

tion is then pumped into the stirred vessel reactor (c) and is gassed with hydrogen in the presence of Raney nickel. Periodic addition of small amounts of hydrogenation catalyst from the catalyst feed tank (d) allows a constant rate of hydrogen conversion in the hydrogenator. Hydrogenated working solution is collected in the oxidizer feed tank (h) through the internal filters in the stirred vessel, thus exploiting the excess pressure in the reactor. The solution is then led into the oxidation step via the safety filter (e). A side stream of hydrogenated working solution is withdrawn and recycled to the precontact column (a).

When the concentration of Raney nickel in the hydrogenation reactor reaches a certain limit, the content of the reactor is drained into the catalyst separator (f). Raney nickel settles to the bottom, and catalyst-free supernatant is pumped back to the hydrogenator.

A significant disadvantage of Raney nickel as catalyst is its limited selectivity, i.e., the ratio of hydroquinone formation to "tetra" formation. BASF largely eliminated this by pretreating the catalyst with ammonium formate [45].

Alternatives were subsequently suggested for pretreating Raney nickel (e.g., nitriles [46], amines [47], and aldehyde solutions [48]).

The pyrophoric properties of Raney nickel also require more stringent safety procedures when handling the material. Raney nickel is still used today in some AO plants, but palladium catalysts are preferred because of their higher selectivity and simpler handling.

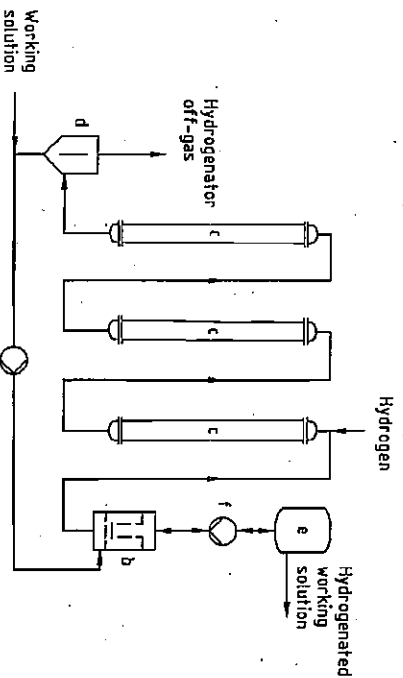


Figure 7. Degussa hydrogenation step
a) Reactor circulating pump; b) Filter; c) Loop reactor; d) Separator; e) Oxidizer feed tank; f) Back flush pump

Degussa Hydrogenation Step. Degussa has proposed the use of palladium black as the hydrogenation catalyst. This exploits the advantages offered by a suspended catalyst and avoids the disadvantages of Raney nickel. Equipment that allows good conversion of hydrogen with very finely distributed palladium black is shown in Figure 7 [49].

The most important feature of the loop reactor (c) is the connection in series of pipes with different diameters. The working solution flows downward in the large pipes at a rate of 0.7–1.5 m/s and flows upward in the narrower pipes at 1.5–3 m/s.

Degussa proposed a carbon filter [50]. A decline in filter performance can be overcome by periodic back flush with hydrogenated working solution through the filter into the hydrogenator.

Advantages of this hydrogenation system are

- 1) almost complete conversion of hydrogen,
- 2) nonpyrophoric catalyst,
- 3) easy exchange of palladium black, and
- 4) easy regeneration of the catalyst.

Laporte Hydrogenation Step. Laporte Chemicals and other companies proposed the use of supported palladium catalysts [51]. These catalysts have the advantage that their particle diameter of 0.06–0.15 mm makes their filtration and recirculation to the reactor simpler than those of palladium black.

Laporte proposed the apparatus shown in Figure 8 for industrial hydrogenation [52]. The

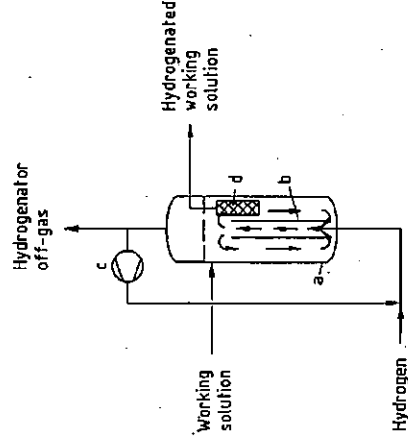


Figure 8. Laporte hydrogenation step
a) Hydrogenator; b) Reactor tubes; c) H_2 compressor; d) Internal filter

reactor contains a series of tubes whose lower ends lie just above the bottom of the reactor and whose top ends are just below the liquid surface. Hydrogen is fed into the bottom of each tube, and very small gas bubbles are formed by distributors. Upward flow occurs in the tube due to the density difference between the solutions in the tube and in the reactor. The catalyst suspension is drawn into the pipe by the continuous flow of working solution. To obtain a sufficiently high airlift effect in the tube, hydrogen must be circulated continuously.

