Supplementary Material 4 - Neon

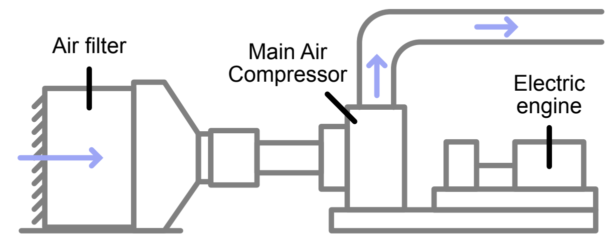
Atmospheric air

Air is made up of 78% nitrogen, 21% oxygen, 0.93% argon, 0.04% carbon dioxide and 0.0018% neon. Other gases are present but in very low concentrations (helium, krypton, xenon, methane, etc.).

Separation of the noble gases neon, krypton and xenon in air separation units is only worthwhile if they have a relatively high minimum capacity of 800 t (depending on price and currently 2000 t) oxygen/d. According to Clarke & Clare (2012), the additional costs for helium/neon production in conjunction with the construction of a new air separation unit are around 1% of the total costs. (Elsner, 2018)

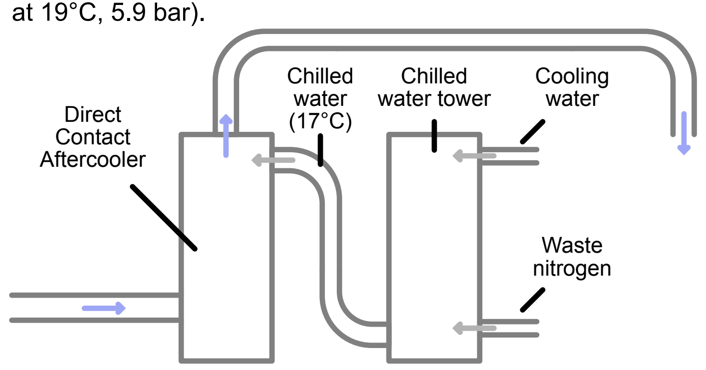
Air compression

The outside air is drawn in and filtered, then compressed to 6 bar to reach a temperature of 90°C.



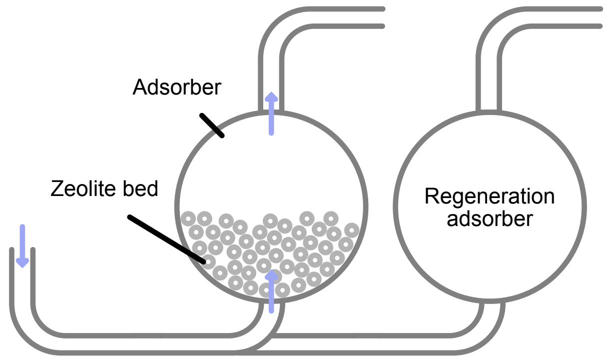
Feed air precooling

The compressed air is chilled through a direct contact aftercooler (DCAC) using chilled water. This step helps to remove moisture by condensation while reducing process temperatures (air out at 19°C, 5.9 bar).



