SUCCINIC ACID AND SUCCINIC ANHYDRIDE

1. Introduction

Succinic acid [110-15-6] (butanedioic acid; 1,2-ethanedicarboxylic acid; amber acid), $C_4H_6O_4$, occurs frequently in nature as such or in the form of its esters. It can be found in animal tissues (1), in vegetables and fruit (2,3), or in spring water (4), and has also been identified in meteorites (5). It is formed in alcoholic fermentation (6) and in the chemical and biochemical oxidation of fats. Succinic acid is present in amber (7) (*Succinum*) and can be obtained by distillation, by which method it was first isolated by Georgius Agricola in 1550.

Succinic anhydride [108-30-5] (3,4-dihydro-2,5-furandione; butanedioic anhydride; tetrahydro-2,5-dioxofuran; 2,5-diketotetrahydrofuran; succinyl oxide), $C_4H_4O_3$, was first obtained by dehydration of succinic acid. The anhydride is produced by hydrogenation of maleic anhydride and the acid by hydration of the anhydride, by hydrogenation of aqueous solutions of maleic acid, or as a by-product in the manufacture of adipic acid (qv) (see MALEIC ANHYDRIDE, MALEIC ACID, AND FUMARIC ACID).

From the chemical point of view, succinic acid and its anhydride are characterized by the reactivity of the two carboxylic functions and of the two methylene groups. Uses range from pharmaceuticals to food, detergents, cosmetics, plastics and resins, plant growth regulators, textiles, photography, and gas and water treatment.

2. Physical Properties

The acid occurs both as colorless triclinic prisms (α-form) and as monoclinic prisms (β-form) (8). The β-form is triboluminescent and is stable up to 137°C; the α-form is stable above this temperature. Both forms dissolve in water, alcohol, diethyl ether, glacial acetic acid, anhydrous glycerol, acetone, and various aqueous mixtures of the last two solvents. Succinic acid sublimes with partial dehydration to the anhydride when heated near its melting point.

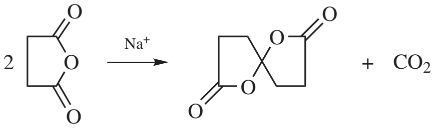
Succinic acid is absorbed from aqueous solutions by anion-exchange resins or active carbon (9–11). Succinic anhydride forms rhombic pyramidal or bipyramidal crystals. It is relatively insoluble in ether, but soluble in boiling chloroform and ethyl acetate. Succinic anhydride reacts with water and alcohols, giving the acid and monoesters, respectively.

Physical properties of the acid and its anhydride are summarized in Table 1. Other references for more data on specific physical properties of succinic acid are as follows: solubility in water at 278.15–338.15 K (12); water-enhanced solubility in organic solvents (13); dissociation constants in water–acetone (10 vol %) at 30–60°C (14), water–methanol mixtures (10–50 vol %) at 25°C (15,16), water–dioxane mixtures (10–50 vol %) at 25°C (15), and water–dioxane–methanol mixtures at 25°C (17); nucleation and crystal growth (18–20); calculation of the enthalpy of formation using semiempirical methods (21); enthalpy of solution (22,23); and enthalpy of dilution (23). For succinic anhydride, the enthalpies of combustion and sublimation have been reported (24).

3. Chemical Properties

Succinic acid and anhydride undergo most of the reactions characteristic of dicarboxylic acids and cyclic acid anhydrides, respectively. Other interesting reactions take place at the active methylene groups.

3.1. Heat. When heated, succinic acid loses water and forms an internal anhydride with a stable ring structure. Dehydration starts at 170°C and becomes rapid at 190–210°C (25). Further heating of succinic anhydride causes decarboxylation and the formation of the dilactone of gamma ketopimelic acid (26) (eq. 1). The same reaction takes place at lower temperatures in the presence of alkali.



(1)

At higher temperatures the presence of alkali causes an explosive reaction that does not stop at the bimolecular stage. Precautions must therefore be taken to exclude traces of alkali when handling succinic anhydride.

Succinic anhydride is stabilized against the deteriorative effects of heat by the addition of small amounts (0.5 wt %) of boric acid (27), the presence of which also decreases the formation of the dilactone of gamma ketopimelic acid (25). Compared with argon, CO_2 has an inhibiting effect on the thermal decomposition of succinic acid, whereas air has an accelerating effect (28,29).

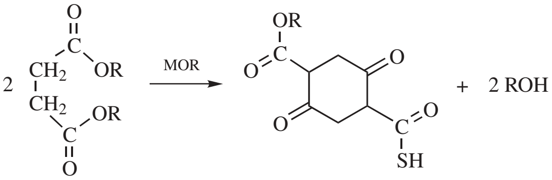
3.2. Hydration and Dehydration. Succinic anhydride reacts slowly with cold water and rapidly with hot water to give the acid. For this reason it must be carefully stored in anhydrous conditions. Succinic acid can be dehydrated to the anhydride by heating at 200°C, optionally in the presence of a solvent (30). Dehydration can also be performed with clay catalysis in the presence of isopropenyl acetate under microwave irradiation (31) or with bis(trichloromethyl) carbonate at room temperature (32).

3.3. Esterification. Succinic anhydride reacts readily with alcohols to give monoesters of succinic acid, which are readily esterified to diesters by the usual methods (33–35).

Dimethyl succinate [106-65-0] (mp 19°C, bp 196°C at atmospheric pressure) can be produced from methanol and the anhydride or the acid, or by hydrogenation of dimethyl maleate (36). The same methods can be used to prepare diethyl succinate [123-25-1] (mp −18°C, bp 216.5°C at atmospheric pressure) and diisopropyl succinate [924-88-9].

Succinic acid diesters are also obtained by one-step hydrogenation (over Pd on charcoal) and esterification of maleic anhydride dissolved in alcohols (37); carbonylation of acrylates in the presence of alcohols and Co complex catalysts (38,39); carbonylation of ethylene in alcohol in the presence of Pd or Pd–Cu catalysts (40,41); hydroformylation of acetylene with Mo and W complexes in the presence of butanol (42); and a biochemical process from dextrose/corn steep liquor, using *Anaerobiumspirillum succiniciproducens* as a bacterium (43).

An important use of dialkyl succinates is in the preparation of dialkyl succinyl succinates (44–46), which are intermediates in the manufacture of quinacridone pigments. The reaction is carried out in the presence of alkali metal alkoxides (eq. 2).



(2)

In many applications succinic acid and anhydride are esterified with polyhydric compounds, ie, polyols (47), cellulose (48), or starch (49,50).

One of the methods used to isolate succinic acid from the waste stream of the adipic acid process is esterification of the mixture of succinic, glutaric, and adipic acid followed by fractionation (51,52).

3.4. Oxidation. Succinic acid reacts with hydrogen peroxide, giving different products that depend on the experimental conditions: peroxysuccinic acid [2279-96-1] $(CH_2COOOH)_2$, oxosuccinic acid [328-42-7] (oxaloacetic acid); malonic acid [141-82-2], or a mixture of acetaldehyde, malonic acid, and malic acid [6915-15-7]. Succinic anhydride in dimethylformamide (DMF) with H_2O_2 gives monoperoxysuccinic acid [3504-13-0], $HOOCCH_2CH_2COOOH$, mp 107°C (53).

