Rupture Testing of UF_6 Transport and Storage Cylinders

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INTRODUCTION

Large steel cylinders for shipment and storage of uranium hexafluoride have been in production since about 1951, in support of the United States Department of Energy (DOE) programs for nuclear fuel enrichment services. These 48-inch diameter cylinders, in 10- and 14-ton capacities and intended for use with feed, tails, and low-enrichment U-235 intermediate product, have been purchased in several minor design variations and comprise about 46,500 cylinders at the present time. In addition, DOE's uranium enrichment operations own a large number of smaller product cylinders: more than 3,000 type 30A steel cylinders, about 1,650 5-, 8-, and 12-inch product cylinders made of nickel and Monel, and about 2,000 small sample cylinders of nickel and Monel. The total number of UF_6 containers in world-wide distribution is unknown but must number well in excess of 100,000 units. Handling accidents, such as the damaged cylinders from the Monte Louis, the Portsmouth, and Kerr-McGee incidents, and many other handling and transport accidents of lesser consequence, along with governmental policies and industrial practices which have a bearing on long-term storage of feed or processed materials all raise proper concerns about the ability of these cylinders to safely contain uranium hexafluoride.

Cylinders for UF_6 containment are designed and built to ASME Boiler and Pressure Vessel Code criteria and conform to the requirements of ANSI N14.1. All of the vessels are simple, right circular cylinders closed by ellipsoidal heads, with the 48-inch cylinders,

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both 10- and 14-ton capacity, incorporating three external stiffening rings into this basic design. Construction practices vary, depending on cylinder size, with the cylinders being spun or weld fabricated from pipe or tubing or from rolled sheet or plate. All of the smaller cylinders (the 1-pound sample cylinder through the 2 1/2-ton product cylinder) are rated for a working pressure of 200 psi, while the 48-inch cylinders are rated for a working pressure of 100 or 200 psi, depending on whether the original design was for storage or for shipping applications. The cylinder design requires a wall thickness which will limit the hoop stress under the most severe internal loading (the hydrostatic test pressure) to the code design allowable stress (nominally one-fourth of the material's minimum ultimate tensile strength). Since the hydrostatic test pressure is specified in ANSI N14.1 as double the working pressure, the cylinder design target provides a safety factor of eight times the nameplate working pressure.

In addition to being designed, built, and maintained to national code standards, the cylinder designs have been qualified by appropriate drop tests to demonstrate their containment safety. As a further verification of their fitness for use as safe containers for UF_6, a number of cylinders have been subjected to burst tests over the past several years. This paper reviews and updates the results of these tests.

PROCEDURE

Whenever possible, the cylinders were obtained from active service for burst testing. Several had been dented or otherwise damaged in in-plant handling mishaps and thus did not qualify for further service. Two 30B cylinders were obtained from a transport services firm in the feed enrichment cycle following their exposure to a warehouse fire which subjected them to local temperatures as high as 1600°F. Three 12-inch cylinders were tested from a group modified for cold trap service in the now defunct centrifuge enrichment plant. Weld-modified 5-inch cylinders were tested to evaluate the effects of a material substitution in the cylinder head and valve coupling. The 48-inch cylinders included a never-filled dented cylinder, a cylinder removed from a storage yard after long storage of tails material, and a dropped cylinder which suffered extensive damage to the stiffening rings.

The test cylinders were emptied, cleaned, and decontaminated as necessary and in some cases were sandblasted on exterior surfaces to facilitate attachment of strain gage instrumentation. The prepared cylinders were fitted with special pressure test adapters, completely filled with water, and connected to one of several high pressure pumping systems. The test pressure was monitored with a large, calibrated pressure gage, and in addition, for the later tests, by a pressure transducer whose output was recorded along with the strain gage data in a computerized data acquisition system. For the last four tests on 48-inch cylinders, a continuous weight record was also acquired by means of a load cell from which the cylinder was suspended during the test. For early tests, the cylinders were covered with heavy, woven rope explosion mats; later tests have been conducted in a floor pit under a heavy steel cover. Failures in these latter tests were observed on a video monitor, and some were taped to provide a permanent record. Volume expansion data were obtained by comparison of after-test circumference measurements at several locations with measurements on the cylinder prior to testing.

In the case of the last four 48-inch cylinders, the water weight gain during the test furnished the basis for the expansion calculation.

DISCUSSION

Most of the cylinder types in present use for transport of UF_6 are conservatively designed to the criteria based on the ASME Boiler and Pressure Vessel Code, and burst tests conducted on all of the sizes of product, feed, and storage cylinders have demonstrated the safety against overpressuring inherent in these designs. Where wall thicknesses are selected on the basis of the Code maximum allowable stresses, the designs give a minimum safety factor of eight times the specified working pressure, and conservatism in specifying minimum ultimate tensile strength values for the materials of construction gives, in practice, actual safety factors in the range of 10 to 15 times the working pressure. The test data show this to be true of the 8- and 12-inch nickel and Monel product cylinders and of the 30B steel product cylinder.

An ultra-conservative system resulted from the approach taken to the 5-inch cylinder design. The working pressure selection did not control the wall thickness, since the cylinder was built from standard shapes: Schedule 40 pipe and matching weld caps. While the choice resulted in lower material cost, it also resulted in a very high safety factor since the Schedule 40 wall thickness for 5-inch pipe greatly exceeds that required by the ASME Code based on working pressure. The net result is that measured burst pressures (in a total of four tests) are nearly 40 times the nameplate working pressure.