FMC Hydrogenation Step. Fixed-bed hydrogenation represents a simple solution for the hydrogenation step; it involves a palladium catalyst and avoids the problem of filtration and recirculation of catalyst into the reactor [55]. The first industrial fixed-bed hydrogenation unit for the AO process was commissioned by FMC (Fig. 9) [53], [54].

The fixed-bed catalyst should have a diameter of 0.2–5 mm, a surface area less than $5 \text{ m}^2/\text{g}$, and a pore volume smaller than $0.03 \text{ cm}^3/\text{g}$ [55]. The working solution is pumped to the top of the reactor. A side stream of the hydrogenated working solution is also fed into the fresh working solution after the heat of reaction has been removed in a heat exchanger (d). This operation results in optimal cross-sectional loading of the fixed bed, which should be $12\text{--}120 \text{ m}^3$ of working solution per square meter per hour. The cat-

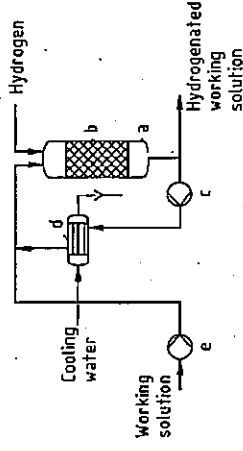


Figure 9. FMC hydrogenation step
a) Fixed-bed reactor; b) Catalyst; c) Reactor circulating pump; d) Heat exchanger; e) Hydrogenator feed pump

alyst must fulfill a number of requirements such as

- 1) high abrasion resistance to allow simplification of the filtration step,
- 2) a long working life because replacing a fixed-bed catalyst is more complicated than replacing a suspended catalyst,
- 3) good productivity, and
- 4) easy regeneration of the catalyst.

4.1.2.2. Oxidation

In industrial plants, the catalyst-free hydrogenated working solution is usually oxidized with slightly pressurized air (up to 0.5 MPa). The oxidizer off-gas is then directed to a series of activated carbon adsorbers to purify it and recover the solvents escaping with it.

For economic reasons, the following objectives are sought in designing industrial oxidation reactors:

- 1) efficient utilization of atmospheric oxygen to reduce the volume of the off-gas and the size of activated carbon adsorbers;
- 2) low compressor pressure to decrease energy costs; and
- 3) small reactor volume or reduced holdup of working solution to lower investment costs for equipment and working solution.

BASF Oxidation Step (Fig. 10). A working solution containing benzene as the quinone solvent has been used at BASF. For safety reasons and to minimize the volume of off-gas, the BASF oxidation step uses a nitrogen–oxygen mixture. The mixture is cycled in a closed circuit, and its composition is kept constant by adding pure oxygen to compensate for the amount consumed in the formation of hydrogen peroxide.

Hydrogenated working solution enters a separator (a) and then flows through four oxidation columns (b) arranged in series as a cascade. Oxi-

rated in the upper part of the reactor. Off-gas from the reactor is fed to the activated carbon adsorption unit, and working solution flows into the second and third reactors which are installed in series. The air needed for oxidation is pressurized with a compressor (c) and fed to the third reactor. The working solution and air flow countercurrently, but both streams are divided into concurrent flow segments.

Laporte Oxidation Step (Fig. 12). In Laporte's Warrington plant, oxidation is carried out in a cocurrent flow column [57]–[61]. The entire volume of the oxidation reactor (a) is used for air gassing. The air and the working solution leaving the top of the column are fed together into a separator (b). The air then reaches the alternately operated two-stage activated carbon adsorbers (c), and the working solution passes to the extraction stage.

Allied Chemical Oxidation Step. To shorten the residence time of the working solution in the oxidation step, Allied Chemical suggested a counterflow reactor in which residence times are less than 2.5 min at a partial oxygen pressure of 70–90 kPa [62].

