Tests of Asbestos-Free Stem Packings for Valves for Elevated Temperature Service

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ABSTRACT

A test program was conducted to evaluate asbestos-free valve stem packing materials proposed for high temperature service. Packing gland bolt loads, stem frictional loads, and packing compression were measured. Tests were performed with room temperature water at pressures to 6250 psig (431 bar) and with steam at pressures to 2200 psig (152 bar). Valve stem diameters from 1.000 to 4.000 inches (25.4 to 101.6 mm), and strokes from 1.68 to 20 inches (42.7 to 508 mm) were included in the testing. Live loading of the packing was evaluated. In all, approximately 100 packing sets were cycle tested over a 12 month period. In addition, effectiveness of several corrosion inhibitors was evaluated in corrosion tests with 24 packing sets. Several successful packing material combinations are identified.

Rockwell International

INTRODUCTION

Practically everyone is aware of the publicized problems that have been associated with asbestos. It is not necessary to detail all of the regulatory impacts that have been felt by construction and other industries. However, by the late 1970's, secondary effects of U.S. regulations took the form of "asbestos-free" clauses in specifications written by a few customers and architect/engineers for industrial valves.

The growth in demand for asbestos-free valves was not as fast as was initially expected. While the elimination of asbestos was not a difficult technical problem in some moderate temperature applications, it still required significant time to identify and prove the performance of cost-effective substitutes. In the area of stem packings for valves for elevated temperature service, asbestos-base packings had been the industry standard for generations, and the technical qualification of substitutes was a major challenge. User interest in asbestos-free valves showed a moderate but steady increase through the early 1980's. In some parts of the world, particularly Australia and Scandanavia, the determination was particularly strong to avoid asbestos-containing equipment; while some nations still have no clear policy to eliminate asbestos, it is likely that this will come in time.

It was known that some U.S. suppliers of packings had discontinued sale of asbestos packings earlier, but early in 1985 JohnCrane®[1] (John Crane-Houdaille, Inc.) announced that it would discontinue its asbestos packings. JohnCrane asbestos packings, particularly 187I, had been used in many Rockwell high temperature valves for many years and were specified in some customer specifications.

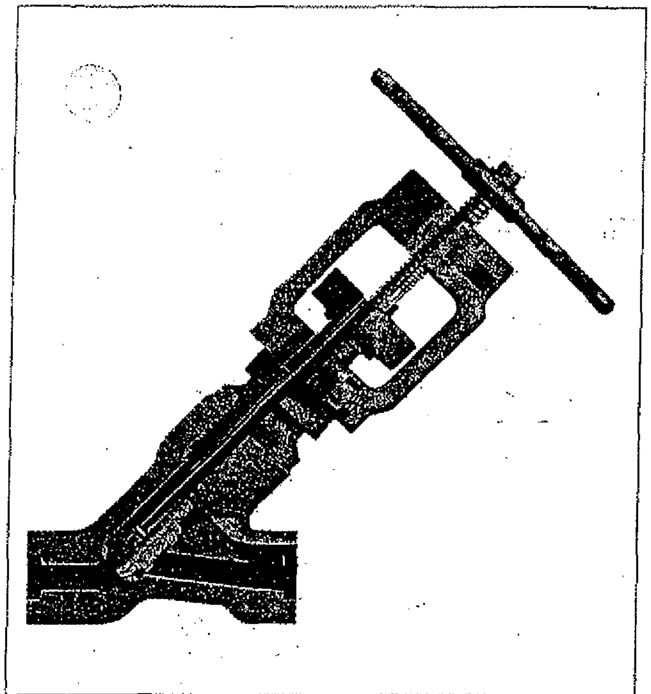


FIGURE 1

Partial Cross-Sectional View of the Univalve.

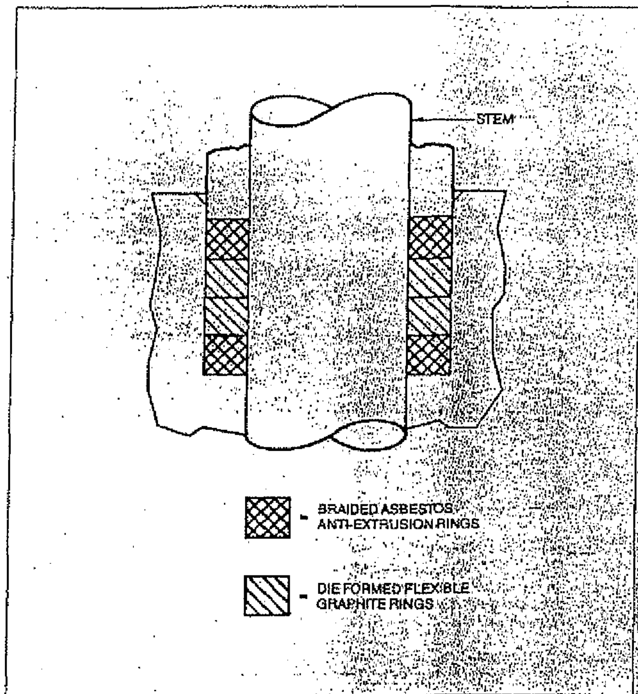


FIGURE 2

Rockwell Univalve Packing Configuration (1979)
Note: Anti-Extrusion Rings are Now Braided Carbon

After a careful review of the developments over the past five to ten years, the Flow Control Division of Rockwell International concluded that the best approach would be to discontinue use of asbestos in the manufacture of valves. Test programs already in progress were expanded in 1985 to assure that use of asbestos could be curtailed, and these programs have been continued to provide qualifications of alternate sources and studies of more cost effective materials. This program has been costly, but it was considered necessary so that Rockwell could stand behind its commitment to assure excellent overall performance of asbestos-free valves.

BACKGROUND

It is perhaps fortunate that other problems with asbestos-base packings had emerged earlier and had stimulated research and testing. Specifically, the performance of asbestos-base packings had never been outstanding, but requirements for periodic retightening and repacking had been accepted as routine in many fossil fuel power plants. When the same packings were applied in nuclear power plants in the 1960's, serious problems were encountered due to (1) inaccessibility of many valves for packing adjustment for prolonged periods, (2) loss of hazardous or precious (e.g. heavy water) fluids, (3) valve damage from packing leakage, and (4) radiation exposure of maintenance people. These problems were well documented in studies in the U.S., Canada, and France.

One successful approach to the leakage problem in nuclear power plants was to use "live loading"—a means for compensating for packing wear and shrinkage by use of springs. Atomic Energy of Canada, Ltd. (AECL) performed major work in this area. One problem was that available asbestos packings displayed so much compaction that very large belleville spring packages were required to maintain the necessary packing sealing forces over a significant period of time. While special valves could be designed to meet AECL criteria, many standard valves did not allow enough space for springs.

Another approach to the reduction of packing leakage in nuclear power plant valves involved application of a new material which had made a timely appearance on the scene. Flexible graphite, initially in the form of Grafoil®[2] from Union Carbide Corporation, was found to offer superior sealing properties in a Rockwell borated water test program in 1971 [1][3], and use of this material was broad in U.S. nuclear power plants by the mid-1970's. However, widespread cost-effective application of flexible graphite to a broad range of high temperature, high pressure valves for nuclear power, fossil power, and other applications required more research and development. Rockwell and others did considerable testing resulting in development of superior *combinations* of flexible graphite and other materials. In the case of Rockwell, such work contributed to an improved stem seal in a new line of forged steel Univalves [2]. These valves (illustrated in Figure 1) have rotating/translating stems with diameters up to 1.125" (28.6 mm) and are made in accordance with ANSI B16.34

JohnCrane is a registered trademark of John Crane-Houdaille, Inc.

[2]Grafoil is a registered trademark of Union Carbide Corporation
[3]Numbers in brackets designate references listed at end of paper

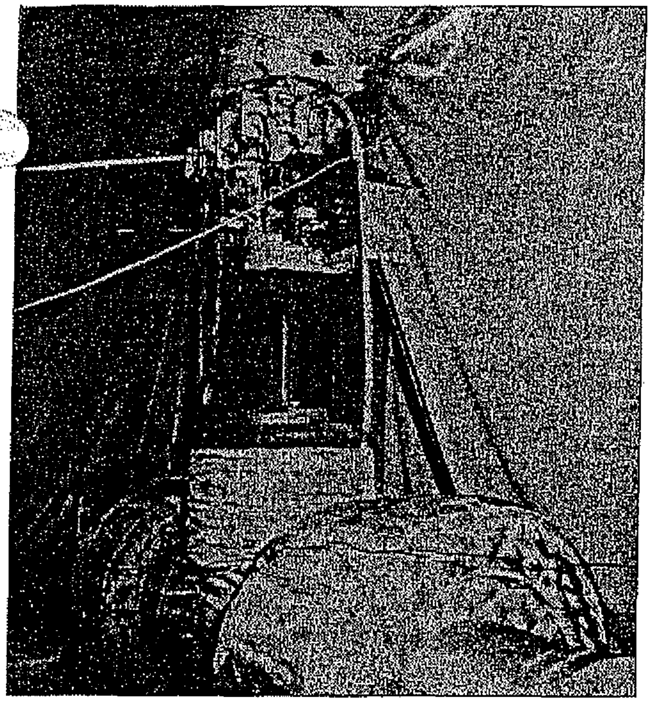


FIGURE 3

Hot Functional Test of Size 30 (DN 750) Rockwell Equiwedge Main Steam Isolation Valve at CETIM Laboratory (Nantes, France).

Classes 1690, 2680, and 4500. They incorporate smaller packing chambers than used in earlier valves to provide more efficient packing loading. Anti-extrusion rings were found necessary to prevent extrusion of flexible graphite rings at the high pressures these valves could encounter in fossil plant applications, but excellent sealing performance was achieved with two JohnCrane 1871 end rings combined with two Grafoil sealing rings in Class 1690 and 2680 valves. The new Univalve packing arrangement is shown in Figure 2. In addition to the excellent test results achieved in the Rockwell laboratory before these valves were released, first hand experience has been developed with 28 such valves in a high temperature steam test facility in the same laboratory; after four years of frequent pressure/temperature cycling at up to 2500 psi (172 bar) and 1050°F (565°C), none of these valves has required repacking and only two required tightening of gland bolts to stop minor leakage. While that stem seal still contained asbestos, it used less asbestos and provided improved performance.

Through work with the Rockwell Valve S.A. (RVSA) plant in France, it was learned that cooperative work between Latty International and Electricite de France (EdF) had led to a solution of the stem leakage problem in EdF Pressurized Water Reactor (PWR) plants. This solution involved some of the same elements that had been so successful in the Rockwell tests, namely asbestos-base anti-extrusion rings combined with flexible graphite interior sealing rings. This combination of Lattytex®[4] 117 and Lattygraf®[4] E1 has been applied successfully in Rockwell valves built in France—in sizes up through size 30 (DN 750) quick-closing Main Steam Isolation Valves (MSIV's). A major qualification program [3] on the first French-built Rockwell MSIV included a hot functional test on steam at 1040 psi (71.7 bar) and 547°F (286°C); this test provided an excellent demonstration of the live-loaded stem packing. Through 600 full stroke cycles, 400 partial stroke "exercise" cycles, and several thermal cycles, there was no observed stem packing leakage. Considering that this valve had a stem diameter of 3.000 inches (76.2 mm) and a travel of 19 inches (483 mm), these test results were considered very good. The MSIV is shown in the steam test facility in Figure 3.

When requirements started to develop for high-temperature asbestos-free valves, most of the demand was for smaller valves which already incorporated flexible graphite sealing rings. While some new proprietary braided asbestos-free materials were evaluated in a Rockwell packing test program [4] in 1980, test results indicated need for frequent readjustments and marginal packing life, particularly at high pressures. That test program therefore concentrated on retention of the flexible graphite sealing rings and finding an acceptable replacement for the asbestos anti-extrusion rings. Others had reported good results with braided graphite "wiper" rings, such as JohnCrane 1625 GF. Rockwell tests showed that these rings prevented extrusion of flexible graphite sealing rings and provided good performance at low and moderate pressures; however, testing at over 4000 psi (275 bar) required frequent packing adjustments and revealed a moderate seepage condition that could not be controlled. Since Rockwell Class 1690, 2680 and 4500 Univalves all have room temperature working pressure ratings above 4000 psi, this combination of available braided graphite end rings with flexible graphite sealing rings was judged inadequate. However, excellent results were obtained when flexible graphite was combined with braided carbon filament top and bottom anti-extrusion rings. Specifically, Garlock®[5] 98 end rings provided good sealing with minimum readjustment in tests with stems 1.000 inch (25.4 mm) in diameter in room temperature water tests at up to 11,000 psi (759 bar). Backup testing at high temperatures revealed no degradation with line fluids at temperatures typical of the highest seen in power plants.

The asbestos-free packing research related to high pressure, high temperature valves paid off an unexpected dividend. A new Rockwell high performance butterfly valve (Classes 150 and 300) was required to meet the fire test requirements of American Petroleum Institute (API), British Standard Institute (BSI), and other user specifications. The same combination of packing materials selected for high pressure valves was adopted for use in the new Rockwell McCannalok® Bidirectional Fire-Seal® butterfly valves. An extensive development and qualification test program [5] demonstrated that this packing combination provided excellent sealing in quarter-turn service at normal pressures and temperatures, and it also met the fire test requirements of API 607 (1980 and 1985), API Spec 6FA (1985), Exxon BP3-14-4 (1980), and British Standard 5146 (1974) in tests witnessed by a third-party inspector.

[4]Lattytex and Lattygraf are registered trademarks of Latty International
[5]Garlock is a registered trademark of Garlock, Inc.

TABLE 1
Packing Sets Tested

Manu[illegible]er	Material* Combination	Material Description	Graphite Ring Density, g/cc	Stem Size Tested	Packing Cross Section, In.	Recommended Gland Bolt Torque, Ft-Lbf†
Braided End Rings/Flexible Graphite Center Rings						
ɜarlock, Inc. Jnion Carbide	Garlock 98/ Grafoil	Braided carbon fibers Corrugated flexible graphite ribbon	1.6	2.375 4.000	0.38 0.50	175 475
ɜarlock, Inc.	Garlock 98/ Graph-Lock	Braided carbon fibers Diamond texturized flexible graphite	1.4	4.000	0.50	414
\. W. Chesterton Company	Style 1-Ci/ GTPI	Braided graphite yarn Corrugated flexible graphite ribbon	1.2	2.375	0.38	330
\. W. Chesteron Company	Style 1-Cl/ GPP	Braided graphite yarn Compressed graphite powder	1.4	1.000	0.25	41
Aartin Merkel ɜmbH & Co. KG	Carbosteam/ Grafiflex	Braided carbon yarn Diamond texturized flexible graphite	1.3/1.4	1.000 2.375	0.25 0.38	40 200
.atty nternational	Lattygraf 6000/ Lattygraf E1	Braided carbon fiber Corrugated flexible graphite ribbon with zinc	1.7	1.000 2.375	0.25 0.38	61.5 108.5
.atty nternational	Lattygraf TSP/ Lattygraf E1	Braided carbon fiber Corrugated flexible graphite ribbon with zinc	1.7	1.000	0.25	61.5
Other Packing Materials Tested						
ɜarlock, Inc.	1200-PBI	*Braided polybenzimidizole fiber*	N.A.	1.000 2.375	0.25 0.38	82 150
Parker Seal Group	*2028***	*Braided construction—* no other description available	N.A.	2.375	0.38	No Recommendation
John Crane- Houdaille, Inc.	*2871***	*Braided construction—* no other description available	N.A.	2.375	0.38	No Recommendation
\. W. Chesterton Company	Style 1800	Inconel reinforced carbon yarn	N.A.	1.000 2.375	0.25 0.38	46 242

* Where applicable, material combinations list braided end rings first, followed by flexible graphite center rings.
** The material tested in this program is no longer available. A revised material using the same identification is currently available.
†Recommendation by manufacturer.

