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Solar Energy Systems--Standards for Rubber Hose

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ABSTRACT

A study of commercial rubber hose was made to develop standards for hose used in solar energy systems. Twelve hoses were evaluated by cycling between temperatures of about 100°C and temperatures as low as -40°C during a period of about seven months. Laboratory tests for bursting strength, compatibility with metals, compression set, ozone resistance, and water vapor transmission were also made.

The results of this study and tests are presented. Based on these findings, a standard for rubber hose used in solar energy systems is proposed.

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1. INTRODUCTION

1.1 BACKGROUND

Rubber hose is used extensively in solar energy systems to connect solar collectors to manifolds and to connect other components in these systems. It is a vital link since failure of a hose makes the system inoperable until replaced. Hose has several advantages for making these connections; namely,

(1) Rubber hose is flexible and thereby easily accommodates some misalignment of components to be connected.

(2) Rubber hose does not place high stresses on the components to be connected.

(3) Rubber hose absorbs vibration arising from pumps, motors, etc.

(4) Rubber hose dampens sound transmission and thereby makes a quieter operating system.

(5) Rubber hose is economical to use.

On the negative side, rubber hose has the following disadvantages:

(1) Leakage at the hose connections frequently occurs.

(2) The life expectancy of rubber hose in the severe environment of solar energy systems is uncertain. Temperatures range from midday summer temperatures near 100°C and cold winter temperatures of -40°C in some locations. Ozone and atmospheric pollutants are other environmental factors.

(3) Maintenance and replacement of rubber hose between the collectors and manifolds are generally difficult and costly.

(4) Rubber hose may not be compatible with the fluid used for heat transfer or the materials to which it is connected.

(5) Rubber hose is not suitable for use above certain temperatures; these temperatures depend on the type of rubber and reinforcement in the hose.

Thus, there is need for development of standards to overcome these disadvantages and to capitalize on the advantages of using rubber hose. Some standards exist for rubber hose used in specific industries; for example, automotive, food, petroleum and railroad. Generally, these standards are not suitable for hose used in solar energy systems, primarily from the aspect of durability under the severe conditions encountered. Some standards for testing hose are applicable; for example, ASTM D 380 Standard Methods for Testing Rubber Hose [1].[1]

ASTM D 3832, Standard Specification for Rubber Seals Contacting Liquids in Solar Energy Systems, is also helpful in developing a standard for rubber hose. This standard is based on a study of rubber seals for solar energy systems reported in NBSIR 77-1437 [2].

1.2 OBJECTIVES

This study had the following objectives:

(1) To identify performance requirements for rubber hose used in solar energy systems

(2) To identify and assess existing test methods for rubber hose and modify the methods or develop new methods as needed.

(3) To evaluate commercially available hose in the laboratory and obtain data needed to recommend specific requirements and tests.

(4) To prepare draft standards for rubber hose for consideration by ASTM as consensus standards.

2. PROBLEM ASSESSMENT

2.1 PERFORMANCE REQUIREMENTS

The primary function of rubber hose used in solar energy systems is to transport the heat transfer fluids between components without leakage. The hose must perform this function when initially installed and after long term exposure to service conditions. In particular, hose should resist deterioration resulting from exposure to elevate temperatures, air, ozone, air pollutants such as oxides of nitrogen and sulfur, heat transfer fluid, etc. The hose should be functional at high operating temperatures and low night temperatures in winter. The hose should not contaminate the heat transfer fluid or corrode the materials to which it is connected.

2.2 PROPERTIES

The following properties are important to assess the quality of materials and performance:

2.2.1 Tensile strength and ultimate elongation of the inner liner and outer rubber cover are properties conventionally used to assess quality

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[1] Numbers in brackets refer to references in the Bibliography at the end of this report.

of rubber vulcanizates. Ultimate elongation is particularly important since failure occurs in any part of the hose where the ultimate elongation is exceeded during flexing.

2.2.2 Flexibility at low temperatures is essential to withstand low winter temperatures without failure.

2.2.3 Fluid compatibility is essential to prevent excessive swelling and degradation of the inner tube. It is assessed by measuring the change in volume, tensile strength, ultimate elongation and hardness resulting from immersion in the fluid.

2.2.4 Resistance to air aging is needed for a long service life. It is assessed by determining the tensile strength before and after conditioning the inner tube and outer rubber cover at elevated temperatures for a specified time. The change in these properties can provide an estimate of the expected life of the rubber portions of the hose [3].

2.2.5 Resistance to ozone is essential for the rubber cover. Small amounts of ozone in the atmosphere cause the rubber cover to crack and subsequently the hose to fail. This phenomenon is distinct from the oxidation in air at elevated temperatures noted in 2.2.4.

2.2.6 Vapor transmission of the hose should be low to minimize loss of heat transfer fluid through the walls of the hose in service and to maintain an efficient system and operation.

2.2.7 Compression set of the hose assesses effectiveness of clamps in preventing leakage at the end connections.

2.2.8 Bursting pressure must be adequate to withstand the fluid pressures in the system and to provide an adequate margin of safety.

2.2.9 Reinforcement fiber is the component of a hose that mainly determines the bursting pressure. The fiber should not be affected by the heat transfer fluid at service temperatures.

2.3 TESTS

Table 1 lists ASTM tests available for assessing some of the properties mentioned in 2.2. Tests for the other properties are described in the next section on laboratory studies.

3. LABORATORY STUDIES

3.1 MATERIALS

Eleven commercial rubber hoses and one polytetrafluorethylene (PTFE) hose with stainless steel fibrous braid were included in the laboratory study. These hoses were not designed for use in solar energy systems.

Table 1. ASTM Standards Applicable for Testing Hose [1]

D 380	Methods for Testing Rubber Hose
D 395[a]	Test for Rubber Property - Compression Set
D 412	Test for Rubber Properties in Tension
D 471	Test for Rubber Properties - Effect of Liquids
D 573	Test for Rubber Deterioration by Heating in Air Oven
D 1149[b]	Test for Rubber Deterioration - Surface Ozone Cracking in a Chamber (Flat Specimen)
D 1349	Rubber - Standard Temperatures and Atmospheres for Testing and Conditioning
D 2769[c]	Method of Testing Rubber Hose Used for Liquified Petroleum Gas - Extractable Material and Vapor Transmission

[a] Requires modification of compression assembly and specimen.

