IHS INTERNATIONAL: US POISED TO LEAD WORLD EXPORTS OF LPG

From Oil and Gas Journal on March 25, 2014:

- 2013 U.S. LPG waterborne exports – 300,000 b/d
- 2020 U.S. LPG waterborne exports – 800,000 b/d

US exports will exceed exports by all of the other suppliers

- 2013 Global LPG production/demand – 8,500,000 b/d
- 2020 Global LPG production/demand – 10,000,000 b/d

Production for domestic use and exports

Based on an article by Warren R. True, OGJ Chief Technology Editor reporting in HIS Senior Director of NGL Research Walt Hart’s opening address to HIS International LPG Seminar in Houston on March 24, 2014.
BUT 2015 LOOKS DIFFERENT THAN 2014

The LPG/NGL spot prices:

- **Propane**
  - 2014 Spring/Summer – average about $1/gallon
  - 2015 Winter – average about $0.5/gallon
  
  *Mt. Belvieu spot pricing published by U.S. Department of Energy*

- **Ethane**
  - Between Summer and Winter of 2014 ethane prices dropped by 41% to about $0.1725/gallon
  
  *Financial Times – “Shale byproduct prices track oil plunge”, December 18, 2014*

- **Is this good or bad for US exports?**
The Exports Continue to Rise

Data 1: U.S. Exports of Propane and Propylene (Thousand Barrels per Day) MPREXUS2 U.S. Exports of Propane and Propylene (Thousand Barrels per Day)

- September 2012 – 148,000 bpd
- September 2013 – 333,000 bpd
- September 2014 – 457,000 bpd
The Exports Continue to Rise

- September 2012 – 0 bpd
- September 2013 – 0 bpd
- September 2014 – 46,000 bpd
Domestic production of Natural Gas Liquids is increasing.
Domestic supply of NGLs exceeds domestic demand.
Domestic pricing of NGLs remains below the pricing in the other parts of the world.
Solution – increase demand by expanding the market via product exports.
PRESENTATION OUTLINE

- Ocean gas carriers
- Sources and types of products
- Components of export facility
- Refrigeration systems
  - Direct systems
  - Indirect systems
  - Cascading systems
  - Handling storage tanks vapors
- Typical system components
  - Air versus evaporative cooling
  - Compression machinery considerations
  - Modularization
Three basic types of ships available on the market:

• **Pressurized (small)**
  - Capacities typically less than 25,000 barrels (4,000 m³) of cargo

• **Semi-pressurized (medium)**
  - Capacities typically up to 190,000 barrels (30,000 m³) of cargo

• **Refrigerated (large and very large)**
  - Capacities typical above 450,000 (70,000 m³) barrels of cargo

Classification based on MARV or Maximum Allowable Relief Valve Setting of the ship tanks.
OCEAN GAS CARRIERS

- Pressurized
  - MARV up to 260 psig
  - Minimum operating temperature above 32 deg F
- Semi-pressurized
  - MARV between 70 and 100 psig
  - Minimum operating temperature -54 deg F available as low as -155 deg F for ethylene transport
- Refrigerated
  - MARV less than 10 psig
  - Typical operating pressure less than 4 psig Minimum operating temperature between -58 and -54 deg F

For transportation of ethane or ethylene onboard fully refrigerated vessels the minimum design operating temperatures will have to be below those listed above.
FIGURE 1 - TYPICAL GAS CARRIERS
TYPES OF PRODUCTS

• Propane:
  • HD-5
    • 90-95% propane
    • Up to 7% ethane, up to 5% propylene, 2-3% butanes
  • Purity propane (HD-2)
    • Minimum 98% propane
    • Balance mainly ethane

