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Category A

DESIGN CRITERION OF PLENUM TO REFLECTOR BLOCK SEAL
FOR HTGR REACTOR VESSEL

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SUMMARY

This report covers a survey of sealing methods as to their adaptability to the requirements of the plenum reflector seal on the HTGR reactor vessel. A leak rate through the seal of 43.8 pounds per hour of helium was established as an acceptable leak. Lap joints of steel to graphite or graphite to graphite with a 100 RMS surface finish met the required leak rate and two basic concepts of this type of seal are illustrated.

INTRODUCTION

The purpose of the seal between the plenum and inner reflector block is to prevent leakage or reduce to a tolerable level the flow of the cold helium bypassing the core. This report is presented to review the characteristics of sealing methods and make recommendations as to the type of seal to be used.

The standard method of measuring the effectiveness of a seal is to compare it with a known leak rate. This implies that there does not exist a seal that does not leak. If a perfect seal cannot be obtained, the requirements of the system must be evaluated to determine the size of the leakage that can be tolerated.

CLASSIFICATION OF SEALS

The sealing of two mating parts involves two operations: a device to hold the parts together, and a means of preventing leakage or reducing the flow of fluid between the common junction.

(1)

Seals may be classified as to their means of sealing as follows:

Class A: Made by joining the two mating parts by the fusion of the materials of one or both pieces or a third material. This seal may or may not act as a load carrying member.

Class B: A chemical adhesive may be used to provide a seal and/or structural strength.

Class C: Gaskets are filler materials which are forced to flow into surface irregularities. These irregularities exist on all surfaces and result in flow paths between joining parts. This class may be further divided into:

(1) Self-sealing - This type deforms under internal pressure to flow into the crevice between the mating parts.

(2) The ordinary gasket yields under an externally applied load.

Class D: Lap joints are two flat surfaces, one butted up against the other.

Class E: The labyrinth seal causes a reduction in flow by adding turning losses into the leak path.

(1) Determination of Leakage Value of Seals, Dept. of Commerce Contract AF33(038-15981) WADC Tech. Report 54-16.

CONDITIONS IMPOSED ON THE SEAL BY THE VESSEL

The seal for the HTGR vessel must accommodate variations in the location of the seating surface. The major variation is due to the reflector blocks being required to tilt radially inward. If a load is not applied by the reflector on the fuel elements, the natural frequency of the elements will be reduced and damage may occur to the fuel element. Since there is a differential expansion between the reflector support and the core when the reactor is in operation, the blocks must move inward. The differential expansion is due to different material and temperature of the plenum, reflector, and reflector support. The amount of this expansion is shown in Figure 1.

Figure 1 Mismatch of Reflector, Plenum and Core at Hot Conditions

a. The innerward tilt required for reflector

Inside dia of reflector - hot condition

$$\begin{aligned} 650^\circ \times 134'' \times 7.4 \times 10^{-6} &= .644'' \\ -800^\circ \times 24 \times 1.3 \times 10^{-6} &= \underline{.025} \\ &= .619 \end{aligned}$$

Outside dia of core - hot condition

$$\begin{aligned} 1,400^\circ \text{ F} \times 108'' \times 1.3 \times 10^{-6} &= +.196 \\ 2a &= .423 \end{aligned}$$

b. Difference between plenum and reflector diameter at hot conditions

$$\begin{aligned} \text{I:D of plenum} &= 1000^\circ \text{ F} \times 138 \times 9.58 \times 10^{-6} = 1.32'' \\ &= \underline{.644} \\ 2b &= .676 \end{aligned}$$

c. Change in vertical height

Total increase in distance from bottom of reflector to center line of nozzle

$$258 \text{ in.} \times 650^\circ \text{ F} \times 7.4 \times 10^{-6} = 1.24''$$

Increase in reflector length

$$144 \times 800 \times 1.3 \times 10^{-6} = .150$$

Increase in plenum

$$114 \times 1000 \times 9.58 \times 10^{-6} = 1.08$$

ALLOWABLE LEAK RATE THROUGH SEAL

Unfortunately, the sensitivity of the instruments on the reactor system is so low that they will only detect large leaks through the core seal. This means that during operation of the reactor it will be impossible to detect a leak in the seal. However, the leak will show up on the efficiency of the system when heat balance is made. We can use the efficiency of the system as our basis of determining an allowable leakage. This can be done if we assume the efficiency of the cycle is directly proportional to the mixed mean temperature of the reactor outlet gas.

