

Assignment 1

Five process flowsheets with accompanying process description are provided. For each process flowsheet, do the following:

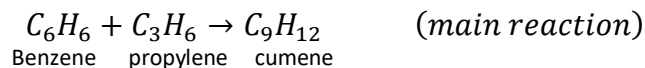
1. Draw independent control valves on the flowsheets to obtain the control degree of freedom.
2. State the key input and output PVs for the process with no installed control system.
3. Assuming distillation column pressures are given, what is the steady state degree of freedom for the process.
4. State reasonable specification variables for the steady state degrees of freedom.
5. Draw a control structure corresponding the specification variables in part 4 above.
6. State the key input and output PVs for the process for the installed control system in part 5 above.

Flowsheet 1

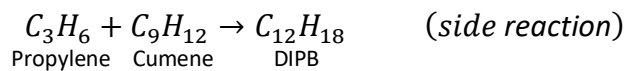
Cumene Process

Process Description

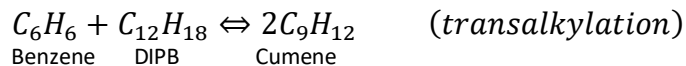
Friedel-Crafts alkylation of benzene with propylene to form cumene is the most common route for industrial-scale cumene production. The main reaction is thus



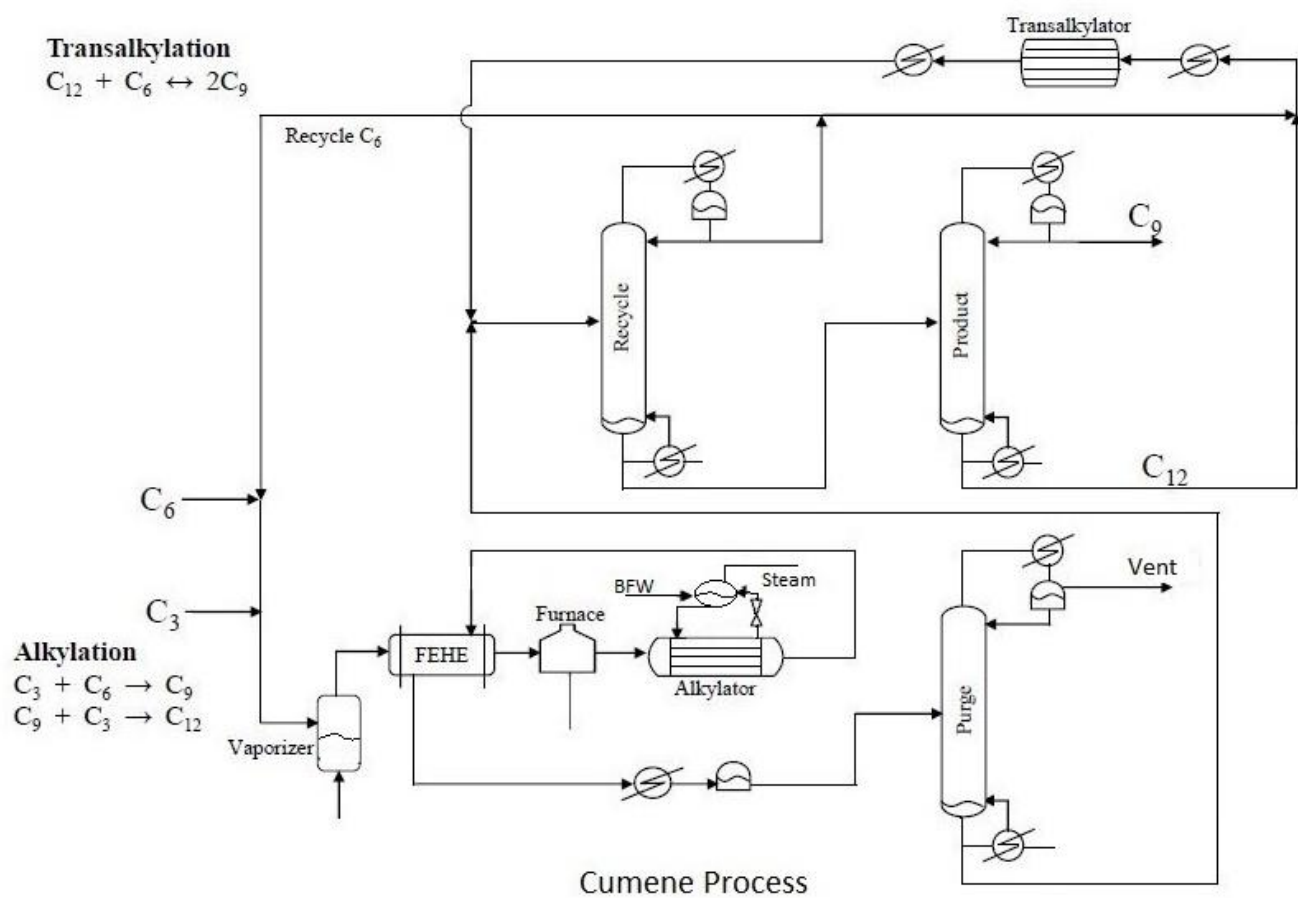
The cumene can further alkylate to di-isopropyl benzene (DIPB) as