Potassium permanganate oxidizes succinic acid to a mixture of malic and tartaric acid [133-37-9]. 3-Hydroxypropionic acid [503-66-2] is obtained with sodium perchlorate. Cerium(IV) sulfate in sulfuric acid medium oxidizes succinic acid to oxaloacetic acid (54).

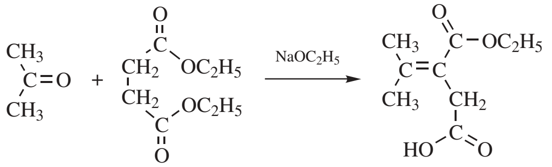
3.5. Hydrogenation. Gas-phase catalytic hydrogenation of succinic anhydride yields γ-butyrolactone [96-48-0] (GBL), tetrahydrofuran [109-99-9] (THF), 1,4-butanediol (BDO), or a mixture of these products, depending on the experimental conditions. Catalysts mentioned in the literature include copper chromites with various additives (55), copper–zinc oxides with promoters (56,57), and ruthenium (58). The same products are obtained by liquid-phase hydrogenation; catalysts used include Pd with various modifiers on various carriers (59,60), Ru on C (61) or Ru complexes (62,63), Rh on C (60), Cu–Co–Mn oxides (63), Co–Ni–Re oxides (64), Cu–Ti oxides (65), Ca–Mo–Ni on diatomaceous earth (66), and Mo–Ba–Re oxides (67). Chemical reduction of succinic anhydride to GBL or THF can be performed with 2-propanol in the presence of ZrO_2 catalyst (68).

3.6. Halogenation. Succinic acid and succinic anhydride react with halogens through the active methylene groups. Succinic acid heated in a closed vessel at 100°C with bromine yields 2,3-dibromosuccinic acid almost quantitatively. The yield is reduced in the presence of excess water as a result of the formation of brominated hydrocarbons. The anhydride gives the mono- or dibromo derivative, depending on the equivalents of bromine used.

Succinyl chloride [543-20-4] is obtained from phosphorous pentachloride and succinic acid, from thionyl chloride and succinic acid or anhydride (69), or from phosgene and succinic anhydride (70).

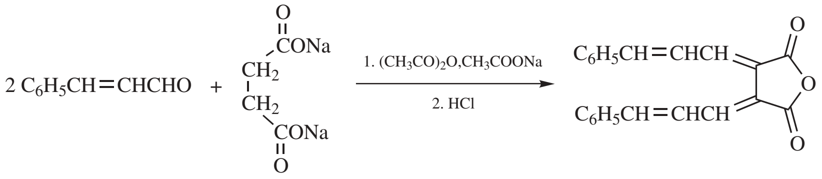
3.7. Condensation with Aldehydes and Ketones. Succinic anhydride and succinic esters in the presence of different catalysts react in the gas phase with formaldehyde to give citraconic acid or anhydride and itaconic acid (71,72). Dialkyl acyl succinates are obtained by reaction of dialkyl succinates with C_{1-4} aldehydes over peroxide catalysts (73).

Succinic esters condense with aldehydes and ketones in the presence of bases, eg, sodium alkoxide or piperidine, to form monoesters of alkylidenesuccinic acids, eg, condensation of diethyl succinate with acetone yields ethyl 2-isopropylidenesuccinate (eq. 3). This reaction, known as Stobbe condensation, is specific for succinic esters and substituted succinic esters (74,75).

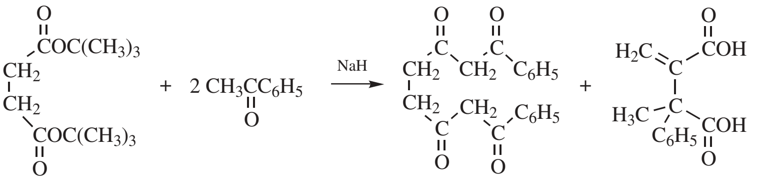


(3)

Aromatic aldehydes (76), eg, cinnamaldehyde, and ketones (77) react in a similar manner (eq. 4). Ketones containing reactive methyl or methylene groups give with succinates, in the presence of sodium hydride, both the Stobbe condensation and the formation of diketones by a Claisen mechanism (78) (eq. 5).

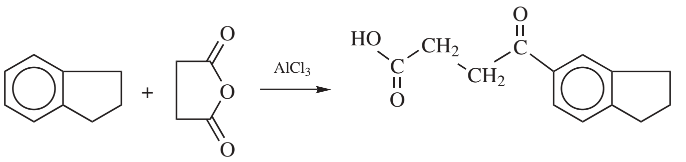


(4)



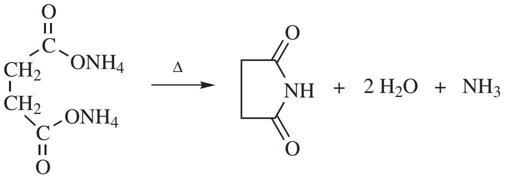
(5)

3.8. Friedel-Crafts Reactions. In the presence of Friedel-Crafts catalysts, succinic anhydride reacts with alkyl benzenes to form alkylbenzoylpropionic acids (79), eg, the reaction with indane gives a 97% yield of 4-oxo-(4,5-indanyl)butyric acid (eq. 6).


(6)

Friedel-Crafts acylation of unsaturated fatty acids can be carried out with succinic anhydride in the presence of alkylaluminium halide (80).

3.9. Reactions with Nitrogen Compounds. Succinimide [123-56-8], mp 126°C, can be prepared by reaction of aqueous solutions of the acid with ammonia (81) or urea (82) (eq. 7). The solution is heated until water and ammonia are no longer evolved and the molten crude succinimide is purified by fractionation. Alternatively, the crude product can be recrystallized from water (81).


(7)

N-Alkyl or *N*-aryl succinimides can be prepared from the corresponding amines (83) or from succinic anhydride, ammonia, and the corresponding alcohol (84). Succinimides are also obtained by vapor-phase hydrogenation of the corresponding maleimides in the presence of a catalyst (85).

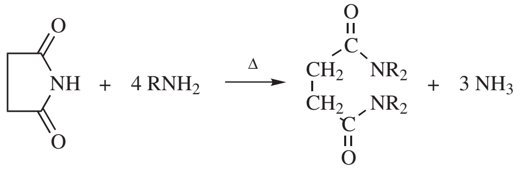
Halogen-substituted succinimides are a class of products with important applications. *N*-Bromosuccinimide [128-08-5], mp 176–177°C, is the most important product in this group, and is prepared by addition of bromine to a cold aqueous solution of succinimide (86) or by reaction of succinimide with $NaBrO_2$ in the presence of HBr (87). It is used as a bromination and oxidation agent in the synthesis of cortisone and other hormones. By its use it is possible to obtain selective bromine substitution at methylene groups adjacent to double bonds without addition reactions to the double bond (88).

N-Chlorosuccinimide [128-09-6], mp 150–151°C, forms orthorhombic crystals and has a chlorine-like odor; it is prepared from succinimide and hypochlorous acid (89). Because of its powerful germicide properties, it is used in disinfectants for drinking water. Like its bromine derivative, it is also a halogenating agent.

Diamines react with two moles of succinic anhydride to give *N*,*N*′-disuccinimides (eq. 8).


