Lecture 12
Air Separation

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Goals

- Describe the basics of the cryogenic separation of air into useful products
- Describe how He is recovered from Natural Gas

Introduction

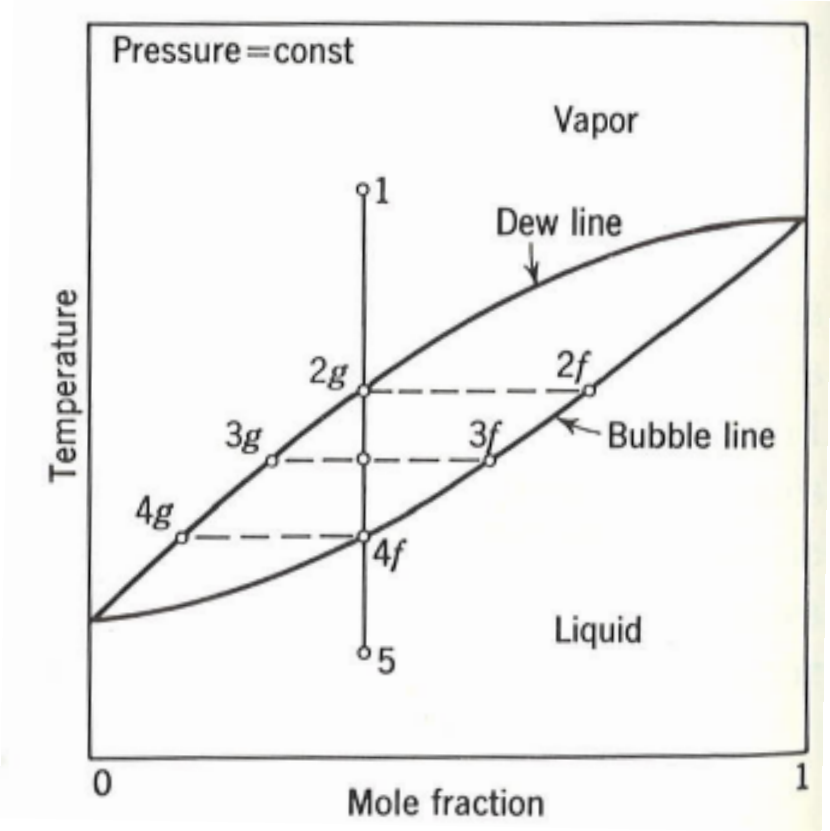
- While other techniques (adsoption, filtering by membranes, certain chemical reactions) exist, cryogenic air separation is the more efficient and mature technology for large scale air separation
- The separation of air into its constituent parts is a major industry and along with MRI systems is the bulk of the economic activity associated with cryogenics
- The technology associated with air separation is both mature and large scale – 10's to 1000's of tons per day per plant
- This industry involves the actual separation of the air and the distribution and storage of the resulting products
- Plants can be stand alone systems to separate air into its components for sale and distribution or can be incorporated into other industrial facilities (chemical plants, steel mills, oil fields) to produce gases specifically for use at that site.

Constituents of Air & Typical Uses

Element	Vol % in Dry Air	Boiling Point at 1 Atm (K)	Typical Uses
Nitrogen	78.08	77	Cryogenics, Enhanced Oil & Gas Recovery, Chemical Plants, Other Purging & Pressurization Uses
Oxygen	20.95	90	Chemical Plants, Steel Mills, Medical Gases, Welding Gases
Argon	0.93	87	Welding Gases, Inert Atmospheres, Incandescent & Florescent Lights
Neon	0.0018	27	Lighting and Signs
Helium	0.0005	4.2	Cryogenics, Welding Gas, Fiber Optics Processing, Lifting (Balloons, Blimps)
Krypton	0.00011	119.8	Incandescent & Florescent Lights
Xenon	0.000009	129	Incandescent & Strobe Lights

