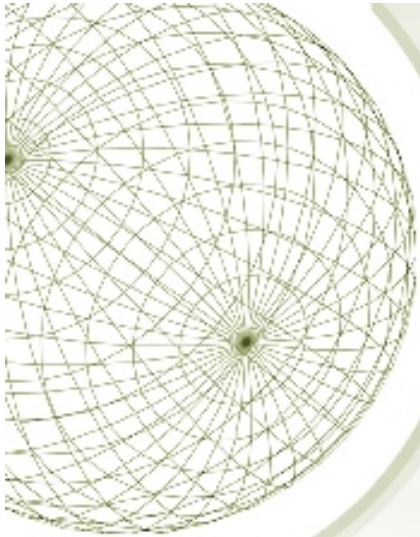


Solvay Process

Industrial Chemistry

Raw Materials and Products

Raw materials:

- Brine (30% w/w solution)
- Calcium carbonate (limestone) – used to make calcium oxide and carbon dioxide feedstock
- Ammonia

Products:

- Sodium carbonate (soda ash)
- Calcium chloride

Uses of Sodium Carbonate

- **Manufacture of glass.** Sodium carbonate, limestone and sand are fused together to make silicates.
- **Softening of hard water.** Soda ash ($Na_2CO_3.10H_2O$) precipitates calcium and magnesium ions from hard water.
- Manufacture of sodium hydrogen carbonate used in baking soda and fire extinguishers.
- **Soap manufacture.** Sodium hydroxide can be made from reacting calcium hydroxide with sodium carbonate.