[b] Requires modification of specimen.

[c] Requires modification of testing conditions and procedure.

The hoses were made by seven manufacturers from the following types of rubber:

CR[2] Chloroprene rubber (neoprene)

EPDM Terpolymer of ethylene, propylene, and a diene

VMQ Silicone rubber having both methyl and vinyl groups on the polymer chain.

The type of reinforcement fiber used in the hoses was not obtained for some hoses, but it appeared that rayon was used in the EPDM hoses. The VMQ hoses had fiber glass or aramid fiber reinforcement.

There were in the study one CR hose, seven EPDM hoses and three VMQ hoses. All hoses had a nominal 16 mm (5/8 in) bore, except one EPDM hose which had a nominal 20 mm (3/4 in) bore. A high resilience EPDM hose was received near the end of the study. The only tests made on this hose were compression set, water vapor transmission, and bursting strength.

3.2 EVALUATION OF HOSE PERFORMANCE

The main part of the study consisted of developing an apparatus for assessing performance of rubber hose and circulating a glycol water mixture through the twelve hoses for a period of more than seven months, cycling the temperature of the fluid from about 100°C to as low as -40°C.

3.2.1 Apparatus

The apparatus consisted essentially of two circulating systems mounted in an enclosure. One system was constructed of steel and stainless steel. The other system was constructed of brass and copper.

A schematic diagram of the circulatory system is shown in Figure 1. It consists of two manifolds between which the 16-mm hoses are connected in the form of a loop. Each loop consists of two specimens of the same hose; each specimen is about 350 mm in length. One specimen is connected to the inlet manifold and the other is connected to the outlet manifold. The specimens are joined at the other end with a U-shaped fitting to which a mass is fastened. The fitting and mass exert a force of about 30 N with steel fittings and about 25 N with copper fittings. Four types of clamps connect the two specimens to the manifolds and U-fitting; namely, a banded clamp (C-1), a screw clamp (C-3), a screw clamp with internal band (C-4), and a plain clamp employing a round-head machine screw and square nut for clamping (C-2). The two screw clamps connected the hose specimens to the manifold, and the banded and plain clamp connected them to the U-fittings.

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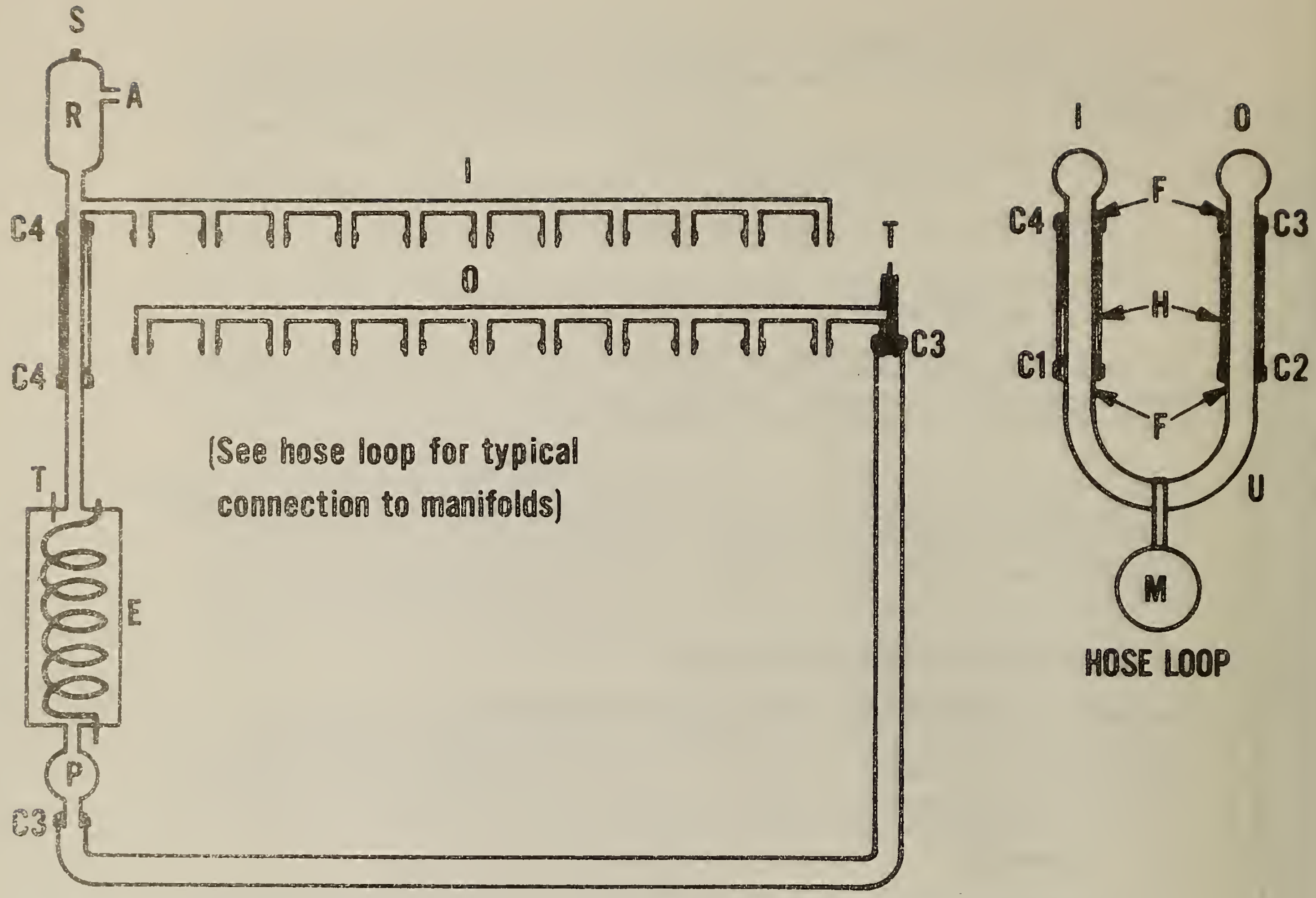
[2] ASTM D1418-77 designations for rubbers [1].



