

**Table 34.3** Classification of Commercial Resins and Plastics by Derivation

I <i>Derivatives of Natural Products</i> (thermoplastic, except where noted)	II <i>Synthetic Resins Formed by Condensation Polymerization</i> (thermoset, except where noted)	III <i>Synthetic Resins Formed by Addition Polymerization</i> (thermoplastic)
A. Natural resins	A. Phenolic resins	A. Polyethylene
1. Fossil and plant resins	1. Phenol-formaldehyde	B. Polypropylene
2. Rosin	2. Phenol-furfural	C. Polyisobutylene
3. Shellac	3. Resorcinol-formaldehyde	D. Fluorocarbon polymers
4. Lignin (thermosetting)	B. Amino resins	E. Polyvinyl acetate and derivatives
B. Cellulose derivatives	1. Urea-formaldehyde	1. Polyvinyl alcohol
1. Regenerated cellulose	2. Melamine-formaldehyde	2. Acetals
a. Viscose	C. Polyesters	F. Other vinyl polymers
b. Cuprammonium	1. Alkyd	1. Polyvinyl ethers
2. Cellulose esters	2. Unsaturated or oil-modified alkyds	2. Divinyl polymers
a. Nitrate	3. Polycarbonates (thermoplastic)	3. Polyvinyl chloride
b. Acetate	D. Polyethers (thermoplastic)	G. Polyvinylidene chloride
c. Propionate	1. Polyformaldehydes	H. Polystyrene
d. Mixed esters (nitrate-acetate, acetate-propionate, acetate-butyrate)	2. Polyglycols	I. Acrylic polymers
3. Cellulose esters	E. Polyurethanes (thermoplastic under some conditions)	
a. Methyl	F. Polyamides (thermoplastic)	
b. Ethyl	G. Epoxides	
c. Carboxymethyl	H. Silicone resins (thermoplastic under some conditions)	
C. Protein derivatives	I. Ionomers	
a. Casein-formaldehyde	J. Polysulfones	
b. Zein (corn protein)-formaldehyde	K. Polyimides	
c. Soybean protein-formaldehyde		

or after, the original condensation polymerization, the long chains of polymer may react with each other to form a "cross-linked" material which is usually harder and tougher than the straight-chain polymer. Properties can be varied for special purposes by regulating the amount of cross-linking.

Another variation in the type of final product is effected by the simultaneous polymerization of two or more types of monomers. By carefully regulating the relative amounts of the monomers and reaction conditions and initiators, the properties of the final polymer can be controlled. Three types of copolymers may be formed, depending upon conditions

Random copolymer,  $M_1M_2M_2M_1M_1M_1M_2$

Alternating copolymer,  $M_1M_2M_1M_2M_1M_2$

Block copolymer,  $M_1M_1M_1M_1M_2M_2M_2M_2$

Properties of plastics can be changed by reinforcement with various materials, usually fibers of some sort. Common reinforcing fibers are cellulose fibers, fiberglass, carbon fibers, aramid fibers, and metal filaments. Table 34.4 shows some comparisons between reinforced and unreinforced plastics.

Engineering plastics<sup>1</sup> are high-strength high-performance materials that can be substituted for many metal uses. There are a wide variety of engineering plastics available. Each one has its own special properties, and thus care must be taken in choosing a resin for a particular use. These materials are often the usual plastics but have been carefully manufactured to possess extra quality properties. These materials show better resistance to wear, impact, and corrosive chemicals and have excellent electrical properties. Some of the uses are automobile bumpers and dashboards, pumps, valves, and gears, and driveshafts and transmissions in heavy-duty equipment. Many of the common resins are in use as engineering plastics such as acetal, fluoroplastics, nylon, polyphenylene oxide, polycarbonate, polyphenylene sulfide, polysulfone, polyether-imide, polyethersulfone and nylon-polyether block amides, and several other copolymers.

The common names of plastics are usually the common or even the principal trade names and often are referred to by abbreviations. Some of the international abbreviations are given in Table 34.5.

**USES AND ECONOMICS.** Plastics are not interchangeable. Each one has its own individual properties and characteristics that make it useful for certain applications. Table 34.6 lists properties and applications for the major commercially produced materials. Tables 34.7 and 34.8 list the selling prices and U.S. production of various representative materials.

## RAW MATERIALS

### *Chemical Intermediates<sup>2</sup> and Monomers*

**PHENOL.**<sup>3</sup> Phenol has been made, over the years, by a variety of processes. Many of the companies producing it use it internally and do not sell it on the open market. The principal

<sup>1</sup>Engineering Plastics, *Chem. Eng.* 89 (16) 42 (1982); *Mod. Plast.* 59 (1) 62 (1982); *Plast. Eng.* 38 (1) 17 (1982).

<sup>2</sup>As in other chapters, intermediates are presented whose chief consumption is in a chemical process industry covered by another chapter.

<sup>3</sup>ECT, 3d ed., vol. 17, 1981, p. 373.

