1;
CONSTRAINT2  .. sum(K,z('I4','J3','K1')) =G= 1;
CONSTRAINT3  .. sum(K,z('I3','J4','K3')) =G= 1;
CONSTRAINT4  .. sum(K,z('I1','J1','K3')) =G= 1;
CONSTRAINT5  .. sum(K,z('I1','J2','K4')) =G= 1;
CONSTRAINT6  .. sum(K,z('I2','J5','K6')) =G= 1;
CONSTRAINT7  .. sum(K,z('I4','J2','K6')) =G= 1;
HOTNOSPLITTING1K1 .. sum(J,z('I1',J,'K1')) =L= 1;
HOTNOSPLITTING2K1 .. sum(J,z('I2',J,'K1')) =L= 1;
HOTNOSPLITTING3K1 .. sum(J,z('I3',J,'K1')) =L= 1;
HOTNOSPLITTING4K1 .. sum(J,z('I4',J,'K1')) =L= 1;
HOTNOSPLITTING1K2 .. sum(J,z('I1',J,'K2')) =L= 1;
HOTNOSPLITTING2K2 .. sum(J,z('I2',J,'K2')) =L= 1;
HOTNOSPLITTING3K2 .. sum(J,z('I3',J,'K2')) =L= 1;
HOTNOSPLITTING4K2 .. sum(J,z('I4',J,'K2')) =L= 1;
HOTNOSPLITTING1K3 .. sum(J,z('I1',J,'K3')) =L= 1;
HOTNOSPLITTING2K3 .. sum(J,z('I2',J,'K3')) =L= 1;
HOTNOSPLITTING3K3 .. sum(J,z('I3',J,'K3')) =L= 1;
```

```
HOTNOSPLITTING4K3 .. sum(J,z('I4',J,'K3')) =L= 1;
HOTNOSPLITTING1K4 .. sum(J,z('I1',J,'K4')) =L= 1;
HOTNOSPLITTING2K4 .. sum(J,z('I2',J,'K4')) =L= 1;
HOTNOSPLITTING3K4 .. sum(J,z('I3',J,'K4')) =L= 1;
HOTNOSPLITTING4K4 .. sum(J,z('I4',J,'K4')) =L= 1;
HOTNOSPLITTING1K5 .. sum(J,z('I1',J,'K5')) =L= 1;
HOTNOSPLITTING2K5 .. sum(J,z('I2',J,'K5')) =L= 1;
HOTNOSPLITTING3K5 .. sum(J,z('I3',J,'K5')) =L= 1;
HOTNOSPLITTING4K5 .. sum(J,z('I4',J,'K5')) =L= 1;
HOTNOSPLITTING1K6 .. sum(J,z('I1',J,'K6')) =L= 1;
HOTNOSPLITTING2K6 .. sum(J,z('I2',J,'K6')) =L= 1;
HOTNOSPLITTING3K6 .. sum(J,z('I3',J,'K6')) =L= 1;
HOTNOSPLITTING4K6 .. sum(J,z('I4',J,'K6')) =L= 1;
COLDNOSPLITTING1K1.. sum(I,z(I,'J1','K1')) =L= 1;
COLDNOSPLITTING2K1.. sum(I,z(I,'J2','K1')) =L= 1;
COLDNOSPLITTING3K1.. sum(I,z(I,'J3','K1')) =L= 1;
COLDNOSPLITTING4K1.. sum(I,z(I,'J4','K1')) =L= 1;
COLDNOSPLITTING5K1.. sum(I,z(I,'J5','K1')) =L= 1;
COLDNOSPLITTING1K2.. sum(I,z(I,'J1','K2')) =L= 1;
COLDNOSPLITTING2K2.. sum(I,z(I,'J2','K2')) =L= 1;
COLDNOSPLITTING3K2.. sum(I,z(I,'J3','K2')) =L= 1;
COLDNOSPLITTING4K2.. sum(I,z(I,'J4','K2')) =L= 1;
COLDNOSPLITTING5K2.. sum(I,z(I,'J5','K2')) =L= 1;
COLDNOSPLITTING1K3.. sum(I,z(I,'J1','K3')) =L= 1;
COLDNOSPLITTING2K3.. sum(I,z(I,'J2','K3')) =L= 1;
COLDNOSPLITTING3K3.. sum(I,z(I,'J3','K3')) =L= 1;
COLDNOSPLITTING4K3.. sum(I,z(I,'J4','K3')) =L= 1;
COLDNOSPLITTING5K3.. sum(I,z(I,'J5','K3')) =L= 1;
COLDNOSPLITTING1K4.. sum(I,z(I,'J1','K4')) =L= 1;
COLDNOSPLITTING2K4.. sum(I,z(I,'J2','K4')) =L= 1;
COLDNOSPLITTING3K4.. sum(I,z(I,'J3','K4')) =L= 1;
COLDNOSPLITTING4K4.. sum(I,z(I,'J4','K4')) =L= 1;
COLDNOSPLITTING5K4.. sum(I,z(I,'J5','K4')) =L= 1;
COLDNOSPLITTING1K5.. sum(I,z(I,'J1','K5')) =L= 1;
COLDNOSPLITTING2K5.. sum(I,z(I,'J2','K5')) =L= 1;
COLDNOSPLITTING3K5.. sum(I,z(I,'J3','K5')) =L= 1;
COLDNOSPLITTING4K5.. sum(I,z(I,'J4','K5')) =L= 1;
COLDNOSPLITTING5K5.. sum(I,z(I,'J5','K5')) =L= 1;
COLDNOSPLITTING1K6.. sum(I,z(I,'J1','K6')) =L= 1;
COLDNOSPLITTING2K6.. sum(I,z(I,'J2','K6')) =L= 1;
COLDNOSPLITTING3K6.. sum(I,z(I,'J3','K6')) =L= 1;
COLDNOSPLITTING4K6.. sum(I,z(I,'J4','K6')) =L= 1;
COLDNOSPLITTING5K6.. sum(I,z(I,'J5','K6')) =L= 1;
APPROACHTEMPK1(I,J) .. dtt(I,J,'K1') =E= ti(I,'K1')-tj(J,'K1');
APPROACHTEMPK2(I,J) .. dtt(I,J,'K2') =E= ti(I,'K2')-tj(J,'K2');
APPROACHTEMPK3(I,J) .. dtt(I,J,'K3') =E= ti(I,'K3')-tj(J,'K3');
APPROACHTEMPK4(I,J) .. dtt(I,J,'K4') =E= ti(I,'K4')-tj(J,'K4');
APPROACHTEMPK5(I,J) .. dtt(I,J,'K5') =E= ti(I,'K5')-tj(J,'K5');
APPROACHTEMPK6(I,J) .. dtt(I,J,'K6') =E= ti(I,'K6')-tj(J,'K6');
APPROACHTEMPK7(I,J) .. dtt(I,J,'K7') =E= ti(I,'K7')-tj(J,'K7');
MODEL TSHIP /ALL/ ;
SOLVE TSHIP USING MIP MINIMIZING ZZ;
DISPLAY z.L,zcu.L,zhu.L,ZZ.L,q.L,qcu.L,qhu.L,ti.L,tj.L;
```

Result of stage model of Retrofit H.E.N. of Example 4 with EMAT = 12.92 °C

GAMS Rev 136 MS Windows 04/05/10 14:46:29 Page 6
General Algebraic Modeling System
Execution
---- 329 VARIABLE z.L exchanger matching between hot I and cold J at stage k

	K1	K2	K3	K4	K5	K6
I1.J1			1.000		1.000	
I1.J2				1.000		
I1.J4	1.000					1.000
I2.J5	1.000		1.000			1.000
I3.J2	1.000				1.000	
I3.J4			1.000			
I3.J5		1.000		1.000		
I4.J2		1.000				1.000
I4.J3	1.000				1.000	

```
I4.J4                          1.000
----   329 VARIABLE zcu.L  cold utility matching with hot I
I1 1.000,   I3 1.000,   I4 1.000
----   329 VARIABLE zhu.L  hot utility matching with cold J
J5 1.000
----   329 VARIABLE ZZ.L              =  474127.937  total energy
----   329 VARIABLE q.L  heat exchanged between hot I and cold J
          K1        K2        K3        K4        K5        K6
I1.J1                                20000.000
I1.J4   1408.000                                          2400.000
I2.J5   5005.587            3958.259                              636.154
I3.J2   1184.400                                3072.354
I3.J4                       84.951
I3.J5             989.565             1575.038
I4.J2             785.005                                 3988.240
I4.J3                                 18550.000
I4.J4                            2707.049
----   329 VARIABLE qcu.L  heat exchanged between cold utility and hot I
I1  4892.000,  I3  2693.692,  I4 19969.705
----   329 VARIABLE qhu.L  heat exchanged between hot utility and cold J
J5 19835.397
----   329 VARIABLE ti.L  temp of hot stream i at hot end of stage k
          K1         K2         K3         K4         K5         K6
I1    327.000    312.920    312.920    312.920    312.920    112.920
I2    220.000    188.715    188.715    163.976    163.976    163.976
I3    220.000    200.260    183.767    182.351    156.101    104.895
I4    160.000    160.000    158.037    158.037    151.270    104.895
 +        K7
I1     88.920
I2    160.000
I3    104.895
I4     94.924
----   329 VARIABLE tj.L  temp of cold stream j at hot end of stage k
          K1         K2         K3         K4         K5         K6
J1    300.000    300.000    300.000    300.000    300.000    100.000
J2    164.000    147.080    135.866    135.866    135.866     91.975
J3    138.000    138.000    138.000    138.000    138.000     85.000
J4    170.000    146.533    146.533    145.117    100.000    100.000
J5    200.823    175.795    170.847    151.056    143.181    143.181
 +        K7
J1    100.000
J2     35.000
J3     85.000
J4     60.000
J5    140.000
EXECUTION TIME     =     0.016 SECONDS   1.5 Mb     WIN212-136
USER: The Petroleum and Petrochemical College        G030915:1142AP-WIN
```

5. Stage model of Retrofit H.E.N. of Example 5(Light Crude Oil) with EMAT = 3.3 °C

```
SETS
    I   hot streams /I1,I2,I3,I4,I5,I6,I7,I8,I9,I10,I11,I12,I13,I14,I15,I16,I17,I18/
    J   cold streams /J1,J2,J3/
    K   Stage no.
/K1,K2,K3,K4,K5,K6,K7,K8,K9,K10,K11,K12,K13,K14,K15,K16,K17,K18,K19,K20,K21,K22,K23/;
PARAMETER TINI(I) /I1=132.25, I2=202.05, I3=216.7, I4=223.1, I5=216.9, I6=202.05, I7=233,
I8=220.4, I9=281.9, I10=256.6, I11=253, I12=276.7, I13=285.4, I14=304.9, I15=324,
I16=330, I17=358.4, I18=370/
        TINJ(J) /J1=30, J2=155, J3=185/
        TOUTI(I)/I1=90, I2=157, I3=143.5, I4=159.9, I5=164.1, I6=173, I7=159.4, I8=189.8,
I9=200, I10=211.7, I11=216.9, I12=223.1, I13=240, I14=256.6, I15=280.6, I16=285.4, I17=290, I18=290/
        TOUTJ(J)/J1=111.61, J2=179.47, J3=480/
        FI(I)   /I1=21.38, I2=203.07, I3=108.33, I4=46, I5=107.54, I6=241.17, I7=75.46,
I8=342.35, I9=129.157, I10=364.14, I11=115.24, I12=50.19, I13=25.99, I14=389.65, I15=46.38,
I16=27.58, I17=148.74, I18=79.5/
        FJ(J)   /J1=476.9, J2=860.4, J3=471/
        OMEGA   /1000000/
        TAL     /1000000/
        EMAT    /3.3/;
VARIABLES
```

```
    dt(I,J,K)  Approach temperature
    dtcu(I)    Approach temperature between cold utility and hot stream
    dthu(J)    Approach temperature between hot utility and cold stream
    q(I,J,K)   heat exchanged between hot I and cold J
    qcu(I)     heat exchanged between cold utility and hot I
    qhu(J)     heat exchanged between hot utility and cold J
    ti(I,K)    temp of hot stream i at hot end of stage k
    tj(J,K)    temp of cold stream j at hot end of stage k
    z(I,J,K)   exchanger matching between hot I and cold J at stage k
    zcu(I)     cold utility matching with hot I
    zhu(J)     hot utility matching with cold J
    ZZ         total energy
    dtt(I,J,K) actual temperature;
POSITIVE VARIABLE dt(I,J,K),dtcu(I),dthu(J),q(I,J,K),qcu(I),qhu(J),tj(J,K);
BINARY VARIABLES  zcu(I),zhu(J),z(I,J,K);