4.1.2.3. Extraction and Drying

In the BASF plant, a sieve-tray extraction column extracts hydrogen peroxide from the

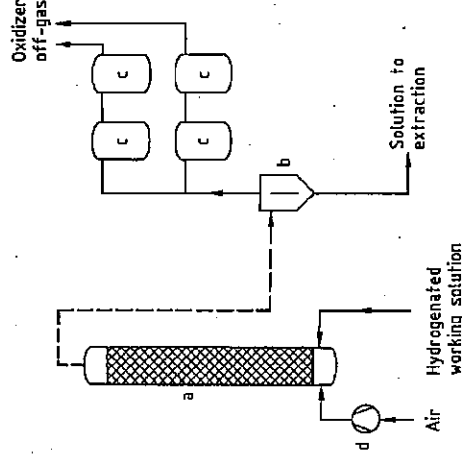


Figure 12. Laporte oxidation step
a) Oxidation reactor; b) Separator; c) Activated carbon adsorber; d) Air compressor

working solution. A number of other extractors, such as packed columns, pulsed packed columns, and Podbielniak extractors, have been proposed.

Working solution leaving the extraction unit contains dispersed water droplets and is fed into coagulators and separators to separate free water. The working solution is then dried to a specific water content.

Because the solubility of water in the working solution depends on temperature, its moisture content can be adjusted by carrying out the extraction at low temperature, separating the dispersed water, and then increasing the temperature of the working solution by about 30 °C before it reaches the hydrogenation step [63].

In extraction and drying according to BASF (Fig. 13), working solution leaving the head of the extraction column (a) is initially freed from entrained water in a water separator (b). The working solution then passes through aqueous potassium carbonate solution for drying (c).

4.1.2.4. Working Solution Purification and Regeneration

During the constant circulation of working solution, degradation products are formed not only from the working compound, but also from the solvents. These degradation products must be removed from the working solution to prevent (1) deterioration of the crude hydrogen peroxide (color, smell, dissolved organic compounds), (2) an increase in density and viscosity of the working solution, and (3) a decrease in surface tension of the working solution, which promotes the formation of an emulsion during extraction. In addition, degradation products decrease the activity and life time of the hydrogenation catalysts.

Numerous methods have been suggested for purifying the working solution and regenerating active quinone from the quinone degradation products. Examples include the following:

- 1) Treatment of the hydrogenated working solution with alkaline substances [44]
- 2) Treatment of the working solution with sodium aluminum silicates at 50–200 °C [64]
- 3) Treatment of the working solution with active aluminum oxide or magnesium oxide at 90–150 °C [65]
- 4) Treatment of the hydrogenated or, preferably, the oxidized working solution at 75–150 °C with calcium, magnesium, or zinc silicates [66]
- 5) Treatment with alkali hydroxide, calcium hydroxide, ammonia, or amines in the presence of oxygen or hydrogen peroxide [67]
- 6) Treatment with concentrated sulfuric acid [68]

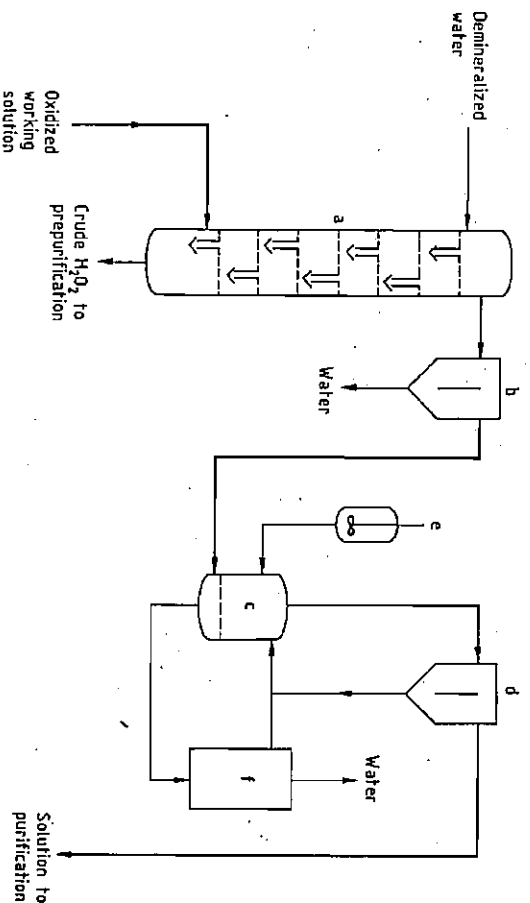


Figure 13. BASF extraction and drying step
a) Sieve-tray extraction column; b) Water separator; c) Drier; d) Potassium carbonate solution separator; e) Potassium carbonate solution make-up and feed tank; f) Potassium carbonate concentration