• Ethane:
  • Purity product – ethane above 98%, balance propane and methane

• Butanes, Propylene and Ethylene:
  • Typically 99%+ pure
<table>
<thead>
<tr>
<th>Composition (liquid fractions)</th>
<th>Pressure (psig)</th>
<th>Temperature (degrees Fahrenheit)</th>
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<tbody>
<tr>
<td></td>
<td>0</td>
<td>2</td>
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<tr>
<td>HD-5</td>
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<tr>
<td>95% C3, 0.5% nC4, 0.5% iC4, 4% C2</td>
<td>-52.7</td>
<td>-47.3</td>
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<td>92% C3, 1% nC4, 1% iC4, 6% C2</td>
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<td>92% C3, 8% C2</td>
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<td>90% C3, 10% C2</td>
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<tr>
<td>HD-2</td>
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<tr>
<td>98% C3, 2% C2</td>
<td>-48.6</td>
<td>-43.2</td>
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<tr>
<td>99% C3, 1% C2</td>
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<td>-41</td>
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<tr>
<td>Purity Ethane</td>
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<td>98% C2, 2% C3</td>
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<tr>
<td>99% C2, 1% C3</td>
<td>-127.4</td>
<td>-123</td>
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<td>98.5% C2, 1% C3, 0.5% C1</td>
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<td>-131.5</td>
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<td>Butanes</td>
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<tr>
<td>100% nC4</td>
<td>31.3</td>
<td>37.5</td>
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<tr>
<td>100% iC4</td>
<td>11</td>
<td>17</td>
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<td>Propylene</td>
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<tr>
<td>100% C3H6</td>
<td>-53.4</td>
<td>-48.2</td>
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<tr>
<td>Ethylene</td>
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<td></td>
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<tr>
<td>100% C2H4</td>
<td>-155.3</td>
<td>-151.3</td>
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<tr>
<td>Ammonia</td>
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<tr>
<td>100% NH3</td>
<td>-27.4</td>
<td>-22.8</td>
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<tr>
<td>Carbon Dioxide</td>
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<tr>
<td>100% CO2</td>
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<td>-</td>
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</tbody>
</table>

Notes:
- Peng-Robinson EOS
- 14.7 psia atmospheric pressure
- CO2 triple point: 75 psia; -69.9 deg F

Figure 2 - Bubble point temperatures of common liquids
COMPONENTS OF EXPORT FACILITY

Typical components of the export facility consist of:

- Optional Inlet separation, filtration and storage
- Optional Dehydration system.
- Refrigeration and boil-off system
- Product storage and loading
- Product metering
COMPONENTS OF EXPORT FACILITY

Facility throughput rates:

- Typically feed rates different from load out rates.
- Feed can be continuous if product supplied via pipeline or from storage; batch if brought in using rail cars.
- Load out rates determined by ship size, turn around time, etc.
- Possible to chill only a part of the feed, especially for semi-pressurized transport.
REFRIGERATION SYSTEMS

• Refrigeration and boil-off system converts warm/high pressure liquid feed into cold/low pressure product stream

  • Feed at close to ambient temperature and pressure around 300 psig or higher
  • Product at bubble point temperature and pressure less than 50 psig (typically at atmospheric pressure)
  • Direct or Open Systems
    • Utilize product itself as a refrigerant
  • Indirect or Closed Systems
    • Utilize closed loop refrigeration system
  • Cascading Systems for ethane and ethylene
DIRECT SYSTEMS

• The systems that utilize product as a refrigerant
  
  • Preferred for purity products such as purity propane and propylene.
  • Feed flashed to intermediate pressure and then flashed again to load-out pressure.
  • Flash vapors removed by two stage compression system, condensed and returned to the feed.
  • Optional subcooler between intermediate and low pressure tanks to reduce over compression power.
  • The refrigeration system can be incorporated to handle boil-off and ship vapor.
  • Butane chilling can be handled by the 2nd stage compression.
FIGURE 5 - TYPICAL OPEN REFRIGERATION SYSTEM FOR LPG EXPORT
IN-DIRECT SYSTEMS

- The systems that utilize closed loop refrigeration system independent from the product

  - Preferred for HD-5 and products having varying composition.
  - Feed refrigerated in single or multiple conventional chillers.
  - Refrigeration handled by a single or two stage compression.
  - Separate compression system required to handle boil-off and ship vapor.
  - Butane chilling handled in a similar fashion to direct systems.
FIGURE 6 - TYPICAL CLOSED REFRIGERATION SYSTEM FOR LPG EXCERPT
CASCADING SYSTEMS

• Typically a mix of direct product and in-direct refrigeration systems in a cascading arrangement
  
  • Utilized for exporting ethane and/or ethylene product.
  • Product pre-chilled by closed loop propane or propylene refrigeration system.
  • Flashed product vapors re-compressed and re-condensed in a cascading condenser against propane or propylene.
  • Both ethane/ethylene and propane/propylene systems utilize independent compression equipment.
  • Increased complexity over direct and in-direct systems used for low vapor pressure product chilling.
FIGURE 7 - TYPICAL REFRIGERATION SYSTEM FOR ETHANE EXPORT
HANDLING STORAGE TANKS VAPORS