While the earlier laboratory tests of the braided car-
›n/flexible graphite packing combination had been con-
ıed to fairly small valve stem sizes, this combination was
›plied selectively in valves with larger stems over the
ıst few years with no field problems. In some severe
›plications, the combination was applied successfully to
place asbestos packings that had given leakage prob-
ms. While field performance results were very good, it
as decided early in 1985 to establish a laboratory data
ıse through testing of braided carbon and flexible graph-
› with larger valve stems. Shortly after this program was
ıderway, the Rockwell decision to curtail use of asbestos
sulted in expansion of the test program to permit evalu-
ion of other promising asbestos-free packings. A survey
as made of packings available in the U.S., Europe and
ıpan, and meetings were held with technical represen-
tives from a number of key packing manufacturers.

While there was a general concensus (not neces-
ırily total agreement) that combinations of flexible graph-
› sealing rings with either braided graphite or braided
ırbon end rings offered the best in asbestos-free packing
›rformance, other asbestos-free high-temperature pack-
gs were available. Manufacturers reported that these
ıckings were either new developments or had been im-
oved significantly over the past five years. Most of these
tter [illegible]ngs were proprietary braided material combi-
ıtions [illegible] which some laboratory and/or field performance
ıccess was reported. Generally, the data available from the manufacturers on these proprietary packings were not sufficiently convincing to permit use of these materials in manufacture of Rockwell valves without further testing. Nevertheless, since such proprietary braided packings offered potential cost savings in comparison with carbon and graphite packings, those which seemed most promising were obtained for testing in the expanded Rockwell program.

Within less than a year after the current program was started, a U.S. regulatory announcement provided the justification (if any was needed) and set a deadline. On January 23, 1986, the U.S. Environmental Protection Agency (E.P.A.) proposed a plan [6] involving immediate prohibition of use of asbestos in certain products and phase-out of domestic mining and importation of asbestos over a ten-year period.

TEST PROGRAM

Previous development work performed with asbestos-free packing materials showed that the resilience of flexible graphite packing material could be taken advantage of to reduce the size of packing chambers. This earlier work centered on smaller forged steel valves, with little laboratory work on larger valves. Large valves have historically had very deep packing chambers using a large number of asbestos packing rings. A major goal of the program was to demonstrate that the volume of asbestos-free

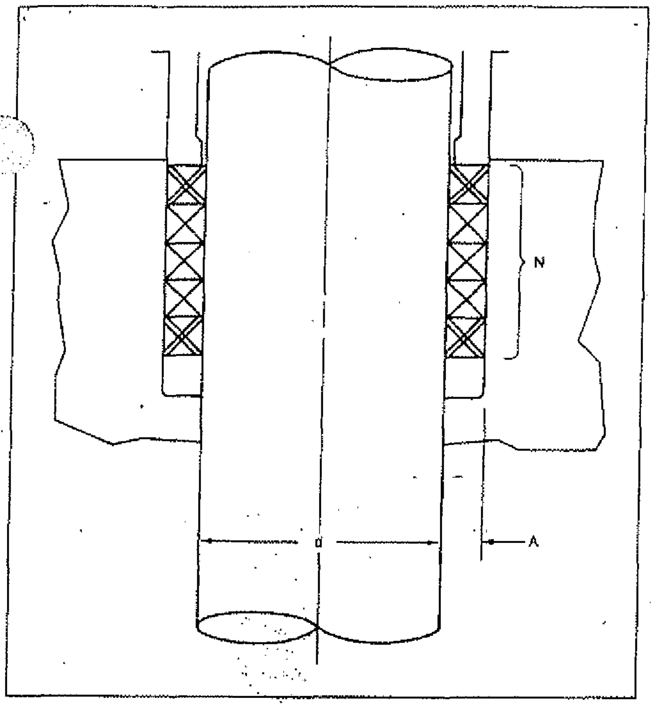


TABLE 2

Sizes of Packing Tested

Stem Diameter d, inches (mm)	Packing Cross Section A, inches (mm)	Number of Rings N
1.000 (25.4)	0.25 (6.4)	4
2.375 (60.3)	0.38 (9.5)	4,5
4.000 (101.6)	0.50 (12.7)	5

packing required to seal the stem could be substantially reduced by both decreasing the packing cross section and reducing the required number of rings. The revised packing chamber designs would then have to be evaluated through sealability and wear cycle tests.

A test program was devised to evaluate performance of asbestos-free packing using the revised packing chamber design. The program was designed to expose the packing to all of the loading conditions that it would encounter from the time it is installed in the valve manufacturer's plant through end use. This involved exposing the packing to valve hydrostatic shell test and seat leakage test pressures (with associated leakage criteria), followed by cycling a valve stem through the packing under high pressure and room temperature or high temperature operating conditions.

Results of earlier tests [4] demonstrated that the packing material combination of Garlock 98 braided carbon end rings and Grafoil flexible graphite center rings would successfully seal valve stems up to Class 4500 opeating conditions. The Grafoil rings used in those tests were formed from Grafoil ribbon by Rockwell so that the density of the rings could be closely controlled. Similarly, Grafoil rings used in the current test program were also formed by Rockwell. Flexible Graphite rings from other manufacturers were obtained preformed (with density per their standard practice). Rockwell specifications for general-service flexible graphite die-formed packing rings call for a density of 1.4 to 1.9 grams/cm³ (87 to 118 lb/ft³), although tighter controls are specified for some special applications. This range has been found to be successful in new valves with good stem and packing chamber finish. Accordingly, Grafoil rings formed by Rockwell for the current program were made to provide a nominal density of 1.6 grams/cm³ (100 lb/ft³). Several packing manufacturers normally supply lower density flexible graphite rings on the grounds that they are more suitable for repacking worn valves. At least one manufacturer [7] offers both "low density" and "high density" flexible graphite rings.

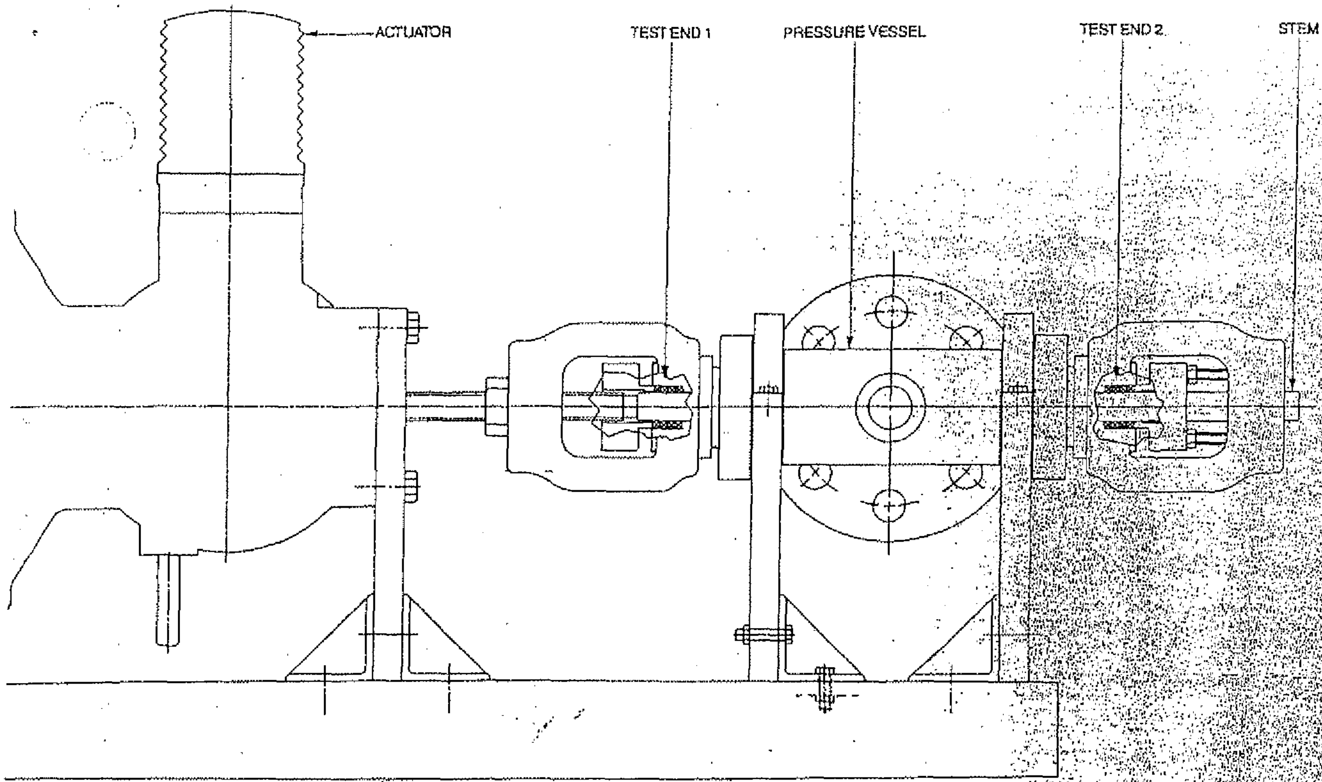
Although the majority of cycle tests performed utilized conventional packing gland bolting to compress the packing into the packing chamber, tests using live loading were also performed. These tests were performed primarily to evaluate live loading in comparison to conventional packing gland bolting. Gland spring sets were designed to accommodate the wear and compaction characteristics of braided carbon/flexible graphite packing combinations observed in previous tests.

The presence of carbon or graphite in many asbestos-free packing materials can cause galvanic corrosion of some valve stem materials. This test program included testing to determine the effectiveness of several corrosion inhibitors currently being used or proposed for use with carbon or graphitic packing materials.

Packings Tested

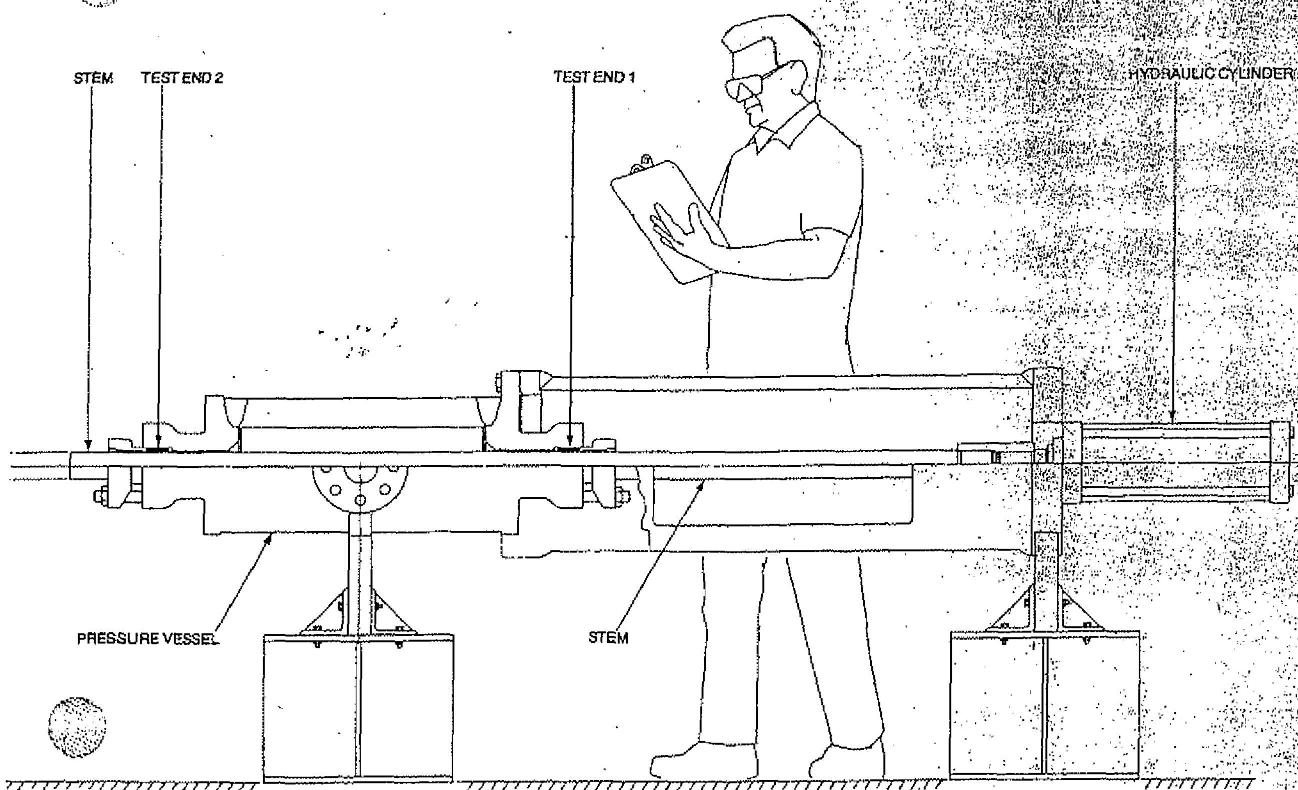
Packings tested in this program include carbon and graphite braided packing, die-formed flexible graphite packing, and other proprietary braided packings. Individual packing materials tested are listed in Table 1. Die formed flexible graphite packing was always tested in conjunction with carbon or graphite braided end rings which served as anti-extrusion rings. An exception to this was testing of one of the proprietary braided packing materials as an anti-extrusion ring for flexible graphite packing. Otherwise, proprietary braided packing rings were normally tested by themselves. Materials to be tested were normally obtained from manufacturers in sets to accommodate the test fixture packing chambers. The only exception is Grafoil rings, which were formed by Rockwell.

Three sizes of packing were tested, as described in Table 2. Manufacturers were advised of the temperature and pressure conditions that the packing would be exposed to before the packing was supplied. They were asked to supply recommendations for loading the packing into the test fixtures, especially the packing gland bolt loading to be used to compress the packing into the packing chamber. It was considered particularly important that manufacturers supply this information for the *new* materials for which there was no Rockwell experience base.



GURE 4A

ve Stem Packing Test Fixture for 1.00 inch (25.4 mm) Diameter Stem.



GURE 4B

ve Stem Packing Test Fixture for 2.375 inch (60.3 mm) Diameter Stem.

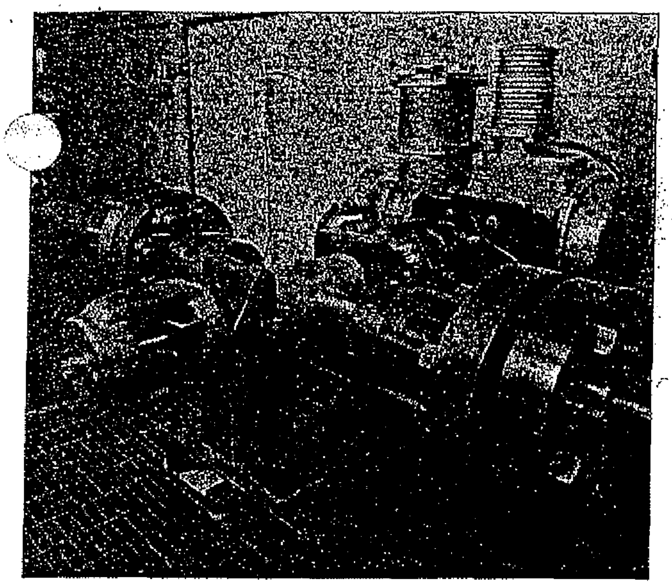


FIGURE 4C

Photograph of 1.000 inch (25.4 mm) Diameter Stem Test Fixture.

