7. Operating instruction for labor
8. Selection of personnel
9. Preconstruction costing
10. Production costs per unit of material

Notebooks must be kept with a daily log of all observations and data. Each page should have a title and date, and at the end of each period a brief résumé must be written of the day's work, signed by initials of the worker and someone who was with him in the laboratory. Notebooks should be deposited with the instructors.

Weekly reports to the class are essential, and weekly written reports should be made. The student should receive practice in presentation. Calculations and reasons for making certain decisions should be presented concisely to the class for criticism. The discussions should be informal.

At the end of the year a complete report should be turned in which includes all calculations, flow sheets, material balances, plans, and layouts, and a carefully executed drawing on plans and elevation of the completed plant, with such detailed drawings as may be necessary to clarify the drawing.

Thus the unit operations and unit processes are correlated not only with each other but also with economic and design considerations of unit process. This is the old industrial chemistry laboratory dressed up to conform to present-day demand.

IS THIS the type of course work that will fulfill the need of the students and of the industrialists? And will the industrialist want a man so trained and start him in his plant with only the necessary of teaching him the details of his own process?

Literature Cited

(1) *Chem. & Met. Eng.*, 43, 58–82 (1936).
(2) Ind. Eng. Chem., 29, 1329–64 (1937).

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MANUFACTURE OF ISOAMYL CHLORIDE

An Example of Chlorination Using Thionyl Chloride

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IN THE manufacture of 5,5′-dialkyl barbituric acid, it has been the practice for many years to use an alkyl bromide as a means of introducing the desired alkyl group into the 5 position of the barbituric acid nucleus. Several years ago it was found at this plant that, by means of the correct technique and proper equipment, ethyl chloride could be satisfactorily substituted for ethyl bromide in this procedure. Such a change resulted not only in a substantial savings but also eliminated the undesirable, but economically necessary, recovery of the by-product sodium bromide which is used in the manufacture of more halide.

The next step was to substitute for the bromide the chloride of the other alkyl group in the 5 position—namely, the isoamyl. The manufacture of this chemical and the chemical engineering involved in its production is to be discussed in this paper.

Thionyl chloride ($SOCl_2$) has long been known as a valuable chlorinating agent, but not until the development of new catalytic methods for making it from carbon monoxide, chlorine, and sulfur dioxide in recent years, has its cost been lowered enough to permit its use in large-scale manufacture (*2*). The fact that it is a low-boiling liquid (boiling point, 78.8° C.) and that the side products of its reaction are gases which can be easily eliminated from the reaction mixture are its two great advantages. Its main disadvantage is its sharp, penetrating odor which irritates the eyes, nasal passages, and throats of workers and thus requires ample ventilation and utmost care in its handling.

Stahler and Schirm (*1*) made a rather comprehensive study of the action of thionyl chloride on methyl, ethyl, propyl, and isobutyl alcohols, and concluded that this reaction proceeded according to the following equations:

$$\mathrm{ROH} + \mathrm{SOCl_2} = \mathrm{RO{-}SOCl} + \mathrm{HCl} \qquad (1)$$

$$\mathrm{RO{-}SOCl} = \mathrm{RCl} + \mathrm{SO_2} \qquad (2)$$

The chlorosulfinyl ester formed in Equation 1 is very unstable and decomposes readily upon heating, as shown in Equation 2. By taking advantage of these reactions, isoamyl chloride can now be produced in the plant economically by the process described below and shown in Figure 1.

Equipment

The equipment for the manufacture of this halide consists of a glass-lined, steam-jacketed kettle, to the vapor outlet of which is connected a 12-foot lead reflux column packed with 1-inch stoneware Raschig rings. Down the outside of this column flows a spray of water for cooling it. This external cooling method has two advantages: (*a*) Should a leak develop in the column, due to corrosion, it will be immediately discovered because the gases evolved from the reaction will fume when in contact with water. (*b*) Since the pressure is always outward, there is no chance, with the development of a leak, for water to enter the column and perhaps spoil the reaction within the kettle.

The outlet from this reflux column is connected to the top of a spiral lead condenser which is brine-cooled. The bottom of this spiral discharges into a 4-inch lead pipe which rises vertically through the center of the spiral and is packed with 1-inch stoneware Raschig rings. This pipe then discharges into the bottom of a 30-foot stoneware absorption tower, 24 inches in diameter and also packed with 1-inch Raschig rings. Water sprays downward through this tower and out to the sewer.

The bottom of the 4-inch vertical pipe within the spiral condenser discharges by means of 1-inch lead pipe either through a U-turn into the reaction kettle or into an iron receiver, which is equipped with a bottom outlet, a Lightnin mixer, and a manhole, and is vented into the stoneware absorption tower.

The reaction kettle is further equipped with an anchor-type agitator, a recording thermometer, an inlet line for the alcohol, and a half-inch lead pipe line connected to a lead-lined, steel thionyl chloride charging tank. It is also provided with a 3-inch bottom outlet discharging to the sewer.

Process of Manufacture

The charge of isoamyl alcohol is pumped by a bronze rotary pump into the reaction kettle and heated to a temperature of 25° C. (77° F.) if necessary. To this is added slowly, by means of dry compressed air under 10 to 12 pounds per square inch pressure, the charge of thionyl chloride which has previously been placed within the lead-lined charging tank. The rate of addition of this thionyl chloride is regulated according to the temperature of the reaction mixture. Shortly after the beginning of this addition the temperature rises rapidly to about 75° C. (167° F.); then it slowly drops to about 40° C. (104° F.). The speed of the addition can be safely increased when the temperature has dropped below 50° C. (122° F.). The entire time for the addition of the chloride requires 7 to 8 hours.

