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Steel by Liquid Lithium**

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**August 1979**

**UWFDM-274**

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by Liquid Lithium

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The mass transfer of type 316 stainless steel into liquid lithium is studied in a forced convection loop. Mass loss data are reported for tubular coupons mounted in the maximum temperature zone of the loop. The loop was operated with a steady maximum temperature of 440C and a steady minimum temperature of 250C.

Four sets of coupons were tested simultaneously in parallel channels, at flow velocities of 45, 65, 96, and 136 cm s<sup>-1</sup>. The coupons were located in hydrodynamic entrance flows, with Reynolds numbers  $DV/\nu$  of 3800 to 11400. The position dependence of the mass transfer rate was examined within each set.

After an initial rapid stage of dissolution lasting less than one month, the mass transfer rates decreased and were constant for the remaining 5 months of operation. The mass transfer rates varied strongly with the fluid velocity, indicating that boundary layer diffusion is an important mechanism in the dissolution.

## INTRODUCTION

Liquid metals, because of their nuclear stability, low vapor pressure and high thermal conductivity, are excellent nuclear reactor coolants. Because of its unique ability to breed tritium, liquid lithium is particularly suited as a coolant for D-T fusion reactors requiring tritium in their fuel cycle. Several designs of first-generation fusion reactors (see Powell et al 1975) have specified a liquid lithium coolant contained in type 316 stainless steel.

Since there are few data on the long-term corrosion of stainless steel by lithium, a forced convection loop has been built to study this problem. The loop has been operated under temperature and flow conditions similar to those proposed in the first generation of D-T fusion reactors, to test the effects of velocity, temperature and position on the dissolution of type 316 stainless steel.

## EXPERIMENTAL PROCEDURES

The flow loop, shown schematically in Figure 1, is constructed entirely of type 316 stainless steel. The loop is filled with "low sodium" natural lithium which was hot trapped with titanium at 600C for one week and was then charged to the loop through a 7 micron stainless steel filter. High purity argon is used as a cover gas to protect the lithium from the atmosphere. Typical analyses of the experimental materials are given in Table 1.

Four sets of coupons are tested simultaneously, in parallel channels in an isothermal hot zone of the loop at 440C. The coupons are 2.54cm long with 0.61cm ID and 0.9mm wall thickness. The 16 coupons in

each test section are held together coaxially by split-tube stringers (Figure 2) to form a continuous tubular assembly with the inner wall exposed to the lithium stream.

The lithium enters the test channels from an electromagnetic pump and a manifold, through calibrated electromagnetic flowmeters. The lithium velocities in the four channels are maintained at 45, 65, 96, and 136  $\text{cm s}^{-1}$ ; the corresponding Reynolds numbers  $DV/\nu$  at 440C range from 3800 to 11400. The coupons extend from 4 to 68 diameters downstream from a sharp contraction at the leading edge of the stringer, where the flow area is reduced by a factor of 4.5.

After leaving the test channels, the lithium recombines into one stream, is cooled from 440 to 250C by passing through a counterflow heat exchanger and a radiator, then is reheated to 420C by a return pass through the heat exchanger and to 440C in an electric heater.

At intervals averaging 25 days, the coupons are removed and weighed to determine the mass flux of stainless steel into the lithium. After each weighing, one coupon from each of the 4 sets is replaced by a fresh coupon, and the remaining coupons are mounted in their usual positions. Coupons are replaced starting from the downstream end of the stringer, to minimize interference with mass transfer from the older coupons. The coupons which are not returned to the loop are stored in methanol for future microscopic examination.

## EXPERIMENTAL RESULTS

Typical data on mass loss versus time are shown in Figure 3. The time scale begins with the onset of operation at 440C hot-zone temperature, after a month of calibration tests at lower temperatures.

