Cellulose Acetate Treatment for Textile Insulation—Development of the Manufacturing Process

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Equipment was developed and a plant constructed for coating textile insulated wire with a film of cellulose acetate. The wire is treated at a speed of 240 feet per minute. Recovery of more than 85 per cent of the acetone used as a solvent is effected with carbon adsorbers. Thorough precautions have been taken to prevent fire and explosion and to render them harmless if they should occur.

INTRODUCTION

IN the telephone plant of the Bell System a large quantity of textile insulated wire is employed for wiring the switchboards and connecting them to the incoming lead covered cables. The insulation on this wire varies with its use in the plant, common constructions in the past being tinned copper wire insulated with two servings of silk and one of cotton, or, where the requirements are not so exacting, enameled wire with two servings of cotton.

The constant demand for better electrical characteristics in telephone circuits has led the engineers of Bell Telephone Laboratories to seek an improved insulation for this wire as discussed in the contemporary paper, "Cellulose Acetate Treatment for Textile Insulation, Engineering Development," by E. B. Wood and D. R. Brobst. The old design wire was affected by the variation in the dielectric properties of the textile insulation with its moisture content which in turn varied with the surrounding humidity. It was found that the application of a thin film of cellulose acetate to the textile insulation considerably stabilized its properties.

The action of the cellulose acetate coating is illustrated in Fig. 1. When the surface of untreated wire is magnified, it is evident that it is a mass of extending fibers and when two conductors lie adjacent, these fibers interlace. Under humid conditions the textile becomes moist and the interlacing fibers afford a path for current leakage. The moist fibers also have a considerably higher dielectric constant than the dry fibers and the electrical capacitance between adjacent wires is increased, therefore, with high humidity. In the lower half of the figure, the treated wire is shown, with the fibers ironed and sealed down by the cellulose acetate process. It is not claimed that the film is free from cracks, for cracks do form in the subsequent twisting and forming operations permitting moisture to enter, but no matter how moist the textile may become, no direct path for the leakage of current is formed as the fibers are separated from one another by two films of cellulose acetate.

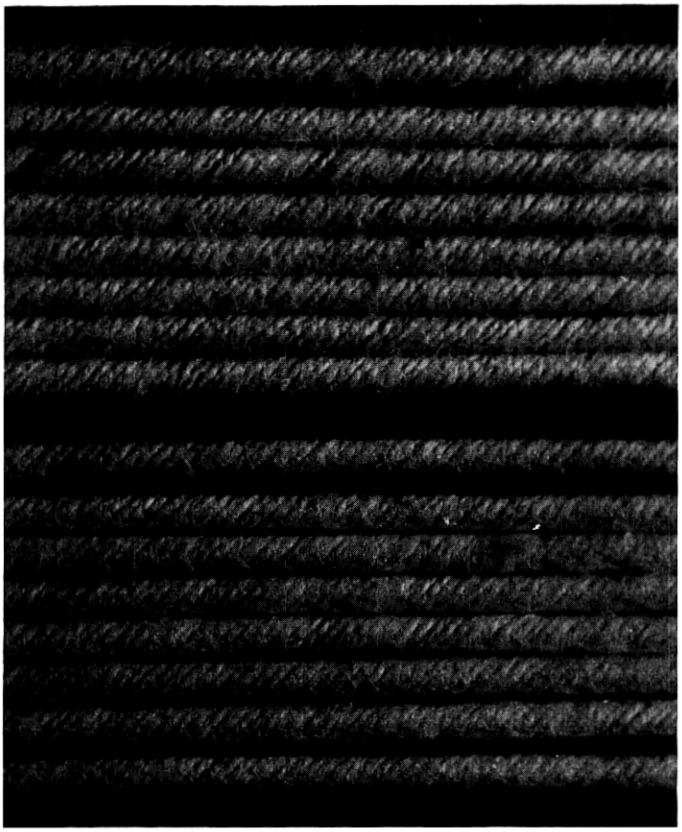

Fig. 1—Textile insulated wire before and after treatment with cellulose acetate. (Enlarged 4 diameters.)