**Table 34.4** Comparison of Some Unreinforced and Reinforced Plastics

	Nylon 6/6				Polyester		Polysulfone	
	40% C		30% C		30% C		30% C	
	Unreinforced	Fiber	Fiber	Unreinforced	Fiber	Unreinforced	Fiber	Fiber
Specific gravity	1.14	1.34	1.46	1.32	1.47	1.52	1.24	1.37
Water absorption, 24 h %	1.6	0.4	0.6	0.08	0.06	0.04	0.20	0.15
Tensile strength, MPa	81	276	214	55	138	134	70	131
Flexural strength, MPa	103	414	290	896	200	193	106	176
Tensile elongation, %	10	3-4	2-3	10	2-3	3-4	50	2-3
Shear strength, MPa	66	96	83	55	—	55	62	48
Heat distortion temp at 1820 kPa, °C	65	260	260	68	221	221	173	184

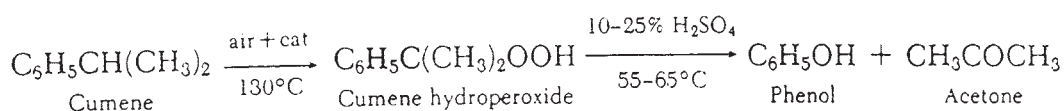
SOURCE: Katz and Milewski (eds.), *Handbook of Fillers and Reinforcements for Plastics*, Van Nostrand Reinhold, New York, 1978

**Table 34.5** International Abbreviations for Names of Plastics

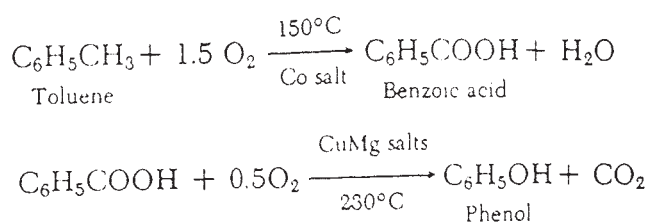
Abbreviation	Name of Plastic
CA	Cellulose acetate
CPVC	Chlorinated poly(vinyl chloride)
MF	Melamine-formaldehyde resins
NBR	Poly(acrylonitrile-co-butadiene)
PAN	Polyacrylonitrile
PC	Bisphenol A polycarbonate
PE	Polyethylene
PETP	Poly(ethylene terephthalate)
PF	Phenol-formaldehyde resins
PIB	Polyisobutylene
PMMA	Poly(methyl methacrylate)
POM	Polyoxymethylene
PP	Polypropylene
PS	Polystyrene
PTFE	Polytetrafluoroethylene
PUR	Polyurethane
PVAC	Poly(vinyl acetate)
PVAL	Poly(vinyl alcohol)
PVB	Poly(vinyl butyral)
PVC	Poly(vinyl chloride)
PVDC	Poly(vinylidene chloride)
PVDF	Poly(vinylidene fluoride)
PVP	Poly(vinyl pyrrolidone)
UF	Urea-formaldehyde resins

SOURCE: Fried, Polymer Technology, Part 1, *Plast. Eng.* 38 (6) 54 (1982).

process in use in the United States is the peroxidation of cumene (isopropyl benzene).



The conversion of cumene to cumene hydroperoxide gives a 25 to 50 percent yield per pass (Fig. 34.1). The cumene hydroperoxide, which has the dangerous explosive properties of other hydroperoxides, decomposes into acetone and phenol in the presence of sulfuric acid. The by-product acetone dominates the acetone market. Phenol can be prepared from toluene, and one small plant in the United States produces it this way. This process is more widely used in Europe.



**Table 34.6** Summary of Resin Properties and Applications

Resin Type	Properties	Applications
Phenolics	Good strength, heat stability, and impact resistance; high resistance to chemical corrosion and moisture penetration, machinability	Impregnating resins, brake lining, rubber resins, electrical components, structural board, laminates, glues, adhesive binders, molds
Aminos	Good heat resistance, solvent and chemical resistance, extreme surface hardness, resistance to discoloration	Molding compounds, adhesives, laminating resins, paper coating, textile treatments, plywood, dinnerware, decorating structures
Polyesters	Extreme versatility in processing, excellent heat, chemical, and flame resistance, low cost; excellent mechanical and electrical properties	Construction, auto-repair putty, laminates, skis, fishing rods, boats and aircraft components, coatings, decorative fixtures, bottles
Alkyds	Excellent electrical and thermal properties, versatility in flexibility or rigidity, good chemical resistance	Electrical insulation, electronic components, putty, glass-reinforced parts, paints
Polycarbonates	High refractive index, excellent chemical, electrical, and thermal properties; dimensional stability; transparent; self-extinguishing; resistant to staining; good creep resistance	Replacement for metals, safety helmets, lenses, electrical components, photographic film, die casting, insulators
Polyamides	Tough, strong, and easily moldable; light; abrasion-resistant; low coefficient of friction; good chemical resistance; self-extinguishing	Unlubricated bearings, fibers, gears, appliances, sutures, fishing lines, tires, watch straps, packaging, bottles
Aromatic polyamides	High-temperature resistance	Reinforcement of organic matrices
Polyimides	High-temperature resistance	Molded parts, films, and laminating resins for high temperature use up to 180°C
Polyurethanes	Extreme versatility when combined with other resins, good physical, chemical, and electrical properties	Insulation, foam inner liners for clothing, rocket fuel binders, elastomers, adhesives
Polyethers	Excellent corrosion resistance to common acids, alkalies, and salts; can be seam-welded and machined to fit any type, shape, or size of structure	Coatings, pump gears, water-meter parts, bearing surfaces, valves
Epoxies	Excellent chemical resistance, good adhesion properties, strong and tough with low shrinkage during cure, excellent electrical properties, good heat resistance	Laminates, adhesives, flooring, linings, propellers, surface coatings, filament-wound structures (rocket cases)
Silicones	Good thermal and oxidative stability, flexible, excellent electrical properties, general inertness	Mold-release agents, rubbers, laminates, encapsulating resins, antifoaming agents, water-resistant uses
Ionomers	Excellent toughness, abrasion resistance, and transparency, outstanding low-temperature flexural properties	Skin and blister packaging, heel lifts, shoes, ski boots, automobile bumpers, golf ball covers
Phenoxies	Ease in molding, good heat stability, low mold shrinkage, self-extinguishing, good cold flow	Surface coatings, adhesives, binders, electronic parts
Polyethylene	Excellent chemical resistance, low power factor, poor mechanical strength, outstanding moisture-vapor resistance, wide degree of flexibility	Packaging films and sheets, containers, wire cable insulation, pipe, linings, coatings, molds, toys, housewares