EQUATIONS
     MINU          objective function minimize utilities
     HOTI(I)       heat balance in hot streams I
     COLDJ(J)      heat balance in cold stream J
     HOTK1(I)      heat balance of hot  at stage K1
     HOTK2(I)      heat balance of hot  at stage K2
     HOTK3(I)      heat balance of hot  at stage K3
     HOTK4(I)      heat balance of hot  at stage K4
     HOTK5(I)      heat balance of hot  at stage K5
     HOTK6(I)      heat balance of hot  at stage K6
     HOTK7(I)      heat balance of hot  at stage K7
     HOTK8(I)      heat balance of hot  at stage K8
     HOTK9(I)      heat balance of hot  at stage K9
     HOTK10(I)     heat balance of hot  at stage K10
     HOTK11(I)     heat balance of hot  at stage K11
     HOTK12(I)     heat balance of hot  at stage K12
     HOTK13(I)     heat balance of hot  at stage K13
     HOTK14(I)     heat balance of hot  at stage K14
     HOTK15(I)     heat balance of hot  at stage K15
     HOTK16(I)     heat balance of hot  at stage K16
     HOTK17(I)     heat balance of hot  at stage K17
     HOTK18(I)     heat balance of hot  at stage K18
     HOTK19(I)     heat balance of hot  at stage K19
     HOTK20(I)     heat balance of hot  at stage K20
     HOTK21(I)     heat balance of hot  at stage K21
     HOTK22(I)     heat balance of hot  at stage K22
     COLDK1(J)     heat balance of cold  at stage K1
     COLDK2(J)     heat balance of cold  at stage K2
     COLDK3(J)     heat balance of cold  at stage K3
     COLDK4(J)     heat balance of cold  at stage K4
     COLDK5(J)     heat balance of cold  at stage K5
     COLDK6(J)     heat balance of cold  at stage K6
     COLDK7(J)     heat balance of cold  at stage K7
     COLDK8(J)     heat balance of cold  at stage K8
     COLDK9(J)     heat balance of cold  at stage K9
     COLDK10(J)    heat balance of cold  at stage K10
     COLDK11(J)    heat balance of cold  at stage K11
     COLDK12(J)    heat balance of cold  at stage K12
     COLDK13(J)    heat balance of cold  at stage K13
     COLDK14(J)    heat balance of cold  at stage K14
     COLDK15(J)    heat balance of cold  at stage K15
     COLDK16(J)    heat balance of cold  at stage K16
     COLDK17(J)    heat balance of cold  at stage K17
     COLDK18(J)    heat balance of cold  at stage K18
     COLDK19(J)    heat balance of cold  at stage K19
     COLDK20(J)    heat balance of cold  at stage K20
     COLDK21(J)    heat balance of cold  at stage K21
     COLDK22(J)    heat balance of cold  at stage K22
     TINHOT(I)     hot temp in
     TINCOLD(J)    cold temp in
     FEHOTK1(I)    feasibility of  hot temp   at stage K1
     FEHOTK2(I)    feasibility of  hot temp   at stage K2
     FEHOTK3(I)    feasibility of  hot temp   at stage K3
     FEHOTK4(I)    feasibility of  hot temp   at stage K4
     FEHOTK5(I)    feasibility of  hot temp   at stage K5
```

FEHOTK6(I)	feasibility of hot temp at stage K6
FEHOTK7(I)	feasibility of hot temp at stage K7
FEHOTK8(I)	feasibility of hot temp at stage K8
FEHOTK9(I)	feasibility of hot temp at stage K9
FEHOTK10(I)	feasibility of hot temp at stage K10
FEHOTK11(I)	feasibility of hot temp at stage K11
FEHOTK12(I)	feasibility of hot temp at stage K12
FEHOTK13(I)	feasibility of hot temp at stage K13
FEHOTK14(I)	feasibility of hot temp at stage K14
FEHOTK15(I)	feasibility of hot temp at stage K15
FEHOTK16(I)	feasibility of hot temp at stage K16
FEHOTK17(I)	feasibility of hot temp at stage K17
FEHOTK18(I)	feasibility of hot temp at stage K18
FEHOTK19(I)	feasibility of hot temp at stage K19
FEHOTK20(I)	feasibility of hot temp at stage K20
FEHOTK21(I)	feasibility of hot temp at stage K21
FEHOTK22(I)	feasibility of hot temp at stage K22
FECOLDK1(J)	feasibility of cold temp at stage K1
FECOLDK2(J)	feasibility of cold temp at stage K2
FECOLDK3(J)	feasibility of cold temp at stage K3
FECOLDK4(J)	feasibility of cold temp at stage K4
FECOLDK5(J)	feasibility of cold temp at stage K5
FECOLDK6(J)	feasibility of cold temp at stage K6
FECOLDK7(J)	feasibility of cold temp at stage K7
FECOLDK8(J)	feasibility of cold temp at stage K8
FECOLDK9(J)	feasibility of cold temp at stage K9
FECOLDK10(J)	feasibility of cold temp at stage K10
FECOLDK11(J)	feasibility of cold temp at stage K11
FECOLDK12(J)	feasibility of cold temp at stage K12
FECOLDK13(J)	feasibility of cold temp at stage K13
FECOLDK14(J)	feasibility of cold temp at stage K14
FECOLDK15(J)	feasibility of cold temp at stage K15
FECOLDK16(J)	feasibility of cold temp at stage K16
FECOLDK17(J)	feasibility of cold temp at stage K17
FECOLDK18(J)	feasibility of cold temp at stage K18
FECOLDK19(J)	feasibility of cold temp at stage K19
FECOLDK20(J)	feasibility of cold temp at stage K20
FECOLDK21(J)	feasibility of cold temp at stage K21
FECOLDK22(J)	feasibility of cold temp at stage K22
FEHOTOUT(I)	feasibility of hot temp out
FECOLDOUT(J)	feasibility of cold temp out
HOTU(I)	hot utility load
COLDU(J)	cold utility load
LogicK1(I,J)	Logical constraint at stage k1
LogicK2(I,J)	Logical constraint at stage k2
LogicK3(I,J)	Logical constraint at stage k3
LogicK4(I,J)	Logical constraint at stage k4
LogicK5(I,J)	Logical constraint at stage k5
LogicK6(I,J)	Logical constraint at stage k6
LogicK7(I,J)	Logical constraint at stage k7
LogicK8(I,J)	Logical constraint at stage k8
LogicK9(I,J)	Logical constraint at stage k9
LogicK10(I,J)	Logical constraint at stage k10
LogicK11(I,J)	Logical constraint at stage k11
LogicK12(I,J)	Logical constraint at stage k12
LogicK13(I,J)	Logical constraint at stage k13
LogicK14(I,J)	Logical constraint at stage k14
LogicK15(I,J)	Logical constraint at stage k15
LogicK16(I,J)	Logical constraint at stage k16
LogicK17(I,J)	Logical constraint at stage k17
LogicK18(I,J)	Logical constraint at stage k18
LogicK19(I,J)	Logical constraint at stage k19
LogicK20(I,J)	Logical constraint at stage k20
LogicK21(I,J)	Logical constraint at stage k21
LogicK22(I,J)	Logical constraint at stage k22
LogicHOT(J)	Logical constraint hot utility
LogicCOLD(I)	Logical constraint cold utility
ApproK1(I,J)	approach temp at stage k1
AApproK1(I,J)	the other approach temp at stage k1
ApproK2(I,J)	approach temp at stage k2
AApproK2(I,J)	the other approach temp at stage k2

ApproK3(I,J)	approach temp at stage k3
AApproK3(I,J)	the other approach temp at stage k3
ApproK4(I,J)	approach temp at stage k4
AApproK4(I,J)	the other approach temp at stage k4
ApproK5(I,J)	approach temp at stage k5
AApproK5(I,J)	the other approach temp at stage k5
ApproK6(I,J)	approach temp at stage k6
AApproK6(I,J)	the other approach temp at stage k6
ApproK7(I,J)	approach temp at stage k7
AApproK7(I,J)	the other approach temp at stage k7
ApproK8(I,J)	approach temp at stage k8
AApproK8(I,J)	the other approach temp at stage k8
ApproK9(I,J)	approach temp at stage k9
AApproK9(I,J)	the other approach temp at stage k9
ApproK10(I,J)	approach temp at stage k10
AApproK10(I,J)	the other approach temp at stage k10
ApproK11(I,J)	approach temp at stage k11
AApproK11(I,J)	the other approach temp at stage k11
ApproK12(I,J)	approach temp at stage k12
AApproK12(I,J)	the other approach temp at stage k12
ApproK13(I,J)	approach temp at stage k13
AApproK13(I,J)	the other approach temp at stage k13
ApproK14(I,J)	approach temp at stage k14
AApproK14(I,J)	the other approach temp at stage k14
ApproK15(I,J)	approach temp at stage k15
AApproK15(I,J)	the other approach temp at stage k15
ApproK16(I,J)	approach temp at stage k16
AApproK16(I,J)	the other approach temp at stage k16
ApproK17(I,J)	approach temp at stage k17
AApproK17(I,J)	the other approach temp at stage k17
ApproK18(I,J)	approach temp at stage k18
AApproK18(I,J)	the other approach temp at stage k18
ApproK19(I,J)	approach temp at stage k19
AApproK19(I,J)	the other approach temp at stage k19
ApproK20(I,J)	approach temp at stage k20
AApproK20(I,J)	the other approach temp at stage k20
ApproK21(I,J)	approach temp at stage k21
AApproK21(I,J)	the other approach temp at stage k21
ApproK22(I,J)	approach temp at stage k22
AApproK22(I,J)	the other approach temp at stage k22
EMATdt1(I,J,K)	EMAT constraint
CONSTRAINT1	constraint no 1
CONSTRAINT2	constraint no 2
CONSTRAINT3	constraint no 3
CONSTRAINT4	constraint no 4
CONSTRAINT5	constraint no.5
CONSTRAINT6	constraint no 6
CONSTRAINT7	constraint no.7
CONSTRAINT8	constraint no.8
CONSTRAINT9	constraint no 9
CONSTRAINT10	constraint no.10
CONSTRAINT11	constraint no.11
CONSTRAINT12	constraint no 12
CONSTRAINT13	constraint no 13
CONSTRAINT14	constraint no 14
CONSTRAINT15	constraint no 15
CONSTRAINT16	constraint no.16
CONSTRAINT17	constraint no.17
CONSTRAINT18	constraint no 18
CONSTRAINT19	constraint no 19
CONSTRAINT20	constraint no.20
CONSTRAINT21	constraint no.21
CONSTRAINT22	constraint no.22
CONSTRAINT23	constraint no.23
CONSTRAINT24	constraint no.24
CONSTRAINT25	constraint no.25
CONSTRAINT26	constraint no.26
CONSTRAINT27	constraint no.27
CONSTRAINT28	constraint no.28
CONSTRAINT29	constraint no.29
CONSTRAINT30	constraint no.30

```
CONSTRAINT31(I,J,K) constraint no.31;
MINU     .. ZZ =E= 10*SUM(I,qcu(I)) + 10*SUM(J,qhu(J))+10*SUM((I,J,K),z(I,J,K))+10*SUM(I,zcu(I))+
10*SUM(J,zhu(J));
HOTI(I)    .. (TINI(I)-TOUTI(I))*FI(I)=E= SUM((J,K),q(I,J,K))+qcu(I);
COLDJ(J)   .. (TOUTJ(J)-TINJ(J))*FJ(J)=E= SUM((I,K),q(I,J,K))+qhu(J);
HOTK1(I)   .. (ti(I,'K1')-ti(I,'K2'))*FI(I)=E= SUM(J,q(I,J,'K1'));
HOTK2(I)   .. (ti(I,'K2')-ti(I,'K3'))*FI(I)=E= SUM(J,q(I,J,'K2'));
HOTK3(I)   .. (ti(I,'K3')-ti(I,'K4'))*FI(I)=E= SUM(J,q(I,J,'K3'));
HOTK4(I)   .. (ti(I,'K4')-ti(I,'K5'))*FI(I)=E= SUM(J,q(I,J,'K4'));
HOTK5(I)   .. (ti(I,'K5')-ti(I,'K6'))*FI(I)=E= SUM(J,q(I,J,'K5'));
HOTK6(I)   .. (ti(I,'K6')-ti(I,'K7'))*FI(I)=E= SUM(J,q(I,J,'K6'));
HOTK7(I)   .. (ti(I,'K7')-ti(I,'K8'))*FI(I)=E= SUM(J,q(I,J,'K7'));
HOTK8(I)   .. (ti(I,'K8')-ti(I,'K9'))*FI(I)=E= SUM(J,q(I,J,'K8'));
HOTK9(I)   .. (ti(I,'K9')-ti(I,'K10'))*FI(I)=E= SUM(J,q(I,J,'K9'));
HOTK10(I)  .. (ti(I,'K10')-ti(I,'K11'))*FI(I)=E= SUM(J,q(I,J,'K10'));
HOTK11(I)  .. (ti(I,'K11')-ti(I,'K12'))*FI(I)=E= SUM(J,q(I,J,'K11'));
HOTK12(I)  .. (ti(I,'K12')-ti(I,'K13'))*FI(I)=E= SUM(J,q(I,J,'K12'));
HOTK13(I)  .. (ti(I,'K13')-ti(I,'K14'))*FI(I)=E= SUM(J,q(I,J,'K13'));
HOTK14(I)  .. (ti(I,'K14')-ti(I,'K15'))*FI(I)=E= SUM(J,q(I,J,'K14'));
HOTK15(I)  .. (ti(I,'K15')-ti(I,'K16'))*FI(I)=E= SUM(J,q(I,J,'K15'));
HOTK16(I)  .. (ti(I,'K16')-ti(I,'K17'))*FI(I)=E= SUM(J,q(I,J,'K16'));
HOTK17(I)  .. (ti(I,'K17')-ti(I,'K18'))*FI(I)=E= SUM(J,q(I,J,'K17'));
HOTK18(I)  .. (ti(I,'K18')-ti(I,'K19'))*FI(I)=E= SUM(J,q(I,J,'K18'));
HOTK19(I)  .. (ti(I,'K19')-ti(I,'K20'))*FI(I)=E= SUM(J,q(I,J,'K19'));
HOTK20(I)  .. (ti(I,'K20')-ti(I,'K21'))*FI(I)=E= SUM(J,q(I,J,'K20'));
HOTK21(I)  .. (ti(I,'K21')-ti(I,'K22'))*FI(I)=E= SUM(J,q(I,J,'K21'));
HOTK22(I)  .. (ti(I,'K22')-ti(I,'K23'))*FI(I)=E= SUM(J,q(I,J,'K22'));
COLDK1(J)  .. (tj(J,'K1')-tj(J,'K2'))*FJ(J)=E= SUM(I,q(I,J,'K1'));
COLDK2(J)  .. (tj(J,'K2')-tj(J,'K3'))*FJ(J)=E= SUM(I,q(I,J,'K2'));
COLDK3(J)  .. (tj(J,'K3')-tj(J,'K4'))*FJ(J)=E= SUM(I,q(I,J,'K3'));
COLDK4(J)  .. (tj(J,'K4')-tj(J,'K5'))*FJ(J)=E= SUM(I,q(I,J,'K4'));
COLDK5(J)  .. (tj(J,'K5')-tj(J,'K6'))*FJ(J)=E= SUM(I,q(I,J,'K5'));
COLDK6(J)  .. (tj(J,'K6')-tj(J,'K7'))*FJ(J)=E= SUM(I,q(I,J,'K6'));
COLDK7(J)  .. (tj(J,'K7')-tj(J,'K8'))*FJ(J)=E= SUM(I,q(I,J,'K7'));
COLDK8(J)  .. (tj(J,'K8')-tj(J,'K9'))*FJ(J)=E= SUM(I,q(I,J,'K8'));
COLDK9(J)  .. (tj(J,'K9')-tj(J,'K10'))*FJ(J)=E= SUM(I,q(I,J,'K9'));
COLDK10(J) .. (tj(J,'K10')-tj(J,'K11'))*FJ(J)=E= SUM(I,q(I,J,'K10'));
COLDK11(J) .. (tj(J,'K11')-tj(J,'K12'))*FJ(J)=E= SUM(I,q(I,J,'K11'));
COLDK12(J) .. (tj(J,'K12')-tj(J,'K13'))*FJ(J)=E= SUM(I,q(I,J,'K12'));
COLDK13(J) .. (tj(J,'K13')-tj(J,'K14'))*FJ(J)=E= SUM(I,q(I,J,'K13'));
COLDK14(J) .. (tj(J,'K14')-tj(J,'K15'))*FJ(J)=E= SUM(I,q(I,J,'K14'));
COLDK15(J) .. (tj(J,'K15')-tj(J,'K16'))*FJ(J)=E= SUM(I,q(I,J,'K15'));
COLDK16(J) .. (tj(J,'K16')-tj(J,'K17'))*FJ(J)=E= SUM(I,q(I,J,'K16'));
COLDK17(J) .. (tj(J,'K17')-tj(J,'K18'))*FJ(J)=E= SUM(I,q(I,J,'K17'));
COLDK18(J) .. (tj(J,'K18')-tj(J,'K19'))*FJ(J)=E= SUM(I,q(I,J,'K18'));
COLDK19(J) .. (tj(J,'K19')-tj(J,'K20'))*FJ(J)=E= SUM(I,q(I,J,'K19'));
COLDK20(J) .. (tj(J,'K20')-tj(J,'K21'))*FJ(J)=E= SUM(I,q(I,J,'K20'));
COLDK21(J) .. (tj(J,'K21')-tj(J,'K22'))*FJ(J)=E= SUM(I,q(I,J,'K21'));
COLDK22(J) .. (tj(J,'K22')-tj(J,'K23'))*FJ(J)=E= SUM(I,q(I,J,'K22'));
TINHOT(I) .. TINI(I) =E= ti(I,'K1');
TINCOLD(J) .. TINJ(J) =E= tj(J,'K23');
FEHOTK1(I) .. ti(I,'K1') =G= ti(I,'K2');
FEHOTK2(I) .. ti(I,'K2') =G= ti(I,'K3');
FEHOTK3(I) .. ti(I,'K3') =G= ti(I,'K4');
FEHOTK4(I) .. ti(I,'K4') =G= ti(I,'K5');
FEHOTK5(I) .. ti(I,'K5') =G= ti(I,'K6');
FEHOTK6(I) .. ti(I,'K6') =G= ti(I,'K7');
FEHOTK7(I) .. ti(I,'K7') =G= ti(I,'K8');
FEHOTK8(I) .. ti(I,'K8') =G= ti(I,'K9');
FEHOTK9(I) .. ti(I,'K9') =G= ti(I,'K10');
FEHOTK10(I).. ti(I,'K10') =G= ti(I,'K11');
FEHOTK11(I).. ti(I,'K11') =G= ti(I,'K12');
FEHOTK12(I).. ti(I,'K12') =G= ti(I,'K13');
FEHOTK13(I).. ti(I,'K13') =G= ti(I,'K14');
FEHOTK14(I).. ti(I,'K14') =G= ti(I,'K15');
FEHOTK15(I).. ti(I,'K15') =G= ti(I,'K16');
FEHOTK16(I).. ti(I,'K16') =G= ti(I,'K17');
FEHOTK17(I).. ti(I,'K17') =G= ti(I,'K18');
FEHOTK18(I).. ti(I,'K18') =G= ti(I,'K19');
FEHOTK19(I).. ti(I,'K19') =G= ti(I,'K20');
FEHOTK20(I).. ti(I,'K20') =G= ti(I,'K21');
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FEHOTK21(I).. ti(I,'K21') =G= ti(I,'K22');
FEHOTK22(I).. ti(I,'K22') =G= ti(I,'K23');
FECOLDK1(J) .. tj(J,'K1') =G= tj(J,'K2');
FECOLDK2(J) .. tj(J,'K2') =G= tj(J,'K3');
FECOLDK3(J) .. tj(J,'K3') =G= tj(J,'K4');
FECOLDK4(J) .. tj(J,'K4') =G= tj(J,'K5');
FECOLDK5(J) .. tj(J,'K5') =G= tj(J,'K6');
FECOLDK6(J) .. tj(J,'K6') =G= tj(J,'K7');
FECOLDK7(J) .. tj(J,'K7') =G= tj(J,'K8');
FECOLDK8(J) .. tj(J,'K8') =G= tj(J,'K9');
FECOLDK9(J) .. tj(J,'K9') =G= tj(J,'K10');
FECOLDK10(J).. tj(J,'K10') =G= tj(J,'K11');
FECOLDK11(J).. tj(J,'K11') =G= tj(J,'K12');
FECOLDK12(J).. tj(J,'K12') =G= tj(J,'K13');
FECOLDK13(J).. tj(J,'K13') =G= tj(J,'K14');
FECOLDK14(J).. tj(J,'K14') =G= tj(J,'K15');
FECOLDK15(J).. tj(J,'K15') =G= tj(J,'K16');
FECOLDK16(J).. tj(J,'K16') =G= tj(J,'K17');
FECOLDK17(J).. tj(J,'K17') =G= tj(J,'K18');
FECOLDK18(J).. tj(J,'K18') =G= tj(J,'K19');
FECOLDK19(J).. tj(J,'K19') =G= tj(J,'K20');
FECOLDK20(J).. tj(J,'K20') =G= tj(J,'K21');
FECOLDK21(J).. tj(J,'K21') =G= tj(J,'K22');
FECOLDK22(J).. tj(J,'K22') =G= tj(J,'K23');
FEHOTOUT(I) .. TOUTI(I) =L= ti(I,'K23');
FECOLDOUT(J).. TOUTJ(J) =G= tj(J,'K1');
HOTU(I) .. (ti(I,'K23')-TOUTI(I))*FI(I) =E= qcu(I);
COLDU(J) .. (TOUTJ(J)-tj(j,'K1'))*FJ(J) =E= qhu(J);
LogicK1(I,J) .. q(I,J,'K1')-OMEGA*z(I,J,'K1') =L= 0;
LogicK2(I,J) .. q(I,J,'K2')-OMEGA*z(I,J,'K2') =L= 0;
LogicK3(I,J) .. q(I,J,'K3')-OMEGA*z(I,J,'K3') =L= 0;
LogicK4(I,J) .. q(I,J,'K4')-OMEGA*z(I,J,'K4') =L= 0;
LogicK5(I,J) .. q(I,J,'K5')-OMEGA*z(I,J,'K5') =L= 0;
LogicK6(I,J) .. q(I,J,'K6')-OMEGA*z(I,J,'K6') =L= 0;
LogicK7(I,J) .. q(I,J,'K7')-OMEGA*z(I,J,'K7') =L= 0;
LogicK8(I,J) .. q(I,J,'K8')-OMEGA*z(I,J,'K8') =L= 0;
LogicK9(I,J) .. q(I,J,'K9')-OMEGA*z(I,J,'K9') =L= 0;
LogicK10(I,J) .. q(I,J,'K10')-OMEGA*z(I,J,'K10') =L= 0;
LogicK11(I,J) .. q(I,J,'K11')-OMEGA*z(I,J,'K11') =L= 0;
LogicK12(I,J) .. q(I,J,'K12')-OMEGA*z(I,J,'K12') =L= 0;
LogicK13(I,J) .. q(I,J,'K13')-OMEGA*z(I,J,'K13') =L= 0;
LogicK14(I,J) .. q(I,J,'K14')-OMEGA*z(I,J,'K14') =L= 0;
LogicK15(I,J) .. q(I,J,'K15')-OMEGA*z(I,J,'K15') =L= 0;
LogicK16(I,J) .. q(I,J,'K16')-OMEGA*z(I,J,'K16') =L= 0;
LogicK17(I,J) .. q(I,J,'K17')-OMEGA*z(I,J,'K17') =L= 0;
LogicK18(I,J) .. q(I,J,'K18')-OMEGA*z(I,J,'K18') =L= 0;
LogicK19(I,J) .. q(I,J,'K19')-OMEGA*z(I,J,'K19') =L= 0;
LogicK20(I,J) .. q(I,J,'K20')-OMEGA*z(I,J,'K20') =L= 0;
LogicK21(I,J) .. q(I,J,'K21')-OMEGA*z(I,J,'K21') =L= 0;
LogicK22(I,J) .. q(I,J,'K22')-OMEGA*z(I,J,'K22') =L= 0;
LogicHOT(J) .. qhu(J)-OMEGA*zhu(J) =L= 0;
LogicCOLD(I).. qcu(I)-OMEGA*zcu(I) =L= 0;
ApproK1(I,J) .. dt(I,J,'K1') =L= (ti(I,'K1')-tj(J,'K1'))+TAL*(1-z(I,J,'K1'));
AApproK1(I,J) .. dt(I,J,'K2') =L= (ti(I,'K2')-tj(J,'K2'))+TAL*(1-z(I,J,'K1'));
ApproK2(I,J) .. dt(I,J,'K2') =L= (ti(I,'K2')-tj(J,'K2'))+TAL*(1-z(I,J,'K2'));
AApproK2(I,J) .. dt(I,J,'K3') =L= (ti(I,'K3')-tj(J,'K3'))+TAL*(1-z(I,J,'K2'));
ApproK3(I,J) .. dt(I,J,'K3') =L= (ti(I,'K3')-tj(J,'K3'))+TAL*(1-z(I,J,'K3'));
AApproK3(I,J) .. dt(I,J,'K4') =L= (ti(I,'K4')-tj(J,'K4'))+TAL*(1-z(I,J,'K3'));
ApproK4(I,J) .. dt(I,J,'K4') =L= (ti(I,'K4')-tj(J,'K4'))+TAL*(1-z(I,J,'K4'));
AApproK4(I,J) .. dt(I,J,'K5') =L= (ti(I,'K5')-tj(J,'K5'))+TAL*(1-z(I,J,'K4'));
ApproK5(I,J) .. dt(I,J,'K5') =L= (ti(I,'K5')-tj(J,'K5'))+TAL*(1-z(I,J,'K5'));
AApproK5(I,J) .. dt(I,J,'K6') =L= (ti(I,'K6')-tj(J,'K6'))+TAL*(1-z(I,J,'K5'));
ApproK6(I,J) .. dt(I,J,'K6') =L= (ti(I,'K6')-tj(J,'K6'))+TAL*(1-z(I,J,'K6'));
AApproK6(I,J) .. dt(I,J,'K7') =L= (ti(I,'K7')-tj(J,'K7'))+TAL*(1-z(I,J,'K6'));
ApproK7(I,J) .. dt(I,J,'K7') =L= (ti(I,'K7')-tj(J,'K7'))+TAL*(1-z(I,J,'K7'));
AApproK7(I,J) .. dt(I,J,'K8') =L= (ti(I,'K8')-tj(J,'K8'))+TAL*(1-z(I,J,'K7'));
ApproK8(I,J) .. dt(I,J,'K8') =L= (ti(I,'K8')-tj(J,'K8'))+TAL*(1-z(I,J,'K8'));
AApproK8(I,J) .. dt(I,J,'K9') =L= (ti(I,'K9')-tj(J,'K9'))+TAL*(1-z(I,J,'K8'));
ApproK9(I,J) .. dt(I,J,'K9') =L= (ti(I,'K9')-tj(J,'K9'))+TAL*(1-z(I,J,'K9'));
AApproK9(I,J) .. dt(I,J,'K10') =L= (ti(I,'K10')-tj(J,'K10'))+TAL*(1-z(I,J,'K9'));
ApproK10(I,J) .. dt(I,J,'K10') =L= (ti(I,'K10')-tj(J,'K10'))+TAL*(1-z(I,J,'K10'));
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AApproK10(I,J).. dt(I,J,'K11') =L= (ti(I,'K11')-tj(J,'K11'))+TAL*(1-z(I,J,'K10'));
ApproK11(I,J) .. dt(I,J,'K11') =L= (ti(I,'K11')-tj(J,'K11'))+TAL*(1-z(I,J,'K11'));
AApproK11(I,J).. dt(I,J,'K12') =L= (ti(I,'K12')-tj(J,'K12'))+TAL*(1-z(I,J,'K11'));
ApproK12(I,J) .. dt(I,J,'K12') =L= (ti(I,'K12')-tj(J,'K12'))+TAL*(1-z(I,J,'K12'));
AApproK12(I,J).. dt(I,J,'K13') =L= (ti(I,'K13')-tj(J,'K13'))+TAL*(1-z(I,J,'K12'));
ApproK13(I,J) .. dt(I,J,'K13') =L= (ti(I,'K13')-tj(J,'K13'))+TAL*(1-z(I,J,'K13'));
AApproK13(I,J).. dt(I,J,'K14') =L= (ti(I,'K14')-tj(J,'K14'))+TAL*(1-z(I,J,'K13'));
ApproK14(I,J) .. dt(I,J,'K14') =L= (ti(I,'K14')-tj(J,'K14'))+TAL*(1-z(I,J,'K14'));
AApproK14(I,J).. dt(I,J,'K15') =L= (ti(I,'K15')-tj(J,'K15'))+TAL*(1-z(I,J,'K14'));
ApproK15(I,J) .. dt(I,J,'K15') =L= (ti(I,'K15')-tj(J,'K15'))+TAL*(1-z(I,J,'K15'));
AApproK15(I,J).. dt(I,J,'K16') =L= (ti(I,'K16')-tj(J,'K16'))+TAL*(1-z(I,J,'K15'));
ApproK16(I,J) .. dt(I,J,'K16') =L= (ti(I,'K16')-tj(J,'K16'))+TAL*(1-z(I,J,'K16'));
AApproK16(I,J).. dt(I,J,'K17') =L= (ti(I,'K17')-tj(J,'K17'))+TAL*(1-z(I,J,'K16'));
ApproK17(I,J) .. dt(I,J,'K17') =L= (ti(I,'K17')-tj(J,'K17'))+TAL*(1-z(I,J,'K17'));
AApproK17(I,J).. dt(I,J,'K18') =L= (ti(I,'K18')-tj(J,'K18'))+TAL*(1-z(I,J,'K17'));
ApproK18(I,J) .. dt(I,J,'K18') =L= (ti(I,'K18')-tj(J,'K18'))+TAL*(1-z(I,J,'K18'));
AApproK18(I,J).. dt(I,J,'K19') =L= (ti(I,'K19')-tj(J,'K19'))+TAL*(1-z(I,J,'K18'));
ApproK19(I,J) .. dt(I,J,'K19') =L= (ti(I,'K19')-tj(J,'K19'))+TAL*(1-z(I,J,'K19'));
AApproK19(I,J).. dt(I,J,'K20') =L= (ti(I,'K20')-tj(J,'K20'))+TAL*(1-z(I,J,'K19'));
ApproK20(I,J) .. dt(I,J,'K20') =L= (ti(I,'K20')-tj(J,'K20'))+TAL*(1-z(I,J,'K20'));
AApproK20(I,J).. dt(I,J,'K21') =L= (ti(I,'K21')-tj(J,'K21'))+TAL*(1-z(I,J,'K20'));
ApproK21(I,J) .. dt(I,J,'K21') =L= (ti(I,'K21')-tj(J,'K21'))+TAL*(1-z(I,J,'K21'));
AApproK21(I,J).. dt(I,J,'K22') =L= (ti(I,'K22')-tj(J,'K22'))+TAL*(1-z(I,J,'K21'));
ApproK22(I,J) .. dt(I,J,'K22') =L= (ti(I,'K22')-tj(J,'K22'))+TAL*(1-z(I,J,'K22'));
AApproK22(I,J).. dt(I,J,'K23') =L= (ti(I,'K23')-tj(J,'K23'))+TAL*(1-z(I,J,'K22'));
EMATdt1(I,J,K) .. dt(I,J,K) =G= EMAT;
CONSTRAINT1 .. sum(J,qhu(J)) =L= 75939;
CONSTRAINT2 .. sum(I,qcu(I)) =L= 207.9;
CONSTRAINT3 .. z('I17','J3','K1') =E= 1;
CONSTRAINT4 .. sum(K,z('I17','J3',K)) =G= 1;
CONSTRAINT5 .. z('I18','J3','K1') =E= 1;
CONSTRAINT6 .. sum(K,z('I18','J3',K)) =G= 1;
CONSTRAINT7 .. z('I15','J3','K1') =E= 1;
CONSTRAINT8 .. sum(K,z('I15','J3',K)) =G= 1;
CONSTRAINT9 .. z('I16','J3','K1') =E= 1;
CONSTRAINT10 .. sum(K,z('I16','J3',K)) =G= 1;
CONSTRAINT11 .. sum(K,z('I14','J3',K)) =G= 1;
CONSTRAINT12 .. sum(K,z('I7','J1',K)) =G= 1;
CONSTRAINT13 .. sum(K,z('I9','J2',K)) =G= 1;
CONSTRAINT14 .. sum(K,z('I8','J2',K)) =G= 1;
CONSTRAINT15 .. sum(K,z('I6','J1',K)) =G= 1;
CONSTRAINT16 .. z('I4','J1','K10') =E= 1;
CONSTRAINT17 .. sum(K,z('I4','J1',K)) =G= 1;
CONSTRAINT18 .. z('I5','J1','K10') =E= 1;
CONSTRAINT19 .. sum(K,z('I5','J1',K)) =G= 1;
CONSTRAINT20 .. sum(K,z('I3','J1',K)) =G= 1;
CONSTRAINT21 .. z('I13','J3','K18') =E= 1;
CONSTRAINT22 .. sum(K,z('I13','J3',K)) =G= 1;
CONSTRAINT23 .. z('I12','J3','K18') =E= 1;
CONSTRAINT24 .. sum(K,z('I12','J3',K)) =G= 1;
CONSTRAINT25 .. z('I11','J3','K18') =E= 1;
CONSTRAINT26 .. sum(K,z('I11','J3',K)) =G= 1;
CONSTRAINT27 .. z('I10','J3','K18') =E= 1;
CONSTRAINT28 .. sum(K,z('I10','J3',K)) =G= 1;
CONSTRAINT29 .. sum(K,z('I2','J1',K)) =G= 1;
CONSTRAINT30 .. sum(K,z('I1','J1',K)) =G= 1;
CONSTRAINT31(I,J,K) .. dtt(I,J,K) =E= ti(I,K)-tj(J,K);