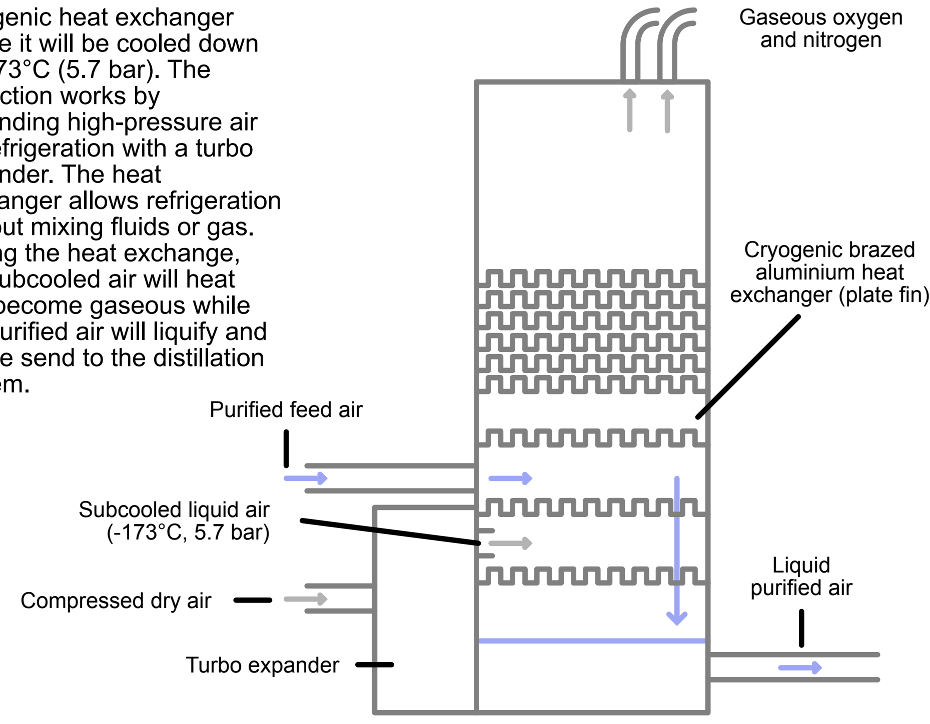
Adsorption

Using a Temperature Swing Adsorption (TSA) process with zeolite material, the air is purified from water, nitrous oxide, carbon dioxide and hydrocarbon molecules to avoid the formation of ice and dry ice during cooling



Cryogenic heat exchange

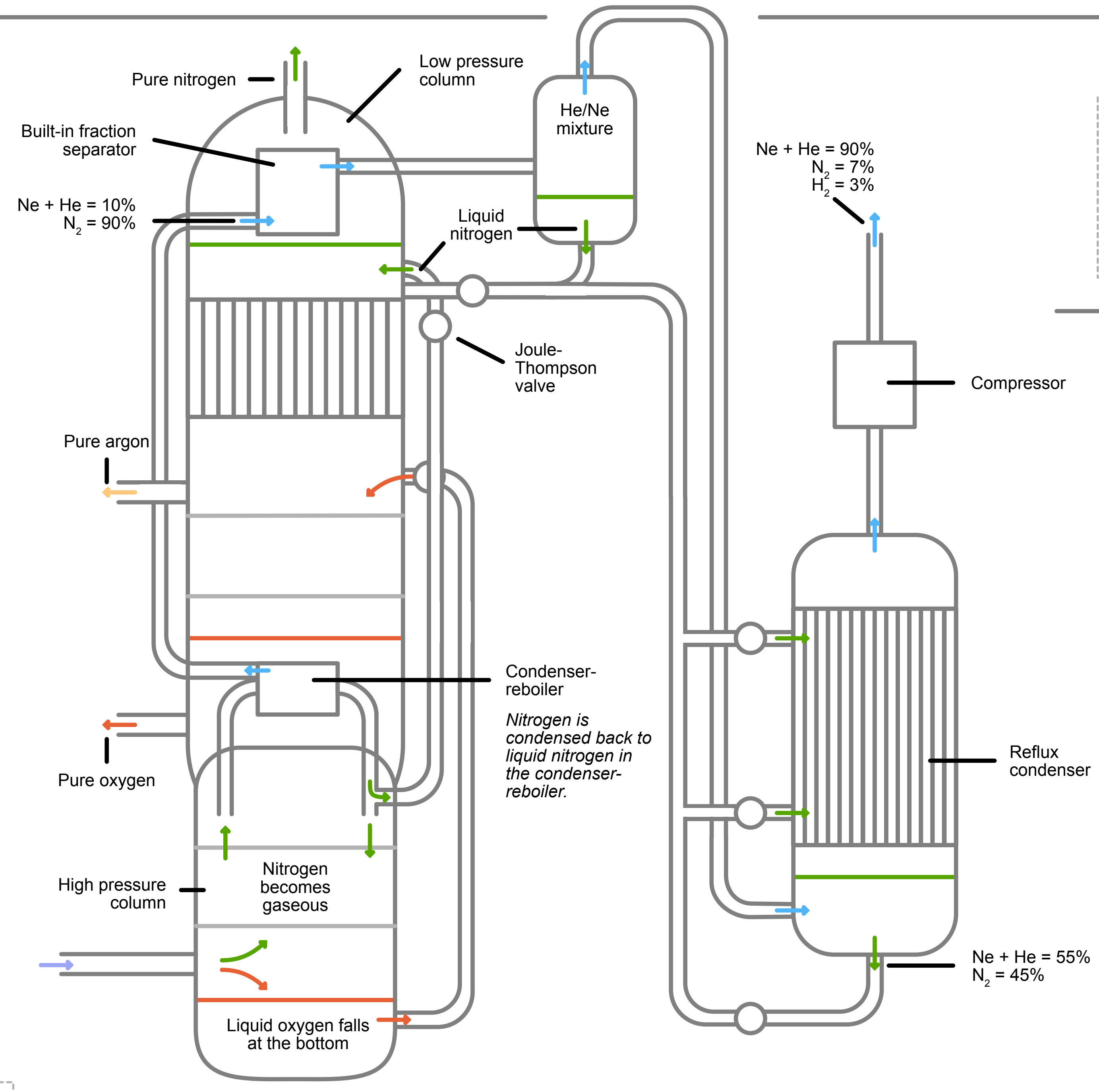
The purified feed air enters a cryogenic heat exchanger where it will be cooled down at -173°C (5.7 bar). The extraction works by expanding high-pressure air for refrigeration with a turbo expander. The heat exchanger allows refrigeration without mixing fluids or gas. During the heat exchange, the subcooled air will heat and become gaseous while the purified air will liquify and will be send to the distillation system.