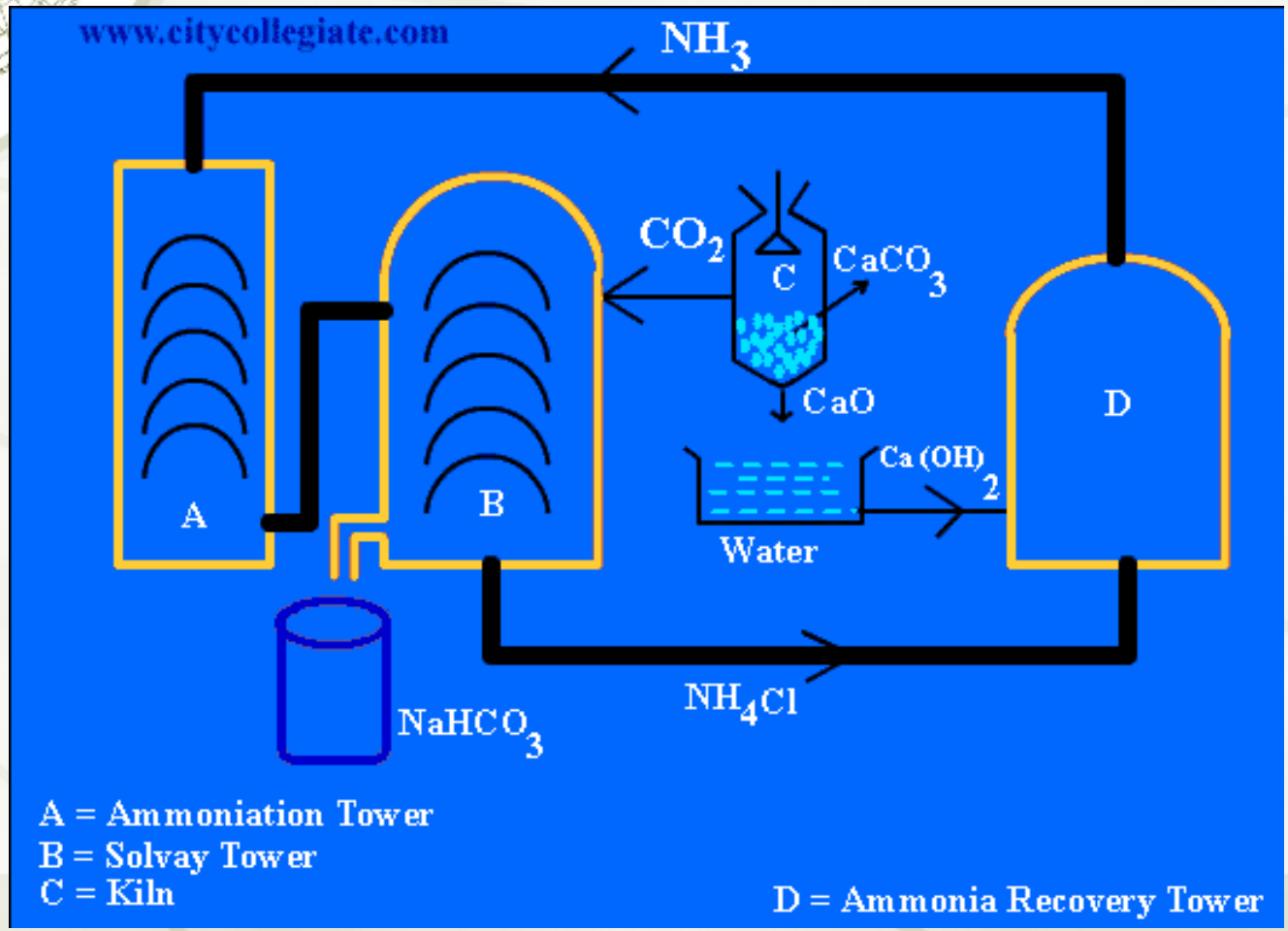
Step 1 – Brine Purification

- Purified to remove contaminants such as Ca^{2+}, K^{+}, Mg^{2+} and SO_4^{2-}.
- Achieved using fractional crystallization.
- Calcium sulfate crystallizes first and is removed before the sodium chloride crystallizes.
- In some countries other chemical methods are used to precipitate other ionic impurities.

Step 2 – Saturating Brine with Ammonia

- Brine flows down over many partitions in an ammonia saturation tower.
- Ammonia dissolves in the brine.
- The tower is cooled because the dissolution of ammonia in water is exothermic.
- The ammoniacal brine contains about 7.5% w/w of ammonia.

Step 2 - Diagram



Step 3 – Production of Sodium Hydrogen Carbonate

- Ammoniated brine is allowed to trickle down a carbonating tower known as Solvay tower. This tower is also fitted with baffle plates. Here brine is mixed with carbon dioxide gas, produced by heating limestone in a separate chamber called "**kiln**".

$$CaCO_3 \rightarrow CaO + CO_2$$

- The baffle plates ensure the flow of solution and ensures that the carbon dioxide reacts with the ammonia solution to form carbonic acid.

Step 3 continued

- Crystals of sodium hydrogen carbonate form as they have a low solubility in the ammoniacal brine. This also drives the reaction to the right.
- The crystals are washed down to the bottom of the tower where it is ice cold and then vacuum-filtered.
- The filtrate contains a solution of ammonium chloride.

Step 3 - Reactions

Formation of carbonic acid:

$CO_2\ (g) + H_2O\ (l) \rightarrow H_2CO_3\ (aq)$

Neutralisation:

$NH_3\ (aq) + H_2CO_3\ (aq) \rightarrow NH_4^+\ (aq) + HCO_3^-\ (aq)$

Crystallisation:

$Na^+\ (aq) + HCO_3^-\ (aq) \rightarrow NaHCO_3\ (s)$

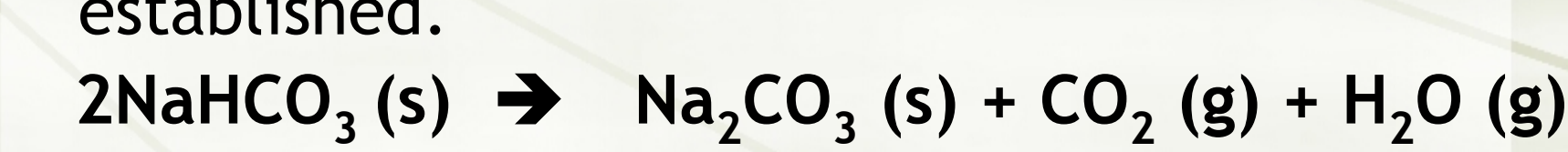
Net Equation

$Na^+\ (aq) + CO_2\ (g) + H_2O\ (l) + NH_3\ (aq) \rightarrow$

$NaHCO_3\ (s) + NH_4^+\ (aq)$

Step 4 – Decomposition of Sodium Hydrogen Carbonate

- Sodium hydrogen carbonate is heated to remove any absorbed ammonia or carbon dioxide.
- Dry sodium hydrogen carbonate is heated in rotary furnace called "**CALCINER**" to give anhydrous sodium carbonate or soda ash. Carbon dioxide is recirculated to carbonation tower. This ensures that equilibrium is never established.



Step 5 – Ammonia Recovery

- The filtrate from step 3 contains ammonium and chloride ions (NH_4Cl).
- Calcium oxide was also product from step 3. CaO is treated with water to form $Ca(OH)_2$ (quicklime).

$$\mathbf{CaO\ (s) + H_2O\ (l) \rightarrow Ca(OH)_2\ (aq)}$$

- Quick lime is heated with the NH_4Cl to form NH_3 and calcium chloride (by product) . Ammonia is used again in this process.

$$\mathbf{2NH_4Cl\ (aq) + Ca(OH)_2\ (aq) \rightarrow}$$
$$\mathbf{CaCl_2\ (aq) + 2NH_3\ (g) + 2H_2O\ (l)}$$