If the efficiency is calculated to three places it means change of .1% in decrease in efficiency due to seal leakage can be detected. Assuming the efficiency to be proportional to the outlet temperature we have

$$\frac{\eta_1}{\eta_2} = \frac{T_1}{T_2} \quad (1.0)$$

η_1 = efficiency with no leakage
 η_2 = efficiency with leakage

T_1 = Outlet gas temperature with no leakage

T_2 = outlet gas temperature with leakage

taking a heat balance between the outlet gas and the inlet gas for bypass flow

$$WT_2 = T_1 (W-P) + PT_g$$

W = weight of gas flowing

P = weight of gas bypass

T_g = temperature of gas bypassed

solving this equation for T_2 and inserting this into the efficiency equation

$$\frac{\eta_1}{\eta_2} = \frac{T_1}{\frac{T_1 (W-P) + PT_g}{W}} \quad (1.1)$$

inserting the .1% decrease in efficiency

$$\frac{1}{.999} = \frac{T_1 W}{T_1 (W-P) + PT_g} \quad (1.2)$$

from which the permissible bypass becomes

$$P = .002W \quad (1.3)$$

If we use 1/20 of this rate for the leaks through the plenum to reflector seal, the permissible leak rate will be set at 43.8 lb/hr.

EVALUATION OF THE FIVE TYPES OF SEALS FOR THE HTGR REACTOR VESSEL:

- (a) The Class A seal would fix the two parts and would not allow the tilting of the reflector. If a flexible member were used, the problem of differential circumferential expansion between the metal seal and the reflector would still exist.
- (b) A Class B seal would require the development of an adhesive which would stand the high temperature and radiation. It would have to be able to stand the smearing out of the rocking motion of the reflector.
- (c) 1. A self-sealing gasket requires a soft, pliable elastic material such as a plastic or rubber. These materials would not be able to retain these properties at the radiation and temperatures involved.
2. The sealing of a conventional gasket is determined by the load applied on the gasket. This load is reduced as a result of internal pressure.

A formula which does not include the effects of the surface or gasket material, but which shows a relationship of external load to internal pressure as the point for leakage to begin is: ⁽²⁾

$$\frac{P_1 - \sigma_{g_2}}{\sigma_g - \sigma_{g_2}} = \frac{A_g}{\Delta A} \quad (2.0)$$

P = internal pressure

σ_g = initial average gasket seating pressure or stress

σ_{g_2} = operating average gasket stress

A_g = original gasket area

ΔA = original gasket area (A_g) minus the gasket area in contact under pressure

When $\Delta A_g / \Delta A$ goes to 1 there is no gasket in contact with the two joining parts and leakage begins. At this time the internal pressure equals the gasket stress.

Deviation from the above formula is due to the irregularities in the surface which produce flow paths and also the type of gasket material. A measure of these effects which is commonly used in flange design is the gasket factor "m". This is the ratio of the average gasket stress (σ_{g_2}) at the pressure at which a leak occurs to the internal pressure (P_1).

Accepted values for "m" have been tabled by the ASME Code in Section VIII (see appendix). These values are conservative, but not the actual values to be expected. Limited experiments have been made to determine "m" and the results have been found to be of the form of curve "a" shown in Figure 2.

(2) Gaskets and Bolted Joints, JAN 1950, II, page 169, Roberts.