The reaction mixture is gently digested overnight at about 65° C. (149° F.) by circulating steam through the jacket of the kettle. It is then refluxed vigorously for 24 hours at about 90° C. (194° F.).

During this 48-hour reaction period the lead reflux column is cooled by the external spray of water, brine is circulated though the condenser, and water is sprayed down the stoneware absorption tower. Laboratory experiments have shown that such an elaborate cooling and condensing system is necessary because during the addition of the chloride, and particularly at the start, the evolution of the gases is so rapid that some of the crude isoamyl chloride formed is entrained with them as they leave the reaction kettle. Therefore, unless these gases are cooled in this specially designed condenser which will return any condensed isoamyl chloride through the U-pipe to the reaction kettle, this chloride will pass out into the absorption tower and be washed down the sewer along with the gases, thereby materially lowering the final yield. It has been calculated that for each pound of thionyl chloride used in this reaction there are formed 2.94 cubic feet of sulfur dioxide and 2.99 cubic feet of hydrogen chloride.

Following the reflux period the crude isoamyl chloride is distilled off through the lead reflux column, which now operates without the external spray, and through the brine condenser. The distillate, however, is not returned through the U-pipe to the reaction kettle but rather is diverted into the iron receiver. It is necessary during this step that the manhole be tightly closed and that the vent pipe on the receiver be opened to the absorption tower, since there is a considerable amount of gas and some unreacted thionyl chloride present in the distillate. When distillation is complete, the small amount of residue left within the reaction kettle is immediately dumped down the sewer; otherwise it will set, upon cooling, to a semisolid, rubberlike mass which can be removed from the reaction kettle only with difficulty.

There is now added to the distillate an amount of distilled water equivalent to about 50 per cent of its volume, and it is washed thoroughly by the aid of the Lightnin mixer in order to remove any occluded gases or unreacted thionyl chloride. After the mixture has been allowed to settle and separate, the lower water layer is drawn off through the bottom outlet of the receiver and discarded. The distillate is next washed in a similar manner with a 10 per cent solution of sodium hydroxide, which is also removed, after separation, through the bottom outlet and discarded. Finally the distillate is washed with another small portion of distilled water which is likewise removed after settling and discarded.

The isoamyl chloride is now transferred from the iron receiver to suitable open-top containers in which it is dried with anhydrous sodium sulfate. After filtering by vacuum it is put into drums, which are placed in storage until the chloride is to be used in a malonic ester synthesis.

After careful laboratory experiments and considerable study of plant operations, optimum yields of isoamyl chloride by this process now amount to 80 per cent or better. Analytical tests show that this material has an average specific gravity at 25° C. of 0.8740 and a boiling range of 95° to 100° C. (boiling point, 98.9° C.), or 203° to 212° F. (210° F.).

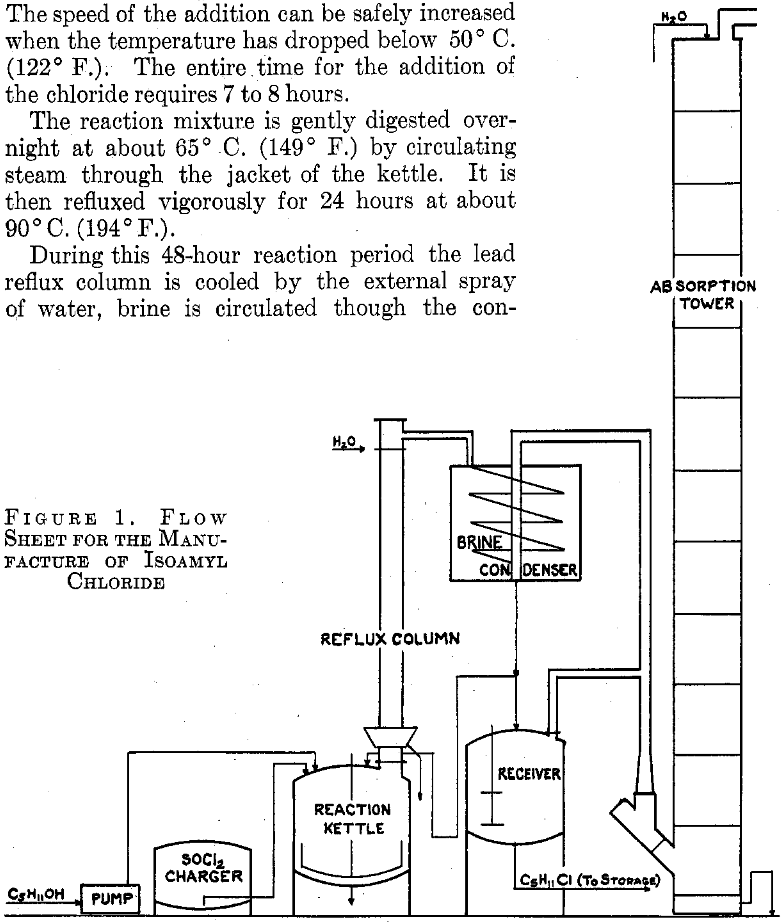

Figure 1. Flow Sheet for the Manufacture of Isoamyl Chloride

Literature Cited

(1) Stahler and Schirm, *Ber.*, 44, 319 (1911).
(2) *Synthetic Organic Chem.*, 3, No. 4 (1930).

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