- 7) Treatment with alkaline hyposulfite solutions, followed by oxidation [69]
- 8) Treatment of the working solution with aqueous sodium hydroxide or potassium hydroxide solution (8–17 mol/L) in the presence of oxidants [70]

4.1.2.5. Purification of Crude Hydrogen Peroxide

The aqueous hydrogen peroxide leaving the extraction is impure. Separators are usually installed after extraction (Section 4.1.2.4). Measures for reducing the amount of dissolved organic compounds include treatment of the crude product with polyethylene [71], ion exchangers [72], or hydrocarbons [73], [74]. Water-soluble organic compounds can also be oxidized by heating and then extracted with suitable solvents (e.g., the quinone solvent) [75]. The effect of purification on carbon content of crude hydrogen peroxide is illustrated in Table 5.

Purified crude product is then usually fed to a distillation unit where it is purified further and concentrated to the usual commercial concentration of 50–70 wt% hydrogen peroxide. This product can be used directly in a number of applications.

Table 5. Processes for purifying crude hydrogen peroxide

Process	Carbon content of H_2O_2 , mg/L		Reference
	Before	After purification	
Extraction with xylene	580	450	[76]
Extraction with methylcyclohexanol acetate	580	390	[76]
Extraction with xylene and methylcyclohexanol acetate	580	370	[76]
Brief treatment with 0.5 wt% activated carbon	134	11	[77]
Treatment with adsorber resin	320	140	[78]

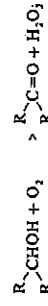
4.1.2.6. Concentration of Hydrogen Peroxide

Water and hydrogen peroxide do not form an azeotrope; their boiling point difference at atmospheric pressure is 50.2°C (Table 1, p. 445). Distillation of water from aqueous hydrogen peroxide can, therefore, be used to concentrate the solution or to completely separate hydrogen peroxide from water. A number of technical safety requirements must be observed. Distillation of dilute solutions has been used industrially to produce commercial 50–70 wt% hydrogen peroxide

solution in electrochemical processes; the technology is described in [3], [5], [79]–[82].

4.2. 2-Propanol Process (Shell Process)

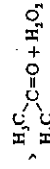
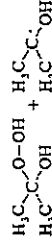
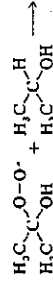
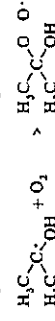
In 1945 HARRIS discovered that primary and secondary alcohols react with oxygen to form hydrogen peroxide and an aldehyde or ketone, respectively [83]:



Oxidation of the alcohol can be carried out in the liquid or the gas phase. Because aldehydes formed in the reaction with primary alcohols are oxidized easily, only the oxidation of secondary alcohols, especially 2-propanol [67–63–6], has industrial importance.

A process for the simultaneous production of hydrogen peroxide and acetone [67–64–1] by atmospheric oxidation of 2-propanol was first suggested by RUST [84], [85]. BROOSKI demonstrated that oxygen in the hydrogen peroxide product originates exclusively from atmospheric oxygen and not from the alcohol [86].

Reaction of 2-propanol with oxygen in the liquid phase does not require a special catalyst because it is catalyzed by the hydrogen peroxide product. However, a small amount (0.5–1 wt%) of hydrogen peroxide is added to 2-propanol to shorten the induction period. The reaction proceeds as follows:



Secondary reactions also take place but are not discussed here. To reduce the formation of byproducts, particularly acetic acid which affects the quality of hydrogen peroxide, only part of

the 2-propanol is oxidized and oxidation is carried out in several consecutive steps at decreasing temperatures [87].

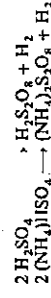
The 2-propanol process is used only in two plants in the Soviet Union, which have been operating since 1968 and 1972. The Shell Oil Company decommissioned its plant in Norco, Louisiana in 1980 [88], [89]; that plant had been in operation since 1957. The technology of the Shell 2-propanol process is described in [6]. The hydrogen peroxide yield of the Russian plants, relative to 2-propanol or atmospheric oxygen, is 90–94%; the acetone yield is 92–94% [90].

