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The Gattermann–Koch Reaction. The Formylation of Isopropylbenzene under Pressure

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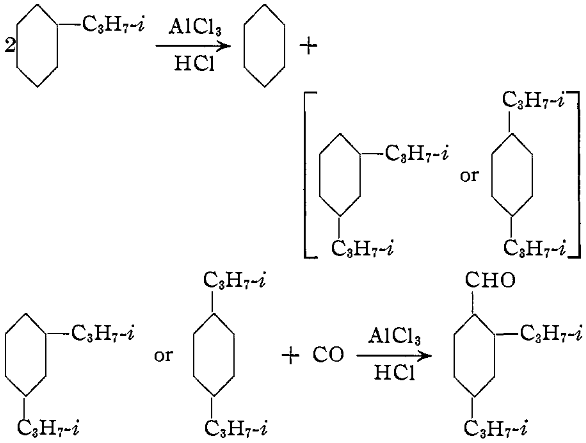
Although a description of the high pressure formylation of benzene utilizing the Gattermann–Koch reaction is available,[2] there are only patent reports[3,4,5] on the pressure formylation of an alkylbenzene. The high pressure formylation of isopropylbenzene and the side reactions have been studied. The reaction of isopropylbenzene and carbon monoxide under pressure with aluminum chloride and hydrogen chloride as catalysts gives chiefly *p*-isopropylbenzaldehyde, small amounts of benzaldehyde and 2,4-diiospropylbenzaldehyde.

The addition of hydrogen chloride was found necessary, and since water is also required,[2,6] it was attempted to add them as hydrochloric acid. The yield of *p*-isopropylbenzaldehyde was increased from 33% when only dry hydrogen chloride was used to 37% with no decrease in the time of absorption of carbon monoxide. To distribute water evenly on the aluminum chloride, twenty-mesh aluminum chloride was raked occasionally in the open air for two hours.[7] This treatment decreased the time of absorption from seven to three hours, and raised the yield to 45%.

The role of benzene, the solvent in the formylation,[8] has never been analyzed. The amount of benzene used can affect the yield of 2,4-diisopropylbenzaldehyde, formation of which could occur through the reactions shown.



The first reaction is known.[9] The diisopropylbenzenes must then be formylated according to the second equation since no diisopropylbenzenes are isolated from the reaction. The first reaction is reversible,[10] hence increasing the amount of benzene should reduce the yield of diisopropylbenzenes and preserve the isopropylbenzene. Increasing the amount of benzene 50% raised the yield of *p*-isopropylbenzaldehyde from 45 to 54%.

The effect of excess aluminum chloride on formylation has been shown.[2,11] A considerable excess of aluminum chloride utilized all the isopropylbenzene without increasing the yield of *p*-isopropylbenzaldehyde. By dropping the ratio of aluminum chloride to isopropylbenzene from 1.31 to 1.10, the yield of *p*-isopropylbenzaldehyde rose from 54 to 60%.

The formation of 2,4-diisopropylbenzaldehyde could also have been effected by alkylation of *p*-isopropylbenzaldehyde with isopropylbenzene and aluminum chloride. *p*-Isopropylbenzaldehyde can be alkylated with isopropyl chloride and aluminum chloride.[5] However, simulating formylation conditions but omitting carbon monoxide yielded neither a diisopropylbenzaldehyde nor benzaldehyde.

The lower boiling by-product of the reaction was benzaldehyde which could be formed by dealkylation of *p*-isopropylbenzaldehyde. *p*-Isopropylbenzaldehyde, benzene, aluminum chloride, and hydrogen chloride were processed together, but only the starting materials were recovered. Hence the benzaldehyde is formed probably by the action of carbon monoxide on benzene.