In practice, further alkylation to small amounts of heavier poly isopropyl benzenes (PIPBs) also occurs. The DIPB (and PIPBs) is converted back to cumene via transalkylation with benzene as



The fresh benzene and fresh C_3 (95% propylene and 5% n-propane) streams are mixed with the recycle benzene, vaporized, and preheated in a feed effluent heat exchanger (FEHE) to recover heat from the hot reactor effluent before being heated to the reaction temperature in a furnace. The heated stream is fed to a cooled packed bed reactor (PBR). The PBR is a shell and tube heat exchanger with catalyst loaded tubes and pressurized hot water circulating on the shell side. The water removes reaction heat and flashes to generate steam in a steam drum. The hot reactor effluent loses sensible heat in the FEHE and is further cooled and condensed using cooling water. The condensate is sent to a three-column light-out-first distillation train. The inert n-propane and small amounts of unreacted propylene are recovered as vapour distillate from the first column. The bottoms is further distilled in the recycle column to recover and recycle unreacted benzene as the distillate. The recycle column bottoms is sent to the product column to recover nearly pure cumene as the distillate and heavy DIPB as the bottoms. The DIPB stream is mixed with a fraction of the benzene recycle stream, heated, and fed to an adiabatic transalkylation reactor where DIPB reacts with benzene to form cumene. The transalkylator effluent is cooled and fed to the recycle column for recovering the benzene and cumene.