4.3. Electrochemical Processes

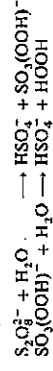
Electrochemical production of hydrogen peroxide is of minor industrial importance compared to the AO process. A few plants still produce hydrogen peroxide by electrolytic processes, for instance the Biochemie Gesellschaft mbH in Austria.

Because electrochemical processes played an important part in the development of hydrogen peroxide and their technology reached a high standard, essential features of the three known cyclic processes are described below. These processes are described in detail in [3], [5].

The basis of electrochemical processes is anodic oxidative coupling of sulfate ions to persulfate ions. Sulfuric acid is oxidized in the Degussa–Weissenstein process, whereas ammonium hydrogen sulfate solutions are used in the Münchner process.



Hydrogen peroxide is formed by hydrolysis of the persulfate ion via the peroxomonosulfate anion:



In the Degussa–Weissenstein and Riedel–Loewenstein processes, persulfuric acid or ammonium persulfate derived from the electrolysis is hydrolyzed directly. In the Münchner process, ammonium persulfate is converted to potassium persulfate which is then hydrolyzed. The Münchner process, therefore, consists of several coupled cyclic processes.

Table 6. Yields and energy consumption of electrochemical processes

Yield or consumption*	Degussa-Weissenstein process	Münchener process	Riedel-Loewenstein process
Current yield, %	73	83	83
Hydrolysis and distillation yield, %	93 96	87 72	82 85
Total yield, %	68-70	1760	68 70.5
Electrical energy, kW·h	1280	1760	1700
Steam, t	1.85	2.5	4.5-4.8
Cooling water, m ³	200	240	250

* Parameters are expressed per 100 kg of hydrogen peroxide (calculated as 100 wt%) in the form of a distilled 35 wt% solution.

All three processes have a very high energy consumption and an unsatisfactory yield of ca. 70% (Table 6).

4.3.1. Degussa-Weissenstein Process

In the Degussa-Weissenstein process (Fig. 14), sulfuric acid is adjusted to a concentration of 550-570 g/L (a) before flowing through

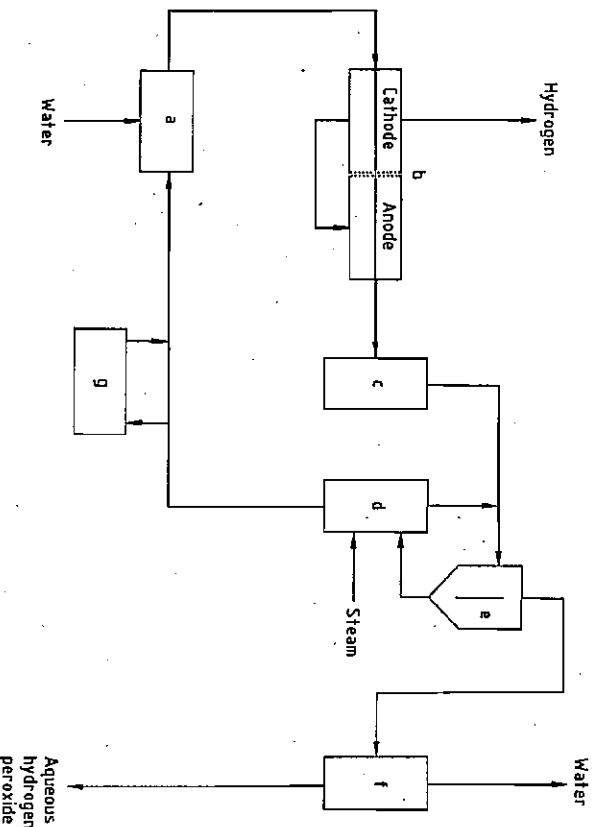


Figure 14. Degussa-Weissenstein process

a) Electrolyzer feed tank; b) Electrolyzer; c) Evaporation and hydrolysis; d) Hydrogen peroxide expulsion and hydrolysis; e) Acid separator; f) Water-hydrogen peroxide fractionating column; g) Acid purification

the catholyte chamber (b) where residual peroxide is destroyed and heavy-metal ions are precipitated. After addition of chemicals to raise the electrochemical potential (e.g., ammonium rhodanide or hydrochloric acid), sulfuric acid passes to the anolyte chamber where persulfuric acid is formed. Hydrolysis of persulfuric acid and distillation of hydrogen peroxide are carried out in two steps (c, d). Hydrolysis is 80-90% completed in (c), and distillation is achieved in approximately equal parts in two steps (c, d). In the expulsion column (d), hydrogen peroxide is expelled from the concentrated sulfuric acid solution by countercurrent steam. Entrained acid is separated in an acid separator (e), and hydrogen peroxide-water vapors are separated in a fractionating column (f). An aqueous solution with a maximum content of 45 wt% hydrogen peroxide is obtained. To purify the circulating solution, part of the stream is distilled constantly (g).

