

increase the asbestos addition as the advantages gained do not warrant the additional asbestos. Under these conditions, that point would appear to be between 50 and 75 ppm asbestos. The most effective approach is a combination of asbestos plus polymer. Asbestos with 1.0 ppm C-149 is superior to asbestos with 2.0 ppm C-149. Both combinations, however, are superior to either the asbestos or the C-149 alone. It would be equally easy to show that the combination has economic advantages over either product alone.

In terms of the conditions on a paper machine, this would be equivalent to a heavily loaded sheet. If we take a typical case of 0.50 per cent (5,000 ppm) headbox fiber consistency, this would amount to a 33 per cent (based on stock) filler loading, a not too uncommon occurrence in a highly-filled sheet. The 50-75 ppm of asbestos would be equivalent to 1.5 per cent of the cellulose stock. The combined furnish consistency would be 0.76 per cent.

In a similar series of laboratory tests conducted on clay slurries of 100 ppm kaolin, the results were quite different. Coagulation with either the polymer or alum was only slight. Asbestos at 25 ppm, on the other hand, showed a remarkable ability to clarify the supernate at these low levels of solids. Under such conditions, it was found that it was not necessary to use a combination of asbestos and organic flocculent as the advantages to be gained by this technique were slight and uneconomical. The ability of the asbestos to supply the nuclei for the floc enables it to clarify effectively even at low levels of solids.

If we again use a typical headbox fiber consistency of 0.50 per cent (5,000 ppm), a level of 100 ppm of clay is equivalent to about two per cent filler based on the stock and an asbestos level of 0.5 per cent. Thus, these laboratory data would indicate that on highly-filled sheets a combination of $\frac{1}{2}$ per cent asbestos plus an organic coagulant or two per cent asbestos alone would be optimum, whereas on low levels of filler, only 0.5 per cent asbestos would be required.

To expect a direct relationship between the laboratory results and machine operation would be an oversimplification since a great many other variables enter into the paper-making system. One of these factors is the type of organic flocculent used. For this reason, a wide variety of these products was investigated and in all cases the results were essentially the same. At high levels of kaolin (1,000 ppm), it was found

that the more effective the polymer, the more effective was the combination. The selection of C-149 was made because it was typical and showed a better than average ability to coagulate clays.

Probably the principal overriding factor in the paper machine conditions is the presence of the cellulose fibers themselves. By virtue of the large diameter of the average cellulose fiber, it is not to be expected that an asbestos fiber ($d = 270 \text{ \AA}$) would cause flocculation except perhaps of the very finest fraction. It is known, however, that in the presence of an anionic wood fiber, the cationic asbestos is attracted and becomes attached. Thus, when adding the mineral fillers, the asbestos acts as a coupling agent whereby the filler particles are attracted to the asbestos fibers that are already attached to the cellulose fiber. In the act of attaching itself to an anionic wood fiber, some of the cationic surface charge is lost, thus reducing its capacity to attract and hold filler (or TiO_2) particles. This accounts for the fact that in over 400 mill trials it was found that more asbestos is required for retention than would be indicated in the laboratory tests. Mill trial experience has shown that for filler retention purposes at least one per cent asbestos is required and, preferably, a level of two per cent is desired. Where heavy loading is necessary, and here is used a figure of > 10 per cent ash in the sheet, not less than 2% per cent and, in some cases, as much as 3 to 3% per cent asbestos is recommended.

Laboratory tests have also shown the effects that can be attributed to the presence of various ions. As has been shown elsewhere, the pH is important. The surface charge of the asbestos is enhanced greatly by lowering the pH with an optimum level in the range of pH 4 to pH 5. Sulfate ions have been found to be detrimental, while the trivalent anions, particularly Al, enhance the surface charge. Thus, the very nature of the water in the machine may influence greatly the ability and efficiency of the asbestos.

Mill trial data

The effect of asbestos on the Fourdrinier machine is often quite dramatic. In one trial, the asbestos was added "on top" of the furnish of a 22.5 classified grade. During the trial period, reel samples were taken and analyzed for filler content. The results of these data are shown in Figure 1. As is common in many mill trials, only one per cent asbestos was added until it was evident there would be no machine problems. After



Mr. Woolery is a graduate from the University of California, holding a BS degree in mining engineering. A member of TAPPI, AIME and ASTM, his experience includes 11 years with Union Carbide in both mineral engineering and asbestos application development.

one hour and twenty minutes, this was raised to the recommended two per cent level. It was apparent that the machine was just reaching equilibrium at the end of the trial. By this time, the clay content of the sheet had risen from 8.86 to 10.44 per cent although no additional clay was added to the system. The asbestos level during this period averaged 1.6 per cent for approximately an 80 per cent retention. Even three hours and twenty minutes after the asbestos addition was stopped, the sheet still contained 0.36 per cent asbestos. The increased retention of fillers was also reflected in the opacity gains noted during the trial. In addition, several side benefits were observed. These included a more closed sheet (a decrease in porosity), slight benefits in smoothness, better printability, and significant gains in show-through.

In certain instances, the entire circuit was sampled to study the effects of the asbestos on the furnish components. In one typical case, we were able to obtain these data on a 39-lb. (50-lb. coated) magazine stock. The sampling points were (1) stuff box, (2) headbox, (3) white water, (4) reel, (5) saveall influent, and (6) saveall effluent. In Figure 2, the analyses of the headbox, stuff box and reel are presented. At the beginning of the trial 2.5 per cent asbestos was added and the clay to the stuff box cut from 24 per cent to 17 per cent. This resulted in a reduction of the clay content in the headbox from 42 to 27 per cent. The clay content in the sheet dropped from 16.5 to 13 per cent, which was augmented by a 1.8 per cent asbestos content for a total sheet content of 14.8 per cent filler. In spite of the filler reduction, the machine retention of clay in-