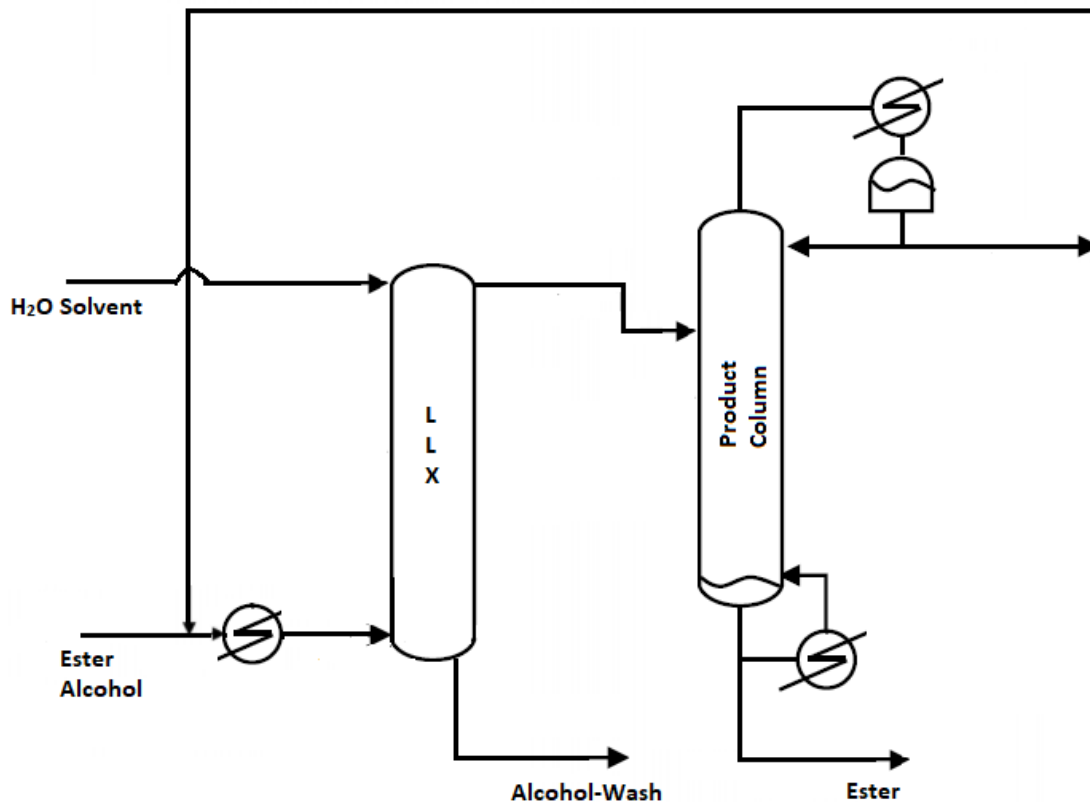


Flowsheet 2

Ester Purification Process

Process Description

The process consists of a liquid-liquid extractor (LLX) followed by an ester product recovery distillation column. The LLX uses water solvent to extract alcohol from the cooled ternary (ester, alcohol and water) feed to the extractor. The alcohol rich extract leaves down the bottoms while the ester rich raffinate leaves up the top. The raffinate is distilled to recover pure ester as the bottom product with the distillate being recycled back to the extractor.



Ester Purification Process

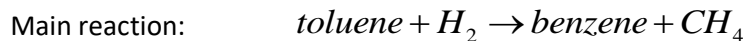
Flowsheet 3

Hydro Dealkylation Process

Process Description

The HDA process produces benzene via the hydrodealkylation of toluene. Methane and diphenyl are also produced as byproducts

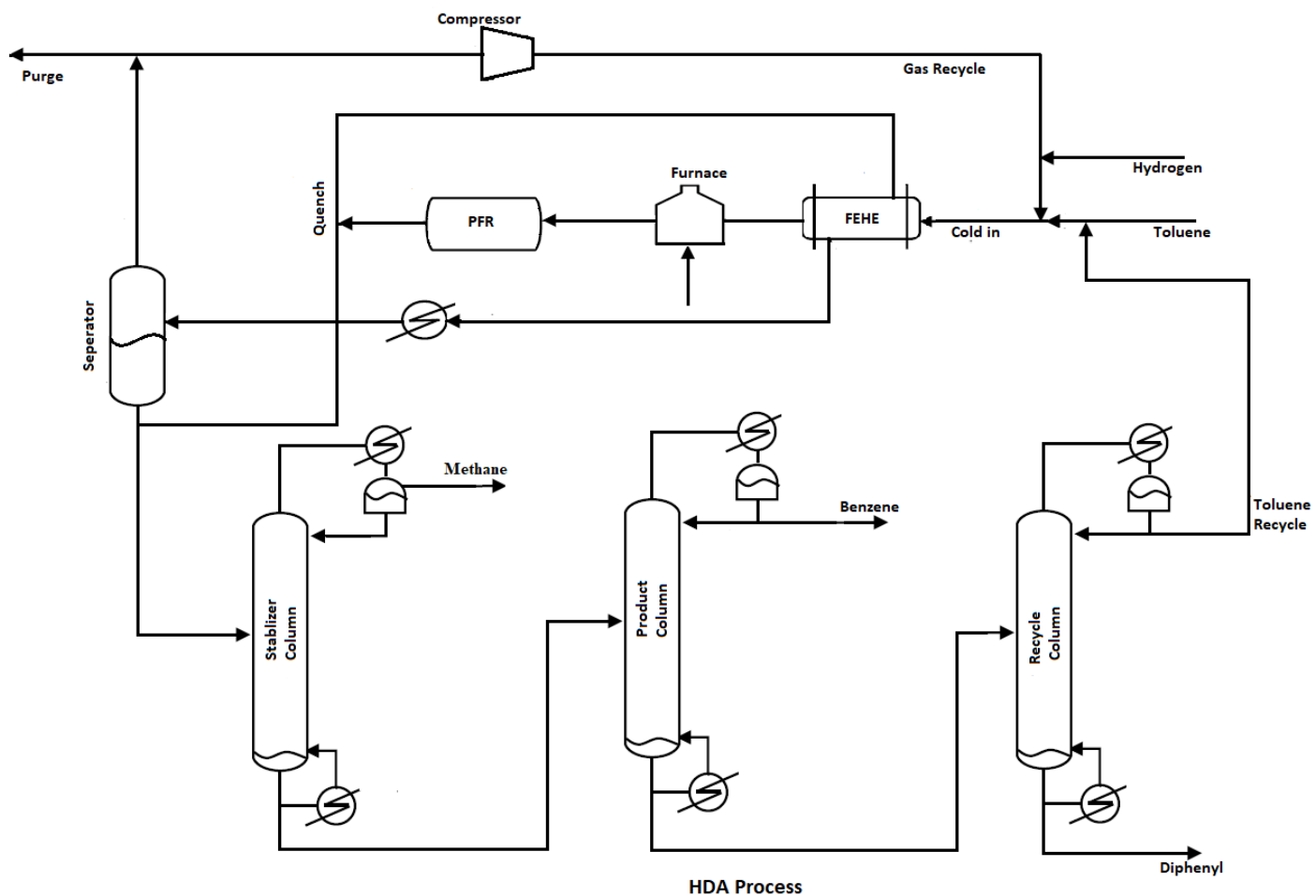
The two main reactions that occur in the reactor section are



