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APPENDICES

Appendix A Keyword Input File for Gas Separation Plant I Simulation.

Input Summary created by Aspen Plus Rel. 11.1 at 11:32:08 Fri Jan 24, 2003

DYNAPLUS DPLUS RESULTS=ON

Unit of Measurements

IN-UNITS SI MASS-FLOW='gm/sec' MOLE-FLOW='mol/sec' PRESSURE=barg &
DELTA-T=DELTA-K PDROP-PER-HT='mbar/m' PDROP=bar

DESCRIPTION "

Gas Processing with Metric Units:

C, bar, tonne/hr, MMscmh, MMkcal/hr, cum/hr.

Simulation Property method

Property Method: PENG-ROB

Flow basis for input: Mole

Stream report composition: Mole flow

DATABANKS PURE11 / AQUEOUS / SOLIDS / INORGANIC / &
NOASPENPCD

PROP-SOURCES PURE11 / AQUEOUS / SOLIDS / INORGANIC

Simulation Component definition

COMPONENTS

NITRO-01 N2 / METHA-01 CH4 / ETHAN-01 C2H6 / PROPA-01 C3H8 /
ISOBU-01 C4H10-2 / N-BUT-01 C4H10-1 / 2-MET-01 C5H12-2 /
N-PEN-01 C5H12-1 / N-HEX-01 C6H14-1 / N-HEP-01 C7H16-1 /
N-OCT-01 C8H18-1 / N-NON-01 C9H20-1 / N-DEC-01 C10H22-1 /
CARBO-01 CO2 / PROPY-01 C3H6-2

Flowsheet Connectivity

```
FLOWSHEET
   BLOCK D70301 IN=S70201-1 OUT=S70301 S70302
   BLOCK D70302 IN=S70301-2 OUT=S70303 S70304
   BLOCK D70303 IN=S70303-1 OUT=S70305 S70306
   BLOCK X70301 IN=S70305 OUT=S70307
   BLOCK V301 IN=S70306 OUT=S70326
   BLOCK T70301-A IN=S70307 S70326 S70313V OUT=S70308 S70312
   BLOCK V302 IN=S70304 OUT=S70325
   BLOCK P70305 IN=S70312 OUT=S70312-1
   BLOCK T70301-B IN=S70325 S70313 S70315V OUT=S70313V  &
      S70314
   BLOCK P70304 IN=S70314 OUT=S70314-1
   BLOCK E302 IN=S70303 S70312-1 S70314-1 S70308 OUT= &
      S70303-1 S70313 S70315 S70309
   BLOCK T70301-C IN=S70315 S70324 S70317V OUT=S70315V  &
      S70316
   BLOCK V303 IN=S70302 OUT=S70324
   BLOCK P70303 IN=S70316 OUT=S70316-1
   BLOCK T70301-D IN=S70317 S70320V OUT=S70317V S70318
   BLOCK P70302 IN=S70318 OUT=S70318-1
   BLOCK E70303 IN=S70605 S70319 OUT=S70606 S70320
   BLOCK T70301-E IN=S70320 OUT=S70320V S70321
   BLOCK P70301 IN=S70321 OUT=S70322
   BLOCK E301 IN=S70201 S70301 S70309 S70316-1 S70318-1  &
      S70322 S70327 OUT=S70201-1 S70301-1 S70317 S70310  &
      S70319 S70323 S70328
   BLOCK SP301 IN=S70323 OUT=S70323-1 S70422
   BLOCK E70407A IN=S70417 S70323-2 OUT=S70417-1 S70419
   BLOCK E70407B IN=S70417-1 S70323-1 OUT=S70418 S70323-2
```

BLOCK M301 IN=S70419 S70422-1 OUT=S70423

BLOCK E70408 IN=S70607 S70423 OUT=S70608 S70401

BLOCK T70401 IN=S70401 OUT=S70404 S70406

BLOCK V401 IN=S70404 OUT=S70327

BLOCK V70406 IN=S70406 OUT=S70407

BLOCK E70404B IN=S70602-1 S70407 OUT=S70603 S70407-1

BLOCK E70404A IN=S70602 S70407-1 OUT=S70602-1 S70408

BLOCK T70402 IN=S70408 S70420-1 OUT=S70409 S70416 S70414

BLOCK E70405 IN=S70409 OUT=S70409-1

BLOCK D70402 IN=S70409-1 OUT=S70410 S70411

BLOCK P70402 IN=S70411 OUT=S70411-1

BLOCK E406 IN=S70422 S70411-1 S70414 REF-IN OUT=S70422-1 &
S70411-2 S70415 REF-OUT

BLOCK SP402 IN=S70411-2 OUT=S70420 S70413

BLOCK V402 IN=S70420 OUT=S70420-1

BLOCK E70409 IN=S70416 OUT=S70417

BLOCK C70301 IN=S70310 OUT=S70311

BLOCK SP302 IN=S70311 OUT=PURGE S70601

BLOCK C70601 IN=S70601 OUT=S70602

BLOCK SP601 IN=S70603 OUT=S70603-1 S70605

BLOCK SP602 IN=S70603-1 OUT=S70603-2 S70607

BLOCK E70601 IN=S70603-2 OUT=S7060321

BLOCK M601 IN=S70606 S70608 OUT=S70608-1

BLOCK M602 IN=S70608-1 S7060321 OUT=S70604

BLOCK E70304 IN=S70301-1 OUT=S70301-2

Input Streams Descriptions

STREAM REF-IN

SUBSTREAM MIXED TEMP=313. PRES=19. MASS-FLOW=102069. <kg/hr>

MOLE-FRAC PROPY-01 1.

STREAM S70201

SUBSTREAM MIXED TEMP=295.5 PRES=43.4

MOLE-FLOW NITRO-01 66.43095 / METHA-01 3255.43027 / ETHAN-01 437.02205 / PROPA-01 233.99101 / ISOBU-01 52.7373 / N-BUT-01 45.90291 / 2-MET-01 12.53645 / N-PEN-01 7.05201 / N-HEX-01 3.47257 / N-HEP-01 & 1.47536 / N-OCT-01 0.49187 / N-NON-01 0.16196 / N-DEC-01 0.06433 / CARBO-01 29.06239 / PROPY-01 0.

Unit Operation Blocks

Mixers

BLOCK M301 MIXER

BLOCK M601 MIXER

BLOCK M602 MIXER

Splitter

BLOCK SP301 FSPLIT

FRAC S70422 0.96

BLOCK SP302 FSPLIT

MOLE-FLOW S70601 3378.378

BLOCK SP402 FSPLIT

FRAC S70413 0.251

BLOCK SP601 FSPLIT

MOLE-FLOW S70605 85.