The data are well fitted by straight lines after the first time interval; the slopes of these lines give the long-time asymptotic mass fluxes. A faster mass loss occurs over the first time interval according to these data (with the calibration period neglected), and is also observed with replacement coupons that start out at the test conditions.

The time pattern of mass loss observed is similar to that found by other workers (Whitlow et al 1979; Tortorelli and DeVan 1979). Tortorelli and DeVan attribute the rapid initial corrosion to depletion of Ni from the outer layer of the stainless steel.

Figure 4 shows the position dependence of the local mass fluxes. Each point is calculated by linear regression of the coupon weighings over a five month interval. The dissolution mass flux decreases initially with  $x/D$  in each test section. This decrease continues until a length Reynolds number  $(x/D)(DV/\nu)$  of  $3 \times 10^5$  is attained; then the mass flux rises abruptly before resuming its downward trend. This behavior suggests that the flow in each test section is initially laminar, or is laminarized by the acceleration through the contraction at  $x/D = 0$ . The abrupt increase in mass flux at  $(xV/\nu) = 3 \times 10^5$  is attributed to the onset or resumption of turbulent flow.

Figure 5 shows the influence of velocity on the mean mass flux,  $\bar{n}$ , between  $x/D = 4$  and 28. This region, comprising the first six coupons of each set, lies upstream of the break points in Figure 4. The data are fitted within 5 percent by the expression

$$\bar{n} = a \sqrt{V} \quad (1)$$

as would be expected if the mass flux were controlled by forced convection in a developing laminar boundary layer.

### DISCUSSION

In these experiments the rate of corrosion of stainless steel by lithium attained a steady value in 3 weeks or less. The long-term steady value is the one of primary interest for nuclear power plant design.

The strong velocity dependence of the long-term dissolution mass flux indicates that convection is an important factor. Furthermore, the  $1/2$  - power velocity dependence in the laminar entrance region is exactly what one would expect if convection were the controlling factor.

The downstream variation of the mass flux is moderated by the cumulative effect of the mass transfer from all upstream surfaces. Therefore, one should not expect, and does not obtain, a flux proportional to  $x^{-.5}$  in the laminar region of the test section.



### Acknowledgments

The authors are grateful to J. H. DeVan and J. E. Strain and the Oak Ridge National Laboratory for their advice and assistance in this study. We also thank the staff of the University of Wisconsin Physical Sciences Laboratory for their work in building and maintaining the equipment, and M. L. Jones for his technical assistance.

This work was funded by the Wisconsin Electric Utilities Research Foundation. Graduate fellowships were provided by the National Science Foundation and the Wisconsin Alumni Research Foundation.

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Table 1. Material Analyses

Type 316 Stainless Steel: analyses by vendor

16.36% Cr	11.75% Ni	2.39% Mo	1.65% Mn
0.63% Si	0.06% C	0.02% P	0.01% S

Lithium: analyses by ORNL

After titanium hot trapping	453 ppm N	-----
After 6 months in loop	50 ppm N	275 ppm O

Titanium: analyses by vendor

40 ppm N	350 ppm O
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Argon: analyses by vendor