Development of Process

Extrusion of a coating as thin as wanted, about 0.0015 inch, appeared to be out of the question. Even if it were possible the coating would not adhere firmly enough to prevent cracking off when the wire is twisted or otherwise roughly handled. The study of method was therefore confined to coating the textile insulated wire from a solution. Several solvents for the flake cellulose acetate were considered but acetone was adopted, at least for the time being, as it was known to have the desired characteristics and would simplify the problems involved. The solution would have to be low in viscosity to produce the thin coating desired and therefore the quantity of acetone used would be high. This made it economical to recover the acetone after it had been driven off from the coated wire.

It was quickly established that the procedure should include several passes of the wire through the cellulose acetate solution with the excess

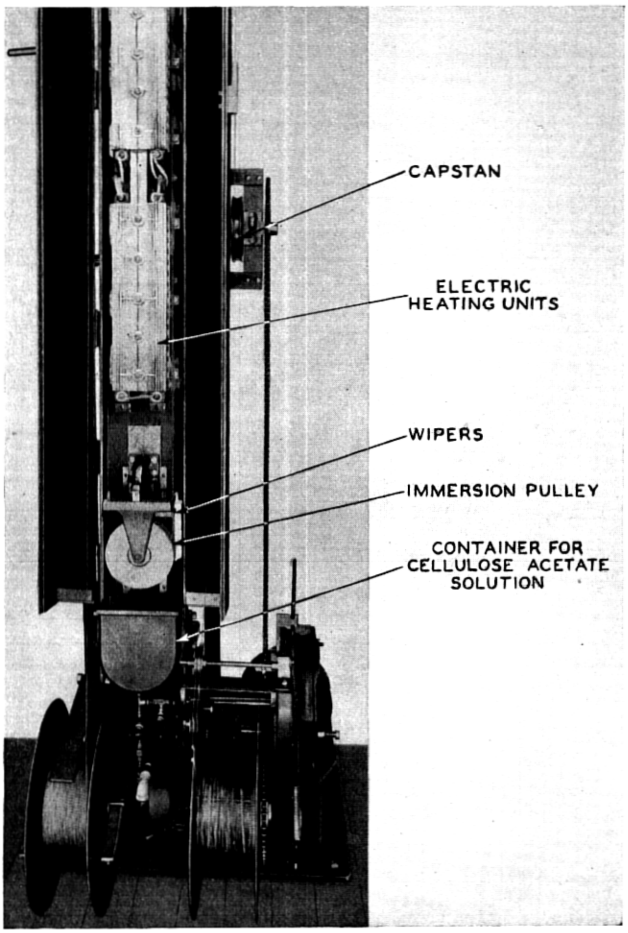

Fig. 2—An experimental machine for treating textile insulated wire with cellulose acetate. The immersion pulley with wiper dies are shown raised for threading.

solution removed and the coating dried after each pass. The source of drying heat was optional and for experimental purposes electrical heating elements were used. The temperature of drying was limited by the tendency of the coating to blister. A rapid circulation of air quickened the rate of drying and with a sufficiently long drying chamber, a high rate of wire travel seemed possible.

An early experimental machine is shown in Fig. 2. At the bottom are the supply reel and the motor driven take-up reel. The cellulose acetate solution is in the small tank near the bottom. The wire passes around the immersion pulleys, shown raised for threading, then past wipers into the drying chamber, over an upper pulley, and down, for a total of four passes, which was later increased to six passes.