BLOCK SP602 FSPLIT

MOLE-FLOW S70607 39.1435

Heat Exchangers (Coolers)

BLOCK E70304 HEATER

PARAM PRES=42.9 DUTY=-2420000.

BLOCK E70405 HEATER

PARAM TEMP=317.982 PRES=16.2

BLOCK E70409 HEATER

PARAM TEMP=323.15 PRES=16.3

BLOCK E70601 HEATER

PARAM PRES=44.6 DUTY=-8450000.

Flash drums

BLOCK D70301 FLASH2

PARAM PRES=43.1 VFRAC=0.923047624

BLOCK D70302 FLASH2

PARAM PRES=42.9 VFRAC=0.922744339

BLOCK D70303 FLASH2

PARAM PRES=42.7 VFRAC=0.772579962

BLOCK D70402 FLASH2

PARAM TEMP=319.982 PRES=16.2

BLOCK T70301-E FLASH2

PARAM TEMP=274.3 PRES=15.

Heat Exchangers

BLOCK E70303 HEATX

PARAM T-HOT=282.858 CALC-TYPE=RATING AREA=76.1 P-UPDATE=YES &U-OPTION=FILM-COEF F-OPTION=GEOMETRY CALC-METHOD=DETAILED

FEEDS HOT=S70605 COLD=S70319

PRODUCTS HOT=S70606 COLD=S70320

EQUIP-SPECS TUBE-NPASS=2 SHELL-DIAM=700. <mm>

TUBES TOTAL-NUMBER=94 PATTERN=SQUARE LENGTH=5000. <mm> &

OUTSIDE-DIAM=25.4 <mm> PITCH=32. <mm> WALL-THICK=2.77 <mm>

NOZZLES SNOZ-INDIAM=16. <in> SNOZ-OUTDIAM=16. <in> &

TNOZ-INDIAM=10. <in> TNOZ-OUTDIAM=10. <in>

SEGB-SHELL NBAFFLE=11 NSEAL-STRIP=0 BAFFLE-CUT=0.25 &

SHELL-BFL-SP=1E-010 TUBE-BFL-SP=1E-010 MID-BFL-SP=430. <mm> &

```
      IN-BFL-SP=430. <mm>
   HOT-SIDE H-OPTION=GEOMETRY SHELL-TUBE=TUBE DP-
OPTION=GEOMETRY
   COLD-SIDE H-OPTION=GEOMETRY DP-OPTION=GEOMETRY
BLOCK E70404A HEATX
   PARAM T-COLD=362.418 CALC-TYPE=RATING AREA=267.  &
      PRES-COLD=16.5 U-OPTION=FILM-COEF F-OPTION=GEOMETRY  &
      CALC-METHOD=DETAILED
   FEEDS HOT=S70602 COLD=S70407-1
   PRODUCTS HOT=S70602-1 COLD=S70408
   EQUIP-SPECS TUBE-NPASS=2 TEMA-TYPE=J SHELL-DIAM=1.05
   TUBES TOTAL-NUMBER=326 LENGTH=5. OUTSIDE-DIAM=25.4 <mm>  &
      PITCH=32. <mm> WALL-THICK=2.77 <mm>
   SEGB-SHELL NBAFFLE=8 BAFFLE-CUT=0.45 MID-BFL-SP=600. <mm>
   HOT-SIDE H-OPTION=GEOMETRY FOUL-FACTOR=0.00018  &
      SHELL-TUBE=SHELL DP-OPTION=GEOMETRY
   COLD-SIDE H-OPTION=GEOMETRY FOUL-FACTOR=0.00018  &
      DP-OPTION=CONSTANT
BLOCK E70404B HEATX
   PARAM DUTY=2318481.667 CALC-TYPE=RATING AREA=267.  &
      P-UPDATE=YES U-OPTION=FILM-COEF F-OPTION=GEOMETRY  &
      CALC-METHOD=DETAILED
   FEEDS HOT=S70602-1 COLD=S70407
   PRODUCTS HOT=S70603 COLD=S70407-1
   EQUIP-SPECS TUBE-NPASS=2 TEMA-TYPE=J SHELL-DIAM=1.05
   TUBES TOTAL-NUMBER=326 LENGTH=5. OUTSIDE-DIAM=25.4 <mm>  &
      PITCH=32. <mm> WALL-THICK=2.77 <mm>
   NOZZLES SNOZ-INDIAM=24. <in> SNOZ-OUTDIAM=18. <in>  &
      TNOZ-INDIAM=8. <in> TNOZ-OUTDIAM=12. <in>
   SEGB-SHELL NBAFFLE=8 BAFFLE-CUT=0.45 MID-BFL-SP=600. <mm>
   HOT-SIDE H-OPTION=GEOMETRY FOUL-FACTOR=0.00018  &
      SHELL-TUBE=SHELL DP-OPTION=GEOMETRY
```

```
   COLD-SIDE H-OPTION=GEOMETRY FOUL-FACTOR=0.00018  &
     DP-OPTION=GEOMETRY
BLOCK E70407A HEATX
   PARAM DUTY=43164.379 CALC-TYPE=RATING P-UPDATE=YES U-
OPTION= & FILM-COEF F-OPTION=GEOMETRY CALC-
METHOD=DETAILED
   FEEDS HOT=S70417 COLD=S70323-2
   PRODUCTS HOT=S70417-1 COLD=S70419
   EQUIP-SPECS SHELL-DIAM=1.05
   TUBES TOTAL-NUMBER=624 LENGTH=6. OUTSIDE-DIAM=25.4 <mm>  &
     PITCH=32. <mm> WALL-THICK=2.77 <mm>
   NOZZLES SNOZ-INDIAM=16. <in> SNOZ-OUTDIAM=16. <in>  &
     TNOZ-INDIAM=10. <in> TNOZ-OUTDIAM=10. <in>
   SEGB-SHELL NBAFFLE=27 BAFFLE-CUT=0.25 MID-BFL-SP=0.221
   HOT-SIDE H-OPTION=GEOMETRY FOUL-FACTOR=0.00018  &
     SHELL-TUBE=TUBE DP-OPTION=GEOMETRY
   COLD-SIDE H-OPTION=GEOMETRY FOUL-FACTOR=0.00018  &
     DP-OPTION=GEOMETRY
BLOCK E70407B HEATX
   PARAM T-HOT=300. CALC-TYPE=RATING P-UPDATE=YES U-OPTION= &
     FILM-COEF F-OPTION=GEOMETRY CALC-METHOD=DETAILED
   FEEDS HOT=S70417-1 COLD=S70323-1
   PRODUCTS HOT=S70418 COLD=S70323-2
   EQUIP-SPECS SHELL-DIAM=1.05
   TUBES TOTAL-NUMBER=624 LENGTH=6. OUTSIDE-DIAM=25.4 <mm>  &
     PITCH=32. <mm> WALL-THICK=2.77 <mm>
   NOZZLES SNOZ-INDIAM=16. <in> SNOZ-OUTDIAM=16. <in>  &
     TNOZ-INDIAM=10. <in> TNOZ-OUTDIAM=10. <in>
   SEGB-SHELL NBAFFLE=27 BAFFLE-CUT=0.25 MID-BFL-SP=0.221
   HOT-SIDE H-OPTION=GEOMETRY FOUL-FACTOR=0.00018  &
     SHELL-TUBE=TUBE DP-OPTION=GEOMETRY
   COLD-SIDE H-OPTION=GEOMETRY FOUL-FACTOR=0.00018  &
```

