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Experimental tests of a fiber-reinforced cellophane membrane for hemodialysis

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In coil and plate types of artificial kidneys, the present use of cellophane tubing for dialysis presents several problems. Cellophane is made from degenerated cellulose which is a highly fragile material. It must be handled or arranged with extreme caution. Consequently, in the assembling and operating of plate and of coil types of artificial kidneys, the problems of leakage and weak points are a constant hazard.

More specificially, in the coil type of artificial kidney the weak cellophane membrane tubing has a tendency to expand into the pores of the spacer, resulting in an inconstant priming volume, loss of dialysis surface, greater thickness of blood channel, and results in variation in rates of urea clearance. Furthermore, the possibility of lowering coil resistance, by using wider tubing and therefore larger cross-sectional area, is limited in the case of cellophane. Wider cellophane tubes can be made only at the cost of increased membrane thickness and therefore reduced mass transfer.

In order to solve the problems associated with the use of cellophane it is necessary to improve the physical properties of the membrane but at the same time not to decrease the mass transfer characteristics. This report presents the evaluation of a fiber-reinforced cellophane membrane.† The membrane was tested for physical strength and urea clearance to discover whether or not a fibrous reinforcement could solve the problem of membrane weakness without impairing mass transfer.

Material and Methods

Membrane. The membrane used in this study was a cellophane membrane supported by a fibrous matting‡ (*Fig. 1*). In the manufacturing process a tubular sheet of the cellulose fiber matting is coated on the outside with degenerated cellulose. The degenerated cellulose then diffuses through the fibrous reinforcement and effectively impregnates all porous

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† *Courtesy of the Union Carbide Corporation, Food Products Division, Chicago, Illinois.*
‡ *Manufactured by C. H. Dexter & Sons, Windsor Locks, Connecticut.*

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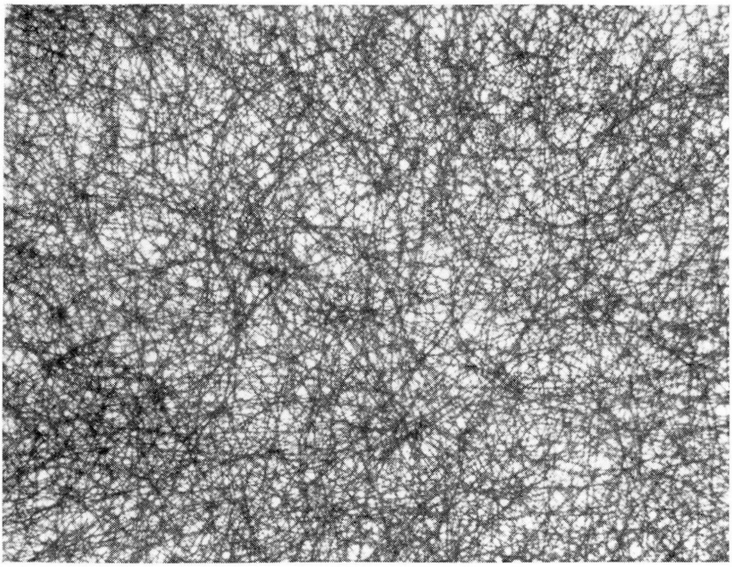

Fig. 1. Closeup photograph of the fibrous cellulose sheet before coating regenerated cellulose over it, showing the structure of the fibrous backing. Magnification X10.

spaces. This membrane will be referred to in this report as reinforced cellophane tubing. It is available in various flat widths and in slightly different thicknesses as shown in *Table 1*. *Table 2* shows the specifications for regular cellophane tubing (*Fig. 2*).

Physical strength tests. Two tests were made to determine the physical strength of the reinforced cellophane membrane. First, the maximum load capacity of the membrane was measured. In this test a short rectangular strip was cut from the membrane tubing both with and against the direction of flow. The length of this strip was 5.08 cm, and measurements of the maximum load capacity were made for several different widths of strip. The strip was wetted, secured between the jaws of an Instron Tensile Testing Instrument,* and kept in a wetted state for the duration of the test. A load, or stress, was applied to the membrane strip by slowly pulling the jaws of the tester apart at a known rate, namely 5.08 cm per minute. This load was recorded† as a function of time. The maximum load capacity was reached when the strip ruptured.

