

Chemical Engineering Design Project - Uhde's Dual Pressure Nitric Acid Process

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Nitric Acid is one of the most important mass produced chemicals in the world due to its extensive use in the fertiliser industry as a raw material for Nitrate fertilisers and as a reagent in many other industries. Uhde GmbH's Dual Pressure Process uses the Ostwald Process for Ammonia Oxidation as a starting point of Nitric Acid production and NO gas absorption to concentrate the nitric acid formed while cooling of the reaction gases. The reaction occurs at a medium pressure and the absorption occurs at a higher pressure, giving us a 62% Nitric Acid solution by weight. All the reactions used are available in the Reaction sets.

Process Description

- Air is pumped into the plant at ambient conditions (1 bar, 25°C), entirely by the suction force provided by the centrifugal compressor. The Air is then fed to the compressor
- The compressor is used to increase the pressure of the air feed to 5 bar, also causing an increase in the temperature to 240-250°C, which is split into 2 parts, 80% going into the reaction mixture and the rest is utilised in the bleaching column.
- Liquid Ammonia from storage is pumped into the plant at -15°C and 12 bar, into Evaporator by a Centrifugal Pump. In the Evaporator, Ammonia is converted to vapor and further superheated to 70°C with the help of LP Steam (4-5 bar, 150°C) in the upper section of the Evaporator.
- The superheated ammonia vapor and the compressed air stream are mixed in a static mixer, coming out at 5 bar, 220-230°C. It is ensured that Ammonia to Air ratio is kept 1:9 by weight.
- The mixer outlet stream is fed into the reactor, which is a shallow bed reactor, with around 8-10 catalyst gauzes, made up of 90%Pt and 10%Rh.
- The catalyst is highly selective, giving a conversion of 96% for Ammonia into Nitric Oxide, gas stream exiting at a temperature of 890°C, consisting mainly of Nitrogen and Oxygen from Air feed and Nitric Oxide formed via Ammonia oxidation. Couple of side reactions also take place in the reactor with a total conversion of 4% for Ammonia.
- The high heat of reaction is used to make steam and heat other streams throughout the plant. A Shell and Tube Heat Exchanger(S&H HX) is used to heat the tail gas coming from Absorption Column to facilitate the abatement process (tail gas is passed through an expander where it drives the compressor shaft), and another S&H HX is used as an economiser, which results in the temperature of the stream to drop to 185°C.
- This decrease in the temperature leads to the oxidation of Nitric Oxide to Nitrogen Dioxide, with the conversion of the reaction increasing with a decrease in the temperature.
- Cooler Condenser-1, is used to cool the stream further, condense water and nitric acid and separate them out for further processing. The temperature of the outlet streams is around 50°C. This drop in temperature allows Nitric Oxide to oxidise to Nitrogen Dioxide at a much higher conversion rate when compared to the previous two heat exchangers. The Cooler

Condenser is modelled as a combination of PFR used to model all the heat exchangers for NO oxidation and an equilibrium reactor to model NO₂ hydration to HNO₃ and a compound separator to get all water and Nitric Acid as condensate

- As Nitrogen Dioxide is produced, with the drop in temperature and elevated pressures, some of it gets absorbed into the condensed Water formed in the reactor. Once absorbed, Nitrogen Dioxide combines with Water to form Nitric Acid and Nitric Oxide, which further gets oxidised to Nitrogen Dioxide, which again forms Nitric acid and so on.
- The Nitric Acid solution in the condensate of the Cooler Condenser-1, is then pumped to the Absorption Column to increase the Nitric Acid concentration in the solution.
- The vapor outlet of the cooler condenser, mainly consisting of NO_x gases, is passed through the NO_x Compressor, elevating the pressure of the stream to 12 bar and the temperature to around 165°C.
- Compressor outlet is fed to Cooler Condenser-2, where process similar to that in Cooler Condenser-1 occurs, providing us with more weak Nitric Acid condensate, which is mixed with Cooler Condenser-1 condensate and pumped to the Absorption Column. Stream cooled after the second compressor is also fed to Absorption Column.
- The Absorption Column, has 35-40 stages, with the NO_x gases fed at the bottom-most stage, process water fed at the top-most stage, acid condensate from the Cooler Condensers fed to an intermediate stage and cooling water coils at every stage throughout the column to maintain the column at a reduced temperature.
- Inside the column, Nitric Oxide oxidation to Nitrogen Dioxide occurs between stages in the vapor phase, and absorption of Nitrogen Dioxide into water and the formation of Nitric Acid from the absorbed Nitrogen Dioxide occurs in the liquid phase on the sieve trays of the column.
- Bottom outlet of the column is called Red Fuming Nitric Acid, due to the red color imparted by the dissolved Nitrogen Dioxide, with its impurities separated out using compound separators, giving us the final product acid with a 62% wt% solution.

Reactive Absorption Column

The Absorption column in the flowsheet is modelled as a normal absorption column followed by a series of reactors to model the actual absorption that occurs in an actual Nitric Acid Dual Pressure Plant. The outlets from top and bottom reactor train is fed to bottom and top respectively to model the actual reactive absorption in the column. Feed include the acid condensate from the cooler condensers, NO gas from the reactor, oxidised to almost 90-95% and process water to reach the desired amount of Nitric Acid Concentration at outlet. Since the oxygen is available in limited amounts, extra O₂ is also added to the top reactor train to mimic the bleaching air being added to the absorption column inlet in the actual process.

Reference -

Thiemann M, Scheibler E, Wiegand KW, "Nitric acid, nitrous acid, and nitrogen oxides", *Ullmann's Encyclopedia of Industrial Chemistry*, Wiley-VCH Verlag GmbH & Co. KGaA, 2000. doi:[10.1002/14356007.a17_293](https://doi.org/10.1002/14356007.a17_293).