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Comparison of D_2O and H_2O Absorption by Acrylic [1]

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Abstract

The rate of absorption of D_2O and H_2O by acrylic and the resultant expansion, have been recorded over a period of 1,177 days at ambient temperature. No difference in the rate of absorption or expansion was discernable within experimental error.

1 Introduction

The rate of absorption of H_2O by acrylic and the subsequent dimensional changes has received considerable study [1]. Unfortunately no independent data could be found regarding the effect of D_2O on acrylic. The acrylic vessel of the Sudbury Neutrino Observatory (SNO) will contain D_2O for a period

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of 5 years (and perhaps longer) and throughout this time will be surrounded by H_2O. Should there be a difference in the rate of absorption of these two liquids by acrylic and a subsequent difference in the expansion of the acrylic, this could induce unacceptable levels of stress in the shell of the vessel.

2 Existing Data

Since the possibility of different rates of expansion of the acrylic is of fundamental importance to the integrity of the acrylic vessel, it was given early consideration by the SNO collaboration, the results of which are summarized below.

In July 1988, W.F. Davidson (NRC) and E.D. Earle (CRL) [2] circulated the results of studies in which they recorded the absorption, by three different sources of acrylic, of H_2O, D_2O and a 2.5% solution of NaCl in H_2O, and the associated dimensional change. "Accelerated" absorption was achieved by immersing the samples in the liquids at temperatures of 66°C for a period of 46 days. The results are summarized in tables 1 and 2 and within the errors are indistinguishable between the three liquids and are in reasonable agreement with the manufacturers published properties. Since it is uncertain whether accelerated absorption of water exactly duplicates the slower water absorption at lower temperatures it was decided to conduct the following tests at ambient temperature both with D_2O and H_2O (for comparison to existing data).

3 Experimental Technique

The tests were conducted according to ASTM D570-88, "Standard Test Method for Water Absorption in Plastics" whereby samples of acrylic are immersed in water and their weight periodically checked. In addition the dimensions of the test samples were recorded at each weighing.

3.1 Preparation of Samples

The acrylic was supplied by Polycast Technology Corp., and is described as their standard UVT formulation. Six test samples were prepared from

Sample ID	Immersion Liquid	Thickness (mm)	$\Delta t/t(\%)$
CY/RO	H_2O	23.42 ± 0.03	0.56 ±0.18
CY/RO	D_2O	23.45 ± 0.03	0.69 ±0.18
CY/RO	H_2O + NaCl	23.37 ± 0.03	1.0034 ±0.18
CY/RO	Blank	23.29 ± 0.03	
Polycast	H_2O	24.38 ± 0.01	0.16 ±0.13
Polycast	H_2O	24.40 ± 0.01	0.25 ±0.13
Polycast	d_2O	24.41 ± 0.02	0.29 ±0.15
Polycast	H_2O + NaCl	24.43 ± 0.01	0.37 ±0.13
Polycast	Blank	24.34 ± 0.03	
Rohm	H_2O	25.64 ± 0.11	1.14 ±0.61
Rohm	D_2O	25.54 ± 0.10	0.75 ±0.56
Rohm	D_2O	25.46 ± 0.10	0.43 ±0.56
Rohm	Blank	25.35 ± 0.10	

Table 1: The results of Davidson and Earle on expansion of acrylic due to liquid absorption.

Sample ID	Dimensions	Uptake by weight
Polycast	4" x 2" x 0.23"	0.22%, 0.21%
Rohm	14cm x 8cm x 0.46cm	0.21%, 0.20%
Rohm and Hass	1.4" x 2.9" x 0.24"	0.18%, 0.18%

Table 2: The results of Davidson and Earle on the absorption of D_2O by acrylic.

this acrylic according to ASTM specifications. The test specimens were 3 inches long by 1 inch wide by 2 inches thick (the thickness of the sheet from which the specimens were taken and the approximate thickness of the shell of the vessel). The machined surfaces of the test specimens were wet polished to an optical finish to remove any surface cracks. Wet polishing was used in order not to raise the temperature of the specimen. The specimens were identified as H1→H3 (for H_2O immersion) and D1→D3 (for D_2O immersion) by scribing in one corner of the sample. This scribe mark was also used as a geometrical reference when making the dimensional measurements. Before the initial weighing of the test specimens they were conditioned by placing them in an oven at 50°C for a period of 24 hours, then allowed to cool in a dissicant.

3.2 Procedure

Immediately after removal from the dissicant the samples were weighed using a Mettler H 34 AR balance, which has a precision of 0.00001gm. These values, shown in table 3, were assumed to represent the weight of the test specimen with no liquid absorbed, and subsequent changes in weight were referred to this value.