A - Air supply connection
C - Hose clamps (see text for types)
E - Heat exchanger
F - Hose nipples, 16 mm O.D.
H - Hose specimens, 350 mm
I - Inlet manifold
O - Outlet manifold
M - Suspended mass
P - Pump
R - Reservoir
S - Supply plug
T - Thermocouples
U - U fitting

Figure 1. Schematic of circulatory system

The inlet manifold is connected to a heat exchanger with the 20-mm hose. The outlet manifold is connected to the input of a centrifugal pump. The output of the pump is directly connected to the heat exchanger. The heat exchanger consists of a coil of 6.35-mm tubing about 3 m in length brazed or welded into a cylindrical vessel having a capacity of about 1100 cm^3. For heating, steam is passed through the coil. For cooling, chilled water or alcohol cooled with liquid nitrogen is passed through the coil. A reservoir pressurized with laboratory air supply is connected to the inlet manifold.

Thermocouples are inserted into the heat exchanger, the outlet manifold, in the alcohol bath, and on the copper steam line, which is also used for the chilled water.

3.2.2 Procedure

The assembled circulatory system was filled with ethylene glycol-water mixture containing 55 percent glycol by volume. The system was evacuated several times during the filling operation to remove all air except that in the reservoir. The system was evacuated through the reservoir. If air was not removed, fluid flow was restricted through one or more hose loops. About 3500 cm^3 of fluid was required to fill the brass and copper system and about 4000 cm^3 was required to fill the steel system. After the system was filled with fluid, the reservoir was pressurized with air at 125 to 150 kPa (laboratory line pressure) and the air supply was closed during heating. The air supply remained open during cooling.

The pump was started and steam was passed through the heat exchanger. When the temperature of the circulating fluid reached 100°C, the flow was regulated to maintain this temperature within 2°C. The pressure increased about 100 kPa when the temperature was raised. Monday through Friday the temperature was reduced once a day by circulating chilled water (7 ± 1°C) or alcohol chilled with liquid nitrogen through the heat exchanger.[3] Alcohol cooling to about -40°C was used generally twice a week and chilled water cooling to about 10°C on the other 3 days. The cooling cycle took about 4 to 5 hours. Nights and weekends, the temperature was maintained at 100°C.

The system was examined for leaks every work day and clamps were tightened if leakage occurred. The fluid level in the reservoir was measured about twice a week and additional glycol-water mixture added to keep the reservoir about half full. Any hose that failed was replaced and the test was continued by repeating the filling operation above.

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[3] Note: In the early part of the performance test, liquid nitrogen was passed directly through the heat exchanger coil. The fluid surrounding the coil froze and the lowest temperature of fluid in the hoses was about -25°C. The use of chilled alcohol overcame this difficulty and temperatures of -40°C or slightly below were obtained.

Temperatures were measured frequently during the cooling cycle and during heating until the temperature is regulated at 100°C. Temperature was stable at nights and weekends unless a hose failure occurs and fluid was lost, but the pressure decreased due to leakage of air or fluid.

3.2.3 Results

The performance test covered a period of 5183 hours (slightly over 7 months). During almost 82% of this period, the temperature of the fluid was about 100°C. Over 2% of this period was devoted to cooling with liquid nitrogen to temperatures around -25°C during the early part and to -40°C for most of the period. The temperatures during the remaining 16% of the period were between 10 and 25°C, which included the time required to replace hoses, examine the fluid, stop leaks, etc.

Table 2 lists the 12 hoses, their dimensions, the number of specimens that failed, and the number of leaks that occurred at the connections The table combines the results of the two circulatory systems. Thus, there are two clamps of each type, one in each system. Leakage occurs at the connections with all four clamps, but much more frequently with the plain clamp (C2). The lowest number of leaks with the banded clamp (C1) connections is misleading since this clamp is not adjustable and leaks must be stopped with another clamp. The type of clamp does not seem critical since no leak occurred at the connections of hoses 6 and 9. The inner tube of hose 6 vulcanizes to the nipple and is very difficult to remove at the end of test. The lining tears and rubber still adheres to the nipple. Leakage at the connections of the VMQ hoses seems to be related to the bore diameters. Hose 9 is free of leaks at connections and has the smallest bore. The largest bore and greatest number of leaks occurs with hose 10; in fact, this hose fits loosely on the nipple. Surprisingly, the screw clamp with internal band does not seem to be better than the regular screw clamp in preventing leaks with either EPDM or VMQ hoses. Hose 7 with a CR cover hardens and stiffens during test so that it is difficult to stop leaks at the connections. The leaks apparently develop from differential thermal expansion and contraction of the hose and nipple, and the high compression set of the hoses to be discussed later.

Hoses 3, 4, and 5 deteriorated rapidly under the conditions of this test; all of the original specimens failed and in the case of hose 4, some replacement specimens also failed. Two of the four specimens of hose 2 and one specimen of hose 10 also had to be replaced. Possible cause of these failures will be discussed under bursting tests in 3.6.

Substantial loss in fluid occurred that could not be entirely ascribed to leakage at the connections. Measurement of the density of the fluid in the circulatory systems revealed an increase in the glycol concentration from the initial 55 percent to about 70 percent. Thus, it was evident that water vapor was transmitted through the walls of some or all hoses. Separate laboratory tests for water vapor transmission were made which are discussed later.

Table 2. Hose Dimensions, Specimen Failures and Leaks at Clamps

Hose	Type	Bore mm	Wall mm	Specimens No. failed	Leaks at Clamps[a] C1[b]	C2	C3	C4
1[c]	EPDM	15.8	3.9	0	1	14	3	1
2	EPDM	16.2	4.3	2	1	20	5	4
3	EPDM	15.0	4.2	4	0	3	0	1
4	EPDM	15.4	3.8	6	0	4	1	1
5	EPDM	15.4	4.0	4	3	21	1	7
6	EPDM	15.5	5.1	0	0	0	0	0
7[c]	CR[d]	15.1	5.0	0	2	32	1	2
8	VMQ	16.0	4.3	0	0	0	0	4
9	VMQ	15.7	4.8	0	0	0	0	0
10	VMQ	16.9	5.2	1	2	-	4	2
11	PTFE	16.2	1.7	0	e	e	e	e
12	EPDM	19.9	4.6	0	-	-	-	5

[a] C1 - Banded clamp; C2-Plain clamp; C3-Screw clamp; C4-Screw clamp with internal band.

[b] When a leak occurred at a banded connection, a screw clamp was applied adjacent to the band.