(cont. next page)

**Table 34.6** Summary of Resin Properties and Applications (*continued*)

Resin Type	Properties	Applications
Polypropylene	Colorless and odorless, low density; good heat resistance, "unbreakable," excellent surface hardness, excellent chemical resistance, good electrical properties	Housewares, medical equipment (can be sterilized), appliances, toys, electronic components, tubing and pipe, fibers and filaments, coatings
Polybutylene	Excellent resistance to abrasive slurries, good chemical resistance, tough, better heat resistance than polyethylene	Pipe and tubing, films, and in blends to lend strength and toughness
Fluorocarbons	Low coefficient of friction, low permeability, low moisture absorption, exceptional chemical inertness, low dielectric strength	Electrical insulation, mechanical seals, gaskets, linings for chemical equipment, bearings, frying-pan coatings, cryogenic applications
Polyvinyl chloride	Excellent physical properties, excellent chemical resistance, ease of processing, relatively low cost, self-extinguishing, ability to be compounded with other resins	Pipe and tubing, pipe fittings, adhesives, raincoats and baby pants, building panels, wastepaper baskets, weather stripping, shoes
Acrylics	Crystal clarity, outstanding weatherability, fair chemical resistance, good impact and tensile strength, resistant to ultraviolet exposure	Decorative and structural panels, massive glazing domes, automotive lens systems, illuminated translucent floor tiles, windows, and canopies, signs, coating, adhesives, elastomers
Polystyrene	Low cost, ease of processing; excellent resistance to acids, alkalis, salts; softened by hydrocarbons; excellent clarity, versatility	Insulation, pipe, foams, cooling towers, thin-walled containers, appliances, rubbers, automotive instruments and panels
Cellulosics	Outstanding toughness, high impact strength, high dielectric strength, low thermal conductivity, high surface luster	Textile and paper finishes, thickening agents, magnetic tapes, packaging, pipe
Furanes	Excellent resistance to both acids and bases, good adhesive properties	Laminates, coatings, impregnants, linings for rocket fuel tanks, floor tiles, abrasive wheels

SOURCES: *Modern Plastics Encyclopedia*, 1981-1982; *Chem. Eng. Prog.* 76 (1) 57 (1980).

**Table 34.7** Selling Price of Various Resins

Type	Average Selling Price, dollars per kilogram					
	1937	1954	1964	1971	1981	1982
Polyethylene	—	0.97	0.46	0.26	1.03	0.88
Vinyls	1.52	0.90	0.64	0.35	0.70	0.70
Styrenes	1.58	0.68	0.46	0.42	1.12	0.99
Phenolics	—	0.57	0.53	0.46	0.99	0.99
Polyesters	—	—	0.68	0.51	1.34	1.17
Urea and melamines	1.21	0.53	0.57	0.77	1.28	1.03
Alkyds	0.44	0.66	0.57	0.77	1.28	1.03
Polyamide (nylon)	—	3.52	2.05	1.21	3.19	—
Polypropylene	—	—	0.53	0.29	0.88	1.17
Epoxy resins	—	—	1.30	1.01	2.20	2.77

SOURCE: *Synthetic Organic Chemicals*, U.S. Tariff Commission

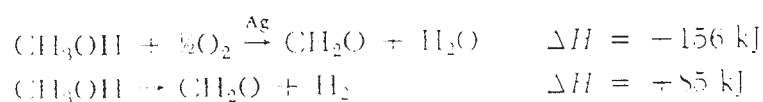
**Table 34.8** Plastics and Resins, U.S. Production (in metric tons)

Material	1974	1979	1981
Polyethylene			
High density	128,700	221,950	212,420
Low density	270,936	354,488	340,925
Polypropylene	—	176,632	176,496
Polyvinyl alcohol	64,400	61,235	61,236
Polyvinyl chloride	220,000	278,420	255,467
Styrene resins	188,335	181,300	163,430
Phenolics	60,555	78,605	58,510
Polyesters	11,320	53,350	44,270
Urea and melamines	45,360	70,170	59,740
Epoxies	11,290	17,795	17,795

SOURCES: *Chem. Eng. News* 60 (8) 6 (1982); 60 (35) 10 (1982); *Chem. Mark. Rep.* October 19, 1981.

