accepted by the separated-"indiscriminate" mothers, since both separated and nonseparated mothers were kept together as one flock except for the short period during which the experimental mothers were separated from their young. Separation of some of these highly gregarious animals had thus influenced the social structure of the herd as a whole, changing the behavior of "control" animals whose early *post partum* experiences had not deliberately been disrupted, but whose environment had been affected in turn by abnormal maternal and filial behavior produced in the experimental members of their group (*4*).

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4. This study was conducted at the Behavior Farm Laboratory of Cornell University and was supported in part by grants from the Josiah Macy, Jr. Foundation and the Ford Foundation. We thank Dr. Howard Liddell, director of the laboratory, and Dr. Helen Blauvelt for advice and aid in planning and in carrying out this study.

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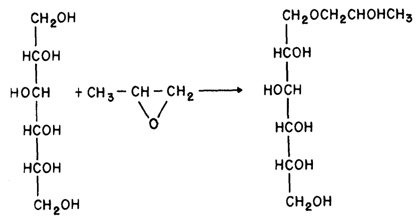
Rigid Urethane Foams Based on Sorbitol Derivatives

Abstract. Present commercial rigid foams are based on polyester raw materials. It has now been demonstrated that certain hydroxyl-terminated polyethers can be used satisfactorily as a major component of rigid urethane foams. These polyethers are hexafunctional materials prepared by reacting propylene oxide with sorbitol.

Commercial rigid urethane foams are prepared at present by reacting a suitable hydroxyl-terminated polyester with tolylene diisocyanate, water, and catalyst. Foaming commences, and the resulting foam is cured under the proper conditions.

Polyesters have been employed in such rigid foam preparations because of their multiple functionality and cross-linking potential. The multiple functionality is ordinarily obtained by the incorporation of glycerol in the polyester, with a branch or side chain arising at each glycerol molecule in the backbone of the polyester chain. In this way, by regulating the glycerol content, it is possible to obtain polyesters of high, moderate, and low degrees of branching. Generally speaking, polyesters used in rigid foams are highly branched, those in flexible foams are unbranched, and those employed in semirigid foams are moderately branched.

By contrast, at the present time, essentially no commercial rigid foams are based on polyethers. It has recently been demonstrated in this laboratory that certain highly functional hydroxyl-terminated polyethers can be used as a major component of rigid urethane foams. These hexafunctional polyethers are prepared by reacting propylene oxide with sorbitol. The addition of the first molecule of propylene oxide to sorbitol can be visualized as follows:



The reaction is carried out at elevated temperature and pressure in the presence of a suitable catalyst. More and more molecules of propylene oxide can be added until there are long chains of proplyene oxide extending from the sites of the original hydroxyl groups of the sorbitol molecule. The initial attack is most heavy on the primary hydroxyls, but after all hydroxyls become secondary the probability of attack at each hydroxyl is perhaps roughly equal to the probability at any other hydroxyl. The final product can be described as a hexafunctional molecule bearing six secondary hydroxyl groups of approximately equal reactivity toward isocyanate. Such products have been prepared with propylene oxide/sorbitol mole ratios of 10/1, 20/1, 40/1, and 80/1. These are pale to colorless free-flowing liquids that are soluble in a variety of solvents.

The molecular weights and approximate hydroxyl numbers of these materials are shown in Table 1.

The compounds of smaller molecular weight have higher hydroxyl numbers and will consequently produce higher concentrations of cross-links in the resulting urethane polymer formed by reaction with tolylene diisocyanate. On the other hand, propylene oxide/sorbitol in the mole ratio of 80/1 produces a much lower concentration of cross-links per unit of mass, and hence might well find use at a suitable concentration in semirigid and flexible foams, as well as in rigid foams.

Table 1. Molecular weights and approximate hydroxyl numbers of products prepared with propylene oxide/sorbitol in various mole ratios. The hydroxyl number is defined as milligrams of potassium hydroxide equivalent to the hydroxyl groups present in 1 gram of compound.

Mole ratio of propylene oxide/ sorbitol	Molecular weight	Hydroxyl number
10/1	760	440
20/1	1340	250
40/1	2500	130
80/1	4830	70

Several of the materials listed in Table 1 have now been used to prepare rigid urethane foams by techniques that are widely known. For example, a foam was formulated from 300 parts (by weight) of 10/1 propylene oxide/sorbitol, 246 parts of tolylene diisocyanate (80/20 isomer ratio), 6.0 parts of water, 1.5 parts of silicone oil, and 0.3 parts of alkaline catalyst. After foaming was substantially complete, the foam was cured for 3 hours at 100°C. The rigid foam produced was white and had a fairly uniform cell size. It had a density of 4.1 lb/ft.^{3} Its compressive strength was 47.8 lb/in.^{2} at 25 percent compression, and 60.1 lb/in.^{2} at 50 percent compression.

The unique property of these new polyether foam ingredients is their high functionality, which causes them to approach the polyesters in cross-linking efficiency. It may also be noted that foams based on polypropylene oxide/sorbitol contain no ester linkages and hence may be more resistant to hydrolytic degradation by dilute acids and alkalis. The high functionality of polypropylene oxide/sorbitol compounds also makes them potentially valuable ingredients in polyurethane coatings and adhesives. One laboratory (*1*) has already observed that the incorporation of sorbitol itself in castor oil/tolylene diisocyanate coatings results in increased coating hardness, speed of cure, tensile strength, and solvent resistance.

This research is being extended at present to an investigation of the incorporation of propylene oxide derivatives of other hexitols in polyurethane foams and coatings.

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