Two capped glass jars were filled with approximately 1 liter of either D_2O or H_2O. The test specimens were inserted in the appropriate jar and arranged in such a way that all specimens were immersed and all surfaces exposed to the liquid. The samples were weighed at the appropriate time intervals (1 day, 1 week, 2 weeks etc.)
Weighing consisted of removing the specimen from the liquid, wiping dry with Kim Wipes making 3 weighings and taking the average. It was important to process each sample at the same rate since the weight of the specimen steadily decreased as it sat on the balance and liquid evaporated from its surfaces. Immediately after weighing, the dimensions were recorded using Sylvac electronic calipers with a resolution of 0.01mm. The identification marks on each block were used as a reference for positioning the calipers. Immediately after measurement the specimens were then returned to the liquid, care being taken to ensure that all surfaces of the specimens were exposed to liquid and the sample was positioned in the original manner.

	H1	H2	H3	D1	D2	D3
Weight (gm)						
Initial	115.4727	115.4615	115.5651	115.8687	115.8455	115.7117
Final	117.0397	116.9981	117.1256	117.40600	117.3890	117.2469
% Change	1.36	1.33	1.35	1.33	1.33	1.33
Width (mm)						
Initial	50.79	50.79	50.75	50.80	50.84	50.81
Final	50.91	50.88	50.85	50.93	50.88	50.92
% Change	0.24	0.18	0.20	0.26	0.08	0.22
Thickness (mm)						
Initial	25.20	25.20	25.20	25.28	25.29	25.18
Final	25.26	25.21	25.24	25.30	25.31	25.27
% Change	0.24	0.04	0.16	0.08	0.08	0.36
Length (mm)						
Initial	76.21	76.22	76.21	76.22	76.23	76.19
Final	76.39	76.35	76.39	76.43	76.59	76.45
% Change	0.24	0.17	0.24	0.27	0.47	0.34

Table 3: Initial and final weights and dimensions of the test specimens

The jars of liquid containing the test specimens were stored at ambient temperature, which is estimated to be approximately 23(+2,-4)°C over the period of the tests. This is a deviation from the ASME specification of ±1°C, but since we are interested in the relative behavior of D_2O and H_2O and all specimens underwent the same temperature fluctuations it is considered that these small fluctuations in temperature are not significant for the purposes of the present test. No attempt was made to control the temperature or to record the actual specimen temperature at the time the data were recorded.

4 Results:

The average percentage increase in weight for the three specimens in D_2O and H_2O as a function of time is shown in figure 1.

The specimens are approximately 70% saturated, (note that acrylic is considered fully saturated when its weight has increased by approximately 2%). To illustrate this, figure 2 shows the percentage increase in the weight of tensile test specimens (ASTM Designation D638-82a) when immersed in water at 60°C. Since these samples are much thinner (0.125 inches) and the water temperature higher, the rate of absorption of water is greatly increased. Saturation of the specimen at approximately 2% can be clearly seen.

The average weight increase for the specimen immersed in H_2O is 1.346% ± 0.020% and for D_2O, 1.329% ± 0.003%. The errors in the measurement are dominated by systematic errors associated with how reproducibly the samples were dried and the length of time the specimens were exposed to the air (duration of measurement). The weight of the sample decreased exponentially as it sat on the balance pan, falling by approximately 0.0025% in 10 minutes as can be seen in figure 3.

To obtain a value of the uncertainty associated with drying the specimen, one specimen was removed from the liquid, weighed three times, replaced in the liquid for 1 minute, then removed, dryed and weighed again. This was repeated five times. Plotting the average weight as a function of time produced