The higher boiling by-product, an aldehyde, was assumed to be 2,4-diisopropylbenzaldehyde, previously mentioned without proof of structure.[5] Its structure was determined here by oxidation to 2,4-diisopropylbenzoic acid, and characterization of the latter as its amide through mixed melting points.[12] The aldehyde was also characterized as a 2,4-dinitrophenylhydrazone. The formation of 2,4-diisopropylbenzaldehyde is in accord with the observation made when *m*- and *p*-xylenes are formylated to give 2,4-dimethylbenzaldehyde.[8,13,14]

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[2] Holloway and Krase, *Ind. Eng. Chem.*, **25**, 497 (1933).

[3] German patent 281,212 [*Frdl.*, **12**, 169] [*C. A.*, **9**, 1830 (1915)].

[4] Meuly, U. S. Patents 2,158,518-9 [*Chem. Zentr.*, **109**, I, 3388 (1938)].

[5] Knorr and Weissenborn, U. S. Patent 1,776,154 [*C. A.*, **24**, 5307 (1930)].

[6] Olson, U. S. Patent 1,935,914 [*C. A.*, **28**, 778 (1934)].

[7] No originality is claimed for this treatment. Information came to the writer that a German plant activated aluminum chloride in this way. This technique may benefit other Friedel-Craft acylations.

[8] Gattermann and Koch, *Ann.*, **347**, 347 (1906).

[9] Heise and Tohl, *ibid.*, **270**, 155 (1892).

[10] Boedtker and Halse, *Bull. soc. chem.*, [4] **19**, 444 (1916).

[11] Hey, *J. Chem. Soc.*, 2476 (1931).

[12] Newton, THIS JOURNAL, **65**, 320 (1943).

[13] Francesconi and Mundici, *Gazz. chim. ital.*, **32**, II, 467 (1902) [*J. Chem. Soc. Abs.*, **84** [I], 426 (1903)].

[14] Mundici, *Gazz. chim. ital.*, **34**, II, 114 (1904) [*J. Chem. Soc. Abs.*, **86** [I], 897 (1904)].

As in the case of benzene[2] cuprous chloride was found unnecessary as a carrier for high pressure formylation.

A pressure of 500 p. s. i. was used here. However, when the same conditions were used at 30 p. s. i., no carbon monoxide was absorbed in seven hours. The poor agitation of the rocking autoclave may be more noticeable at low pressure than at high.

Procedures

_p_-Isopropylbenzaldehyde.—To a mixture of 210 g. (1.75 moles) of isopropylbenzene and 315 g. (4.05 moles) of benzene saturated with hydrogen chloride in a lead-lined rocking autoclave,[15] was added 255 g. (1.92 moles) of aluminum chloride (technical) which previously had been ground to pass 20-mesh and exposed in a one-inch layer to air for two hours with frequent stirring. The autoclave was then purged with carbon monoxide (commercial) from a cylinder and carbon monoxide added to a pressure of 500 p. s. i. at 25–30°. After the pressure dropped to 300 p. s. i., it was again raised to 500 p. s. i. This was repeated until no drop occurred (two and one-half hours) whereafter the pressure was maintained for an hour longer.

The reaction mixture was poured onto 2500 g. of ice acidified with 5 cc. of concentrated hydrochloric acid and separated. The oil layer was washed with 500-cc. portions of water and 5% sodium carbonate solution, and filtered to break the emulsion. After separation the oil layer was washed twice with 500-cc. portions of water.

The oil was charged to a round-bottom flask headed by a 36-inch fractionating column packed with glass helices. Distillation was continued under atmospheric pressure until the pot temperature reached 131°, the distillate being benzene. Then, under a vacuum of 135 mm., 40.5 g. of isopropylbenzene (b. p. 95° at 135 mm.) were recovered. Distillation at 35 mm. gave 11 g. of benzaldehyde (b. p. 83–88° at 35 mm.) contaminated with a small amount of isopropylbenzene, 126 g. of _p_-isopropylbenzaldehyde (b. p. 131–135° at 35 mm.), 60.3% yield based on the recovered isopropylbenzene, and 25 g. of 2,4-diisopropylbenzaldehyde. A residue of about 25 g. remained.