(8)

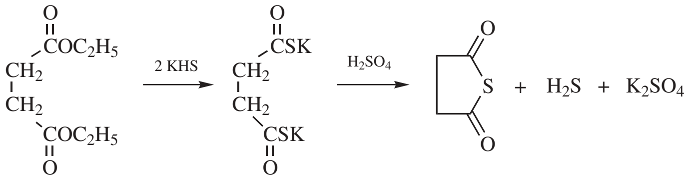
Succinic acid reacts with urea in aqeous solution to give a 2:1 compound having mp 141°C (90,91), which has low solubility in water. A method for the recovery of succinic acid from the wastes from adipic acid manufacture is based on this reaction (92). The monoamide succinamic acid [638-32-4], NH_2-$COCH_2CH_2COOH$, is obtained from ammonia and the anhydride or by partial hydrolysis of succinimide. The diamide succinamide [110-14-5], $(CH_2CONH_2)_2$, mp 268–270°C, is obtained from succinyl chloride and ammonia or by partial hydrolysis of succinonitrile. Heating succinimide with a primary amine gives *N*-alkylsuccinimides (eq. 9).



(9)

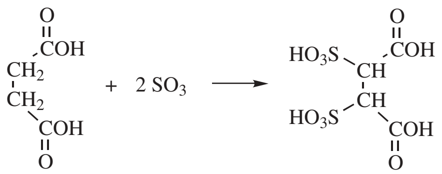
One-step manufacture of 2-pyrrolidinone can be effected by reaction of succinic acid or anhydride with NH_3 and H_2 in the presence of Pd–Al_2O_3 catalyst in water or ether (93).

3.10. Reactions with Sulfur Compounds. Thiosuccinic anhydride [3194-60-3] is obtained by reaction of diethyl or diphenyl succinate [621-14-7] with potassium hydrogen sulfide followed by acidification (eq. 10). Thiosuccinic anhydride is also obtained from succinic anhydride and hydrogen sulfide under pressure (94).



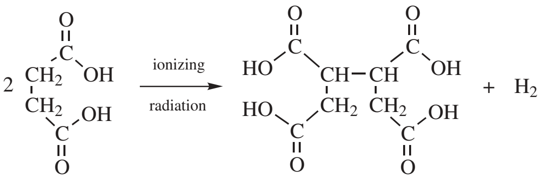
(10)

Sulfur trioxide reacts with both methylene groups to yield 2,3-disulfosuccinic acid [54060-35-4] (eq. 11) (see Sulfur compounds).



(11)

3.11. Miscellaneous Reactions. Radiolysis at room temperature of diluted aqueous solutions of succinic acid produces 1,2,3,4-butane tetracarboxylic acid [1703-58-8] (95), which has numerous industrial and agricultural applications (eq. 12).



(12)

3.12. Degradation.

Heating of succinic acid or anhydride yields γ-ketopimelic dilactone, cyclohexane-1,4-dione, and a mixture of decomposition products that include acetic acid, propionic acid, acrylic acid, acetaldeide, acrolein, oxalic acid, cyclopentanone, and furane. In argon atmosphere, thermal degradation of succinic anhydride takes place at 340°C (96). Electrolysis of succinic acid produces ethylene and acetylene.

4. Manufacture and Processing

Succinic anhydride is manufactured by catalytic hydrogenation of maleic anhydride [108-31-6]. In the most widely used commercial process this reaction is performed in the liquid phase, at temperatures of 120–180°C and at moderate pressures, in the range of 500–4000 kPa (72–580 psi). Catalysts mentioned in the patent literature include nickel (97), Raney nickel (98,99), palladium on different carriers (100,101), and palladium complexes (102). The hydrogenation of the double bond is exothermic: $\Delta H = -133.89$ kJ/mol (-32 kcal/mol) (103).

The reactor is designed to provide efficient heat removal and a good contact of the gas (hydrogen) with the solid catalyst and the liquid reaction mixture. Depending on plant capacity, hydrogenation can be batch (97) or continuous. Continuous hydrogenation is performed in three-phase fixed-bed reactors (101) or in a cascade of two or three continuous-stirred-tank reactors with the catalyst suspended as a powder in the liquid reaction mixture. Standard precautions for hydrogenation reactions, eg, inertization with nitrogen at startup and shutdown and on-line continuous oxygen analyzers connected to interlocks, must be taken to prevent, at any time, the simultaneous presence in the hydrogenation reactor of oxygen and hydrogen. The yield of the hydrogenation reaction is virtually theoretical. Impurities detected in raw succinic anhydride include small amounts (300–2000 ppm each) of unconverted maleic anhydride, γ-butyrolactone, butyric acid, and propionic acid.

After separation of the catalyst by filtration, raw succinic anhydride is purified by distillation under reduced pressure, ie, 4–13 kPa (30–98 mm Hg), and flaked. The material of construction of the plant is stainless steel. Typical specific consumptions for the production of one metric ton of succinic anhydride are maleic anhydride at 1050 kg; hydrogen, 300 m^3; steam, 4500 kg; cooling water, 100 m^3; electricity, 350 kW; nitrogen, 100 m^3; and methane, 100 m^3. Effluents to be disposed of are hydrogen vent, low and high boiling by-products from the distillation unit, and exhausted catalyst.

In the early 1990s, processes were developed for the production of 1,4-butanediol and γ-butyrolactone by gas-phase catalytic hydrogenation of maleic anhydride (104–106). Succinic anhydride is obtained as a partial hydrogenation by-product in these processes. It can be recycled to complete the hydrogenation to the desired products, or be separated and purified.

The simplest route to succinic acid is by hydration of its anhydride. Pure succinic anhydride is dissolved in hot water, succinic acid is formed, separated as crystals upon cooling, filtered, and dried.

Succinic acid can also be produced by catalytic hydrogenation of aqueous solutions of maleic or fumaric acid in the presence of noble metal catalysts, ie, palladium, rhodium, ruthenium, or their mixtures, on different carriers (107,108) or on Raney nickel (109).

A mixture of succinic (15–25 wt %), glutaric (45–55 wt %), and adipic acid (25–35 wt %) is obtained as a by-product in the oxidation of cyclohexane to adipic acid.

Various techniques have been proposed for the recovery of pure succinic acid, including extraction (110–112), selective crystallization (113–116), heating to dehydrate the acid and subsequent recovery of succinic anhydride by distillation (117), esterification followed by fractionation of the mixture of the esters (51,52), and separation as urea adduct (92).

Other preparations of succinic acid mentioned in the literature are electrochemical reduction of maleic or fumaric acid (118), ultrasound-promoted Zn–acetic acid reduction of maleic or fumaric acid (119), reduction of maleic acid with H_3PO_2 at room temperature (120), electrochemical reduction of CO_2 in the presence of ethylene (121), oxidation of furfural (122,123), oxidation of 1,4-butanediol catalyzed by $Pd–C/Pb(OOCCH_3)_2$ system (124), oxidation of coal by RuO_4 (125,126), carbonylation of acrylic acid in the presence of cobalt (127) or rhodium (128), CO, and H_2, and fermentation of glucose from wet milling of corn (129). A method for producing succinic acid from industrial-grade hydrolysates has been reported (130).

Succinic anhydride can be prepared from succinic acid by dehydration; it operates in high boiling solvent (30), in the presence of clays as a catalyst (31), or at room temperature with triphosgene (32).

5. Shipment

Succinic acid and succinic anhydride are sold in 25-kg net polyethylene (PE) bags having cardboard box protection for the anhydride, in 70-liter (50-kg net) fiber drums, and in 55-gallon (275-lb; 125-kg net) drums. The two products must be stored in a fresh, dry, ventilated area. Succinic anhydride must be carefully protected from moisture during transportation and storage to avoid hydrolysis to succinic acid.