10 ppm N	1 ppm O
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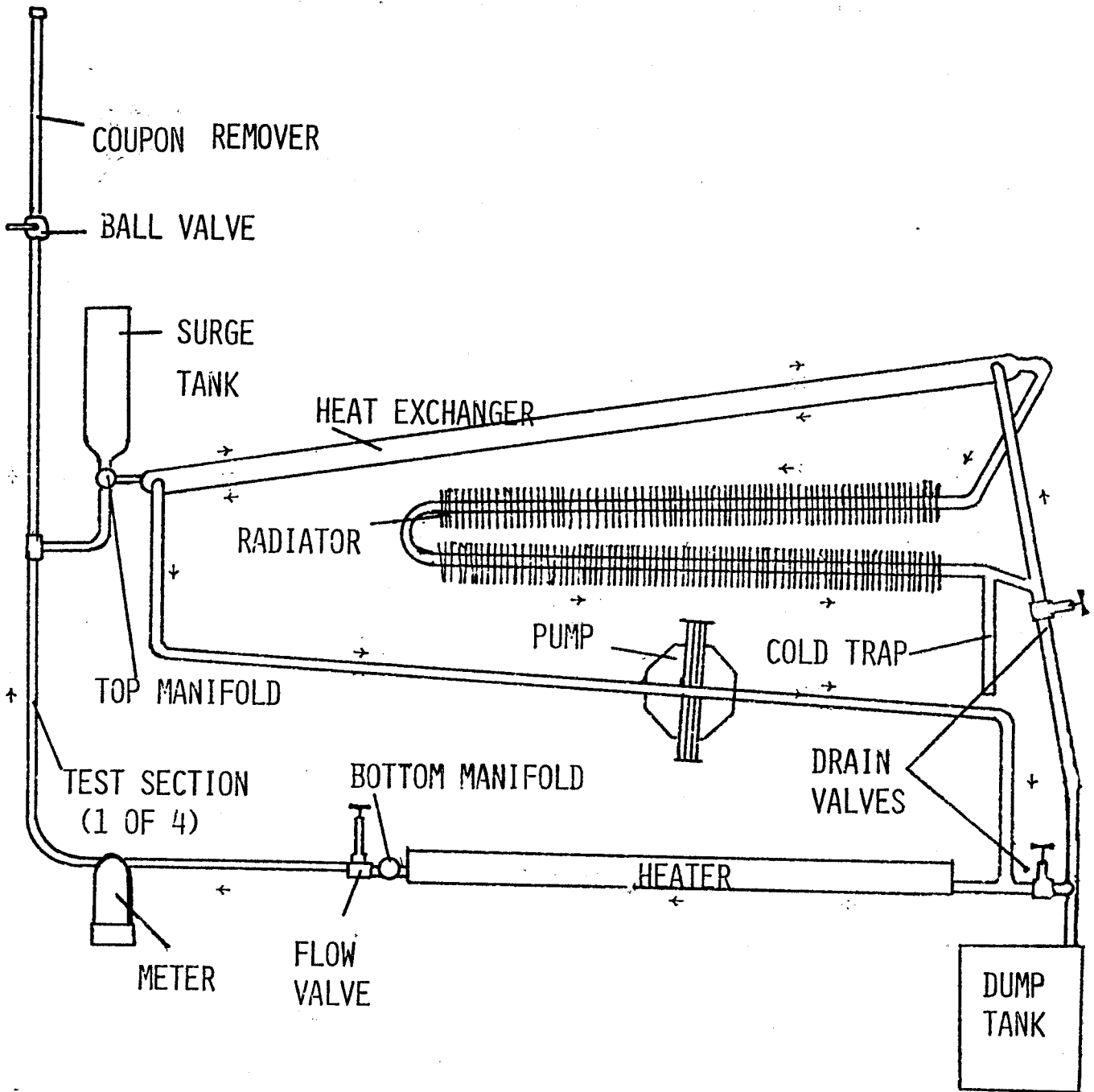


FIGURE 1. Lithium Loop.