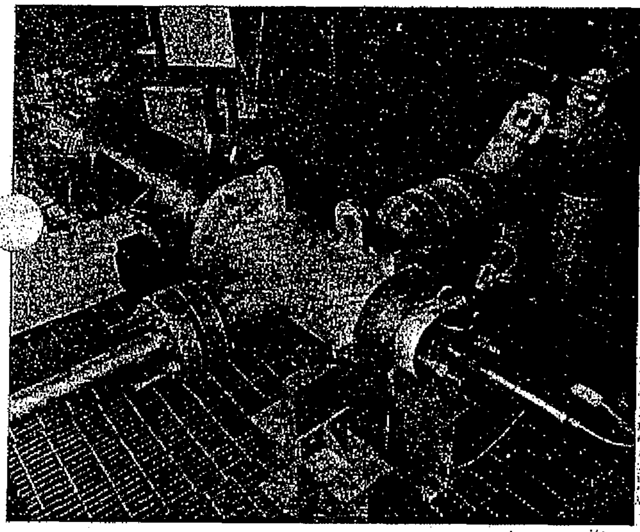


FIGURE 4D

Photograph of 2.375 inch (60.3 mm) Diameter Stem Test Fixture.

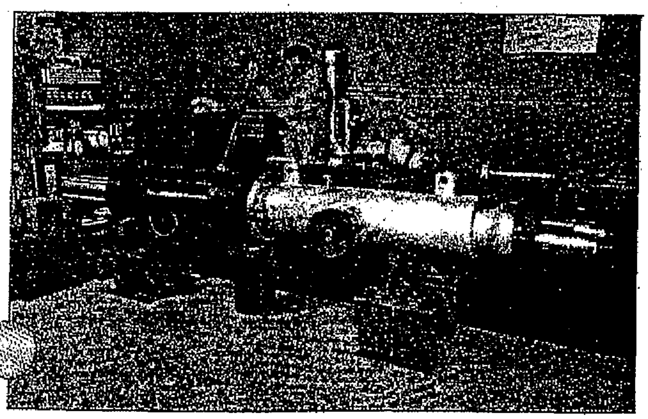


FIGURE 4E

Photograph of 4.000 inch (101.6 mm) Diameter Stem Test Fixture.

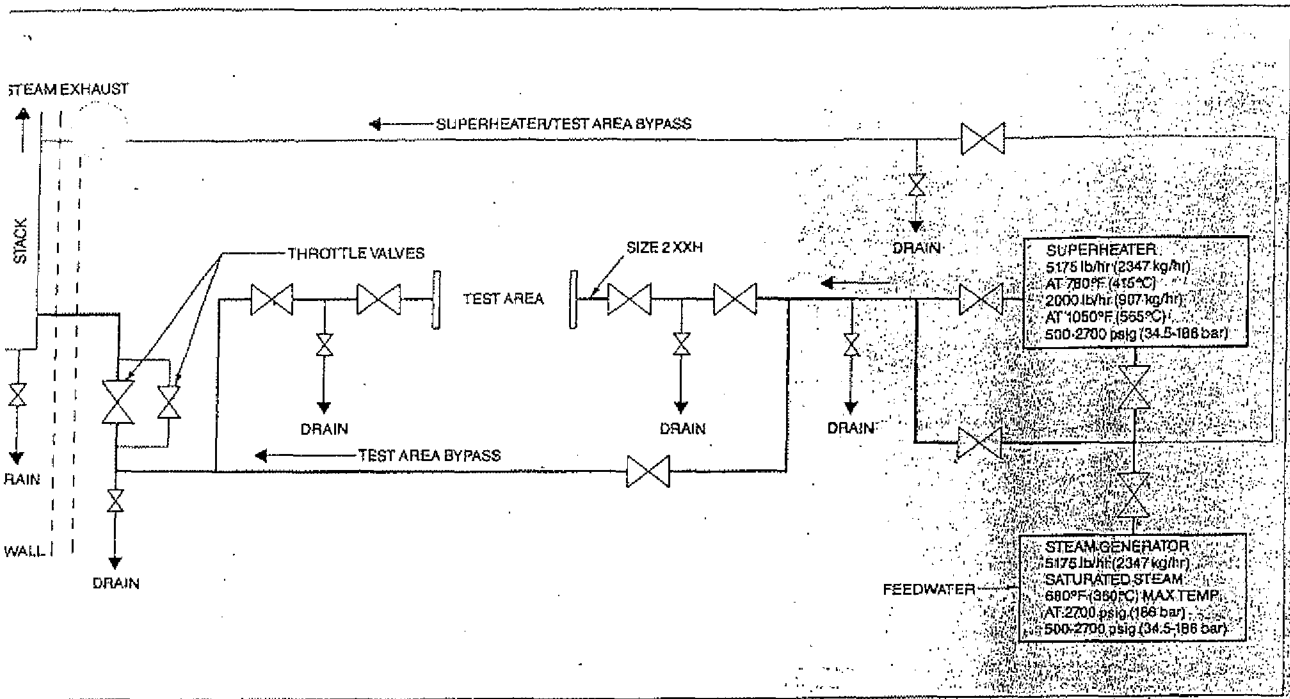
Test Equipment and Facilities

Three test fixtures were used in the course of cycle testing the packing materials. These are shown in Figure 4. Each fixture consisted of a tubular pressure vessel with a packing chamber at each end. A simulated valve stem extended completely through both packing chambers and was connected to an actuator on one end. This design allowed two tests of any particular packing material to be performed at one time. Also, it provided a pressure balanced stem design, so that the actuator had to work against stem packing friction only (no stem blowout load). Stems were made from heat treated AISI 410 stainless steel with a hardness of Rockwell C27 to 35 and a surface finish of very close to 32 microinches (0.80 micrometer), which represents a conservative upper bound on allowable stem surface finishes. This is the normal Rockwell standard for valve stems, although the manufacturing processes normally produce a smoother finish on smaller stems. Some specifiers and manufacturers call for smoother stem finishes, particularly for modulating control valves which are exposed to continuous cycling, but this finish has been found satisfactory in normal on-off valve service. Packing chamber bores were machined to provide a finish of 125 microinches (3.1 micrometers). Again some manufacturers promote smoother packing chamber finishes, but this has not been found necessary in Rockwell tests. All fixtures were designed to operate at 2200 psig (152 bar) at 1000°F (538°C) or 6250 psig (431 bar) at room temperature. These design conditions were chosen to permit simulation of valve service conditions for up to Class 2500 valves per ANSI B16.34.

The smallest fixture was constructed to represent service conditions in small forged steel valves and had a stem diameter of 1.000 inch (25.4 mm). The stem reproduced the helical motion typical of small forged steel valves. Stem travel was 1.68 inches (42.7 mm) and one complete cycle was completed in 30 seconds. The packing chamber was designed to hold 4 packing rings of 0.25 inch (6.4 mm) square cross section. The two packing gland bolts for each packing chamber were 0.625 inch (15.9 mm) diameter, 11 threads/inch (2.3 mm/thread). The packing chamber and gland arrangement simulated one already in use in Rockwell Univalves.

The next largest fixture was built to represent medium size valves, incorporating a 2.375 inch (60.3 mm) stem with translational stem motion only. Stem travel was 10 inches (254 mm), and one complete cycle (extension and retraction) was completed in 45 seconds. Specifically the stem size and travel represented a size 10 Class 2500 Rockwell Equiwedge gate valve. The packing chamber in this fixture was designed to hold a junk ring and 5 packing rings of 0.38 inch (9.5 mm) square cross section. Packing gland bolting was 1.00 inch (25.4 mm) diameter, 8 threads/inch (3.2 mm/thread). Two bolts were used for each packing gland. Stem actuation was by a hydraulic cylinder coupled to the stem. Strain gages on the coupling allowed stem frictional load measurements to be made. Strain gages on the packing gland bolting allowed loads to be monitored during ambient temperature tests (these were removed to avoid damage during hot tests). Hydraulic cylinder pressures were also monitored as a backup to the stem load measurements obtained from the coupling.

The largest fixture was built to represent large cast steel valves, and had a 4.000 inch (101.6 mm) diameter stem, also with translational stem motion only. Stem travel was



IGURE 5

ıckwell Steam Generator Test Loop.

) inch 08 mm). The packing chamber in this fixture as designed to hold a junk ring and 5 packing rings of 50 inch (12.7 mm) square cross section. Packing gland olting was 1.25 inch (31.8 mm) diameter, 12 threads/inch .1 mm/thread). Two bolts were used for each packing gland. acking gland bolting was not instrumented on this fixture. gain, stem actuation was by a hydraulic cylinder coupled the stem. This permitted one complete cycle to be performed within 90 seconds. Hydraulic cylinder pressures ere monitored to determine stem packing frictional loads.

Packing rings of square cross sections were used in l cases. In the case of braided rings, this shape is normal ecause the ring is cut from a "rope" that is square or round d die formed to be a square. Each ring naturally had one ap when installed in the packing chamber, and rings were acked in the chamber so that the gaps in upper rings ere all rotated 90° from the gap in the next lower ring. exible graphite rings are die formed as short tubes and e not limited to a square cross section. It is probable that, ithin limits, shorter washers or taller tubes of flexible aphite would also function similarly providing they have e same volume and density as the assemblies of square oss section rings tested. Square cross sections were sed for this program because of successful prior experience with this form. The die formed rings were cut agonally at two locations to facilitate installation in alves, and the split locations were staggered at 90° at sem The gap in adjacent braided anti-extrusion ngs installed 90° from the splits in the flexible aphite ring.

Room temperature tests were performed by filling e fixture with water and pressurizing it to the test presıre using a pneumatically driven hydraulic pump. High temperature tests were performed in the Rockwell steam generator loop (see Figure 5). The steam generator is capable of providing saturated steam up to 680°F (360°C). A superheater originally installed with the steam generator was not available for this test, so higher temperatures were produced in an electrically heated test loop. This loop (see Figure 6) has a capability of 900°F (482°C) at 2500 psig (172 bar).

At least two tests of each packing material were planned and performed unless the first test was unsuccessful. These were a room temperature test using water as the test medium, and a high temperature test using saturated steam. Braided carbon (or graphite)/flexible graphite packing combinations were tested at 6250 psig (431 bar) during room temperature tests, and 650°F (343°C) at 2200 psig (152 bar) (saturated steam) during hot tests. While valves used in high temperature service are not normally exposed to room temperature pressures this high, they are rated for such pressures by ANSI B16.34. Since manufacturers show the B16.34 ratings (e.g. 6250 psi [431 bar] at up to 100°F [38°C] for Class 2500 valves) in catalogs, it was necessary to verify that the packings can withstand the rated conditions.

Proprietary braided packings were in general tested at 2250 psig (155 bar) (Class 900 100°F/38°C rating) during room temperature tests. This lower pressure testing condition was decided upon after early tests indicated that such materials might not meet requirements for highest pressure valves but might be cost effective for Class 900 and lower. Hot test conditions were generally the same as for the braided carbon/flexible graphite packing material combinations.

Test conditions used in this program were chosen based on earlier packing tests performed by Rockwell

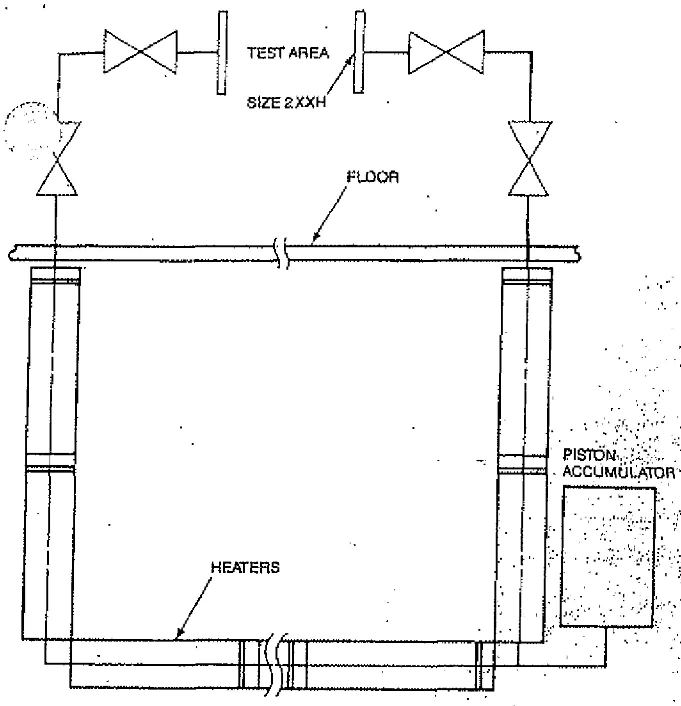


FIGURE 6

Electrically Heated Test Loop Schematic Diagram.

1]. Results of those tests demonstrated that the braided carbon/flexible graphite packing material combinations are not adversely affected by higher temperatures typical of normal steam valve applications. Therefore, 650°F (343°C) was considered adequate to demonstrate acceptable performance in applications involving larger stem sizes than previously tested, and also for proving the performance of other packing materials considered to be "equivalent" to the materials previously tested. Because the high temperature performance of the proprietary braided materials was unknown, most of those that were reasonably successfuly at 650°F (343°C) were subsequently tested at 900°F (452°C) using the electrically heated test loop.

At the beginning of each test, the packing was assembled into the test fixture according to the manufacturers' instructions (when provided). The amount of packing compression at installation was measured and recorded. The packing was first exposed to the shell test pressure and then to the seat leakage test pressure (ANSI B16.34) for the pressure class conditions being tested. Packing leakage was allowed at shell test pressure (1.5 × 100°F rating) but was not allowed at seat leakage test pressure (1.1 × 100°F rating).

For room temperature tests, the pressure was then reduced to the appropriate 100°F (38°C) rating (see Table 3), and stem cycling was started. Packing was checked periodically for leakage. When leakage occurred, the fixture was depressurized and packing gland bolt torque either restored to its original value, or, if that was not effective, increased above its original value until the leakage was stopped. Testing was completed when 2500 cycles (1.000 inch [25.4 mm] fixture) or 1000 cycles (larger fixtures) were completed. These wear cycle limits were selected to provide a conservative upper boundary on expected operation of on-off valves. Normally, larger valves are not operated as frequently as smaller valves. Packing gland bolt loads and stem frictional loads were recorded periodically throughout each test.

For high temperature tests, after completion of shell testing and seat leakage pressure testing, the test fixture was installed in the steam generator loop (Figure 5). At the beginning of each day, the packing was hydrostatically tested with room temperature water at 2500 psig (172 bar) and checked for leakage. Leakage was measured and packing gland bolts retorqued, if required. Then the steam generator was started and the test fixture heated up.