4.3.2. Münchener Process

In the Münchener process (Fig. 15), acid ammonium sulfate is electrolyzed in electrolyzers without diaphragms.

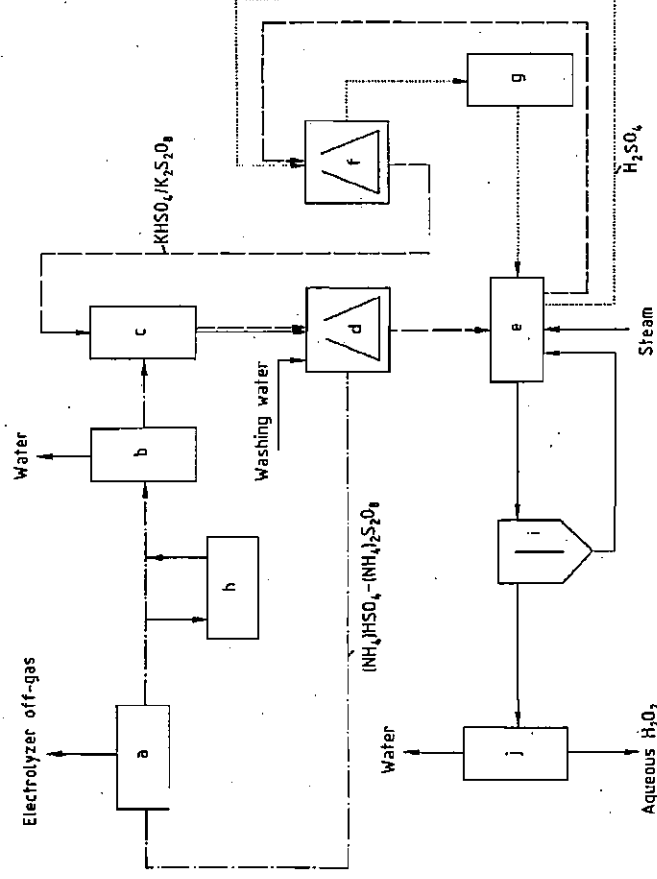


Figure 15. Münchner process

a) Electrolyzer; b) Vacuum cooler; c) Conversion (crystallization); d) Centrifuge; e) Hydrolysis-distillation; f) Centrifuge; g) Sulfuric acid purification; h) Purification of cycle solution; i) Acid separator; j) Fractionating column

The circulating solution contains 300 g of $(\text{NH}_4)_2\text{SO}_4$, 40 g of K_2SO_4 , 100 g of H_2SO_4 , and 57.6 g of $\text{S}_2\text{O}_8^{2-}$ per liter before entering the electrolyzer. Its persulfate concentration is increased to 115.2 g/L by the electrolytic process. After electrolysis, the circulating solution is cooled and concentrated in a vacuum cooler (b) by evaporation of water and then fed into a crystallizer (c). Half of the persulfate is precipitated as potassium persulfate by addition of potassium hydrogen sulfate and separated in a centrifuge (d). The supernatant mother liquor diluted with washing water is returned to the electrolyzer. Solid potassium persulfate is hydrolyzed (e) and hydrogen peroxide is steam distilled.

The remaining potassium hydrogen sulfate-sulfuric acid residue is separated in a centrifuge (f). Sulfuric acid is recycled to the hydrolysis and distillation stage (e) via a purification stage (g). Potassium hydrogen sulfate is returned to the crystallizer (c) for precipitation of persulfate.

To purify the circulating solution, a side stream is mixed with ammonia in the purification

step (h) to precipitate iron. The hydrogen peroxide-water vapors formed during hydrolysis and distillation are led through an acid separator (i) and separated in the rectification step (j). Because hydrolysis is carried out batchwise, the initial vapor mixture is rich in hydrogen peroxide, giving a distillate of 60 wt% which then drops to 20 wt%.