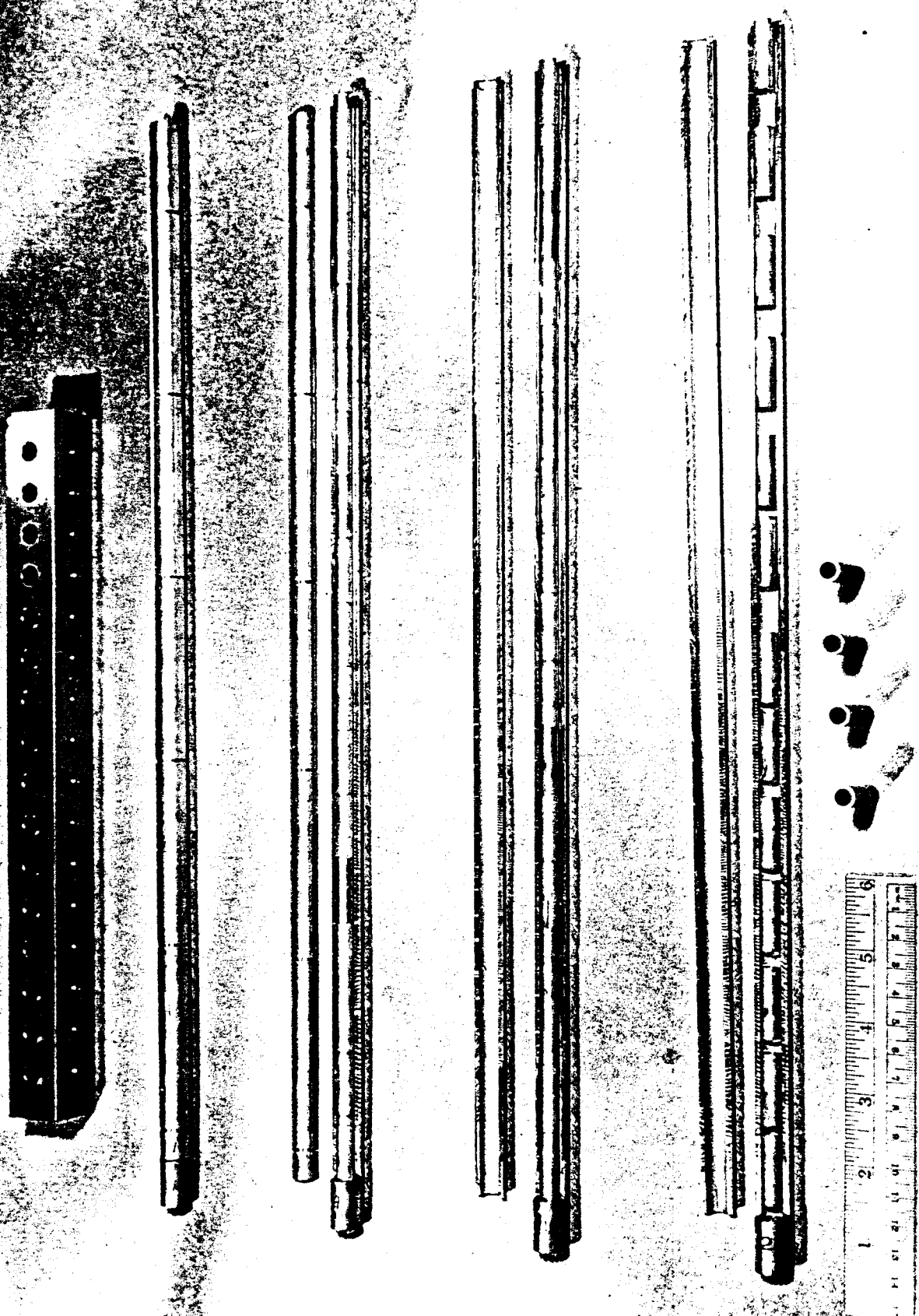


FIGURE 2. Type 316 stainless steel coupons and stringers. Individual coupons are shown in foreground. Fixture in background is used when machine grinding coupons to exact length.