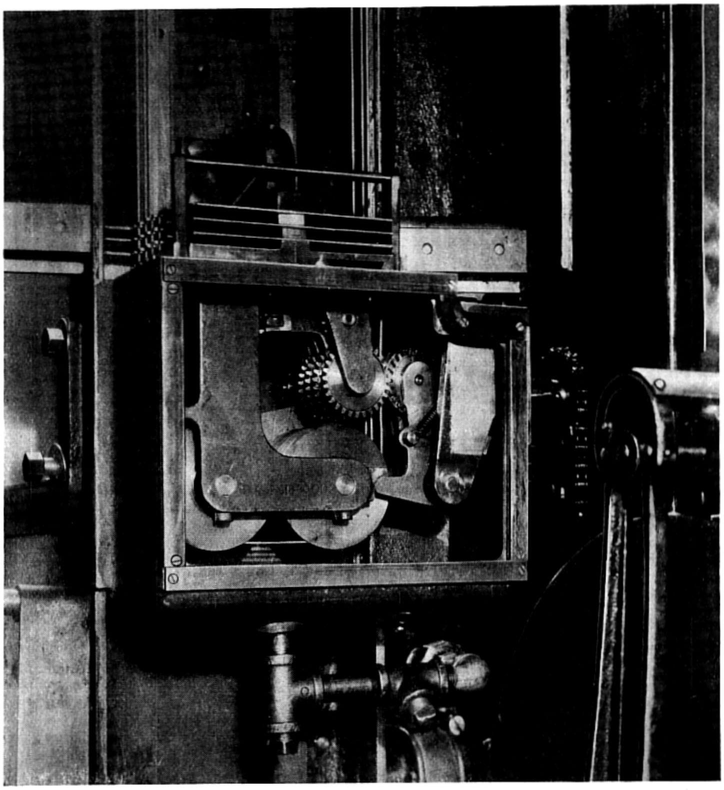

Fig. 3—A later experimental machine, equipped with rotating dies for removing the excess cellulose acetate and pressing down the textile fibers.

It was found that stationary wipers quickly became clogged by a mixture of lint from the textile serving and half dried cellulose acetate solution, and the rotating dies shown in Fig. 3 were designed. These dies are the heart of the machine and their construction and adjustment were found to be critical. It was necessary that they should allow wire splices and enlarged places in the textile insulated wire to pass, and to permit this the right hand dies were carried on spring arms allowing them to back away. They were driven in the same direction as the wire travel but at one-third the speed. The slower speed causes a wiping action on the wire, ironing down the fibers, but still tends to feed wire splices through the dies. The size of the grooves must be proportioned exactly for each gauge of wire, the first pass being the largest. This is necessary so the extending fibers will be gathered in rather than caught between the dies and cut off. Dur-

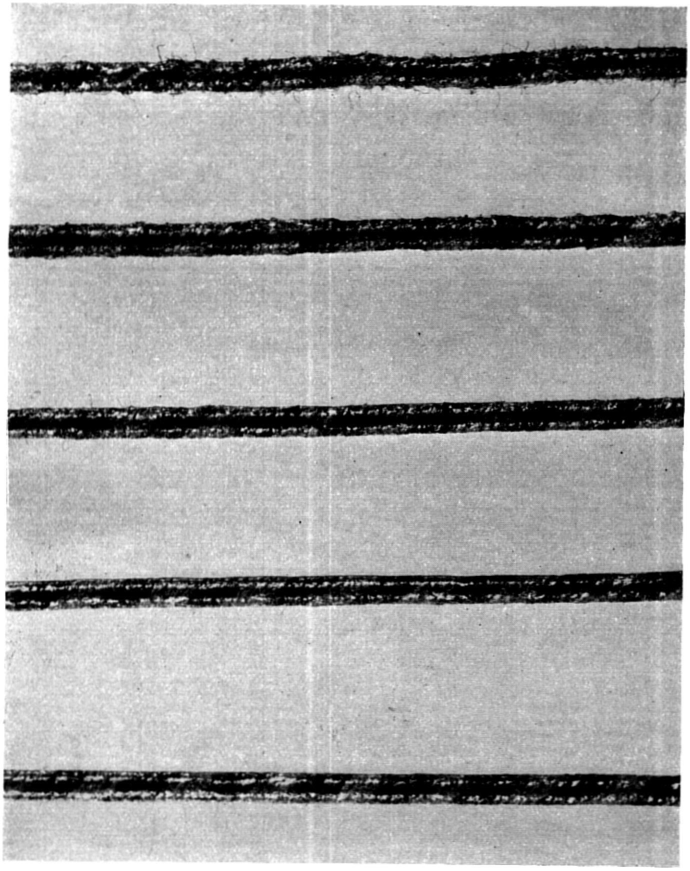

Fig. 4—An enlargement showing the gradual pressing down of the textile fibers and smoothing of the cellulose acetate coating as the wire receives the successive applications.

ing the next three passes these fibers are gradually ironed down, as illustrated in Fig. 4, while the fifth and sixth passes are largely for smoothing down and sizing. Adjustments were provided for lining the dies up with the wire so the pressure on both sides of the wire would be equal, resulting in an even coating. Means were provided for quickly removing the dies for cleaning as it was expected that soaking them in acetone would be necessary at frequent intervals.