4.4. Other Processes

A number of reactions and processes for the production of hydrogen peroxide are described in the literature. Some of them are no longer economical (e.g., the barium peroxide, azobenzene, and Kruisch processes). Others (e.g., production from hydrogen and oxygen or cathodic reduction of oxygen) have no industrial importance.

Only a few examples can be described here; detailed information may be found in the literature [1], [3], [5].

4.4.1. Production from Peroxy Compounds

Peroxy compounds can be decomposed to form hydrogen peroxide. Examples of such reactions, which include the historically important Thénard reaction of barium peroxide with nitric or sulfuric acid, are listed in Table 7.

4.4.2. Production from Hydrogen and Oxygen

Direct reaction of hydrogen and oxygen to form hydrogen peroxide can be achieved in a number of ways but is not industrially important. Available processes are either uneconomical or difficult to execute. However, the most important hydrogen peroxide manufacturing process—the AO process—also allows production of hydrogen peroxide from its elements.

Table 7. Production of hydrogen peroxide from peroxy compounds

Peroxy compound	Reaction	Reference
BaO_2	reaction of barium peroxide with H_2SO_4 in the presence of a small amount of HCl allows quantitative conversion; ca. 6% aqueous H_2O_2 solutions are obtained	[91]
BaO_2	as above, but in the presence of HCl and H_3PO_4	[92]
Na_2O_2	sodium peroxide solutions are passed through acidic ion exchangers to exchange Na^+ for H^+	[93]
$(\text{C}_2\text{H}_5)_2\text{CO}-\text{OH}$	<i>tert</i> -butyl hydroperoxide is hydrolyzed to <i>tert</i> -butanol and H_2O_2 in the presence of H_2SO_4 in a fractionating column	[94]
$(\text{CH}_3)_2\text{CO}-\text{OH}$	H_2O_2 and di- <i>tert</i> -butyl peroxide are formed from <i>tert</i> -butyl hydroperoxide in 50% H_2SO_4	[95]
$\text{H}_3\text{C}-\text{C}(=\text{O})-\text{O}-\text{OH}$	peracetic acid is hydrolyzed to CH_3COOH and H_2O_2 in the presence of H_2SO_4 to shift the equilibrium to H_2O_2 ; CH_3COOH is reacted with an alcohol and the ester is distilled	[96]
$\text{H}_3\text{C}-\text{C}(=\text{O})-\text{O}-\text{OH}$	peracetic acid is hydrolyzed with acidic ion exchangers, and the equilibrium mixture is separated by distillation	[97]

Examples of hydrogen peroxide synthesis from hydrogen and oxygen follow:

- 1) Silent electrical discharge into a reaction gas containing 95% hydrogen and 5% oxygen, in the presence of water vapor at 150–160°C and 100 kPa, and subsequent condensation of hydrogen peroxide result in a 10% aqueous solution. The minimum electrical energy needed to produce 1 kg of hydrogen peroxide is 40 kW·h [98].
- 2) Addition of hydrogen, oxygen, and nitrogen to acetone in the presence of hydrochloric acid, sulfuric acid, and palladium–silica gel catalyst results in hydrogen peroxide yields of 50% relative to hydrogen [99].
- 3) Hydrogen and oxygen react to form hydrogen peroxide in a biphasic liquid system (water–organic solvent) with a catalyst of the L_2PdX_2 type (L = phosphorus-containing ligand, X = halogen, preferably chlorine). The catalyst is soluble in organic solvents but generally insoluble in water [100].
- 4) Reaction of hydrogen and oxygen proceeds in the presence of a nitrite or a nitrogen-containing organic compound, a strong acid, and a palladium catalyst [101].
- 5) Homogeneously catalyzed reaction of hydrogen and oxygen occurs in a biphasic liquid system (water–organic solvent) in the presence of a promoter. Compounds of the IrCl(CO)X_2 type are used as catalysts (X = P, As, or Sb; R = phenyl, alkyl, or cyclohexyl) [102].

4.4.3. Production by Autoxidation of Organic Compounds

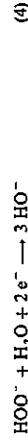
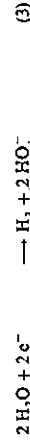
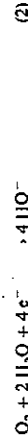
Autoxidation processes for the production of hydrogen peroxide include the AO process and the 2-propanol process discussed in Sections 4.1 and 4.2. The azobenzene process has occasionally been used on a commercial scale. Analogous to the AO process, azobenzene is reduced to hydrazobenzene which is then oxidized to azobenzene. The reaction proceeds at alkaline pH and results in formation of $\text{Na}_2\text{O}_2 \cdot 8\text{H}_2\text{O}$ [103]–[105].