The second test performed was a modification of the first and is commonly referred to as stress-relaxation. The preparations were exactly the same as those for the first test. However, the stress applied to the membrane

* *Model Type TT-C, Instron Engineeering Corporation, Quincy, Massachusetts.*

† *Speedomax Type 6 High-Speed Graphic Recorder, Leeds and Northrup Company, Philadelphia, Pennsylvania.*

Table 1.—*Specifications of reinforced cellophane tubing (Union Carbide Corporation)*

Casing size	Average flat width, in.	Normal thickness, mils
⅘	2.20	3.45
1	2.70*	3.45
2, 20	3.24	3.45
2½, 30, 31, 33	3.80	3.45
4, 40, 41, 43	4.36	3.45
5	4.58	3.45
5N	4.93	3.45
6M	5.26	3.45
6S, 60	5.48	3.45
6½	5.64	3.55
7	5.93	3.55
8	6.36	3.55
9, 90	6.76	3.55
10	7.48	3.65
11	8.16	3.65
12	9.06	3.65

* Used for urea clearance test.

Table 2.—*Tubing specifications of regular cellophane (seamless regenerated cellulose, viscose process, Union Carbide Corporation)*

Dialysis tubing, normal size	Flat width (av.), in.	Diameter (av.), in.	Wall thickness (av.), in.	Standard roll size (random length, ft.)
8	0.4	0.25	0.0020	100 (1,500)
20	1.0	0.64	0.0008	100 (1,000)
27	1.3	0.83	0.0010	100 (1,000)
36	1.7*	1.08	0.0010	100 (1,000)
1⅞	3.0	1.91	0.0016	50 (500)
3¼	4.9	3.12	0.0035	50 (500)

* Used for urea clearance test.

strip was stopped at a specified value before rupture occurred. The stress was again recorded as a function of time throughout the entire test. After the forced stress was stopped, there was no elongation of the membrane strip except that from relaxation of the cellulose itself in the membrane.

Urea clearance test. In this test the urea clearances of the regular and of the reinforced cellophane membranes were determined, using the Kolff four-coil washing machine artificial kidney.[1, 2] Only one of the four coils was used. The membrane in the coil had a total surface area of 0.36 sq meter. This was not the effective area, because allowances were not made for un-

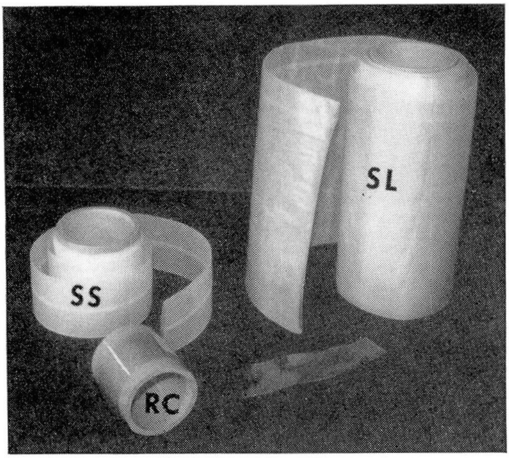

Fig. 2. Photograph showing the largest (SL) and smallest widths (SS) of reinforced cellophane tubing, and the currently used regular cellophane (RC).

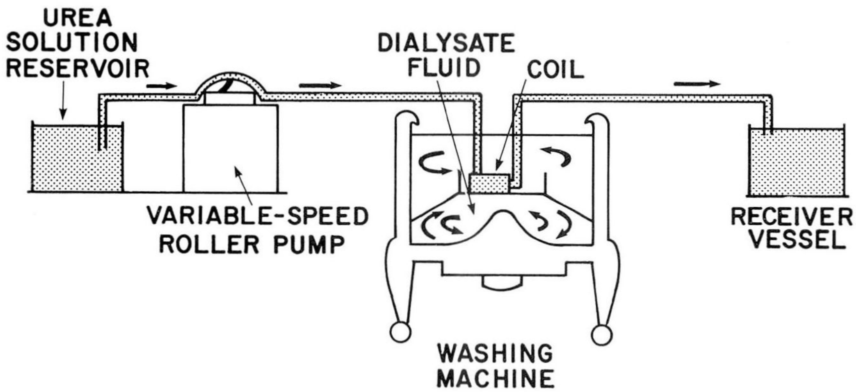

Fig. 3. Schematic illustration of the experimental apparatus used in urea clearance tests.

used dialysis area. Unused dialysis area refers to the membrane surface used in sealing the tubing outlets and the surface covered by the spacer mesh. The regular cellophane tubing was 4.5 cm wide, and the reinforced cellophane tubing was 6.7 cm wide. Together with the plastic spacer screen the tubing was coiled around a hard cylindric polyvinyl chloride core. The outside diameter of the core was 11.43 cm. The pore dimension of the plastic screen* was 4 mm (between parallel fibers). The inlet and outlet coil tubing junctions were sealed with a wire-reinforced plastic tube and a screw clamp. The completed coil was placed in the washing machine and connected to the rest of the experimental apparatus, illustrated schematically in *Figure 3*.