The density and viscosity of the cellulose acetate solution have an important bearing on the process. It was desirable to use as little acetone as possible as this would hasten the drying operation and with less acetone in the process, less acetone would be lost.

To obtain the maximum effect from the film of cellulose acetate, it was desirable that the coating be as free from extending fibers and as smooth as possible. Passing the coated wire while still plastic over pulleys so arranged that the entire circumference of the wire would come in contact with the pulleys, was found to produce a polishing effect.

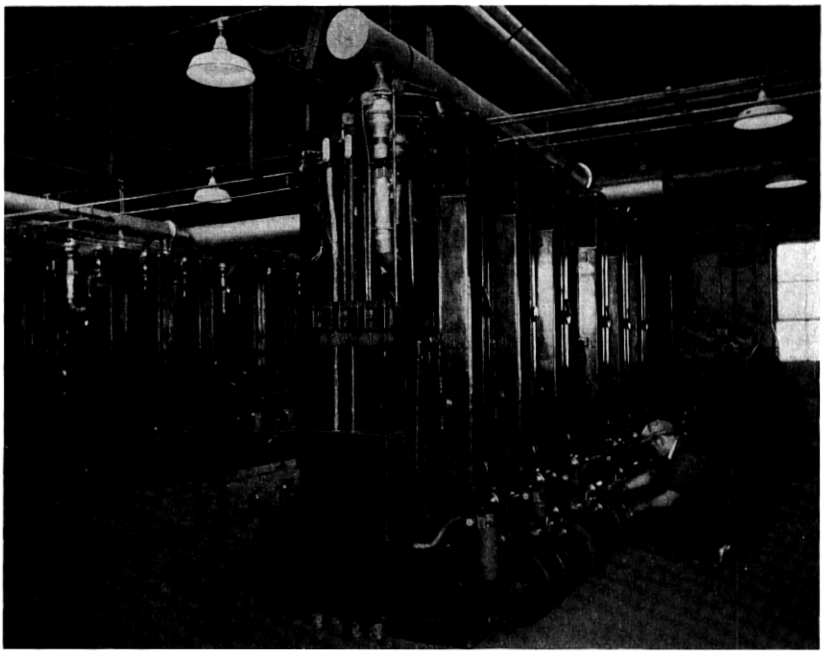

Fig. 5—An installation of machines for treating textile insulated wire with cellulose acetate.

Commercial Installation

With the essentials of the cellulose acetate coating process determined, the design of a commercial machine was undertaken. Figs. 5 and 6 show a number of these machines which, it will be seen, are in many ways similar to the experimental machine previously illustrated. Each head is separately driven by a two-speed electric motor and there is a second motor for circulating the air within the head. The main drive motor is connected so that it rotates the wiping dies continuously so they will not freeze up, and the take-up reel and the capstan are operated through a hand clutch. Six passes of wire were decided upon as giving better control of the coating than afforded by four passes. Electric heating elements were selected as being compact and