The _p_-isopropylbenzaldehyde reduced Tollens reagent. Oxidation with alkaline potassium permanganate gave _p_-isopropylbenzoic acid, m. p. 115°.[16] Calcd.: neut. equiv., 164. Found: neut. equiv., 162.

Benzaldehyde was characterized as its phenylhydrazone, m. p. 156°. A mixed melting point with an authentic specimen suffered no depression.

The higher boiling aldehyde was redistilled. Fifteen g. was recovered: n^{20}_{D} 1.5241, d^{20}_{4} 0.9461, b. p. 127° (13 mm.).

Anal. Calcd. for $C_{13}H_{18}O$: C, 82.10; H, 9.47. Found: C, 82.14; H, 9.45.

Oxidation of Diisopropylbenzaldehyde.—Oxidation of diisopropylbenzaldehyde with alkaline potassium permanganate gave low yields of 2,4-diisopropylbenzoic acid, m. p. 107–107.5°.[17] Calcd.: neut. equiv., 206. Found: neut. equiv., 204. Newton[12] records a melting point of 107.5–108.5°.

2,4-Diisopropylbenzamide.—Half a gram of the above acid was treated with an excess of thionyl chloride[18] and then converted to the amide; melting point 156.5°. A mixed melting point with a sample prepared by Newton's[12] method showed no depression.

2,4-Dinitrophenylhydrazone of 2,4-Diisopropylbenzaldehyde.—One gram of 2,4-diisopropylbenzaldehyde was treated with 2 g. of 2,4-dinitrophenylhydrazine in alcohol.[19] The yield of red needles, m. p. 156.5–157.5°, was 2.5 g. (90% yield). The product was dissolved in 20 cc. of cold benzene. Addition of 15 cc. of low boiling petroleum caused the precipitation of 2.2 g. of tiny red needles, m. p. 156.5–157.5°.

Anal. Calcd. for $C_{19}H_{22}O_4N_4$: N, 15.20. Found: N, 15.00.

Attempted Alkylation of _p_-Isopropylbenzaldehyde with Isopropylbenzene.—To a mixture of 225 g. of benzene and 74 g. of isopropylbenzene, saturated with hydrogen chloride, 80 g. of aluminum chloride was added and then 74 g. of _p_-isopropylbenzaldehyde in forty-five minutes at 24–27°. After stirring for two hours, the mixture was poured onto 800 g. of ice and separated. The oil layer was washed with water, 5% sodium carbonate solution, and again with water. Distillation through a 3-ft. column packed with helices gave benzene, isopropylbenzene, and _p_-isopropylbenzaldehyde in 90% recoveries. The small residue showed no evidence of 2,4-diisopropylbenzaldehyde.

Attempted Dealkylation of _p_-Isopropylbenzaldehyde.—The conditions of the experiment recorded above were repeated omitting the 74 g. of isopropylbenzene. Only the starting materials were recovered.

Summary

A study has been made of some factors in the pressure formylation of isopropylbenzene. The structure and mode of formation of the by-products of the reaction have been discussed.

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[15] American Instrument Company, Silver Springs, Md.; lead-lined at Hilton-Davis.

[16] Meyer, *J. prakt. Chem.*, [2] **34**, 100 (1886), reports the melting point as 116–117°.

[17] Niedzielski and Nord, *J. Org. Chem.*, **8**, 147 (1943). These authors report the formation of diisopropylbenzaldehydes through application of the Gattermann reaction to both isopropylbenzene and _m_-diisopropylbenzene. The corresponding acids melt at 186° and 190°, respectively; the 2,4-dinitrophenylhydrazones melt at 133° and 143°.

[18] McElvain, THIS JOURNAL, **53**, 1173 (1931).

[19] Allen, *ibid.*, **52**, 2955 (1930).