Cryogenic Air Separation

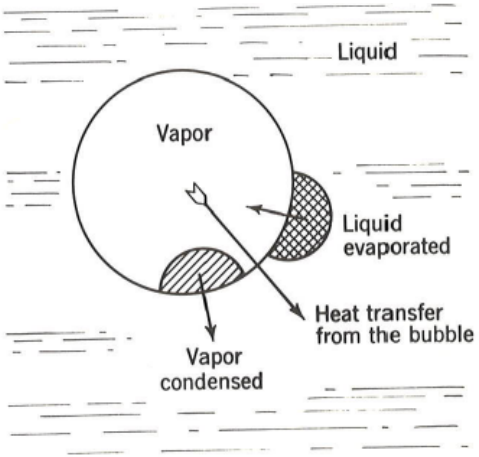
- All component gases (except He) are produced from air
  - He is recovered from certain natural gas fields where is concentration is 0.2 - 2 % or better
- In air separation plants, the working fluid is air which is of course a mixture not a pure fluid
- A basic principle of cryogenic air separation is Rectification
  - This is the cascading of evaporations and condensations done in counterflow



From Barron Cryogenic Systems

Cryogenic Air Separation

- Consider an idealized 2 component system (e.g. N_2 & O_2)
- As the bubbles move through the liquid, the higher boiling point component condenses out
- Thus, the bubbles become progressively richer in the lower boiling point component (N_2) while the liquid flowing downwards becomes richer in the higher boiling point component (O_2)



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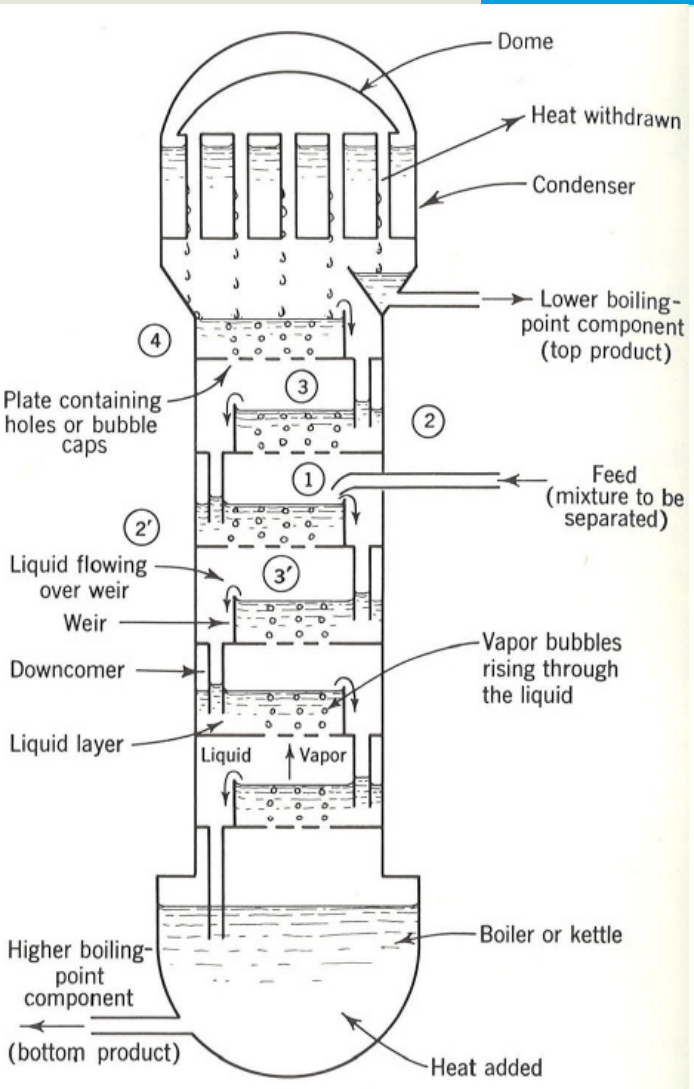
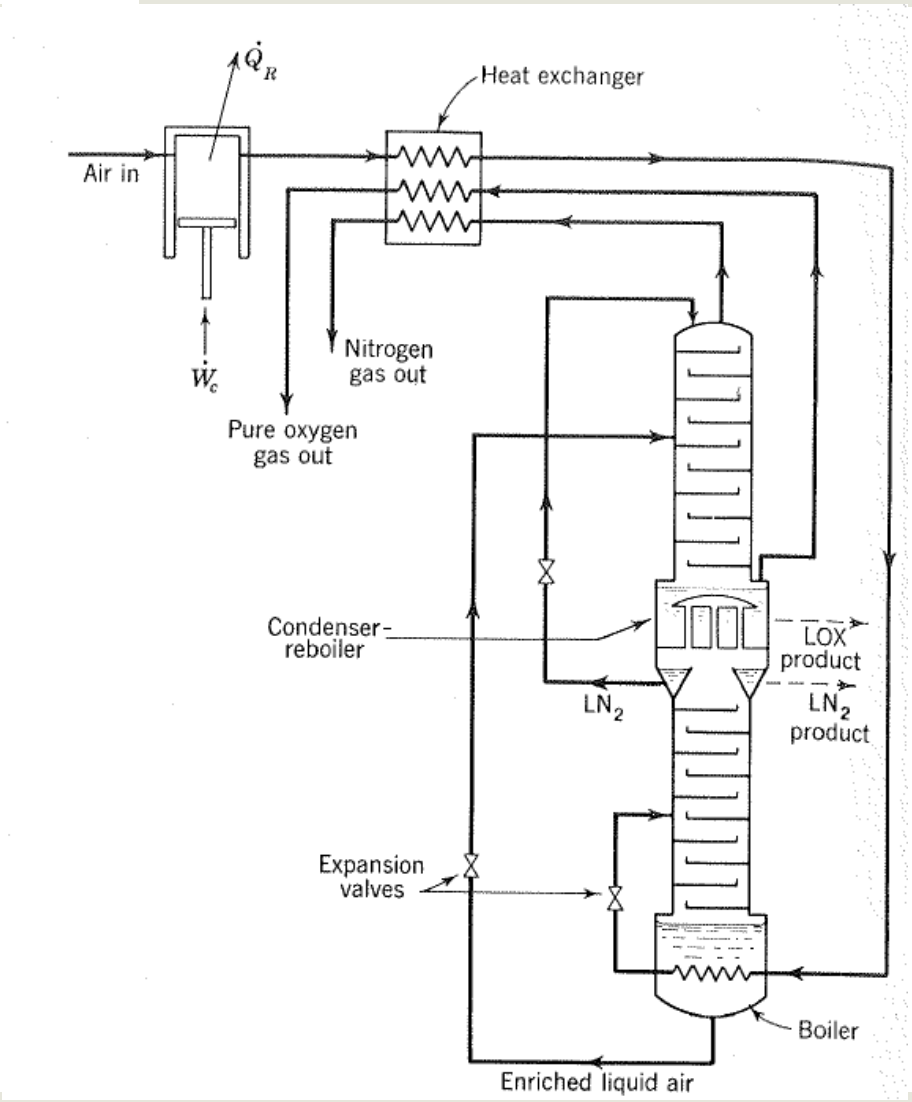


