ASU and CO$_2$ Processing Units for Oxyfuel CO$_2$ Capture Plants

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WORKSHOP ON OPERATING FLEXIBILITY OF POWER PLANTS WITH CCS
Imperial College, London, UK
11th – 12th November 2009
Oxyfuel combustion requires...

- Air Separation Units
- Steam Boiler & Turbine
- CO$_2$ Purification & Compression
- CO$_2$ Transport & Sequestration

Steam Boiler & Turbines

O$_2$ Supply

Oxygen

Coal

Flue Gas Recycle

MW$_e$
Large air separation units (ASUs)
Demonstrated Air Separation Capabilities

- **Technology base**
  - Cryogenic air separation
    - Up to 7,000 t/d
    - plus co-product nitrogen, argon, and other rare gases
    - Nitrogen only configurations
  - Non cryogenic air separation
    - From 2 t/d
    - Adsorption (PSA/VSA)
    - Membrane

- **Experience**
  - Worldwide presence
    - >1,200 air separation units owned or sold
    - >500 units operated and maintained
  - Major pipeline systems include:
    - US Gulf Coast
    - California
    - Rotterdam, Netherlands
    - China
    - Korea
    - South Africa
Experience - Large ASU Projects and Train Scale-up

- Market drives ASU scale-up
- Proven 70% scale-up
- Quoting 5,000+ tonne/day today
Overview Of The Process

Main and Boost Air Compression

Air Cooling and Pretreatment

Cryogenic Separation

Storage

Air

Heat

Oxygen

Heat
Process Cycle Selection Criteria

- Oxygen demand profile
  - Purity
  - Pressure
  - Demand pattern, quantities, duration, frequency

- Argon co-production required?

- Power evaluation criteria

- Capex sensitivity

- Process integration philosophy

- Utility constraints, e.g. steam availability & quality, water consumption

- Operating constraints, e.g. availability, reliability, time to on stream, ramp rate.
A5000 Single Train
VLASU Integration challenges to Oxycoal power plants

Design based on customer’s specific requirements:

- Parasitic load
  - Power vs. Capital costs
  - Purity requirements
  - Co-products
  - Compression integration

- Manufacturing
  - Transport of ASU(s) to site
  - Reducing construction / erection costs and risks

- Operability
  - Fit with customer’s use patterns
    - Turndown / ramping up
  - Advanced control capabilities

- Reliability
Compression: VLASU Design Considerations

- Compression is typically a large component of the cost stack
- We consider power valuation when designing # of trains
  - Multistage or single stage cooling
- Cooling water integration
  - Location of plant
  - Cost of cooling water / Type of systems
- Compression Driver
  - Steam turbines
  - Gas turbines
  - Motor technology / Starting system
- Erection / Packaging strategy
  - Field erect
  - Shop modules (pre-package)
- Cost Impacts
  - Axial vs. In-line cost or integral gear (up to 7000 TPD)
  - Need for soft start as compressor motors increase in size
  - Limited or reverse economies of scale for large vessels, piping and valves
  - Shipping costs or transportation limits
Compression: Design Considerations

Oryx- Qatar – 2x3500 TPD

- MAC—Steam Turbine—BAC
- Air Cooled Condenser
- Shop Skids
- String Test

A5000 and A7000 TPD – Single Train Compression
- Axial main air compressor (no GT integration)
- In-line boost air and nitrogen compressors
- Four large suppliers = GE, MHI, Siemens, MAN

A5000:
GE Frame 7
Siemens STC 1000
MAN AR130-AR140
MHI M501D

A7000:
GE Frame 7 - Frame 9
Siemens STC 1300
MHI M501F

A5000 and A7000 TPD – (2x Compression – Multitrain)
- Integral gear (GT Copco or STC) or In-line air compressors (RIK)
- Integral gear or In-line boost air and nitrogen compressors (if N2 needed)
Air Products operates the majority of plants that it designs and builds.

Thousands of man-years of ASU operating experience includes customers that require 100% availability of products:

- Average plant availability is greater than 99%
  - Average duration of plant trip is ~16 hr
  - Spare parts handling strategies in place
  - Maintenance shutdown once/3+ yrs
    - Coincide with normal power plant maintenance
- Instantaneous back-up systems in place today in safety-sensitive and electronic applications
Operability: Plant Ramping, Advanced Controls technology

- Benefits of Advanced Control capabilities
  - Lower power consumption
  - Higher product recoveries
  - Faster disturbance response and mitigation
  - Faster response to changing product demands
  - Higher multi-plant efficiency

- ASU ramping capabilities
  - 1%/min typical
  - 2%/min achievable with advanced control
  - 3%/min possible when “designed in”
  - Higher rates possible by using liquid oxygen backup
Oxyfuel CO\textsubscript{2} Purification

- Oxyfuel combustion of coal produces a flue gas containing:
  - CO\textsubscript{2} + H\textsubscript{2}O
  - Any inerts from air in leakage or oxygen impurities
  - Oxidation products and impurities from the fuel (SO\textsubscript{x}, NO\textsubscript{x}, HCl, Hg, etc.)