[c] Hose was purchased locally. Other hoses were supplied by the manufacturers.

[d] CR cover; type of rubber in lining is not known.

[e] Special fittings are required with the stainless steel braided hose. None of these connections leaked.

3.3 OZONE RESISTANCE

Rubber components in outdoor service frequently crack and fail from ozone in the atmosphere. Therefore, it is important that the outer rubber cover of hose used in solar energy systems have good ozone resistance.

3.3.1 Procedure

The procedures in ASTM D 380 and D 1149 were used. The 12 hoses were exposed in an ozone chamber having an ozone partial pressure of about 100 mPa (100 parts per hundred million at an atmospheric pressure of 100 kPa). The temperature of the chamber was maintained at 40°C. Hose specimens about 350 mm in length were bent in a semicircle and held in place by inserting the ends over aluminum plugs 16 or 19 mm in diameter which were centered 230 mm apart on an aluminum plate. After exposure in the chamber for 166 hours, the specimens were examined for cracks.

3.3.2 Results

Numerous cracks were visible on the edge of the CR (neoprene) hose in tension. No cracking was observed in the other hoses.

3.4 COMPRESSION SET

The ability of a clamp to maintain a seal at a hose connection depends on the clamp maintaining pressure on the hose at both high and low temperatures. Rubber under compression takes a set. Usually, this property is measured on rubber alone. For solar energy systems, the compression set of the composite hose is important. Therefore, modifications in the standard test are necessary.

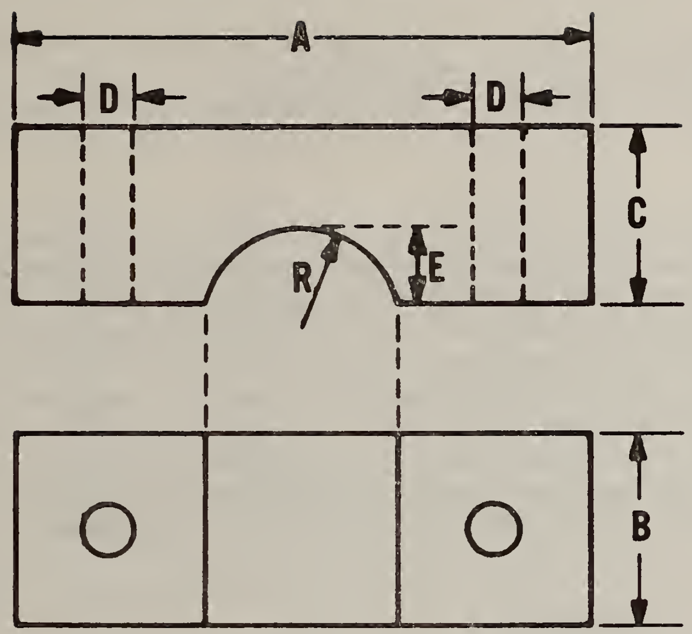
3.4.1 Procedure

ASTM D 395 was modified as follows: A specimen of hose about 50 mm in length was used. An aluminum plug either 16 or 19 mm in diameter was placed in the bore and the outside diameter was measured. The specimen was placed in the compression clamps shown in Figure 2 and the bolts were tightened to compress the walls of the hose 25 percent. The compression apparatus was then placed in an oven at 100 ± 1°C and allowed to remain for either 94, 166 or 190 hours. After removing the apparatus from the oven, the bolts were released and the outside diameter of the hose under the clamps was measured after 30 minutes.

3.4.2 Calculations

Compression set was calculated by the following equation:

$$C = \frac{100\,(A - B)}{A - D}$$



A - 5R, minimum
B - 25 mm
C - 10 mm + R, minimum
D - Holes to clear bolts
E - 3/8 O.D. + 1/8 I.D. of hose, maximum
R - 1/2 O.D. of hose, minimum

Figure 2. Compression clamp (two required)

where C = compression set in percent of compression

A = initial outside diameter of hose with plug

B = outside diameter of hose with plug after recovery

D = outside diameter of hose with plug during compression.

3.4.3 Results

At the end of the period in the oven, the bolts in the apparatus having a CR or EPDM specimen were loose indicating 100 percent compression set. There was no recovery during the 30-minute cooling period, as can be seen from the results in Table 3. The VMQ hoses 8 and 9 had high set, but there was still some compression stress on the hose when they were removed from the oven in the 96 h and 166 h tests. VMQ hose 10 was the only one with low compression set. A high resilience EPDM hose was received from one of the manufacturers after the performance test was completed. This hose was under considerable compression stress when removed from the oven, and was comparable to the VMQ hoses in compression set.

3.5 WATER VAPOR TRANSMISSION

Since the performance test indicated water vapor transmission through the walls of some or all of the hoses, a separate test for this property was made. Since there is no standard method at the present time, the following method was used.

3.5.1 Procedure

Hose specimens about 350 mm in length were used. Metal plugs either 16 or 19 mm in diameter were inserted in one end of the hoses, and clamped with a screw clamp. The hoses were filled to about 80 percent of their capacity with water and the other end plugged so that the distance between the metal plugs was 300 mm. Screw clamps were then fastened to this end. The masses of the assembled hoses and of equivalent lengths of hose used as blanks were determined. The two sets of hoses were placed in an oven at 100 $\pm$ 1°C. The masses of the hose were determined daily except on weekends. The test was terminated after seven days. After the oven test for water vapor transmission was completed, the metal plugs were examined for corrosion. In tests 2 and 3, aluminum plugs were used in both ends. In test 1, steel plugs were used in one end and on the other end brass plugs were used in the nominal 16-mm hoses and a copper plug was used in the nominal 20-mm hose. In test 3 an ethylene glycol-water mixture was used containing equal masses of each. The rate of water vapor transmission was determined by deducting the loss in mass of the "blank" hose from the loss in mass of the assembled hose containing fluid.

Table 3. Compression Set

Hose	Type	Compression Set at 100°C - Percent		
		94 h	166 h	190 h
1	EPDM	100+	100+	100+
2	EPDM	100+	100+	100+
3	EPDM	100+	100+	100+
4	EPDM	100+	100+	100+
5	EPDM	100+	100+	100+
6	EPDM	100+	96	100+
7	CR	93	100+	100+
8	VMQ	99	84	100+
9	VMQ	39	72	100+
10	VMQ	5	32	33
11	PTFE	test is not applicable		
12	EPDM	100+	100+	100+
13[a]	EPDM	-	87	-

+ Compression set is over 100 percent.