In 1982 almost  $1 \times 10^9$  kg was produced in the United States at a price of 70 to 75 cents per kilogram.<sup>4</sup>

**FORMALDEHYDE.**<sup>5</sup> Formaldehyde results from the exothermic oxidation and endothermic dehydrogenation of methanol as shown in Fig. 34.2.



These two reactions occur simultaneously in commercial units in a balanced reaction, called autothermal because the oxidative reaction furnishes the heat to cause the dehydrogenation to take place. About 50 to 60 percent of the formaldehyde is formed by the exothermic reaction. The oxidation requires 1.6 m<sup>3</sup> of air per kilogram of methanol reacted, a ratio that is

<sup>4</sup>Key Chemicals, *Chem. Eng. News* 60 (31) 10 (1982).

<sup>5</sup>Walker, *Formaldehyde*, ACS Monograph 159, Reinhold, New York, 1964; Austin, Industrially Significant Organic Chemicals, *Chem. Eng.* 81 (11) 101 (1974); Diem, Formaldehyde Routes Bring Cost, Production Benefits, *Chem. Eng.* 85 (5) 83 (1978); ECT, 3d ed., vol. 11, 1981, p. 231.

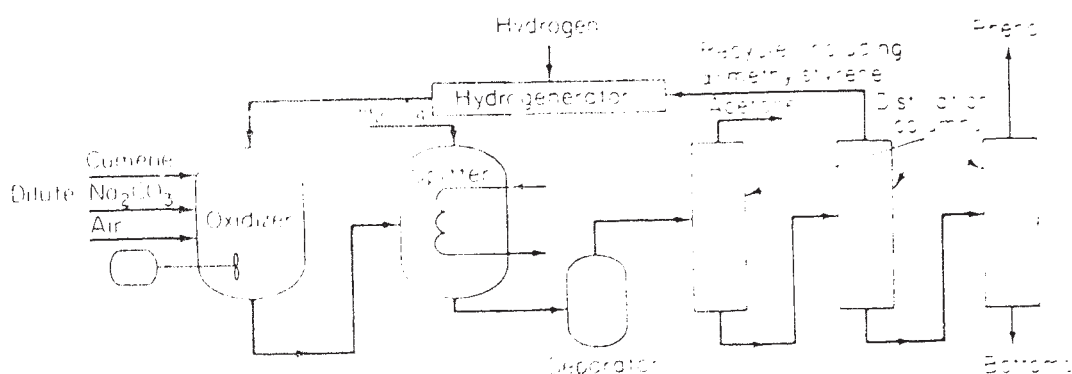


Fig. 34.1. Phenol from cumene production flowchart

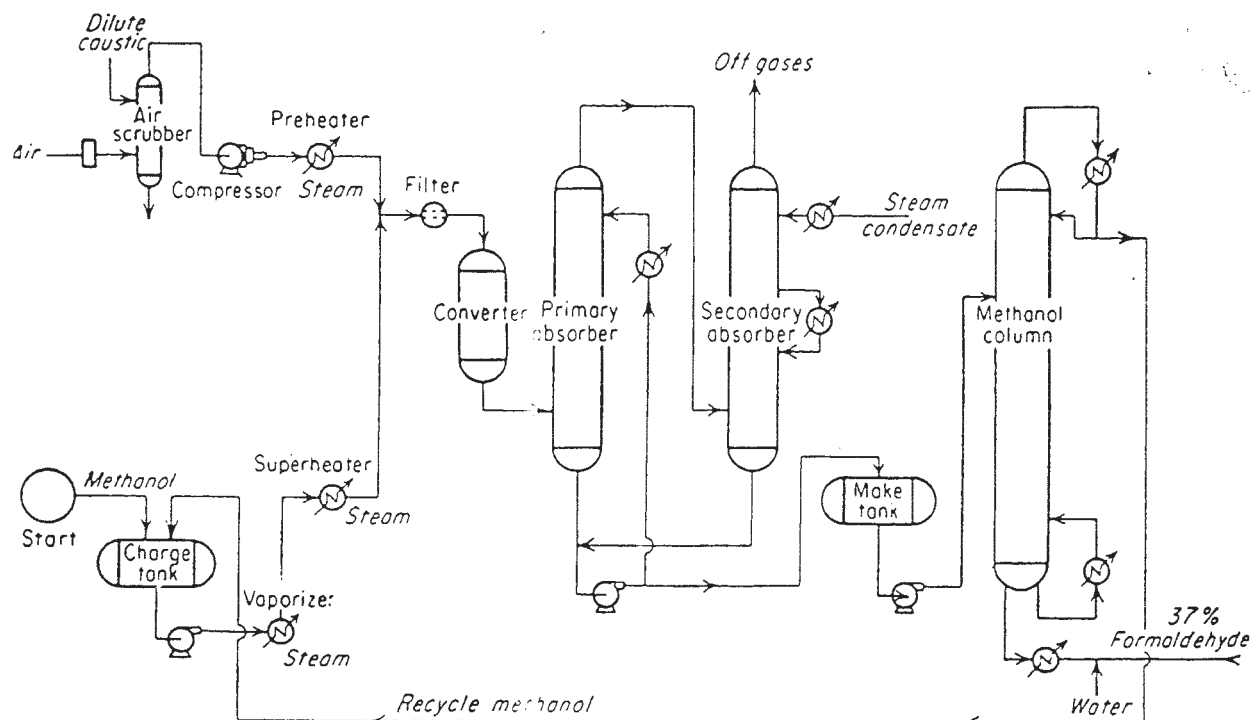
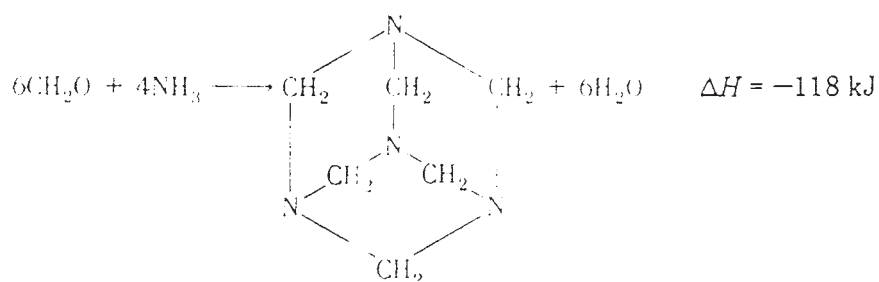