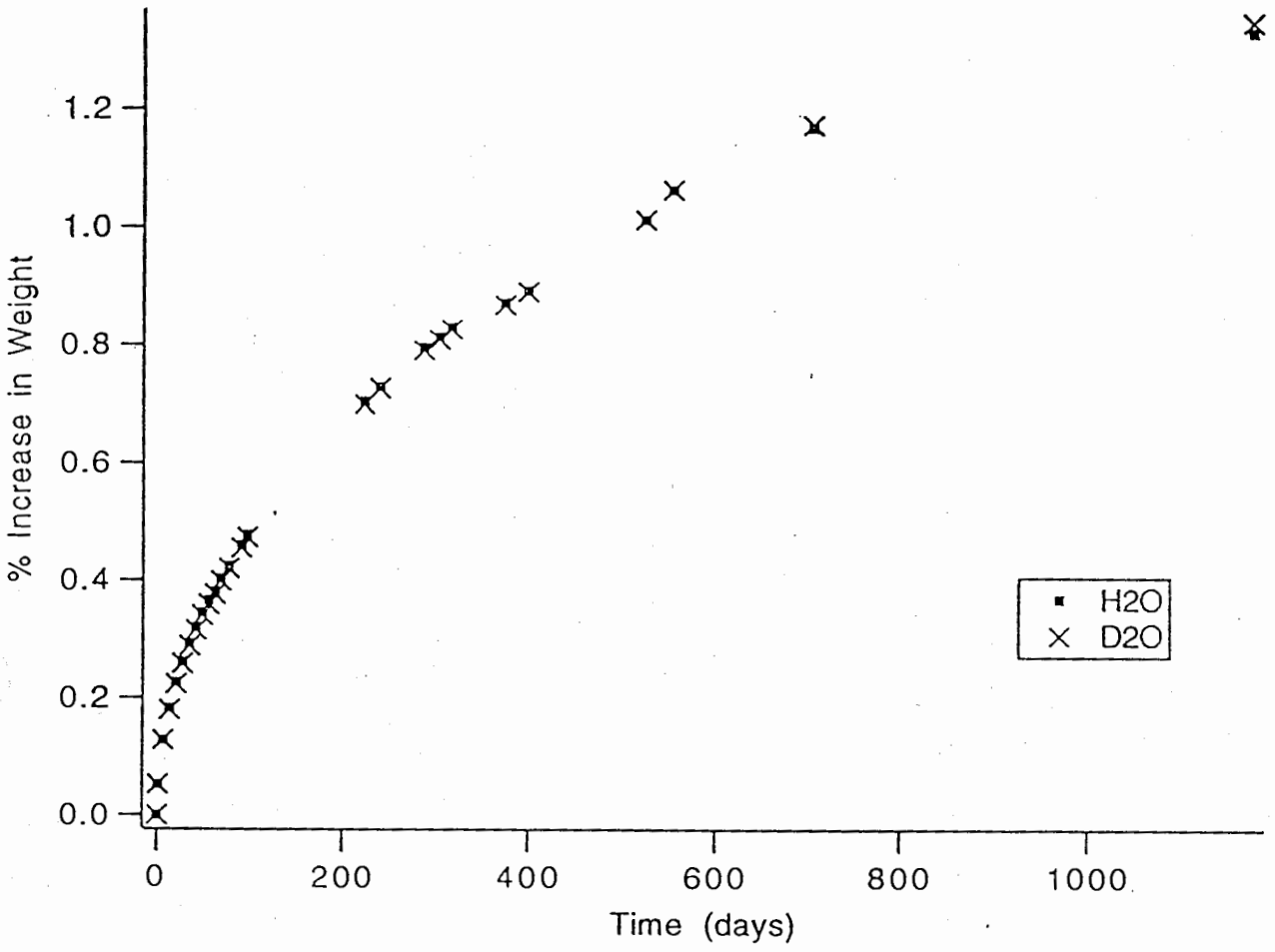

Figure 1: The average percentage increase in weight for the test specimens. The dominant errors are systematic and do not show on the scale used.