DP-OPTION=GEOMETRY

BLOCK E70408 HEATX

PARAM T-HOT=328.15 CALC-TYPE=RATING AREA=145. PRES-COLD=28. &

U-OPTION=FILM-COEF F-OPTION=GEOMETRY CALC-METHOD=DETAILED

FEEDS HOT=S70607 COLD=S70423

PRODUCTS HOT=S70608 COLD=S70401

EQUIP-SPECS SHELL-DIAM=0.6

TUBES TOTAL-NUMBER=418 LENGTH=6000. <mm> &

OUTSIDE-DIAM=19.05 <mm> PITCH=25. <mm> WALL-THICK=2.11 <mm>

SEGB-SHELL NBAFFLE=13 BAFFLE-CUT=0.45 MID-BFL-SP=448. <mm>

HOT-SIDE H-OPTION=GEOMETRY SHELL-TUBE=SHELL &

DP-OPTION=GEOMETRY

COLD-SIDE H-OPTION=GEOMETRY DP-OPTION=CONSTANT

Multi-stream Heat Exchangers (Cold Boxes)

BLOCK E301 MHEATX

HOT-SIDE IN=S70201 OUT=S70201-1 TEMP=255.45 PRES=43.1 &

FREE-WATER=NO

HOT-SIDE IN=S70301 OUT=S70301-1 TEMP=240.3 PRES=42.9 &

FREE-WATER=NO

COLD-SIDE IN=S70309 OUT=S70310 TEMP=288.347 PRES=14.3 &

FREE-WATER=NO

COLD-SIDE IN=S70316-1 OUT=S70317 TEMP=259.591 PRES=15. &

FREE-WATER=NO

COLD-SIDE IN=S70318-1 OUT=S70319 TEMP=273.3 PRES=15. &

FREE-WATER=NO

COLD-SIDE IN=S70322 OUT=S70323 TEMP=288.347 PRES=30.1 &

FREE-WATER=NO

COLD-SIDE IN=S70327 OUT=S70328 PRES=10.7 FREE-WATER=NO

BLOCK E302 MHEATX

HOT-SIDE IN=S70303 OUT=S70303-1 PRES=42.7 FREE-WATER=NO

COLD-SIDE IN=S70312-1 OUT=S70313 TEMP=211.914 PRES=15. &
FREE-WATER=NO

COLD-SIDE IN=S70314-1 OUT=S70315 TEMP=229.29 PRES=15. &
FREE-WATER=NO

COLD-SIDE IN=S70308 OUT=S70309 TEMP=229.69 PRES=14.8 &
FREE-WATER=NO

BLOCK E406 MHEATX

COLD-SIDE IN=S70422 OUT=S70422-1 TEMP=315.97 PRES=29.9 &
FREE-WATER=NO

HOT-SIDE IN=S70411-1 OUT=S70411-2 TEMP=301. PRES=16.5 &
FREE-WATER=NO

HOT-SIDE IN=S70414 OUT=S70415 TEMP=302. PRES=16. &
FREE-WATER=NO

HOT-SIDE IN=REF-IN OUT=REF-OUT PRES=18. FREE-WATER=NO

Distillation Columns

Demethanizer Column

BLOCK T70301-A RADFRAC

PARAM NSTAGE=16 EFF=MURPHREE

COL-CONFIG CONDENSER=NONE KEY-SELECT=SPLIT-FRACTI

FEEDS S70307 1 / S70326 7 / S70313V 16

PRODUCTS S70312 16 L / S70308 1 V

P-SPEC 1 15.

COL-SPECS DP-COL=0. MOLE-D=3395.15623

SPEC 1 TEMP 193.116 STAGE=16

VARY 1 MOLE-D 3300. 3700.

REPORT TARGET

STEFF-SEC SECNO=1 1 15 0.667

BLOCK T70301-B RADFRAC

PARAM NSTAGE=6 EFF=MURPHREE

COL-CONFIG CONDENSER=NONE KEY-SELECT=SPLIT-FRACTI

FEEDS S70325 1 / S70313 1 / S70315V 6

PRODUCTS S70313V 1 V / S70314 6 L

P-SPEC 1 15.

COL-SPECS MOLE-D=482.743

SPEC 1 TEMP 221.806 STAGE=6

VARY 1 MOLE-D 400. 600.

REPORT TARGET

STEFF-SEC SECNO=1 1 5 0.8

BLOCK T70301-C RADFRAC

PARAM NSTAGE=10 EFF=MURPHREE

COL-CONFIG CONDENSER=NONE KEY-SELECT=SPLIT-FRACTI

FEEDS S70315 1 / S70324 1 / S70317V 10

PRODUCTS S70315V 1 V / S70316 10 L

P-SPEC 1 15.

COL-SPECS MOLE-D=272.82669

SPEC 1 TEMP 247.297 STAGE=10

VARY 1 MOLE-D 200. 400.

REPORT TARGET

STEFF-SEC SECNO=1 1 9 0.667

BLOCK T70301-D RADFRAC

PARAM NSTAGE=12 EFF=MURPHREE

COL-CONFIG CONDENSER=NONE KEY-SELECT=SPLIT-FRACTI

FEEDS S70317 1 / S70320V 12

PRODUCTS S70317V 1 V / S70318 12 L

P-SPEC 1 15.

COL-SPECS MOLE-D=210.36294

SPEC 1 TEMP 267.193 STAGE=12

VARY 1 MOLE-D 100. 400.