TABLE 3

Test Pressures

Pressure Class	Shell Test Pressure psig (bar)	Seat Test Pressure Psig (bar)	Cycle Test Pressure psig (bar)
600	2250 (155)	1650 (114)	1500 (103)
900	3375 (233)	2475 (171)	2250 (155)
1500	5625 (388)	4125 (284)	3750 (259)
2500	9375 (647)	6875 (474)	6250 (431)

The first two complete cycles each day were performed to simulate a relatively cold stem moving into relatively hot packing, a condition encountered, for example, when valves in steam service stand open for a long period of time and are closed to shut off flow. In the test, the end of the stem furthest out of the fixture was allowed to cool to approximately 100°F (38°C), and then stroked into the packing. Packing temperatures were approximately 540°F (282°C). These "thermal equilibrium" tests were designed to evaluate effects of "thermal taper" of valve stems, since the cool, extended portion of the stem is significantly smaller in diameter than the portion in the packing chamber. In the case of a stem with a nominal diameter of 4.000 inches (101.6 mm), the diameter difference is about 0.012" (0.30 mm). Following the first two complete cycles, wear cycling resumed at the same rate as in the ambient temperature tests. The test was complete when 1000 cycles were completed. Typically, packing in the two larger fixtures underwent three thermal cycles during the hot tests. Packing in the small fixture normally underwent two thermal cycles.

Throughout all tests, stem frictional load was monitored periodically on a strip chart recorder. Stem frictional load is the force necessary to move the stem through the packing, and is a result of the packing being squeezed against the stem to provide a seal.

At the end of all tests, final packing compression was measured and recorded. Packing compression was determined by measuring the axial position of the packing gland before any bolting loads were applied, and then measuring the axial position of the gland at the end of the test (or other point of interest). The difference between these two measurements is the amount of compression and when divided by the nominal packing stack height yields the percentage compression of the packing set.

At the end of the test, the torque remaining on the packing gland bolts was measured and recorded. In selected tests, gland bolt loads and stem friction loads were logged over a range of test pressures at room temperatures. Test fixtures were then disassembled and the packing examined.

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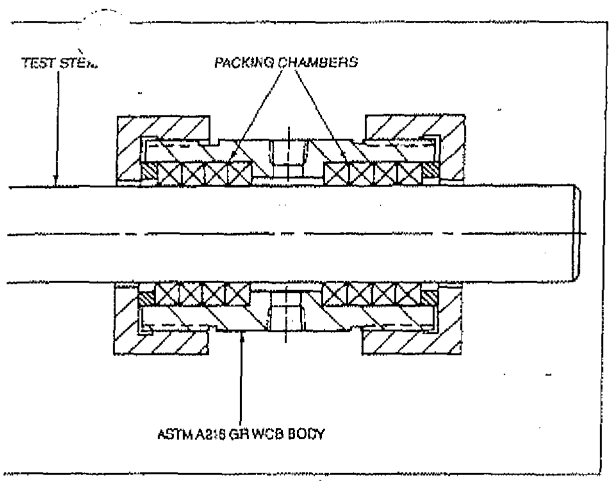

ɜURE 7

osion Test Fixture.

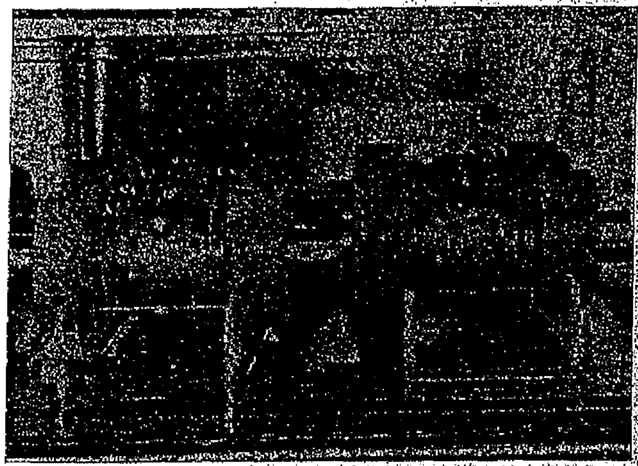

FIGURE 8

Photograph Showing Corrosion Test Fixtures in Test Oven.

rrosion Tests

The corrosion tests were performed to determine effectiveness of the various corrosion inhibitors being ıd or recommended for use with carbon or graphitic :king materials. It was the intent of this study to examine h corrosion of valve stems and of packing chambers. ɜ test fixtures used in the corrosion test program are ıwn in Figure 7.

These fixtures were constructed to represent actual ve packing chambers with a valve stem extending ough them. The "stems" were made from typical valve n materials, heat treated and finished similarly to actual ve stems. The fixture bodies were made from ASTM 16 Grade WCB, a material from which many large cast el valves are typically made.

Before starting the test, all surfaces were cleaned emove any machining oil. The packing to be tested was ded into the fixtures and slightly compressed. Tap water ıpproximately 600 psi (41 bar) was then injected into the :king through the holes in the center of the fixture body. ıssure was maintained until the packing leaked and the :king was wet. Then, the fixtures were placed into a ar plastic container, and the container placed into a ıperature controlled oven for the period of the test (see ure 8). Approximately two quarts (2 liters) of distilled ter w... aced in the bottom of the container. Once :h day, the oven was heated to approximately 100°F °C) and held there for one hour. This was done to ıure a 100% humidity environment around the test ures. Each test was completed when the required test e had elapsed. Two tests were completed after 650 hours (27 days). One test was extended to 2000 hours (83 days). Upon completion of the test, the fixtures were removed from the oven and disassembled. Stem and packing chamber surfaces were inspected to determine the extent of the corrosion, if any.

RESULTS

Table 4 presents cycle test results for all packings tested to date in this program. Results for flexible graphite packings and other proprietary braided packings are discussed individually below.

Flexible Graphite With Braided Carbon and Graphite End Rings

2.375 Inch Stem Tests:

Earlier tests had included extensive room temperature and high temperature verification of braided carbon/flexible graphite packing material combinations in valves with a stem diameter of 1.000 inch (25.4 mm); the first part of the current program emphasized testing with larger stems.

Testing of flexible graphite packing materials began with two room temperature tests of a reference material combination, Garlock 98 end rings with Grafoil center rings, in the 2.375-inch (60.3 mm) stem test fixture. This testing, as well as most other room temperature testing of flexible graphite packing materials, was performed at 6250 psig (431 bar). Packing gland bolt torques of 175 ft-lbf (237 N.m) were used in these tests, corresponding to a pressure loading on the packing of approximately 6500 psi (448 bar), slightly higher than the test pressure.

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TABLE 4
Cycle Test Results

1.00 Inch (25.4 mm) Diameter Stem Test Results

Manufacturer	Material Combination	Test Number	Bolt Torque Ft-Lbf	Packing Pressure Load, psi	Test Temp. F	Test Press. psig	Stem Torque Ft-Lbf	Packing Compression %	Packing Adjustments Required	Number of Cycles Completed	Notes/ Comments
Martin Merkel GmbH & Co. KG	Carbosteam/ Grafiflex	1-K	40	7800	70	6250	37.5	NA	2/8	1361	1,2
Latty International	Lattygraf 6000/ Lattygraf E1	1-H	40	7800	70	6250	30	27	1/1	2500	
Latty International	Lattygraf TSP/ Lattygraf E1	1-J	40	7800	650	2200	35	28	0/0	1000	
Garlock, Inc.	1200-PBI	1-B	82	16000	70	2250	68	25	0/1	2500	
		1-D	82	16000	650	2200	102	20	0/0	796	3
A. W. Chesterton Company	Style 1-CI/GPP	1-C	41	8000	70	2250	40	NA	2/1	2500	1
		1-E	41	8000	650	2200	55	NA	1/0	1000	1
A. W. Chesterton Company	Style 1800	1-L	46	9000	70	2250	33	27	0/2	2500	
		1-M	46	9000	900	2000	28	41	2/2	1000	22
Garlock, Inc. Union Carbide	Garlock 1200-PBI/ Grafoil	1-F	41	8000	650	2200	55	33	3/3	1000	10
		1-G	41	8000	650	2200	18	37	1/1	1000	
		1-I	40	7800	900	2200	28	22	0/1	500	11

2.375 Inch (60.33 mm) Diameter Stem Test Results

Manufacturer	Material Combination	Test Number	Bolt Torque Ft-Lbf	Packing Pressure Load, psi	Test Temp. F	Test Press. psig	Stem Friction Lbf	Packing Compression %	Packing Adjustments Required	Number of Cycles Completed	Notes/ Comments
Garlock, Inc. Union Carbide	Garlock 98/ Grafoil	5	125	4600	70	6250	1200	28	0/0	1000	
		24	125	4600	650	2200	2300	30	2/1	1000	
		1	175	6500	70	6250	2500	NA	0/0	1000	
		2	175	6500	70	6250	1500	29	0/0	1000	
		3	175	6500	650	2200	3000	29	0/0	1000	
		4	175	6500	650	2200	1500	23	NA	1347	16
		26	—	3100/4400	650	2200	2500	20	0/0	1000	Live loaded
		19	175	6500	70	6250	3200	33	1/1	2500	Extended Cycle Testing
		20	50	1850	70	1500	1500	26	0/0	1000	15
		21	50	1850	572	1246	1200	16	3/3	1000	15
A. W. Chesterton Company	Style 1-CI/GTPI	14	330	12200	70	6250	4000	NA	2/3	1000	4
		15	330	12200	70	6250	4000	NA	2/1	1000	4
		16	330	12200	650	2200	3800	NA	0/0	1000	4
Martin Merkel GmbH & Co. KG	Carbosteam/ Grafiflex	27	200	7400	70	6250	2700	32	0/0	1000	17
		28	200	7400	650	2200	2700	36	1/1	1000	
Latty International	Lattygraf 6000/ Lattygraf E1	23	200	7400	70	6250	3500	28	0/0	1000	5
		31	200	7400	650	2200	3900	24	1/1	1000	
Garlock, Inc.	1200-PBI	6	150	5600	70	2250	2500	30	0/0	1000	
		7	150	5600	70	3750	3400	27	1/1	1100	
		8	150	5600	70	6250	NA	28	2/2	1000	6
		9	150	5600	650	2200	900	26	1/1	376	12,3
		10	150	5600	650	2200	750	25	1/1	327	13,3
		17		5600	650	2200	1500	27	3/2	700	9,7
Parker Seal Group	Parker 2028	11	150	5600	70	2250	1800	32	1/1	1200	14
		12	150	5600	650	2200	600	38	4/4	790	9,3
John Crane-Houdaille, Inc.	Crane 287I	13	175	6500	70	2250	5700	29	2/2	200	8
A. W. Chesterton Company	Style 1800	29	240	8900	70	2250	2800	35	2/2	1000	
		30	240	8900	650	2200	N/A	30	0/0	0.5	21

4.000 Inch (101.6 mm) Diameter Stem Test Results

Manufacturer	Material Combination	Test Number	Bolt Torque Ft-Lbf	Packing Pressure Load, psi	Test Temp. F	Test Press. psig	Stem Friction Lbf	Packing Compression %	Packing Adjustments Required	Number of Cycles Completed	Notes/ Comments
Garlock, Inc. Union Carbide	Garlock 98/ Grafoil	4-A	475	6500	70	6250	4000	33	0/0	1000	18
		4-B	350	4750	650	2200	5900	3	1/1	1000	19,20
		4-C		3100-4400	650	2200	7100	N/A	1/1	1000	Live loaded
Garlock, Inc.	Garlock 98/ Graph-Lock	4-D	414	5600	650	2200	6100	26	1/1	641	23,24

General Notes:

Where two materials are listed together, the first is the anti-extrusion ring material and the second is the center ring material.
Packing adjustments required shows the number of adjustments required for test end 1 followed by number of adjustments required for test end 2.
Stem friction loads listed are largest measured during each test.
Notes/Comments:

1. Extra braided end ring required to prevent packing gland from bottoming out.
2. Test stopped due to excessive ambient temperature leakage.
3. Could not pass ambient temperature hydrotest at 2600 psig after cooldown from hot testing.
4. Extra braided end rings required for sealing.
5. Recommended bolt torques too low to provide sealing.
6. Torque increased to 175 Ft-Lbf after 500 cycles.
7. Torque established at 300 ft-lbf to maintain desired packing pressure loading after relaxation.
8. Test stopped due to excessive ambient temperature leakage.
9. Packing gland bolt torques increased to 175 ft-lbf after 160 cycles.
10. Gland bolt torques increased to 50 ft-lbf at 248 cycles.
11. Test terminated normally at 500 cycles.
12. Gland bolt torques increased to 175 ft-lbf after 6 cycles.
13. Gland bolt torques increased to 175 ft-lbf after heatup but before first stem cycle.
14. Retorque at 1000 cycles *successful* at *stopping* minor leakage. Extra 200 cycles completed as verification.
15. Gland bolt torques increased to 75 ft-lbf during seat leakage.
16. Packing did not leak after gland bolt torques at one end were reduced to 6 ft-lbf.
17. Three retorques required to seal against seat leakage test pressure.
18. Gland bolt torques were decreased to 350 ft-lbf at 0 cycles because stem frictional load was large enough that the hydraulic cylinder could extend but not retract.
19. Test 4B was a continuation of Test 4A, with the test fixture not being repacked before the start of the test. Gland bolt torques were restored to 350 ft-lbf before the start of the test.
20. Compression represents additional compression after retorquing to 350 ft-lbf in preparation for this test.
21. Test was stopped after severe leakage developed during first "thermal equilibrium" cycle.
22. Packing adjusted after first thermal equilibrium cycle to stop leakage.
23. First 100 cycles completed at room temperature, 6250 psig.
24. Test stopped after 641 total cycles for maintenance on steam generator.

Results of this testing were very good. Two 1000 cycle tests were completed with no adjustments of the packing required at all. Compression of the packing at the conclusion of testing (but with bolt loads still applied) was approximately 29%, with most of the compression occurring as a result of initial bolt preloading and hydrostatic testing. Normally, very little additional compression of the packing was observed during the subsequent cycle testing. Stem frictional loads averaged approximately 3000 lbf (13,300 N) per 5-ring packing set.

Probably the most interesting observation made during these first two tests was that during the cycle testing, while the test fixture was at test pressure, the measured packing gland bolt load quickly approached a load equal (within experimental accuracy) to the hydrostatic end load on the packing due to test pressure. That the force measured at one end of the packing set is approximately equal to the force being applied at the other end suggests the axial pressure within the packing is, to a reasonable extent, evenly distributed, and additionally suggests that the packing is to a great extent pressure energized. This result was unexpected.

Results of hot testing of the reference material design were equally as good. The initial test setup was the same as for the room temperature tests described above. As noted previously, the first two complete cycles of the stem each day were thermal equilibrium cycles, which involved cycling a relatively cold stem into a hot packing chamber. During this part of the testing, minor visible steam leakage through the packing was observed; it started part way during stem motion and stopped when stem motion stopped or within a few seconds thereafter. During such thermal equilibrium cycles, there was no leakage at the opposite end of the fixture where the hot stem came out of the packing chamber and a *hotter* section of stem entered the chamber (simulating opening of a valve that was already hot).

Leakage through the packing was not visually observed during normal continuous wear cycling. Stem frictional loads during this test were approximately the same as had been observed during room temperature testing.

At this point in the testing, it was observed that after depressurization at the end of 1000 cycles, packing gland bolt torques had decreased to provide a pressure loading on the packing of approximately 3270 psi (225 bar), a 50% reduction from the initial preload value of 6500 psi (448 bar). This result suggested that it may be possible to lose a significant amount of packing gland bolt preload during normal operation. Therefore, Test No. 4 was performed to find out what would happen during high temperature operation if practically all packing gland bolt preload was lost.