6. Specifications

Commercial specifications of succinic acid and succinic anhydride are given in Table 2.

7. Analytical Methods

Various methods can be used to analyze succinic acid and succinic anhydride, depending on the characteristics of the material. Methods generally used to control specifications of pure products include acidimetric titration for total acidity or purity; comparison with Pt–Co standard calibrated solutions for color; oxidation with potassium permanganate for unsaturated compounds; subtracting from the total acidity the anhydride content measured by titration with morpholine for content of free acid in the anhydride; atomic absorption or plasma spectroscopy for metals; titration with $AgNO_3$ or $BaCl_2$ for chlorides and sulfates, respectively; and comparison of the color of the sulfide solution of the metals with that of a solution with a known Pb content for heavy metals.

Techniques used for the determination of small concentrations of succinic acid or anhydride in various substances include gc or capillary gc in fruit and vegetables (131), eggs (132), rain (133), and liquors from wood (134); ion chromatography in rainwater (135), streams from the adipic acid process (136), and food (137); gc/ms in amber (138); hplc in wine and champagne (139,140), vinegar (141), beverages (142), apples (143), as well as milk and cheese (144,145); and polarography in γ-butyrolactone (146). Succinic acid can be separated from other organic acids by liquid chromatography by using cation-exchange resins as a stationary phase (147).

8. Health and Safety Factors

Succinic acid is Generally Recognized As Safe (GRAS) by the U.S. FDA (148) and is approved as a flavor enhancer, as a pH control agent in condiments, and for use in meat products. It causes irritation to the eyes (149), skin, mucous membranes, and upper respiratory tract. LD_{50} in rat is 2260 mg/kg. Succinic acid, like most materials in powder form, can cause dust explosion.

Succinic anhydride is extremely irritating to the eyes (149). It causes skin, mucous membranes, and respiratory tract irritation. It may be a sensitizer. There is no evidence of carcinogenic activity in male or female rats given 50 or 100 mg/kg succinic anhydride (150); the Ames test is negative (151). LD_{50} in rat 1510 mg/kg. There are no established exposure limits for ACGIH TLV or TWA.

Succinic acid and anhydride should be handled with rubber or plastic gloves; safety goggles and a dust filter are recommended when handling the products in powder form. A full-face gas mask with a type A (brown) filter cartridge should be worn when handling molten products.

Incineration in an approved combustion plant is the preferred method of disposal. Wastewater from succinic acid processes is suitable for biological degradation by activated sludge (152). Polymeric sorbents (153) and ferric chloride treatment processes (154) can also be used for wastes containing succinic acid. Chemical oxygen demand has been determined by the permanganate method (155).

9. Uses

Table 3 summarizes many of the uses mentioned in the literature.

An important use of succinic acid and anhydride is the production of inherently degradable polymers (see POLYMERS, ENVIRONMENTALLY DEGRADABLE). Other important applications are in the fields of food additives (qv), detergents, cosmetics (qv), pigments (qv), toners, cement additives, soldering fluxes, as well as in the synthesis of pharmaceutical products.

BIBLIOGRAPHY

"Succinic Acid and Succinic Anhydride" in *ECT* 1st ed., Vol. 13, pp. 180–191, by W. H. Gardner and L. H. Flett, Allied Chemical & Dye Corp.; in *ECT* 2nd ed., Vol. 19, pp. 134–150, by P. Turi, Sandoz, Inc.; in *ECT* 3rd ed., Vol. 21, pp. 848–864, by L. O. Winstrom, Consultant; in *ECT* 4th ed., Vol. 22, pp. 1074–1102, by C. Fumagalli, LONZA SpA; "Succinic Acid and Succinic Anhydride" in *ECT* (online), posting date: December 4, 2000, by C. Fumagalli, LONZA SpA.

CITED PUBLICATIONS

1. W. Zurburg, *Adattamenti Biochim. Anim. Acquatici Carenza Ossigeno, Atti Incontro Biochim Mar.* **1**, 39–66 (1982).
2. I. Calvarano, M. Calvarano, and G. Di Giacomo, *Essenze Deriv. Agrum.* **59**(1), 5–17 (1989).
3. D. H. Picha, *J. Agric. Food Chem.* **33**(4), 743–745 (1985).
4. K. Kawamura and A. Nissenbaum, *Org. Geochem.* **18**(4), 469–476 (1992).
5. E. T. Peltzer and co-workers, *Adv. Space Res.* **4**(12), 69–74 (1984).
6. F. Radler, *Microbiol. Ind. Aliment. Ann. Congr. Int.* **2**, 5–16 (1980).
7. J. S. Mills, R. White, and L. J. Gough, *Chem. Geol.* **47**(1–2), 15–39 (1984).
8. N. N. Petropavlov and S. B. Yarantsev, *Kristallografiya* **28**(6), 1132–1139 (1983).
9. C. Y. C. Lee, O. E. Pedram, and A. L. Hines, *J. Chem. Eng. Data* **31**(2), 133–136 (1986).
10. H. Li and co-workers, *Taiyuan Gongxueyuan Xuebao* (2), 59–67 (1984).
11. Y. Onal and Z. Tez, *Doga: Turk Kim. Derg.* **13**(1), 49–56 (1989).
12. A. Apelblat and E. Manzurola, *J. Chem. Thermodyn.* **19**(3), 317–320 (1987).
13. J. N. Starr and C. J. King, *Energy Res. Abstr.* **17**(8), Abstr. No. 21954 (1992).
14. M. F. Amira, S. A. El-Shazly, and M. M. Khalil, *Thermochim. Acta* **115**, 1–10 (1987).
15. G. Papanastasiou, I. Ziogas, and D. Jannakoudakis, *Chem. Chron.* **15**(3), 147–160 (1986).
16. G. Papanastasiou, G. Stalidis, and D. Jannakoudakis, *Bull. Soc. Chim. Fr.* **1984** (9–10), 255–259 (1984).