FIGURE 2

Some gasket materials exhibit a "stickiness" or adhesion of the joined parts. This results in a depression of the Curve "a" to a lower position of Curve "b". This adhesion usually causes a tearing of the gasket. When the value of "m" is greater than one, an increase in width of the gasket (g_1 remaining the same) will result in a reduction in leakage. Test data shows a depression of the curve when the width of the gasket is increased. Curves for asbestos, copper and lead are given in the appendix.

If it was decided to use a gasket without considering the restraint on the rocking of the reflector, the limit of force available to seat a gasket would be set by the strength of the graphite. In order to prevent the graphite from taking a permanent set, the load would have to be less than the yield strength of graphite. Little data is available on the yield strength, but for mold and crucible graphite with a compressive strength of 6000 psi, the yield will probably not be over 3000 psi. This requirement would eliminate solid metal gasket and corrugated metal gaskets. The corrugated metal gasket is a means of improving the sealing by decreasing the bearing area and increasing the seating stress. The gaskets with low initial seating pressures are those of asbestos with rubber or vegetable binder, but these binders are not suitable for the temperature and radiation levels to be expected in the HTGR.

(d) The lap joint effectiveness is a function of the surface finish. As the surfaces are made smoother the number and size of leak paths are

reduced. An evaluation of surface finish effects on thermal conductances between metallic surfaces in contact has been made by Fenech and Rohsenow⁽³⁾. This report has developed data on surface condition which can be used to determine characteristics of a flow path between two surfaces.

In the report the surface was visualized as a series of peaks and valleys, where the peaks are rough pyramidal in form (see Figure 3). For the aluminum and iron surfaces in the report it was found they had a ratio of height to base of 1:15.

FIGURE 3

It was also found that on machined surfaces, the distance from the peak to valley was 3 to 4 times the RMS value. RMS (root mean square deviation) is a measure of surface roughness and is defined as

$$\text{RMS in } 10^{-6} \text{ inches} = \sqrt{\frac{1}{L} \int_0^L y^2 dx} \quad (3.0)$$

where y is the vertical height at any point, x shown in Figure 4.

FIGURE 4

(3) Thermal Conductance of Metallic Surface in Contact, H. Fenech and W. M. Rohsenow, M.I.T. - AEC Contract AT(30-1)-2079.

Since the base to height ratio of the pyramidal surfaces is 15 to 1, for purposes of flow calculations the surface may be considered as flat plates, and the distance between the two plates be selected as 8 times RMS value. The permissible leak rate can be determined by: ⁽⁴⁾

(4.0)

$$\frac{\Delta p}{\Delta L} = \frac{12 \mu G}{Z^2 g_c \rho} = \frac{12 \mu W}{Z^3 g_c \rho \pi D}$$

p = absolute pressure (intensity of) pounds per ft²

L = width of sealing surface - feet

μ = absolute viscosity of fluid lb/sec.ft

ω = mass rate of flow - pound of fluid/sec

g_c = conversion factor 32.2 ft.lbs/sec² lbs force

D = diameter of seal in feet

ρ = density, pound fluid/ft³

G = mass velocity lbs of fluid/sec ft²

Z = vertical distance between plate

Figure 5 shows four flow rate curves at various pressures and lengths of path as computed from formula (4.0). The rapid rise of flow as the RMS increases above 150 can be seen from this graph. From Figure 5 it can be seen that to insure that the leakage is below 43.8 lbs/hr (the limit of acceptable leakage), a specific RMS finish should be maintained on the sealing surfaces. Curve A shows that for a pressure drop of 3.5 psi, a two inch wide seal will give a satisfactory tightness for up to a 300 RMS finish. Machined metal surfaces usually run about 100 RMS, and graphite machined surfaces 16 to 32 RMS. Thus, if a reasonable amount of flatness can be preserved, a two inch wide metal to graphite contact will make a good seal.

(e) The labyrinth seal will only be effective in the full turbulent range and then only when the flow becomes quite high.