"Real World" Examples of Air Separation via Rectification

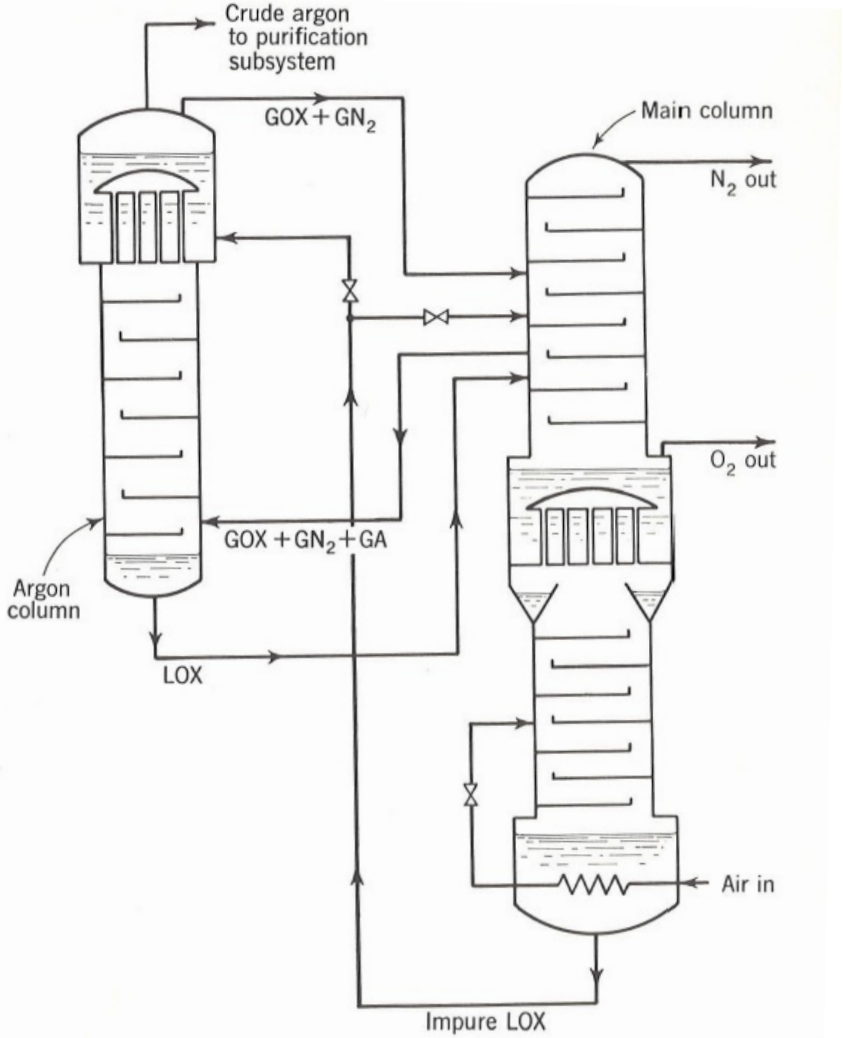
- Still Idealized – there is much proprietary detail
- However, note that basic cryogenic engineering techniques still apply:
  - Compression
  - Isenthalpic (JT) expansion
  - Isentropic expansion
  - Appropriate use of heat exchangers between flows of different temperatures
  - Clever use of different boiling points as a function of pressure
  - Everything is in cryostats and connected via transfer lines
- Which components are are recovered and in what form depends on the customer specific economics and applications
- All examples come from Barron's Cryogenic Systems