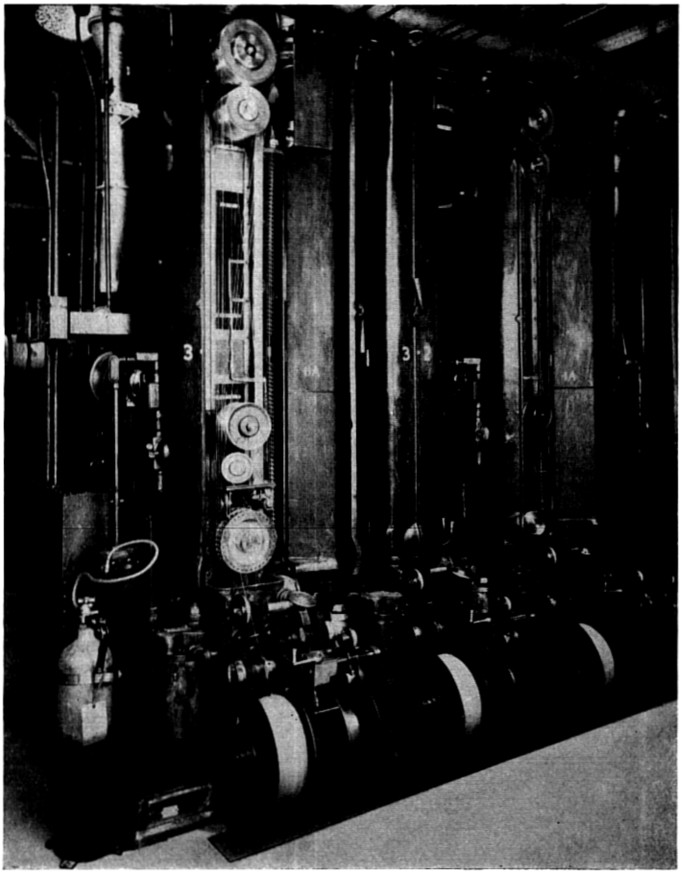

Fig. 6—Cellulose acetate wire coating machine.

easily controlled. In the schematic view, Fig. 7, are shown the method of air supply, the circulation of the air within the drying chamber, and the exhausting of the acetone-air mixture.

In making a commercial installation of the new machines, it was necessary to go into the questions of preparing and circulating the cellulose acetate solution, recovering the acetone, and making the entire process as safe as possible from the hazards that are always present when using a solvent such as acetone.

Fig. 8 illustrates the general arrangement of the equipment. Two buildings are used instead of one to separate the large quantities of solution present in the mixing room from the room in which the coating machines with their electrical equipment are located. The acetone is pumped from the underground storage tanks to the mixers. The cellulose acetate is weighed out from bins and added to the mixers and the

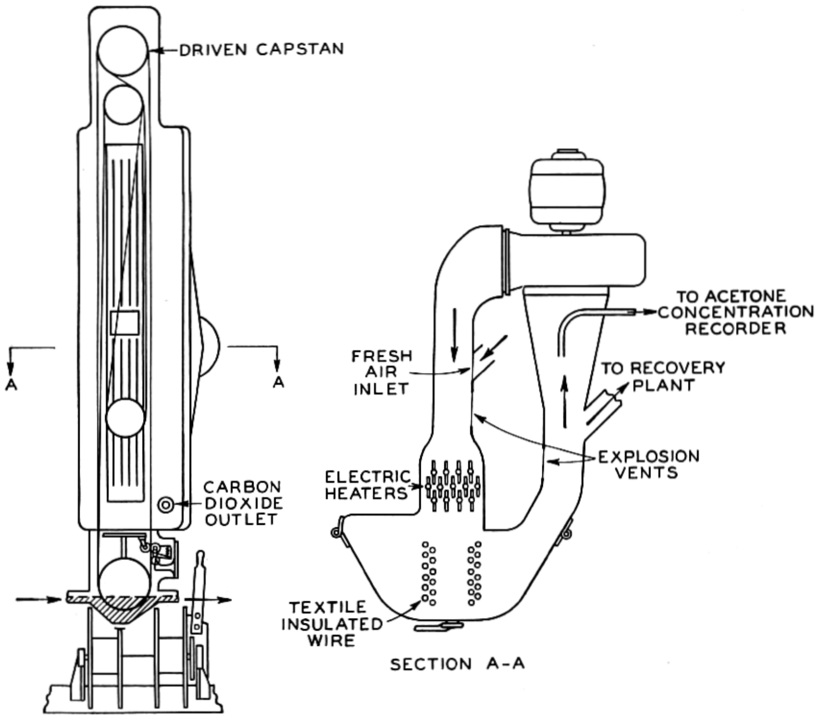

Fig. 7—Schematic view of one coating head.

whole stirred for several hours until fully dissolved. One gallon of acetone is used to ten ounces of cellulose acetate. The solution is then pumped continuously from the mixers to the machines. From the machines it flows to a sump by gravity and from the sump is forced back to the mixers. The reasons for circulating the cellulose acetate solution are to keep it homogeneous, to keep the amount of solution in or near the machines as small as possible, and to permit control and maintenance of its viscosity at one location instead of in the individual dope pots.

It was found that the viscosity of the solution had to be maintained within close limits, as the weight of film left on the wire changes with the viscosity. To continuously indicate the viscosity, a constant amount of solution is pumped through an orifice and the back pressure developed is measured by a pressure gauge, the gauge being calibrated for viscosity. Deviations from the required viscosity are corrected by the addition of acetone or a more concentrated solution that is kept in readiness.