Fig. 34.2. Flowchart for the manufacture of formaldehyde.

maintained when passing separate streams of these two materials forward. Fresh and recycle methanol are vaporized, superheated, and passed into the methanol-air mixer. Atmospheric air is purified, compressed, and preheated to 54°C in a finned heat exchanger. The products leave the converter at 620°C and at 34 to 69 kPa absolute. The converter is a small water-jacketed vessel containing the silver catalyst. About 65 percent of the methanol is converted per pass. The reactor effluent contains about 25% formaldehyde, which is absorbed with the excess methanol and piped to the make tank. The latter feeds the methanol column for separation of recycle methanol overhead, the bottom stream containing the formaldehyde and a few percent methanol. The water intake adjusts the formaldehyde to 37% strength (marketed as formalin). The yield from the reaction is 85 to 90 percent. The catalyst is easily poisoned so stainless-steel equipment must be used to protect the catalyst from metal contamination.

In 1982 about  $2.2 \times 10^6$  t of 37% solution (formalin) was produced in the United States at a price of 19 to 20 cents per kilogram.<sup>6,6a</sup>

**HEXAMETHYLENETETRAMINE.** Evaporation of the reaction product of formaldehyde and ammonia produces hexamethylenetetramine.

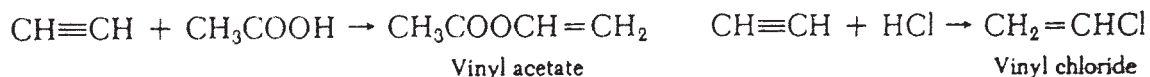


<sup>6</sup>Key Chemicals, *Chem. Eng. News* 60 (13) 26 (1982).

<sup>6a</sup>t = 1000 kg.

This compound finds use as a urinary antiseptic (Urotropine), in the rubber industry, in the preparation of the explosive cyclonite (Chap. 22), and mainly in making phenol-formaldehyde resins, where it is known as "hexa."

**VINYL ESTERS.** The addition of acids to acetylene furnishes esters.

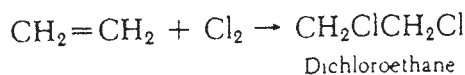


If two molecules of acid react, a compound such as 1,1-ethane diacetate is formed:

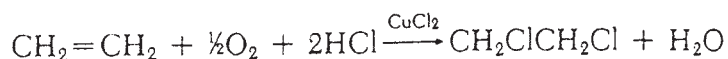


Vinyl chloride is usually prepared by the oxychlorination (dehydrochlorination) of ethylene.<sup>7</sup> See Fig. 34.3 which presents a flowchart for the following reactions.

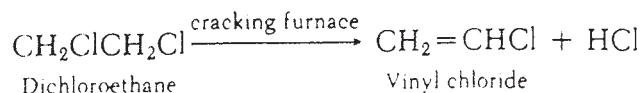
### CHLORINATION



### OXYCHLORINATION



### DEHYDROCHLORINATION



<sup>7</sup>Austin, *The Industrially Significant Organic Chemicals*, *Chem. Eng.* 81 (6) 87 (1974); *Encyclopedia of Polymer Science and Technology*, Wiley, New York, 1964-1971 (referred to hereafter as EPST), vol. 16, 1971, p. 315; *Hydrocarbon Process.* 60 (11) 235 (1981).