17. G. Papanastasiou and I. Ziogas, *Bull. Soc. Chim. Fr.* (5), 725–730 (1985).
18. Y. Qiu and A. C. Rasmuson, *AIChE J.* **37**(9), 1293–1304 (1991).
19. Y. Qiu and A. C. Rasmuson, *AIChE J.* **36**(5), 665–676 (1990).
20. J. W. Mullin and M. J. L. Whiting, *Ind. Eng. Chem. Fundam.* **19**(1), 117–121 (1980).
21. C. B. Aakeroy, *Theochem* **100**(2–3), 259–267 (1992).
22. A. Apelblat, *J. Chem. Thermodyn.* **18**(4), 351–357 (1986).
23. S. Taniewska-Osinska, M. Tkaczyk, and A. Apelblat, *J. Chem. Thermodyn.* **22**(7), 715–720 (1990).
24. M. Y. Yang and G. Pilcher, *J. Chem. Thermodyn.* **22**(9), 893–898 (1990).
25. Technical data, Lonza S.p.A., Italy, 1996.
26. U.S. Pat. 2,302,321 (Nov. 17, 1942), H. Hopff and H. Griesshaber (to Alien Property Custodian).
27. U.S. Pat. 4,257,958 (Mar. 24, 1981), J. C. Powell (to Texaco Inc.).
28. K. Muraishi and Y. Suzuki, *Thermochim. Acta* **232**(2), 195–203 (1994).
29. K. Muraishi, Y. Suzuki, and A. Kikuchi, *Thermochim. Acta* **239**(1–2), 51–59 (1994).
30. Ger. Offen. 2,319,574 (Nov. 14, 1974), W. Mesch and A. Wittwer (to BASF AG).
31. D. Villemin, L. Bouchta, and A. Loupy, *Synth. Commun.* **23**(4), 419–424 (1993).
32. R. Kocz, J. Roestamadji, and S. Mobashery, *J. Org. Chem.* **59**(10), 2913–2914 (1994).
33. H. J. Bart and co-workers, *Int. J. Chem. Kinet.* **26**(10), 1013–1021 (1994).
34. M. M. Amirkhanyan and M. F. Elanyan, *Tr. IREA* **46**, 7–10 (1984).
35. I. A. El-Magly, E. S. Nasr, and M. S. El-Samanoudy, *J. Synth. Lubr.* **7**(2), 89–103 (1990).
36. Austrian Pat. AT 383,115 (May 25, 1987), H. Hornich and J. Schaller (to Chemie Linz AG).
37. Hung. Pat. 41727 (May 28, 1987), L. Torkos and co-workers (to Nitroil Vegyipari Termelo-Fejleszto Kozos Vallalat).
38. Ger. Offen. DE 3,332,018 (March 21, 1985), J. G. Reuvers, W. Richter, and R. Kummer (to BASF AG).
39. Jpn. Kokai Tokkyo Koho JP 06199736 (July 19, 1994), A. Matsuda and co-workers (to Kogyo Gijutsuin).
40. U.S. Pat. 4,667,053 (May 19, 1987), J. J. Lin (to Texaco Inc.).
41. G. E. Morris and co-workers, *J. Chem. Soc., Chem. Commun.* (6), 410–411 (1987).
42. L. G. Bruk and co-workers, *Izv. Akad. Nauk SSSR, Ser. Khim* (1), 232–234 (1983).
43. Eur. Pat. Appl. EP 389,103 (Sept. 26, 1990), D. A. Glassner and R. Datta (to Michigan Biotechnology Institute).
44. Eur. Pat. Appl. EP 536083 (Apr. 7, 1993), C. D. Campbell and E. E. Jaffe (to CIBA-GEIGY AG).
45. Ger. Offen. DE 3104644 (Aug. 19, 1982), M. Rolf and co-workers (to Bayer AG).
46. Jpn. Kokai Tokkyo Koho JP 5885,843 (May 23, 1983) (to Mitsui Toatsu Chemicals, Inc.).
47. K. Geckeler and E. Bayer, *Polym. Bull.* **3**(6–7), 347 (1980).
48. J. A. Cuculo, *Text. Res. J.* **41**(5), 375 (1971).
49. P. C. Trubiano, in O. B. Wurzburg, ed., *Modified Starches: Properties and Uses*, CRC Press, Inc., Boca Raton, Fla., pp. 131–147, 1987.
50. U.S. Pat. 4,231,803 (Nov. 4, 1980), E. M. Bovier and co-workers (to Anheuser-Busch, Inc.).
51. U.S. Pat. 4,105,856 (Aug. 8, 1978), C. A. Newton (to El Paso Products Co.).
52. U.S. Pat. 3,991,100 (Nov. 9, 1976), S. Hochberg (to E. I. du Pont de Nemours & Co., Inc.).
53. Brit. Pat. 1,139,507 (Jan. 8, 1969), E. G. E. Hawkins (to Distiller Co. Ltd.).
54. B. M. Rao, T. P. Sastry, and T. S. Parekh, *Z. Phys. Chem. (Leipzig)* **264**(5), 906–919 (1983).

55. Eur. Pat. Appl. EP 373,947 (June 20, 1990), S. Suzuki, H. Inagaki, and H. Ueno (to Tonen Co., Ltd.).
56. Jpn. Kokai Tokkyo Koho JP 02233627 (Sept. 17, 1990), S. Sadakatsu, H. Inagaki, and H. Ueno (to Tonen Co. Ltd.).
57. U.S. Pat. 4,810,807 (Mar. 7, 1989), J. R. Budge and S. E. Pedersen (to Standard Oil Co.).
58. U.S. Pat. 4,301,077 (Nov. 17, 1981), F. A. Pesa and A. M. Graham (to Standard Oil Co.).
59. Jpn. Kokai Tokkyo Koho JP 05,222,022 (Aug. 31, 1993), T. Fuchigami and co-workers (to Tosoh Corp.; Sagami Chem. Res.).
60. PCT Int. Appl. WO 9202,298 (Feb. 20, 1992), R. E. Ernst and J. B. Michel (to E. I. du Pont de Nemours & Co., Inc.).
61. Jpn. Kokai Tokkyo Koho JP 06,157,491 (June 3, 1994), T. Fuchigami and co-workers (to Tosoh Corp.).
62. Eur. Pat. Appl. EP 420062 (Apr. 3, 1991), C. Miyazawa and co-workers (to Mitsubishi Kasei Corp.).
63. Ger. Offen. DE 3,726,509 (Feb. 16, 1989), R. Fisher and co-workers (to BASF AG).
64. U.S. Pat. 5,086,030 (Feb. 4, 1992), G. Bjornson and J. J. Stark (to Phillips Petroleum Co.).
65. U.S. Pat. 4,929,777 (May 29, 1990), G. Irick, Jr., P. N. Mercer, and K. E. Simmons (to Eastman Kodak Co.).
66. Jpn. Kokai Tokkyo Koho JP 01,143,865 (June 6, 1989), S. Takigawa and co-workers (to Nissan Chemical Industries, Ltd.; Nissan Girdler Catalyst Co., Ltd.).
67. Jpn. Kokai Tokkyo Koho 63,088,045 (Apr. 19, 1988), K. Hasegawa, T. Aoki, and S. Seo (to Mitsubishi Petrochemical Co., Ltd.).
68. K. Takahashi, M. Shibagaki, and H. Matsushita, *Bull. Chem. Soc. Jpn.* **65**(1), 262–266 (1992).
69. C. G. Calin and co-workers, *Ind. Usoara* **36**(9), 407–411 (1989).
70. U.S. Pat. 3,810,940 (May 14, 1974), C. F. Hauser (to Union Carbide Corp.).
71. Ger. Offen. 2,352,468 (May 30, 1974), R. Berg and co-workers (to Pfizer, Inc.).
72. Jpn. Kokai JP 49101327 (Sept. 25, 1974), T. Shimizui and C. Fujii (to Denki Kagaku Kogyo KK).
73. Jpn. Kokai Tokkyo Koho JP 61,243,047 (Oct. 29, 1986), H. Yoshida and co-workers (to Nippon Shokubai Kagaku Kogyo Co., Ltd.).
74. H. Stobbe, *Ber.* **26**, 2312 (1893).
75. W. S. Johnson and G. H. Daub, in R. Adams and co-workers, eds., *Organic Reactions*, Vol. **6**, John Wiley & Sons, Inc., New York, 1951, 2–73.
76. J. M. Lawlor and M. B. McNamee, *Tetrahedron Lett.* **24**(21), 2211–2212 (1983).
77. Czech. Pat. CS 225,399 (June 30, 1985), J. Krepelka and M. Simonova.
78. G. H. Daub and W. S. Johnson, *J. Am. Chem. Soc.* 1950, **72**, 501–504 (1950).
79. G. Peto, in G. A. Olah, ed., *Friedel-Krafts and Related Reactions*, Vol. **3**, Pt. 1, Wiley-Interscience, New York, 1964, 550–663.
80. U. Biermann and J. O. Metzger, *Fett. Wiss. Technol.* **94**(9), 329–332 (1992).
81. Jpn. Kokai Tokkyo Koho JP 04,282,361 (Oct. 7, 1992), M. Fukuhara and S. Oda (to Daihaci Chemical Industry Co., Ltd.).
82. Israel Pat. 38,852 (Nov. 29, 1974), A. Stern and co-workers (to Makhteshim Chemical Works Ltd.).
83. Jpn. Kokai Tokkyo Koho JP 6006,659 (Jan. 14, 1985) (to Showa Denko KK).
84. U.S. Pat. 4,841,069 (June 20, 1989), R. J. Olsen (to Amoco Corp.).
85. U.S. Pat. 4,851,546 (July 25, 1989), A. M. Graham and T. G. Attig (to Standard Oil Co.).
86. L. Horner and E. H. Winkelmann, *Angew. Chem.* **71**, 349 (1959).