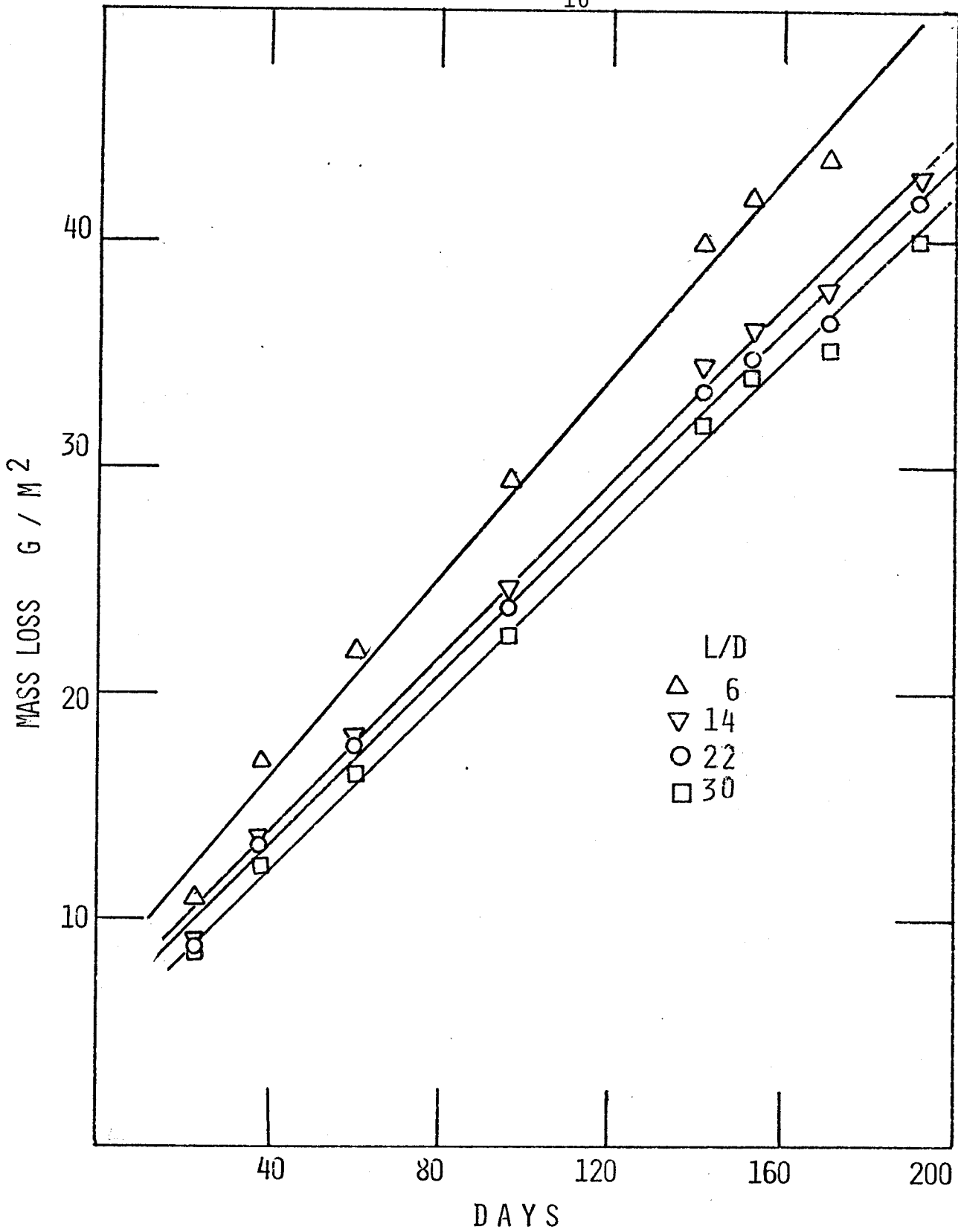