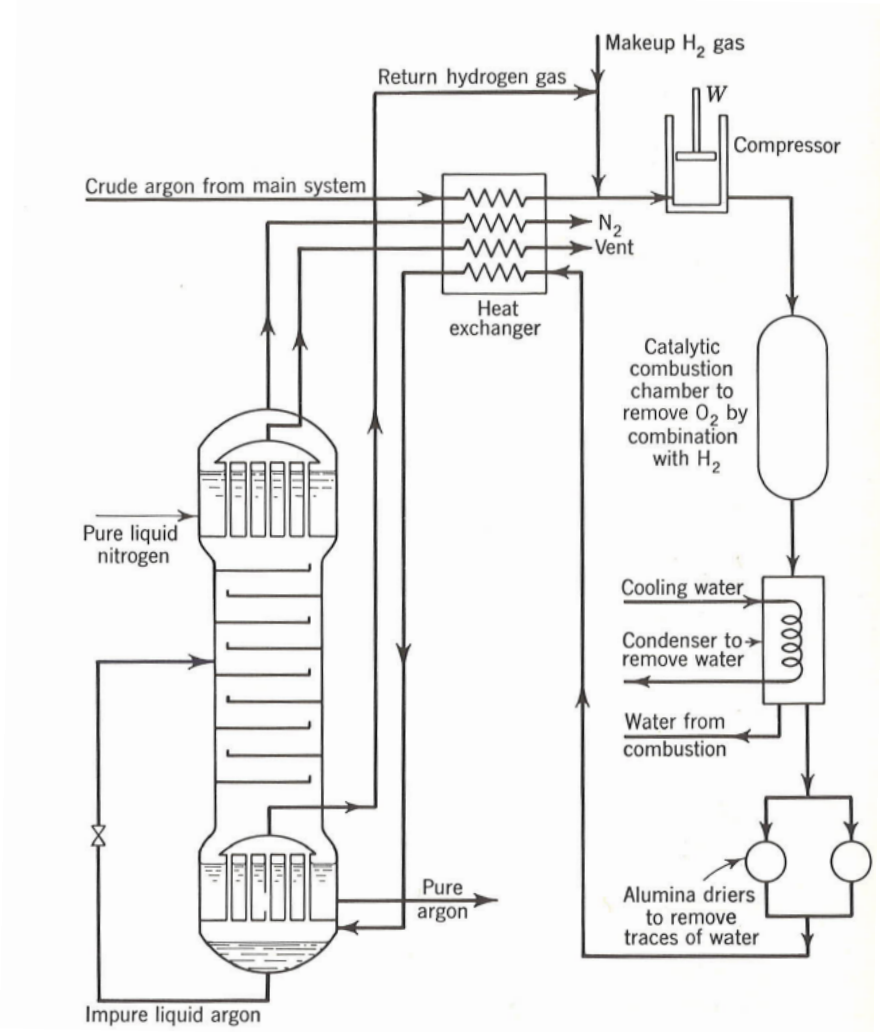
Linde Double Column System



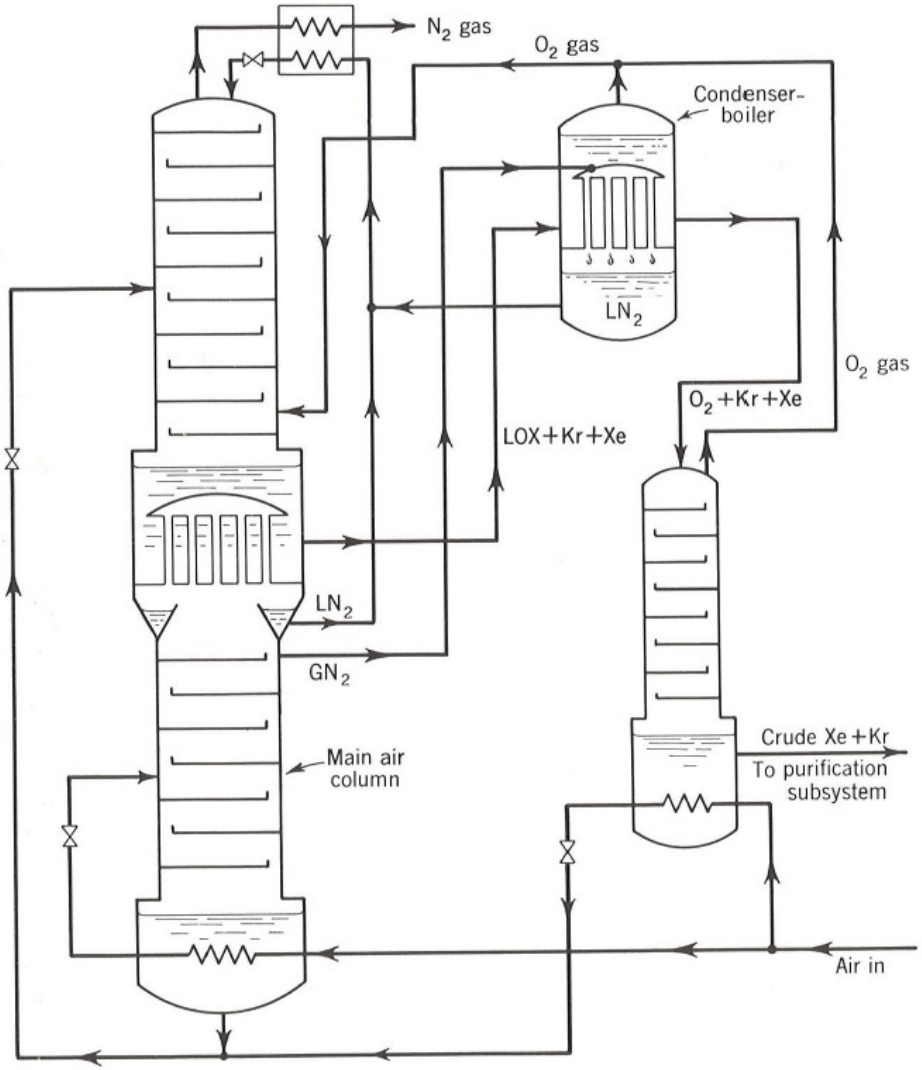
Note:
1) Use of JT expansion & HXs
2) Lower half of column operates at 5 Atm. while upper half operates 1 Atm.
3) The boiling point of N2 @ 5 ATM is higher than that of O2 at 1Atm
4) The warmer N2 vapor serves to boil off the O2 and is condensed by this process