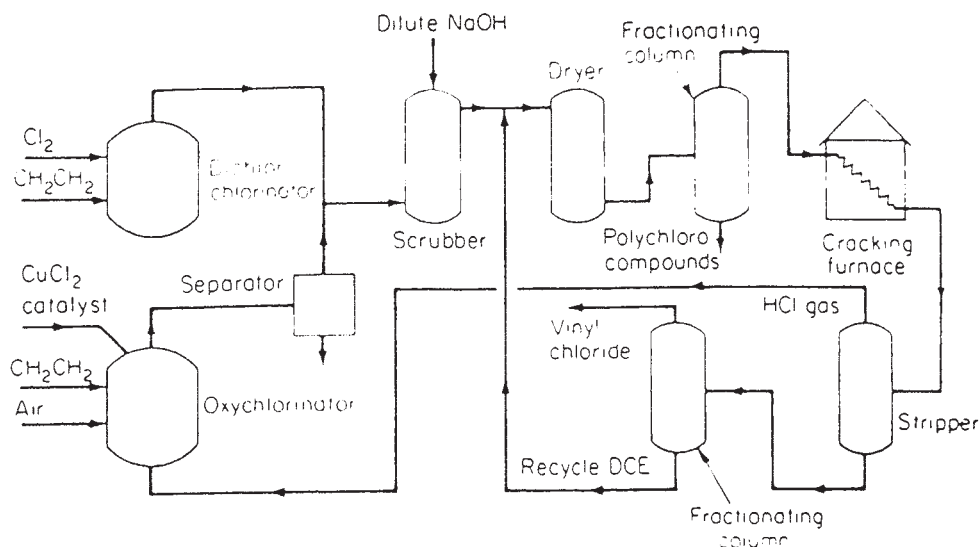
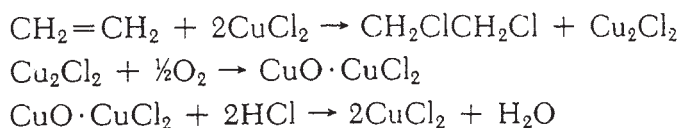


Fig. 34.3. Flowchart for the production of vinyl chloride

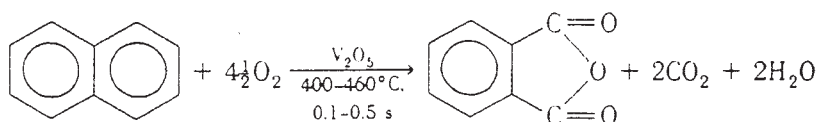
The  $\text{CuCl}_2$  catalyst (on an inert fixed carrier) may react as follows:



Exposure to vinyl chloride vapors, even in very small concentrations, causes some workers to develop liver cancer. The government requires that worker exposure to vinyl chloride monomer be no more than 1 ppm over an 8-h period, and no more than 5 ppm for any 15-min period. To achieve this requires extensive and expensive pollution-abatement systems.<sup>8</sup>

Vinyl acetate<sup>9</sup> is also made from ethylene in a vapor phase process. The feed mixture is ethylene, acetic acid, and oxygen, and is circulated through a fixed-bed tubular reactor. The catalyst is a noble metal, probably palladium, and has a life of several years.

**PHTHALIC ANHYDRIDE.**<sup>10</sup> Phthalic anhydride is one of the most important intermediates for the plastics industry. Figure 34.4 lists the end-use pattern of this compound. The processes for the preparation of phthalic anhydride are controlled oxidation of *o*-xylene or naphthalene.



Oxidation is one of the very useful chemical conversions in organic technology. The cheapest agent is air, but oxygen is sometimes employed. For liquid-phase reactions a great many oxidizing agents are in industrial use, such as nitric acid, permanganates, pyrolusite, dichromates, chromic anhydride, hypochlorites, chlorates, lead peroxide, and hydrogen peroxide. Water and carbon dioxide and many other oxidized substances are the by-products of the main oxidation. When charcoal or carbon (amorphous) changes to carbon dioxide  $\Delta H = -404 \text{ kJ/g-mol}$ ,<sup>11</sup> and when hydrogen burns to water (gaseous),  $\Delta H = -242 \text{ kJ/g-mol}$ . These energy changes, although the basis of combustion, frequently accompany controlled oxidation, as in the making of phthalic anhydride and maleic acid. In most oxidations, even when the formation of carbon dioxide and water can be repressed, the energy change is exothermic and large. This requires particular care in the design and construction of the equipment to ensure efficient heat transfer and to prevent the controlled oxidation from becoming combustion.

The naphthalene process, with a suitable catalyst, was discovered by Gibbs and Conover.<sup>12</sup>

<sup>8</sup>Bertram, Minimizing Emissions from Vinyl Chloride Plants, *Environ. Sci. Techol.* **11** 864 (1977).

<sup>9</sup>Carron and Galloway, Vinyl Acetate from Ethylene, *Chem. Eng.* **80** (9) 92 (1973); *Hydrocarbon Process.* **60** (11) 233 (1981); *Modern Plastics Encyclopedia*, 1981-1982 (referred to hereafter as MPE).

<sup>10</sup>ECT, 3d ed., vol. 17, 1982, pp. 738-746.

<sup>11</sup>For carbon, the equivalent  $\text{kJ/kg} = -32,560$ ; for hydrogen,  $-120,950$ .

<sup>12</sup>U.S. Patent 1,285,217 (1918).