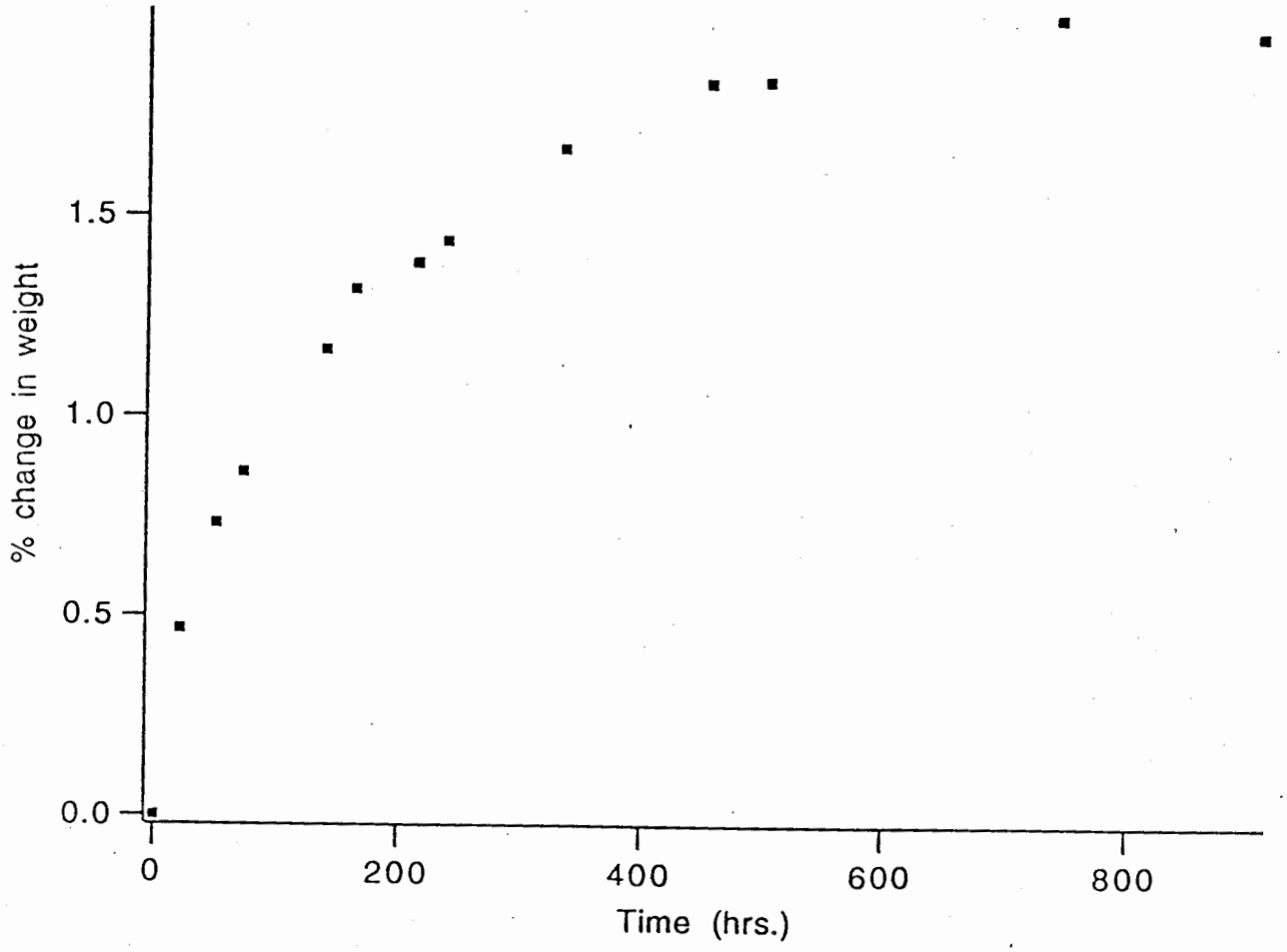

Figure 2: The percentage increase in weight for tensile test specimens immersed in water at 60°C. Saturation can be seen to occur at approximately 2%.