RECOMMENDATIONS

The use of a flat lapped joint for the seal in the HTGR reactor is feasible. However, due to non-uniform heating of the plenum and reflector, there will be warping of the surfaces. This will reduce the effectiveness of seal. The details of this design are to be worked out and the selection

⁽⁴⁾ Heat Transmission - McAdams.

of materials used will depend upon the effect of friction on wear rates in helium. The sketch shown on Figure 6 indicates two methods of this type of sealing.

The design in 6(a) has been proposed previously by P. Fortescue and D. Nicoll. The sealing surface is indicated to be between the sealing block and reflector, and the side of the sealing block and retainer. The space A allows the differential pressure to hold the seal down on the reflector. The tube (B) allows the pressure into space A. The block is held against the side of the retainer by the differential pressure across the core.

The design in 6(b) has only one sealing surface and, thus, one leak path. This seal would require an upward force on the reflector block to hold the block in contact with the seal plate. This can be obtained by springs or a counterweight.

FIGURE 5

(a)

(b)

FIGURE 6

Scale $1/2" = 1"$

Experimental Values of Sealing Factors "m" for Fiber, Lead and Copper Gaskets - from Gaskets and Bolted Joints, Journal of Applied Mechanics, Vol. II, 1950, Page 169
I. Roberts

Table UA-47.1

SECTION VIII UNFIRED PRESSURE VESSELS

TABLE UA-47.1 GASKET MATERIALS AND CONTACT FACINGS

Gasket Factors (m) for Operating Conditions and Minimum Design Seating Stress (y)				Refer to Table UA-47.2	
NOTE: This table gives a list of many commonly used gasket materials and contact facings with suggested design values of m and y that have generally proved satisfactory in actual service when using effective gasket seating width b given in Table UA-47.2. The design values and other details given in this table are suggested only and are not mandatory.				Facing limitations	Use column
Gasket material	Gasket factor m	Min design seating stress y	Sketches and notes		
Rubber without fabric or a high percentage of asbestos fiber: Below 75 Shore Durometer 75 or higher Shore Durometer	0.50 1.00	0 200		Use 1, 4, 6 only	II
Asbestos with a suitable binder for the operating conditions	$\frac{1}{8}$ thick $\frac{1}{16}$ thick $\frac{1}{32}$ thick	2.00 2.75 3.50			
Rubber with cotton fabric insertion	1.25	400			
Rubber with asbestos fabric insertion, with or without wire reinforcement	3-ply 2-ply 1-ply	2.25 2.50 2.75	 	None	
Vegetable fiber	1.75	1100		1, 4, 6	
Spiral-wound metal, asbestos filled	Carbon Stainless or Monel	2.50 3.00			
Corrugated metal, asbestos inserted or Corrugated metal, jacketed asbestos filled	Soft aluminum Soft copper or brass Iron or soft steel Monel or 4-6% chrome Stainless steels	2.50 2.75 3.00 3.25 3.50	 	Use 1a only	
Corrugated metal	Soft aluminum Soft copper or brass Iron or soft steel Monel or 4-6% chrome Stainless steels	2.75 3.00 3.25 3.50 3.75			
Flat metal jacketed asbestos filled	Soft aluminum Soft copper or brass Iron or soft steel Monel 4-6% chrome Stainless steels	3.25 3.50 3.75 3.50 3.75 3.75	 	Use 1a, 2* only	
Grooved metal	Soft aluminum Soft copper or brass Iron or soft steel Monel or 4-6% chrome Stainless steels	3.25 3.50 3.75 3.75 4.25		Use 1, 2, 3 only	
Solid flat metal	Soft aluminum Soft copper or brass Iron or soft steel Monel or 4-6% chrome Stainless steels	4.00 4.75 5.50 6.00 6.50		None	I
Ring joint	Iron or soft steel Monel or 4-6% chrome Stainless steels	5.50 6.00 6.50		Use 8 only	

* The surface of a gasket having a lip should be against the smooth surface of the facing and not against the nubbin.