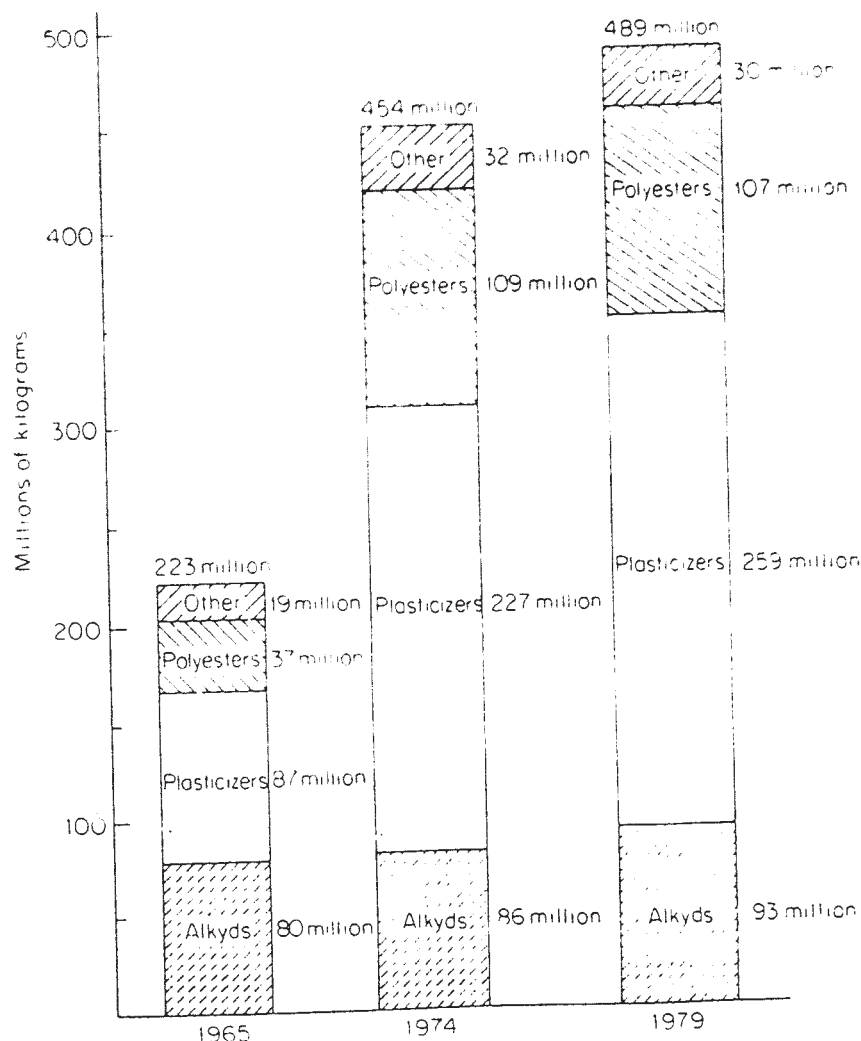


Fig. 34.4. Phthalic anhydride end-use pattern

It was also necessary to work out efficient equipment to remove the great amount of heat liberated and to keep the temperature within favorable narrow limits. One of the successful devices was that patented by Downs<sup>13</sup> and depicted in principle in Fig. 34.5. In the Downs reactor the temperature is controlled by raising or lowering the boiling point of mercury by raising and lowering the pressure of an inert gas (nitrogen) on the mercury boiling and condensing system. Other heat-transfer media have been proposed, such as water, sulfur, diphenyl, diphenyl oxide, mercury amalgams, and mixed molten nitrate-nitrite. The products from the reaction are rapidly cooled to about 125°C (approximately the dew point of phthalic anhydride) and then sublimed or distilled.

Fundamental changes have been made in the manufacture of phthalic anhydride. The first was a change in the source of the naphthalene. The dwindling supply from coal tar was supplemented by developing a purer one from petrochemicals by demethylating methyl-naphthalenes (Chap. 37). The second change was to use a fluidized bed of the catalyst  $V_2O_5$  instead of the long successful fixed bed. The third change was the use of *o*-xylene in either of the above procedures. A fourth change was to develop other catalysts which would work

<sup>13</sup>U.S. Patent 1,604,739 (1926); 1,789,909 (1931); 1,873,876 (1932).

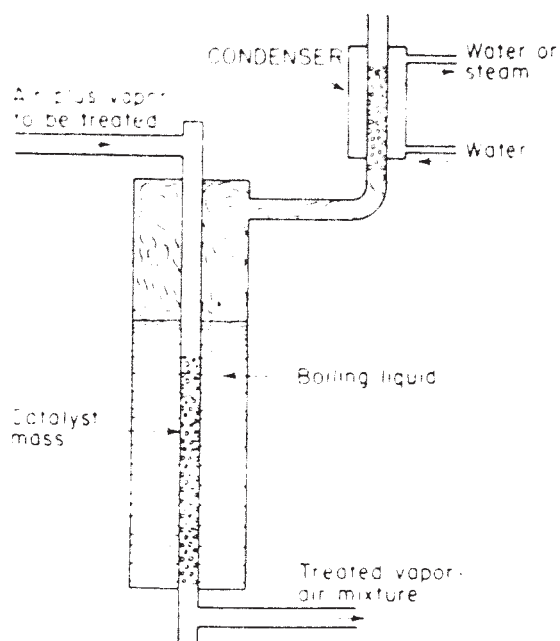


Fig. 34.5. Apparatus for the removal of reaction heat by the boiling of a liquid

favorably on either naphthalene or *o*-xylene. The fifth change involved removing the large heat of reaction by using a molten salt bath. This made it possible to recover some of this heat of reaction to generate steam. Certain of these changes are illustrated in Fig. 34.6 for a fixed-bed process, and more details are available in the references<sup>14</sup>

If naphthalene is burned completely to carbon dioxide and water, 41,570 kJ/kg of naphthalene is liberated. For naphthalene conversion to phthalic anhydride,  $\Delta H = -12,700$  kJ/kg of naphthalene oxidized. During the actual operation of this reaction an exothermic reaction of from 14,000 to more than 23,000 kJ/kg of naphthalene occurs, owing to an amount of complete combustion that always takes place.

