# ABB Lummus Global, Inc.

## Lummus Process Technology

## Randall Gas Technologies

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GPA Convention
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# A Review of the Basics for Superior Design

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## Why Thermodynamic Analysis?

- Minimum/Ideal Work
- With Actual Work known, it gives the process efficiency.
- Identifies areas in the process with large lost work or Operations that are "**Highly Irreversible**"

## What is a reversible process?

- A reversible process is a process that undergoes a change in infinitesimally small steps such that, at all times, the system remains at equilibrium or infinitesimally away from equilibrium.
- All heat transfer is to or from the environment via a Carnot engine.
- A reversible process must produce useful work.

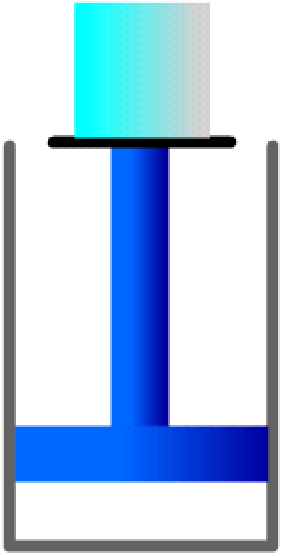
 

# Introduction (…cont.)

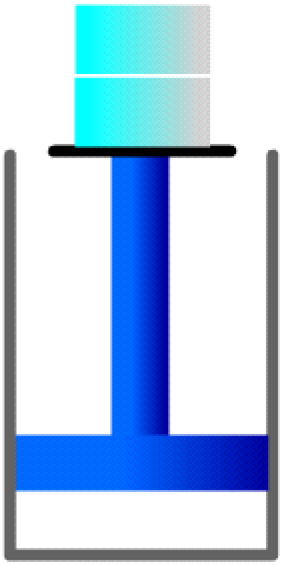
For a plant to be reversible

- Every operation in the process has to be reversible

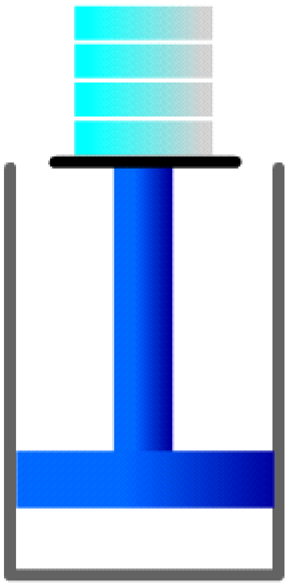
# One Block Movie



# Two Block Movie



# Four Block Movie



# Types of Lost Work

- Chemical Lost Work: Irreversible chemical reactions.
- Heat Transfer Lost Work: Temperature gradient.
- Mass Transfer Lost Work: Mixing of streams with different composition.
- Momentum Lost Work: Pressure drop or irreversible change in pressure.

# Definitions

- **Ideal Work**

  For a work requiring process, this is the minimum work required to accomplish the process.

- **Shaft Work**

  This is the work of rotating shafts like compressors, expanders and pumps etc.

- **Lost Work**

  The difference between the Ideal and shaft work.

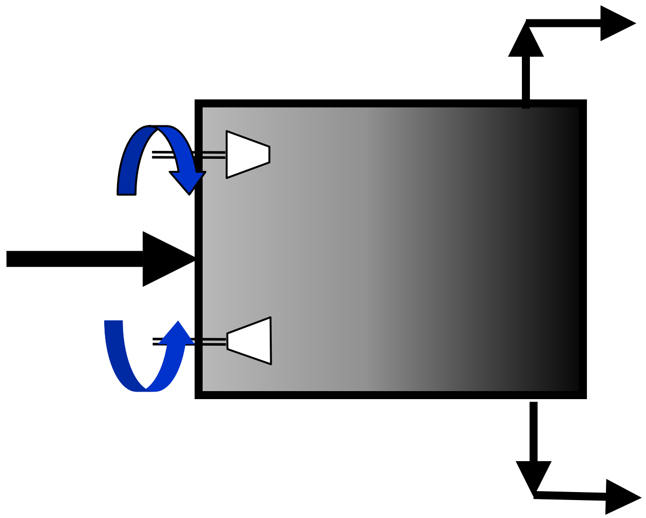
# Thermodynamic Calculations

The Entire Process

$$W_{ideal} = T_e \Delta S - \Delta H$$

$$W_{shaft} = \sum W_i$$

$$W_{lost} = W_{ideal} - W_{shaft}$$



# Thermodynamic Calculations, Cont.

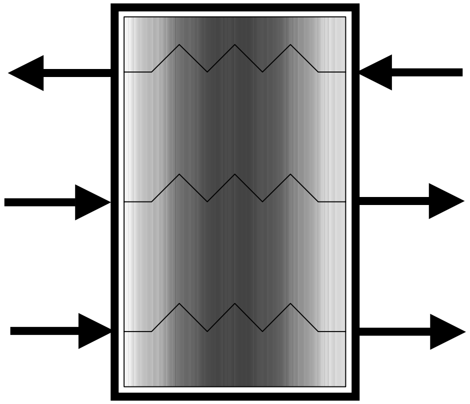
Heat Exchangers

$$W_{ideal} = T_e \Delta S - \Delta H$$

$$\Delta H = 0$$

$$W_{shaft} = 0$$

$$W_{lost} = W_{ideal} = T_e \Delta S$$



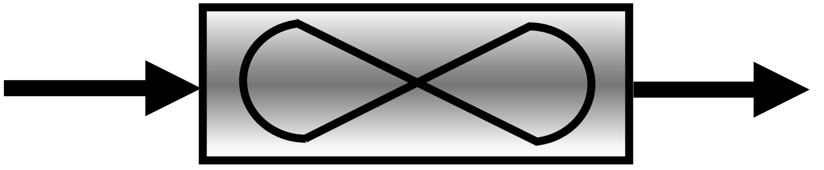
# Thermodynamic Calculations, Cont.

Non Adiabatic Heat Exchangers and simplifying assumptions

Air Coolers

$$W_{ideal}=T_e\Delta S-\Delta H$$

$$W_{shaft} = 0$$



$$W_{lost} = W_{ideal}$$

# Thermodynamic Calculations, Cont.

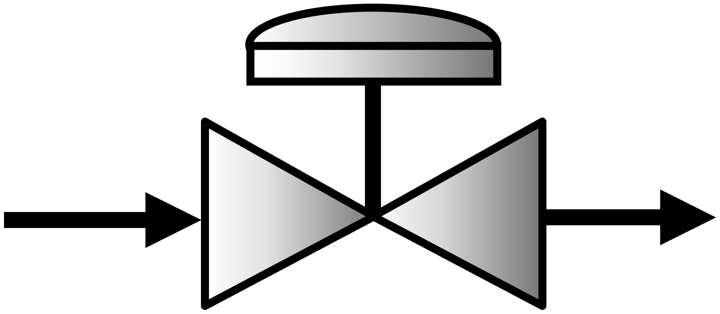
Valves

$$W_{ideal} = T_e \Delta S - \Delta H$$

$$\Delta H = 0$$

$$W_{shaft} = 0$$

$$W_{lost} = W_{ideal} = T_e \Delta S$$



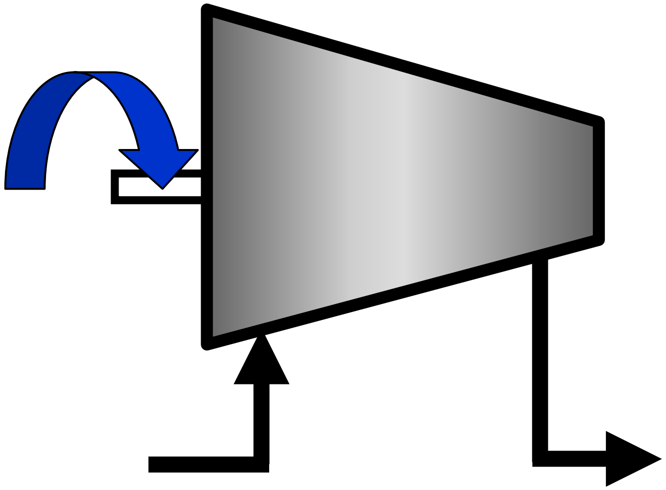
# Thermodynamic Calculations, Cont.

Compressors, pumps, expanders

$$W_{ideal} = T_e \Delta S - \Delta H$$

$$W_{shaft} = W_{actual}$$

$$W_{lost} = W_{ideal} - W_{shaft}$$





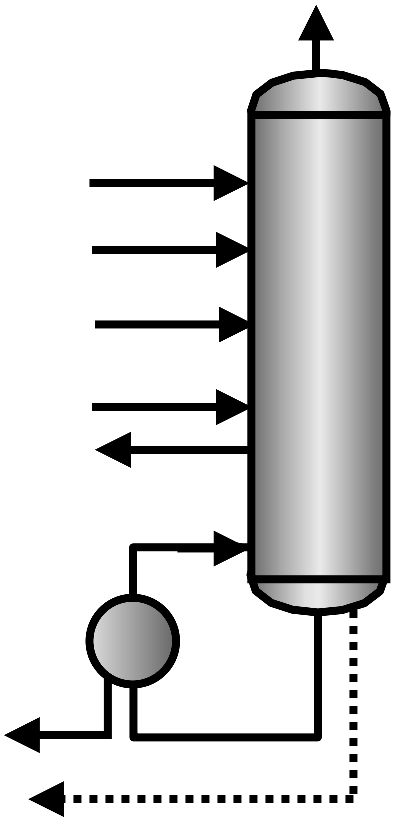


ABB

# Thermodynamic Calculations, Cont.

## Distillation Columns

Isolate the column from the heat exchangers!