- Purification requires:
  - Cooling to remove water
  - Compression to 30 bar: integrated SOx/NOx/Hg removal
  - Low Temperature Purification
    - Low purity, bulk inerts removal
    - High purity, Oxygen removal
  - Compression to pipeline pressure
Air Products’ Oxyfuel CO\textsubscript{2} Capture Technology

- Raw Flue Gas
- Sour Compression
  - Condensate Collection
  - Process Condensate
- Heat Recovery
- Boiler Steam Cycle
- CO\textsubscript{2} Compression
- Auto-Refrigerated Inerts ( +O\textsubscript{2} ) Removal Process
- Air Products PRISM\textsuperscript{®} Membrane
  - O\textsubscript{2} and CO\textsubscript{2} Rich [To Boiler]
  - Inerts Vent [To Atmosphere]
- Product CO\textsubscript{2}
Air Products’ CO₂ Compression and Purification System: Removal of SO₂, NOx and Hg

- SO₂ removal: 100%
- NOx removal: 90-99%

1.02 bar
30°C
67% CO₂
8% H₂O
25%
Inerts
SOx
NOx

30 bar to Driers
Saturated 30°C
76% CO₂
24% Inerts
Auto-Refrigerated Partial Condensation with CO\textsubscript{2} and O\textsubscript{2} recovered to the boiler

Driers

30 bar Raw CO\textsubscript{2}
Saturated 30°C
76% CO\textsubscript{2} 24% Inerts

To Boiler
Air Products’ CO₂ Purification and Compression Technology for Oxyfuel

**Sour Compression**
- SOₓ, NOₓ, Hg
- Removal

**Auto-Refrigerated**
- Inerts Removal
  - Ar, N₂, O₂

**Air Products’ PRISM® Membrane**
- For enhanced CO₂ + O₂ Recovery

- **SOₓ/NOₓ removed in compression system**
  - NO is oxidised to NO₂ which oxidises SO₂ to SO₃
  - The Lead Chamber Process
- **FGD and DeNOₓ systems**
- **Optimisation**
- **Elimination**
- **Low NOₓ burners are not required for oxyfuel combustion**
- **Hg will also be removed, reacting with the nitric acid that is formed**

- **Removal minimises compression and transportation costs.**
- **Optional O₂ removal for EOR-grade CO₂**
- **CO₂ capture rate of 90% with CO₂ purity >95%**
- **CO₂ capture rate depends on raw CO₂ purity which depends on air ingress**

- **Inerts vent stream is clean, at pressure and rich in CO₂ (~25%) and O₂ (~20%)**
- **Polymeric membrane unit – selective for CO₂ and O₂ – in vent stream will recycle CO₂ and O₂ rich permeate stream to the boiler.**
- **CO₂ capture rate increases to >97% and ASU size/power reduced by ~5%**
Path to from Lab to Demo

Cylinder fed bench rig

160 kW_{th} oxy-coal rig

15 MW_{th} oxy-coal combustion unit

30 MW_{th} oxy-coal pilot plant

1 MW_{th} slip stream

6 kW_{th} slip stream

0.3 MW_{th} slip stream

1 MW_{th} slip stream

DOE Project
Host: Alstom, Windsor, CT

50+MW_e oxy-fuel Demonstration

Schwarze Pumpe, Germany
ASU/CPU/Boiler Process Integration: Goals and Methods

- Reduce cost/improve efficiency without compromising operability

  “Easy” integrations
  - Use of by-product energy (Steam)
  - Combined utility systems (Cooling Water)
  - Air/nitrogen integration with gas turbines

  “Harder” integrations
  - Internal streams between process units
  - Start-up requires other units to be in operation
Summary

- There is a major new industry requirement for ASUs from fossil-fuel fired power generation.

- ASUs have changed a great deal in the past 15 years:
  - New cycles
  - Structured packing for distillation
  - More power efficient

- Single train sizes over 5000 tonne/day

- CO₂ Purification Units (CPU) being developed to purify raw CO₂

- Integration between ASU and CPU
It is about more than just $O_2$...

- **Air Products has APPLICATION EXPERIENCE**
  - Large oxygen/air separation equipment to all type of applications and industries (Power, Gasification, Metals, Refining / Petrochemicals, etc.)

- **Air Products has INTEGRATION EXPERIENCE**
  - Air separation plants in all integration modes
    - Oxygen supply control system
      - Load following, start-up shutdown, peak-shaving
    - MAC heat recovery
    - Off-gas oxygen recovery for boiler blended to LASU $O_2$
    - Standalone, nitrogen integrated, and air/nitrogen integrated (IGCC)

- **Air Products has MEGA-TRAIN EXPERIENCE**
  - Operating very large single train air separation plants since 1997 in Rozenburg, The Netherlands (3250 t/d); also installed a 2x3500 t/d unit in Qatar

- **Air Products demonstrates RELIABILITY**
  - First company to supply high-reliability tonnage oxygen for power projects without oxygen backup

- **Air Products provides OTHER GAS PRODUCTS**
  - Broad industrial gas industry experience creates synergies with $H_2$, CO, and $CO_2$ markets
Thank you

tell me more
www.airproducts.com