[a] Hose received after performance test on other hoses was completed.

3.5.2 Results

The results of the water vapor transmission tests are given in Table 4. The lowest transmission rate occurs with hose 11 (PTFE). The highest rates occur with the VMQ hoses. The ethylene glycol-water mixture in these hoses in test 3 increases substantially in density, confirming the experience in the performance test. The transmission rate for EPDM hoses is generally less than 20 percent of that for the VMQ hoses, and the increase in density of glycol-water mixture in EPDM hoses is about 15 percent of that in VMQ hoses.

The condition of the metal plugs at the end of tests 1 and 2 is given in Table 5. Hose 10 causes pitting corrosion of the aluminum plugs, and the VMQ hoses 8, 9 and 10 cause corrosion of the steel plugs. EPDM hoses 2 and 6 cause slight corrosion of the steel plugs. The metal plugs in the other hoses range from clean to dark discoloration with no evidence of corrosion. The condition of the water in the hoses at the end of test 1 is shown in the last column of Table 5.

In hoses where corrosion of the steel plugs occurred, the water has a dark brown rust color with sediment. It should be noted that distilled water was used with no inhibitor in tests 1 and 2. The ethylene glycol used in test 3 has inhibitor, so metal corrosion would not be expected in a 7-day test. It is evident that the compounding materials in some hoses are likely to cause corrosion, and the compounding materials in other hoses inhibit corrosion to some degree.

3.6 BURSTING PRESSURE

Hose used in solar energy systems must have sufficient strength to withstand fluid pressures in the system and provide a reasonable margin of safety. Usually the minimum bursting pressure is required to be five times the maximum working pressure. The hose must retain sufficient strength for many years under service conditions. Accordingly, the bursting pressures of the hoses are examined in essentially new condition and after completion of the performance test.

3.6.1 Procedure

The procedure in ASTM D 380 was followed, except the specimens were about 350 mm in length. A hand operated hydraulic pump was used to apply fluid pressure. The pressure was increased as rapidly as the pump permitted.

Since there was insufficient material of some hoses to test unused hoses, tests were made on specimens used in the water vapor transmission test. The four specimens of each hose remaining from the performance test were also tested. Some of these specimens were replacements and had only short service exposure.

Table 4. Water Vapor Transmission at 100°C

Hose	Type	Vapor Transmission (g/day)			Density[a]
		Test 1	Test 2	Test 3[b]	kg/m^3
1	EPDM	--	0.57	0.66	1064
2	EPDM	0.48	0.46	0.46	1060
3	EPDM	0.67	0.70	0.61	1059
4	EPDM	0.81	0.80	0.71	1062
5	EPDM	0.80	0.80	0.92	1064
6	EPDM	0.48	0.46	0.55	1060
7	CR	1.43	1.74	0.82	1062
8	VMQ	5.31	5.23	3.51	1099
9	VMQ	5.30	5.03	3.48	1098
10	VMQ	4.71	4.92	3.43	1099
11	TFPE[c]	0.21	--	--	--
12	EPDM[d]	0.89	0.91	1.06	1062
13	EPDM[e]	0.82	--	--	--

[a] Density of glycol-water mixture after test 3. Original density of mixture 1055 kg/m^3.

[b] Ethylene glycol-water mixture (equal masses of each). Same specimens as in test 2.

[c] Stainless steel wire braid cover.

[d] Nominal bore 20 mm; nominal bore of other hoses 16 mm.

[e] High resilience EPDM hose submitted after completion of performance tests.

Table 5. Effect of Hose on Metal Plugs in Water Vapor Transmission Tests (166 hours at 100°C)

Hose	Aluminum	Brass	Steel	Water
	Test 2	Test 1	Test 1	Test 1
1	c	-	-	-
2	c	d	e	x3
3	b	c	c	x1
4	b	c	c	x2
5	c	c	d	w
6	b	d	e	w
7	d	c	a	w
8	a	b	f	z
9	c	c	f	z
10	f	b	f	z
11	-	-	-	z*
12	b	d	a	w
13	-	d	c	y

a clean or nearly clean

b very slight discoloration

c slight discoloration

d dark discoloration

e slight corrosion

f corrosion

w clear

x1 slightly cloudy

x2 slight sediment

x3 slight rust color

y sediment

z dark brown rust and sediment

* The rust in the water came from iron pipe caps on this hose. It was not feasible to use plugs with clamps in testing the PTFE hose with stainless steel wire braided cover.

3.6.2 Results

Table 6 lists the bursting pressures in kilopascals. It is evident that all rubber hoses lost strength in the performance test. The values for hose 12 decreased from over 7500 kPa to less than 10 percent of the initial value. The bursting values for hoses used in the water vapor transmission tests tend to be lower than those subjected to the same heat in the dry condition (compare column a and b). The bursting values for VMQ hoses tend to decrease less in the performance test than those for other hoses. This difference in behaviour is apparently attributable to the reinforcement materials in these hoses. Although the reinforcement in all hoses was not obtained, it appears that rayon fiber was used in hoses that decreased in bursting strength greatly. This fiber is known to deteriorate rapidly at high temperature in the presence of moisture.

4. DISCUSSION

This study achieved the objective of determining the important requirements of hose used in solar energy systems. Laboratory tests are available to assess these requirements, except for deterioration of reinforcement material. A short laboratory test is not adequate to assess this characteristic. However, the behaviour of fibers at various temperatures in many environments is known or could be established. Fibers which deteriorate extensively under service conditions in solar energy systems should be precluded from use as reinforcement for hose.

Although some of the hoses survived the performance test without leakage at the connections or failure, none is ideal for use with aqueous fluids below 100°C in solar energy systems. The PTFE hose with stainless steel braid is expensive and requires special fittings. It is recommended for use in industrial systems operating at very high temperatures with non-aqueous heat transfer fluids or pressurized aqueous fluids. The VMQ hoses have a high transmission of water vapor through their walls. They are not recommended for use with aqueous heat transfer fluids, but should be useful with compatible non-aqueous fluids that do not pass through the walls. The EPDM hoses tested have two weaknesses. The reinforcement used in them deteriorates rapidly at high temperatures when transporting aqueous fluids. They also have 100 percent compression set so that leakage at the connections is bound to be a problem. The high resilience EPDM hose that was submitted later should overcome these weaknesses. This hose has knit aramid reinforcement, so it should be suitable for transporting aqueous heat transfer fluids. However, the knit construction may not withstand applications with repeated flexing and impulse. The CR hose has the weaknesses of the EPDM hose plus two others. The ozone resistance of this hose is not adequate for use in solar energy systems and the hardening and stiffening that occurs in service makes leakage at the connections difficult to stop.