A different picture is given by the 48-inch cylinders, those reinforced with three external stiffening rings. As far as can be determined by reviews of the drawings in all issues of *ORO-651*, the drawings have always specified a full-penetration butt weld for the stiffening ring (e.g., the drawings for 48X, 48Y, and 48G in ANSI N14.1 - 1987). In practice this has not been consistently achieved. With partial penetration welds, the rupture tests we have run on one cylinder each of the 48OM, 48Y, and 48A designations have all shown this weld to initiate the cylinder failure. The butt weld fails from the outer edge, progressing toward the pressure envelope. When the fracture reaches the attachment weld, it propagates through it and into the pressure envelope, at a total pressure rather lower than the pressure envelope, by itself, is capable of withstanding. Since none of these tests involved a cylinder built as specified in the drawing, the later tests in the current series were structured to give information on the influence of the stiffening ring.

A 48A cylinder filled with UF_6 was dropped from a straddle carrier while being transferred to storage (at ambient temperature) but suffered no apparent damage except for torn and broken stiffening rings where the cylinder skidded along the road surface. The UF_6 was cold discharged, and the cylinder was cleaned, decontaminated, and added to the test group. The cylinder expansion was accompanied by an "unzipping" of the center stiffening ring, step by step along the attachment weld segments, in both directions. A triple-length attachment weld step, reinforced by a shorter step on the opposite side of the ring, furnished enough restraint to localize deformation and failure at this point. The rupture pressure was 1,432 psi at a volume expansion of over 16%.

Note that this expansion volume is considerably greater than was obtained in any of the cylinders where the butt weld failure localized the cylinder rupture. The burst was unspectacular, resulting in a quiet, longitudinal break about 1 inch long, which released the test fluid slowly and closed spontaneously when excess pressure was relieved. Repair welds were made at the butt joint location on the stiffening rings of a 48G cylinder furnished from the Paducah cylinder storage yards. Failure in the burst test was sudden and violent, with a longitudinal tear over a full span between stiffening rings (~ 40 inches), and then extending about 10 inches along the stiffening ring attachment welds at either side. Several cubic feet of water were expelled, and a large opening (the largest of any in the rupture test series) was left in the cylinder wall, although the volume expansion (%) was the same as that given by the dropped cylinder with torn stiffening rings. The rupture pressure was 975 psi and the expansion in volume was 16.6%.

SUMMARY AND CONCLUSIONS

Cylinder tests have been conducted on pressure vessels of all the sizes and designs in current commercial use in the production, transport, and storage of UF_6. The test results have demonstrated a general conformance of the cylinders to the criteria set forth in their designs. Several of the test cylinders were taken from active service. Some were made available after handling mishaps and resultant damage, while others were tested to evaluate the effects of modifications or repairs. None of the handling damage, repairs, or modifications appeared to influence either the location or the mode of rupture; therefore, all of the results are viewed as representative of the cylinders currently in use for shipping and storage.

The tests have shown the extreme conservatism of design in the case of the 5-inch cylinder, the only ANSI N14.1 product cylinder qualified for use at 100% U-235 enrichment. They have also shown that the larger cylinders with similar design, the 8- and 12-inch nickel and Monel cylinders, and the 30B steel cylinder, consistently give burst pressure safety factors of 10 to 15 times the nameplate working pressure. The tests have demonstrated a basic tendency toward brittle fracture in overpressuring the type 30A cylinder, which is now obsolete and is to be phased out of the transport cycle by 1994. Finally, recent tests have shown that deficient stiffening ring butt welds serve to localize rupture of the 48-inch cylinders with an associated penalty in ultimate pressure.

1. The 8- and 12-inch nickel and Monel cylinders give operating safety factors well in excess of the Code minimum values--typically 12 to 15 times the working pressure.

2. The 5-inch cylinders, built from standard pipe and pipe weld caps, have burst pressures in the neighborhood of 40 times their nameplate working pressures.

3. The 30B steel cylinder, similar in configuration to the smaller nickel and Monel cylinders, responds to overpressurization in similar fashion. The burst pressure is more than ten times the rated working pressure.

4. The 30A cylinder, not an ANSI N14.1 design, is not suited to safe containment of UF_6 in situations where excessive pressures might be encountered. Its design favors brittle fracture on overpressurization and presents a significant risk of release of the entire contents of the cylinder.

5. The 48-inch cylinders are handicapped by a generally poor butt weld on the stiffening rings. Overpressurization breaks this weld, and the fracture thus generated then propagates into the pressure envelope, sometimes at pressures below the design level of eight times the nameplate working pressure.

REFERENCES

Uranium Hexafluoride: Handling Procedures and Container Criteria, ORO-651 Revision 5, United States Department of Energy, Oak Ridge Operations Office, Oak Ridge, Tennessee 37831 (April 1977).

RUPTURE TEST DATA FOR UF_6 CYLINDERS

CYLINDER TYPE	MATERIAL	WALL THICKNESS inch	WORKING PRESSURE psi	RUPTURE PRESSURE psi	VOLUME INCREASE %
5A	MONEL	1/4	200	8250	–
5A	MONEL w/NICKEL COUPLING	1/4	200	7950 (Avg. of 3 Tests)	21
8A	MONEL	3/16	200	2950	–
8B	NICKEL	3/16	200	2450	–
12A	NICKEL	0.200	200	2400	30
12B	MONEL	0.250	200	2260	53
30A*	A285 STEEL	13/32	250	1250 (Avg. of 2 Tests)	20**
30B	A516 STEEL	1/2	200	2320 (Avg. of 2 Tests)	34
48OM	A285 STEEL	5/16	100	870	9
48Y	A516 STEEL	5/8	200	1770	6
48A	A285 STEEL	5/8	200	1285	6
48A	A285 STEEL	5/8	200	1432	16
48G	A285 STEEL	5/16	100	975	17

*OBSOLETE

**VOLUME INCREASE DUE TO INVERSION OF CONCAVE HEADS AT INTERNAL PRESSURE OF 900-1,000 psi

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