$$W_{ideal}=T_e\Delta S-\Delta H$$

$$\Delta H=0,\ W_{shaft} = 0$$

$$W_{ideal} = T_e\Delta S= W_{lost}$$

# Applications to Gas Plants – $C_3$ Recovery

## Conventional Propane Recovery

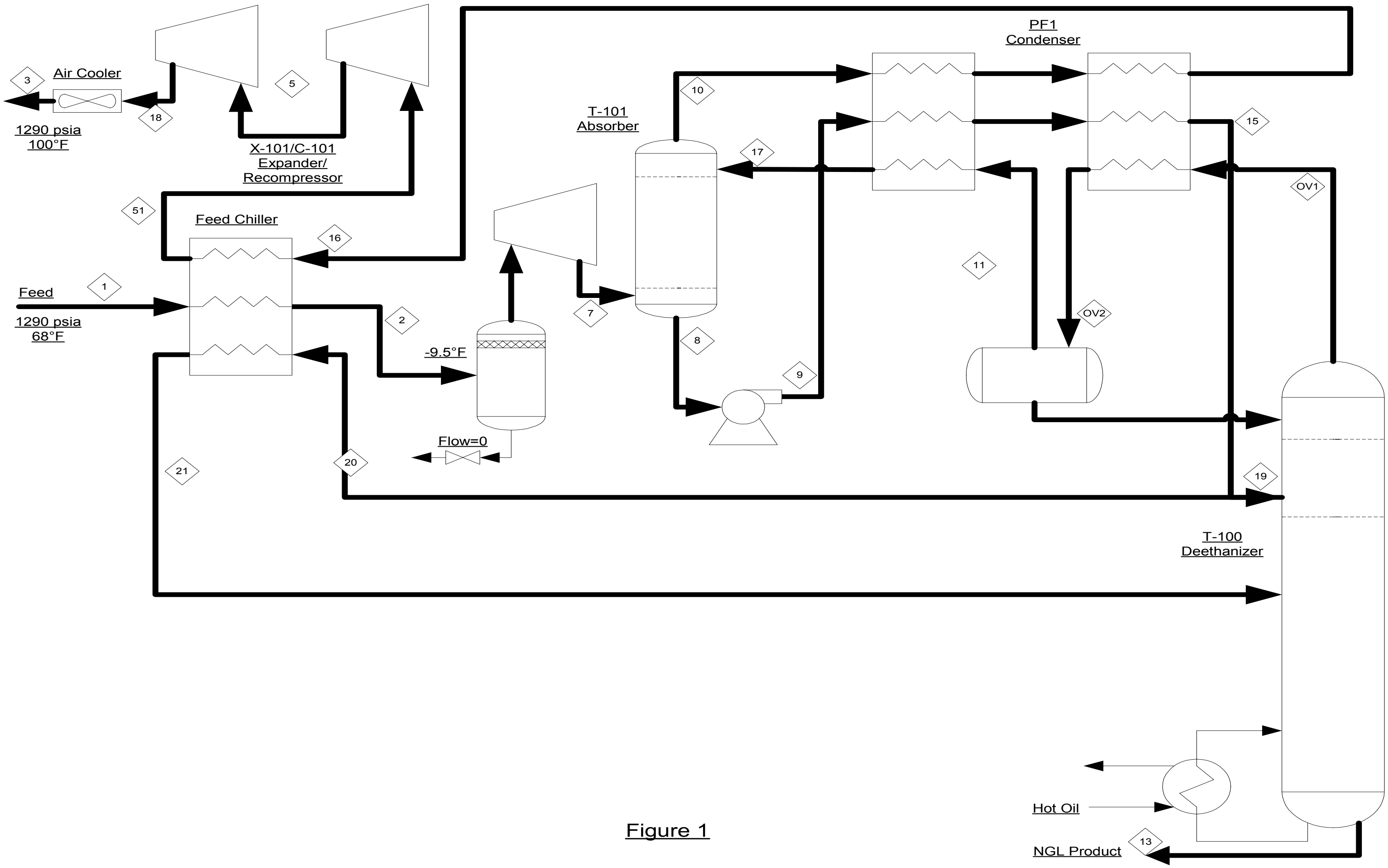



Figure 1

# Application to Gas Plants – $C_3$ Recovery

## Conventional Propane Recovery

- Calculate the ideal and lost work for the entire process.
- Disconnect the process into individual adiabatic processes.
- Calculate the ideal and lost work for each individual operation.
- Add up the total and lost work as a check.

# Recommended Approach

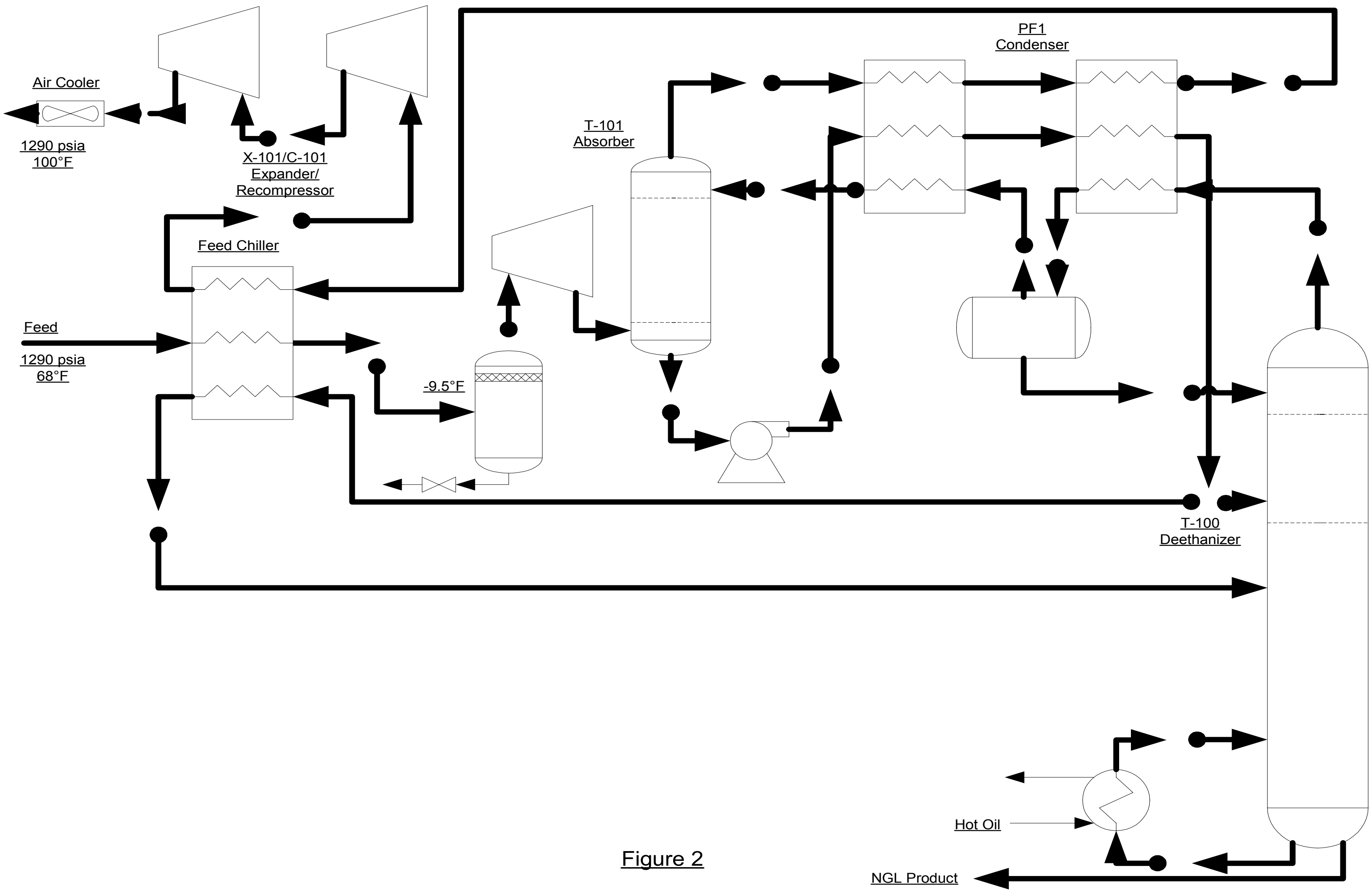
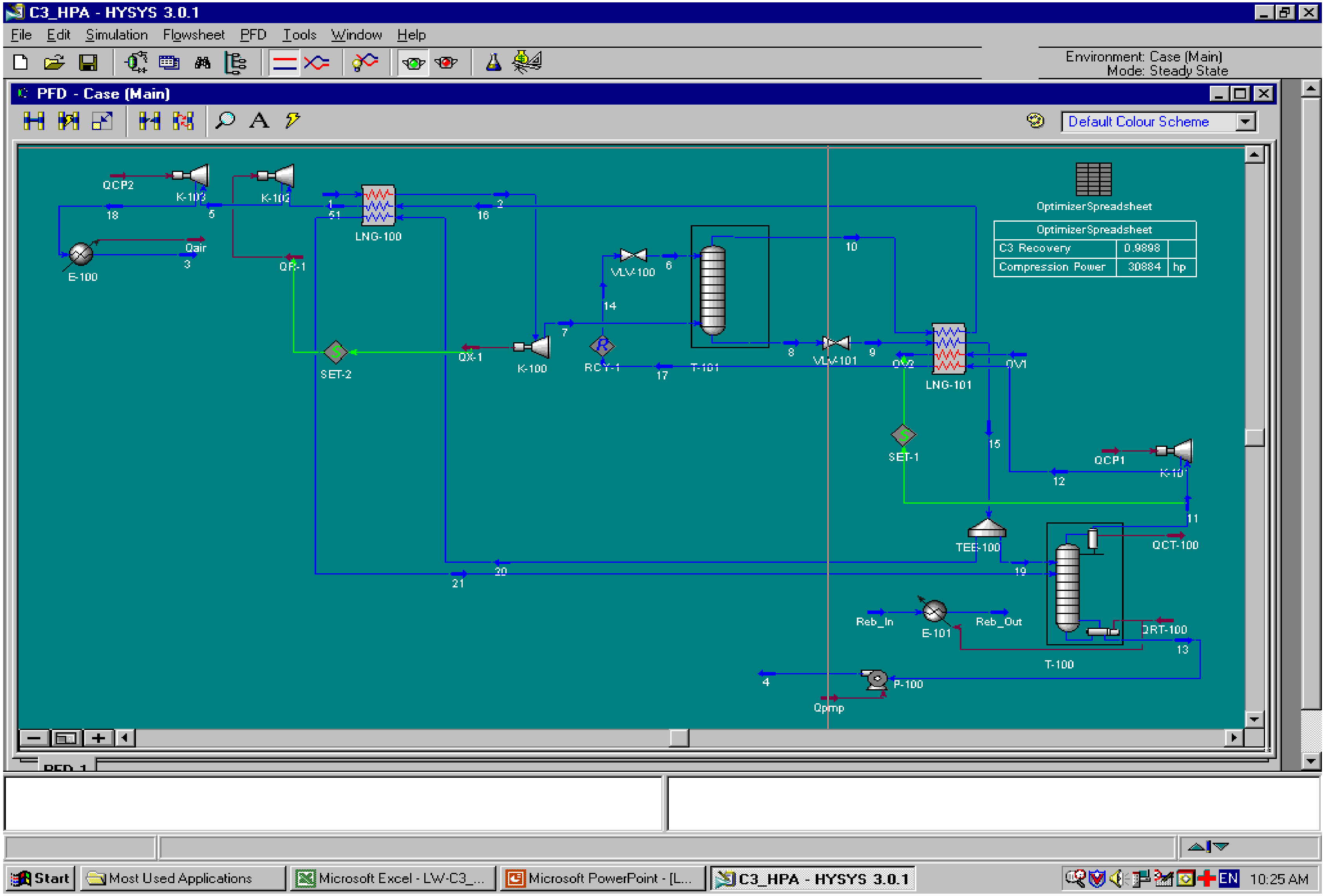