* *Union Carbide Corporation, Plastic Division, Wayne, New Jersey.*

Table 3.—*The maximum load capacity of regular cellophane and of reinforced cellophane*

Type of membrane	Strip sample alignment as to flow	Membrane thickness, in.	Strip sample width, in.	Maximum load capacity at rupture point, kg
Regular cellophane	With	0.0017	0.808	2.4
	Against	0.0017	0.858	2.05
Reinforced cellophane	With	0.0067	0.783	7.9
	Against	0.0067	0.549	5.4

As a substitute for blood a solution of 200 mg urea per 100 ml of tap water was used. The dialysate bath was tap water and was heated initially to 38 C. For a series of flow rates, ranging from 20 to 140 ml per minute, the urea solution was pumped through the coil, letting the flow equilibrate at each setting. At equilibrium a sample was taken of the urea solution at both the coil inlet and the coil outlet. The samples were analyzed* and the urea clearance was calculated by the formula:

$$\text{Urea clearance} = \text{flow rate} \times \text{fractional urea concentration change.}$$

Results

Physical tests. The results of the maximum-load capacity test are shown in *Table 3.* A comparison is made between regular cellophane and reinforced cellophane to illustrate the superior physical strength of the reinforced cellophane membrane.

Figures 4 and 5 show the comparison of stress-relaxation curves for regular cellophane and for reinforced cellophane. The differences in physical strength are shown qualitatively for two different types of stress, time varying or constant.

Urea clearance test. The urea clearances of the regular and of the reinforced cellophane membranes are plotted in *Figure 6* for various flow rates. The urea clearance of the reinforced cellophane membrane reached a plateau of about 25 ml per minute at a flow rate of 100 ml per minute. Further increases in flow rate did not change this urea clearance. The same plateau reached by the regular cellophane membrane corresponded to a urea clearance of 42 ml per minute.

Discussion

While no exact degree of improvement can be obtained from the data presented, it can be accurately said that the physical strength of the rein-

* *Technicon AutoAnalyzer Colorimeter, Model 1, Technicon Instruments Corporation, Chauncey, New York.*

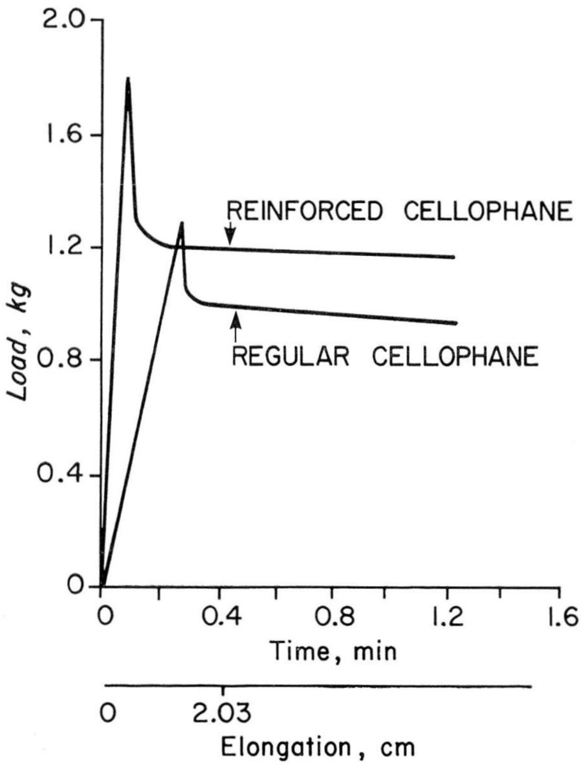

Fig. 4. Graph showing comparison of stress-relaxation of reinforced cellophane and of regular cellophane, with the samples cut in the direction of flow.

forced cellophane membrane is more than twice that of the regular cellophane membrane.

The stress-relaxation curves of the reinforced cellophane, compared to similar curves for regular cellophane, yielded two important pieces of information about the physical properties of the two different membranes. The loading portion of the curve, that is, the part of the curve before the peak, shows that the reinforced cellophane deforms less than does regular cellophane for an identical load. This means that under identical conditions of stress the reinforced membrane will change its physical properties, such as pore size, much less than will the regular cellophane membrane.