REPORT TARGET

STEFF-SEC SECNO=1 1 11 0.8

Deethanizer column

BLOCK T70401 RADFRAC

```
PARAM NSTAGE=91 EFF=MURPHREE
COL-CONFIG CONDENSER=TOTAL KEY-SELECT=SPLIT-FRACTI
FEEDS S70401 30
PRODUCTS S70404 1 L / S70406 91 L
P-SPEC 1 27.7 / 2 28.
COL-SPECS Q1=-10580000. DP-COL=0.2 MOLE-B=359.78221
SC-REFLUX OPTION=1
SPEC 1 MOLE-FRAC 0.000999 COMPS=ETHAN-01 STREAMS=S70406
VARY 1 MOLE-B 300. 600.
TRAY-REPORT TRAY-OPTION=ALL-TRAYS PROPERTIES=AVAILMX
CRITICAL GASPROPS HXDESIGN TDEW THERMAL TXPORT VLE
REPORT TARGET
STEFF-SEC SECNO=1 2 89 0.697 / SECNO=2 1 1 0.4
```

Depropanizer column

BLOCK T70402 RADFRAC

```
PARAM NSTAGE=81 EFF=MURPHREE
COL-CONFIG CONDENSER=NONE KEY-SELECT=SPLIT-FRACTI
FEEDS S70408 56 / S70420-1 1
PRODUCTS S70409 1 V / S70416 81 L / S70414 41 L  &
   MOLE-FLOW=158.141
P-SPEC 1 16.5
COL-SPECS DP-COL=0.2 MOLE-D=688.525
SPEC 1 TEMP 432.278 STAGE=81
VARY 1 MOLE-D 600. 800.
REPORT TARGET
STEFF-SEC SECNO=1 1 81 0.69135802
```

Pumps

BLOCK P70301 PUMP

```
PARAM DELP=15.4 EFF=0.72
```

BLOCK P70302 PUMP

PARAM DELP=2.04 EFF=0.75

BLOCK P70303 PUMP

PARAM DELP=2.09 EFF=0.75

BLOCK P70304 PUMP

PARAM DELP=2.11 EFF=0.68

BLOCK P70305 PUMP

PARAM DELP=2.09 EFF=0.68

BLOCK P70402 PUMP

PARAM DELP=4.4 EFF=1.

Compressors

BLOCK C70301 COMPR

PARAM TYPE=ISENTROPIC PRES=17.9 SEFF=0.77

BLOCK C70601 COMPR

PARAM TYPE=ISENTROPIC PRES=45.3 SEFF=0.735

Expanders

BLOCK X70301 COMPR

PARAM TYPE=ISENTROPIC PRES=16. SEFF=1. NPHASE=2

BLOCK-OPTION FREE-WATER=NO

Valves

BLOCK V301 VALVE

PARAM P-OUT=15.

BLOCK V302 VALVE

PARAM P-OUT=15.

BLOCK V303 VALVE

PARAM P-OUT=15.

BLOCK V401 VALVE

PARAM P-OUT=11.

BLOCK V402 VALVE

PARAM P-OUT=16.5

BLOCK V70406 VALVE

PARAM P-OUT=16.7

Convergence method and options

EO-CONV-OPTI

CONV-OPTIONS WEGSTEIN MAXIT=200

STREAM-REPOR MOLEFLOW MOLEFRAC PROPERTIES=GASPROPS

CRITICAL HXDESIGN TDEW THERMAL TXPORT VLE AVAILMX ENTROPY

Appendix B Stream Results from Simulation Model.

The results of each stream compose of temperature, pressure, flowrate, composition and selected properties.

The stream results were shown in Table form as shown in Table B1 and the stream name was assigned according to the plant flowsheet as shown in Figure B1.

For feed and product streams, the stream name are assigned as followed:

Stream name of feed stream	=	S70201
Stream name of sale gas product	=	S70604
Stream name of ethane product	=	S70328
Stream name of propane product	=	S70413
Stream name of LPG product	=	S70415
Stream name of natural gasoline product	=	S70418

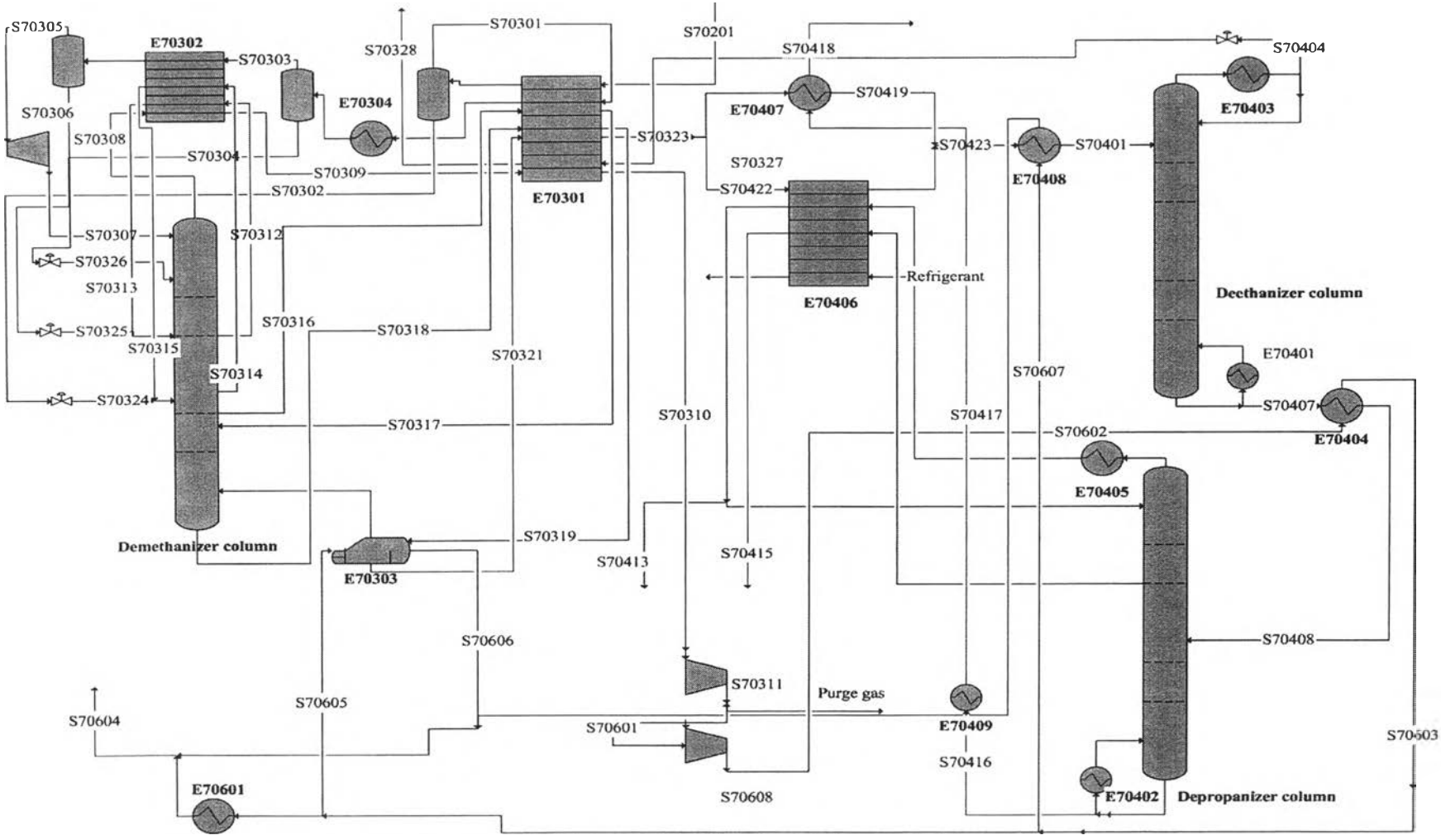

Figure B1 Stream name and location in gas separation plant I.