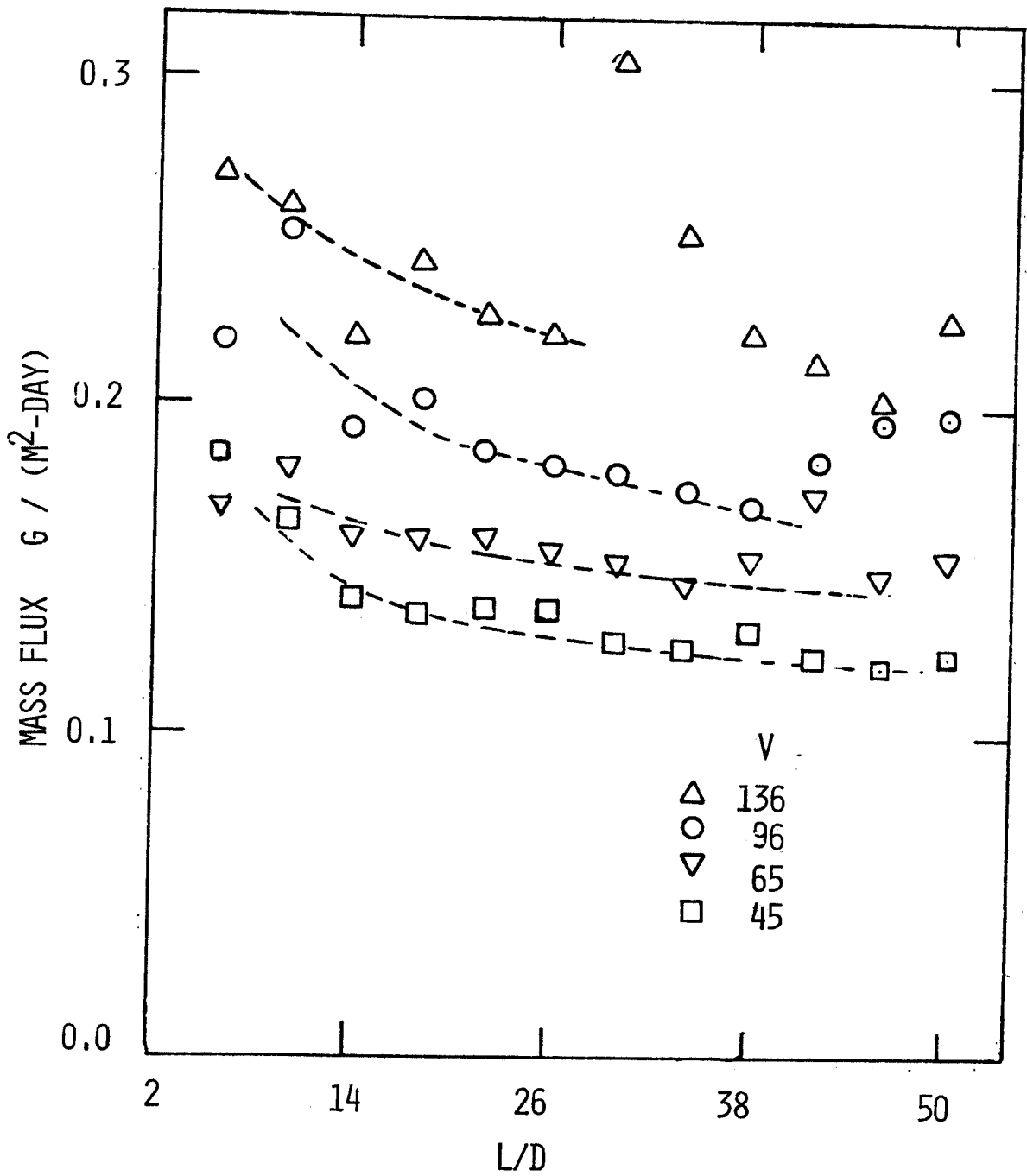


