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March 3, 1952

This document consists
of 7 pages.

TO: G. M. ROY

FROM: B. R. ELDER *BREEDER*SUBJECT: PERMISSIBLE DESIGN PRESSURES FOR 2S-HL4-72S CLAD PROCESS TUBES1. SUMMARY

The following are the maximum recommended design pressures when using 2S-HL4-72S clad process tubes:

- a. Long duration (Operating Pressure) - 500 psi at tube entry.
- b. Short duration (Emergency Pressure) - 600 psi at any point along tube length.

c. If severe distortion of some tubes (as of fringe tubes in older piles) is expected the operating pressure limit of the tubes in question should be lowered to compensate for the expected distortion.

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If pressures in excess of the above are anticipated an alternate higher strength tube material should be considered.

These recommended values are based on a minimum safety factor of 1.5 (ratio of operating stress to yield), the use of conservative values in calculations throughout the report, and a survey of the creep, corrosion and bursting test information currently available. An outline of the criteria used in establishing these limits is included in this report for the readers' information.

The readers' attention is directed to HW 23411 (Technical Section Report currently being issued) which covers permissible pressures in existing piles.

2. Object

This report has been issued to define the maximum allowable emergency and standard operating design pressures for clad 2S-H 14 process tubes. The establishment of a definite limit should enable those engaged in process design to proceed on a factual basis.

3. Calculation of Tube Stresses

All tube stresses in this report were calculated using the minimum allowed 2S-H14 tube wall thickness; the 72S thickness was neglected entirely. The reason for this becomes obvious when corrosion is considered (see section 4a).

Tube wall stresses were calculated using the formulas for a thin walled tube with stresses uniformly distributed about the axis:

$$S_{\max} = \frac{P(a^2 + b^2)}{b^2 - a^2}$$

where S max = Maximum hoop stress

P = pressure - psi

a = inside radius

b = outside radius

The above calculations were checked using the Barlow formulae:

$$S = \frac{PD}{2t}$$

S = Hoop stress

P = Pressure

D = Inside Diameter

t = Wall Thickness

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No axial forces were considered since the tube is free to move within the unit and must overcome only the force of friction and the restraint of the pigtail. These axial forces will not exceed those noted below in any case. Severely deformed tubes are, of course, subject to different stresses and therefore a different pressure limitation should be used when considering these tubes.

The table below shows the expected wall stresses for a given pressure.

Pressure	Stress #/in. ²			
	by $S \frac{PD}{2t}$		by $S_{max} \frac{P(a^2 + b^2)}{b^2 - a^2}$	
	Standard	Enlarged	Standard	Enlarged
700 psi	12,680	12,995	12,760	13,055
650 psi	11,770	12,060	11,850	12,125
600 psi	10,870	11,130	10,940	11,190
550 psi	9,960	10,200	10,025	10,260
500 psi	9,055	9,280	9,115	9,325
450 psi	8,150	8,350	8,200	8,395
400 psi	7,245	7,425	7,295	7,460
350 psi	6,340	6,500	6,380	6,350
300 psi	5,435	5,570	5,470	5,600
250 psi	4,530	4,640	4,560	4,665
200 psi	3,620	3,715	3,645	3,730
150 psi	2,715	2,785	2,735	2,800
100 psi	1,810	1,860	1,825	1,865

Yield str. - 2S-H14

25°C - 14,000 psi
100°C - 10,000 psi

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4. Standard Operating Pressures

The considerations in establishing a maximum standard operating pressure are as follows:

- a. Corrosion - It is very possible that corrosion of a process tube could reduce the effective tube cross-section to the point that failure would take place after extended service. R. G. Wheeler, who has conducted numerous examinations of the process tubes removed after 4 or 5 years of operation, states that corrosion does not penetrate beyond the 10 mil layer of 72S aluminum.* One exception to this would be in the front face Van-Stone, where more extensive corrosion has been noted. This corrosion is, however, in the area supported by the nozzle.

The effect of corrosion in reducing wall thickness is adequately compensated for by neglecting the 10 mil layer of 72S inside of the process tubes during stress calculations. All calculations shown above were therefore made neglecting the thickness of the 72S layer.

While considering corrosion, it might be well to note that the establishment of a pressure limitation based on expected corrosion beyond the 72S layer is neither economical nor reasonable since failure due to corrosion would result in any event regardless of stress. If it is found that corrosion is penetrating beyond the 72S layer it would certainly be desirable to change tube materials to prevent this.

Stress corrosion is not considered a problem when using 2 S aluminum; any increase in corrosion rate due to increased stresses is considered to be negligible.

- b. Creep - The possibility exists that present process tubes would creep at high operating pressures. In an effort to evaluate this factor, two sections of standard annulus process tubing (18 1/2 long) were tested for 10,000 hours at 400 psi fluid pressure and two sections at 600 psi fluid pressure.** Both tests were conducted in an oil bath at 100°C. The specimens exhibited no secondary creep - maximum deformation was 0.0005 inches/inch of circumference. Cycling stresses which sometimes tend to accelerate creep had no effect on the specimens.