Results of Test No. 4 were surprising. After initial test setup, hydrotesting and 570 hot wear cycles, gland bolt torques on one packing gland were intentionally removed completely, then retightened to reduced levels of 15 ft-lbf (20 N.m), and then to 5 ft-lbf (7 N.m) torque to determine the impact on packing leakage during high temperature operation. Leakage in this test was virtually the same as in the previous hot test. These results indicate that some other phenomenon is occurring which helps the packing to seal. This supports previous test results showing that this packing combination tends to be pressure energized after it is initially compressed at installation.

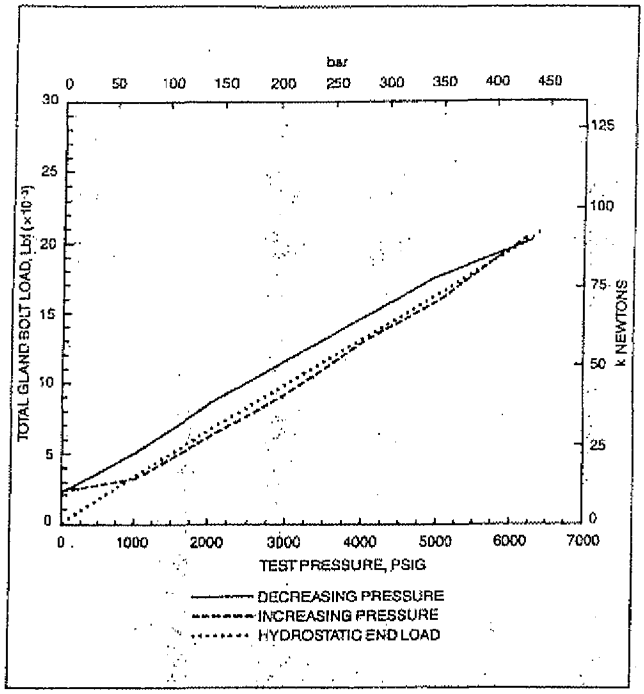

FIGURE 9

Packing Gland Bolt Load vs. Test Pressure, Garlock 98/Grafoil Combination Test 5 - Room Temp - End of Test.

In a further consideration of the previous results, Test No. 5 was performed. In this test, packing gland bolt preload torques of 125 ft-lbf (169 N.m) were used to determine if reduced initial bolt loading would adversely affect packing performance. This torque produced a gland pressure of just 4600 psi (317 bar) or just 74% of the test pressure.

Results from Test No. 5 indicated that although retorquing to 125 ft-lbf was required after hydrotest to seal at the seat leakage test pressure (6875 psi or 474 bar), no retorquing was required during this 1000 cycle room temperature test. High temperature testing (Test 24) using this same packing gland bolt torque yielded slightly degraded (but acceptable) performance, with one packing set retorqued twice and the other end once to control packing leakage during the 1000 cycle test.

Results of measurements made at the end of Test No. 5 to determine the effect of test pressure on packing gland bolt load are shown in Figure 9. Test pressure was gradually reduced from 6250 psig (431 bar) to 0 psig and then back again. At each data point, the stem was cycled a few times to eliminate residual effects from the last pressure tested. Bolt loads were summed to determine total gland load, which is plotted in the figure. These data are compared to the hydrostatic force on the packing. The gland pressure at zero test pressure had declined from the 4600 psi (317 bar) pretest value to just 680 psi (47 bar), yet the packings continued to seal at all pressures to 6250 psig (431 bar). It is clear that as the hydrostatic end load on the

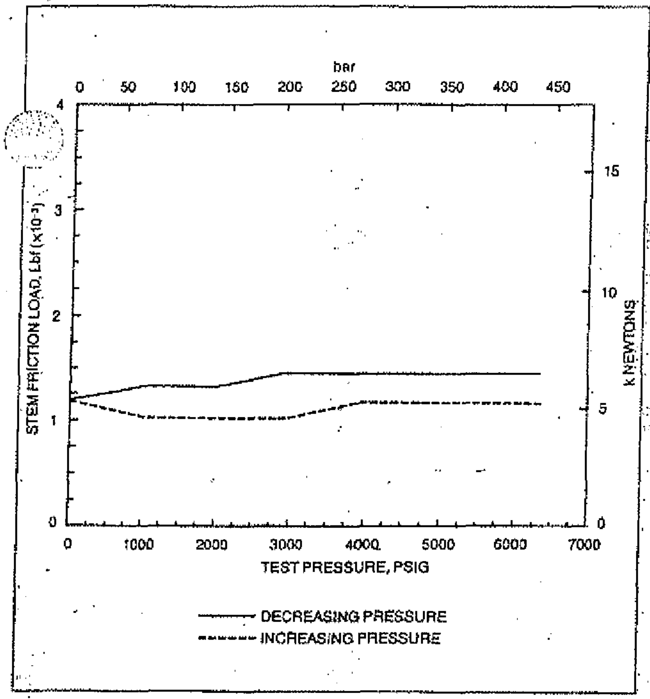

FIGURE 10

Stem Friction Load vs. Pressure, Garlock 98/Grafoil Combination Test 5 - Room Temp - End of Test.

packing increases above that resulting from total gland bolt preload on the packing, total gland bolt load and the hydrostatic load on the packing are very nearly equal.

Figure 10 shows measurements made at the end of Test No. 5 to determine the impact of test pressure on stem packing friction load. These data were taken in the same manner as the data shown in Figure 9. These results indicate that for the reference material design, stem packing friction loads are essentially independent of test pressure. This was unexpected.

These results have some very interesting implications with respect to effect of loadings on this packing material combination. It is reasonable to assume, although not proven here, that there is a minimum initial amount of axial compression (i.e., gland bolt load) of the packing required to make it seal properly. This is due primarily to the radial flow of the packing required to take up clearances between the packing and the stem and packing chamber sidewall. Then, if the hydrostatic end load on the packing is greater than this mimimum load, packing performance would be expected to be good, although not necessarily perfect. This is not to say that total loss of packing gland bolt preload is acceptable. However, this does mean that, assuming the packing was installed properly to begin with, live loading of the packing (using belleville spring washers, for example) would not be expected to dramatically improve packing performance, since the packing is already "live-loaded" by line pressure.

All previous tests of the reference material design in this test program had a test duration of 1000 cycles. In order to demonstrate a reasonable amount of performance margin, Test No. 19 was performed. This was an ambient temperature test at 6250 psig (431 bar), but with a duration of 2500 cycles. During the course of this test, adjustment of each packing set was required only once. These results indicate that the reference packing material combination has an adequate performance margin. Additionally, because the test (as well as all others in this program) was performed using a stem with a 32 microinch (0.80 micrometer) surface finish, this surface finish is acceptable for valve stems, at least as a worst case. In all tests of flexible graphite packing and braided end rings, stems were found to polish to a finish of about 20 microinches (0.50 micrometers) during cycle tests; stems were removed from test fixture and "roughened" to 32 microinches between tests. As a result of these test results, tests to determine packing performance with stems having smoother surface finishes were not performed. While finer stem finish might offer some advantage in control valves which cycle continuously, it does not appear to be a factor in on-off valve service.

Tests No. 20 and 21 were performed to determine if packing sets with just 4 rings of the reference material combination could be used with valve stems as large as 2.375 inch (60.3 mm) diameter at operating conditions up to those of Class 600 valves. Ambient temperature performance of the packing sets was very good, with no adjustments of the packing required during the 1000 cycle test duration. Performance during hot testing at 572°F and 1246 psig (300°C and 86 bar) was also successful. Leakage of steam through the packing during hot testing was minimal. Three adjustments of each packing set were required during the test, which was more than normal but acceptable for most applications. These adjustments were all required to seal ambient temperature water at 2500 psig (172 bar) during hydro-testing after cooldown from hot testing. These results indicate that the 4-ring packing sets of the reference packing material combination can be used successfully in Class 600 applications with stems as large a 2.375 inch (60.3 mm) diameter.

2.375 Inch Stem Test—Live Loaded

Test No. 26 was performed to assess the impact of live loading on the packing material. Live loading was accomplished by applying belleville washer stacks in place of the standard gland bolting. The washer stacks were designed and pre-conditioned according to the AECL proposed design criteria [8] using 2500 psig (172 bar) as the design operating pressure. The 2500 psig design pressure was chosen because the high temperature tests could only be performed at 2200 psig (152 bar) and it was desired to design the spring stacks based on the actual test pressure. The stacks were designed to deliver 1.25 to 1.75 times the hydrostatic loading on the packing over a spring travel of 0.116 inches (2.95 mm). Spring travel requirement was derived based on results of previous tests. The spring stacks are shown in Figure 11.

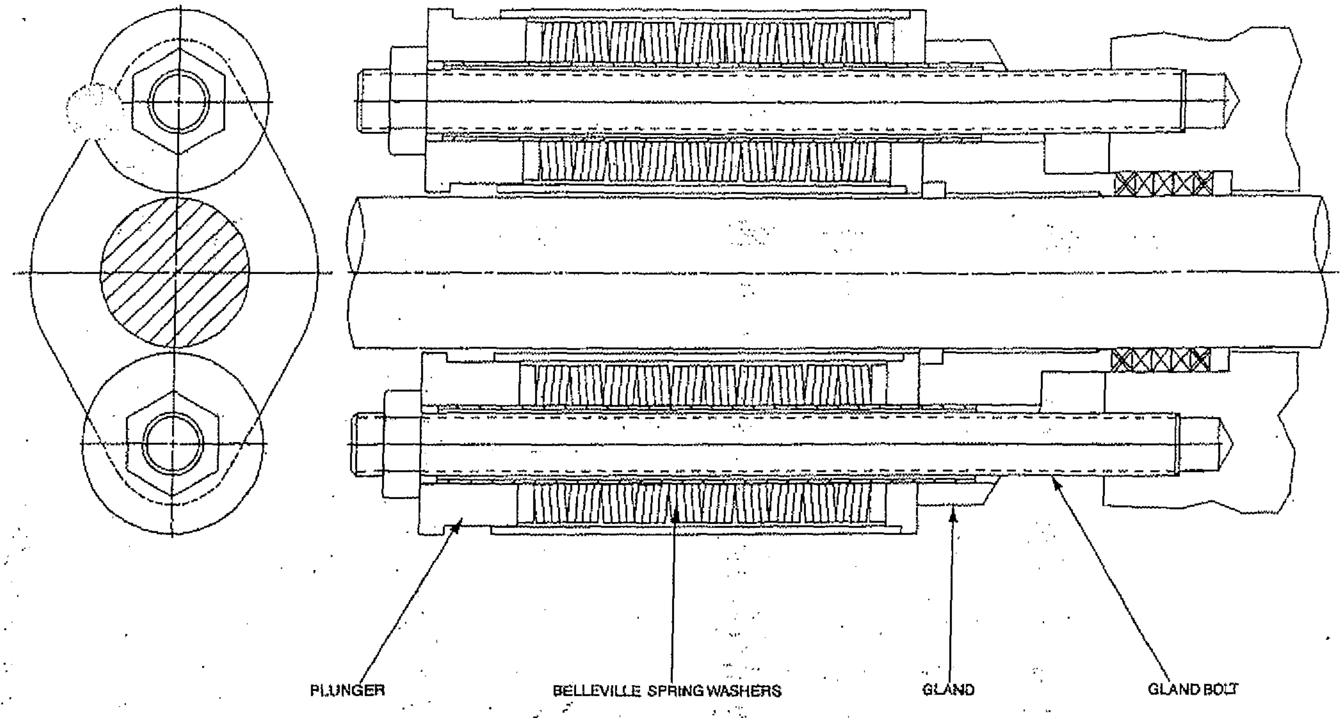

FIGURE 11

Live Loading Arrangement.

In preparation for testing, the packing was installed two rings at a time and compressed using a gland pressure load of 6500 psi (448 bar) before the next two rings were installed. The fifth ring was installed individually in the same manner. This procedure was used for consistency with that previously used in assembling Rockwell nuclear power plant valves with live-loaded packings. The standard bolting apparatus was then replaced with the live loading apparatus. Lines were previously scribed on the spring stack plunger (see Figure 11) to indicate the 125% and 175% load positions and were used to establish the configuration of the spring stacks prior to the start of testing.

The first 500 cycles of this test were performed at room temperature and 2250 psig (155 bar). Room temperature performance was very good, with no leakage observed. The stem began "groaning" at approximately 19 cycles and stopped at approximately 170 cycles. This was not observed in previous tests without live loading. The last 500 cycles of this test were performed at 650°F (343°C) and 2200 psig (152 bar). On the first day of testing, thermal equilibrium cycles exhibited no leakage (an improvement), and no leakage was noted during normal wear cycles. On the second day of testing, however, the packing leaked steam during thermal equilibrium cycling to approximately the same transient degree as packing with standard gland bolting. Wear cycling was without incident. These results indicate that live loading improves packing performance, but not as significantly as might have been expected. During testing, gland travel for test ends 1 and 2 was .081 (2.1 mm) and .064 inches (1.6 mm) respectively (well within the 0.116 inch (2.95 mm) design spring travel).

Stem frictional loads observed during this test are compared to loads observed in earlier tests in Figure 12. Data in curves 1 and 2 were taken from tests performed at 6250 psig (431 bar) using standard bolting, with the difference being the initial gland bolt torque. Curves 1 and 2 show a definite increase in stem frictional load with increasing initial gland bolt torque. Data from the live loaded packing test show higher stem packing friction occurring for a lower test pressure and lower unit pressure loading on the packing. The step increase in the magnitude of the stem frictional load with the live loaded packing at 500 cycles occurred after the test fixture had been reconfigured for the hot portion of the test, and has no specific explanation; since several days were required for the reconfiguration, a simple "time set" effect may have been involved.

4.000 Inch Stem Tests:

Testing of braided carbon/flexible graphitic packing material combinations was also conducted in the 4.000 inch (101.6 mm) diameter stem test fixture. Testing in this fixture was performed in the same manner as in the 2.375 inch (60.33 mm) test fixture. Packing was loaded into the fixture and the gland bolts torqued to 475 ft-lbf (644 N.m), sufficient to provide 6500 psi (448 bar) pressure loading on the packing. This is the same value used in most tests in the 2.375 inch fixture.

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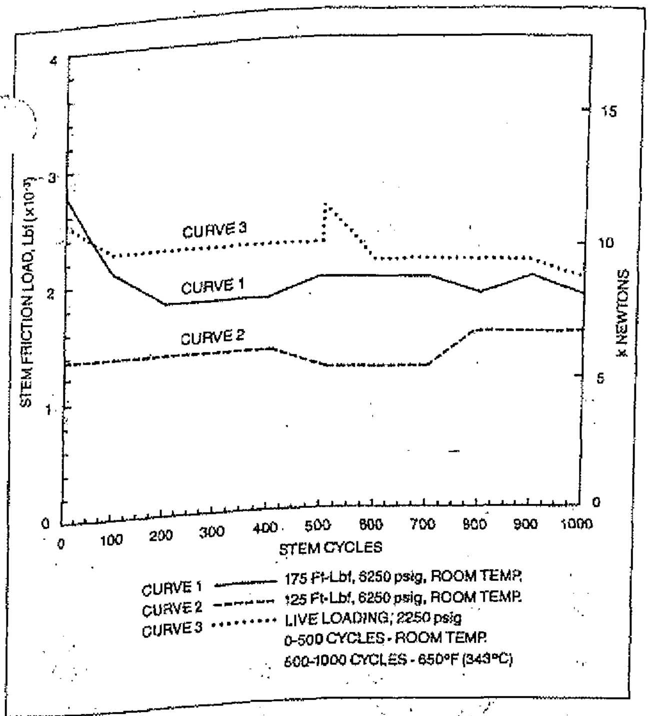

FIGURE 12

Stem Friction Load vs. Cycles, Garlock 98/Grafoil Combination Normal Bolting vs. Live Loading.