Other autoxidation processes have been suggested, such as the oxidation of hydrocarbons, alcohols, and hydrazine, but they have no commercial significance. They are usually carried out in the gas phase at high temperature and give a multicomponent reaction mixture due to subsequent secondary reactions.

4.4.4. Production by Cathodic Reduction of Oxygen

The formation of hydrogen peroxide (max. 1% solution) by cathodic reduction of oxygen was reported by Traube in 1882 [106]. The process was improved by Fischer and Priess who introduced pressurized electrolysis (ca. 10 MPa),

which gave 1.3–2.7 % hydrogen peroxide solutions with current efficiencies of 83–90 % [107]. Although BERL attempted to bring cathodic oxygen reduction to technological maturity [108], [109], this process is not yet used on an industrial scale. Apart from the desired reduction of oxygen to hydrogen peroxide according to Equation (1)



Equations (2) and (3) occur, which reduce current efficiency, and the hydrogen peroxide formed can be destroyed by reduction (Eq. 4). Equation (3) ultimately leads to the formation of a detonating gas atmosphere in the electrolyzer. Work on cathodic reduction with oxygen has been resumed [110], [111]. Gas cathodes and > 3500 h of operation allow current efficiencies > 90 %. The following methods are suggested for industrial use and yield a 10 % aqueous hydrogen peroxide solution which must be brought to the commercial concentration of 50–70 wt% by distillation.

1) Use of caustic potash as the working electrolyte, anodic oxygen production, precipitation of peroxide as calcium peroxide, reaction of calcium peroxide with carbon dioxide and water to form hydrogen peroxide and calcium carbonate, and conversion of the latter into carbon dioxide and calcium oxide results in the net reaction:



2) Use of potassium chloride solution as the working electrolyte with anodic chlorine production, otherwise follows method 1.



3) Use of potassium chloride as the working electrolyte with anodic chlorine production, precipitation of peroxide with calcium chloride, release of hydrogen peroxide by reaction of calcium peroxide with carbon dioxide and water, and conversion of calcium carbonate with hydrochloric acid to calcium chloride. The net reaction is



5. Storage and Transportation [4]

The decomposition of hydrogen peroxide caused by catalytic impurities and the associated release of heat have been described in Chapters 2 and 3. Great care must be taken in production,

storage, and transportation to prevent these impurities from entering the hydrogen peroxide solution and to ensure that hydrogen peroxide is put only into perfectly clean containers. Because commercial hydrogen peroxide always contains small quantities of catalytic impurities, the stabilization of peroxide solutions is extremely important. The stabilizing effects of inorganic and organic compounds are described in detail in [3].

Sodium pyrophosphate [7722-88-5] and sodium stannate [12058-66-1] are the preferred stabilizers and are added separately or together [112], [113]. Organic compounds are not stable enough for use with concentrated hydrogen peroxide; they are preferred for dilute solutions [114], [115].

Aluminum (99.5%), aluminum–magnesium alloys, or stainless steels are good construction materials. Because of their corrosion resistance, polyethylene containers and storage tanks are preferred for hydrogen peroxide concentrations up to 50 wt%. Before metallic tanks and containers can be used, their surfaces must be passivated. Iron particles may become attached to the surface during the rolling of aluminum, and they must be removed. Aluminum is, therefore, treated with dilute sodium hydroxide and then passivated with dilute nitric acid. Because hydrogen forms during the caustic treatment of aluminum with sodium hydroxide, safety precautions must be taken to avoid a detonating gas atmosphere. It is extremely important to ensure that no hydrogen peroxide is trapped, e.g. between closed valves. If decomposition occurs, extremely high pressures result which lead to very serious explosions.

Hydrogen peroxide is admitted for air transport only up to a concentration of 40 wt% (IATA regulations).

No special regulations apply to the transport of solutions of up to 8 wt% hydrogen peroxide. Table 8 lists international regulations for rail (RID), road (ADR), and sea (IMDG code) transport of more highly concentrated solutions.

Table 8. Transport regulation for hydrogen peroxide

	H ₂ O ₂ concentration, wt%			
	8–20	20–60	> 60	
RID/ADR	8, No. 62c	8, No. 62b	5.1, No. 1	
IMDG Code	5.1	5.1	5.1	
UN No.	2984	2014	2015	
	package group III	package group II	package group I	