Fresh+recycle toluene is mixed with fresh hydrogen (3% methane impurity) and fed to the reaction section of the process, where it is first preheated in a feed-effluent heat exchanger (FEHE) to recover heat from the hot reactor effluent and then heated to the reaction temperature (621 °C) in a fired furnace before being fed to an adiabatic PFR.

An excess of hydrogen is required to prevent coking in the reactor at high temperature. The minimum acceptable ratio of hydrogen to aromatics in the reactor is 5:1. The per-pass conversion of toluene is ~70%. The excess H_2 absorbs reaction heat with the reactor exit stream being at 667 °C, which is an acceptable temperature rise. This hot effluent is quenched to 621 °C by adding a cold liquid stream to prevent further reaction. The quenched effluent is used to preheat the cold feed in the FEHE. The cooled effluent is further cooled and partially condensed using a water-cooled heat exchanger. The condensate is collected in a flash tank separator and fed to a three-column light-out-first separation train after using a small fraction to quench the hot reactor effluent. The non-condensable (mostly H_2 and CH_4) are recycled back to the reactor after purging a small fraction to allow a way out for the CH_4 . The gas recycle stream helps to maintain the 5:1 ratio of hydrogen to toluene. Another important feature of this recycle is that the recycled methane acts as a heat sink to help maintain a reactor outlet temperature of <704 °C to prevent significant hydrocarbon cracking inside the reactor.

In the light-out-first separation train, the first column purges fuel gas (mostly CH_4 and H_2) as vapour distillate and recovers benzene, toluene and diphenyl down the bottoms. The bottoms is further separated in the product column to recover benzene product up the top with toluene and diphenyl leaving down the bottoms. This bottom is separated in the recycle column to recover and recycle toluene up the top and discharging heavy diphenyl product down the bottoms.



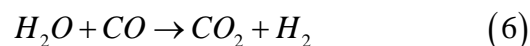
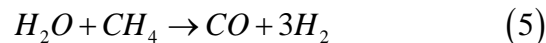
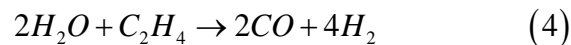
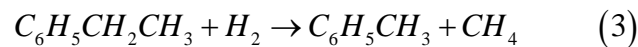
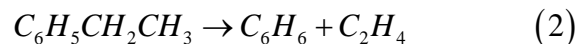
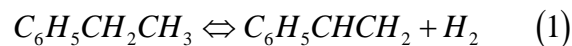
Flowsheet 4