The first two tests performed in this fixture were a room temperature test at 6250 psig (431 bar) and a 650°F, 2200 psig (343°C, 152 bar) test, respectively. After assembly of the fixture prior to beginning the first test, it was discovered that the hydraulic cylinder could extend but not retract against the frictional load caused by the packing. Therefore, gland bolt torques were reduced to 350 ft-lbf (475 N.m) to reduce the stem friction load. While this produced a gland pressure load of just 4800 psi (330 bar), it was decided to proceed. Tests 5 and 24 (Table 4) with the 2.375 inch fixture had produced successful results with a similar packing pressure load. The fixture was then pressurized to the seat leakage test pressure (6875 psig/474 bar) to verify proper sealing of the packing. When proper sealing had been verified, cycling of the stem was started. Results of this first test were good, with just 2 adjustments to each packing set being required during the 1000 cycle test.

After all measurements had been made at the end of this first test (4A), it was decided not to disassemble and repack the fixture, but rather to simply restore the gland bolt torque of 350 ft-lbf (475 N.m) and go directly into the 650°F (343°C) test. This was done primarily to save time, although the results demonstrate considerable performance margin.

High temperature tests in the 4.000 inch (101.6 mm) fixture were performed in the same manner as those in the 2.375 inch (60.33 mm) fixture. The only change was in thermal equilibrium cycling. Because of the size and mass of the stem and the time required to heat and cool it, only one thermal equilibrium cycle was performed at the beginning of each test day, as opposed to two in previous tests.

Performance during this second test was also good. No leakage was observed during the first thermal cycle. During the second through the fourth thermal cycle, minor leakage was noted during thermal equilibrium cycles. Minor leakage during hydrostatic testing at 2500 psig (172 bar) at the end of the second thermal cycle prompted an adjustment of both packing sets to stop the leakage. No additional adjustments to the packing were required.

Upon disassembly following Test 4B, full-stroke scoring of the stem was observed at test end 1. Foreign material found in the test fixture (resulting from manufacture and heat treatment) was the probable cause. Even with this scoring, however, test end 1 sealed leak tight against a hydrostatic test pressure of 2500 psig (172 bar) at the end of the test. While certainly not intentional, this test demonstrated the ability of this packing combination to "heal" the effects of a valve stem damaged in this manner.

The Garlock 98/Graph-lock material combination was also tested in the 4.000-inch (101.6 mm) test fixture. Only one test of the material was performed. The first 100 cycles of the test were performed at room temperature/6250 psig (431 bar). The remaining 541 cycles were performed at 650°F/2200 psig (343°C/152 bar). Testing was stopped at 641 cycles due to maintenance requirements on the steam generator. Room temperature performance was good. Additionally, no leakage was observed during wear cycling at high temperature. Performance during "thermal equilibrium" cycling was good at the beginning, but the amount of leakage and time before it stopped increased with each thermal cycle; higher initial gland bolt torques (i.e., gland pressure loading on the packing) might have solved this problem.

4.000 Inch Stem Test—Live Loaded:

Testing of the live-loaded packing (Test 4-C in Table 4) in the 4.000 inch (101.6 mm) test fixture was conducted in a slightly different manner than in previous tests. Test end 2 (see Figure 4B) was fitted with belleville washer stacks while test end 1 remained with conventional gland bolting. This arrangement allowed the full 20 inch (508 mm) stem stroke to be maintained, while at the same time providing a repeat test with conventional gland bolting.

In this test, as in the previous live-loaded packing test, the first two rings of packing were loaded into the test fixture and compressed to 6500 psi (448 bar) gland pressure. These first two rings were then followed by the second two, and finally the last ring in the same manner. Both test ends were packed this way. Belleville washer stacks were then fitted on test end 2, while the gland bolt torques on test end 1 were adjusted to 350 ft-lbf (475 N.m).

The spring stacks used in this test were designed to provide 125 to 175% of the hydrostatic end load on the packing at 2500 psig (172 bar) over a travel of 0.112 inches (2.84 mm). Results from the previous two tests in this test fixture indicated that for tests 4-A and 4-B combined, total gland motion due to gland readjustments was approximately 0.102 inches (2.58 mm), so that the design should be adequate.

The first 500 cycles were performed at room temperature, 2250 psig (155 bar). Significant motion of the live-loaded gland (0.050 inch/1.27 mm) was observed during the first 100 cycles of the test. Gland motion continued at a much reduced rate until at the end of 500 cycles, total live-loaded gland travel had reached 0.082 inch (2.16 mm).

tal gland motion with conventional bolting was approximately 0.004 inch (0.10 mm). Neither end was exhibiting ıy sign ... akage during these first 500 cycles.

T... st fixture was next installed into the steam ɜnerator test loop in preparation for high temperature 50°F, 2200 psig) (343°C, 152 bar) testing. A total of three ermal cycles was completed during this test. At the beginng of each thermal cycle, one "thermal equilibrium" cycle as conducted. During the first thermal equilibrium cycle, ɪe live-loaded packing did not leak, while slight leakage as observed from the conventionally loaded packing. uring the second thermal cycle, leakage of approximately ıe same magnitude was observed from both packing seats.

At the end of the second thermal cycle and after the ɪst fixture had cooled to room temperature, it was observed ıat the live-loaded gland travel had exceeded that for 'hich the belleville spring stacks were designed. There- ɔre, the spring stacks were restored to the 175% load conition prior to the heatup for the third thermal cycle. At this ame time, the conventional gland bolt torque was restored ɔ 350 ft-lbf (475 N.m).

No leakage was observed from either packing hamber during thermal equilibrium cycling at the beginıing of the third thermal cycle. Throughout the wear cycling ıortion of the hot test, no leakage was observed coming rom either packing set. Also, no leakage was observed hrough either packing set during room temperature ıydrostatic testing of the packing following cooldown after ɜach thermal cycle. The maximum stem packing friction oad of 7100 lbf (31.5 KN) was observed at the beginning ɔf the ...ŋ temperature portion of the test.

Alternate Carbon and Graphite Packing Materials:

Material combinations with braided carbon or graphite end rings and flexible graphite central rings from other manufacturers were tested variously in two of the cycle test fixtures. In general, assuming that proper gland bolt preloads were specified, performance of these packings was comparable to that of the reference material combination. Short discussions of each material combination tested follow.

Chesterton®[6] Style 1-CI/GTPI packing material combination was tested in the 2.375 inch (60.3 mm) stem test fixture. The packing gland bolt torque recommendation from Chesterton for this material combination was the highest of all materials tested and resulted in the highest stem friction loads measured during testing of the graphitic materials. In spite of this, however, the first room temperature test performed using this material (Test 14) showed poor results because of minor uncontrollable leakage from both packing chambers. It was noted that the Chesterton Style 1-CI end ring is of braided graphite (not carbon) construction, and a similar problem was encountered with different braided graphite end rings at high pressures in earlier Rockwell tests [4]. Nevertheless, this problem was solved in a subsequent ambient temperature test by installing an additional Style 1 end ring next to the packing gland in each packing chamber after hydrostatic test. With this ch... both room temperature and high temperature sealing performance was good, but packing friction was quite high. However, this change made the 5 ring packing chamber into a 6 ring packing chamber, and it requires additional manufacturing assembly steps (adding a packing ring after initial compression).

Martin Merkel Carbosteam®[7]/Grafiflex®[7] packing material combination was tested in both the 2.375 inch (60.3 mm) and 1.000 inch (25.4 mm) stem test fixtures. Performance in the 2.375 inch fixture during both room temperature and high temperature testing was very good. Room temperature testing of this material in the 1.000 inch test fixture was troubled by leakage which could not be controlled. Martin Merkel has been consulted about this problem. A high temperature test in the 1.000 inch fixture was not performed.

The Lattygraf 6000/E1 packing material combination was tested in both the 1.00 inch (25.4 mm) and 2.375 inch (60.3 mm) test fixtures. Room temperature and high temperature performance in the 1.000 inch test fixture was very good. A problem with obtaining the correct packing gland bolt torques from the supplier hindered the testing in the 2.375 inch test fixture. The first torque recommendation received appeared to be too low, although recommended gland pressure loading (500 bar or 7200 psi) appeared to be approximately correct. A revised torque value received from the Latty U.S. representative was too high and the packing friction caused the actuator to stall. A third recommendation was low, and the packing leaked. At this point, Rockwell gradually increased the torque to 200 ft-lbf (271 N.m) and achieved an effective seal. Performance in the room temperature test then was very good, although packing friction was still somewhat high. Performance in the high temperature test was also good, with only one adjustment of each packing set required during the 1000 cycle test. Stem frictional load was slightly higher than in the room temperature test.

Proprietary Braided Packing Materials

Proprietary braided packing materials from several manufacturers were tested. All of these packing materials were rated by the manufacturers for high temperature, high pressure service at the time they were submitted for tests. During this test program, all of these packing materials were tested at 2250 psig (155 bar) during room temperature testing, and at 650°F (343°C), 2200 psig (152 bar) during high temperature testing. The high temperature test conditions are very close to a Class 900 operating condition. Packing compression for all materials tested averaged around 30%. Generally, but with one notable exception, materials which performed best tended to maintain packing gland bolt preload well. This is because these proprietary materials tend to undergo volume loss during heatup, usually related to volatization of substances contained in the packing. That volume reduction translates directly into loss of gland preload.

With one exception, performance of these proprietary materials during ambient temperature testing was very good. One specifically was tested at up to 6250 psig (431 bar) and performed very well. However, with two exceptions, most proprietary braided packings failed to perform satisfactorily during high temperature testing. Discussions of the individual materials tested are presented below.

[6]Chesterton is a registered trademark of the A. W. Chesterton Co.

[7]Carbosteam and Grafiflex are registered trademarks of Martin Merkel Gmbh & Co.

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Several tests of Garlock 1200-PBI were performed during the test program. This material performed very well at room temperature, with no adjustments of the packing required in 1000 cycles at 2250 psig (155 bar). Room temperature testing was carried to 6250 psig (341 bar) with very good results. Three high temperature tests of this material were performed. The first two tests showed similar results, those being significant leakage during thermal equilibirium cycling, followed by a gradual increase in steam leakage during normal wear cycling. In addition, the packing could not be made to seal ambient temperature water at 2500 psi (172 bar) following cooldown after only one thermal cycle, indicating that it had hardened and lost its resilience. Increases in gland bolt loading produced no measurable packing compression, and post-test examination disclosed that packing rings had fused into a single, rigid tubular form.

These results were reveiwed with Garlock representatives who offered specific recommendations to improve packing performance. These changes substantially improved performance with the final high temperature test lasting 700 cycles, almost twice as long as previous tests. Steam leakage through the packing was also substantially reduced, but the packing could not be made to seal against room temperature water at 2500 psi (172 bar) after cooldown following the second thermal cycle. Testing was stopped at that point.

Although high temperature test results for Garlock 1200-PBI by itself were not encouraging, some potential was seen for this material as an anti-extrusion ring for use with flexible graphite packing material. The hardening of the rings (which prevented successful test results with these rings alone) made the material a good candidate as an anti-extrusion ring.

Three tests (1-F, 1-G, 1-I) of a Garlock 1200-PBI/Grafoil material combination were performed in the 1.000 inch (25.4 mm) diameter stem test fixture to determine the performance of this material combination. Testing consisted of two tests at 650°F (343°C) and one test at 900°F (483°C), both at 2200 psig (152 bar). No room temperature testing was performed, as previous results indicated that room temperature performance of both materials should be satisfactory.

Results of the first two tests were good, with performance during the second test being somewhat better than the first. The presence of the flexible graphite in the packing set gave it the resilience required to provide adjustability to control leakage, and the Garlock 1200-PBI functioned well as an anti-extrusion devise. The third test at 900°F (482°C) again showed good performance of this material combination. Over the 500 cycle duration of the test, one packing set was adjusted once and the other set not at all. The test was terminated at 500 cycles as an adequate demonstration.

Parker 2028 material was tested in the 2.375 inch (60.3 mm) stem test fixture. After this test was completed, Parker stopped production of the material tested and later introduced a new packing material carrying the same identification number. Since the material tested is no longer produced, discussion of the results of the testing will be brief. Compression of this packing was high at the torque required to effect a seal, 32 to 38 percent. Room temperature performance was good. At the beginning of high temperature testing, melted packing material was noted coming out of the packing chambers. However, high temperature performance started off good but gradually degraded until, during the fourth thermal cycle, the testing was stopped due to excessive steam leakage. Rockwell has not tested the new 2028 material.

JohnCrane 2871 was the only packing tested which could not pass the room temperature screening test. A high temperature test was not attempted. This packing is no longer available from JohnCrane. A new JohnCrane material, EX-363, was received for testing but not in time for inclusion of results in this paper.

Two Chesterton packings were tested in this part of the test program, these being the Style 1-CI/GPP (graphite powder packing) combination and the Style 1800 packing material. The Style 1-CI/GPP material combination was tested only in the 1.000 inch (25.4 mm) stem test fixture. Both room temperature and high temperature performance were good. Again, however, an extra Style 1 end ring had to be added to the top of each packing chamber, because packing compression caused the glands to bottom out, leaving no further adjustment. This made the original 4 ring packing chamber a 5 ring packing chamber and involves use of additional assembly labor to add the fifth ring.

The Chesterton Style 1800 packing was tested in both the 2.375 inch (60.3 mm) and the 1.000 inch (25.4 mm) stem test fixtures. Testing in the larger fixture was performed first. Room temperature performance was good, although initial cycling caused extrusion of an alarming amount of wear debris from the gland. During the first cycle of the high temperature test, however, the packing started leaking steam severely, so the test was stopped. After cooldown, a room temperature hydrotest at 2500 psi (172 bar) showed significant leakage. While this leakage could be controlled through tightening the gland bolting, the test was curtailed and Chesterton was consulted.

About this same time, room temperature testing of this material was being completed in the smaller (1.000 inch/25.4 mm stem) test fixture. It was decided to omit the 650°F (343°C) test and proceed to test the material in the electrically heated loop at 900°F (482°C) and 2200 psig (152 bar). Initial results during this test were the same as in the previous hot test—significant steam leakage during the first stem cycle. However, at this point the test fixture was depressurized and the gland bolt torques, which had dropped to a very low value, were restored to their original value. This solved the leakage problem, and subsequent high temperature performance of this packing was very good. Chesterton was consulted, and their representative claimed that because this packing is a "jam" packing, it should be retorqued after initial heatup and prior to stem cycling. These results indicate that performance of this packing in the larger fixture would probably have been acceptable if it had been retightened after heatup, but an additional high temperature test of the material in the larger fixture has not been performed. The need for retightening when hot before cycling is a significant disadvantage.

Corrosion Test Results

The test fixtures were removed from the test oven and disassembled after the specified test periods. Stem surfaces and the surfaces inside the stuffing boxes were examined for corrosion. A description of the packings tested is presented in Table 5.