MODEL TSHIP /ALL/ ;
SOLVE TSHIP USING MIP MINIMIZING ZZ;
DISPLAY ZZ.L,z.L,zcu.L,zhu.L,q.L,qcu.L,qhu.L,ti.L,tj.L;
```

Result of stage model of Retrofit H.E.N. of Example 5(Light Crude Oil) with EMAT = 3.3 °C

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GAMS Rev 136  MS Windows                    04/05/10 14:58:44 Page 6
General Algebraic Modeling System
Execution
----   485 VARIABLE ZZ.L            =   757833.567  total energy
----   485 VARIABLE z.L  exchanger matching between hot I and cold J at stage k
           K1      K2      K3      K6      K10     K12
```

```
I1 .J1                    1.000
I2 .J1           1.000
I3 .J1                                                1.000
I4 .J1                                      1.000
I4 .J2   1.000
I5 .J1                                      1.000
I5 .J1                             1.000
I7 .J1   1.000
I8 .J2   1.000
I9 .J2                    1.000
I14.J3                                      1.000
I15.J3   1.000
I16.J3   1.000
I17.J3   1.000
I18.J3   1.000

   +     K18       K20       K21

I9 .J3                    1.000
I10.J3   1.000
I11.J3   1.000
I12.J3   1.000
I13.J3   1.000
I14.J3           1.000

----   485 VARIABLE zcu.L  cold utility matching with hot I
                ( ALL       0.000 )

----   485 VARIABLE zhu.L  hot utility matching with cold J

J3 1.000

----   485 VARIABLE q.L  heat exchanged between hot I and cold J

           K1        K2        K3        K6        K10       K12

I1 .J1                      903.305
I2 .J1             9148.303
I3 .J1                                                      7929.756
I4 .J1                                           2700.488
I4 .J2    206.712
I5 .J1                                           5678.112
I6 .J1                                 7005.988
I7 .J1   5553.856
I8 .J2  10475.910
I9 .J2                    10371.366
I14.J3                                          12933.167
I15.J3   2012.892
I16.J3   1230.068
I17.J3  10173.816
I18.J3   6360.000

   +       K18       K20       K21

I9 .J3                      206.592
I10.J3  16349.886
I11.J3   4160.164
I12.J3   2690.184
I13.J3   1179.946
I14.J3             5886.928

----   485 VARIABLE qcu.L  heat exchanged between cold utility and hot I
                ( ALL       0.000 )

----   485 VARIABLE qhu.L  heat exchanged between hot utility and cold J

J3 75761.357

----   485 VARIABLE ti.L  temp of hot stream i at hot end of stage k

           K1         K2         K3         K4         K5         K6

I1     132.250    132.250    132.250     90.000     90.000     90.000
I2     202.050    202.050    157.000    157.000    157.000    157.000
I3     216.700    216.700    216.700    216.700    216.700    216.700
I4     223.100    218.606    218.606    218.606    218.606    218.606
I5     216.900    216.900    216.900    216.900    216.900    216.900
I6     202.050    202.050    202.050    202.050    202.050    202.050
I7     233.000    159.400    159.400    159.400    159.400    159.400
I8     220.400    189.800    189.800    189.800    189.800    189.800
I9     281.900    281.900    281.900    201.600    201.600    201.600
I10    256.600    256.600    256.600    256.600    256.600    256.600
I11    253.000    253.000    253.000    253.000    253.000    253.000
I12    276.700    276.700    276.700    276.700    276.700    276.700
I13    285.400    285.400    285.400    285.400    285.400    285.400
I14    304.900    304.900    304.900    304.900    304.900    304.900
I15    324.000    280.600    280.600    280.600    280.600    280.600
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I16	330.000	285.400	285.400	285.400	285.400	285.400
I17	358.400	290.000	290.000	290.000	290.000	290.000
I18	370.000	290.000	290.000	290.000	290.000	290.000

+	K7	K8	K9	K10	K11	K12
I1	90.000	90.000	90.000	90.000	90.000	90.000
I2	157.000	157.000	157.000	157.000	157.000	157.000
I3	216.700	216.700	216.700	216.700	216.700	216.700
I4	218.606	218.606	218.606	218.606	159.900	159.900
I5	216.900	216.900	216.900	216.900	164.100	164.100
I6	173.000	173.000	173.000	173.000	173.000	173.000
I7	159.400	159.400	159.400	159.400	159.400	159.400
I8	189.800	189.800	189.800	189.800	189.800	189.800
I9	201.600	201.600	201.600	201.600	201.600	201.600
I10	256.600	256.600	256.600	256.600	256.600	256.600
I11	253.000	253.000	253.000	253.000	253.000	253.000
I12	276.700	276.700	276.700	276.700	276.700	276.700
I13	285.400	285.400	285.400	285.400	285.400	285.400
I14	304.900	304.900	304.900	304.900	271.708	271.708
I15	280.600	280.600	280.600	280.600	280.600	280.600
I16	285.400	285.400	285.400	285.400	285.400	285.400
I17	290.000	290.000	290.000	290.000	290.000	290.000
I18	290.000	290.000	290.000	290.000	290.000	290.000

+	K13	K14	K15	K16	K17	K18
I1	90.000	90.000	90.000	90.000	90.000	90.000
I2	157.000	157.000	157.000	157.000	157.000	157.000
I3	143.500	143.500	143.500	143.500	143.500	143.500
I4	159.900	159.900	159.900	159.900	159.900	159.900
I5	164.100	164.100	164.100	164.100	164.100	164.100
I6	173.000	173.000	173.000	173.000	173.000	173.000
I7	159.400	159.400	159.400	159.400	159.400	159.400
I8	189.800	189.800	189.800	189.800	189.800	189.800
I9	201.600	201.600	201.600	201.600	201.600	201.600
I10	256.600	256.600	256.600	256.600	256.600	256.600
I11	253.000	253.000	253.000	253.000	253.000	253.000
I12	276.700	276.700	276.700	276.700	276.700	276.700
I13	285.400	285.400	285.400	285.400	285.400	285.400
I14	271.708	271.708	271.708	271.708	271.708	271.708
I15	280.600	280.600	280.600	280.600	280.600	280.600
I16	285.400	285.400	285.400	285.400	285.400	285.400
I17	290.000	290.000	290.000	290.000	290.000	290.000
I18	290.000	290.000	290.000	290.000	290.000	290.000

+	K19	K20	K21	K22	K23
I1	90.000	90.000	90.000	90.000	90.000
I2	157.000	157.000	157.000	157.000	157.000
I3	143.500	143.500	143.500	143.500	143.500
I4	159.900	159.900	159.900	159.900	159.900
I5	164.100	164.100	164.100	164.100	164.100
I6	173.000	173.000	173.000	173.000	173.000
I7	159.400	159.400	159.400	159.400	159.400
I8	189.800	189.800	189.800	189.800	189.800
I9	201.600	201.600	201.600	200.000	200.000
I10	211.700	211.700	211.700	211.700	211.700
I11	216.900	216.900	216.900	216.900	216.900
I12	223.100	223.100	223.100	223.100	223.100
I13	240.000	240.000	240.000	240.000	240.000
I14	271.708	271.708	256.600	256.600	256.600
I15	280.600	280.600	280.600	280.600	280.600
I16	285.400	285.400	285.400	285.400	285.400
I17	290.000	290.000	290.000	290.000	290.000
I18	290.000	290.000	290.000	290.000	290.000

---- 485 VARIABLE tj.L temp of cold stream j at hot end of stage k

	K1	K2	K3	K4	K5	K6
J1	111.610	99.964	80.781	78.887	78.887	78.887
J2	179.470	167.054	167.054	155.000	155.000	155.000
J3	319.148	277.159	277.159	277.159	277.159	277.159

+	K7	K8	K9	K10	K11	K12
J1	64.197	64.197	64.197	64.197	46.628	46.628
J2	155.000	155.000	155.000	155.000	155.000	155.000
J3	277.159	277.159	277.159	277.159	249.700	249.700

+	K13	K14	K15	K16	K17	K18
J1	30.000	30.000	30.000	30.000	30.000	30.000