Styrene Process

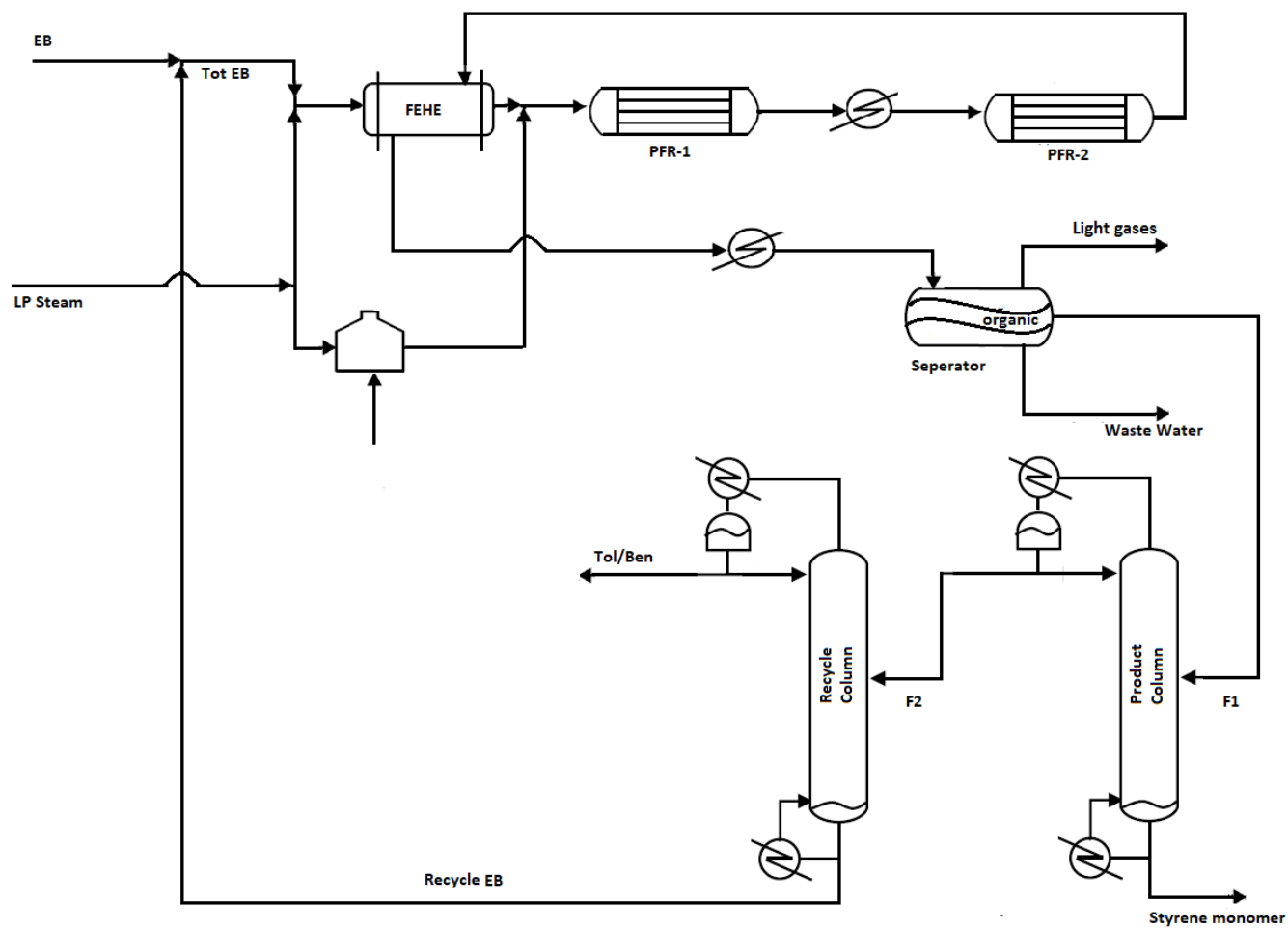
Process Description

Styrene is produced by the vapor-phase adiabatic dehydrogenation of ethyl benzene (EB) in two consecutive PFRs using potassium-promoted iron oxide catalyst. The overall reaction is endothermic, equilibrium limited and requires high temperature and low pressure. Steam is added to the reactor for better temperature control, to lower the partial pressure of EB (and thus shift equilibrium to the right) and to prevent coking of catalyst. Temperature control is very crucial due to many side reactions in the reactor. The molar ratio of steam to EB in the feed entering the reactor should be between 10 and 20.