Table B1 Stream results from simulation

Stream name	S70201	S70301	S70302	S70303	S70304	S70305	S70306	S70307
Temperature (K)	295.500	255.500	255.500	234.400	234.400	206.700	206.700	173.000
Pressure (barg)	43.400	43.100	43.100	42.900	42.900	42.700	42.700	16.000
Vapor fraction	1.000	1.000	0.000	1.000	0.000	1.000	0.000	0.883
Mole flow (mol/s)	4145.831	3826.800	319.032	3531.158	295.642	2728.102	803.056	2728.102
Mass flow (kg/s)	86.505	74.399	12.106	65.181	9.218	47.237	17.945	47.237
Volume flow (m^3/s)	1.926	1.422	0.024	1.134	0.020	0.658	0.046	1.623
Enthalpy (MMkcal/hr)	-290.594	-268.072	-32.560	-246.196	-27.560	-188.955	-65.892	-191.249
Density (gm/cc)	0.045	0.052	0.503	0.057	0.471	0.072	0.389	0.029
Composition								
Nitrogen	0.016	0.017	0.002	0.018	0.003	0.022	0.006	0.022
Methane	0.785	0.826	0.296	0.862	0.398	0.918	0.672	0.918
Ethane	0.105	0.098	0.190	0.086	0.244	0.049	0.213	0.049
Propane	0.056	0.040	0.255	0.023	0.239	0.005	0.084	0.005
iso-butane	0.013	0.006	0.094	0.002	0.054	0.000	0.008	0.000
n-butane	0.011	0.004	0.091	0.001	0.043	0.000	0.005	0.000
iso-pentane	0.003	0.001	0.031	0.000	0.008	0.000	0.000	0.000
n-pentane	0.002	0.000	0.018	0.000	0.004	0.000	0.000	0.000
n-hexane	0.001	0.000	0.010	0.000	0.001	0.000	0.000	0.000
n-heptane	0.000	0.000	0.005	0.000	0.000	0.000	0.000	0.000
n-octane	0.000	0.000	0.002	0.000	0.000	0.000	0.000	0.000
n-nonane	0.000	0.000	0.001	0.000	0.000	0.000	0.000	0.000
n-decane	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
CarbonDioxide	0.007	0.007	0.006	0.007	0.009	0.006	0.011	0.006

(Cont.)

Table B1 (Continued) Stream results from simulation

Stream name	S70308	S70309	S70310	S70311	S70312	S70313	S70314	S70315
Temperature (K)	171.900	229.700	288.300	307.400	193.100	211.900	221.800	229.300
Pressure (barg)	15.000	14.800	14.300	17.900	15.000	15.000	15.000	15.000
Vapor Frac	1.000	1.000	1.000	1.000	0.000	0.227	0.000	0.056
Mole Flow (mol/sec)	3385.559	3385.559	3385.559	3385.559	678.167	678.167	728.530	728.530
Mass Flow (kg/sec)	56.363	56.363	56.363	56.363	19.105	19.105	24.144	24.144
Volume Flow (m3/sec)	2.414	3.760	5.100	4.404	0.037	0.176	0.046	0.086
Enthalpy (MMkcal/hr)	-231.820	-225.228	-218.872	-216.984	-66.108	-64.430	-73.705	-73.067
Density (gm/cc)	0.023	0.015	0.011	0.013	0.512	0.109	0.522	0.280
Composition								
Nitrogen	0.020	0.020	0.020	0.020	0.000	0.000	0.000	0.000
Methane	0.958	0.958	0.958	0.958	0.337	0.337	0.160	0.160
Ethane	0.018	0.018	0.018	0.018	0.479	0.479	0.528	0.528
Propane	0.000	0.000	0.000	0.000	0.128	0.128	0.219	0.219
iso-butane	0.000	0.000	0.000	0.000	0.011	0.011	0.032	0.032
n-butane	0.000	0.000	0.000	0.000	0.006	0.006	0.024	0.024
iso-pentane	0.000	0.000	0.000	0.000	0.000	0.000	0.004	0.004
n-pentane	0.000	0.000	0.000	0.000	0.000	0.000	0.002	0.002
n-hexane	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
n-heptane	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
n-octane	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
n-nonane	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
n-decane	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
CarbonDioxide	0.004	0.004	0.004	0.004	0.039	0.039	0.031	0.031

(Cont.)

Table B1 (Continued) Stream results from simulation

Stream name	S70316	S70317	S70318	S70319	S70321	S70322	S70323	S70324
Temperature (K)	247.300	259.600	267.200	273.300	274.300	276.000	288.300	239.600
Pressure (barg)	15.000	15.000	15.000	15.000	15.000	30.400	30.100	15.000
Vapor Frac	0.000	0.110	0.000	0.102	0.000	0.000	0.000	0.256
Mole Flow (mol/sec)	955.864	955.864	867.614	867.614	760.273	760.273	760.273	319.032
Mass Flow (kg/sec)	35.586	35.586	33.554	33.554	30.142	30.142	30.142	12.106
Volume Flow (m3/sec)	0.068	0.182	0.067	0.164	0.060	0.061	0.063	0.109
Enthalpy (MMkcal/hr)	-100.627	-98.866	-90.863	-89.625	-79.322	-79.211	-78.321	-32.560
Density (gm/cc)	0.521	0.195	0.504	0.205	0.500	0.498	0.478	0.111
Composition								
Nitrogen	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.002
Methane	0.078	0.078	0.026	0.026	0.014	0.014	0.014	0.296
Ethane	0.502	0.502	0.519	0.519	0.496	0.496	0.496	0.190
Propane	0.259	0.259	0.284	0.284	0.307	0.307	0.307	0.255
iso-butane	0.056	0.056	0.062	0.062	0.069	0.069	0.069	0.094
n-butane	0.049	0.049	0.054	0.054	0.060	0.060	0.060	0.091
iso-pentane	0.013	0.013	0.015	0.015	0.016	0.016	0.016	0.031
n-pentane	0.007	0.007	0.008	0.008	0.009	0.009	0.009	0.018
n-hexane	0.004	0.004	0.004	0.004	0.005	0.005	0.005	0.010
n-heptane	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.005
n-octane	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.002
n-nonane	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.001
n-decane	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
CarbonDioxide	0.029	0.029	0.026	0.026	0.020	0.020	0.020	0.006

(Cont.)