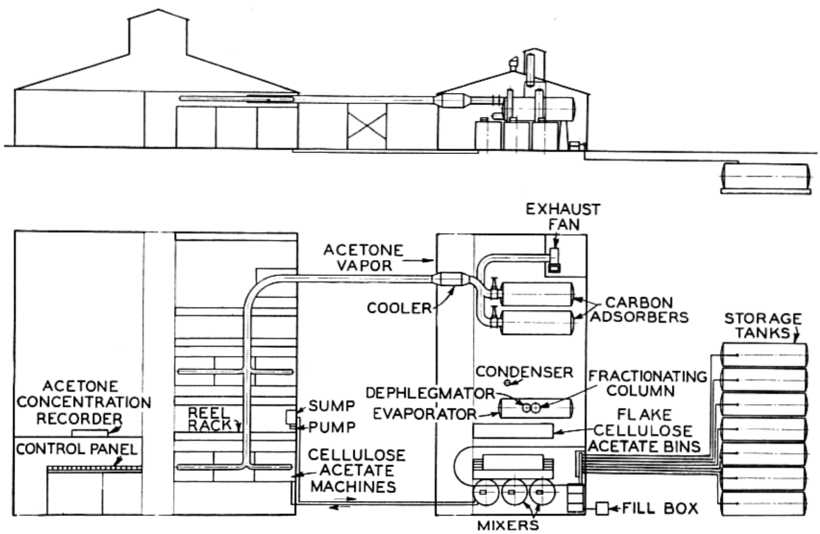

Fig. 8—Schematic of the wire treating plant at the Kearny, New Jersey works of the Western Electric Company.

To keep the amount of acetone solvent low for the required viscosity, the temperature of the solution is kept at about 86° F. Although a higher temperature would require the use of even less solvent, it would increase the loss by evaporation. To maintain the desired temperature, a water coil was installed in the mixer, the water in turn being heated by steam. This indirect method was used instead of installing steam coils directly in the mixer as the latter would result in boiling the cellulose acetate solution and the coils would become heavily coated with cellulose acetate. The mixers are equipped with standard propeller type agitators driven through gear reduction by totally enclosed motors.

During the drying operation the acetone is evaporated giving a mixture of air and acetone vapors within the drying chambers. This mixture would be explosive if the concentration of acetone vapors were

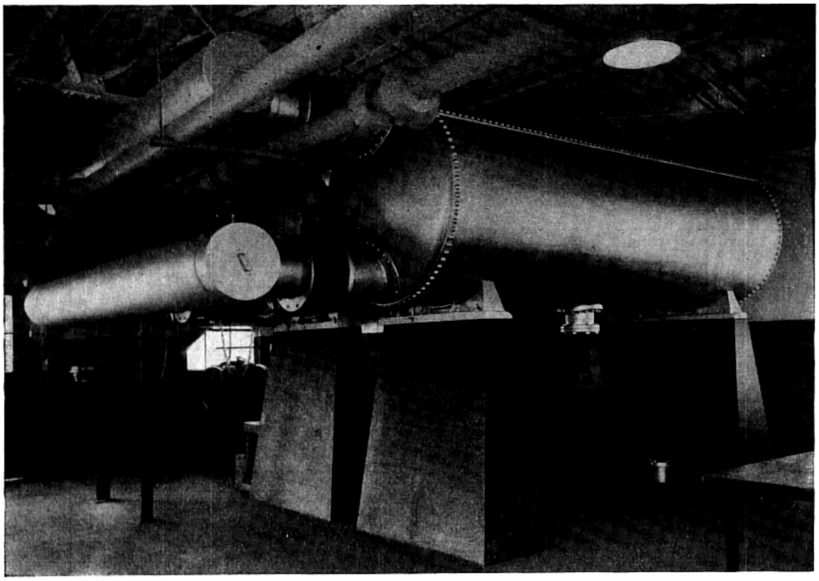

Fig. 9.—Charcoal adsorbers for removing the acetone vapors from the exhaust from the treating machines.