```
J2   155.000   155 000   155.000   155 000   155.000   155.000
J3   249.700   249.700   249.700   249.700   249.700   249.700
+      K19       K20       K21       K22       K23
J1    30.000    30.000    30.000    30.000    30.000
J2   155.000   155 000   155 000   155 000   155.000
J3   197.937   197.937   185.439   185.000   185.000
EXECUTION TIME    =    0.031 SECONDS   2.1 Mb    WIN212-136
USER: The Petroleum and Petrochemical College    G030915:1142AP-WIN
```

6. Retrofit of stage model of Retrofit H.E.N. of Example 6(Heavy Crude Oil) with EMAT = 20.2 °C

```
SETS
   I  hot streams /I1,I2,I3,I4,I5,I6,I7,I8,I9,I10,I11,I12,I13,I14,I15,I16,I17,I18,I19,I20,I21,I22/
   J  cold streams /J1,J2,J3,J4,J5,J6,J7,J8,J9,J10/
   K  Stage no.
/K1,K2,K3,K4,K5,K6,K7,K8,K9,K10,K11,K12,K13,K14,K15,K16,K17,K18,K19,K20,K21,K22,K23/;
PARAMETER TINI(I) /I1=151.9, I2=216.2, I3=216.7, I4=223.1, I5=216.9, I6=216.2, I7=233,
I8=220.4, I9=281.9, I10=256.6, I11=253, I12=276.7, I13=285.4, I14=304.9, I15=324,
I16=330, I17=358.4, I18=370/
      TINJ(J) /J1=30, J2=155, J3=185/
      TOUTI(I)/I1=90, I2=157, I3=143.5, I4=159.9, I5=164.1, I6=173, I7=159.4, I8=189.8,
I9=200, I10=211.7, I11=216.9, I12=223.1, I13=240, I14=256.6, I15=280.6, I16=285.4, I17=290, I18=290/
      TOUTJ(J)/J1=122.1, J2=182.75, J3=480/
      FI(I)  /I1=23.15, I2=185.4, I3=108.33, I4=46, I5=107.54, I6=203.6, I7=75.46,
I8=342.35, I9=129.157, I10=364.14, I11=115.24, I12=50.19, I13=25.99, I14=389.65, I15=46.38,
I16=27.58, I17=148.74, I18=79.5/
      FJ(J)  /J1=467.4, J2=758.7, J3=577.7/
      OMEGA  /1000000/
      TAL    /1000000/
      EMAT   /20.2/;
VARIABLES
   dt(I,J,K)  Approach temperature
   dtcu(I)   Approach temperature between cold utility and hot stream
   dthu(J)   Approach temperature between hot utility and cold stream
   q(I,J,K)  heat exchanged between hot I and cold J
   qcu(I)    heat exchanged between cold utility and hot I
   qhu(J)    heat exchanged between hot utility and cold J
   ti(I,K)   temp of hot stream i at hot end of stage k
   tj(J,K)   temp of cold stream j at hot end of stage k
   z(I,J,K)  exchanger matching between hot I and cold J at stage k
   zcu(I)    cold utility matching with hot I
   zhu(J)    hot utility matching with cold J
   ZZ        total energy
   dtt(I,J,K) actual temperature;
POSITIVE VARIABLE dt(I,J,K),dtcu(I),dthu(J),q(I,J,K),qcu(I),qhu(J),tj(J,K);
BINARY VARIABLES  zcu(I),zhu(J),z(I,J,K);
EQUATIONS
   MINU          objective function minimize utilities
   HOTI(I)       heat balance in hot streams I
   COLDJ(J)       heat balance in cold stream J
   HOTK1(I)       heat balance of hot  at stage K1
   HOTK2(I)       heat balance of hot  at stage K2
   HOTK3(I)       heat balance of hot  at stage K3
   HOTK4(I)       heat balance of hot  at stage K4
   HOTK5(I)       heat balance of hot  at stage K5
   HOTK6(I)       heat balance of hot  at stage K6
   HOTK7(I)       heat balance of hot  at stage K7
   HOTK8(I)       heat balance of hot  at stage K8
   HOTK9(I)       heat balance of hot  at stage K9
   HOTK10(I)       heat balance of hot  at stage K10
   HOTK11(I)       heat balance of hot  at stage K11
   HOTK12(I)       heat balance of hot  at stage K12
   HOTK13(I)       heat balance of hot  at stage K13
   HOTK14(I)       heat balance of hot  at stage K14
   HOTK15(I)       heat balance of hot  at stage K15
   HOTK16(I)       heat balance of hot  at stage K16
   HOTK17(I)       heat balance of hot  at stage K17
   HOTK18(I)       heat balance of hot  at stage K18
   HOTK19(I)       heat balance of hot  at stage K19
   HOTK20(I)       heat balance of hot  at stage K20
```

HOTK21(I)	heat balance of hot at stage K21
HOTK22(I)	heat balance of hot at stage K22
COLDK1(J)	heat balance of cold at stage K1
COLDK2(J)	heat balance of cold at stage K2
COLDK3(J)	heat balance of cold at stage K3
COLDK4(J)	heat balance of cold at stage K4
COLDK5(J)	heat balance of cold at stage K5
COLDK6(J)	heat balance of cold at stage K6
COLDK7(J)	heat balance of cold at stage K7
COLDK8(J)	heat balance of cold at stage K8
COLDK9(J)	heat balance of cold at stage K9
COLDK10(J)	heat balance of cold at stage K10
COLDK11(J)	heat balance of cold at stage K11
COLDK12(J)	heat balance of cold at stage K12
COLDK13(J)	heat balance of cold at stage K13
COLDK14(J)	heat balance of cold at stage K14
COLDK15(J)	heat balance of cold at stage K15
COLDK16(J)	heat balance of cold at stage K16
COLDK17(J)	heat balance of cold at stage K17
COLDK18(J)	heat balance of cold at stage K18
COLDK19(J)	heat balance of cold at stage K19
COLDK20(J)	heat balance of cold at stage K20
COLDK21(J)	heat balance of cold at stage K21
COLDK22(J)	heat balance of cold at stage K22
TINHOT(I)	hot temp in
TINCOLD(J)	cold temp in
FEHOTK1(I)	feasibility of hot temp at stage K1
FEHOTK2(I)	feasibility of hot temp at stage K2
FEHOTK3(I)	feasibility of hot temp at stage K3
FEHOTK4(I)	feasibility of hot temp at stage K4
FEHOTK5(I)	feasibility of hot temp at stage K5
FEHOTK6(I)	feasibility of hot temp at stage K6
FEHOTK7(I)	feasibility of hot temp at stage K7
FEHOTK8(I)	feasibility of hot temp at stage K8
FEHOTK9(I)	feasibility of hot temp at stage K9
FEHOTK10(I)	feasibility of hot temp at stage K10
FEHOTK11(I)	feasibility of hot temp at stage K11
FEHOTK12(I)	feasibility of hot temp at stage K12
FEHOTK13(I)	feasibility of hot temp at stage K13
FEHOTK14(I)	feasibility of hot temp at stage K14
FEHOTK15(I)	feasibility of hot temp at stage K15
FEHOTK16(I)	feasibility of hot temp at stage K16
FEHOTK17(I)	feasibility of hot temp at stage K17
FEHOTK18(I)	feasibility of hot temp at stage K18
FEHOTK19(I)	feasibility of hot temp at stage K19
FEHOTK20(I)	feasibility of hot temp at stage K20
FEHOTK21(I)	feasibility of hot temp at stage K21
FEHOTK22(I)	feasibility of hot temp at stage K22
FECOLDK1(J)	feasibility of cold temp at stage K1
FECOLDK2(J)	feasibility of cold temp at stage K2
FECOLDK3(J)	feasibility of cold temp at stage K3
FECOLDK4(J)	feasibility of cold temp at stage K4
FECOLDK5(J)	feasibility of cold temp at stage K5
FECOLDK6(J)	feasibility of cold temp at stage K6
FECOLDK7(J)	feasibility of cold temp at stage K7
FECOLDK8(J)	feasibility of cold temp at stage K8
FECOLDK9(J)	feasibility of cold temp at stage K9
FECOLDK10(J)	feasibility of cold temp at stage K10
FECOLDK11(J)	feasibility of cold temp at stage K11
FECOLDK12(J)	feasibility of cold temp at stage K12
FECOLDK13(J)	feasibility of cold temp at stage K13
FECOLDK14(J)	feasibility of cold temp at stage K14
FECOLDK15(J)	feasibility of cold temp at stage K15
FECOLDK16(J)	feasibility of cold temp at stage K16
FECOLDK17(J)	feasibility of cold temp at stage K17
FECOLDK18(J)	feasibility of cold temp at stage K18
FECOLDK19(J)	feasibility of cold temp at stage K19
FECOLDK20(J)	feasibility of cold temp at stage K20
FECOLDK21(J)	feasibility of cold temp at stage K21
FECOLDK22(J)	feasibility of cold temp at stage K22
FEHOTOUT(I)	feasibility of hot temp out

FECOLDOUT(J)	feasibility of cold temp out
HOTU(I)	hot utility load
COLDU(J)	cold utility load
LogicK1(I,J)	Logical constraint at stage k1
LogicK2(I,J)	Logical constraint at stage k2
LogicK3(I,J)	Logical constraint at stage k3
LogicK4(I,J)	Logical constraint at stage k4
LogicK5(I,J)	Logical constraint at stage k5
LogicK6(I,J)	Logical constraint at stage k6
LogicK7(I,J)	Logical constraint at stage k7
LogicK8(I,J)	Logical constraint at stage k8
LogicK9(I,J)	Logical constraint at stage k9
LogicK10(I,J)	Logical constraint at stage k10
LogicK11(I,J)	Logical constraint at stage k11
LogicK12(I,J)	Logical constraint at stage k12
LogicK13(I,J)	Logical constraint at stage k13
LogicK14(I,J)	Logical constraint at stage k14
LogicK15(I,J)	Logical constraint at stage k15
LogicK16(I,J)	Logical constraint at stage k16
LogicK17(I,J)	Logical constraint at stage k17
LogicK18(I,J)	Logical constraint at stage k18
LogicK19(I,J)	Logical constraint at stage k19
LogicK20(I,J)	Logical constraint at stage k20
LogicK21(I,J)	Logical constraint at stage k21
LogicK22(I,J)	Logical constraint at stage k22
LogicHOT(J)	Logical constraint hot utility
LogicCOLD(I)	Logical constraint cold utility
ApproK1(I,J)	approach temp at stage k1
AApproK1(I,J)	the other approach temp at stage k1
ApproK2(I,J)	approach temp at stage k2
AApproK2(I,J)	the other approach temp at stage k2
ApproK3(I,J)	approach temp at stage k3
AApproK3(I,J)	the other approach temp at stage k3
ApproK4(I,J)	approach temp at stage k4
AApproK4(I,J)	the other approach temp at stage k4
ApproK5(I,J)	approach temp at stage k5
AApproK5(I,J)	the other approach temp at stage k5
ApproK6(I,J)	approach temp at stage k6
AApproK6(I,J)	the other approach temp at stage k6
ApproK7(I,J)	approach temp at stage k7
AApproK7(I,J)	the other approach temp at stage k7
ApproK8(I,J)	approach temp at stage k8
AApproK8(I,J)	the other approach temp at stage k8
ApproK9(I,J)	approach temp at stage k9
AApproK9(I,J)	the other approach temp at stage k9
ApproK10(I,J)	approach temp at stage k10
AApproK10(I,J)	the other approach temp at stage k10
ApproK11(I,J)	approach temp at stage k11
AApproK11(I,J)	the other approach temp at stage k11
ApproK12(I,J)	approach temp at stage k12
AApproK12(I,J)	the other approach temp at stage k12
ApproK13(I,J)	approach temp at stage k13
AApproK13(I,J)	the other approach temp at stage k13
ApproK14(I,J)	approach temp at stage k14
AApproK14(I,J)	the other approach temp at stage k14
ApproK15(I,J)	approach temp at stage k15
AApproK15(I,J)	the other approach temp at stage k15
ApproK16(I,J)	approach temp at stage k16
AApproK16(I,J)	the other approach temp at stage k16
ApproK17(I,J)	approach temp at stage k17
AApproK17(I,J)	the other approach temp at stage k17
ApproK18(I,J)	approach temp at stage k18
AApproK18(I,J)	the other approach temp at stage k18
ApproK19(I,J)	approach temp at stage k19
AApproK19(I,J)	the other approach temp at stage k19
ApproK20(I,J)	approach temp at stage k20
AApproK20(I,J)	the other approach temp at stage k20
ApproK21(I,J)	approach temp at stage k21
AApproK21(I,J)	the other approach temp at stage k21
ApproK22(I,J)	approach temp at stage k22
AApproK22(I,J)	the other approach temp at stage k22