Table B1 (Continued) Stream results from simulation

Stream name	S70325	S70326	S70327	S70328	S70401	S70404	S70407	S70408
Temperature (K)	213.900	178.200	242.500	292.800	313.500	273.100	343.600	362.400
Pressure (barg)	15.000	15.000	11.000	10.700	28.000	27.700	16.700	16.500
Vapor Frac	0.294	0.365	0.285	1.000	0.234	0.000	0.342	1.000
Mole Flow (mol/sec)	295.642	803.056	403.005	403.005	760.273	403.005	357.268	357.268
Mass Flow (kg/sec)	9.218	17.945	12.177	12.177	30.142	12.177	17.966	17.966
Volume Flow (m3/sec)	0.098	0.248	0.177	0.751	0.164	0.030	0.170	0.464
Enthalpy (MMkcal/hr)	-27.560	-65.892	-37.149	-33.352	-75.021	-37.149	-37.789	-34.379
Density (gm/cc)	0.094	0.072	0.069	0.016	0.184	0.404	0.106	0.039
Composition								
Nitrogen	0.003	0.006	0.000	0.000	0.000	0.000	0.000	0.000
Methane	0.398	0.672	0.027	0.027	0.014	0.027	0.000	0.000
Ethane	0.244	0.213	0.935	0.935	0.496	0.935	0.001	0.001
Propane	0.239	0.084	0.000	0.000	0.307	0.000	0.652	0.652
iso-butane	0.054	0.008	0.000	0.000	0.069	0.000	0.148	0.148
n-butane	0.043	0.005	0.000	0.000	0.060	0.000	0.128	0.128
iso-pentane	0.008	0.000	0.000	0.000	0.016	0.000	0.035	0.035
n-pentane	0.004	0.000	0.000	0.000	0.009	0.000	0.020	0.020
n-hexane	0.001	0.000	0.000	0.000	0.005	0.000	0.010	0.010
n-heptane	0.000	0.000	0.000	0.000	0.002	0.000	0.004	0.004
n-octane	0.000	0.000	0.000	0.000	0.001	0.000	0.001	0.001
n-nonane	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
n-decane	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
CarbonDioxide	0.009	0.011	0.038	0.038	0.020	0.038	0.000	0.000

(Cont.)

Table B1 (Continued) Stream results from simulation

Stream name	S70413	S70414	S70415	S70416	S70417	S70418	S70419	S70422
Temperature (K)	301.000	351.600	302.000	432.300	323.100	300.000	311.900	288.300
Pressure (barg)	16.500	16.600	16.000	16.700	16.300	16.300	30.100	30.100
Vapor Frac	0.000	0.000	0.000	0.000	0.000	0.000	0.057	0.000
Mole Flow (mol/sec)	173.548	158.141	158.141	25.579	25.579	25.579	30.411	729.862
Mass Flow (kg/sec)	7.649	8.361	8.361	1.956	1.956	1.956	1.206	28.937
Volume Flow (m3/sec)	0.016	0.018	0.016	0.004	0.003	0.003	0.004	0.061
Enthalpy (MMkcal/hr)	-17.972	-17.955	-18.968	-3.427	-3.941	-4.029	-3.044	-75.188
Density (gm/cc)	0.489	0.458	0.535	0.458	0.605	0.629	0.335	0.478
Composition								
Nitrogen	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Methane	0.000	0.000	0.000	0.000	0.000	0.000	0.014	0.014
Ethane	0.002	0.000	0.000	0.000	0.000	0.000	0.496	0.496
Propane	0.998	0.378	0.378	0.000	0.000	0.000	0.307	0.307
iso-butane	0.000	0.333	0.333	0.002	0.002	0.002	0.069	0.069
n-butane	0.000	0.284	0.284	0.036	0.036	0.036	0.060	0.060
iso-pentane	0.000	0.003	0.003	0.470	0.470	0.470	0.016	0.016
n-pentane	0.000	0.001	0.001	0.270	0.270	0.270	0.009	0.009
n-hexane	0.000	0.000	0.000	0.136	0.136	0.136	0.005	0.005
n-heptane	0.000	0.000	0.000	0.058	0.058	0.058	0.002	0.002
n-octane	0.000	0.000	0.000	0.019	0.019	0.019	0.001	0.001
n-nonane	0.000	0.000	0.000	0.006	0.006	0.006	0.000	0.000
n-decane	0.000	0.000	0.000	0.003	0.003	0.003	0.000	0.000
CarbonDioxide	0.000	0.000	0.000	0.000	0.000	0.000	0.020	0.020

(Cont.)

Table B1 (Continued) Stream results from simulation

Stream name	S70423	S70601	S70602	S70603	S70604	S70605	S70606	S70607
Temperature (K)	315.800	307.400	398.500	370.900	307.600	370.900	282.900	370.900
Pressure (barg)	29.900	17.900	45.300	45.149	44.600	45.149	45.128	45.149
Vapor Frac	0.193	1.000	1.000	1.000	1.000	1.000	1.000	1.000
Mole Flow (mol/sec)	760.273	3378.378	3378.378	3378.378	3378.378	85.000	85.000	39.144
Mass Flow (kg/sec)	30.142	56.243	56.243	56.243	56.243	1.415	1.415	0.652
Volume Flow (m3/sec)	0.141	4.394	2.346	2.165	1.735	0.054	0.038	0.025
Enthalpy (MMkcal/hr)	-75.081	-216.524	-206.848	-210.258	-217.851	-5.290	-5.557	-2.436
Density (gm/cc)	0.213	0.013	0.024	0.026	0.032	0.026	0.037	0.026
Composition								
Nitrogen	0.000	0.020	0.020	0.020	0.020	0.020	0.020	0.020
Methane	0.014	0.958	0.958	0.958	0.958	0.958	0.958	0.958
Ethane	0.496	0.018	0.018	0.018	0.018	0.018	0.018	0.018
Propane	0.307	0.000	0.000	0.000	0.000	0.000	0.000	0.000
iso-butane	0.069	0.000	0.000	0.000	0.000	0.000	0.000	0.000
n-butane	0.060	0.000	0.000	0.000	0.000	0.000	0.000	0.000
iso-pentane	0.016	0.000	0.000	0.000	0.000	0.000	0.000	0.000
n-pentane	0.009	0.000	0.000	0.000	0.000	0.000	0.000	0.000
n-hexane	0.005	0.000	0.000	0.000	0.000	0.000	0.000	0.000
n-heptane	0.002	0.000	0.000	0.000	0.000	0.000	0.000	0.000
n-octane	0.001	0.000	0.000	0.000	0.000	0.000	0.000	0.000
n-nonane	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
n-decane	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
CarbonDioxide	0.020	0.004	0.004	0.004	0.004	0.004	0.004	0.004

(Cont.)