Nitrogen and oxygen separation

Liquid air enters the high pressure column which separates oxygen and nitrogen. Liquid oxygen falls at the bottom of the column and later enters the low pressure column. Nitrogen becomes gaseous in the high pressure column, enters the condenser-reboiler that liquify it again and then enter the top of the low-pressure column. In the low pressure column, liquid oxygen accumulutes at the bottom in a purer form. Argon accumulates in the medium pressure section and is recovered. Nitrogen accumulates in a purer form at the top of the column.

In the condenser-reboiler, helium and neon accumulate due to their lower boiling point and reduce the efficiency of the condenser. Helium and neon are sent to another column with nitrogen and enter a reflux condenser that liquifies remaining nitrogen and produces helium and neon mixture concentrated at 90%.

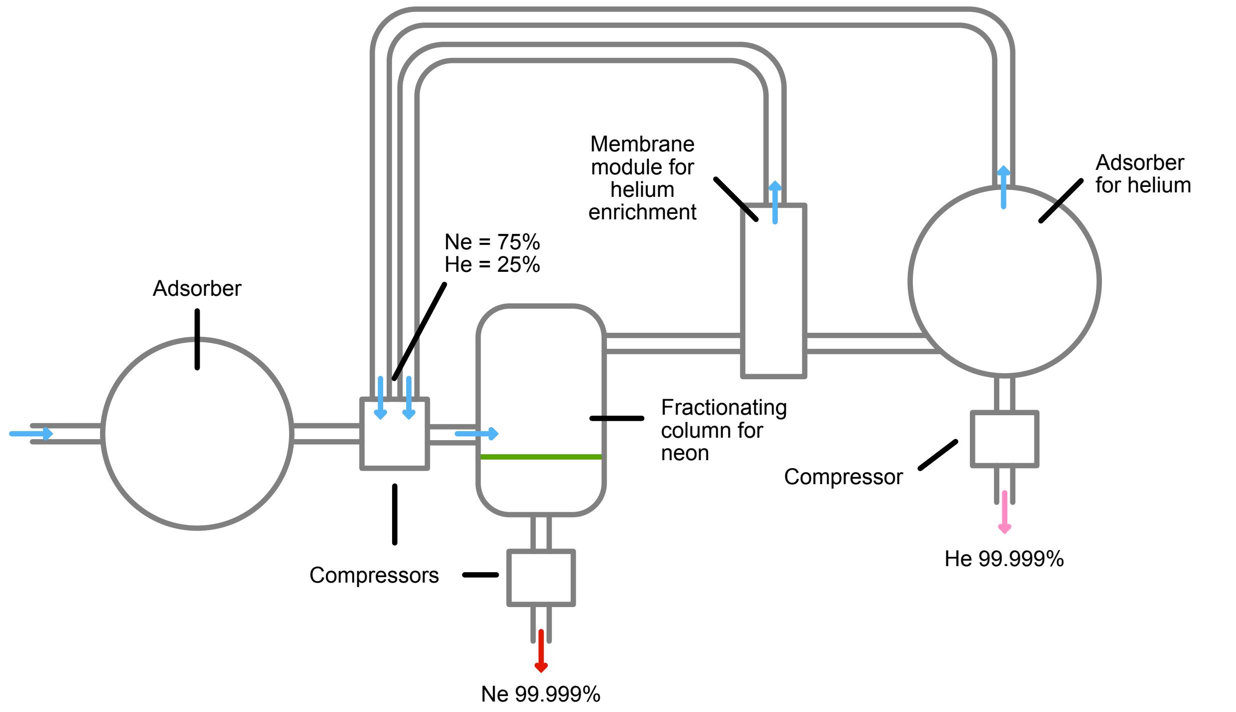


Boiling temperatures for gases

Oxygen: –183 °C
Argon: –186 °C (1 bar)
Nitrogen: –196 °C
Neon: –246 °C (1 bar)
Neon: –229 °C (27.7 bar)
Helium: –269 °C (1 bar)