FIGURE 3. Mass loss of type 316 stainless steel in lithium at 440C. Lithium velocity=96 cm s<sup>-1</sup>. DV/v=8100.



**FIGURE 4.** Effect of downstream distance on local mass flux from type 316 stainless steel into lithium at 440C.

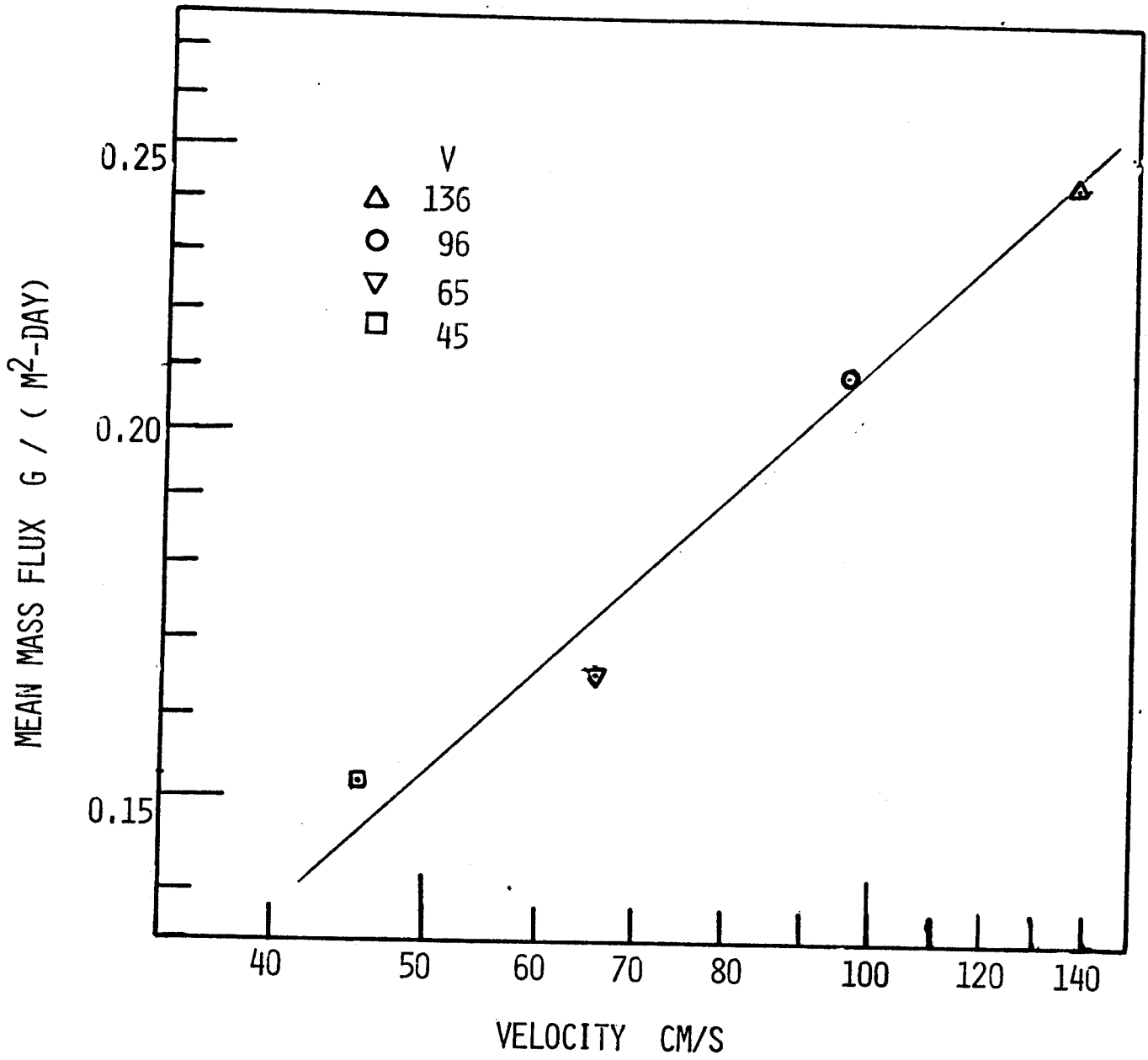


FIGURE 5. Effect of velocity on mean mass flux from type '316 stainless steel into lithium at 440C.  $x/D = 4$  to 28.