87. S. Kajigaeshi and co-workers, *Bull. Chem. Soc. Jpn.* **58**(2), 769–770 (1985).
88. J. H. Incremona, *Diss. Abstr.* **B27**(7), 2295 (1967).
89. D. Matte and co-workers, *Can. J. Chem.* **70**(1), 89–99 (1992).
90. C. H. Walker, *Sep. Sci.* **2**(3), 399 (1967).
91. H. Wiedenfeld and F. Knock, *Acta Crystallogr. Sect. C: Cryst. Struct. Commun.* **C46** (6), 1038–1040 (1990).
92. Jpn. Kokai Tokkyo Koho JP 81, 10,897 (Mar. 11, 1981), (to Asahi Chemical Industry Co., Ltd.).
93. U.S. Pat. 4,904,804 (Feb. 27, 1990), M. S. Matson (to Phillips Petroleum Co.).
94. T. Takido and co-workers, *Yuki Gosei Kagaku Kyokai Shi* **31**(10), 826 (1973).
95. A. Negron-Mendoza and G. Albarran, *Radiat. Phys. Chem.* **42**(4–6), 973–976 (1993).
96. T. Ando, Y. Fujimoto, and S. Morisaki, *J. Hazard. Mater.* **28**(3), 251–280 (1991).
97. Faming Zhuanli Shenqing Gongkai Shuomingshu CN 1,078,716 (Nov. 24, 1993), X. Ma (to Weinan Science and Technology Information Institute).
98. Faming Zhuanli Shenqing Gongkai Shuomingshu CN 1,063,484 (Aug. 12, 1992), X. Tang.
99. Czech. Pat. CS 218,083 (June 15, 1984), J. Sraga and P. Hrnciar.
100. Rus. Pat. 721,406 (Mar. 15, 1980), A. Avots, V. Kuplenieks, and D. Kreille (to Institute of Organic Synthesis Academy of Sciences Latvian SSR).
101. P. Ruiz and co-workers, *Chemical Catalyst Reaction Modeling*, ACS, Washington, D. C., 1984, 15–36.
102. Rus. Pat. SU 1,541,210 (Feb. 7, 1990), G. A. Tolstikov and co-workers (to Bashkir Institute of Chemistry).
103. S. Minoda and M. Miyajima, *Hydrocarbon Process.* **49**, 176–178 (Nov. 1970).
104. G. L. Castiglioni and co-workers, *Chem. Ind.* 510–511 (July 1993).
105. G. L. Castiglioni and co-workers, *Erdoel Kohle* **47**, 146–149, 337–341 (1994).
106. U.S. Pat. 5,196,602 (Mar. 23, 1993), J. R. Budge, T. G. Attig, and A. M. Graham (to Standard Oil Co.).
107. J. Hanika, J. Horych, and V. Ruzicka, *Sb. Vys. Sk. Chem.-Technol. Praze, Org. Chem. Technol.* **C28**, 35–47 (1983).
108. Jpn. Kokai Tokkyo Koho JP 02,121,946 (May 9, 1990), K. Fujita, M. Kokubu, and M. Takeda (to Kyowa Yuka Co., Ltd.).
109. Rom. Pat. RO 79,020 (June 30, 1982), S. D. Paucescu and co-workers (to Intreprinderea Chimica Dudesti).
110. U.S. Pat. 2,840,607 (June 6, 1958), E. C. Attane, Jr., and co-workers (to Union Oil Co.).
111. U.S. Pat. 3,329,712 (July 4, 1967), D. E. Danley and G. L. Whitesell (to Monsanto Co.).
112. Brit. Pat. 1,216,844 (Dec. 23, 1970), W. Bowyer and co-workers (to ICI Ltd.).
113. U.S. Pat. 3,338,959 (Aug. 29, 1967), C. T. Sciance and L. S. Scott (to E. I. du Pont de Nemours & Co., Inc.).
114. Pol. Pat. 51,539 (July 20, 1966), L. Dworakowski and co-workers (to Spoldzielnia Pracy Chemikow Argon).
115. Rus. Pat. 405,861 (Nov. 5, 1973), I. Ya. Lubyanitskii and co-workers.
116. Jpn. Kokai 7719,618 (Feb. 15, 1977) (to BP Chemicals Ltd).
117. PCT Int. Appl. WO 8804,650 (June 30, 1988), J. B. Copper (to BP Chemicals Ltd.).
118. R. Fujita and T. Sekine, *Denki Kagaku oyobi Kogyo Butsuri Kagaku* **50**(6), 491–493 (1982).
119. A. P. Marchand and G. M. Reddy, *Synthesis* (3), 198–200 (1991).
120. X. Wang and Y. Guan, *Chin. Chim. Lett.* **4**(5), 407–408 (1993).
121. G. I. Shul'zhenko and Y. B. Vasil'ev, *Izv. Akad. Nauk SSSR, Ser. Khim.* (6), 1377–1380 (1991).