An examination of the tubing after completion of the tests showed pitting due to the water present; the outside tube dimensions were unchanged from the original measurements.

In view of the above, creep is not considered a problem below 600 psi. A definite permissible upper limit is not known.

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* HW 18725 Physical Properties of Irradiated Process Tubing
R. G. Wheeler

** See Reactor Unit Design Staff Monthly Progress Reports 1950-51 for history of tests. Also Reactor Test Section Progress Reports 1950-51 All HDC documents.

- c. Safety Factor - It is necessary that some margin of safety be allowed when establishing maximum permissible pressures. It is felt that a factor based on yield is applicable in our case. In view of the facts noted below, this factor based on yield has been set at 1.5, a value higher than some factors used in the aircraft industry based on ultimate. The facts favoring a low safety factor are as follows:
- (1) Less than 85 % of the tube minimum allowable cross-section has been used in stress calculations. (Strength of 72-S was disregarded.)
 - (2) The probable load is reasonably well known for non-deformed tubing.
 - (3) Calculated stresses are a maximum.
 - (4) The tubes are extensively tested and examined prior to installation, thus insuring that standards are met.
 - (5) Strengths used for permissible pressure calculations are minimum rather than maximum. For example, Reynolds gives yields of 16,000 for 2S - 1/2H at 25°C and 13,000 at 150°C. The lower Alcoa values of 14,000 at 25°C and 10,000 at 100°C are used.
 - (6) The zone where the maximum stress (i.e. lowest factor of safety) exists is at lowest temperatures and radiation levels.
 - (7) The tubes are normally harder than H-14 as received and thus have even greater strengths than those used above.
- d. Radiation * Radiation (neutron bombardment) seems to have a slight work hardening effect on process tubes. No accelerated corrosion has been noted. The work hardening will probably increase the strength of the process tubes. Any gain in strength due to this factor has been neglected in this report. The effect of radiation on creep rate is not well known. Tests to date indicate only a slight effect.**
- e. Bursting Tests - Bursting tests indicate that new tubing fails at pressures in the order of 1000 pounds. A tube section removed from the pile after service withstood a pressure of 800 psi without failure.***

* See AEC-500, Survey of Effects of Radiation

** HW-20939 - Final Report, Production Test 105-381-P. Creep of Aluminum R. E. Githens

***Communication R. G. Wheeler - 1704-B Area

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- f. Temperature and Pressures along Tube Length - A consideration of the pile operating conditions reveals that a desirable condition exists when this factor is reviewed: i.e. The pressure is a maximum where the temperature is a minimum and pressure a minimum where temperature is a maximum. To adequately consider this factor, we will select points 10 ft., 20 ft., 30 ft., and 40 ft. from the inlet end of a process tube and establish the approximate pressure and temperature. This pressure will be established on the basis of 500 psi inlet 140,000 gpm flow, an enlarged annulus and a ΔT of 70°C (5°C over the expected ΔT .) (RDA-3 Tube)

Location	Tube Pressure psi (absolute)	Tube Temperature	Resulting Tube Stress #/in. ²
Inlet	500	20° C	9325
10 ft.	500	32° C	9325
20 ft.	400	56° C	7460
30 ft.	250	80° C	4665
40 ft.	150	*90° C	2800
Outlet	less than 150	*90° C	Less than 2800

* exceeds planned maximum outlet by 5°C .

- g. Permissible Operating Pressure - All pertinent factors having been considered and the desired safety factor established - the permissible operating pressure can now be established by dividing the yield strength at a given temperature by 1.5. Using the yield values given in Alcoa's booklet - "Aluminum and its Alloys" this division yields the following results:

Temperature °C	Strength Yield	Permissible Working Stress
25	14,000	9,350
100	10,000	6,650

An inspection of tube stress vs. pressures outlined in Section 3, above, reveals that a pressure of 500 psi is the maximum permissible standard operating pressure. The factor of safety is a minimum of 1.5 only at the tube inlet. At points further downstream the safety factor approaches 2 and 3.

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5. Emergency Operating Pressure - (i.e. Short Duration Pressures - approximately 5 min. or less.)

To provide a flow of 140,000 gpm at 500 psi inlet tube pressure a header pressure of 600 psi is required. This pressure (600 psi) is therefore the maximum pressure that the tubes would be required to withstand under emergency conditions other than those that would result in the tube melting. In view of the creep and bursting data above, it seems reasonable that the tubes can safely withstand 600 psi. Pressures in excess of 600 psi would exceed the yield strength by too great a factor and could result in plastic deformation of the tube. It is therefore recommended that a limit of 600 pounds pressure be used and in the event that it seems desirable to exceed this pressure a series of bursting tests be made to explore possible upward revisions of this limit.

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