Argon Separation & Purifaction





Xenon & Krypton Recovery



A Large Scale Example

Linde Air Separation plant for N2 for enhanced oil recovery

17,500 t/d N2

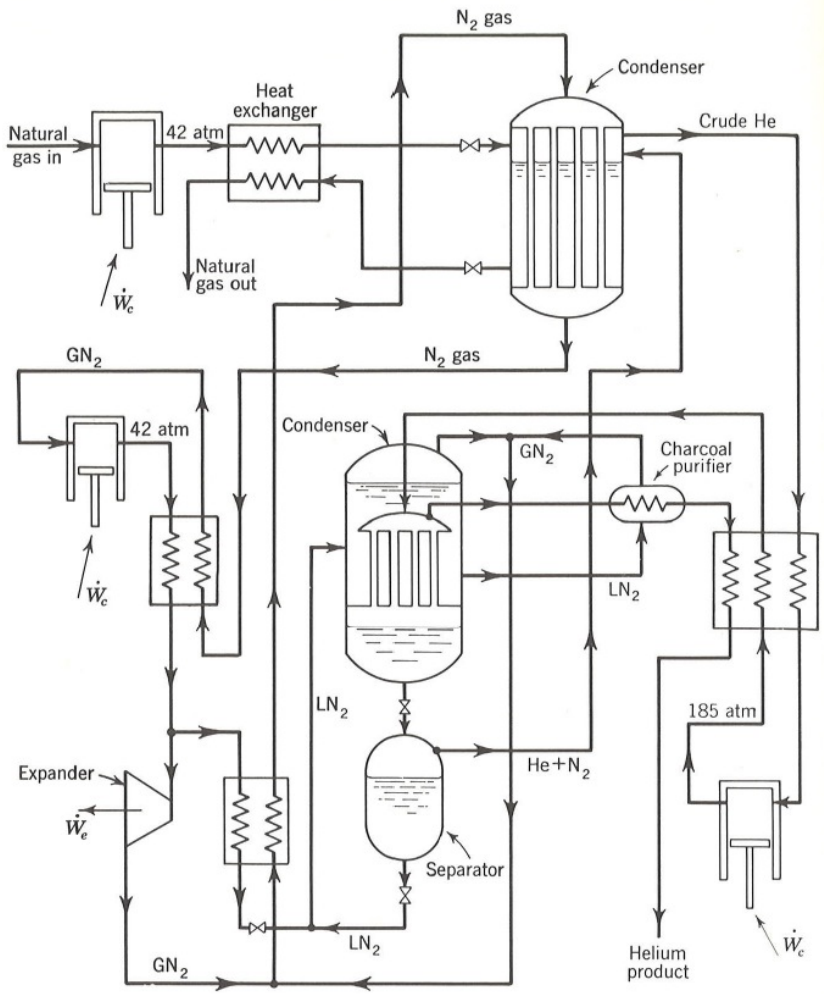
Built for Pemex (Mexico)

Courtesy Linde

Helium Supply

- He was first discovered in the solar spectrum only later on Earth
- Almost all He on earth is a result of Alpha decay from radioactive elements in the Earth's crust
- Helium is recovered as a byproduct of some but not all Natural gas wells
- Helium was considered a strategic element and a US federal reserve was established in Oklahoma
- Today the supply of He gas is quite volatile
  - US Federal He Reserve is being sold off
  - New sources of He gas are being developed in the Algeria, Qatar, Australia and Russia among other places.
  - Rapid increase in natural gas exploration and production may open up new supplies

Helium Recovery from Natural Gas (US Bureau Of Mines Process)



From Barron Cryogenic Systems

Issues with Helium Supply

- World wide the estimate is that we have 100 years of He left in the ground
- Currently, the US is estimated to become a net importer of He gas in 10 – 15 years
- Prices of He gas have gone up
  - » MSU paid $9.87 per 100 SCF in 2005 and paided $18.59 per 100 SCF in 2012
- Some spot shortages have occurred for complicated reasons

- How will this impact cryogenics? (~ 28 % of all He is used in cryogenics)
  - Larger investment in both recovery and storage systems (with power backups)
  - Increased motivation for low loss or Zero Boil Off cryostats
  - Increased use of cryogen free systems using small cryocoolers

  - ^{3}He is has other complications – rarer, lack of production and use in Nuclear Security applications