The performance of hose 6 which vulcanized to the nipples indicates that adhesives could be used effectively to obtain leak proof connections. However a high resilience hose should not require an adhesive

Table 6. Bursting Pressures

Hose	Type	Bursting Pressures in kPa					
		a	b	c	d	e	f
1	EPDM		2210	1240	1100	1240	970
2	EPDM	7000+	5930	1100*	6620*	970	970
3	EPDM	2340	1240	1380*	830*	2000*	2340*
4	EPDM	3310	2620	1240*	830*	—	1100*
5	EPDM	3030	2620	2260*	1380	2380*	830
6	EPDM	7000+	7000+	3100	6760	2140	2620
7	CR	6070	6270	2340	2070	1720	970
8	VMQ	2480	1930	1380	2480	1650	1310
9	VMQ	4830	4270	4410	3450	3720	3720
10	VMQ	7500+	7500+	4900	5790	5790	6760*
11	PTFE	not tested					
12	EPDM	7500+	7500+	550	--	690	--
13	EPDM	3450	3450	--	--	--	--

[a] Specimens used as blanks and heated at 100°C for 166 h.

[b] Specimen used for water vapor transmission and heated at 100°C for 166 h.

[c] Specimens connected to inlet manifold of brass and copper system.

[d] Specimens connected to outlet manifold of brass and copper system.

[e] Specimens connected to inlet manifold of steel system.

[f] Specimens connected to outlet manifold of steel system.

* Replacement specimens.

+ Specimen did not fail at this pressure.

to be leakproof. Further the type of clamp used is not critical if the hose has high resilience, which offers promise in developing clamps easy to install and reliable in service.

5. PROPOSED STANDARD

Based upon the results of this study, a proposed standard specification for rubber hose used in solar energy systems has been prepared and is given in the Appendix. This standard has requirements for the following characteristics:

(1) Physical properties of inner tube and outer cover before and after accelerated aging.

(2) Resistance to ozone of the outer rubber cover.

(3) Compatibility of the inner tube with the heat transfer fluid.

(4) Flexibility at low temperatures.

(5) Compression set of the composite hose.

(6) Bursting pressure of the composite hose.

(7) Vapor transmission through the hose walls of the heat transfer fluid.

(8) Effect of hose on heat transfer fluid and metal.

(9) Reinforcement material.

Hose conforming to this standard should give good performance in solar energy systems and not require maintenance when properly installed.

6. ACKNOWLEDGMENT

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APPENDIX

PROPOSED STANDARD SPECIFICATION FOR RUBBER HOSE USED IN SOLAR ENERGY SYSTEMS

1. SCOPE:

1.1 This specification establishes quality requirements for rubber hose used to convey liquids in solar energy systems to provide producers, distributors, and users with criteria to evaluate this product. Particular applications may necessitate other requirements that would take precedence over these requirements when specified.

1.2 An annex covers connections of rubber hose to the solar energy system.

1.3 This specification does not include requirements pertaining to the fabrication or installation of the hose.

1.4 This specification does not cover hose made from plastics.

2. APPLICABLE DOCUMENTS

2.1 ASTM Standards

D 380 Testing Rubber Hose

D 395 Test Method for Rubber Property -- Compression Set

D 1349 Rubber - Standard Temperatures and Atmospheres for Testing and Conditioning

D 1566 Definitions of Terms Relating to Rubber

D 3832 Specification for Rubber Seals Contacting Liquids in Solar Energy Systems

2.2 Other Standards

ISO 1307 Rubber Hose - Bore Sizes, Test Pressures and Tolerances on Length

3. ORDERING INFORMATION

Purchase orders shall include the following information:

3.1 Reference to this standard, ASTM xxxx

3.2 Inside diameter

3.3 Length

3.4 Type and Class (see 4.1 and 4.2)

3.5 Type of fluid to be conveyed.

3.6 Maximum service temperature

Note 1 - This temperature normally occurs under stagnation conditions and maximum radiation flux.

3.7 Maximum working pressure

3.8 Other requirements

4. CLASSIFICATION

4.1 Types

Type C, intended for use in cold climates (below -10°C in winter)

Type W, intended for use in warm climates (above -10°C in winter)

4.2 Classes

Class A, intended for use with aqueous fluids at 100°C or less

Class AT, intended for use with aqueous fluids above 100°C

Class N, intended for use with nonaqueous fluids

Note 2 - Aqueous fluids include water and antifreeze solutions.

5. TERMINOLOGY

5.1 Nipple - a cylindrical tubular attachment, one end of which is securely inserted and retained in the end of a hose, to convey fluid to or from the hose.

5.2 Definitions of other terms are given in ASTM D 1566

6. STANDARD SIZES

6.1 The following internal diameters are standard:

mm	in
10.0	0.38
12.5	0.50
16.0	0.63
20.0	0.75
25.0	1.00
31.5	1.25
40.0	1.50
50.0	2.00

Note 3 - The metric and inch sizes are not identical. The metric sizes are based on the R10 series of preferred numbers given in ISO 1307.

6.2 The internal diameter shall not exceed the specified value in 6.1 and shall not be less than this value by more than 1.5 mm or 0.06 in for sizes of 20 mm or less, or 3.0 mm or 0.12 in for sizes above 20 mm.

6.3 The tolerance on length shall be ± 3 mm or ± 1 percent of the length whichever is larger.

7. REQUIREMENT

7.1 Construction - The hose shall consist of an inner tube, reinforcement and outer cover. The outer cover may be rubber or a fibrous material (metallic or non-metallic) that is part of the reinforcement. The inner tube and rubber cover shall be smooth, uniform in thickness, and free from pitting, pinholes, blisters and other defects.

Note 4 - Intentional pricks in rubber cover to allow vapors to escape from reinforcement or lengthwise ribs on outer cover are not considered defects.