None of the 17-4PH (H-1100) stems showed any evidence of corrosion. Even the control (no corrosion inhibitor) packing set did not corrode the 17-4PH stem. This is consistent with previous results obtained for stems made from 17-4PH.

The 410 SS stem material next to the control (no corrosion inhibitor) packing set exhibited pitting .001 to .003 inches (0.03 to 0.08 mm) deep (see Figure 13). The 410 SS stems protected from corrosion by the zinc washers, the aluminum washers, and the non-metallic corrosion inhibitor exhibited some discoloration but no pitting. Results with the zinc washers were subsequently confirmed in a 2000 hour test (see Table 5). After 2000 hours, however, a stem protected by aluminum washers showed significant pitting, and a stem protected by the non-metallic corrosion inhibitor displayed minor pitting.

Results of corrosion tests with zinc and aluminum "dusted" graphite rings were mixed. In a previous Rockwell test program [4], flexible graphite rings were "dusted" by applying the dust between the layers of the graphite ribbon and then forming the ring, and thus trapping the dust inside the ring. However, a survey of several major packing manufacturers indicated that dusted rings are usually made by applying a tackifying agent and then the metallic dust to the external surfaces of the packing ring. The tackifying agent is required because the dust will normally not adhere to the flexible graphite rings. When the test stems were removed from the fixtures in Tests 1 and 2, it was observed that every stem surface which had been adjacent to dusted Grafoil packing had an adherent buildup of Grafoil, the metallic dust, and the tackifying agent. At the conclusion of the first test, it was thought that an insufficient curing time for the tackifying agent was the cause of this problem. However, similar results were observed at the end of the second test, even with factory-supplied dusted rings. Effects of this adhesion of materials to the stem are still under evaluation.

No corrosion of the 410 SS stem surfaces which had been adjacent to zinc-dusted rings was observed. However, significant corrosion under the aluminum-dusted graphite rings was observed in both tests 1 and 2, with pits as bad as those observed for the control packing set (see Figure 14).

Corrosion protection using interleaved zinc foil was found to be good in Test 2. However, corrosion protection from the interleaved aluminum foil was found to be poorer, with pitting observed on the 410 SS stem under the Grafoil rings. However, pitting was less severe than that observed with the aluminum dust.

The Garlock 1200-PBI included in Test 2 exhibited behavior similar to the aluminum-dusted graphite rings. Upon removal from the test fixture, the stem which had been adjacent to the 1200-PBI was found to have packing material adhered to it. When this material was removed from the stem, significant pitting of the stem was observed. Because 1200-PBI reportedly uses aluminum dust on the outside of the ring as a corrosion inhibitor (some zinc powder is included in the core material for corrosion protection also), this result is consistent with results obtained with aluminum dusted graphite rings in both Tests 1 and 2. Garlock has been consulted regarding these observations.

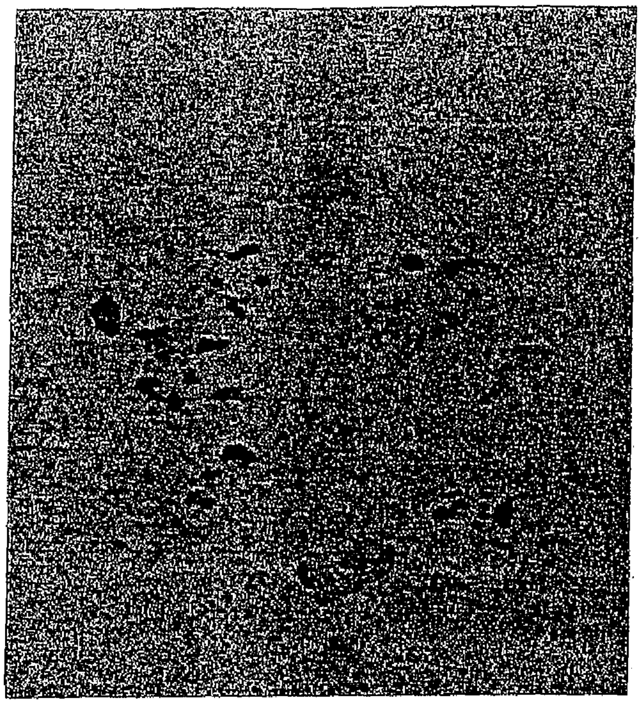


FIGURE 13

Close-up Photograph Showing Pitting of 410 SS Stem Caused by Control Packing Set in Test 1.

Results with the Lattygraf 6000/E1 and the Chesterton Style 1-CI/GTPI material combinations were very good, with no corrosion observed on the 410 SS stems adjacent to these materials.

Corrosion was noted on all of the carbon steel stuffing box inside surfaces and was most severe under braided end rings. The corrosion under these rings was characterized as being extensive with deep pitting. Corrosion was most severe under the rings at the bottom of packing chambers. This was true regardless of whether the braided rings had corrosion inhibitor in them or not. Corrosion under the center rings was reasonably uniform but much less severe than that observed under the end rings.

These results indicate that the observed corrosion of the stuffing box surfaces was due primarily to the presence of water next to the surface; that is, there would have seen similar results if the stuffing boxes had simply been immersed in water by themselves. The fact that the corrosion was observed to be worse under the braided end rings is probably due to the fact that they are somewhat porous and retain more water than the flexible graphite rings.

CONCLUSIONS

In a technical field which had seen only slow changes over several generations, developments over the past 15 years in valve stem packings seem remarkably accelerated. The pace has been accelerated even more over the past

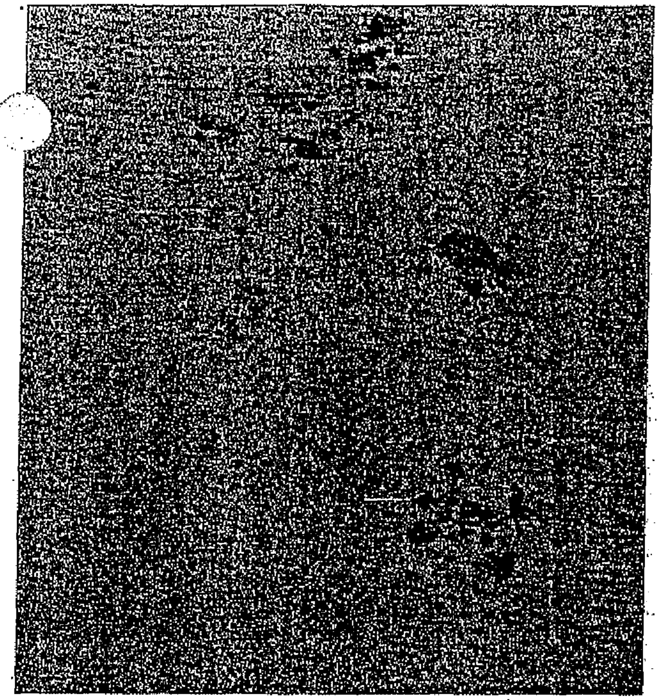


FIGURE 14

Close-up Photograph Showing Pitting of 410 SS Stem Caused by Aluminum Dusted Grafoil Rings In Test 1.

year or two. In a period of such acceleration, it is a major challenge to draw "conclusions"; the conclusions could change within 3 months if someone invents a really new material.

Barring the invention of a new material, such as one combining the merits of polytetrafluoroethylene (PTFE), carbon fibers, and flexible graphite, the tests conducted by Rockwell suggest some important conclusions that should permit major improvements in stem sealing in valves for elevated temperature service. It is recognized that others (e.g. Electric Power Research Institute) are conducting independent research work that may produce somewhat different results, but it is believed that results of the Rockwell test program are significant. Elimination of use of asbestos is the goal addressed most in this paper, but improvement in stem sealing performance is also an important result of the program.

While sealing performance results are emphasized in this paper, cost effectiveness was not overlooked. Most, if not all, asbestos-free packing materials are more costly today than the asbestos-base products they may have to replace. Note that asbestos-base packings were not tested as a "control" in the experiments; this was deliberate, because asbestos is not an alternative and because its performance was marginal in many past applications. The *hazards* of packing leakage in valves for nuclear power [plan]ts stimulated the first modern research on packings, [but t]he *costs* of packing leakage (energy loss, product loss) have been recognized in fossil power plants, refineries, and other installations. Thus, replacement of asbestos packings with materials offering *equivalent* performance was not a realistic option. A new "state of the art" had to be recognized as a requirement.

TABLE 5

Corrosion Test Description
Test Run No. 1—650 Hour Duration

Stem Material	Packing Set No.	Packing Material Description
410 SS	1A	Garlock 98 end rings—no corrosion inhibitor Grafoil center rings—no corrosion inhibitor (control packing set)
410 SS	1B	Garlock 98 end rings—no corrosion inhibitor Grafoil center rings—Union Carbide phosphorus based corrosion inhibitor (GTK)
410 SS	2A	Garlock 98 end rings—no corrosion inhibitor Grafoil center rings—no corrosion inhibitor Zinc washers between packing layers
410 SS	2B	Garlock 98 end rings—zinc impregnated Grafoil center rings—zinc dusted
410 SS	3A	Garlock 98 end rings—no corrosion inhibitor Grafoil center rings—no corrosion inhibitor Aluminum washers between packing layers
410 SS	3B	Garlock 98 end rings—aluminum dusted Grafoil center rings—aluminum dusted
17-4PH	4A	Garlock 98 end rings—no corrosion inhibitor Grafoil center rings—no corrosion inhibitor (control)
17-4PH	4B	Garlock 98 end rings—no corrosion inhibitor Grafoil center rings—Union Carbide phosphorus based corrosion inhibitor (GTK)
17-4PH	5A	Garlock 98 end rings—no corrosion inhibitor Grafoil center rings—no corrosion inhibitor Zinc washers between packing layers
17-4PH	5B	Garlock 98 end rings—zinc impregnated Grafoil center rings—zinc dusted
17-4PH	6A	Garlock 98 end rings—no corrosion inhibitor Grafoil center rings—no corrosion inhibitor Aluminum washers between packing layers
17-4PH	6B	Garlock 98 end rings—aluminum dusted. Grafoil center rings—aluminum dusted

Test Run No. 2—650 Hour Duration

Stem Material	Packing Set No.	Packing Material Description
410 SS	9A	Garlock 98 end rings—Aluminum dusted Grafoil center rings—Aluminum dusted
410 SS	9B	Garlock 98 end rings—Zinc impregnated Grafoil center rings—Zinc dusted
410 SS	10A	Garlock 98 end rings—Zinc impregnated Grafoil center rings—layered Zinc foil
410 SS	10B	Garlock 98 end rings—Aluminum dusted Grafoil center rings—layered Aluminum foil
410 SS	11A	Garlock 1200-PBI
410 SS	11B	Lattygraf 6000 end rings Lattygraf E1 center rings
410 SS	12A	Chesterton Style 1-CI end rings Chesterton GTPI center rings
410 SS	12B	Garlock 98 end rings—Zinc impregnated Graph-lock center rings—Zinc dusted Factory prepared packing set

Test Run No. 3—2000 Hour Duration

Stem Material	Packing Set No.	Packing Material Description
410 SS	7A	Garlock 98 end rings—no corrosion inhibitor Grafoil center rings—no corrosion inhibitor (control packing set)
410 SS	7B	Garlock 98 end rings—zinc impregnated Grafoil center rings—Union Carbide phosphorus based corrosion inhibitor (GTK)
410 SS	8A	Garlock 98 end rings—no corrosion inhibitor Grafoil center rings—no corrosion inhibitor Zinc washers between packing layers
410 SS	8B	Garlock 98 end rings—no corrosion inhibitor Grafoil center rings—no corrosion inhibitor Aluminum washers between packing layers

Best Packing Material Combinations

Results of the current program show no fundamental change in comparison to earlier Rockwell reports. Good stem sealing performance requires a *combination* of packing materials in high-pressure, high-temperature applications. The *best* sealing results were achieved with combinations of flexible graphite internal sealing rings and anti-extrusion rings of braided carbon or graphite. Among the various combinations of these materials tested, the reference material design of Garlock 98 end rings with Grafoil sealing rings gave the best results overall. Perhaps this is related to greater Rockwell experience in applying these materials, which have been tested and applied for over five years. *All* combinations of these basic materials, supplied by several manufacturers, exhibited performance that was significantly better than that produced by proprietary braided asbestos-free packings.

One constituent of the packing material combination often overlooked is the corrosion inhibitor. While these and prior Rockwell tests suggest that this may not be an issue with AISI 316 or 17-4 PH stainless steel stems as used in some valves in nuclear power and chemical processing applications, it is difficult to base long-term confidence on results of short-term tests. Certainly, history shows that stems of 400-series stainless steels require protection when used with packings having high concentrations of carbon or graphite. Even heavily graphited packings of braided asbestos have used zinc powder for years as a sacrificial anode. Previous Rockwell tests had shown that zinc powder and zinc washers can also offer protection when properly applied with braided carbon and flexible graphite packing rings. This was reaffirmed in this program, except that a question remains to be answered relative to an adhesion effect noted when "dusted" flexible graphite rings were tested. This program also showed promising results with flexible graphite rings with newer non-metallic inhibitors (e.g. Grafoil GTK, Chesterton GTPI). However, use of aluminum as a sacrificial anode gave mixed results. The position of aluminum in the electromotive series suggests that it should be *better* than zinc, but test results did not support this; one theory is that aluminum forms a tenacious oxide on the surface and then becomes "unavailable" for anodic protection. While evaluation of corrosion pitting tests is inherently somewhat subjective, a quantitative ranking method was devised based on depth of pits, number of pits per unit area, and time of testing. Table 6 provides a coarse "grading" of corrosion protection systems based on this method, with some bias from results of prior Rockwell tests. Generally, it is considered that a corrosion protection system with an "A" grade should be at least as effective as prior zinc-impregnated asbestos packings in protecting 400-series stainless steel stems. Lower-rated systems may be satisfactory with more corrosion-resistant stems, depending on the fluids and service conditions involved.

As a group, the proprietary braided asbestos-free packings (tested as sets without other materials) were a disappointment. Some earlier examples tested in 1980 showed marginal performance, but better results were expected when this program was undertaken in 1985. Two manufacturers withdrew packings or changed them after Rockwell tests (not necessarily because of these results).

TABLE 6

Relative Grading of Corrosion Protection Systems

Grade	Material
A	Zinc washers between packing rings Impregnated zinc dust External zinc dust with tackifying agent[1] Non-metallic inhibitors Interleaved zinc foil in flexible graphite
B	Aluminum washers between packing rings
C	Interleaved aluminum foil in flexible graphite External aluminum dust with tackifying agent[1]
D	No corrosion inhibitor

1. Adherent buildup of packing material on stem OD currently being evaluated.

Other materials tested in this program cannot be "graded" because they had such different strengths and weaknesses. Individual users may find some of these materials quite acceptable in their own specific applications. However, despite the cost advantages offered by some of these materials, none can yet be recommended as a general service replacement for asbestos-base packing in valves rated for the full pressure/temperature ranges shown in current catalogs.