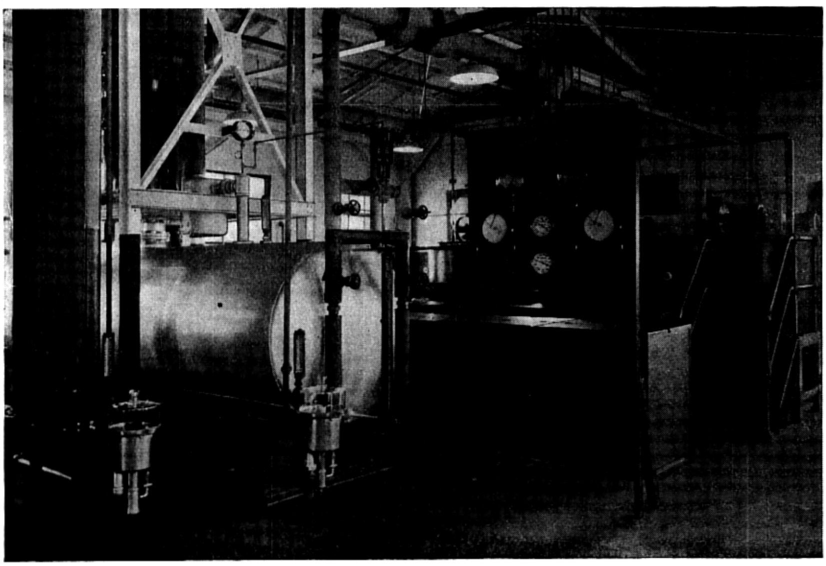

Fig. 10—Equipment for the distillation of acetone.

allowed to get between approximately 2.5 per cent and 13 per cent by volume and at the concentration of 5 per cent an explosive force of as high as 75 pounds per square inch might result. To eliminate the possibility of a vapor explosion, enough of the mixture is constantly drawn away through an exhaust duct so that the concentration of acetone will not exceed 1.5 per cent. The vapors are conducted back to the building in which the mixing was performed and the acetone is recovered.

The acetone recovery system shown in Figs. 9 and 10 consists of activated carbon adsorbers, a condensing tower, and a dehydrating plant. The air and acetone mixture coming through the exhaust header from the coating machines passes through a water cooler to the carbon adsorbers where the acetone is adsorbed and the air is exhausted through the roof. After about an hour's operation, the carbon in one of the tanks has adsorbed as much acetone as it can without allowing a portion of it to pass through and the air valves are switched to pass the acetone air mixture through the other adsorber. Steam at low pressure is then admitted to the first adsorber and the acetone is driven off. The steam and acetone vapors are condensed, giving a condensate that averages about half water and half acetone. This flows by gravity to one of the outside underground storage tanks where it is held until it can be dehydrated. When a supply of water-acetone has accumulated, it is pumped to the evaporator and the dehydrating is performed in the usual way. The recovered acetone flows by gravity to another of the underground tanks for reuse. Samples are taken at intervals to insure that the dehydration is complete, that no foreign materials are present and that no breakdown of the acetone has occurred. More than 85 per cent of the acetone purchased is recovered.

There were, of course, other types of recovery systems available, but for our purpose the carbon adsorption process was most economical. Scrubbing with water or other absorbing mediums would not give as high a percentage of recovery and would be more expensive to install and operate. Freezing out the acetone would not be as economical with the low concentration of acetone-air mixture that it was felt must be maintained to afford safety from explosion.

Precautions Against Fire

Throughout the engineering of this installation, the greatest precautions were taken against possible fire and explosion. Double forty-mesh screens were installed close to the junction of the vent pipes with the underground tanks. The mixing tanks were equipped with explosion reliefs consisting of .002 inch thick sheet aluminum. The tanks were vented to the recovery system, with a fire screen installed in the vent line. Attached to the mixing tanks is a carbon dioxide fire extinguishing system. One opening is within the tank and another one is above the explosion relief. This carbon dioxide system will be released automatically if a quick rise in temperature occurs within the mixer and it can also be operated through a hand pull box on the outside of the building. Operation of the carbon dioxide system in the mixers or in any other place in the cellulose acetate plant causes all electric power in both buildings to be turned off instantly, sounds a siren and calls the fire department.

To avoid the possibility of static sparks while loading the flake cellulose acetate into the mixer, a humid atmosphere is obtained by injecting steam. The danger is further lessened by the avoidance of metal in the container used for carrying the flake acetate.