7.2 Inner Tube and Outer Rubber Cover - These rubber components shall comply with the requirements given in Table 1.

7.3 Hose - The composite hose shall comply with the requirements given in Table 2.

7.4 Reinforcement Material - The reinforcement shall be stable in the presence of vapors of the heat transfer fluid at service temperature as determined from the change in bursting pressure of the hose in a prequalification test (see 9.3.2).

Table 1. Requirements for Inner Tube and Outer Rubber Cover

PROPERTY	REQUIREMENT
Ultimate elongation, min, %	250
Tensile strength, min, MPa	6.2
lb/in^2	900
Resistance to heating[a]	
Change in ultimate elongation, max, %	−40
Change in tensile strength, max, %	−20
Resistance to heat transfer fluid[b]	
Change in ultimate elongation, max, %	±25
Change in tensile strength, max, %	±25
Change in hardness, max	±10
Change in volume, max, %	±15
Resistance to ozone of outer cover	
100 mPa[c] for 166 h at 40°C	no cracking
Resistance to low temperature	
Type C hose only, −40°C	no cracking

[a] Class A hose shall be heated at 125 ± 2 °C for 166 ± 2 h. Class AT and N hose shall be heated for 166 ± 2 h at a standard temperature in ASTM D 1349 between 25 and 49°C above maximum service temperature, but not less than 125°C. These test temperatures are: 125, 150, 175, 200, 225 and 250°C.

[b] Inner tube of Class A and AT hose shall be immersed in a mixture containing equal volumes of ethylene glycol and water for 166 ± 2 h at 100 ± 2 °C. Inner tube of Class N hose shall be immersed in heat transfer fluid used in solar energy system for 166 ± 2 h at a standard test temperature in ASTM D 1349 next above maximum service temperature, but not less than 100°C. If the vapor pressure of the fluid is above atmospheric pressure at the test temperature, the next lower standard test temperature shall be used.

[c] 100 mPa ozone partial pressure is equivalent to 100 pphm at standard atmospheric pressure of 100 kPa.

Table 2. Requirement for Composite Hose

PROPERTY	REQUIREMENT
Compression set, max, %	85[a]
Bursting pressure, min	five times working pressure
Vapor transmission rate, max, μ g/(m·s)	3.5[b,c]
Effect on aluminum, brass, copper and steel	no corrosion[d]
Effect on fluid	no sediment or dark discoloration[e]
Stability of reinforcement maximum decrease in bursting pressure, %	50

---

[a] Set is measured after conditioning under 25% compression for 166 ± 2 h at 100 ± 2 °C for Class A hose and at standard test temperature in ASTM D 1349 between 25 and 49°C above maximum service temperature, but not less than 125°C (See footnote a, Table 1 for standard test temperatures).

[b] Equivalent to 0.9 g/day for a specimen having an internal length of 300 mm between plugs.

[c] The requirement for Class N hose with specified fluids should be agreed between supplier and purchaser of hose.

[d] Condition of plugs at the end of the test for vapor transmission rate. Discoloration of plugs without corrosion is permitted.

[e] Condition of fluid at end of test for vapor transmission rate. Slight cloudiness or slight discoloration is permitted.

The bursting pressure should decrease less than 50 percent for stable material.

8. SAMPLING

8.1 The inspection and test procedures specified are to be used to determine conformance of products to the requirements of this Standard. Each producer or distributor whose products are represented as conforming to this Standard may utilize statistically based sampling plans which are appropriate for each particular manufacturing process and product characteristic. Essential records shall be kept to document with a high degree of assurance that all requirements of this Standard have been met.

8.2 In case of dispute between purchaser and seller regarding quality, five pieces of hose shall be taken from the lot at random and those attributes in dispute shall be tested for compliance with this Standard. If one piece does not conform, a second set of five pieces may be taken and tested. If two or more of the ten pieces do not conform, the lot may be rejected.

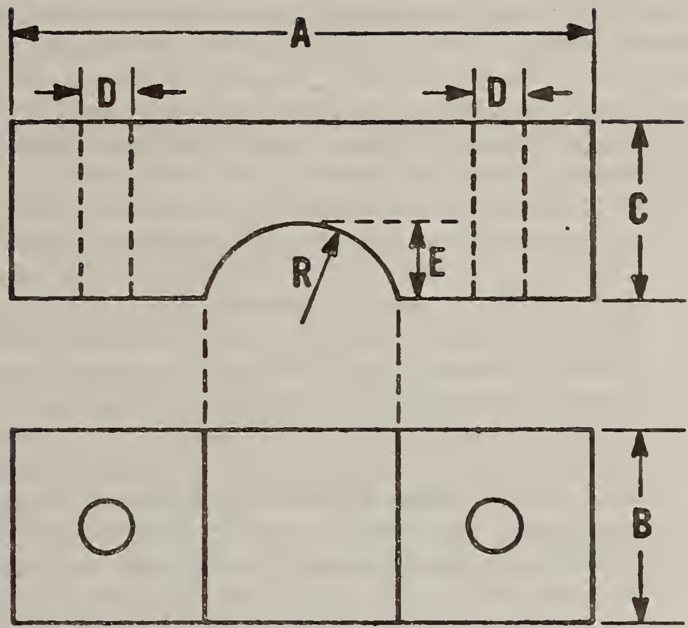
9. TESTING

9.1 Hose shall be tested according to ASTM D 380 for requirements in Table 1.

9.2 Hose shall be tested for compression set and bursting pressure by the following procedures:

9.2.1 Compression Set - Use the procedure for Method B in ASTM D 395 except that the specimen shall consist of a piece of hose at least 50 mm in length and the compression plates shall have the curvature of the outside of the hose as illustrated in Figure 1. Place a metal cylinder having an outside diameter (A) equal to the inner diameter of hose given in 6.1. Measure the outside diameter (B) of hose with cylinder in place. Place specimen between compression plates and tighten bolts until hose is compressed to 0.75B + 0.25A. Place the apparatus in an oven at temperature given in footnote a, Table 2 and leave for 166 $\pm$ 2 h. Remove the apparatus from the oven, loosen clamping bolts, and after 30 minutes measure the outside diameter (C) of hose at the center of the clamping area. Calculate compression set in percent of compression, which is 400 (B - C)/(B - A).