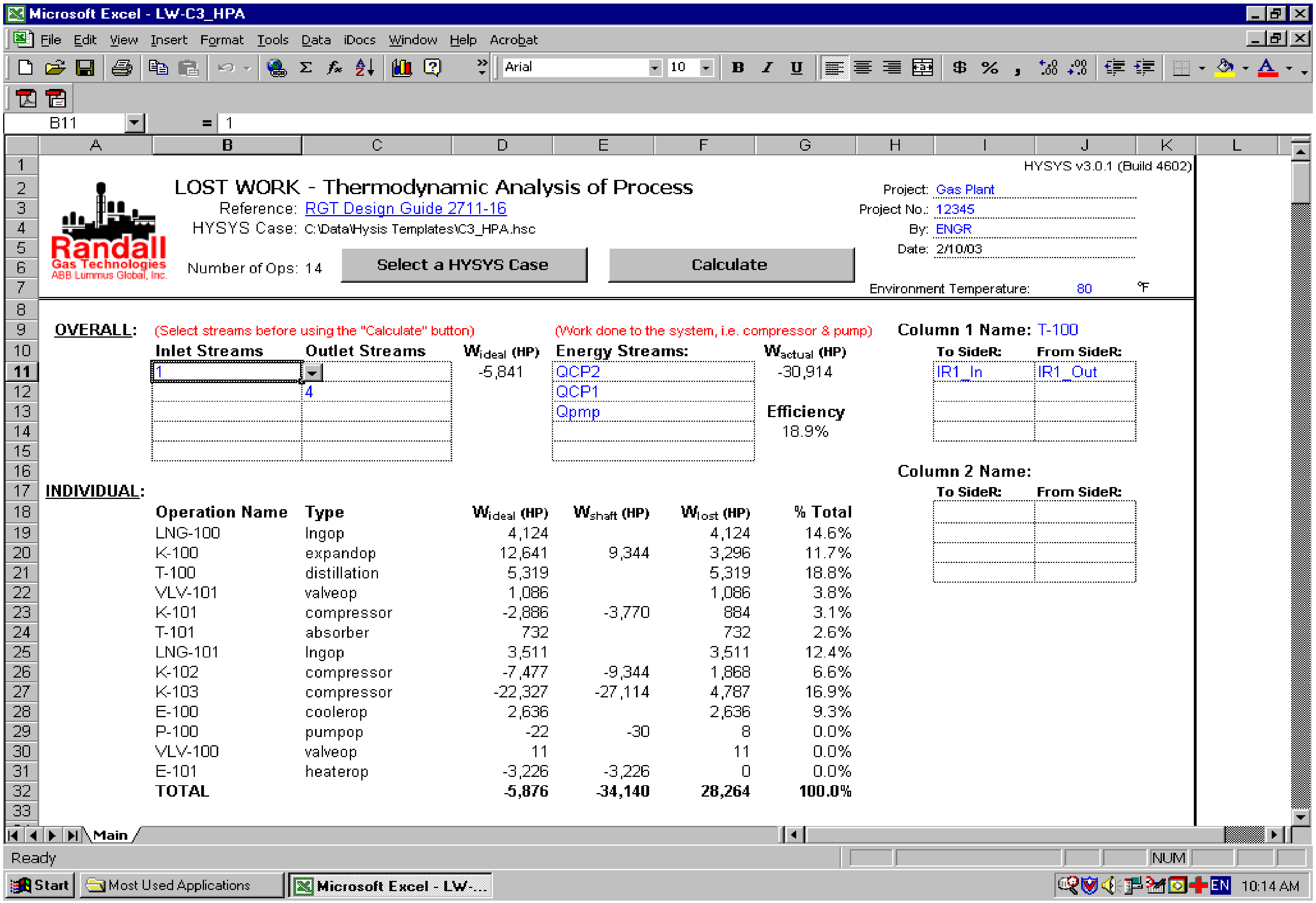

Figure 2

# Simulation tools and Spreadsheets



# Simulation tools and Spreadsheets



Microsoft Excel - LW-C3_HPA

File Edit View Insert Format Tools Data iDocs Window Help Acrobat

B11 = 1

HYSYS v3.0.1 (Build 4602)

**LOST WORK - Thermodynamic Analysis of Process**

Randall Gas Technologies ABB Lummus Global, Inc.

Reference: RGT Design Guide 2711-16

HYSYS Case: C:\Data\Hysis Templates\C3_HPA.hsc

Number of Ops: 14

Select a HYSYS Case | Calculate

Project: Gas Plant
Project No.: 12345
By: ENGR
Date: 2/10/03

Environment Temperature: 80 °F

**OVERALL:** (Select streams before using the "Calculate" button) (Work done to the system, i.e. compressor & pump)

| Inlet Streams | Outlet Streams | $W_{ideal}$ (HP) | Energy Streams: | $W_{actual}$ (HP) |
|---|---|---|---|---|
| 1 | | -5,841 | QCP2 | -30,914 |
| | 4 | | QCP1 | |
| | | | Qpmp | Efficiency |
| | | | | 18.9% |

Column 1 Name: T-100

| To SideR: | From SideR: |
|---|---|
| IR1_In | IR1_Out |

Column 2 Name:

| To SideR: | From SideR: |
|---|---|
| | |

**INDIVIDUAL:**

| Operation Name | Type | $W_{ideal}$ (HP) | $W_{shaft}$ (HP) | $W_{lost}$ (HP) | % Total |
|---|---|---|---|---|---|
| LNG-100 | lngop | 4,124 | | 4,124 | 14.6% |
| K-100 | expandop | 12,641 | 9,344 | 3,296 | 11.7% |
| T-100 | distillation | 5,319 | | 5,319 | 18.8% |
| VLV-101 | valveop | 1,086 | | 1,086 | 3.8% |
| K-101 | compressor | -2,886 | -3,770 | 884 | 3.1% |
| T-101 | absorber | 732 | | 732 | 2.6% |
| LNG-101 | lngop | 3,511 | | 3,511 | 12.4% |
| K-102 | compressor | -7,477 | -9,344 | 1,868 | 6.6% |
| K-103 | compressor | -22,327 | -27,114 | 4,787 | 16.9% |
| E-100 | coolerop | 2,636 | | 2,636 | 9.3% |
| P-100 | pumpop | -22 | -30 | 8 | 0.0% |
| VLV-100 | valveop | 11 | | 11 | 0.0% |
| E-101 | heaterop | -3,226 | -3,226 | 0 | 0.0% |
| **TOTAL** | | **-5,876** | **-34,140** | **28,264** | **100.0%** |

Main

Ready NUM

Start | Most Used Applications | Microsoft Excel - LW-... 10:14 AM

# Application to Gas Plants – $C_3$ Recovery

Thermodynamic Analysis of Conventional Propane Recovery

| Equipment | $W_{ideal}$ | $W_{shaft}$ | $W_{lost}$ | % of lost |
|---|---|---|---|---|
| Exchangers | 11,805 | 0 | 11,805 | **27.9** |
| Valves | 43 | 0 | 43 | **0.1** |
| Columns | 6,842 | 0 | 6,842 | **16.2** |
| Rotating Equipment | -25,652 | -42,299 | 18,647 | **44.0** |
| Air Cooler | 5,014 | 0 | 5,014 | **11.8** |
| Reboiler | -4,034 | -4,034 | 0 | **0** |
| Total | **-5,981** | **-48,333** | **42,352** | 100.0 |

# Applications to Gas Plants – $C_3$ Recovery

## Conventional Propane Recovery

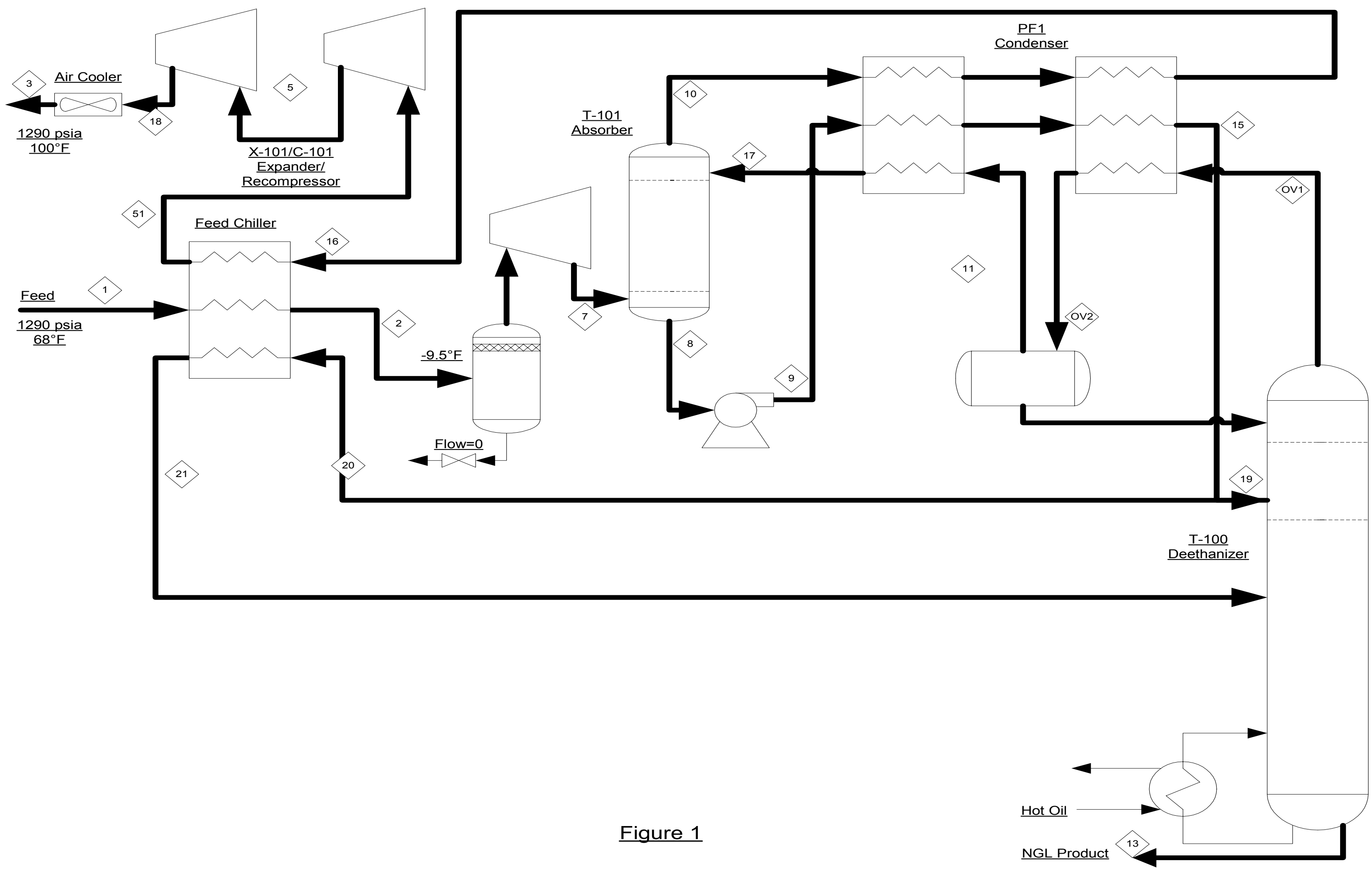



Figure 1




Randall Gas Technologies

# New Concept Development

The High Pressure Absorber - HPA

- Operate the absorber at high pressure (500 to 700 psia). This pressure is limited by the approach to critical conditions and the amount of refrigeration needed from the expander to keep the process self refrigerated.
- Install a compressor to compress the net deethanizer overhead.
- Eliminate the pump at the bottom of the absorber.