Modern modifications of the process have been made to reduce the amount of energy required. These low-energy processes increase the hydrocarbon-to-air loadings so that they

<sup>14</sup>Zimmer, Low Air-Feedrate Cuts Phthalic Anhydride Costs, *Chem. Eng.* 51 (5) 52 (1974); Phthalic Anhydride Made with Less Energy, *Chem. Eng.* 56 (3) 62 (1979); Dow and Miserlis Recover Power from Phthalic Plants, *Hydrocarbon Process.* 56 (4) 167 (1977).

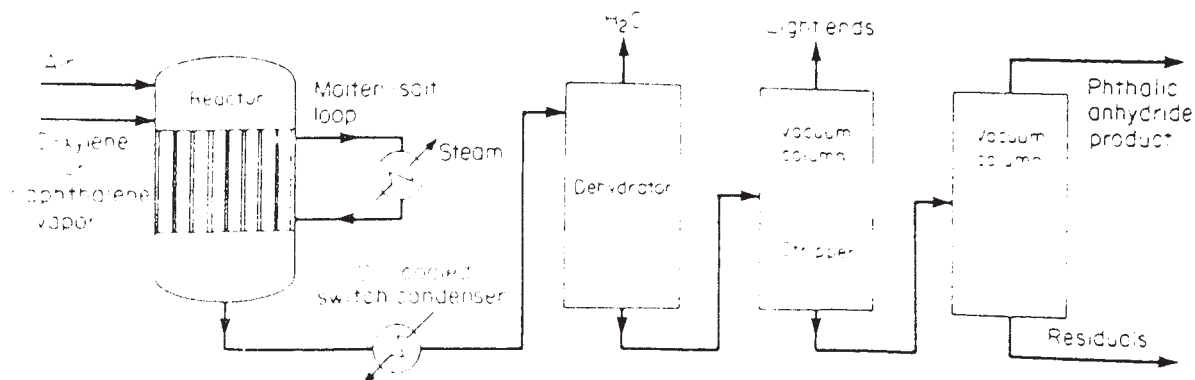


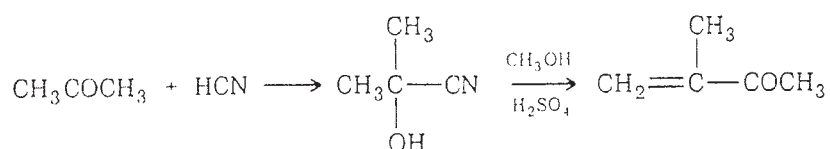
Fig. 34.6. Phthalic anhydride via fixed bed oxidation.

are in the explosive range. The lower explosive limit for *o*-xylene- or naphthalene-air mixtures is 43 g/m<sup>3</sup> at STP, but the processes operate at 60 g/m<sup>3</sup> air at STP. The reactor has been designed to withstand explosions and the catalyst, V<sub>2</sub>O<sub>5</sub> plus TiO<sub>2</sub> on an inert carrier, serves to deter an explosion. It is claimed that electrical requirements have been cut from 3300 to 600 MJ per metric ton of anhydride produced and the fuel-oil requirements have been eliminated.

**METHYL ACRYLATE AND METHACRYLATE.**<sup>15</sup> Methyl and ethyl acrylate and methyl, ethyl, and butyl methacrylate monomers are manufactured in large tonnages. The procedures for preparing acrylate resins, following the Dow-Badische-Reppe synthesis, are based on the reaction:



The conventional method of preparing methyl methacrylate, MMA, has been by the reaction of hydrogen cyanide with acetone and subsequent treatment with methyl alcohol.



The newest process for producing MMA uses a catalytic oxidation of isobutylene or *tert*-butyl alcohol, claimed to give yields of 70 percent. At present, however, *tert*-butyl alcohol is more valuable as an octane enhancer in gasoline, so the cyanohydrin process will continue to be used.

## Other Raw Materials

**NATURAL PRODUCTS.** *Cellulose*, the structural material of the plant world, is itself a polymer composed of 50 to 100 units of the disaccharide cellobiose. Cellobiose on hydrolysis yields two molecules of glucose and is similar to maltose. However, maltose is an  $\alpha$ -glucoside while cellobiose is a  $\beta$ -glucoside. The separation and purification of cellulose is discussed in Chap. 33.

**PLASTICIZERS.** Plasticizers are organic compounds added to plastics to improve workability during fabrication, to extend or modify the natural properties of the plastics, and to develop new, improved properties not present in the original resin. Plasticizers reduce the viscosity and make shaping and forming easier. They also impart flexibility and other desired properties to the finished product.

<sup>15</sup>ECT, 3d ed., vol. 1, 1978, pp. 386-409; MPE, 1981-1982; *Chem. Eng. News* 59 (30) 37 (1981); *Chem. Week* 129 (5) 37 (1981).