9.2.2 Bursting Pressure - Determine the bursting pressure in accordance with ASTM D 380.



A - 5R, minimum

B - 25 mm

C - 10 mm + R, minimum

D - Holes to clear bolts

E - 3/8 O.D. + 1/8 I.D. of hose, maximum

R - 1/2 O.D. of hose, minimum

Figure 1. Compression clamp (two required)

9.3 Prequalification tests of hose shall be made for vapor transmission rate, effect on metals and fluid, and stability of reinforcement. These tests shall be made for each rubber composition and reinforcement material for initial qualification of hose design, and are not required for quality control of manufacture. The following procedures shall be used:

9.3.1 Vapor Transmission Rate and Effect on Metals and Fluid Prepare metal plugs from aluminum, brass, copper, and steel 50 mm in length from rods having a diameter equal to the inner diameter of hose given in 6.1. Cut six hose specimens 350 mm in length. Place an aluminum plug in one end of one specimen to a depth of 25 mm and clamp. Place a brass plug in second specimen and clamp. Place a copper plug in third specimen and clamp. Place a steel plug in fourth specimen and clamp. Fill these specimens with the heat transfer fluid used in Class N hose or water (Class A or AT hose), to about 75 mm of open end. Insert aluminum plug in first specimen, brass plug in second specimen, copper plug in third specimen, and steel plug in fourth specimen, so that distance between plugs is 300 mm, and clamp. Determine the masses of the four hose assemblies and the two specimens without fluid. Place the six hose specimens in an oven at 100 ± 1°C when testing Class A or AT hose, and at a standard test temperature in ASTM D 1349 next above the maximum service temperature, but not less than 100°C, when testing Class N hose. Determine the masses after 24 h and tighten clamps on specimens containing fluid. Return the specimens to the oven for six more days. Remove the specimens from the oven, allow them to cool to room temperature, and determine their masses. Deduct the average loss in mass of the two dry specimens from the average loss in mass of the four specimens containing fluid. Calculate the vapor transmission rate in $\mu g/(m^2 s)$. Disassemble the four hose assemblies and examine the condition of the fluid and plugs.

9.3.2 Stability of Reinforcement - Cut ten hose specimens approximately 350 mm in length. Insert hose nipples in the ends of five specimens and clamp. Connect one nipple of each assembly to a fluid reservoir of about 100 cm^3 capacity. Fill the hose and reservoir through the other nipple with the heat transfer fluid used in Class N hose or water in tests of Class A or AT hose to about 90% of capacity. Close the filling nipple by any suitable means and place the five hose assemblies in an oven at 100 ± 2°C when testing Class A or Class AT hose, and at a standard test temperature in ASTM D 1349 nearest the maximum service temperature, but not less than 100°C, when testing Class N hose. Examine the fluid level in the assemblies after two and four months, and add fluid if the level has decreased below 80% of capacity. After six months, remove the specimens from the oven, disconnect the reservoirs, and measure the bursting pressure of each specimen, including the five specimens that were not filled and heated with fluid. Calculate the change in average bursting pressure of the two sets of specimens as a percent of the bursting pressure of specimens not heated.

10. MARKING

10.1 Name, brand or trademark of manufacturer.

10.2 Type and class.

10.3 Reference to this standard, ASTM Dxxxx.

10.4 Other information required by manufacturer or purchaser.

11. PACKAGING

11.1 Hose shall be protected by suitable packaging to prevent damage during shipment or storage prior to installation in solar energy system.

12. INSTRUCTIONS

12.1 Installation instructions should be included with each package. The Annex gives guidance on information to be included to assure long leak-free service. Instructions are not necessary for hose supplied with end fittings unless special precautions during installation or maintenance procedures must be followed.

ANNEX

A1. CONNECTION OF HOSE TO SOLAR ENERGY SYSTEM

The means for fastening the hose to components in the solar energy system is critical. The two mechanisms commonly employed are through end fittings on the hose or clamps. Materials that resist corrosion is essential. The following provisions are general requirements and not complete specifications for these connections.

A.1.1 Hose Nipples - Outside diameter shall be not less than the specified value in 6.1 and shall not exceed this value by more than 3 mm, including serrations or enlargement to prevent slippage.

A.1.2 End Fittings - Hose equipped with end fittings shall withstand a minimum tensile force of 1.3 kN(300 lb). In the bursting pressure test (9.2.2), the hose shall not move out of the end fittings more than 1.6 mm (0.06 in). Rubber seals in end fittings shall comply with ASTM D 3832. The design of the end fitting shall be agreed between purchaser and supplier.

A.1.3 Clamps - Hose intended for use with clamps shall be shipped with instructions for proper clamping to prevent slippage of hose from the connecting tubes in the solar energy system and cutting of the hose by the clamps. The instructions should emphasize that one or more ridges between the clamp and end of hose nipple is essential to prevent slippage, that the clamps should have a wide surface to support the clamping forces without cutting of the hose. The instructions should also include recommendations for use of adhesives to prevent leakage and reduce or eliminate maintenance during long service.

A.1.4 Compatibility - The rubber hose, metal components and circulating fluid should be compatible in order to minimize metal corrosion and deterioration of rubber hose and fluid. Specifications for compatibility beyond the provisions in Table 2 and 9.3 should be agreed between purchaser and seller.

A.1.5 Expansion Joints - Hose connections in solar energy systems that also serve as expansion-contraction joints should be designed so that straight hose acccomodates motion by flexure and not by axial compression and tension. Hose made with one or more bellows to accomodate axial compressive and tensile movement should accomodate the maximum motion likely to occur under extreme service conditions without placing significant stress on the components connected.

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16. ABSTRACT *(A 200-word or less factual summary of most significant information. If document includes a significant bibliography or literature survey, mention it here.)*

A study of commercial rubber hose was made to develop standards for hose used in solar energy systems. Twelve hoses were evaluated by cycling between temperatures of about 100°C and temperatures as low as -40°C during a period of about seven months. Laboratory tests for bursting strength, compatibility with metals, compression set, ozone resistance, and water vapor transmission were also made.

The results of this study and tests are presented. Based on these findings, a standard for rubber hose used in solar energy systems is proposed.

17. KEY WORDS *(six to twelve entries; alphabetical order; capitalize only the first letter of the first key word unless a proper name; separated by semicolons)*

Hose; hose specifications; rubber hose; solar energy systems

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