# HPA for Propane Recovery

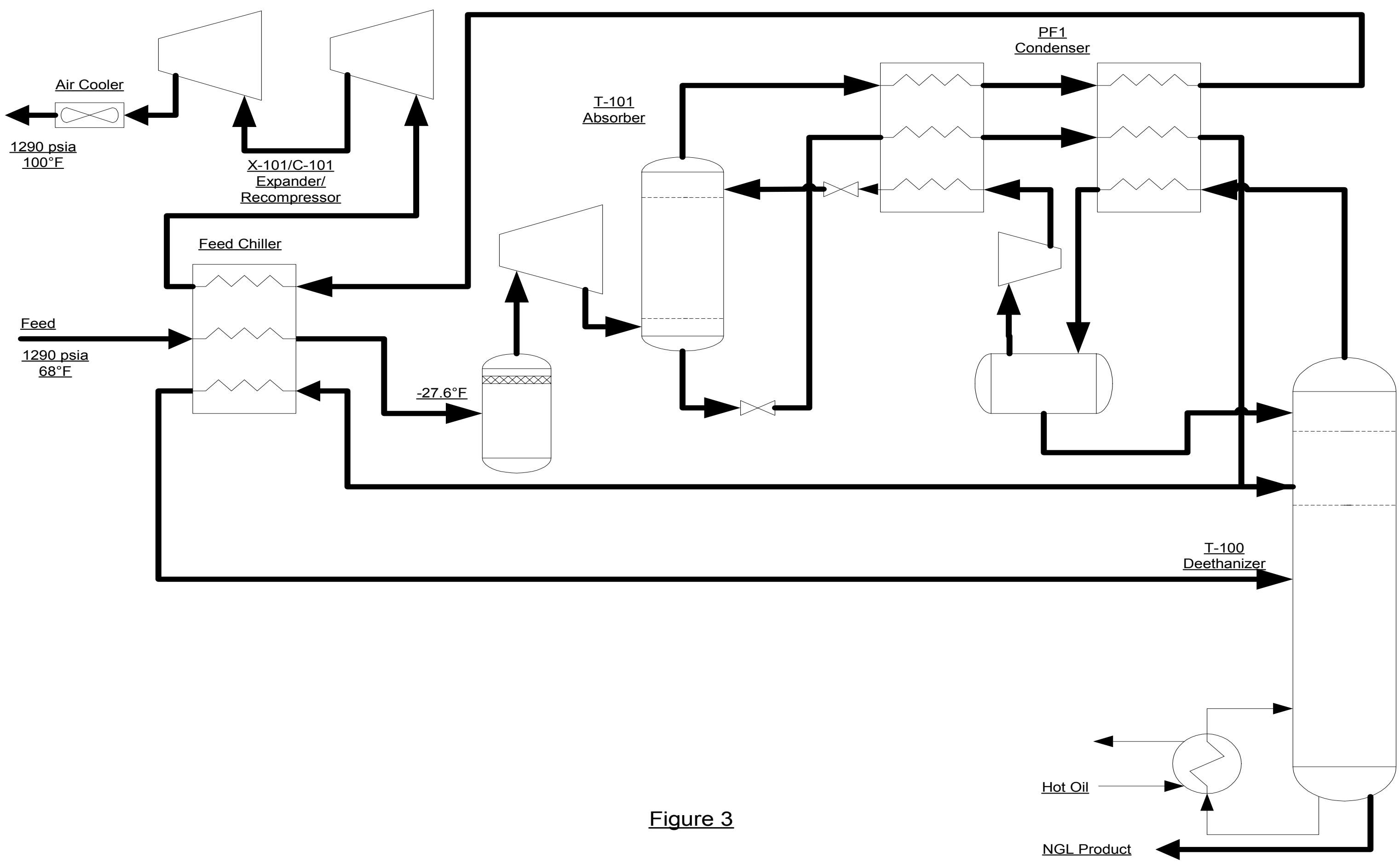



Figure 3

# Application to Gas Plants – $C_3$ Recovery

Thermodynamic Analysis of the HPA Process for Propane Recovery

| Equipment | $W_{ideal}$ | $W_{shaft}$ | $W_{lost}$ | % of lost |
|---|---|---|---|---|
| Exchangers | 7,634 | 0 | 7,634 | **27.0** |
| Valves | 1,097 | 0 | 1,097 | **3.9** |
| Columns | 6,051 | 0 | 6,051 | **21.4** |
| Rotating Equipment | -20,071 | -30,914 | 10,843 | **38.4** |
| Air Cooler | 2,636 | 0 | 2,636 | **10.5** |
| Reboiler | -3,226 | -3,226 | 0 | **9.3** |
| Total | **-5,876** | **-34,140** | **28,264** | 100.0 |

# HPA – $C_3$ Recovery

Comparison to Conventional Two-Tower Scheme

| | Conventional Scheme | | HPA Scheme | |
|---|---|---|---|---|
| | Lost Work | Percent | Lost Work | Percent |
| Exchangers | 11,805 | **27.9** | 7,634 | **27.0** |
| Valves | 43 | **0.1** | 1,097 | **3.9** |
| Columns | 6,842 | **16.2** | 6,051 | **21.4** |
| Rotating Equipment | 18,647 | **44.0** | 10,843 | 38.4 |
| Air Cooler | 5,014 | **11.8** | 2,636 | **10.5** |

| | | |
|---|---|---|
| Total Lost Work | **42,352** | **28,264** |
| Total Actual Work | **44,299** | **30,914** |

# Factors favoring the HPA Process for $C_3$ recovery

The High Pressure Absorber - HPA

- With reasonable heat integration, if the temperature of the residue gas stream entering the recompressor is significantly colder than the temperature of the feed then the expander is generating excessive refrigeration and the absorber can be operated at higher pressure.

# HPA for Propane Recovery

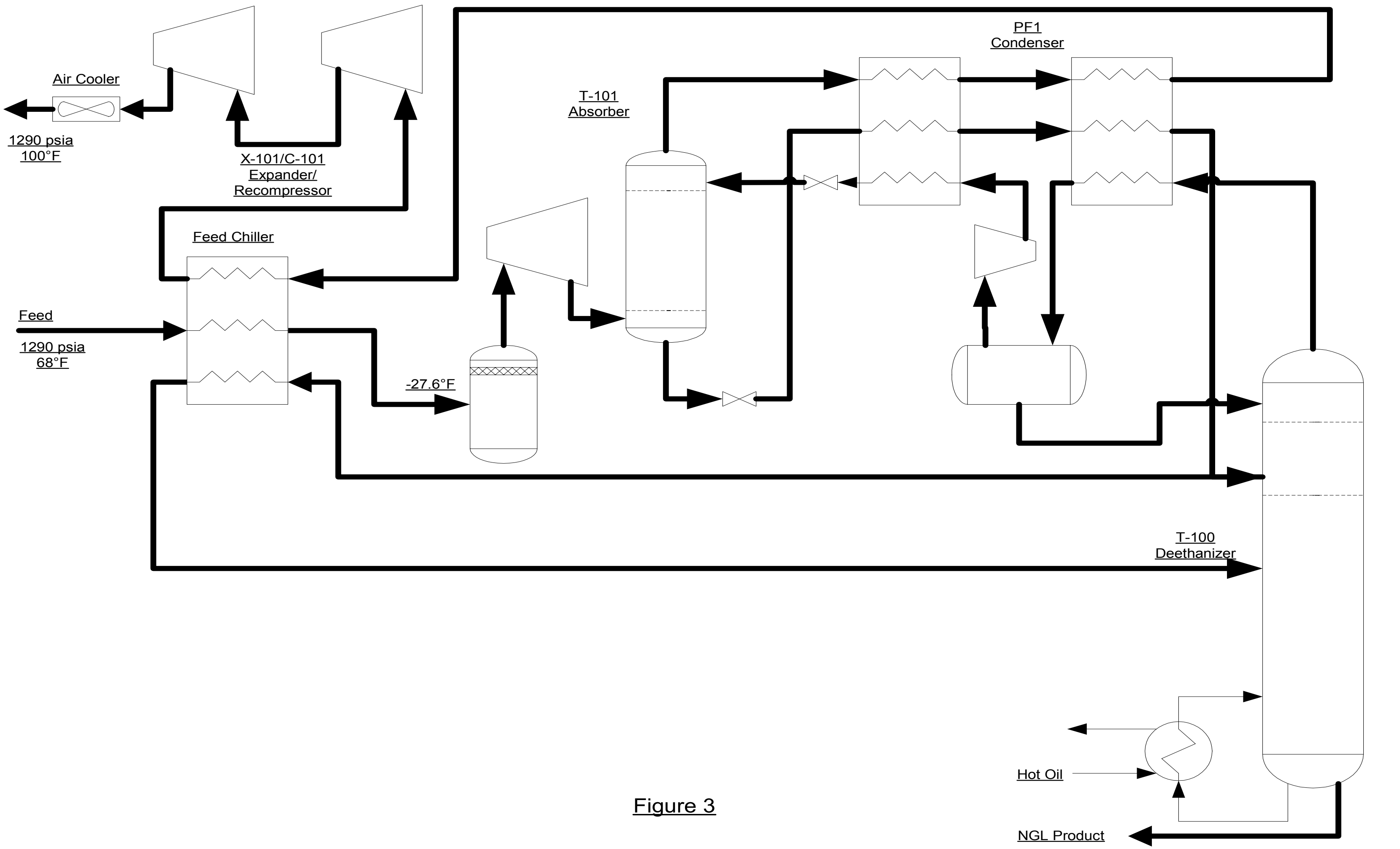
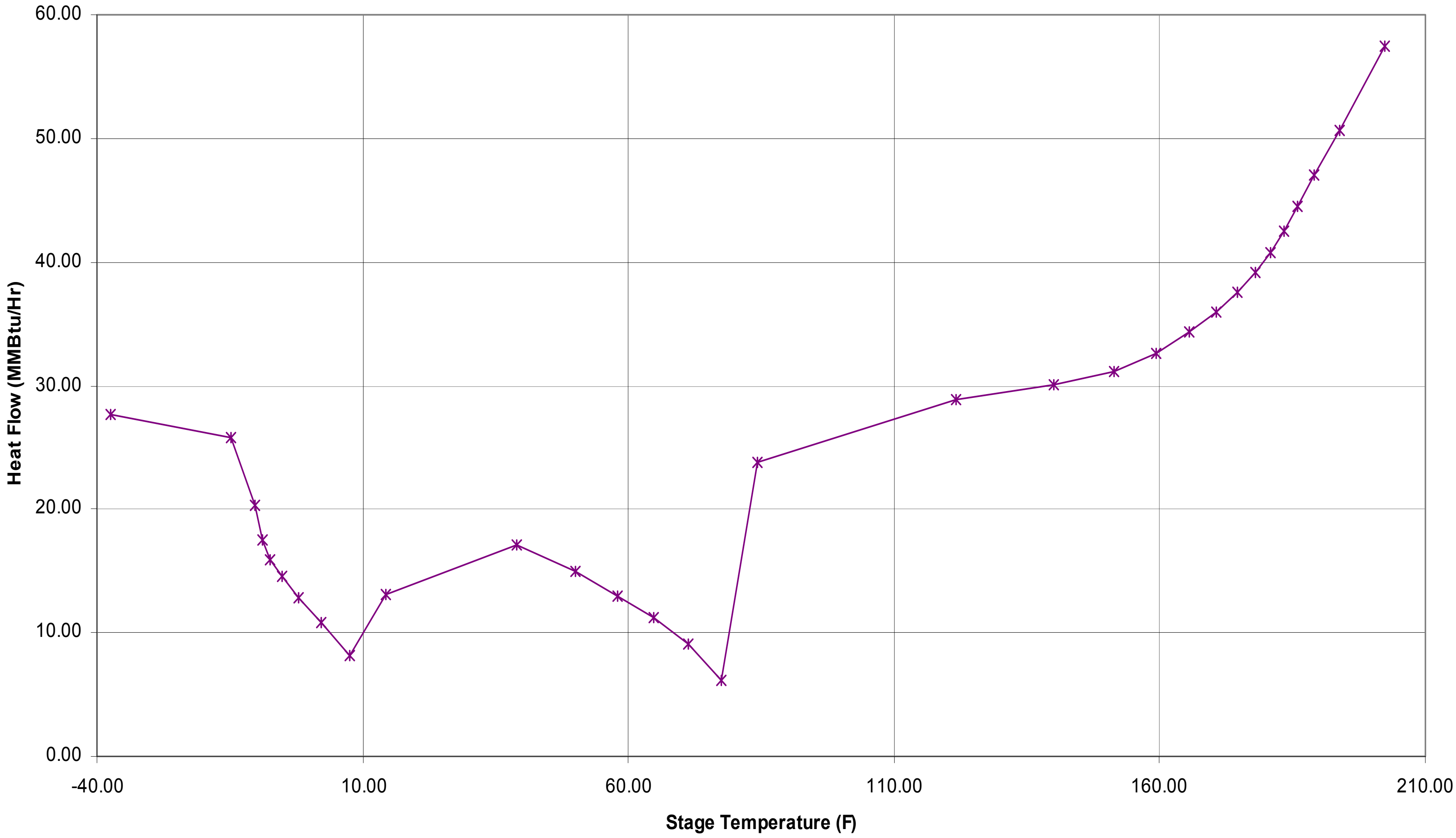