Table B1 (Continued) Stream results from simulation

Stream name	S70608	PURGE	Refrigerant
Temperature (K)	328.100	307.400	313.000
Pressure (barg)	45.149	17.900	19.000
Vapor Frac	1.000	1.000	0.000
Mole Flow (mol/sec)	39.144	7.181	673.766
Mass Flow (kg/sec)	0.652	0.120	28.353
Volume Flow (m3/sec)	0.022	0.009	0.059
Enthalpy (MMkcal/hr)	-2.496	-0.460	3.443
Density (gm/cc)	0.030	0.013	0.479
Composition			
Nitrogen	0.020	0.020	0.000
Methane	0.958	0.958	0.000
Ethane	0.018	0.018	0.000
Propane	0.000	0.000	0.000
iso-butane	0.000	0.000	0.000
n-butane	0.000	0.000	0.000
iso-pentane	0.000	0.000	0.000
n-pentane	0.000	0.000	0.000
n-hexane	0.000	0.000	0.000
n-heptane	0.000	0.000	0.000
n-octane	0.000	0.000	0.000
n-nonane	0.000	0.000	0.000
n-decane	0.000	0.000	0.000
CarbonDioxide	0.004	0.004	0.000
Propylene	0.000	0.000	1.000

Appendix C Economic Analysis of Heat Exchanger Network.

C1 Capital Investment

The capital investment for the heat exchanger network modification is calculated based on the required number of new heat exchangers and the additional heat transfer area for the existing heat exchangers in the modified network. For the modified network of Gas Separation Plant Unit I, it does not require any new heat exchangers or additional area for the existing heat exchangers. Therefore, this modification does not require the capital investment.

C2 Operating cost saving calculation

Since the energy consumption in modified network is reduced from the existing network, which implies that the energy cost portion in total operating cost will be reduced. The utility consumption of the current and modified network is compared and the result is shown in Table C1.

Table C1 Comparison of utility consumption between current and modified network

Utility	Current network (MW)	Modified network (MW)	Utility saving (MW)
Refrigerant @ E70304	2.42	2.30	0.12
Cooling water @ E70409	1.56	0.74	0.82
Cooling water @ E70601	8.45	4.69	3.76
Total	12.43	7.73	4.70

The utility cost is shown in Table 3.2 and it is shown again in Table C2.

Table C2 Utility data for GSP I

Utility	Type	Inlet Temp (K)	Outlet Temp (K)	h (W/m^2-K)	Price (US$/unit)	Unit
Refrigerant	Cold	230.95	230.95	2029.31	0.0355	kW-hr
CW*	Cold	308.15	318.15	499.22	0.0060	m^3
MPS†	Hot	478.15	478.15	15000.00	8.0000	Ton
LPS‡	Hot	416.15	416.15	7500.00	6.5000	Ton

* Cooling Water

† Medium Pressure Steam

‡ Low Pressure Steam

From Table C1 and C2, the calculation of utility cost saving was done by calculating the operating saving due to reduction in each utility type as shown below.

The calculation of operating cost saving due to reduction of refrigerant consumption (Saving_1) is shown below:

Saving_1 = 0.12 MW x (1000 kW/MW) x (US$ 0.0355/kW-hr) x (8760 hr/yr)

= US$ 36,743.53 /yr

Since the cooling water supply and return temperature is different in two coolers (E70409 and E70601); therefore, the calculation of operating cost saving due to reduction of cooling water consumption is separated into two parts.

The calculation of operating cost saving due to reduction of cooling water consumption of E70409 (Saving_2) is shown below:

Cooling water data:

Supply temperature: 312.15 K Return temperatures: 318.15 K

Heat capacity : 4186.00 J/kg-K Density : 991.00 kg/m^3

For 1 m^3 of cooling water,

The amount of heat removed = $C_p\Delta T$

= (4186 J/kg-K) x (318.15-312.15 K) x (991 kg/m^3)

= 24889956 J/m^3

The amount of heat saving = 0.82 MW

The amount of CW saving

= 0.82 MW x (1,000,000 W/MW) x (31,536,000 s/yr) x (1 J/W.s) /(24889956 J/m^3)

= 1,035,048.19 m^3/yr

Operating cost saving due to reduction in CW consumption of E70409 (Saving_2)

Saving_2 = 1,035,048.19 m^3/yr x (US$ 0.006/m^3)

= US$ 6,210.29/yr

The calculation of operating cost saving due to reduction of cooling water consumption of E70601 (Saving_3) is shown below:

Cooling water data:

Supply temperature: 308.15 K Return temperatures: 313.15 K

Heat capacity : 4180.00 J/kg-K Density : 992.00 kg/m^3

For 1 m^3 of cooling water,

The amount of heat removed = $C_p\Delta T$

= (4180 J/kg-K) x (313.15-308.15 K) x (992 kg/m^3)

= 20732800 J/m^3

The amount of heat saving = 3.76 MW

The amount of CW saving

= 3.76 MW x (1,000,000 W/MW) x (31,536,000 s/yr) x (1 J/W.s) /(20732800 J/m^3)

= 5,719,215.93 m^3/yr

Operating cost saving due to reduction in CW consumption of E70601 (Saving_3)

Saving_3 = 5,719,215.93 m^3/yr x (US$ 0.006/m^3)

= US$ 34,275.07/yr

Total operating cost saving is calculated by summing Saving_1, Saving_2, and Saving_3, that is

Total saving = Saving_1 + Saving_2 + Saving_3

= US$ 36,743.53/yr + US$ 6,210.29/yr + US$ 34,275.07/yr

= US$ 77228.89/yr

C3 Economic analysis

The economic analysis for the modified heat exchanger network was done to calculate payback period and internal rate of return (IRR) for project evaluation. However, in this project, there is no investment, thus payback time is zero and IRR cannot be determined.

Appendix D Exergy Analysis.