The second part of the curve illustrates the behavior of the membrane under constant stress, a situation comparable to that occurring in the coil of an artificial kidney. The reinforced cellophane membrane will deform more slowly, since the fibrous matting inhibits deformation of the cellulose.

The urea clearance of the reinforced cellophane membrane, although

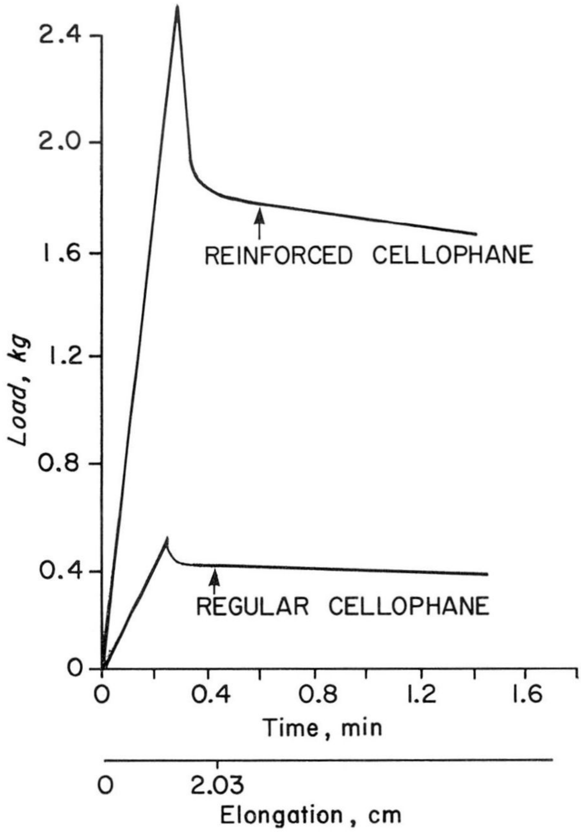

Fig. 5. Graph showing comparison of stress-relaxation of reinforced cellophane and of regular cellophane, with the samples cut against the direction of flow.

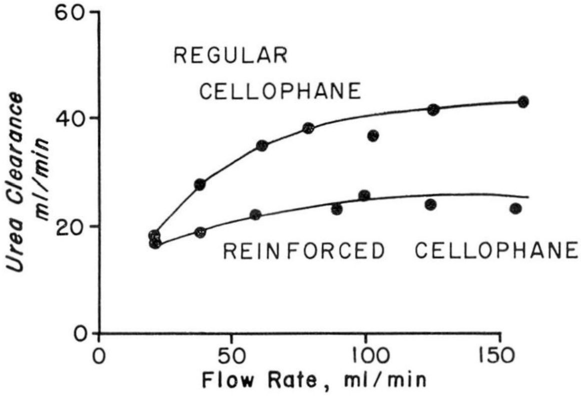

Fig. 6. Graph showing comparison of urea clearance rates of reinforced cellophane and of regular cellophane for various "blood" flow rates.

about 40 percent less than that of the regular cellophane membrane, nevertheless is adequate for the proper functioning of the artificial kidney.

With the superior physical strength of the reinforced cellophane membrane established, and the question of urea clearance answered, the solution to the problems posed in the beginning of this study can be considered. The problem of membrane fragility is considerably lessened, since the reinforced cellophane was proved to be stronger than regular cellophane. The deforming tendencies of regular cellophane and their effects on urea clearance and priming volume can also be reduced by using the stronger reinforced cellophane membrane. In addition, with the reinforced cellophane membrane it may be possible to use spacer screens with larger pores and different construction, since expansion of the membrane into the pores will not be so pronounced as with regular cellophane. This might aid in improving dialysate fluid circulation patterns. Finally, the availability of the reinforced cellophane membrane in various tube widths greatly enhances the possibility of lowering the resistance to flow in the coil type of artificial kidney.

Summary

A new, fiber-reinforced cellophane membrane was tested for physical strength and urea clearance to determine whether or not it might solve various problems, in plate and in coil types of artificial kidneys, now encountered with the use of regular cellophane tubing. The reinforced cellophane membrane was found to be of superior physical strength, but was inferior to the regular cellophane membrane in urea clearance; its use as a hemodialysis membrane, however, is still feasible. The favorable results of the tests suggest that further study of this reinforced cellophane membrane as a possible clinical substitute for the currently used regular cellophane membrane in artificial kidneys is advisable.

References

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