Figure 3

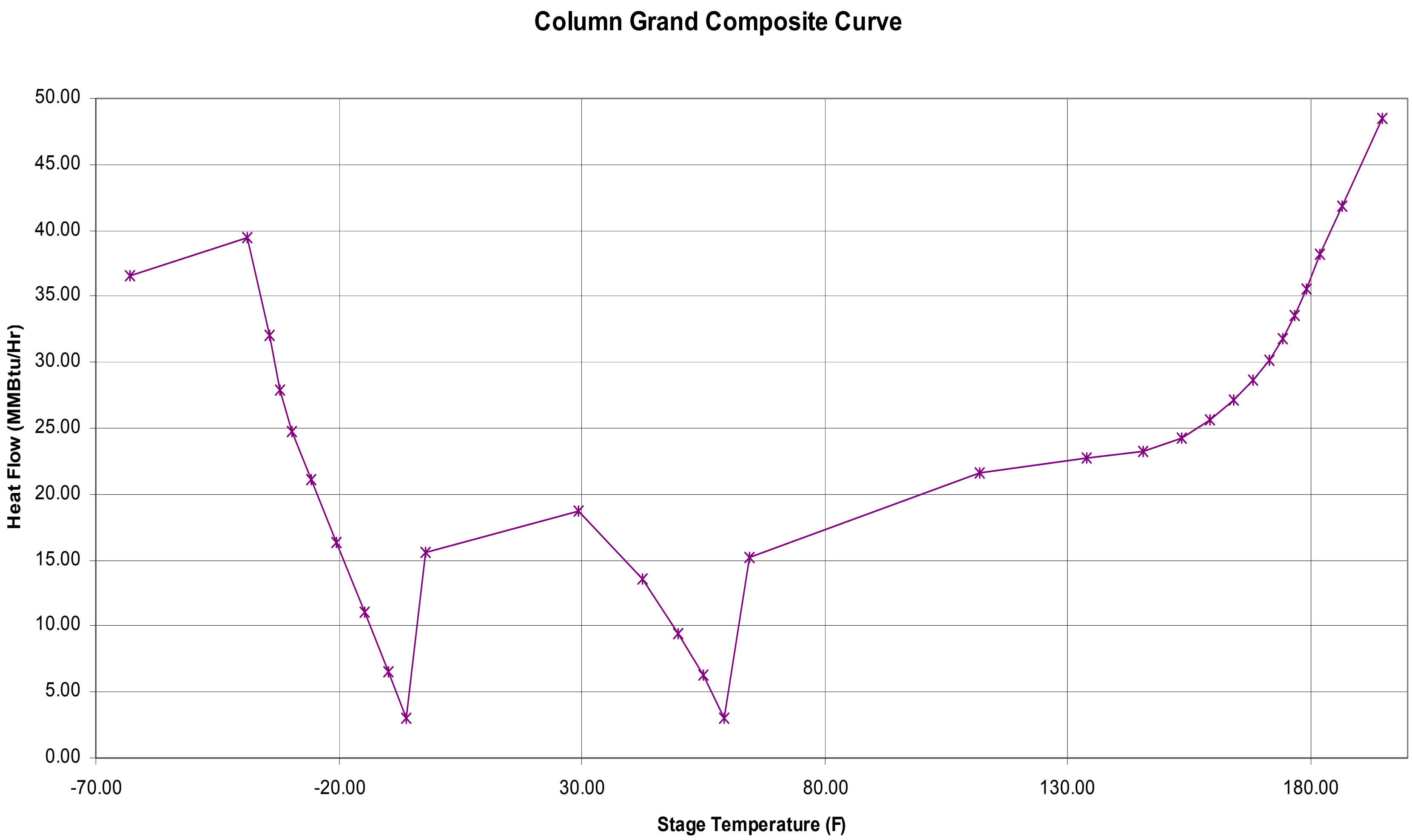
 

# Deethanizer CGCC – Conventional $C_3$ Recovery



# Deethanizer CGCC – HPA $C_3$ Recovery



# Application to Ethane Recovery

## Conventional Ethane Recovery

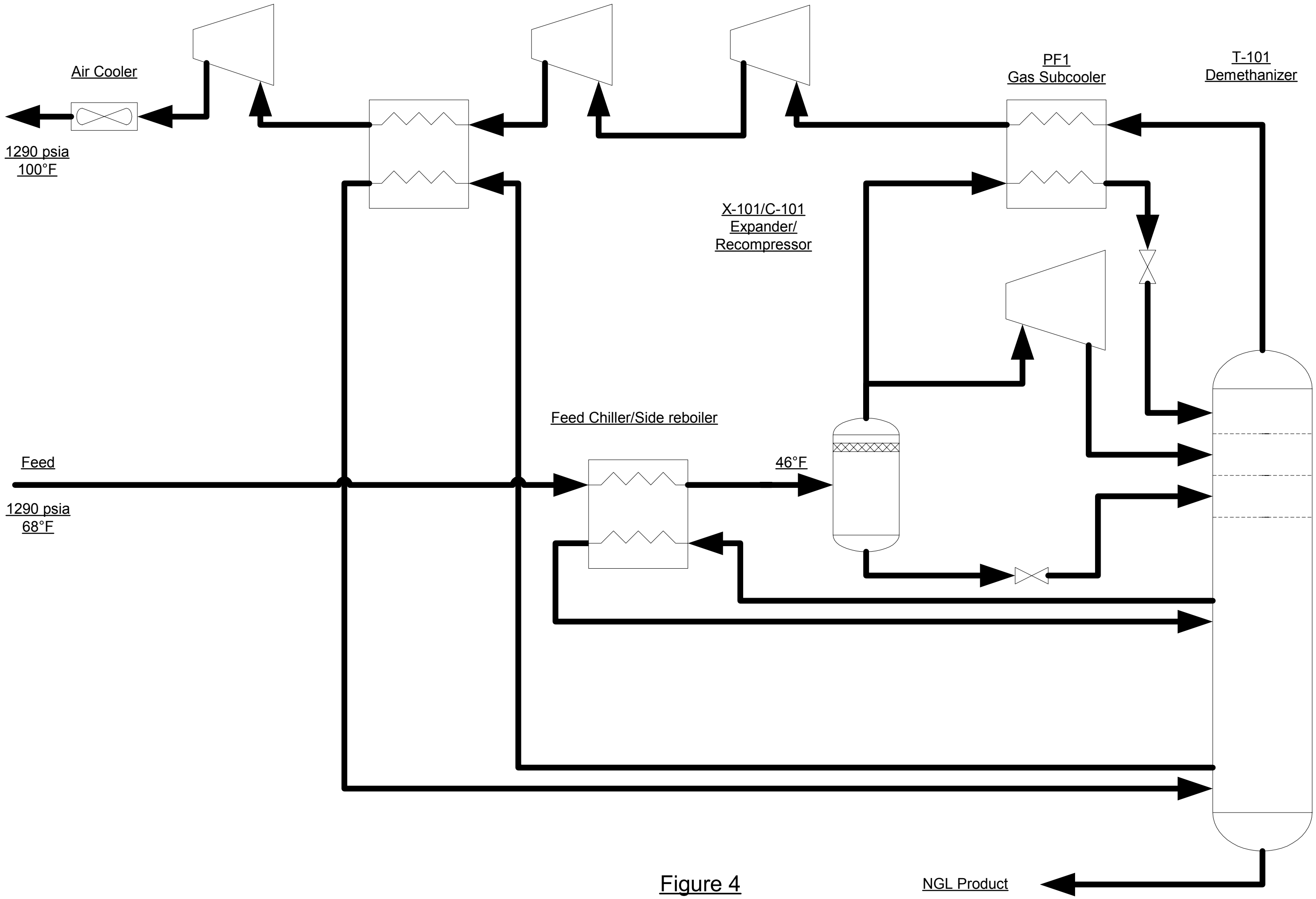



Figure 4

# Application to Gas Plants – $C_2$ Recovery

Thermodynamic Analysis of a Conventional Ethane Recovery Process

| Equipment | $W_{ideal}$ | $W_{shaft}$ | $W_{lost}$ | % of lost |
|---|---|---|---|---|
| Exchangers | 5,773 | 0 | 5,773 | **15.2** |
| Valves | 4,184 | 0 | 4,184 | **11.0** |
| Columns | 6,539 | 0 | 6,539 | **17.2** |
| Rotating Equipment | -30,383 | -47,348 | 16,965 | **44.6** |
| Air Cooler | 4,573 | 0 | 4,573 | **12.0** |
| Total | **-9,313** | **-47,348** | **38,035** | 100.0 |