122. L. A. Badovskaya and co-workers, *Khim. Sel'sk Khoz.* (1), 59–60 (1990).
123. M. J. N. Garcia and M. B. Iglesias, *Acta Cient. Compostelana* **22**(2–4), 809–817 (1985).
124. M. Akada and co-workers, *Bull. Chem. Soc. Jpn.* **66**(5), 1511–1515 (1993).
125. L. M. Stock and S. H. Wang, *Fuel* **65**(11), 1552–1562 (1986).
126. E. S. Olson, J. W. Diehl, and M. L. Froehlich, *Fuel Process. Technol.* **15**, 319–326 (1987).
127. Jpn. Kokai Tokkyo Koho JP 02,06,427 (Jan. 10, 1990), N. Okada and O. Takahashi (to Idemitsu Kosan Co., Ltd.).
128. Eur. Pat. Appl. EP 188,209 (July 23, 1986), P. M. Burke (to E. I. du Pont de Nemours & Co., Inc.).
129. *Chem. Mark. Rep.* **246**, 5 (Oct. 10, 1994).
130. U.S. Pat. 6, 743, 610 (June 1, 2004), M. L. Donnelly, C. Y. Sanville-Millard, and N.-P. Nghiem (to the University of Chicago).
131. M. Morvai and I. Molnar-Perl, *Chromatographia* **34**(9–10), 502–504 (1992).
132. S. Littmann, E. Schulte, and L. Acker, *Z. Lebensm.-Unters. Forsch.* **175**(2), 101–105 (1982).
133. K. Kawamura, S. Steinberg, and I. R. Kaplan, *Int. J. Environ. Anal. Chem.* **19**(3), 175–188 (1985).
134. R. Alen, K. Niemela, and E. Sjostrom, *J. Chromatogr.* **301**(1), 273–276 (1984).
135. M. Matsumoto, *Taiki Osen Gakkaishi* **23**(1), 64–71 (1988).
136. J. C. Tompsen and R. H. Smith, *Process Control Qual.* **2**(1), 55–58 (1992).
137. I. Yoshida, K. Hayakawa, and M. Miyazaki, *Eisei Kagaku* **31**(5), 317–323 (1985).
138. G. C. Galletti and R. Mazzeo, *Rapid. Commun. Mass Spectrom.* **7**(7), 646–650 (1993).
139. J. Wang and co-workers, *Sepu* **11**(3), 183–185 (1993).
140. D. Tusseau and C. Benoit, *J. Chromatogr.* **395**, 323–333 (1987).
141. Y. Maeda and co-workers, *Shizuoka-ken Eisei Kankyo Senta Hokoku* **28**, 47–50 (1985).
142. R. M. Marce and co-workers, *Chromatographia* **29**(1–2), 54–58 (1990).
143. G. D. Blanco and co-workers, *Chromatographia* **25**(12), 1054–1058 (1988).
144. K. Shimazaki and co-workers, *Obihiro Chikusan Daigaku Gakujutsu Kenkyu Hokoku, Dai-1-Bu* **15**(2), 101–105 (1987).
145. G. Panari, *Milchwissenschaft* **41**(4), 214–216 (1986).
146. D. Sun and X. Li, *Fenxi Huaxue* **11**(2), 138–139 (1983).
147. Jpn. Kokai Tokkyo Koho JP 05,38,455 (Feb. 19, 1993), S. Ishiguro and S. Shioda (to Showa Denko KK).
148. *Fed. Reg.* **44**(68), 20656 (Apr. 6, 1979).
149. R. J. Lewis, Sr., *Sax's Dangerous Properties of Industrial Materials*, Wiley on-line, Oct. 2004.
150. R. Melnick, Report NTP-TR-373, NIH/PUB-90-2828, National Toxicology Program, Research Triangle Park, N.C., 1990.
151. M. Ishidate Jr., T. Sonufi, and K. Yoshikawa, *GANN Monograph on Cancer Research* **27**, 95–108 (1981).
152. G. W. Malaney and co-workers, *Water Pollut. Control Fed. Pt. 2* **41**(2), R-18 (1969).
153. M. Wojaczynska and co-workers, *Metody Fizikochem Oczszczania Wody Sciekow, Mater. Conf.*, 2nd Nauk Miedzynar Konf., Vol. 1, 1979.
154. Jpn. Kokai Tokkyo Koho JP 8020,652 (Feb. 14, 1980), T. Ogasa and co-workers (to Sumitomo Metal Mining Co., Ltd.).
155. H. Matsumoto, S. Miyajima, and R. Matsumoto, *Eisei Kagaku* **35**(1), 86–92 (1989).
156. K. Takeno, R. L. Legge, and R. P. Pharis, *Plant Phisiol.* **67**(suppl.), 581 (1981).
157. A. M. Reinbol'd, G. S. Pasechnik, and D. P. Popa, *Izv. Akad Nauk Mold. SSR, Ser. Biol. Khim. Nauk* (4), 55–59 (1989).

158. J. L. Boucher, I. H. Wang, and R. A. Romine, *Prepr. Am. Chem. Soc., Div. Pet. Chem.* **35**(3), 556–561 (1990).
159. U.S. Pat. Appl. 20050267003 (Dec. 1, 2005), N. Camenzind and P. Hanggi (to Ciba Specality Chimicals Corp.).
160. S. Sankarapapavinasam, F. Pushpanaden, and M. F. Ahmed, *Bull. Electrochem.* **5** (5), 319–323 (1989).
161. U. J. Moeller, *Mineraloeltechnik* **38**(2), 31 (1993).
162. S. I. Pol'kin and co-workers, in A. M. Gol'man and I. L. Dmitrieva, eds., *Flotatsionnye Reagenty*, Nauka, Moscow, 1986, pp. 104–109.
163. S. A. Merritt and M. Dagenais, *J. Electrochem. Soc.* **140**(9), L138–L139 (1993).
164. C. Van der Veen, H. Buitendijk, and C. F. Lerk, *Eur. J. Pharm. Bipharm.* **37**(4), 238–242 (1991).
165. K. Thoma and T. Zimmer, *Pharm. Ind.* **51**(1), 98–101 (1989).
166. S. R. Desai and co-workers, *Drug Dev. Ind. Pharm.* **15**(5), 671–689 (1989).
167. U.S. Pat. Appl. 20020058712 (May 16, 2002), P. A. Sneed.
168. R. Takayanagi, F. Umeda, and M. Sakamoto, *Kassei Sanso Furi Rajikaru* **2**(6), 779–783 (1991).
169. B. M. Khadilkar and S. R. Bhayade, *Indian J. Chem. Sect. B.* **32B**(3), 338–342 (1993).
170. D. C. Phan, N. H. Do, and L. T. Phan, *Tap Chi Duoc Hoc* (5), 10–12 (1992).
171. U.S. Pat. Appl. 20040254157 (Dec. 16, 2004), T. Rolle and co-workers.
172. G. J. Quallich, M. T. Williams, and R. C. Friedmann, *J. Org. Chem.* **55**(16), 4971–4973 (1990).
173. A. V. Zvyagintseva and co-workers, *Izv. Vyssh. Uchebn. Zaved. Khim. Khim. Tekhnol.* **31**(12), 91–95 (1988).
174. Z. Zuo and G. Wang, *Cailiao Baohu* **26**(1), 4–9 (1993).
175. Z. A. Miroshnik and A. I. Falicheva, *Izv. Vyssh. Uchebn. Zaved. Khim. Khim. Tekhnol.* **32**(8), 63–65 (1989).
176. B. Radziuniene and V. Skominas, *Liet. TSR Mokslu Akad. Darb. Ser. B.* (4), 25–32 (Russ.) (1986).
177. R. Tarozaite and A. Luneckas, *Chemija* (1), 83–90 (1990).
178. A. M. T. van der Putten and J. W. G. Bakker, *J. Electrochem. Soc.* **140**(8), 2229–2235 (1993).
179. Z. Guo, *Cailiao Baohu* **25**(5), 46–48 (1993).
180. J. Bielinski and E. Skudlarska, *Oberflaeche-Surf.* **26**(3), 76–82 (1985).
181. T. Osaka, *Hyomen Gijutsu* **44**(10), 767–773 (1993).
182. P. Auger and co-workers, *J. Labelled Comp. Radiopharm.* **33**(4), 263–276 (1993).
183. A. Patel, R. C. Poller, and E. B. Rathbone, *Appl. Organomet. Chem.* **1**(4), 325–329 (1987).
184. B. A. K. Andrews, E. J. Blanchard, and R. M. Reinhardt, *Am. Dyest. Rep.* **79**(9), 48, 50, 52, 54, 94 (1990).
185. H. Shiozaki, M. Tsukada, and M. Matsumura, *Nippon Sanshigaku Zasshi* **57**(2), 165–168 (1988).
186. J. D. Mobley, O. W. Hargrove Jr., and J. D. Colley, *Proc. Annu. Meet. Air Pollut. Control Assoc.* **75**(4) (1982).
187. J. D. Colley and co-workers, *Proceedings of the 8th Symposium on Flue Gas Desulfurization*, Palo Alto, Calif., 1983.
188. E. Dunnigham and G. Parker, *FRI Bull.* **176**, 58–66 (1992).
189. H. Zhang, Y. Sun, and B. Han, *Pige Keji* (4), 27–29 (1987).