Neon and helium purification

After passing through the reflux condenser, the He/Ne mixture enters a first adsorber, which filters out the impurities. After being compressed at 180 bar and cooled at -220 °C, the neon and helium then enter a fractional distillation column where a large proportion of the neon becomes liquid is separated from the helium who remains gaseous due to their different boiling temperatures. The remaining neon and helium go through a further series of purification steps using membranes and sorbents. This cycle is repeated to produce pure neon and helium.



Inputs/outputs for a 300,000 m3/hr external compression air-separation plant (Linde) (Zhang et al.)

Inputs

Electricity (1,648,443 MWh) →
Steam (115,293 tons)
Water (2,719,600 m3)
Molecular sieve (101.0 kg)
Aluminum oxide (69.7 kg)
Pearlite (30.5 m³)
Lubricant (32.6 tons)

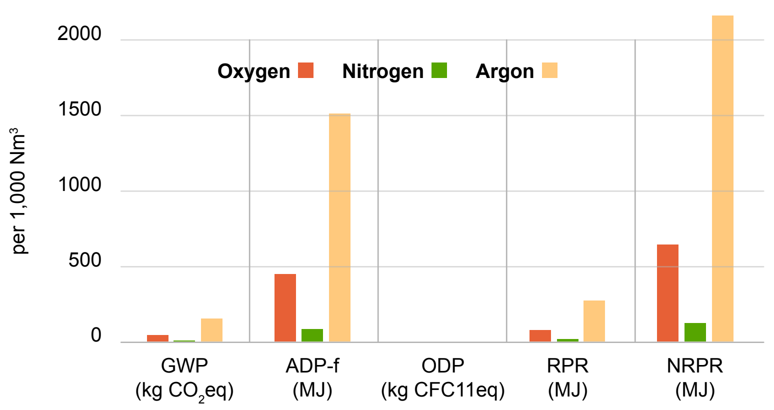
Outputs

Waste oil drum (1.25 tons)
Used paint bucket (3.4 tons)
Waste lead-acid battery (3.35 tons)
Used oil (42.8 tons)
Oily rags (4.8 tons)

According to EIGA, ouputs should also include Polychlorinated Biphenyl (PCB), Volatile Organic Compounds (VOC): Hydrochlorofluorocarbons (HCFC), Chlorofluorocarbons (CFC), Hydrofluorocarbons (HFC), chlorinated solvents, discharges of contaminated water.

Because of the additional steps and compressions required to obtain pure neon from the He/Ne mixture, it seems logical that the environmental footprint of pure neon production is greater than that of argon.

Impacts for 1,000 Nm3 industrial gas product from the air-separation plant (Zhang et al.)



GWP: Global warming potential
ADP-f: Abiotic depletion potential (ADP-fossil fuels)
ODP: Ozone Depletion Potential
RPR: Renewable primary resources
NRPR: Non-renewable primary resources

Crude neon production (2017 - estimated)
720,000 Nm³

Crude He/Ne production plants (2018 - incomplete)

China (18 plants) (23.6% of production)
Various locations, Hubei x9 (WISCO)
Ma'anshan, Anhui x3
Tangshan, Hebei
Handan, Hebei
Panzhihua, Sichuan
Huzhou, Jiangsu
Guangzhou, Guangdong
Shaoguan, Guangdong
Nanjing, Jiangsu

Germany (2 plants)
Leuna x2 (Linde AG, 40,000 Nm3/a)

France (1 plant)
Le Blanc-Mesnil

Netherlands (1 plant)
IJmuiden

Russia (3 plants)
Nischni Tagil
Lipezk
Orsk

Ukraine (5 plants) (29.7% of production)
Krywyj Rih
Mariupol x2
Zaporizhia
Dzerzhinsky