# Application to Gas Plants – $C_2$ Recovery

## New Concept

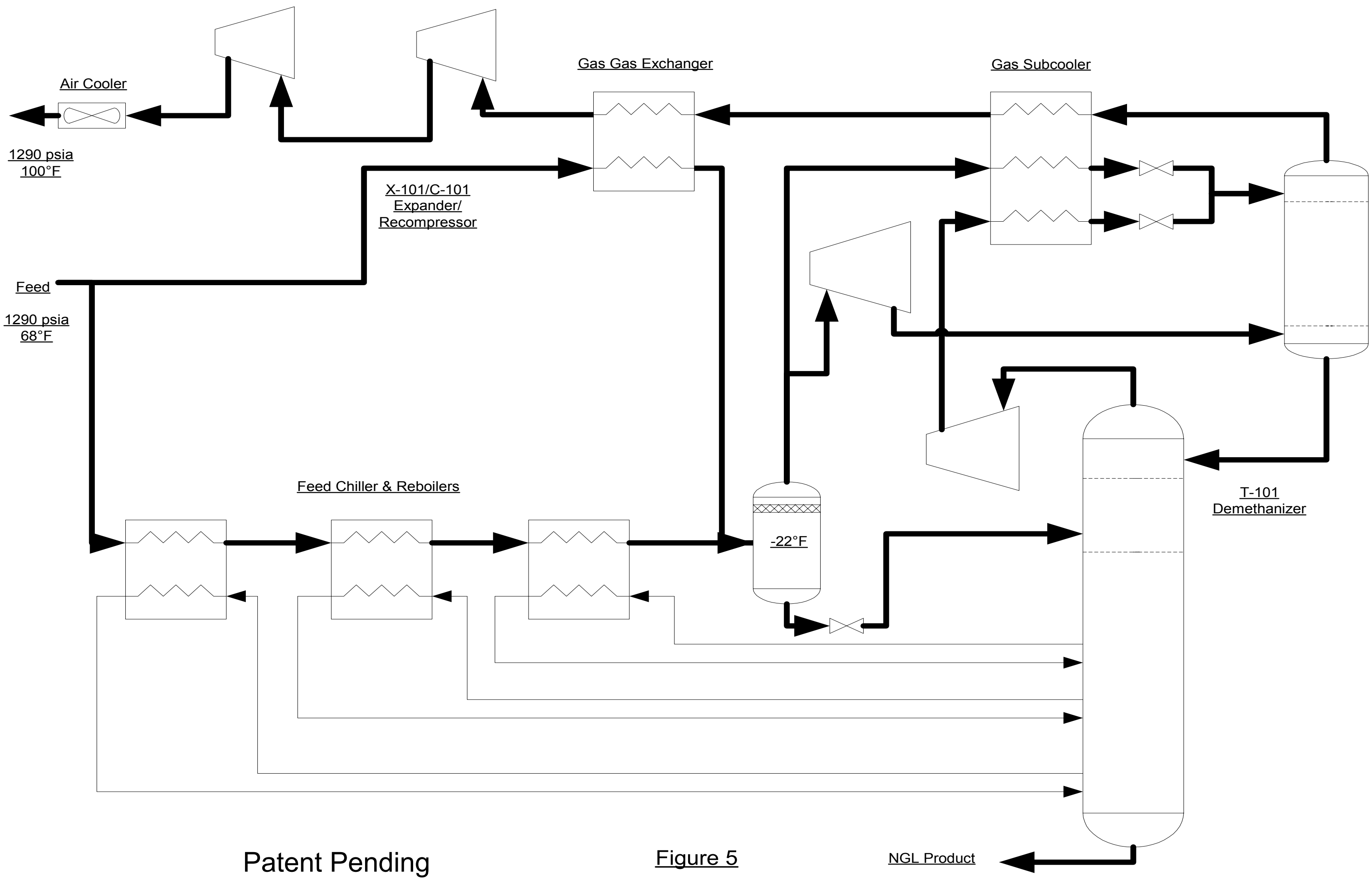



Figure 5

# Application to Gas Plants – $C_2$ Recovery

Thermodynamic Analysis of HPA for Ethane Recovery

| Equipment | $W_{ideal}$ | $W_{shaft}$ | $W_{lost}$ | % of lost |
|---|---|---|---|---|
| Exchangers | 4,248 | 0 | 4,248 | **13.0** |
| Valves | 3,498 | 0 | 3,498 | **10.7** |
| Columns | 6,976 | 0 | 6,976 | **21.4** |
| Rotating Equipment | -28,709 | -42,501 | 13,792 | **42.3** |
| Air Cooler | 4,058 | 0 | 4,058 | **12.5** |
| Total | **-9,929** | **-42,501** | **32,572** | 100.0 |

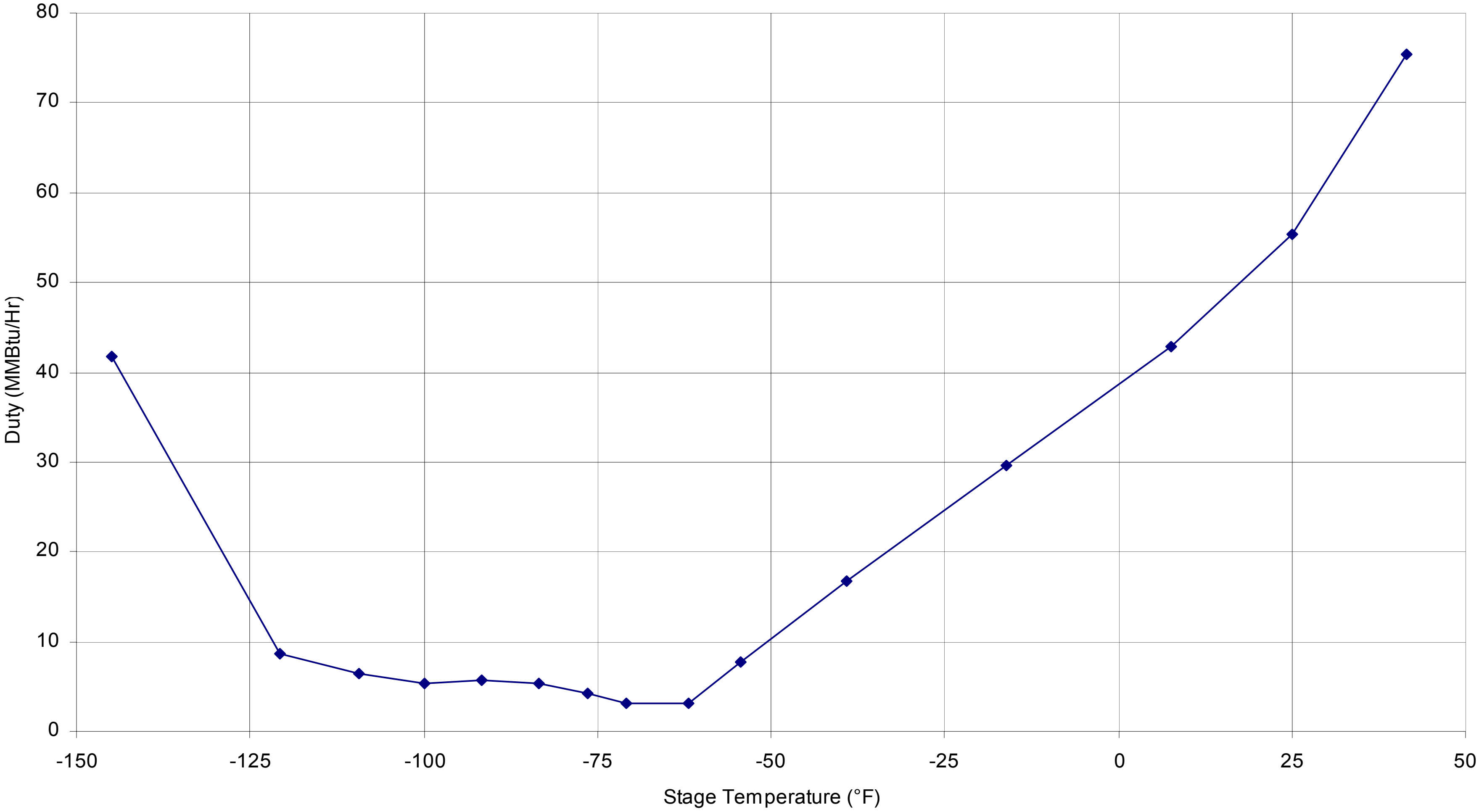
# Comparison for the $C_2$ Recovery Process

## Comparison to Conventional GSP Scheme

| | Conventional Scheme | | HPA Scheme | |
|---|---|---|---|---|
| | Lost Work | Percent | Lost Work | Percent |
| Exchangers | 5,773 | **15.2** | 4,248 | **13.0** |
| Valves | 4,184 | **11.0** | 3,498 | **10.7** |
| Columns | 6,539 | **17.2** | 6,976 | **21.4** |
| Rotating Equipment | 16,965 | **44.6** | 13,792 | **42.3** |
| Air Cooler | 4,573 | **12.0** | 4,058 | **12.5** |