D1 Stream exergy

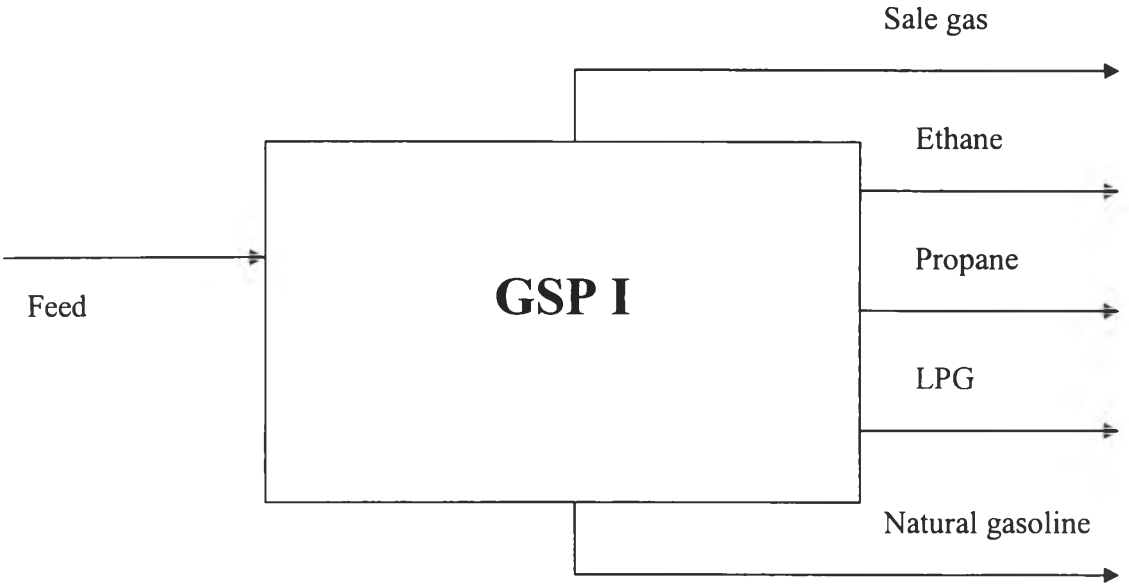

Figure D1 Block diagram of GSP I.

The stream exergy was calculated for the feed and product streams of GSP I as shown in Figure D1. Stream exergy was calculated by summing stream thermal and chemical exergy. Stream thermal exergy was obtained as a result of Aspen Plus stream's properties report. Chemical exergy was obtained by molar averaging of standard chemical exergy for all components that present in the stream. The results for stream exergy before and after modification are shown in Table D1 and D2, respectively. The useful exergy of the process in this process is the separation work which was calculated by the difference between product stream exergy and feed stream exergy. From the calculation, the process useful exergy before and after modification are:

Useful exergy before modification:	3.122 MW
Useful exergy after modification:	3.585 MW

Table D1 Stream exergy before modifications

Exergy (MW)	Feed	Product				
		Sale gas	Ethane	Propane	LPG	NGL
Thermal	-168.938	-141.562	-16.514	-3.324	-3.223	-0.345
Chemical	4229.566	2784.226	573.111	372.731	400.331	92.716
Total	4060.628	2642.665	556.597	369.407	397.109	92.371

Table D2 Stream exergy after modifications

Exergy (MW)	Feed	Product				
		Sale gas	Ethane	Propane	LPG	NGL
Thermal	-168.938	-141.562	-16.567	-3.307	-3.223	-0.316
Chemical	4229.566	2784.226	576.447	370.332	400.082	5.918
Total	4060.628	2642.665	559.880	367.025	396.859	5.602

D2 Equipment exergy loss

The equipment exergy loss was calculated by the availability balance for most of the equipment, except heat exchangers and multi-stream heat exchangers. For heat exchangers, exergy loss can be calculated by using equation 3.8. The exergy loss of multi-stream heat exchangers can also be calculated by using equation 3.8; however, the multi-stream heat exchangers have to be re-modeled by using the heat exchangers connected in series and exchanged heat until all of the stream operating condition is the same as those of multi-stream heat exchangers. When the modeling was finished, equation 3.8 was used to calculate exergy loss in each component. The exergy loss of multi-stream heat exchanger is the sum of the exergy loss of all components in the model.

The results for equipment exergy loss before and after modification are shown in Table D3

Table D3 Equipment exergy loss before and after modifications

Distillation columns

Equipment name	Exergy loss before modification (MW)	Exergy loss after modification (MW)
Demethanizer	1.297	1.297
Deethanizer	1.267	1.267
Depropanizer	0.730	0.730
Total	**3.293**	**3.293**

Heat Exchangers

Equipment name	Exergy loss before modification (MW)	Exergy loss after modification (MW)
E70303	0.126	0.105
E70304	0.120	0.143
E70404	0.439	0.393
E70407	0.007	0.003
E70408	0.158	0.121
E70409	0.585	0.610
E70601	6.652	6.504
Total	**8.087**	**7.879**

Multi-stream heat exchangers

Equipment name	Exergy loss before modification (MW)	Exergy loss after modification (MW)
Coldbox_1	1.287	1.287
Coldbox_2	1.981	1.981
Coldbox_3	0.592	0.592
Total	**3.859**	**3.859**

(Cont.)

Table D3 (Continued) Equipment exergy loss before and after modifications

Flash drums

Equipment Name	Exergy loss before modification (MW)	Exergy loss after modification (MW)
D70301	0.000	0.000
D70302	0.001	0.001
D70303	0.000	0.000
Total	**0.002**	**0.002**

Valves

Equipment Name	Exergy loss before modification (MW)	Exergy loss after modification (MW)
V301	0.477	0.477
V302	0.165	0.165
V303	0.171	0.171
V401	0.158	0.158
V406	0.094	0.094
Total	**1.066**	**1.066**

Compressors and Expanders

Equipment Name	Exergy loss before modification (MW)	Exergy loss after modification (MW)
C70301	0.493	0.493
C70601	2.291	2.291
X70301	0.000	0.000
Total	**2.784**	**2.784**

(Cont.)

Table D3 (Continued) Equipment exergy loss before and after modifications

Pumps

Equipment Name	Exergy loss before modification (MW)	Exergy loss after modification (MW)
P70301	0.043	0.043
P70302	0.006	0.006
P70303	0.007	0.007
P70304	0.007	0.007
P70305	0.007	0.007
Total	**0.069**	**0.069**

D3 Exergetic efficiency

Exergetic efficiency can be calculated by using equation 3.6. The result of calculation is shown in Table D4.

Table D4 Exergetic efficiency of GSP I before and after modifications

	Before modification	**After modification**
Useful exergy (MW)	3.122	3.585
Exergy loss (MW)	19.091	18.882
Exergetic efficiency (%)	14.013	15.908

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Research Agreement

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