In the coating machines themselves, precautions have been taken both to prevent fires and to render them harmless if they should occur. A temperature well above 1,000° F. is required to ignite acetone and the electric heating elements are operated at about half this temperature. The temperature of the drying chamber is controlled by a pyrometer which turns on or shuts off the electric heating current as required. As a further safeguard, a second temperature control, set at a slightly higher temperature, is arranged to act if the first one fails, shutting off the current and sounding a gong. Here again a carbon dioxide fire extinguishing system is permanently attached with an outlet in each drying chamber. Automatic discharge would be difficult to control because of the temperature conditions in the chamber and the carbon dioxide is controlled entirely from hand pull boxes. Hand CO_2 equipment is also available in convenient locations. Explosion vents covered with aluminum foil are located in the rear of each unit.

However, as previously mentioned, there is no danger of explosion of the acetone-air mixture in the drying chamber if the percentage of acetone is maintained at less than the amount that will propagate flame, about 2.5 per cent. Acetone-air analysis instruments of a standard make are permanently installed, taking readings from each of the drying chambers and from various points in the exhaust lines. These instruments operate on the basis of difference between the thermal conductivities of air and of atmospheres containing various amounts of acetone vapor. Two platinum coils, heated by a constant electric current, form two arms of a Wheatstone Bridge. Around one of these coils is room atmosphere, containing whatever moisture and other impurities it may, while around the other coil are the gases drawn from the drying chamber, cooled down to the same temperature, containing acetone vapors in addition to the constituents of the room atmosphere. The different thermal conductivities of the gases around the two coils cause a difference in temperature and therefore a change in resistance of the platinum coils which causes a reading on the galvanometer. The instrument is calibrated to read directly in per cent acetone. If a reading greater than the allowed maximum of 1.8 per cent concentration is encountered, a gong is sounded and the head is immediately switched to half speed until the trouble is located and remedied. The percentage of acetone concentration can be varied by increasing or decreasing the amount of room air drawn through the machine to the recovery system.

To avoid all sparks in the main rooms, where some acetone vapor may exist, a separate control room with entry from the outside only is provided. Lead covered cables running through sealed ducts connect the machines with the control room and all fuses and relays are in this room. Switches on the machines are oil immersed or fully enclosed and gas tight. A magnesite floor is provided to prevent the striking of sparks from reels or tools that may be dropped and brass floor plates are used instead of steel for the same reason.

Although the present installation is well protected from fire and explosion, there are still a number of characteristics of acetone that are not well known, and it is probable that more exact knowledge would make it possible to achieve safety in future installations at less expense. A study is therefore under way in cooperation with the Bureau of Mines at Pittsburgh to determine these unknown characteristics of acetone. Among the unknown quantities are the exact lower limit of acetone vapor concentration that is explosive under conditions such as are encountered in our drying chambers, the effectiveness of various relief openings, the probability of ignition from various sources, especially static sparks, and the force of explosions possible from various concentrations.

Recent Developments

A new coating machine has been developed that operates at a higher speed, is simpler to operate and is still better safeguarded against fire and explosion. It consists of eight coating units on a common base, four units being on each side. Instead of electrical heating elements in each coating unit one steam heater supplies hot air to a number of machines. The temperature is automatically controlled at the heater, leaving the operator free to watch the supply and take up of the wire. A wire speed of 240 feet per minute has been obtained compared to

150 feet per minute with the electrically heated machines. With an overall efficiency of 90 per cent, the production per head is 13,000 feet per hour.

Ample explosion reliefs have been included in the new machines. For the chamber itself, a diaphragm of aluminum foil that will rupture leads to an open space between the machines. On the top of the air ducts above the machines, vents are located that will relieve any explosive pressure in this part of the system before it reaches dangerous proportions.

Although the coating of textile served wire with cellulose acetate is being performed successfully, it is felt that the ultimate design of machine or maximum efficiency have not been reached. There is promise in the possibility of using more viscous solutions of cellulose acetate, thus reducing the amount of acetone to be evaporated and recovered. Other solvents than acetone are to be tried. Higher machine speeds may be found possible and operating methods will be developed that will increase the uniformity of the product.