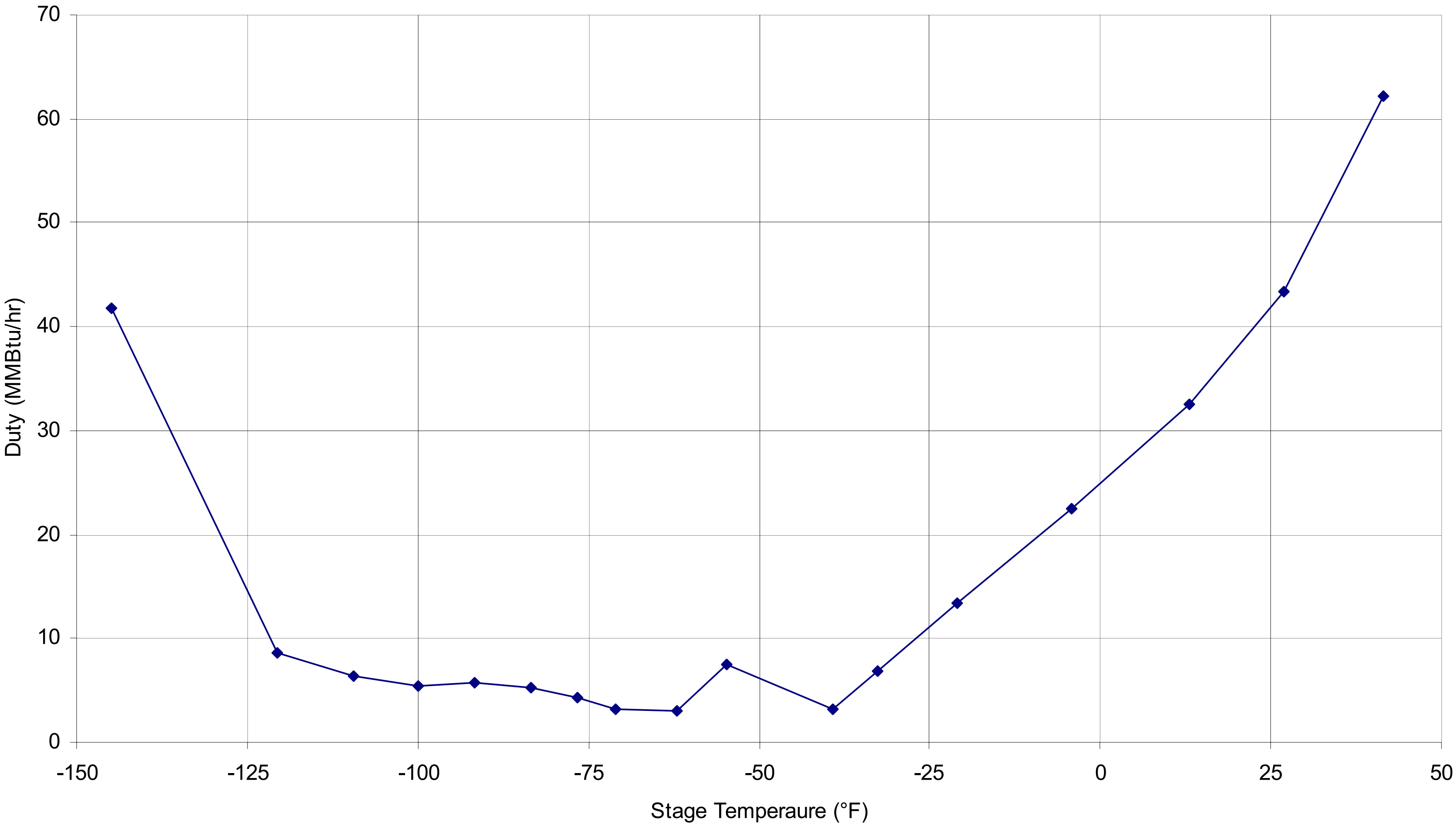
| | | |
|---|---|---|
| Total Lost Work | **38,035** | **32,572** |
| Total Actual Work | **47,348** | **42,501** |

# Demethanizer CGCC – No Side Reboilers



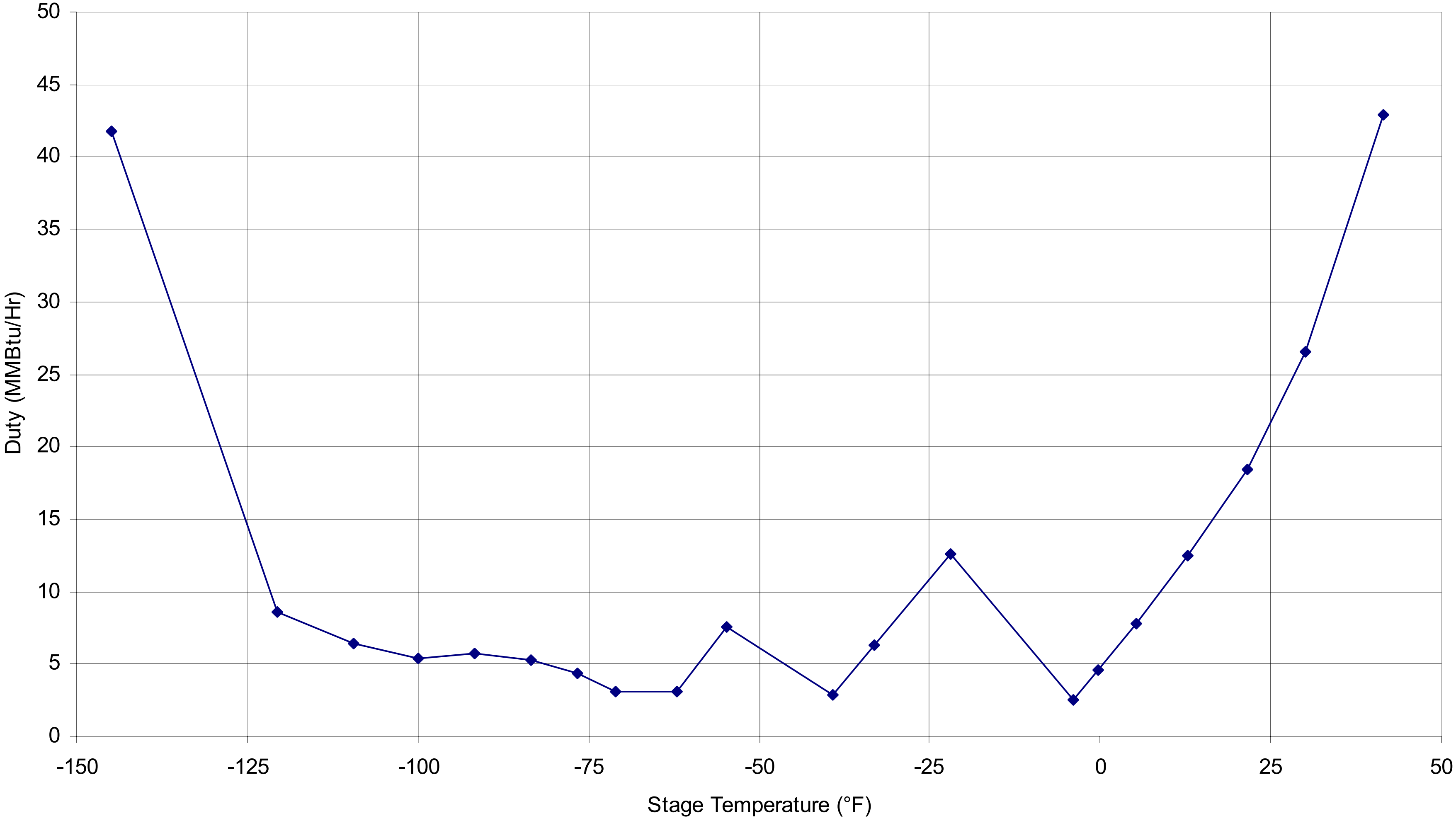

 

# Demethanizer CGCC – 1 Side Reboiler



# Demethanizer CGCC – 2 Side Reboilers



# Application to Ethane Recovery

## Conventional Ethane Recovery

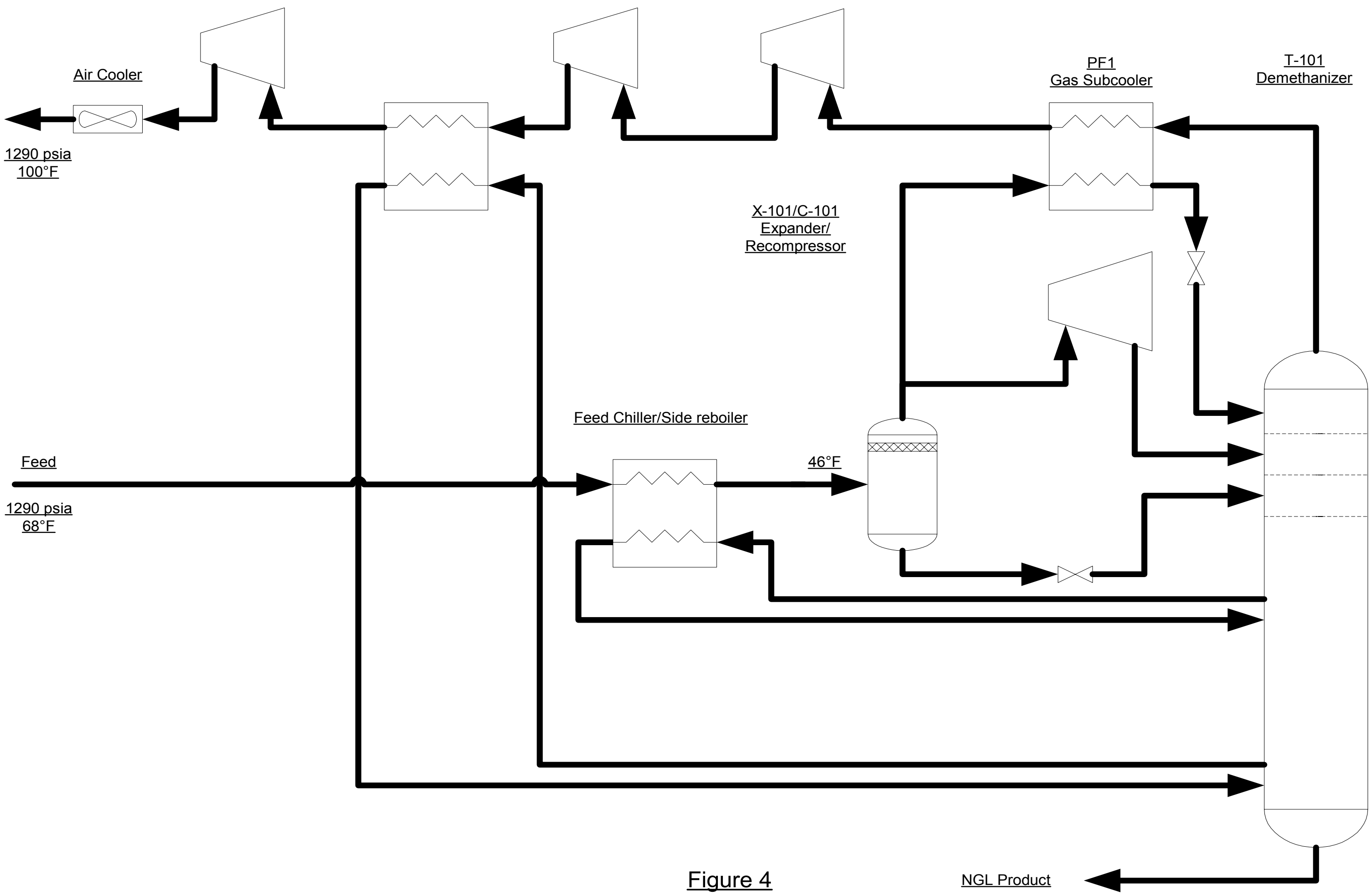
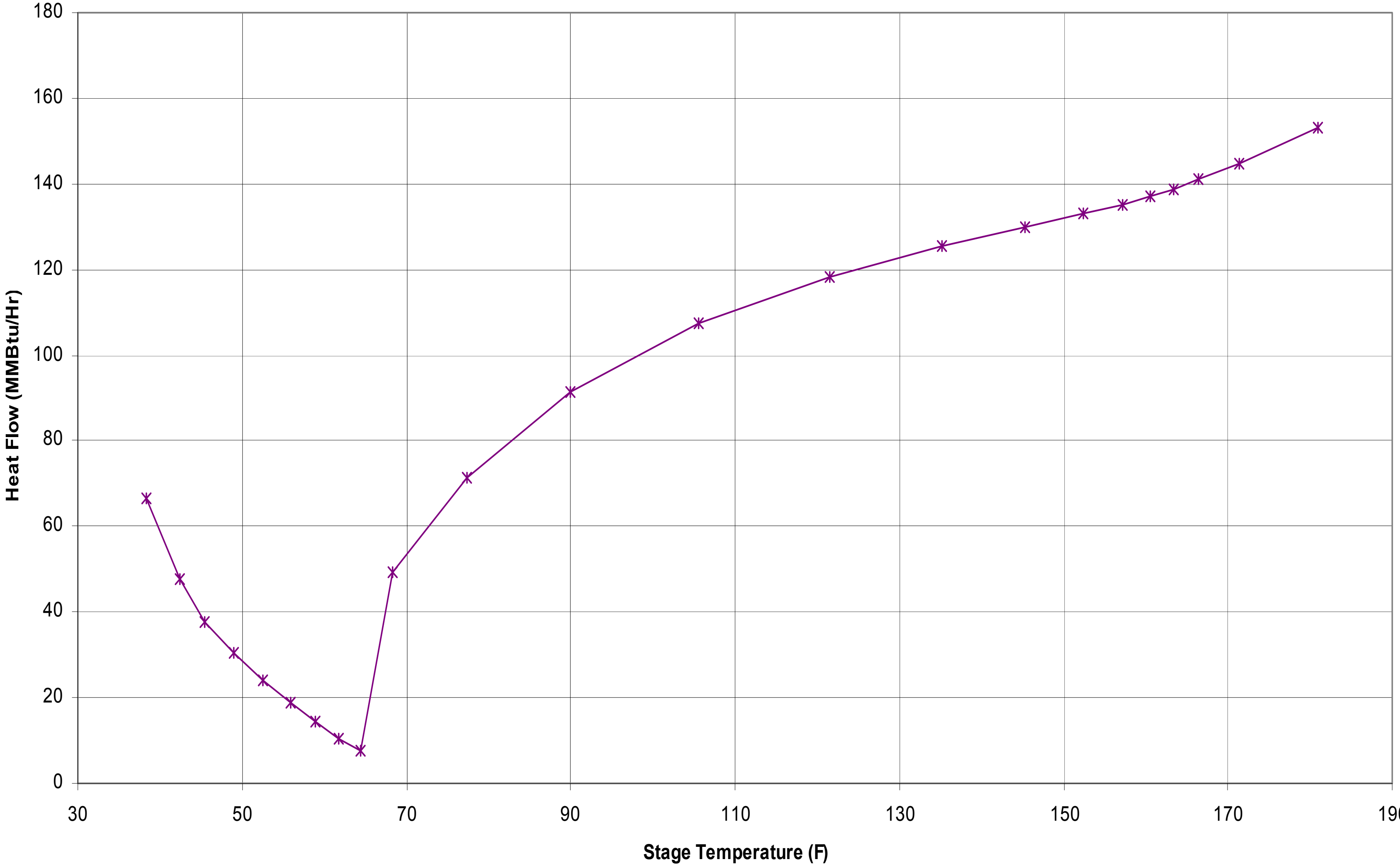