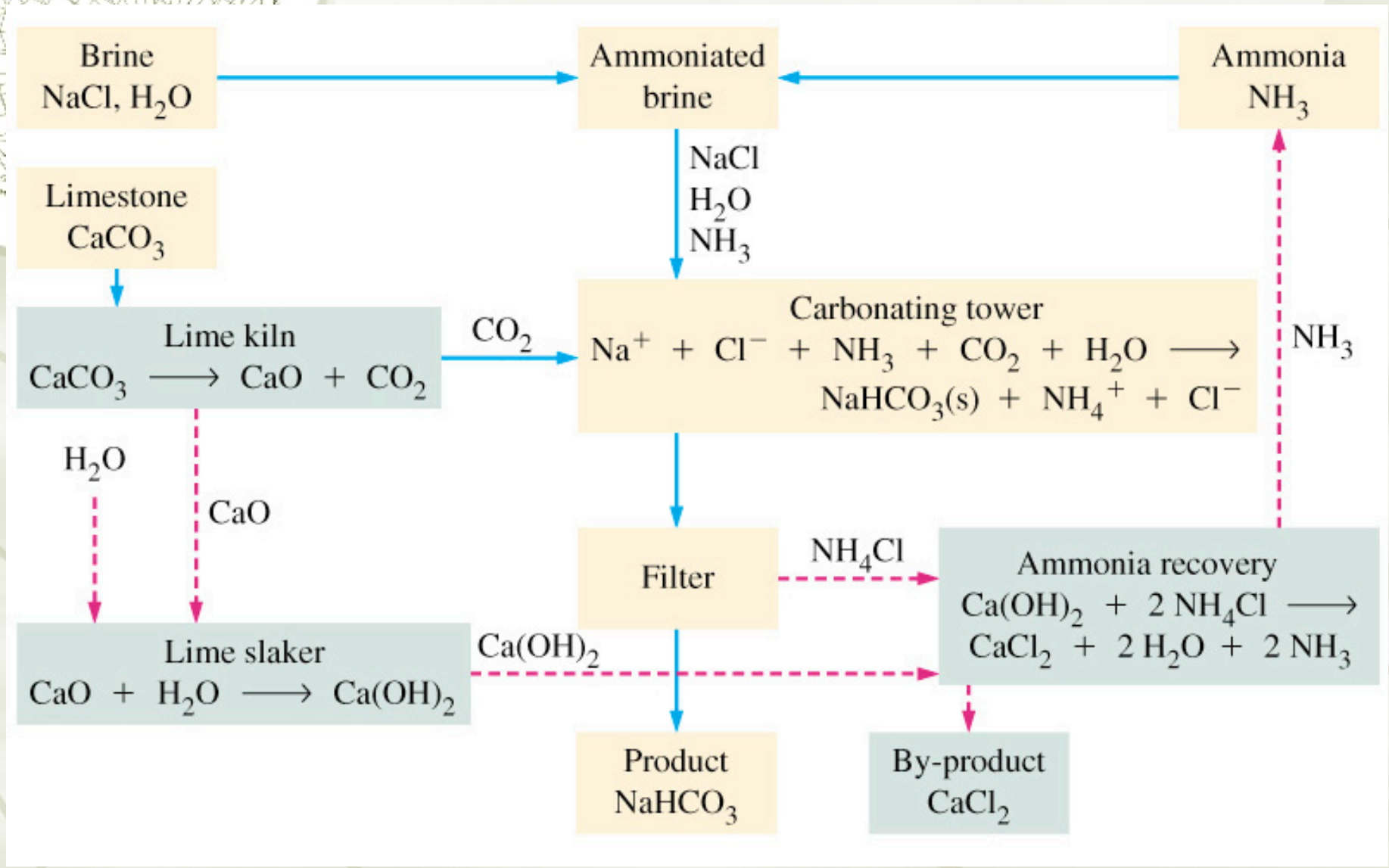
Overall Reaction

$$CaCO_3\,(s) + 2NaCl\,(aq) \rightarrow$$

$$CaCl_2\,(aq) + Na_2CO_3\,(s)$$

The calcium chloride is the unwanted product.

Summary Flowchart



Factors Used to Determine Location of Solvay Plant

- Located near raw materials such as limestone quarries, salt lakes or mines and ammonia production plants.
- Also determined by cost of raw materials and costs of transportation, availability of sites for disposal of wastes and the availability of markets for sodium carbonate.

Environmental Factors

- Waste disposal – some calcium chloride is sold as an additive to concrete mixtures and as soil treatments. Can be disposed of in the ocean but not into lakes or rivers.
- Disposal of excess calcium hydroxide is a problem. It is reacted with hydrochloric acid to produce more calcium chloride.
- Thermal pollution from large amounts of heat generated in the process.