```
    EMATdt1(I,J,K)    EMAT constraint
    CONSTRAINT1       constraint no 1
    CONSTRAINT2       constraint no.2
    CONSTRAINT3       constraint no 3
    CONSTRAINT4       constraint no.4
    CONSTRAINT5       constraint no.5
    CONSTRAINT6       constraint no 6
    CONSTRAINT7       constraint no.7
    CONSTRAINT8       constraint no 8
    CONSTRAINT9       constraint no.9
    CONSTRAINT10      constraint no.10
    CONSTRAINT11      constraint no.11
    CONSTRAINT12      constraint no 12
    CONSTRAINT13      constraint no 13
    CONSTRAINT14      constraint no 14
    CONSTRAINT15      constraint no.15
    CONSTRAINT16      constraint no 16
    CONSTRAINT17      constraint no.17
    CONSTRAINT18      constraint no.18
    CONSTRAINT19      constraint no.19
    CONSTRAINT20      constraint no.20
    CONSTRAINT21      constraint no.21
    CONSTRAINT22      constraint no.22
    CONSTRAINT23      constraint no 23
    CONSTRAINT24      constraint no.24
    CONSTRAINT25      constraint no.25
    CONSTRAINT26      constraint no.26
    CONSTRAINT27      constraint no.27
    CONSTRAINT28      constraint no 28
    CONSTRAINT29      constraint no.29
    CONSTRAINT30      constraint no.30
    CONSTRAINT31(I,J,K)      constraint no.31;
MINU    .. ZZ =E= 10*SUM(I,qcu(I)) + 10*SUM(J,qhu(J))+10*SUM((I,J,K),z(I,J,K))+10*SUM(I,zcu(I))+
10*SUM(J,zhu(J));
HOTI(I)   .. (TINI(I)-TOUTI(I))*FI(I)=E= SUM((J,K),q(I,J,K))+qcu(I);
COLDJ(J)  .. (TOUTJ(J)-TINJ(J))*FJ(J)=E= SUM((I,K),q(I,J,K))+qhu(J);
HOTK1(I)  .. (ti(I,'K1')-ti(I,'K2'))*FI(I)=E= SUM(J,q(I,J,'K1'));
HOTK2(I)  .. (ti(I,'K2')-ti(I,'K3'))*FI(I)=E= SUM(J,q(I,J,'K2'));
HOTK3(I)  .. (ti(I,'K3')-ti(I,'K4'))*FI(I)=E= SUM(J,q(I,J,'K3'));
HOTK4(I)  .. (ti(I,'K4')-ti(I,'K5'))*FI(I)=E= SUM(J,q(I,J,'K4'));
HOTK5(I)  .. (ti(I,'K5')-ti(I,'K6'))*FI(I)=E= SUM(J,q(I,J,'K5'));
HOTK6(I)  .. (ti(I,'K6')-ti(I,'K7'))*FI(I)=E= SUM(J,q(I,J,'K6'));
HOTK7(I)  .. (ti(I,'K7')-ti(I,'K8'))*FI(I)=E= SUM(J,q(I,J,'K7'));
HOTK8(I)  .. (ti(I,'K8')-ti(I,'K9'))*FI(I)=E= SUM(J,q(I,J,'K8'));
HOTK9(I)  .. (ti(I,'K9')-ti(I,'K10'))*FI(I)=E= SUM(J,q(I,J,'K9'));
HOTK10(I) .. (ti(I,'K10')-ti(I,'K11'))*FI(I)=E= SUM(J,q(I,J,'K10'));
HOTK11(I) .. (ti(I,'K11')-ti(I,'K12'))*FI(I)=E= SUM(J,q(I,J,'K11'));
HOTK12(I) .. (ti(I,'K12')-ti(I,'K13'))*FI(I)=E= SUM(J,q(I,J,'K12'));
HOTK13(I) .. (ti(I,'K13')-ti(I,'K14'))*FI(I)=E= SUM(J,q(I,J,'K13'));
HOTK14(I) .. (ti(I,'K14')-ti(I,'K15'))*FI(I)=E= SUM(J,q(I,J,'K14'));
HOTK15(I) .. (ti(I,'K15')-ti(I,'K16'))*FI(I)=E= SUM(J,q(I,J,'K15'));
HOTK16(I) .. (ti(I,'K16')-ti(I,'K17'))*FI(I)=E= SUM(J,q(I,J,'K16'));
HOTK17(I) .. (ti(I,'K17')-ti(I,'K18'))*FI(I)=E= SUM(J,q(I,J,'K17'));
HOTK18(I) .. (ti(I,'K18')-ti(I,'K19'))*FI(I)=E= SUM(J,q(I,J,'K18'));
HOTK19(I) .. (ti(I,'K19')-ti(I,'K20'))*FI(I)=E= SUM(J,q(I,J,'K19'));
HOTK20(I) .. (ti(I,'K20')-ti(I,'K21'))*FI(I)=E= SUM(J,q(I,J,'K20'));
HOTK21(I) .. (ti(I,'K21')-ti(I,'K22'))*FI(I)=E= SUM(J,q(I,J,'K21'));
HOTK22(I) .. (ti(I,'K22')-ti(I,'K23'))*FI(I)=E= SUM(J,q(I,J,'K22'));
COLDK1(J) .. (tj(J,'K1')-tj(J,'K2'))*FJ(J)=E= SUM(I,q(I,J,'K1'));
COLDK2(J) .. (tj(J,'K2')-tj(J,'K3'))*FJ(J)=E= SUM(I,q(I,J,'K2'));
COLDK3(J) .. (tj(J,'K3')-tj(J,'K4'))*FJ(J)=E= SUM(I,q(I,J,'K3'));
COLDK4(J) .. (tj(J,'K4')-tj(J,'K5'))*FJ(J)=E= SUM(I,q(I,J,'K4'));
COLDK5(J) .. (tj(J,'K5')-tj(J,'K6'))*FJ(J)=E= SUM(I,q(I,J,'K5'));
COLDK6(J) .. (tj(J,'K6')-tj(J,'K7'))*FJ(J)=E= SUM(I,q(I,J,'K6'));
COLDK7(J) .. (tj(J,'K7')-tj(J,'K8'))*FJ(J)=E= SUM(I,q(I,J,'K7'));
COLDK8(J) .. (tj(J,'K8')-tj(J,'K9'))*FJ(J)=E= SUM(I,q(I,J,'K8'));
COLDK9(J) .. (tj(J,'K9')-tj(J,'K10'))*FJ(J)=E= SUM(I,q(I,J,'K9'));
COLDK10(J) .. (tj(J,'K10')-tj(J,'K11'))*FJ(J)=E= SUM(I,q(I,J,'K10'));
COLDK11(J) .. (tj(J,'K11')-tj(J,'K12'))*FJ(J)=E= SUM(I,q(I,J,'K11'));
COLDK12(J) .. (tj(J,'K12')-tj(J,'K13'))*FJ(J)=E= SUM(I,q(I,J,'K12'));
COLDK13(J) .. (tj(J,'K13')-tj(J,'K14'))*FJ(J)=E= SUM(I,q(I,J,'K13'));
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COLDK14(J) .. (tj(J,'K14')-tj(J,'K15'))*FJ(J)=E= SUM(I,q(I,J,'K14'));
COLDK15(J) .. (tj(J,'K15')-tj(J,'K16'))*FJ(J)=E= SUM(I,q(I,J,'K15'));
COLDK16(J) .. (tj(J,'K16')-tj(J,'K17'))*FJ(J)=E= SUM(I,q(I,J,'K16'));
COLDK17(J) .. (tj(J,'K17')-tj(J,'K18'))*FJ(J)=E= SUM(I,q(I,J,'K17'));
COLDK18(J) .. (tj(J,'K18')-tj(J,'K19'))*FJ(J)=E= SUM(I,q(I,J,'K18'));
COLDK19(J) .. (tj(J,'K19')-tj(J,'K20'))*FJ(J)=E= SUM(I,q(I,J,'K19'));
COLDK20(J) .. (tj(J,'K20')-tj(J,'K21'))*FJ(J)=E= SUM(I,q(I,J,'K20'));
COLDK21(J) .. (tj(J,'K21')-tj(J,'K22'))*FJ(J)=E= SUM(I,q(I,J,'K21'));
COLDK22(J) .. (tj(J,'K22')-tj(J,'K23'))*FJ(J)=E= SUM(I,q(I,J,'K22'));
TINHOT(I) .. TINI(I) =E= ti(I,'K1');
TINCOLD(J) .. TINJ(J) =E= tj(J,'K23');
FEHOTK1(I) .. ti(I,'K1') =G= ti(I,'K2');
FEHOTK2(I) .. ti(I,'K2') =G= ti(I,'K3');
FEHOTK3(I) .. ti(I,'K3') =G= ti(I,'K4');
FEHOTK4(I) .. ti(I,'K4') =G= ti(I,'K5');
FEHOTK5(I) .. ti(I,'K5') =G= ti(I,'K6');
FEHOTK6(I) .. ti(I,'K6') =G= ti(I,'K7');
FEHOTK7(I) .. ti(I,'K7') =G= ti(I,'K8');
FEHOTK8(I) .. ti(I,'K8') =G= ti(I,'K9');
FEHOTK9(I) .. ti(I,'K9') =G= ti(I,'K10');
FEHOTK10(I).. ti(I,'K10') =G= ti(I,'K11');
FEHOTK11(I).. ti(I,'K11') =G= ti(I,'K12');
FEHOTK12(I).. ti(I,'K12') =G= ti(I,'K13');
FEHOTK13(I).. ti(I,'K13') =G= ti(I,'K14');
FEHOTK14(I).. ti(I,'K14') =G= ti(I,'K15');
FEHOTK15(I).. ti(I,'K15') =G= ti(I,'K16');
FEHOTK16(I).. ti(I,'K16') =G= ti(I,'K17');
FEHOTK17(I).. ti(I,'K17') =G= ti(I,'K18');
FEHOTK18(I).. ti(I,'K18') =G= ti(I,'K19');
FEHOTK19(I).. ti(I,'K19') =G= ti(I,'K20');
FEHOTK20(I).. ti(I,'K20') =G= ti(I,'K21');
FEHOTK21(I).. ti(I,'K21') =G= ti(I,'K22');
FEHOTK22(I).. ti(I,'K22') =G= ti(I,'K23');
FECOLDK1(J) .. tj(J,'K1') =G= tj(J,'K2');
FECOLDK2(J) .. tj(J,'K2') =G= tj(J,'K3');
FECOLDK3(J) .. tj(J,'K3') =G= tj(J,'K4');
FECOLDK4(J) .. tj(J,'K4') =G= tj(J,'K5');
FECOLDK5(J) .. tj(J,'K5') =G= tj(J,'K6');
FECOLDK6(J) .. tj(J,'K6') =G= tj(J,'K7');
FECOLDK7(J) .. tj(J,'K7') =G= tj(J,'K8');
FECOLDK8(J) .. tj(J,'K8') =G= tj(J,'K9');
FECOLDK9(J) .. tj(J,'K9') =G= tj(J,'K10');
FECOLDK10(J).. tj(J,'K10') =G= tj(J,'K11');
FECOLDK11(J).. tj(J,'K11') =G= tj(J,'K12');
FECOLDK12(J).. tj(J,'K12') =G= tj(J,'K13');
FECOLDK13(J).. tj(J,'K13') =G= tj(J,'K14');
FECOLDK14(J).. tj(J,'K14') =G= tj(J,'K15');
FECOLDK15(J).. tj(J,'K15') =G= tj(J,'K16');
FECOLDK16(J).. tj(J,'K16') =G= tj(J,'K17');
FECOLDK17(J).. tj(J,'K17') =G= tj(J,'K18');
FECOLDK18(J).. tj(J,'K18') =G= tj(J,'K19');
FECOLDK19(J).. tj(J,'K19') =G= tj(J,'K20');
FECOLDK20(J).. tj(J,'K20') =G= tj(J,'K21');
FECOLDK21(J).. tj(J,'K21') =G= tj(J,'K22');
FECOLDK22(J).. tj(J,'K22') =G= tj(J,'K23');
FEHOTOUT(I) .. TOUTI(I) =L= ti(I,'K23');
FECOLDOUT(J).. TOUTJ(J) =G= tj(J,'K1');
HOTU(I) .. (ti(I,'K23')-TOUTI(I))*FI(I) =E= qcu(I);
COLDU(J) .. (TOUTJ(J)-tj(j,'K1'))*FJ(J) =E= qhu(J);
LogicK1(I,J) .. q(I,J,'K1')-OMEGA*z(I,J,'K1') =L= 0;
LogicK2(I,J) .. q(I,J,'K2')-OMEGA*z(I,J,'K2') =L= 0;
LogicK3(I,J) .. q(I,J,'K3')-OMEGA*z(I,J,'K3') =L= 0;
LogicK4(I,J) .. q(I,J,'K4')-OMEGA*z(I,J,'K4') =L= 0;
LogicK5(I,J) .. q(I,J,'K5')-OMEGA*z(I,J,'K5') =L= 0;
LogicK6(I,J) .. q(I,J,'K6')-OMEGA*z(I,J,'K6') =L= 0;
LogicK7(I,J) .. q(I,J,'K7')-OMEGA*z(I,J,'K7') =L= 0;
LogicK8(I,J) .. q(I,J,'K8')-OMEGA*z(I,J,'K8') =L= 0;
LogicK9(I,J) .. q(I,J,'K9')-OMEGA*z(I,J,'K9') =L= 0;
LogicK10(I,J) .. q(I,J,'K10')-OMEGA*z(I,J,'K10') =L= 0;
LogicK11(I,J) .. q(I,J,'K11')-OMEGA*z(I,J,'K11') =L= 0;
LogicK12(I,J) .. q(I,J,'K12')-OMEGA*z(I,J,'K12') =L= 0;
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LogicK13(I,J) .. q(I,J,'K13')-OMEGA*z(I,J,'K13') =L= 0;
LogicK14(I,J) .. q(I,J,'K14')-OMEGA*z(I,J,'K14') =L= 0;
LogicK15(I,J) .. q(I,J,'K15')-OMEGA*z(I,J,'K15') =L= 0;
LogicK16(I,J) .. q(I,J,'K16')-OMEGA*z(I,J,'K16') =L= 0;
LogicK17(I,J) .. q(I,J,'K17')-OMEGA*z(I,J,'K17') =L= 0;
LogicK18(I,J) .. q(I,J,'K18')-OMEGA*z(I,J,'K18') =L= 0;
LogicK19(I,J) .. q(I,J,'K19')-OMEGA*z(I,J,'K19') =L= 0;
LogicK20(I,J) .. q(I,J,'K20')-OMEGA*z(I,J,'K20') =L= 0;
LogicK21(I,J) .. q(I,J,'K21')-OMEGA*z(I,J,'K21') =L= 0;
LogicK22(I,J) .. q(I,J,'K22')-OMEGA*z(I,J,'K22') =L= 0;
LogicHOT(J) .. qhu(J)-OMEGA*zhu(J) =L= 0;
LogicCOLD(I) .. qcu(I)-OMEGA*zcu(I) =L= 0;
ApproK1(I,J) .. dt(I,J,'K1') =L= (ti(I,'K1')-tj(J,'K1'))+TAL*(1-z(I,J,'K1'));
AApproK1(I,J) .. dt(I,J,'K2') =L= (ti(I,'K2')-tj(J,'K2'))+TAL*(1-z(I,J,'K1'));
ApproK2(I,J) .. dt(I,J,'K2') =L= (ti(I,'K2')-tj(J,'K2'))+TAL*(1-z(I,J,'K2'));
AApproK2(I,J) .. dt(I,J,'K3') =L= (ti(I,'K3')-tj(J,'K3'))+TAL*(1-z(I,J,'K2'));
ApproK3(I,J) .. dt(I,J,'K3') =L= (ti(I,'K3')-tj(J,'K3'))+TAL*(1-z(I,J,'K3'));
AApproK3(I,J) .. dt(I,J,'K4') =L= (ti(I,'K4')-tj(J,'K4'))+TAL*(1-z(I,J,'K3'));
ApproK4(I,J) .. dt(I,J,'K4') =L= (ti(I,'K4')-tj(J,'K4'))+TAL*(1-z(I,J,'K4'));
AApproK4(I,J) .. dt(I,J,'K5') =L= (ti(I,'K5')-tj(J,'K5'))+TAL*(1-z(I,J,'K4'));
ApproK5(I,J) .. dt(I,J,'K5') =L= (ti(I,'K5')-tj(J,'K5'))+TAL*(1-z(I,J,'K5'));
AApproK5(I,J) .. dt(I,J,'K6') =L= (ti(I,'K6')-tj(J,'K6'))+TAL*(1-z(I,J,'K5'));
ApproK6(I,J) .. dt(I,J,'K6') =L= (ti(I,'K6')-tj(J,'K6'))+TAL*(1-z(I,J,'K6'));
AApproK6(I,J) .. dt(I,J,'K7') =L= (ti(I,'K7')-tj(J,'K7'))+TAL*(1-z(I,J,'K6'));
ApproK7(I,J) .. dt(I,J,'K7') =L= (ti(I,'K7')-tj(J,'K7'))+TAL*(1-z(I,J,'K7'));
AApproK7(I,J) .. dt(I,J,'K8') =L= (ti(I,'K8')-tj(J,'K8'))+TAL*(1-z(I,J,'K7'));
ApproK8(I,J) .. dt(I,J,'K8') =L= (ti(I,'K8')-tj(J,'K8'))+TAL*(1-z(I,J,'K8'));
AApproK8(I,J) .. dt(I,J,'K9') =L= (ti(I,'K9')-tj(J,'K9'))+TAL*(1-z(I,J,'K8'));
ApproK9(I,J) .. dt(I,J,'K9') =L= (ti(I,'K9')-tj(J,'K9'))+TAL*(1-z(I,J,'K9'));
AApproK9(I,J) .. dt(I,J,'K10') =L= (ti(I,'K10')-tj(J,'K10'))+TAL*(1-z(I,J,'K9'));
ApproK10(I,J) .. dt(I,J,'K10') =L= (ti(I,'K10')-tj(J,'K10'))+TAL*(1-z(I,J,'K10'));
AApproK10(I,J).. dt(I,J,'K11') =L= (ti(I,'K11')-tj(J,'K11'))+TAL*(1-z(I,J,'K10'));
ApproK11(I,J) .. dt(I,J,'K11') =L= (ti(I,'K11')-tj(J,'K11'))+TAL*(1-z(I,J,'K11'));
AApproK11(I,J).. dt(I,J,'K12') =L= (ti(I,'K12')-tj(J,'K12'))+TAL*(1-z(I,J,'K11'));
ApproK12(I,J) .. dt(I,J,'K12') =L= (ti(I,'K12')-tj(J,'K12'))+TAL*(1-z(I,J,'K12'));
AApproK12(I,J).. dt(I,J,'K13') =L= (ti(I,'K13')-tj(J,'K13'))+TAL*(1-z(I,J,'K12'));
ApproK13(I,J) .. dt(I,J,'K13') =L= (ti(I,'K13')-tj(J,'K13'))+TAL*(1-z(I,J,'K13'));
AApproK13(I,J).. dt(I,J,'K14') =L= (ti(I,'K14')-tj(J,'K14'))+TAL*(1-z(I,J,'K13'));
ApproK14(I,J) .. dt(I,J,'K14') =L= (ti(I,'K14')-tj(J,'K14'))+TAL*(1-z(I,J,'K14'));
AApproK14(I,J).. dt(I,J,'K15') =L= (ti(I,'K15')-tj(J,'K15'))+TAL*(1-z(I,J,'K14'));
ApproK15(I,J) .. dt(I,J,'K15') =L= (ti(I,'K15')-tj(J,'K15'))+TAL*(1-z(I,J,'K15'));
AApproK15(I,J).. dt(I,J,'K16') =L= (ti(I,'K16')-tj(J,'K16'))+TAL*(1-z(I,J,'K15'));
ApproK16(I,J) .. dt(I,J,'K16') =L= (ti(I,'K16')-tj(J,'K16'))+TAL*(1-z(I,J,'K16'));
AApproK16(I,J).. dt(I,J,'K17') =L= (ti(I,'K17')-tj(J,'K17'))+TAL*(1-z(I,J,'K16'));
ApproK17(I,J) .. dt(I,J,'K17') =L= (ti(I,'K17')-tj(J,'K17'))+TAL*(1-z(I,J,'K17'));
AApproK17(I,J).. dt(I,J,'K18') =L= (ti(I,'K18')-tj(J,'K18'))+TAL*(1-z(I,J,'K17'));
ApproK18(I,J) .. dt(I,J,'K18') =L= (ti(I,'K18')-tj(J,'K18'))+TAL*(1-z(I,J,'K18'));
AApproK18(I,J).. dt(I,J,'K19') =L= (ti(I,'K19')-tj(J,'K19'))+TAL*(1-z(I,J,'K18'));
ApproK19(I,J) .. dt(I,J,'K19') =L= (ti(I,'K19')-tj(J,'K19'))+TAL*(1-z(I,J,'K19'));
AApproK19(I,J).. dt(I,J,'K20') =L= (ti(I,'K20')-tj(J,'K20'))+TAL*(1-z(I,J,'K19'));
ApproK20(I,J) .. dt(I,J,'K20') =L= (ti(I,'K20')-tj(J,'K20'))+TAL*(1-z(I,J,'K20'));
AApproK20(I,J).. dt(I,J,'K21') =L= (ti(I,'K21')-tj(J,'K21'))+TAL*(1-z(I,J,'K20'));
ApproK21(I,J) .. dt(I,J,'K21') =L= (ti(I,'K21')-tj(J,'K21'))+TAL*(1-z(I,J,'K21'));
AApproK21(I,J).. dt(I,J,'K22') =L= (ti(I,'K22')-tj(J,'K22'))+TAL*(1-z(I,J,'K21'));
ApproK22(I,J) .. dt(I,J,'K22') =L= (ti(I,'K22')-tj(J,'K22'))+TAL*(1-z(I,J,'K22'));
AApproK22(I,J).. dt(I,J,'K23') =L= (ti(I,'K23')-tj(J,'K23'))+TAL*(1-z(I,J,'K22'));
EMATdt1(I,J,K) .. dt(I,J,K) =G= EMAT;
CONSTRAINT1 .. sum(J,qhu(J)) =L= 107439.7;
CONSTRAINT2 .. sum(I,qcu(I)) =L= 220.76;
CONSTRAINT3 .. z('I17','J3','K1') =E= 1;
CONSTRAINT4 .. sum(K,z('I17','J3',K)) =G= 1;
CONSTRAINT5 .. z('I18','J3','K1') =E= 1;
CONSTRAINT6 .. sum(K,z('I18','J3',K)) =G= 1;
CONSTRAINT7 .. z('I15','J3','K1') =E= 1;
CONSTRAINT8 .. sum(K,z('I15','J3',K)) =G= 1;
CONSTRAINT9 .. z('I16','J3','K1') =E= 1;
CONSTRAINT10 .. sum(K,z('I16','J3',K)) =G= 1;
CONSTRAINT11 .. sum(K,z('I14','J3',K)) =G= 1;
CONSTRAINT12 .. sum(K,z('I7','J1',K)) =G= 1;
CONSTRAINT13 .. sum(K,z('I9','J2',K)) =G= 1;
CONSTRAINT14 .. sum(K,z('I8','J2',K)) =G= 1;
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CONSTRAINT15 .. sum(K,z('I6','J1',K)) =G= 1;
CONSTRAINT16 .. z('I4','J1','K10') =E= 1;
CONSTRAINT17 .. sum(K,z('I4','J1',K)) =G= 1;
CONSTRAINT18 .. z('I5','J1','K10') =E= 1;
CONSTRAINT19 .. sum(K,z('I5','J1',K)) =G= 1;
CONSTRAINT20 .. sum(K,z('I3','J1',K)) =G= 1;
CONSTRAINT21 .. z('I13','J3','K18') =E= 1;
CONSTRAINT22 .. sum(K,z('I13','J3',K)) =G= 1;
CONSTRAINT23 .. z('I12','J3','K18') =E= 1;
CONSTRAINT24 .. sum(K,z('I12','J3',K)) =G= 1;
CONSTRAINT25 .. z('I11','J3','K18') =E= 1;
CONSTRAINT26 .. sum(K,z('I11','J3',K)) =G= 1;
CONSTRAINT27 .. z('I10','J3','K18') =E= 1;
CONSTRAINT28 .. sum(K,z('I10','J3',K)) =G= 1;
CONSTRAINT29 .. sum(K,z('I2','J1',K)) =G= 1;
CONSTRAINT30 .. sum(K,z('I1','J1',K)) =G= 1;
CONSTRAINT31(I,J,K) .. dtt(I,J,K) =E= ti(I,K)-tj(J,K);
MODEL TSHIP /ALL/ ;
SOLVE TSHIP USING MIP MINIMIZING ZZ;
DISPLAY ZZ.L,z.L,zcu.L,zhu.L,q.L,qcu.L,qhu.L,ti.L,tj.L;
```

Result of retrofit of stage model of Retrofit H.E.N. of Example 6(Heavy Crude Oil) with EMAT = 20.2 °C

GAMS Rev 136 MS Windows 04/05/10 16:02:38 Page 6
General Algebraic Modeling System
Execution