- Tank vapors have to be removed or tank pressure will rise.
  - Liquids are typically stored at low pressure and temperature.
  - Vapor is generated due to ambient heat leak and vapor displacement by liquid during product loading
    - Vapor displacement called a “piston effect” governs boil off rates especially for large loading rates.
  - Propane or high vapor pressure liquid vapors will be removed by a compression equipment, re-condensed and returned to the tank
  - Butane vapors will be re-condensed against propane and pumped back to the tank.
TYPICAL SYSTEM COMPONENTS

- Components typical for any refrigeration system
  - MAWP below 350 - 400 psig (24 - 28 barg)/ANSI class 300
  - Compression – mainly oil flooded screw and centrifugal
    - 2 x 50%, 2 x 100%, 3 x 33%, etc.
    - Multiple units beneficial if plant throughput rates expected to vary
  - Conventional shell and tube heat exchangers
    - TEMA C and ASME section VIII, Div.1 design
  - Conventional ASME pressure vessels
  - API or refrigeration style manual valves
  - Carbon steel materials of construction for temperatures above -50 deg F (-46 deg C)
  - Stainless steel materials for temperatures below -50 deg F (-46 deg C)
AIR VS. EVAPORATIVE COOLING

• Air cooled – temperature approach based on dry bulb temperature
• Evaporative – temperature approach based on wet bulb temperature
  • ASHRAE data (0.4%) for Port Arthur, Texas
    • Design DBT – 94.2 deg F
    • Design WBT – 78.1 deg F
  • Evaporative cooling reduces condensing temperature
  • This results in decreased 2nd stage compressors discharge pressure and power
    • Evaporative coolers require treated make-up water
• Should we be designing the systems based on the highest load and temperatures occurring 0.4% of the time or less?
• Oil flooded screw compressors
  • Positive displacement machinery
  • Off-the shelf design
  • Approximately max. 6000-7000 ACFM at suction per machine
  • Driven by 2 or 4 motor driver or gas engine
  • Lube oil used for bearing and seal lubrications as well as rotors sealing and compressed gas cooling
  • Slide valve capacity control to 15-20% of its maximum capacity
  • Oil carryover less than 10 or 1 ppmw
OIL FLOODED SCREW COMPRESSOR – COURTESY OF HOWDEN
OIL FLOODED SCREW COMPRESSOR – COURTESY OF HOWDEN
ASSEMBLED 1ST AND 2ND STAGE SCREW COMPRESSORS
CROSS-SECTIONAL VIEW OF AN OIL FLOODED SCREW COMPRESSOR – COURTESY OF HOWDEN
CROSS-SECTIONAL VIEW OF AN OIL FLOODED SCREW COMPRESSOR – COURTESY OF HOWDEN
Centrifugal compressors

- Dynamic machinery
- Custom design
  - Between-the-bearing multistage
  - Integrally geared multistage
- Large flow capacities
- Driven by 2 or 4 motor drivers or gas turbines
  - Through a gearbox
- Lube oil free compression with dry gas seal system
- Pre-rotational vanes and diffusers if available used for capacity control
- Some turndown
- Surge control required
INTEGRALLY GEARED CENTRIFUGAL COMPRESSOR – COURTESY OF ATLAS COPCO
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Core/Gearbox

- Horizontally-split gearbox for easy access to gearing bearings and seals
- Helical, speed increasing gears
- Rotor assembly precisely balanced by computer analysis of predicted rotor dynamics
- Horizontally-split bearings and seals are easily replaced
- Bearing and gear inspection without disassembling of casing or gas piping
INTEGRALLY GEARED CENTRIFUGAL COMPRESSOR – COURTESY OF ATLAS COPCO
MODULARIZATION

Just like any other refrigeration system, the LPG export systems can be modularized

- Systems built in controlled manufacturing type environment
- Modules fitted, piped, tubed, wired and painted
- Minimized field installations costs and time
- Fully integrated design
SCREW COMPRESSOR DRIVETRAIN
CHILLING TRAIN
THANK YOU!

• Questions?