Figure 4

# More on Column Targeting



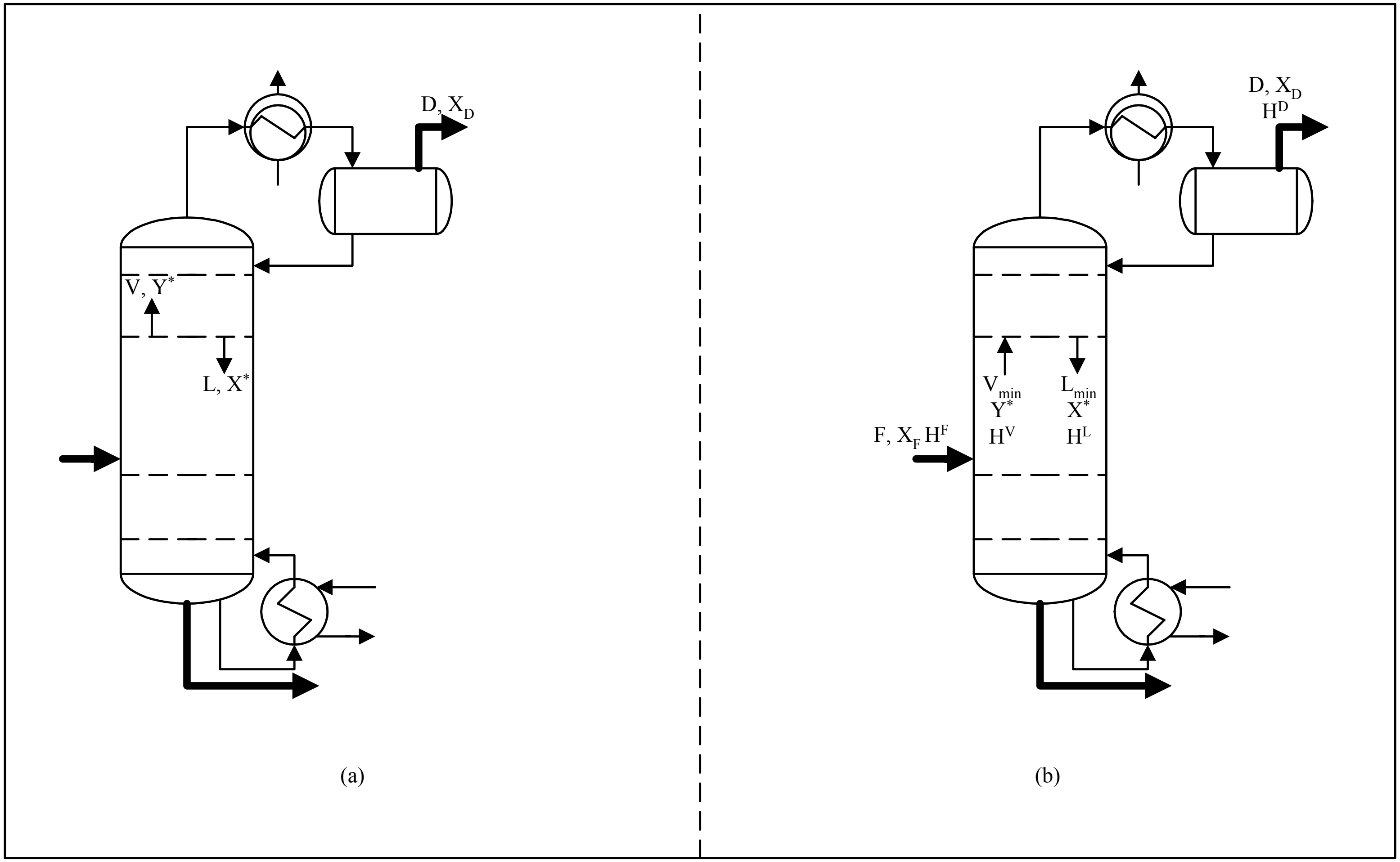
# More on Column Targeting

- Minimum Condenser/reboiler duties.
- Percent above minimum reflux/stripping.
- Maximum amount of heat that can be added/removed by a side exchanger.
- A measure of reversibility.

# Column Targeting

- Let's consider a simple distillation column with a condenser and a reboiler. By definition, the streams exiting the ideal stage are at equilibrium.



# Column Targeting

- An overall material balance yields

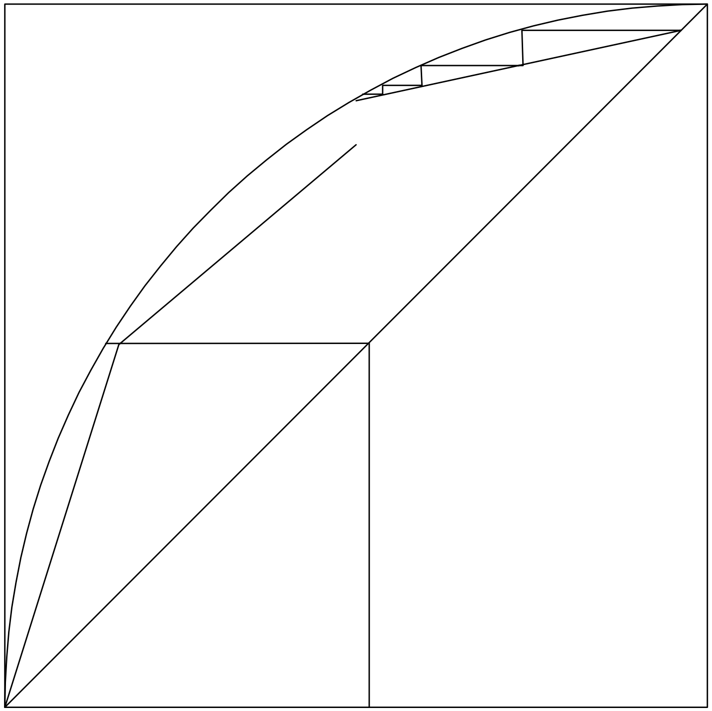
$$V_{\min} = D + L_{\min}$$

- A light key component material balance yields

$$Y^{*} V_{\min} = X_{D} D + X^{*} L_{\min}$$

Solve for $L_{min}$ and $V_{min}$

$$H_{deficit} = H^{V} V_{\min} - H^{L} L_{\min} - H^{D} D$$



# Conclusions & Recommendations

- The statue was already in the rock…All I had to do was take it out… Michel Angelo
- With current computer technology, thermodynamic analysis of a process is no longer a tedious process.

*Thank You!*

# High Pressure Absorber Process – $C_3$ Recovery
(Pat. Pending)

## Comparison to Traditional Two-Tower Scheme

| | Two-Tower Scheme | High Pressure Absorber |
|---|---|---|
| Absorber Pressure,psig | 440 | 700 |
| Residue Comp. HP | 44,242 | 30,913 |
| Overhead Compression | --- | 3,770 |
| Major Equipment Count | 12 | 12 |
| Plate-Fin UA / $10^6$ | 5.1 | 19.3 |
| Cooling/Heating, mmbtu/hr | 177 | 126 |

# High Pressure Absorber Process – $C_2$ Recovery

## Comparison to Traditional Two-Tower Scheme

| | Two-Tower Scheme | High Pressure Absorber |
|---|---|---|
| Absorber Pressure,psig | --- | 580 |
| Residue Comp. HP | 47,348 | 42,498 |
| Overhead Compression | --- | 5,210 |
| Major Equipment Count | 12 | 14 |
| Plate-Fin UA / $10^6$ | 20.6 | 47.7 |
| Cooling/Heating, mmbtu/hr | 108 | 100 |
| $CO_2$ Freezing Margin,°F | | |



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