```
----   485 VARIABLE ZZ.L           = 1072409.367  total energy
----   485 VARIABLE z.L  exchanger matching between hot I and cold J at stage k
          K1       K9      K10      K11      K13      K16
I1 .J1                               1.000
I2 .J1            1.000
I3 .J1   1.000
I4 .J1                    1.000
I4 .J2                             1.000
I5 .J1                    1.000
I6 .J1                                        1.000
I8 .J2   1.000
I14.J3                             1.000
I15.J3   1.000
I16.J3   1.000
I17.J3   1.000
I18.J3   1.000
   +     K18      K19      K22
I4 .J1   1.000
I7 .J1                    1.000
I9 .J2            1.000
I9 .J3   1.000
I10.J3   1.000
I11.J3   1.000
I12.J3   1.000
I13.J3   1.000
----   485 VARIABLE zcu.L  cold utility matching with hot I
          ( ALL      0.000 )
----   485 VARIABLE zhu.L  hot utility matching with cold J
J3 1.000
----   485 VARIABLE q.L  heat exchanged between hot I and cold J
          K1       K9      K10      K11      K13      K16
I1 .J1                              1432.985
I2 .J1        10975.680
I3 .J1   7929.756
I4 .J1                  1350.162
I4 .J2                           225.569
I5 .J1                  5678.112
I6 .J1                                       8795.520
I8 .J2  10475.910
I14.J3                          18820.095
I15.J3   2012.892
I16.J3   1230.068
I17.J3  10173.816
I18.J3   6360.000
```

+	K18	K19	K22
I4.J1	1331.469		
I7.J1			5553.856
I9.J2		10352.446	
I9.J3	225.512		
I10.J3	16349.886		
I11.J3	4160.164		
I12.J3	2690.184		
I13.J3	1179.946		

---- 485 VARIABLE qcu.L heat exchanged between cold utility and hot I

(ALL 0.000)

---- 485 VARIABLE qhu.L heat exchanged between hot utility and cold J

J3 107218.937

---- 485 VARIABLE ti.L temp of hot stream i at hot end of stage k

	K1	K2	K3	K4	K5	K6
I1	132.250	132.250	132.250	90.000	90.000	90.000
I2	202.050	202.050	157.000	157.000	157.000	157.000
I3	216.700	216.700	216.700	216.700	216.700	216.700
I4	223.100	218.606	218.606	218.606	218.606	218.606
I5	216.900	216.900	216.900	216.900	216.900	216.900
I6	202.050	202.050	202.050	202.050	202.050	202.050
I7	233.000	159.400	159.400	159.400	159.400	159.400
I8	220.400	189.800	189.800	189.800	189.800	189.800
I9	281.900	281.900	281.900	201.600	201.600	201.600
I10	256.600	256.600	256.600	256.600	256.600	256.600
I11	253.000	253.000	253.000	253.000	253.000	253.000
I12	276.700	276.700	276.700	276.700	276.700	276.700
I13	285.400	285.400	285.400	285.400	285.400	285.400
I14	304.900	304.900	304.900	304.900	304.900	304.900
I15	324.000	280.600	280.600	280.600	280.600	280.600
I16	330.000	285.400	285.400	285.400	285.400	285.400
I17	358.400	290.000	290.000	290.000	290.000	290.000
I18	370.000	290.000	290.000	290.000	290.000	290.000

+	K7	K8	K9	K10	K11	K12
I1	90.000	90.000	90.000	90.000	90.000	90.000
I2	157.000	157.000	157.000	157.000	157.000	157.000
I3	216.700	216.700	216.700	216.700	216.700	216.700
I4	218.606	218.606	218.606	218.606	159.900	159.900
I5	216.900	216.900	216.900	216.900	164.100	164.100
I6	173.000	173.000	173.000	173.000	173.000	173.000
I7	159.400	159.400	159.400	159.400	159.400	159.400
I8	189.800	189.800	189.800	189.800	189.800	189.800
I9	201.600	201.600	201.600	201.600	201.600	201.600
I10	256.600	256.600	256.600	256.600	256.600	256.600
I11	253.000	253.000	253.000	253.000	253.000	253.000
I12	276.700	276.700	276.700	276.700	276.700	276.700
I13	285.400	285.400	285.400	285.400	285.400	285.400
I14	304.900	304.900	304.900	304.900	271.708	271.708
I15	280.600	280.600	280.600	280.600	280.600	280.600
I16	285.400	285.400	285.400	285.400	285.400	285.400
I17	290.000	290.000	290.000	290.000	290.000	290.000
I18	290.000	290.000	290.000	290.000	290.000	290.000

+	K13	K14	K15	K16	K17	K18
I1	90.000	90.000	90.000	90.000	90.000	90.000
I2	157.000	157.000	157.000	157.000	157.000	157.000
I3	143.500	143.500	143.500	143.500	143.500	143.500
I4	159.900	159.900	159.900	159.900	159.900	159.900
I5	164.100	164.100	164.100	164.100	164.100	164.100
I6	173.000	173.000	173.000	173.000	173.000	173.000
I7	159.400	159.400	159.400	159.400	159.400	159.400
I8	189.800	189.800	189.800	189.800	189.800	189.800
I9	201.600	201.600	201.600	201.600	201.600	201.600
I10	256.600	256.600	256.600	256.600	256.600	256.600
I11	253.000	253.000	253.000	253.000	253.000	253.000
I12	276.700	276.700	276.700	276.700	276.700	276.700
I13	285.400	285.400	285.400	285.400	285.400	285.400
I14	271.708	271.708	271.708	271.708	271.708	271.708
I15	280.600	280.600	280.600	280.600	280.600	280.600
I16	285.400	285.400	285.400	285.400	285.400	285.400
I17	290.000	290.000	290.000	290.000	290.000	290.000
I18	290.000	290.000	290.000	290.000	290.000	290.000

+	K19	K20	K21	K22	K23
I1	90.000	90.000	90.000	90.000	90.000
I2	157.000	157.000	157.000	157.000	157.000
I3	143.500	143.500	143.500	143.500	143.500
I4	159.900	159.900	159.900	159.900	159.900
I5	164.100	164.100	164.100	164.100	164.100
I6	173.000	173.000	173.000	173.000	173.000
I7	159.400	159.400	159.400	159.400	159.400
I8	189.800	189.800	189.800	189.800	189.800
I9	201.600	201.600	201.600	200.000	200.000
I10	211.700	211.700	211.700	211.700	211.700
I11	216.900	216.900	216.900	216.900	216.900
I12	223.100	223.100	223.100	223.100	223.100
I13	240.000	240.000	240.000	240.000	240.000
I14	271.708	271.708	256.600	256.600	256.600
I15	280.600	280.600	280.600	280.600	280.600
I16	285.400	285.400	285.400	285.400	285.400
I17	290.000	290.000	290.000	290.000	290.000
I18	290.000	290.000	290.000	290.000	290.000

---- 485 VARIABLE tj.L temp of cold stream j at hot end of stage k

	K1	K2	K3	K4	K5	K6
J1	111.610	99.964	80.781	78.887	78.887	78.887
J2	179.470	167.054	167.054	155.000	155.000	155.000
J3	319.148	277.159	277.159	277.159	277.159	277.159

+	K7	K8	K9	K10	K11	K12
J1	64.197	64.197	64.197	64.197	46.628	46.628
J2	155.000	155.000	155.000	155.000	155.000	155.000
J3	277.159	277.159	277.159	277.159	249.700	249.700

+	K13	K14	K15	K16	K17	K18
J1	30.000	30.000	30.000	30.000	30.000	30.000
J2	155.000	155.000	155.000	155.000	155.000	155.000
J3	249.700	249.700	249.700	249.700	249.700	249.700

+	K19	K20	K21	K22	K23
J1	30.000	30.000	30.000	30.000	30.000
J2	155.000	155.000	155.000	155.000	155.000
J3	197.937	197.937	185.439	185.000	185.000

EXECUTION TIME = 0.125 SECONDS 4.2 Mb WIN212-136
USER: The Petroleum and Petrochemical College G030915:1142AP-WIN

Source code of Microsoft C++ in relocation concept 1

```
#include<stdio.h>
#include<conio.h>
#include<math.h>
void main()
{  int i,j,k,n,p,v,s=0,a,b,d,g;
   int h; /* number of hot stream*/
          int c; /* number of cold stream*/
          double z=0.3333;
   char name[50];
          char matching[40][10];
          float U[20][20];
          double dt[20][20][3];
          double dtret[20][20][3];
          double q[20][20][2],
          double qret[20][20][2];
          double sum,summ;
          double vv[20][20][2];
          double A[20][20][2];
          double Aret[20][20][2];
          double L[20][20][2];
          double Lret[20][20][2];
          int one[20][20][2],two[20][20][2],three[20][20][2];
          int oone[20][20][2][5],ttwo[20][20][2][5],tthree[20][20][2][5];
          int hex[20][20][2],yy[20][20][2];
          int fix,invest1,invest2;
          float expo1,expo2;
          FILE *fptr;
          fptr = fopen("BASECASE.txt","r");
```

```
        if(fptr ==NULL)
  {printf("This basecase file can not be opend.\n");}
        else
                printf("This basecase file is opend.\n");
/*--------------------------------------------------------------------------------*/
                printf("\n\n*****Base Case*****\n\n");
            fscanf(fptr,"%s",name);
                printf("%s",name);
                fscanf(fptr,"%d",&h);                /*1.Read number of hot streams*/
                printf(" %d\n",h);
                fscanf(fptr,"%s",name);
                printf("%s",name);
                fscanf(fptr,"%d",&c);                /*2.Read number of cold streams*/
                printf(" %d\n\n\n",c);
/*--------------------------------------------------------------------------------*/
     fscanf(fptr,"%s",name);
                printf("%s",name);
                fscanf(fptr,"%s",name);
                printf("\n%s",name);
                fscanf(fptr,"%d",&fix);
                printf(" %d\n",fix);
                fscanf(fptr,"%s",name);
                printf("%s",name);
                fscanf(fptr,"%d",&invest1);
                printf(" %d\n",invest1);
                fscanf(fptr,"%s",name);
                printf("%s",name);
                fscanf(fptr,"%f",&expo1);
     printf(" %0.2f\n",expo1);
/*--------------------------------------------------------------------------------*/
                fscanf(fptr,"%s",name);
                printf("%s",name);
                fscanf(fptr,"%s",name);
                printf("\n%s",name);
                fscanf(fptr,"%d",&invest2);
                printf(" %d\n",invest2);
                fscanf(fptr,"%s",name);
                printf("%s",name);
                fscanf(fptr,"%f",&expo2);
     printf(" %0.2f\n",expo2);
/*--------------------------------------------------------------------------------*/
            fscanf(fptr,"%s",name);              /*3. Read Ui*/
                printf("\n\n\n%s",name);
                for(i=0;i<h;i++)
      for(j=0;j<c;j++)
                 {
                   fscanf(fptr,"%s",name);
                   printf("\n\n%s\n",name);
        fscanf(fptr,"%f",&U[i][j]);
                   printf(" %.3f",U[i][j]);
                 }
/*--------------------------------------------------------------------------------*/
                fscanf(fptr,"%s",name);
                printf("\n\n%s\n",name);
            fscanf(fptr,"%s",name);
                printf("\n        %s",name);
            fscanf(fptr,"%s",name);
                printf(" %s",name);
                fscanf(fptr,"%s",name);
                printf(" %s\n",name);
/*--------------------------------------------------------------------------------*/
     n=h*c;
          p=0;
                for(i=0;i<h;i++)
      for(j=0;j<c;j++)
                 {
                  fscanf(fptr,"%s",matching[p]);
                  printf("\n%s",matching[p]);
                  for(k=0;k<3;k++)
                  {
                  fscanf(fptr,"%lf",&dt[i][j][k]);
```

```
                    printf("  %.3lf",dt[i][j][k]);
                    }
                    p++;
                   }
        fscanf(fptr,"%s",name);
                   printf("\n\n\n%s\n",name);
        fscanf(fptr,"%s",name);
                   printf("      %s",name);
                   fscanf(fptr,"%s",name);
                   printf("      %s\n",name);
                   for(i=0;i<h;i++)
    for(j=0;j<c;j++)
                   {
                    fscanf(fptr,"%s",name);
                    printf("\n%s",name);
                    for(k=0;k<2;k++)
                    {
                    fscanf(fptr,"%lf",&q[i][j][k]);
                    printf("  %.3lf",q[i][j][k]);
                    }
                   }
        fclose(fptr);
/*--------------------------------------------------------------------------------------*/
        fptr = fopen("RETROFIT.txt","r");
        if(fptr ==NULL)
  {
                   printf("\n\n\nThis retrofit file can not be opend.\n");
        }
        else
                   printf("\n\n\nThis retrofit file is opend.\n");
/*--------------------------------------------------------------------------------------*/
        printf("\n\n*****Retrofit Case*****\n\n");
                   fscanf(fptr,"%s",name);
                   printf("\n\n%s\n",name);
        fscanf(fptr,"%s",name);
                   printf("\n          %s",name);
        fscanf(fptr,"%s",name);
                   printf("  %s",name);
                   fscanf(fptr,"%s",name);
                   printf("  %s\n",name);
                   for(i=0;i<h;i++)
    for(j=0;j<c;j++)
                   {
                    fscanf(fptr,"%s",name);
                    printf("\n%s",name);
                    for(k=0;k<3;k++)
                    {
                    fscanf(fptr,"%lf",&dtret[i][j][k]);
                    printf("  %.3lf",dtret[i][j][k]);
                    }
                   }
        fscanf(fptr,"%s",name);
                   printf("\n\n\n%s\n",name);
        fscanf(fptr,"%s",name);
                   printf("      %s",name);
                   fscanf(fptr,"%s",name);
                   printf("      %s\n",name);
                   for(i=0;i<h;i++)
    for(j=0;j<c;j++)
                   {
                    fscanf(fptr,"%s",name);
                    printf("\n%s",name);
                    for(k=0;k<2;k++)
                    {
                    fscanf(fptr,"%lf",&qret[i][j][k]);
                    printf("  %.3lf",qret[i][j][k]);
                    }
                   }
        fclose(fptr);
/*--------------------------------------------------------------------------------------*/
   for(i=0;i<h;i++)
```