CARLO FUMAGALLI
LONZA SpA

Table 1. **Physical Properties of Succinic Acid and Succinic Anhydride**

Property	Succinic acid	Succinic anhydride
molecular weight	118.09	100.08
melting point, °C	188	119.6
boiling point at 101.3 kPa (=1 atm), °C	dehydration, 235	261
boiling/sublimation point, Pa[a], in °C		
133.3		92
267	156–157	
667		115
1,333		128
6,667		169
13,332		189
density, g/cm^3		
solid, 20°C		1.2
solid, 25°C	1.572	
solubility, g/100 g solvent		
in water at 0°C	2.8	
in water at 100°C	121	
96% ethanol at 15°C	10	
ethyl ether at 15°C	1.2	
methylene chloride at bp	insoluble	6.6
chloroform at bp	insoluble	3.7
in water at 25°C		
pK_1	4.16	
pK_2	5.61	
enthalpy of combustion, kJ/mol[b]	−1491	−1537.9
enthalpy of formation at 298.15 K, kJ/mol[b]	−940.5	−607.8
heat capacity at 298.15 K, J/(mol·K)[b]	153	
enthalpy of solution, kJ/mol[b]	−27.3	
enthalpy of sublimation, kJ/mol[b]		80.7
enthalpy of fusion, kJ/mol[b]		20.41
dielectric constant at 3–97°C, 5 kHz	2.29–2.90	
flammability point, °C		147

[a] To convert Pa to mm Hg, divide by 133.3.

[b] To convert kJ/mol to kcal/mol, divide by 4.184.

Table 2. **Specifications of Succinic Acid and Succinic Anhydride**

Property	Succinic acid	Succinic anhydride
melting point, °C, min	185.0	
solidification point, °C, min		118.3
physical appearance	small white crystals	white flakes
color (APHA), molten, max		100
total acidity (purity), %, min	99.5[a]	99.5[b]
free acidity (as succinic acid), %, max		1
water content (Karl Fisher), %, max	1.0	
unsaturated compounds, %, max	0.2[c]	0.2[d]
ash, %, max	0.1	
chlorides, ppm, max		100
iron, ppm, max	5	
lead, ppm, max	5	
arsenic, ppm, max		3
sulfates (as SO_4), ppm, max	500	400
heavy metals (as Pb), ppm, max	10	10
fineness, <2 mm (<10 mesh), %	100	
appearance of solution (1 g in 10-mL H_2O at 50°C)	clear, colorless	
organic impurity (1 g in 10-mL H_2SO_4 concentration)	clear, colorless	

[a] As succinic acid.

[b] As succinic anhydride.

[c] As maleic acid.

[d] As maleic anhydride.

Table 3. **Uses of Succinic Acid and Succinic Anhydride**

Use
Adhesives and sealants
hot-melt adhesives
adhesive primers for aluminized surfaces
Agriculture[a]
plant growth regulators
herbicide compositions
fungicides
pesticidal effervescent granules
insecticides
mosquito attractants
Building and construction[b]
cement additives and cement compositions
asphalt paving materials
Ceramics
manufacture of porous titanium oxide
manufacture of sinterable boehmite powder
manufacture of porous ceramics
Coating, pigments, dyes, inks
coating compositions
automobile topcoats
powder coating
radiations, uv-curable coating compositions
photocurable ink compositions
toners
quinacridone pigments
dye intermediates
Corrosion inhibitors[c]
for steel, copper, and alloys
for coatings
for antifreeze
for metalworking oils
for lead in perchloric acid
boiler-water treatment
Detergents, cleaning agents, emulsifiers, antiscaling agents
dishwashing detergent compositions
fabric incrustation prevention and softeners
liquid laundry detergents
hard-surface detergent compositions
acid cleaning compositions
bleaching compositions
biodegradable aqueous filter cleaning compositions
solid soaps
detergent powders and tablets
granular detergent compositions
Electric and electronic
solution for electrolytic capacitors
cleaner for printed circuit boards
gettering compounds
Electrochemistry
electrochemical stripping of silver
electrodialysis
electrochemical graining of aluminum

Table 3. (*Continued*)

Use
Food
disodium succinate used as food seasoning
condiments
food preservative
carbon dioxide-generating compositions for cold drinks
beverages prepared from apricot or plum purees
Household products
deodorants for air
deodorization, sanitation of toilets
Lithography
photosensitive lithographic plates
diazo photosensitive compositions
aqueous developer for lithographic printing plates
Lubricants[d]
synthetic lubricants
metalworking lubricating oils
lubricants for thermoplastics
lubricant compositions for electrical contacts
Metallurgy[c]
ore processing
etching agents
manufacture of nickel powder
bath for polishing steel
binder compositions in sintering of steels
Paper
deinking agents for recycling waste paper
paper sizing composition
Personal care
effervescent bath tablets
denture cleaners and mouthwashes
cosmetic compositions and moisturizers
adhesive sheets for application to the skin
hair rinses
cleansing solution for contact lenses
deodorant napkins for hands
Pharmaceuticals[f]
effervescent tablets, programmed drug release
antiseptic tablets
disinfectants and antibacterials
ischemia protection
treatment of wounds
bioabsorbable sutures
hardening composition for dental materials
drug detection reagent
buffer for serum
fibromyalgea treatment
derivatives in pharmaceuticals
Photography
in bleaching or bleach fixing solutions

Table 3. (*Continued*)

Use
Plating[g]
electroplating baths for Ni, Zn, Cr, Au
electroless plating for Ag, Ni, Ni–P, Ni–Mo–P, Co, Cu, Pd
electroless plating of magnetic materials
electroless Ni coating of piezoceramics
Polymers and resins
biodegradable polymers
biodegradable packaging foams
curing agent for epoxy resins
epoxy elastomers
preparation of liquid crystals
modified polyamides
water-soluble polymers
Reagent in chemical synthesis[h]
dehydrating agent
acylating agent
oligonucleotide synthesis
Soldering
pastes and fluxes
Textiles and fibers[i]
finishes for silk or cellulosic fabrics
dyeing aids for cotton or polyamide fibers
succinylation of silk
wet strengthening agents
adhesive composition for textile laminates
textile bleaching agents
Water and gas treatment[j]
bactericide tablets for swimming pools
algicide compositions
treatment of water for use in beauty parlor
flue gas desulfurization
air purification and disinfection
Miscellaneous[k]
catalyst manufacture
fireproofing aids
wood treatment
superconductor manufacture
electrolyte for lithium batteries
leather manufacture
animal feeds

---

[a] Refs. 156, 157.

[b] Ref. 158.

[c] Refs. 159, 160.

[d] Ref. 161.

[e] Refs. 162, 163.

[f] Refs. 164–172.

[g] Refs. 173–181.

[h] Refs. 182, 183.

[i] Refs. 184–186.

[j] Refs. 186, 187.

[k] Refs. 188, 189.