Fresh EB and a part of the low-pressure steam (LPS) are initially mixed and then preheated in a feed effluent heat exchanger (FEHE) that recovers heat from the reactor effluent stream. The remaining LPS is superheated in a furnace to a higher temperature and then mixed with the preheated. It is then fed to the two adiabatic PFRs, in series with a heater in between, for the production of styrene. The six main reactions that occur in the reactors are as follows



The reactor effluent is cooled in the FEHE and further cooled in a cooler before being sent to the three-phase separator, where the light non-condensables are vented and wastewater is removed from the aqueous layer. The intermediate organic layer is sent to a set of distillation columns for styrene separation from the other components. In the first column (i.e., product column), operating under vacuum to prevent styrene polymerization, styrene is removed as the bottom product, and the top product is sent to a second column (i.e., recycle column) to recover unreacted EB as bottoms and the two by-products, toluene and benzene, as the distillate. The bottoms unreacted EB stream is recycled to the reaction section. As the boiling points of styrene and EB are very close, the first column requires a very large number of stages for effective separation, typically 70 to 100.



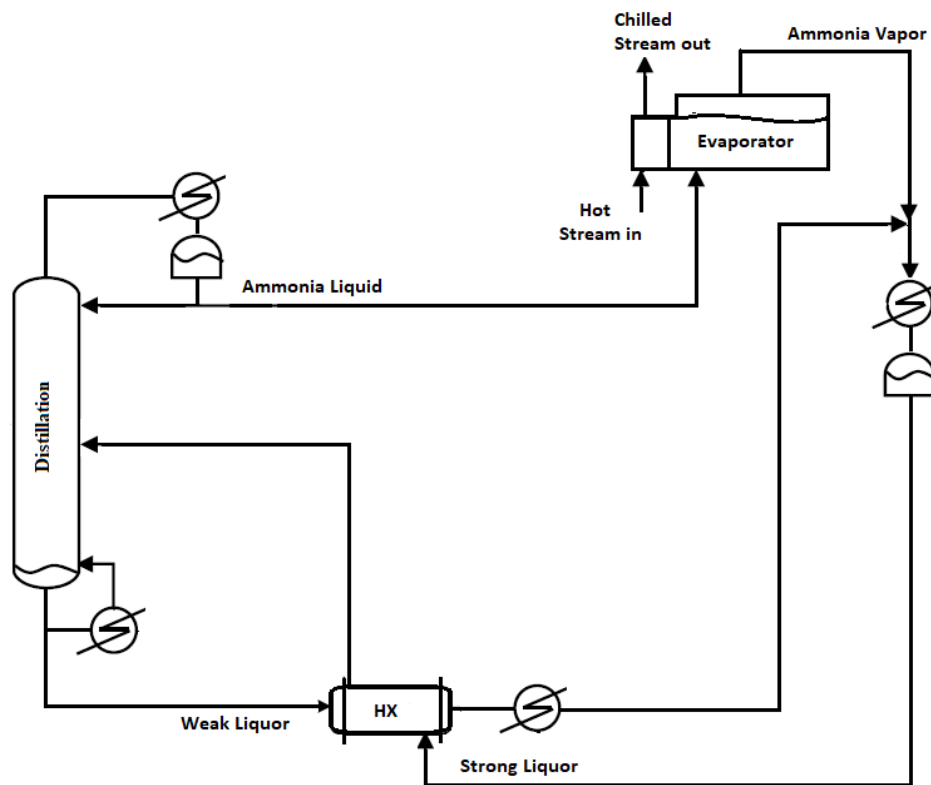
Flowsheet 5

Ammonia Absorption Refrigeration Process

Process Description

When a process requires temperature lower than those attainable by cooling water (less than 100°F), refrigeration must be used. Most refrigeration systems use compression refrigeration, but occasionally absorption refrigeration systems are employed if an inexpensive low level heat source is available.

Here we use Ammonia as a refrigerant. Ammonia is produced as the distillate product from a distillation column operating at high pressure so that cooling water can be used in the condenser. The liquid ammonia is flashed into an evaporator operating at low pressure. The boiling ammonia cools the process stream. The vapor ammonia is mixed with a weak-liquor water stream from the distillation column bottoms, cooled, condensed and collected a surge tank. This strong-liquor (ammonia rich) is preheated in a process-to-process heat exchanger (HX) and then fed into the distillation column to separate the water and ammonia. The HX recovers heat from the hot column bottoms.



NH₃ Absorption Refrigeration Process