```
for(j=0;j<c;j++)
        {
        L[i][j][0] = pow(((dt[i][j][0]+dt[i][j][1])*(dt[i][j][0]*dt[i][j][1])*0.5),z);
L[i][j][1] = pow(((dt[i][j][1]+dt[i][j][2])*(dt[i][j][1]*dt[i][j][2])*0.5),z);
        Lret[i][j][0] = pow(((dtret[i][j][0]+dtret[i][j][1])*(dtret[i][j][0]*dtret[i][j][1])*0.5),z);
        Lret[i][j][1] = pow(((dtret[i][j][1]+dtret[i][j][2])*(dtret[i][j][1]*dtret[i][j][2])*0.5),z);
        }
        printf("\n\n");
        for(i=0;i<h;i++)
for(j=0;j<c;j++)
        {
A[i][j][0] =    q[i][j][0]/(L[i][j][0]*U[i][j]);
        A[i][j][1] =    q[i][j][1]/(L[i][j][1]*U[i][j]);
        if(A[i][j][0]<0)
A[i][j][0]=0;
        if(A[i][j][1]<0)
A[i][j][1]=0;
        Aret[i][j][0] =  qret[i][j][0]/(Lret[i][j][0]*U[i][j]);
        Aret[i][j][1] =  qret[i][j][1]/(Lret[i][j][1]*U[i][j]);
        if(Aret[i][j][0]<0)
Aret[i][j][0]=0;
        if(Aret[i][j][1]<0)
Aret[i][j][1]=0;
        }
Aret[3][2][0] = 909;
        printf("\n\n*****Existing Heat Exchanger Area*****\n\n");
        printf("\n\n       K1      K2\n\n");
        p=0;
for(i=0;i<h;i++)
for(j=0;j<c;j++)
        {
                printf("%s   ",matching[p]);
                printf("%0.0lf   %0.0lf\n",A[i][j][0],A[i][j][1]);
                p++;
        }
printf("\n\n*****Retrofit Heat Exchanger Area*****\n\n");
        printf("\n\n       K1      K2\n\n");
        p=0;
        for(i=0;i<h;i++)
for(j=0;j<c;j++)
        {
                printf("%s   ",matching[p]);
                printf("%0.0lf   %0.0lf\n",Aret[i][j][0],Aret[i][j][1]);
          p++;
        }
printf("\n*******************************************\n");
        sum=0;
for(i=0;i<h;i++)
for(j=0;j<c;j++)
for(k=0;k<2;k++)
                if(Aret[i][j][k]>0)
            sum=sum+fix+(invest1*pow(Aret[i][j][k],expo1));
                        printf("\n==>Area cost of Grassroot==>%lf\n",sum);
        printf("\n*******************************************\n");
/*----------------------------------------------------------------------------------------*/
/*      1.Finding that heat exchanger is the same matching in retrofit              */
  for(i=0;i<20;i++)
    for(j=0;j<20;j++)
      for(k=0;k<2;k++)
                          hex[i][j][k]=0;
 v=0;
         for(i=0;i<h;i++)
   for(j=0;j<c;j++)
     for(k=0;k<2;k++)
      if((A[i][j][k]==Aret[i][j][k])&&(A[i][j][k]>0))
                        {  v++;
                          A[i][j][k]=0;
                                 Aret[i][j][k]=0;
                                 q[i][j][k]=0;
                                 qret[i][j][k]=0;
                          hex[i][j][k]=1;
```

```
                                        }
  if(v>0)
          {s++;
           printf("\n\n%d.Unmoved and fix-sized Heat Exchanger\n",s);
           printf("==>There area %d heat exchanger are not moved\n",v);
          }
           for(i=0;i<h;i++)
      for(j=0;j<c;j++)
        for(k=0;k<2;k++)
                                          if(hex[i][j][k]==1)
  printf("==>Unmoved heat exchanger at hot-cold stream is %d-%d at stage %d\n",i+1,j+1,k+1);
/*-----------------------------------------------------------------------------------------*/
/*              2.1.Check where fixed-size heat exchanger moved to?                    */

  for(i=0;i<20;i++)
     for(j=0;j<20;j++)
       for(k=0;k<2;k++)
                                  {  hex[i][j][k]=0;
                                     one[i][j][k]=0;
                                     two[i][j][k]=0;
                                     three[i][j][k]=0;
                                  }
          for(i=0;i<h;i++)
    for(j=0;j<c;j++)
       for(k=0;k<2;k++)
         if(A[i][j][k]>0)
                                   {  v=0;
          for(a=0;a<h;a++)
            for(b=0;b<c;b++)
              for(d=0;d<2;d++)
                                       if(A[i][j][k]==Aret[a][b][d])
                                                      {  v++;
                                                       one[i][j][k]=a;
                                                             two[i][j][k]=b;
                three[i][j][k]=d;
                                                      }
                                     if(v==1)
                                        hex[i][j][k]=1;
                                   }
  sum=0;
  for(i=0;i<h;i++)
     for(j=0;j<c;j++)
       for(k=0;k<2;k++)
                                          sum=sum+hex[i][j][k];
          if(sum>0)
          {  s++;
     printf("\n\n%d.There are %d heat exchanger to move",s,sum);
          }
  for(i=0;i<h;i++)
     for(j=0;j<c;j++)
       for(k=0;k<2;k++)
         if(hex[i][j][k]==1)
                                          {printf("\n==>Existing fix-sized heat exchanger at %d-%d at stage
%d moves to %d-%d at stage %d  in retrofit\n",i+1,j+1,k+1,one[i][j][k]+1,two[i][j][k]+1,three[i][j][k]+1);
         A[i][j][k]=0;
                                           q[i][j][k]=0;
                                           Aret[one[i][j][k]][two[i][j][k]][three[i][j][k]]=0;
                                           qret[one[i][j][k]][two[i][j][k]][three[i][j][k]]=0;
                                          }
/*-----------------------------------------------------------------------------------------*/
/*              2.2.Check where fixed-size heat exchanger moved to?(version2)          */
           for(i=0;i<20;i++)
     for(j=0;j<20;j++)
       for(k=0;k<2;k++)
                                  {   hex[i][j][k]=0;
                                     for(p=0;p<5;p++)
                                          {
                                                      yy[i][j][k]=0;
                                       oone[i][j][k][p]=0;
                                       ttwo[i][j][k[[p]=0;
                                       tthree[i][j][k][p]=0;
```

```
}
}
sum=0;
for(i=0;i<h;i++)
for(j=0;j<c;j++)
for(k=0;k<2;k++)
if(A[i][j][k]>0)
{ v=0;
g=0;
for(a=0;a<h;a++)
for(b=0;b<c;b++)
for(d=0;d<2;d++)
if(A[i][j][k]==Aret[a][b][d])
{ v++;
oone[i][j][k][g]=a;
ttwo[i][j][k][g]=b;
tthree[i][j][k][g]=d;
g++;
sum++;
}
if(v>1)
hex[i][j][k]=1;
yy[i][j][k]=g;
}
if(sum>0)
{ s++;
printf("\n\n%d.More Existing heat exchanger is moved\n",s);
}
for(i=0;i<h;i++)
for(j=0;j<c;j++)
for(k=0;k<2;k++)
if(hex[i][j][k]==1)
{ a=oone[i][j][k][0];
b=ttwo[i][j][k][0];
d=tthree[i][j][k][0];
p=1;
while(p<yy[i][j][k])
{
if(abs((int)(q[i][j][k]-
qret[a][b][d]))>abs((int)(q[i][j][k]-qret[oone[i][j][k][p]][ttwo[i][j][k][p]][tthree[i][j][k][p]])))
{
a=oone[i][j][k][p];
b=ttwo[i][j][k][p];
d=tthree[i][j][k][p];
}
p++;
}
printf("==>Heat Exchanger at %d-%d at stage %d's moved to %d-%d at stage %d in retro-
fit\n",i+1,j+1,k+1,a+1,b+1,d+1);
A[i][j][k]=0;
q[i][j][k]=0;
Aret[a][b][d]=0;
qret[a][b][d]=0;
}
/*---------------------------------------------------------------------------------------------*/
/*          3.Check where unfixed-size heat exchanger moved to?                    */
Sum=0;
g=0;
p=0;
for(i=0;i<h;i++)
for(j=0;j<c;j++)
for(k=0;k<2;k++)
if(A[i][j][k]>0)
{
p++;
g++;
}
if(g>0)
{
s++;
printf("\n\n%d.The unfixed size of heat exchanger\n\n",s);
```

```
            }
          for(g=0;g<p;g++)
            {
            for(i=0;i<20;i++)
    for(j=0;j<20;j++)
    for(k=0;k<2;k++)
            {  vv[i][j][k]=0;
                        one[i][j][k]=0;
              two[i][j][k]=0;
                        three[i][j][k]=0;
            }
    for(i=0;i<h;i++)
    for(j=0;j<c;j++)
    for(k=0;k<2;k++)
            {  sum=1000000;
                        if(A[i][j][k]>0)
                        {
                                    for(a=0;a<h;a++)
        for(b=0;b<c;b++)
        for(d=0;d<2;d++)
        {  if(Aret[a][b][d]>0)
                                                {
                                                if(abs(A[i][j][k]-Aret[a][b][d])<sum)
                                                {
                                                sum=abs(A[i][j][k]-Aret[a][b][d]);
                                                one[i][j][k]=a;
                                                two[i][j][k]=b;
                                                three[i][j][k]=d,
                                                vv[i][j][k]=sum;
                                                }
                                                }
                                    }
                        }

            }
            sum=1000000;
    for(i=0;i<h;i++)
    for(j=0;j<c;j++)
    for(k=0;k<2;k++)
      if(A[i][j][k]>0)
        if(vv[i][j][k]<sum)
                        {
                                    sum=vv[i][j][k];
                          a=i;
                                    b=j;
                                    d=k;
                        }
            if((a==one[a][b][d])&&(b==two[a][b][d])&&(d==three[a][b][d]))
            {
                        printf("==>Heat Exchanger is the same matching at %d-%d stage %d\n\n",a+1,b+1,d+1);
              if(A[a][b][d]>Aret[one[a][b][d]][two[a][b][d]][three[a][b][d]])
      printf("- Remove %0.0lf m2\n\n",A[a][b][d]-Aret[one[a][b][d]][two[a][b][d]][three[a][b][d]]);
              if(Aret[one[a][b][d]][two[a][b][d]][three[a][b][d]]>A[a][b][d])
      printf("+ Add %0.0lf m2\n\n",Aret[one[a][b][d]][two[a][b][d]][three[a][b][d]]-A[a][b][d]);
            }
    else  {
                printf("==>Heat Excganger moved from %d-%d stage %d to %d-%d stage %d in retro-
fit\n",a+1,b+1,d+1,one[a][b][d]+1,two[a][b][d]+1,three[a][b][d]+1);
       if(A[a][b][d]>Aret[one[a][b][d]][two[a][b][d]][three[a][b][d]])
       printf("- Remove %0.0lf m2\n\n",A[a][b][d]-Aret[one[a][b][d]][two[a][b][d]][three[a][b][d]]);
                if(Aret[one[a][b][d]][two[a][b][d]][three[a][b][d]]>A[a][b][d])
       printf("+ Add %0.0lf m2\n\n",Aret[one[a][b][d]][two[a][b][d]][three[a][b][d]]-A[a][b][d]);
            }summ=summ+(invest2*pow(abs(Aret[one[a][b][d]][two[a][b][d]][three[a][b][d]]-
A[a][b][d]).expo2));
            A[a][b][d]=0;
            q[a][b][d]=0;
            Aret[one[a][b][d]][two[a][b][d]][three[a][b][d]]=0;
    qret[one[a][b][d]][two[a][b][d]][three[a][b][d]]=0;
            }
/*----------------------------------------------------------------------------------------------------*/
/*                          4.Finding that new exchanger                          */
```

```
sum=0;
                  for(i=0;i<h;i++)
 for(j=0;j<c;j++)
 for(k=0;k<2;k++)
   if((Aret[i][j][k]>0)&&(A[i][j][k]==0))
        sum++;
if(sum>0)
                  {
                                  s++;
   printf("\n%d.Have a new Exchanger\n",s);
}
for(i=0;i<h;i++)
 for(j=0;j<c;j++)
 for(k=0;k<2;k++)
   if((Aret[i][j][k]>0)&&(A[i][j][k]==0))
                                  {
                                                printf("==>New Exchanger at %d-%d at stage %d\n",i+1,j+1,k+1);

                                                summ=summ+fix+invest1*pow(Aret[i][j][k],expo1);

                                        Aret[i][j][k]=0;
                                                qret[i][j][k]=0;
                                  }
printf("\n*******************************************\n");
             printf("\n==>Area cost of Retrofit==>%lf\n",summ);
                       printf("\n*******************************************\n");
getch();
/*------------------------------------------------------------------------------------------*/
```

Source code of Microsoft C++ in relocation concept 2

```
#include<stdio.h>
#include<conio.h>
#include<math.h>
void main()
{  int i,j,k,n,p,v,s=0,a,b,d,g;
   int h; /* number of hot stream*/
          int c; /* number of cold stream*/
          double z=0.3333;
   char name[50];
          char matching[40][10];
          float U[20][20];
          double dt[20][20][3];
          double dtret[20][20][3];
          double q[20][20][2];
          double qret[20][20][2];
          double sum,summ;
          double vv[20][20][2];
          double A[20][20][2];
          double Aret[20][20][2];
          double  L[20][20][2];
          double  Lret[20][20][2];
          int one[20][20][2],two[20][20][2],three[20][20][2];
          int oone[20][20][2][5],ttwo[20][20][2][5],tthree[20][20][2][5];
          int hex[20][20][2],yy[20][20][2];
          int fix,invest1,invest2;
          float expo1,expo2;
          FILE *fptr;
          fptr = fopen("BASECASE.txt","r");
          if(fptr ==NULL)
  {
                    printf("This basecase file can not be opend.\n");
          }
          else
                    printf("This basecase file is opend.\n");
/*------------------------------------------------------------------------------*/
                    printf("\n\n*****Base Case*****\n\n");
            fscanf(fptr,"%s",name);
                    printf("%s",name);
                    fscanf(fptr,"%d",&h);              /*1.Read number of hot streams*/
                    printf("  %d\n",h);
```

```
fscanf(fptr,"%s",name);
printf("%s",name);
fscanf(fptr,"%d",&c);                /*2.Read number of cold streams*/
printf(" %d\n\n\n",c);
/*------------------------------------------------------------------------------------*/
fscanf(fptr,"%s",name);
printf("%s",name);
fscanf(fptr,"%s",name);
printf("\n%s",name);
fscanf(fptr,"%d",&fix);
printf(" %d\n",fix);
fscanf(fptr,"%s",name);
printf("%s",name);
fscanf(fptr,"%d",&invest1);
printf(" %d\n",invest1);
fscanf(fptr,"%s",name);
printf("%s",name);
fscanf(fptr,"%f",&expo1);
printf(" %0.2f\n",expo1);
/*------------------------------------------------------------------------------------*/
fscanf(fptr,"%s",name);
printf("%s",name);
fscanf(fptr,"%s",name);
printf("\n%s",name);
fscanf(fptr,"%d",&invest2);
printf(" %d\n",invest2);
fscanf(fptr,"%s",name);
printf("%s",name);
fscanf(fptr,"%f",&expo2);
printf(" %0.2f\n",expo2);
/*------------------------------------------------------------------------------------*/
fscanf(fptr,"%s",name);              /*3. Read Ui*/
printf("\n\n\n%s",name);
for(i=0;i<h;i++)
for(j=0;j<c;j++)
        {
        fscanf(fptr,"%s",name);
        printf("\n\n%s\n",name);
fscanf(fptr,"%f",&U[i][j]);
        printf("  %.3f",U[i][j]);
        }
/*------------------------------------------------------------------------------------*/
fscanf(fptr,"%s",name);
printf("\n\n%s\n",name);
fscanf(fptr,"%s",name);
printf("\n        %s",name);
fscanf(fptr,"%s",name);
printf("  %s",name);
fscanf(fptr,"%s",name);
printf("  %s\n",name);
/*------------------------------------------------------------------------------------*/
n=h*c;
p=0;
for(i=0;i<h;i++)
for(j=0;j<c;j++)
        {
        fscanf(fptr,"%s",matching[p]);
        printf("\n%s",matching[p]);
        for(k=0;k<3;k++)
        {
        fscanf(fptr,"%lf",&dt[i][j][k]);
        printf("  %.3lf",dt[i][j][k]);
        }
        p++;
        }
fscanf(fptr,"%s",name);
printf("\n\n\n%s\n",name);
fscanf(fptr,"%s",name);
printf("     %s",name);
fscanf(fptr,"%s",name);
printf("     %s\n",name);
```