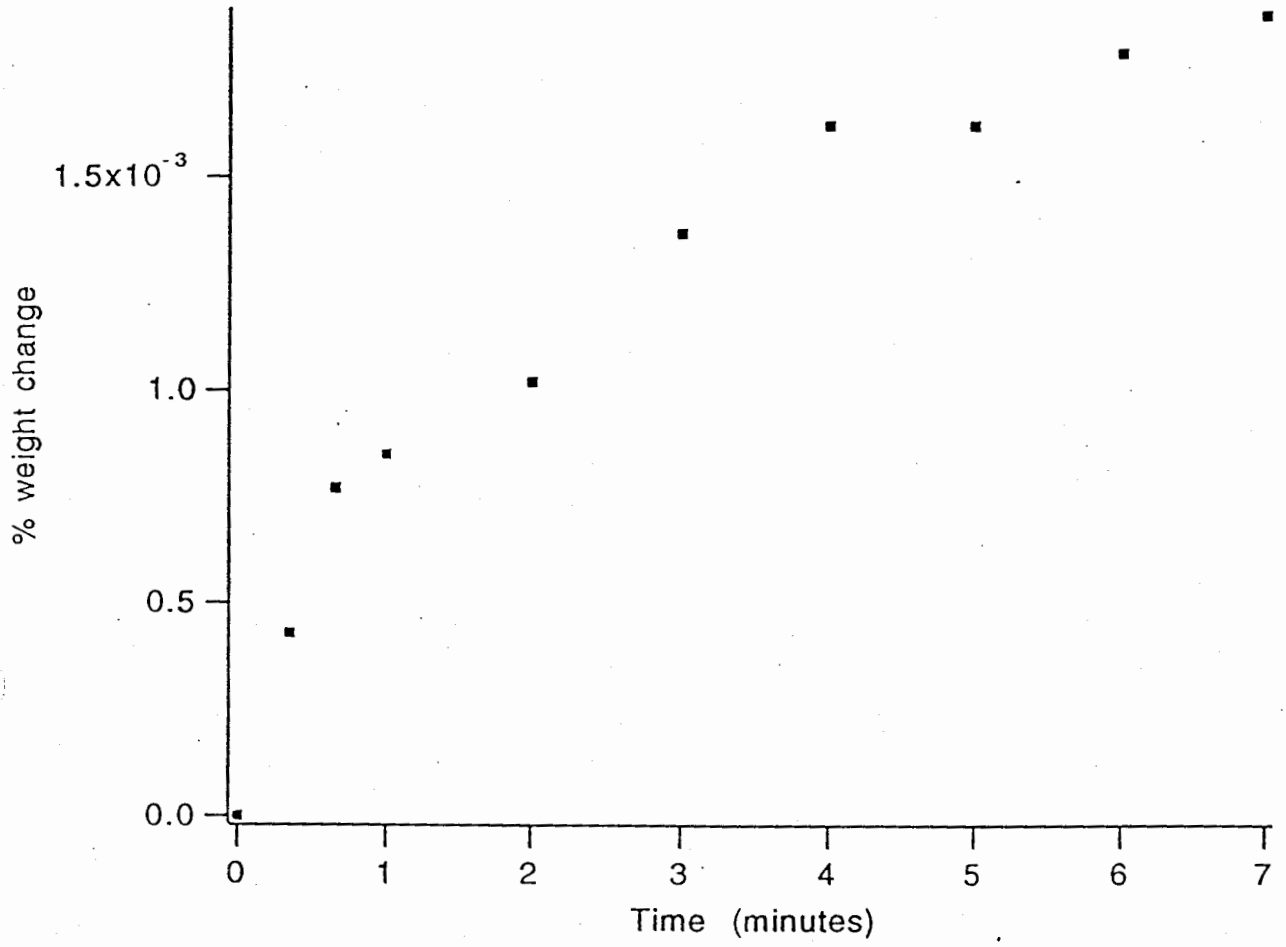

Figure 3: The decrease in weight as a function of time for a test specimen after it has been removed from the liquid.

a curve essentially identical to that of figure 3, showing that desorption, not reproducibility of wiping the sample dry is the dominant systematic error. The dimensional changes of the specimens are given in table 3. To investigate if the errors are associated with the failure to reproducibly position the calipers each time a measurement was made, a set of measurements were made using precisely scribed guide lines to position the calipers. Ten measurement were made for each dimension, yielding the results; length 76.40 $\pm$0.03, width 50.92 $\pm$ 0.01, thickness 25.34 $\pm$ 0.02. Measuring the same block at a different location and using only the block ID mark for positioning, yielded 76.42 $\pm$ 0.02, 50.96 $\pm$ 0.02. The difference is insignificant and suggests that the measurement technique is incapable of achieving the accrucy desired.

If one considers the change in width-thickness-length product (effectively a change in volume) then the average percentage change for D_2O is 0.72$\pm$0.14 and for H_2O 0.57$\pm$0.14. Within the errors associated with the measurements there is no difference in the expansion of the acrylics in the two liquids.

5 Conclusions

The rate of absorption for H_2O and D_2O by weight is, within the errors associated with the present data, identical, and for H_2O in agreement with existing data. It is the dimensional change which is the primary concern since this could lead to stress developing in the acrylic. Again, within statistics there is no difference in the dimensional change due to immersion in D_2O or H_2O. This result is in agreement with the findings of Davidson and Earle, although both data sets have significant errors associated with them.
For the sake of argument let us assume that the numbers represent a real difference. In this case difference in the average linear expansion between D_2O and H_2O (the strain, ΔL/L), is 0.05%. Since the modulus of acrylic is 4x10^{5}psi, then the stress developed due to the differential expansion is approximately 200psi. This on its own is tolerable, although in conjunction with other stresses found in the vessel may prove to be a concern.
The dimensional errors associated with the present work are large. If the question of stress is still a concern it is suggested that a clearer measure of

possible stress could be obtained by exposing a sheet of acrylic to D_2O on one side and H_2O on the other side and looking for distortion of the sheet. This would provide a very sensitive measurement of any difference in expansion due to absorption of the two liquids.

References

[1] Plots of water absorption by various grades of acrylic are available from suppliers such as **Rohm**, (Darmstadt, Germany) or **Polycast**, (Connecticut, USA).

[2] "D_2O Absorption in Acrylic", W.F. Davidson and E.D. Earle, July, 1988, (Unpublished).