One reservation must be expressed with respect to all of the new asbestos-free packings for high temperature service. This relates to the long term service life to be expected with these materials at very high temperatures (950 to 1100°F [510 to 593°C] or higher) with various flow media. As noted previously, Rockwell tests of braided carbon/flexible graphite packing combinations has shown no degradation with line fluid temperatures through the highest normally encountered in power plants. Nevertheless, laboratory tests are necessarily of limited duration. While there are no known problems from field applications of these packings, published data on the various packing rings and materials are less than complete in providing valve manufacturers and end users with the confidence desired for all applications. It is considered that the packing and material manufacturers should take the lead in developing such application engineering data, and it is clear that several manufacturers are active in such research. Of course, valve manufacturers should also cooperate, advising the fluid sealing industry well about the conditions that packings will encounter in valves; for example, the relationship between packing temperature and line fluid temperature is more likely to be known by the valve manufacturer (the temperature difference may be less than 100°F [56°C] in a high temperature gate valve but as much as 500°F [278°C] in a globe valve with an internal thermal barrier).

Since the current program is ongoing, some results are incomplete. Preliminary results suggest that combinations of available proprietary braided asbestos-free packings and flexible graphite rings will give acceptable performance in some valves. Specifically, Garlock 1200 PBI anti-extrusion rings seem to be effective combined with Grafoil sealing rings. This combination provided good sealing performance in tests simulating a small valve (1.000 inch or 25.4 mm stem) at pressures and temperatures representative of typical Class 900 valve service. Stem corrosion test results with this material produced some adverse results that require further evaluation.

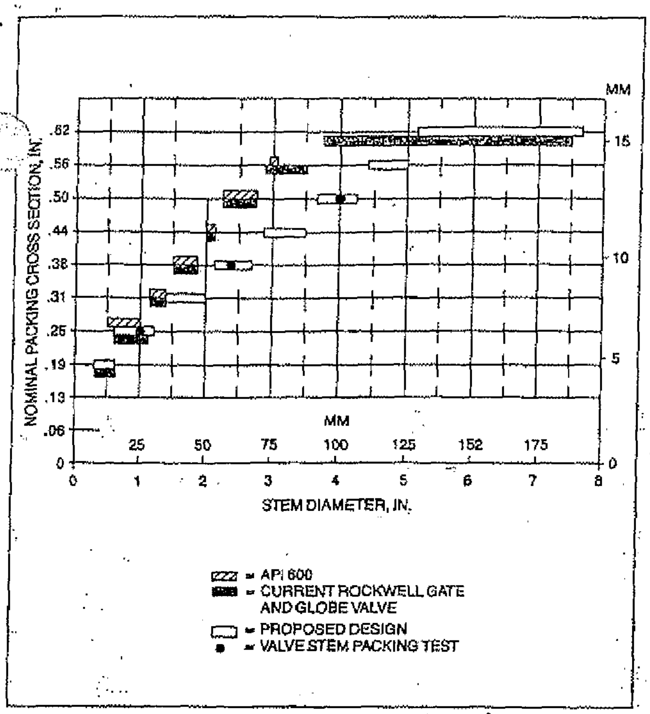


FIGURE 15

Packing Cross Section Comparisons.

Packing Chamber Design

With one major exception, standards for design of valves for elevated temperature service do not specify packing chamber design or packing materials. The exception is the American Petroleum Institute API Standard 600, *Steel Gate Valves, Flanged and Buttwelding Ends.* The eighth edition (January 1981) specifies braided asbestos packing and specifies packing width (cross section) and numbers of packing rings for valve stem diameters from 0.62 to 3.00 inches (15.7 to 76.2 mm). While many high temperature valves, particularly those used in power plant service, do not have to comply with API Standard 600, some valve manufacturers tend to follow some parts of this standard but not others. For example, most larger Rockwell globe and gate valves designed in the past used the cross-sectional packing widths from this standard (extrapolating upward for stems larger than 3.000 inches [76.2 mm] diameter) but not the requirement for number of rings—which was considered unreasonable for normal service.

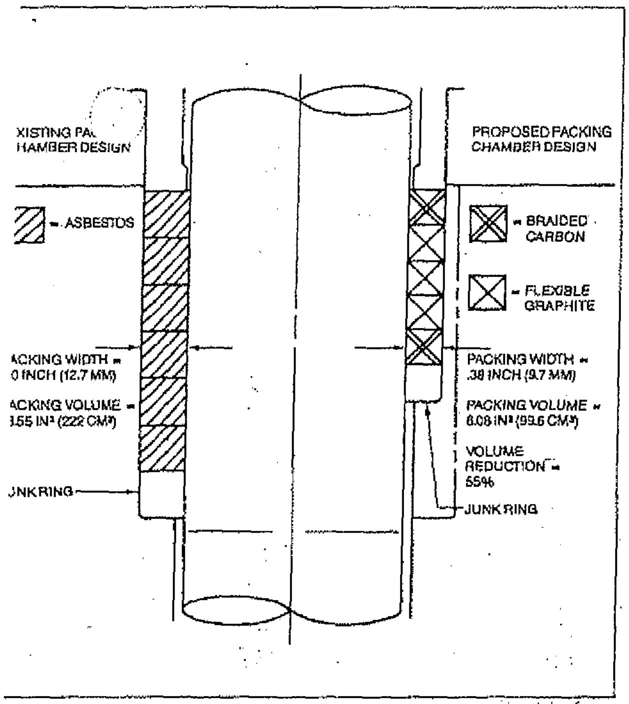
Aside from partial guidance from API Standard 600, packing chamber design was largely based on individual manufacturers' experience, engineering folklore, and rules-of-thumb (e.g. packing chamber depth of 1.5 times stem diameter). Particularly in small valves, packing chambers were often disproportionately large—sometimes because of a general feeling that "more packing means better sealing". So long as large packing chambers could be filled with inexpensive asbestos packing, and so long as users did not complain too much about the need for occasional retightening of glands and periodic repacking, it was found that packing chambers of widely different designs all gave "acceptable" sealing.

The demand for better sealing performance, which developed first in nuclear power applications in the early 1970's, led to some serious questions concerning packing chamber design. Flexible graphite packings demonstrated clearly improved sealing, but such packings were very expensive at first. Early packing rings of laminated construction required interference fits and very "delicate" assembly work. The cost of filling a packing chamber designed for inexpensive asbestos packing became a major issue. Further, it was sometimes found necessary to compress flexible graphite packing rings one or two at a time when they were used in deep packing chambers; this procedure added even more cost to a valve due to increased assembly labor.

In earlier Rockwell work with flexible graphite packings, it was found that even *one* continuous ring provided excellent sealing performance. Further research and development on valves with smaller stems [2,4] led to the use of two flexible graphite sealing rings to allow repacking with split rings with the splits offset. When used with either asbestos or braided carbon top and bottom rings, excellent performance was achieved *without* sequential loading; the four-ring set could be loaded simply as one set. Additionally, in the earlier program, it was shown that a 1.125 inch (28.6 mm) diameter stem could be sealed effectively with a packing cross-sectional width of 0.25-inch (6.4 mm), although API Standard 600 called for a step-up to 0.31-inch (7.9 mm) cross section at this diameter. This was a small increment but it gave some confidence that smaller cross sections could be applied effectively with even larger stem diameters.

In early work in 1985 on the current program, plans were made to allow for testing of *5-ring* packing sets with larger stems, strictly for conservatism. Also, it was decided to use packing cross-sectional widths smaller than shown in the API Standard 600 tables. The dimensions shown in Table 2 for the two larger stems result in packing widths 0.12 inches (0.3 mm) smaller than listings or extrapolations of API dimensions, but test results showed excellent performance with the better packing material combinations. In discussions with representatives of packing manufacturers early in the current program, it was found that several agreed with the Rockwell approach and some would have gone even further in reducing packing widths. Thus, it is not claimed that this approach was original with Rockwell, but it is believed that the current program is first to provide confirmatory test data.

Figure 15 provides a plot of packing cross-sectional width vs. stem diameter, showing (1) API Standard 600 dimensions, (2) the prior experience base with Rockwell globe and gate valves, and (3) the tentative proposed basis for new Rockwell valve designs. The dimensional combinations proven by these and prior tests are shown on the graph.



IGURE 16

acking Chamber Designs, Size 10 Class 2500 Rockwell Equiwedge ate Valve.

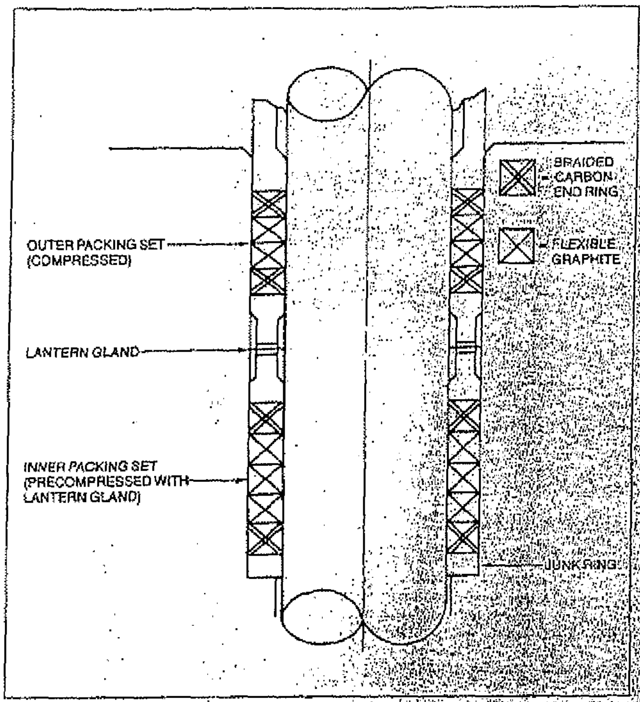


FIGURE 17

Packing Chamber with Lantern Gland. Proportions shown are typical for a 1.500 inch (38.1 mm) stem in Class 900 or higher valve.

As a further illustration, Figure 16 illustrates a size) Class 2500 Rockwell Equiwedge gate valve packing ıamber as designed for asbestos-base packing and as ·oposed for modern carbon and graphite packing. The ɜw dimensionsal configuration represents one of those ısted in this program. The 55% reduction in packing ıamber *volume* not only makes premium packing ıaterials more affordable but also assures better sealing ɜrformance. Note also that tests of a similar packing ıamber with just four rings (as used with smaller stems) ere successful at conditions representative of Class 600 ıd lower valves with a 2.375-inch (60.3 mm) diameter stem.

Some users of valves in particularly hazardous serce have insisted on double packing chambers with a ıantern gland" and a "leak off" connection between ıem, permitting the leakage from the first packing set to e piped off to a "safe" location. This construction has dicıted even deeper packing chambers in past designs. Unıss these packing chambers were packed carefully, lower acking rings were lightly loaded and the "double packing" ffered no better sealing than a single set. While not reuired in most services, the modern packings do permit double packing with a chamber depth little greater than ɜquired with single packings sized for asbestos rings. igure 17 illustrates such a design with a lower packing omb[illegible]on similar to that in Figure 16, precompressed ıith the lantern gland before installation of the upper acking combination.

While practical realities prevent instantaneous changes in all high temperature valves to apply optimized packing chamber dimensions, the results of this program will be applied to new designs and to redesign of existing valves as opportunities develop. In the interim, partial results can be applied by reduction of the number of packing rings, using metal spacers where appropriate. Similar steps can be taken in repacking installed valves in the field, but this also involves consideration of valve stem and packing chamber condition (wear, corrosion, pitting, etc.). The latter factors are outside the scope of this paper.

Advantages and Disadvantages of Live-Loaded Packings

There is no reason to dispute the success of AECL and EdF in applying live loading to critical service valves in nuclear power plants. A recent report by the Electric Power Research Institute (EPRI) [9] documents the AECL experience well and proposes design criteria for applying live-loading to new packing materials. Rockwell has supplied valves meeting AECL specifications [8], and live-loaded valves have also been built and tested to satisfy EdF requirements [3]. There is no reason to suspect the reliability of any of these designs.

One problem arising from trying to apply live loading to general service valves is that "System Pressure" is a necessary input number for design calculations for spring assemblies for live-loaded packing glands [9]. This input is usually available in Design Specifications for special valves for nuclear plants. For many general service valves, however, users' orders show only an ANSI B16.34 class or some similar rating; with only this input, a manufacturer might have to design all valve gland springs for the 100°F (38°C) ratings of such valves; this pressure could be from two to three times higher than any service pressure that the valves would actually encounter in high-temperature service. A design practice meeting such a worst-case criterion would obviously not be cost-effective. At best, two or three different spring sets would have to be available for each valve to be selected based on individual users' operating pressures. However, the present state of the art involves custom design of live loading assemblies for specific valve operating pressures. The special design work, extra parts, larger yoke to allow space for springs, and additional assembly labor combine to make a proper live loading system a quite expensive accessory; while it is apparent that this expense has "paid" off well in live-loaded valves with asbestos packing in nuclear service, it is not clear that live loading is attractive or necessary in general service valves (fossil fuel power, typical refinery valves, etc.) that probably represent over 99% of all applications.

While Rockwell laboratory tests of live-loaded packings have been limited, tests of current braided carbon end rings with flexible graphite sealing rings and live loading show little improvement over results of tests of the same packings *without* live loading. Even with conventional gland bolting, the best current packing material combinations sealed well in both room temperature water and saturated steam tests; in many tests, 1000 stem cycles and several thermal cycles were completed with no requirements for readjustment. Generally, with the best materials, the *worst* performance noted was transient steam leakage during a portion of the stem travel with the larger valve stems during "thermal equilibrium" cycles. This is attributable to "thermal taper", the difference in diameter between the hot stem initially in the packing and the cooler extended stem. This condition is maximized with large valves, simply because the stem diameter is large and the long extended stem is cooler. The transient leakages witnessed during this program were never severe or unsafe, but it was expected that live loading would stop them; while there was some improvement with live loading, it did not meet expectations even though the loadings were slightly higher than listed in the recent EPRI report for similar materials and pressures [9]. Neverthless, live loading does offer an additional degree of insurance for valves in very critical services.

Summary

Elimination of asbestos in the stem seals in valves for elevated temperature service was not an easy task, and several major programs have been required to prove the adequacy of asbestos-free replacements. However, in all Rockwell valves where asbestos stem seals have been replaced, the test programs have proven that the new seals provide *improved* performance. The material which has made this improvement possible is flexible graphite, but mere replacement of asbestos packings with flexible graphite did not solve all problems. *Combinations* of materials and innovations in stem seal design were required in a number of cases to achieve the required performance and to apply new materials cost effectively. In addition to the programs described in this paper and in listed Rockwell references, major programs were involved in developing stem seals for improved tapered plug valves. While these plug valves are not normally used at the very high temperatures that globe and gate valves encounter, these valves provided excellent laboratory, manufacturing, and field service experience with carbon and graphite stem seals. Counting all valve types, hundreds of thousands of Rockwell valves have been shipped using stem seals containing modern braided carbon and/or flexible graphitic materials, and overall performance has been excellent. The present program gives confidence that the same success can be expected with the material combinations and packing chamber designs evolved through the present program for large high-temperature valves.

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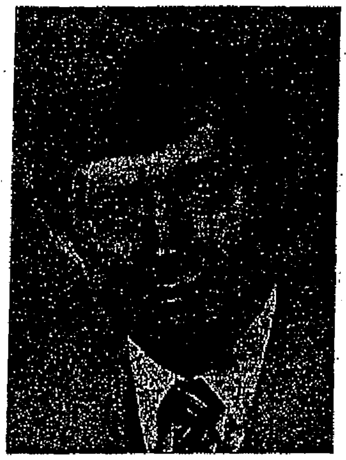

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