```
                    for(i=0;i<h;i++)
    for(j=0;j<c;j++)
                        {
                         fscanf(fptr,"%s",name);
                         printf("\n%s",name);
                         for(k=0;k<2;k++)
                         {
                         fscanf(fptr,"%lf",&q[i][j][k]);
                         printf("  %.3lf",q[i][j][k]);
                         }
                        }
            fclose(fptr);
/*-------------------------------------------------------------------------------------------*/
            fptr = fopen("RETROFIT.txt","r");
            if(fptr ==NULL)
  {
                    printf("\n\n\nThis retrofit file can not be opend.\n");
            }
            else
                    printf("\n\n\nThis retrofit file is opend.\n");
/*-------------------------------------------------------------------------------------------*/
            printf("\n\n*****Retrofit Case*****\n\n");
                    fscanf(fptr,"%s",name);
                    printf("\n\n%s\n",name);

              fscanf(fptr,"%s",name);
                    printf("\n          %s",name);
              fscanf(fptr,"%s",name);
                    printf("  %s",name);
                    fscanf(fptr,"%s",name);
                    printf("  %s\n",name);
                    for(i=0;i<h;i++)
    for(j=0;j<c;j++)
                        {
                         fscanf(fptr,"%s",name);
                         printf("\n%s",name);
                         for(k=0;k<3;k++)
                         {
                         fscanf(fptr,"%lf",&dtret[i][j][k]);
                         printf("  %.3lf",dtret[i][j][k]);
                         }
                        }
              fscanf(fptr,"%s",name);
                    printf("\n\n\n%s\n",name);
              fscanf(fptr,"%s",name);
                    printf("      %s",name);
                    fscanf(fptr,"%s",name);
                    printf("      %s\n",name);
                    for(i=0;i<h;i++)
    for(j=0;j<c;j++)
                        {
                         fscanf(fptr,"%s",name);
                         printf("\n%s",name);
                         for(k=0;k<2;k++)
                         {
                         fscanf(fptr,"%lf",&qret[i][j][k]);
                         printf("  %.3lf",qret[i][j][k]);
                         }
                        }
            fclose(fptr);
/*-------------------------------------------------------------------------------------------*/
   for(i=0;i<h;i++)
   for(j=0;j<c;j++)
            {
            L[i][j][0] = pow(((dt[i][j][0]+dt[i][j][1])*(dt[i][j][0]*dt[i][j][1])*0.5),z);
   L[i][j][1] = pow(((dt[i][j][1]+dt[i][j][2])*(dt[i][j][1]*dt[i][j][2])*0.5),z);
            Lret[i][j][0] = pow(((dtret[i][j][0]+dtret[i][j][1])*(dtret[i][j][0]*dtret[i][j][1])*0.5),z);
            Lret[i][j][1] = pow(((dtret[i][j][1]+dtret[i][j][2])*(dtret[i][j][1]*dtret[i][j][2])*0.5),z);
            }
            printf("\n\n");
            for(i=0;i<h;i++)
```

```
for(j=0;j<c;j++)
        {
A[i][j][0] =    q[i][j][0]/(L[i][j][0]*U[i][j]);
        A[i][j][1] =    q[i][j][1]/(L[i][j][1]*U[i][j]);
        if(A[i][j][0]<0)
A[i][j][0]=0;
        if(A[i][j][1]<0)
A[i][j][1]=0;
        Aret[i][j][0] =  qret[i][j][0]/(Lret[i][j][0]*U[i][j]);
        Aret[i][j][1] =  qret[i][j][1]/(Lret[i][j][1]*U[i][j]);
        if(Aret[i][j][0]<0)
Aret[i][j][0]=0;
        if(Aret[i][j][1]<0)
Aret[i][j][1]=0;
        }
Aret[3][2][0] = 909;
        printf("\n\n*****Existing Heat Exchanger Area*****\n\n");
        printf("\n\n        K1      K2\n\n");
        p=0;
for(i=0;i<h;i++)
for(j=0;j<c;j++)
        {
                printf("%s   ",matching[p]);
                printf("%0.0lf   %0.0lf\n",A[i][j][0],A[i][j][1]);
                p++;
        }
printf("\n\n*****Retrofit Heat Exchanger Area*****\n\n");
        printf("\n\n        K1      K2\n\n");
        p=0;
        for(i=0;i<h;i++)
for(j=0;j<c;j++)
        {
                printf("%s   ",matching[p]);
                printf("%0.0lf   %0.0lf\n",Aret[i][j][0],Aret[i][j][1]);
          p++;
        }
printf("\n******************************************\n");
        sum=0;
for(i=0;i<h;i++)
for(j=0;j<c;j++)
for(k=0;k<2;k++)
                if(Aret[i][j][k]>0)
            sum=sum+fix+(invest1*pow(Aret[i][j][k],expo1));
                        printf("\n==>Area cost of Grassroot==>%lf\n",sum);
        printf("\n******************************************\n");
/*----------------------------------------------------------------------------*/
/*      1 Finding that heat exchanger is the same matching in retrofit        */
 for(i=0;i<20;i++)
   for(j=0;j<20;j++)
     for(k=0;k<2;k++)
                        hex[i][j][k]=0;
 v=0;
        for(i=0;i<h;i++)
   for(j=0;j<c;j++)
     for(k=0;k<2;k++)
      if((A[i][j][k]==Aret[i][j][k])&&(A[i][j][k]>0))
                        {  v++;
                          A[i][j][k]=0;
                                Aret[i][j][k]=0;
                                q[i][j][k]=0;
                                qret[i][j][k]=0;
                          hex[i][j][k]=1;
                        }
if(v>0)
        {s++;
        printf("\n\n%d.Unmoved and fix-sized Heat Exchanger\n",s);
        printf("==>There area %d heat exchanger are not moved\n",v);
        }
        for(i=0;i<h;i++)
   for(j=0;j<c;j++)
     for(k=0;k<2;k++)
```

```
if(hex[i][j][k]==1)
printf("==>Unmoved heat exchanger at hot-cold stream is %d-%d at stage %d\n",i+1,j+1,k+1);
/*------------------------------------------------------------------------------------------*/
/*              2.1 Check where fixed-size heat exchanger moved to?                         */

for(i=0;i<20;i++)
   for(j=0;j<20;j++)
     for(k=0;k<2;k++)
                         { hex[i][j][k]=0;
                           one[i][j][k]=0;
                           two[i][j][k]=0;
                           three[i][j][k]=0;
                         }
        for(i=0;i<h;i++)
   for(j=0;j<c;j++)
     for(k=0;k<2;k++)
       if(A[i][j][k]>0)
                         { v=0;
        for(a=0;a<h;a++)
          for(b=0;b<c;b++)
            for(d=0;d<2;d++)
                              if(A[i][j][k]==Aret[a][b][d])
                                         { v++;
                                           one[i][j][k]=a;
                                                   two[i][j][k]=b;
            three[i][j][k]=d;
                                         }

                           if(v==1)
                             hex[i][j][k]=1;
                         }
sum=0;
for(i=0;i<h;i++)
   for(j=0;j<c;j++)
     for(k=0;k<2;k++)
                              sum=sum+hex[i][j][k];
        if(sum>0)
        { s++;
   printf("\n\n%d.There are %d heat exchanger to move",s,sum);
        }
for(i=0;i<h;i++)
   for(j=0;j<c;j++)
     for(k=0;k<2;k++)
       if(hex[i][j][k]==1)
                              {printf("\n==>Existing fix-sized heat exchanger at %d-%d at stage
%d moves to %d-%d at stage %d  in retrofit\n",i+1,j+1,k+1,one[i][j][k]+1,two[i][j][k]+1,three[i][j][k]+1);
       A[i][j][k]=0;
                               q[i][j][k]=0;
                               Aret[one[i][j][k]][two[i][j][k]][three[i][j][k]]=0;
                               qret[one[i][j][k]][two[i][j][k]][three[i][j][k]]=0;
                              }
/*------------------------------------------------------------------------------------------*/
/*              2.2.Check where fixed-size heat exchanger moved to?(version2)               */
              for(i=0;i<20;i++)
   for(j=0;j<20;j++)
     for(k=0;k<2;k++)
                         {  hex[i][j][k]=0;
                            for(p=0;p<5;p++)
                                  {
                                           yy[i][j][k]=0;
                             oone[i][j][k][p]=0;
                             ttwo[i][j][k][p]=0;
                             tthree[i][j][k][p]=0;
                                  }
                         }
   sum=0;
              for(i=0;i<h;i++)
   for(j=0;j<c;j++)
     for(k=0;k<2;k++)
                         if(A[i][j][k]>0)
                         { v=0;
```

```
g=0;
for(a=0;a<h;a++)
for(b=0;b<c;b++)
for(d=0;d<2;d++)
if(A[i][j][k]==Aret[a][b][d])
{ v++;
oone[i][j][k][g]=a;
ttwo[i][j][k][g]=b;
tthree[i][j][k][g]=d;
g++;
sum++;
}
if(v>1)
hex[i][j][k]=1;
yy[i][j][k]=g;
}
if(sum>0)
{ s++;
printf("\n\n%d More Existing heat exchanger is moved\n",s);
}
for(i=0;i<h;i++)
for(j=0;j<c;j++)
for(k=0;k<2;k++)
if(hex[i][j][k]==1)
{ a=oone[i][j][k][0];
b=ttwo[i][j][k][0];
d=tthree[i][j][k][0];
p=1;
while(p<yy[i][j][k])
{
if(abs((int)(q[i][j][k]-
qret[a][b][d]))>abs((int)(q[i][j][k]-qret[oone[i][j][k][p]][ttwo[i][j][k][p]][tthree[i][j][k][p]])))
{
a=oone[i][j][k][p];
b=ttwo[i][j][k][p];
d=tthree[i][j][k][p];
}
p++;
}
printf("==>Heat Exchanger at %d-%d at stage %d's moved to %d-%d at stage %d in retro-
fit\n",i+1,j+1,k+1,a+1,b+1,d+1);
A[i][j][k]=0;
q[i][j][k]=0;
Aret[a][b][d]=0;
qret[a][b][d]=0;
}
/*----------------------------------------------------------------------------------------------------*/
/*            3.Check additional or removal fixed heat exchanger?                    */
sum=0;
for(i=0;i<h;i++)
for(j=0;j<c;j++)
for(k=0;k<2;k++)
if((A[i][j][k]>0)&&(Aret[i][j][k]>0))
sum++;
if(sum>0)
{ s++;
printf("\n%d.Additional or Removal fixed Heat Exchanger Area\n",s);
}
summ=0;
for(i=0;i<h;i++)
for(j=0;j<c;j++)
for(k=0;k<2;k++)
if((A[i][j][k]>0)&&(Aret[i][j][k]>0))
{
summ=summ+(invest2*pow(abs(A[i][j][k]-Aret[i][j][k]),expo2));

if(A[i][j][k]>Aret[i][j][k])
printf("\n==>Remove Heat exchanger Area at %d-%d stage
%d==>%0.0lf\n",i+1,j+1,k+1,(A[i][j][k]-Aret[i][j][k]));
if(A[i][j][k]<Aret[i][j][k])
```

```
                                        printf("\n==>Add Heat exchanger Area at %d-%d stage
%d==>%0.0lf\n",i+1,j+1,k+1,(Aret[i][j][k]-A[i][j][k]));
                                                A[i][j][k]=0;
                                                q[i][j][k]=0;
                                                Aret[i][j][k]=0;
                                                qret[i][j][k]=0;                    }
/*---------------------------------------------------------------------------------------------*/
/*            4.Check where unfixed-size heat exchanger moved to?                       */
            g=0;
            p=0;
            for(i=0;i<h;i++)
    for(j=0;j<c;j++)
    for(k=0;k<2;k++)
                    if(A[i][j][k]>0)
                    {
                                p++;
                      g++;
                    }
    if(g>0)
            {
                    s++;
      printf("\n\n%d.The unfixed size of heat exchanger\n\n",s);
            }
            for(g=0;g<p;g++)
            {
              for(i=0;i<20;i++)
    for(j=0;j<20;j++)
    for(k=0;k<2;k++)
            {  vv[i][j][k]=0;
                    one[i][j][k]=0;
              two[i][j][k]=0;
                    three[i][j][k]=0;
            }



    for(i=0;i<h;i++)
    for(j=0;j<c;j++)
    for(k=0;k<2;k++)
            {  sum=1000000;
                    if(A[i][j][k]>0)
                    {
                                for(a=0;a<h;a++)
        for(b=0;b<c;b++)
        for(d=0;d<2;d++)
        {  if(Aret[a][b][d]>0)
                                                {
                                                if(abs(A[i][j][k]-Aret[a][b][d])<sum)
                                                {
                                                sum=abs(A[i][j][k]-Aret[a][b][d]);
                                                one[i][j][k]=a;
                                                two[i][j][k]=b;
                                                three[i][j][k]=d;
                                                vv[i][j][k]=sum;
                                                }}}}}
            sum=1000000;
    for(i=0;i<h;i++)
    for(j=0;j<c;j++)
    for(k=0;k<2;k++)
      if(A[i][j][k]>0)
        if(vv[i][j][k]<sum)
                    {
                                sum=vv[i][j][k];
                      a=i;
                                b=j;
                                d=k;
                    }
            if((a==one[a][b][d])&&(b==two[a][b][d])&&(d==three[a][b][d]))
            {
                    printf("==>Heat Exchanger is the same matching at %d-%d stage %d\n\n",a+1,b+1,d+1);
             if(A[a][b][d]>Aret[one[a][b][d]][two[a][b][d]][three[a][b][d]])
```

```
printf("- Remove %0.0lf m2\n\n",A[a][b][d]-Aret[one[a][b][d]][two[a][b][d]][three[a][b][d]]);
        if(Aret[one[a][b][d]][two[a][b][d]][three[a][b][d]]>A[a][b][d])
printf("+ Add %0.0lf m2\n\n",Aret[one[a][b][d]][two[a][b][d]][three[a][b][d]]-A[a][b][d]);
        }               else    {
        printf("==>Heat Excganger moved from %d-%d stage %d to %d-%d stage %d in retro-
fit\n",a+1,b+1,d+1,one[a][b][d]+1,two[a][b][d]+1,three[a][b][d]+1);
    if(A[a][b][d]>Aret[one[a][b][d]][two[a][b][d]][three[a][b][d]])
    printf("- Remove %0.0lf m2\n\n",A[a][b][d]-Aret[one[a][b][d]][two[a][b][d]][three[a][b][d]]);
        if(Aret[one[a][b][d]][two[a][b][d]][three[a][b][d]]>A[a][b][d])
    printf("+ Add %0.0lf m2\n\n",Aret[one[a][b][d]][two[a][b][d]][three[a][b][d]]-A[a][b][d]);
        }
        summ=summ+(invest2*pow(abs(Aret[one[a][b][d]][two[a][b][d]][three[a][b][d]]-A[a][b][d]),expo2));
        A[a][b][d]=0;
        q[a][b][d]=0;
        Aret[one[a][b][d]][two[a][b][d]][three[a][b][d]]=0;
  qret[one[a][b][d]][two[a][b][d]][three[a][b][d]]=0;}
/*------------------------------------------------------------------------------------------*/
/*                      5.Finding that new exchanger                        */
    sum=0;
                for(i=0;i<h;i++)
     for(j=0;j<c;j++)
      for(k=0;k<2;k++)
       if((Aret[i][j][k]>0)&&(A[i][j][k]==0))
           sum++;
    if(sum>0)
                {
                            s++;
       printf("\n%d.Have a new Exchanger\n",s);
    }
    for(i=0;i<h;i++)
     for(j=0;j<c;j++)
      for(k=0;k<2;k++)
       if((Aret[i][j][k]>0)&&(A[i][j][k]==0))
                    {
                            printf("==>New Exchanger at %d-%d at stage %d\n",i+1,j+1,k+1);

                            summ=summ+fix+invest1*pow(Aret[i][j][k],expo1);
                        Aret[i][j][k]=0;
                            qret[i][j][k]=0;
                    }
                    printf("\n******************************************\n");
            printf("\n==>Area cost of Retrofit==>%lf\n",summ);
                printf("\n******************************************\n");
                    getch();
/*------------------------------------------------------------------------------------------*/
```

Example1

life time | 3 | *year*

Basecase	*Utility*	*Cost of u*	*cost*
hot u.	11,275.00	120	1,353,000.00
cold u.	9,267.00	20	185,340.00

				Investment		*Profit($)=saving-investment*	
Qh	*Qc*	*Qh saving*life time*	*Qc saving*life time*	*1.minmove cost*	*2.mix and match cost*	*minmove*	*mix and match*
6884.92	4877.32	1,580,428.80	263,380.80	825,172.72	941,194.22	1,018,636.88	902,615.38
7500	5492.4	1,359,000.00	226,476.00	660,186.84	720,337.29	925,289.16	865,138.71
7800	5792.4	1,251,000.00	208,476.00	641,182.71	722,835.95	818,293.29	736,640.05
8300	6292.4	1,071,000.00	178,476.00	531,195.25	568,955.65	718,280.75	680,520.35
8800	6792.4	891,000.00	148,476.00	518,529.00	580,667.83	520,947.00	458,808.17
9900	7892.4	495,000.00	82,476.00	183,481.66	189,731.70	393,994.34	387,744.30
10000	7992.4	459,000.00	76,476.00	211,391.17	255,700.90	324,084.83	279,775.10
11275	9267	-	-	-	-	-	-

Relocation in Concept 1: Profit at 6,884.92 in hot utility = 1,580,428.80 + 263,380.80 – 825,172.72 = 1,018,636.88

Relocation in Concept 2: Profit at 6,884.92 in hot utility = 1,580,428.80 + 263,380.80 – 941,192.22 = 902,615.38

ต้นฉบับ หน้าขาดหาย