U.S.A. (11 plants) (46.6% of production)
Claymont, DE
Warren, OH
Pittsburgh, PA
La Porte, TX x2 (Linde AG, 40,000 Nm3/a)
Burns Harbor, IN x2
Calumet, IN x3
Bayport, TX

South Korea (2022)
Gwangyang (TEMC)

Pure neon production (2017 - inferred)
360,000 Nm³

He/Ne purification plants (2018/2022 - incomplete)

China
Wuhan, Hubei (WISCO)
Tangshan, Hebei
Handan, Hebei
Zhangjiagang, Jiangsu
Huzhou, Jiangsu
Guangzhou, Guangdong
Shaoguan, Guangdong

Germany
Leuna x2 (Linde AG)

France
Le Blanc-Mesnil

Netherlands
IJmuiden

Ukraine
Krywyj Rih (Cryoin)
Mariupol x2 (Ingas, UMG RT Gas)

U.S.A.
Burns Harbor, IN x2
Alpha, NJ

South Korea (2022)
Gwangyang (TEMC, 22,000 Nm3/a)

Crude neon gas specifications	
Crude gas flow to coldbox	33 Nm3/h
Pressure	29.6 bara
Temperature	308 K
Nitrogen fraction	28.55%
Argon fraction	0.0002%
Oxygen fraction	1.500%
Helium fraction	15.17%
Hydrogen fraction	0.000%
Neon fraction	54.78%
Carbon monoxide fraction	0.0001%

Liquid neon product	
Flow	11.5 Nm3/h
Pressure	1.7 bara
Temperature	29 K
Neon	99.9997%
Helium	0.0003%

Sources : Elvers, B. (1991). **Ullmann's encyclopedia of industrial chemistry** (Vol. 17, pp. 363-376). Hoboken, NJ: Verlag Chemie ; Bondarenko, V. L., Losyakov, I. A., D'yachenko, O. V., & D'yachenko, T. V. (2019). **Analysis of losses in high-purity neon production technology. Part 1. Extraction of a Ne–He mixture as a by-product of air separation**. Chemical and Petroleum Engineering, 54, 728-734 ; Bondarenko, V. L., Losyakov, I. A., D'yachenko, O. V., & D'yachenko, T. V. (2019). **Analysis of Losses in High-Purity Neon Production Technology. Part 2.* Processing of a Ne–He Mixture to Obtain Pure Products**. Chemical and Petroleum Engineering, 54, 735-745 ; Aneke, M., & Wang, M. (2015). **Potential for improving the energy efficiency of cryogenic air separation unit (ASU) using binary heat recovery cycles**. Applied Thermal Engineering, 81, 223-231 ; Zhang, M., Cheng, C., Zhao, Y., & Wang, B. (2024). **Life Cycle Assessment for Industrial Gas Production in China** ; Boeck, S. (2010, April). **Purification and Liquefacttion of Neon Using a Helium Refrigeration Cycle**. In AIP Conference Proceedings (Vol. 1218, No. 1, pp. 275-277). American Institute of Physics ; EIGA, **Environmental Impacts of Air Separation Units** ; Bondarenko, V. L., Simonenko, Y. M., Chyhrin, A. A., & Medushevsky, E. V. (2022). **Energy-Saving Technologies in Industrial Neon Production Plants**. Chemical and Petroleum Engineering, 58(1), 33-41; Saedi, M., Mehrpooya, M., Delpisheh, M., & Zaitsev, A. (2022). **Proposal and energy/exergy analysis of a novel cryogenic air separation configuration for the production of neon and argon**. Chemical Papers, 76(11), 7075-7093 ; Kravchenko, M. B., Grudka, B. G., & Lavrenchenko, G. K. (2021). **Improved Technology for Obtaining Enriched Neon-Helium Mixtures**. Chemical and Petroleum Engineering, 56, 907-917; Bondarenko, V. L., Dyachenko, T. V., & Simonenko, Y. M. (2010). **Technology for Ne–He mixture enrichment in stepped reflux condensers**. Chemical and Petroleum Engineering, 46, 281-290 ; Elsner, H. (2018). **Edelgase – Versorgung wirklich kritisch? [Noble gases – supply really critical?]** – DERA Rohstoffinformationen 39: 197 S., Berlin ; Georgitzikis, K. and Delia, E., **Rare Gases (Krypton, Neon, Xenon): Impact assessment for supply security**, European Commission, 2022, JRC130349.

Crédits : Gauthier Roussilhe