Steam Reformer Tube Testing - a Status Report

Tube inspection in place, vital in the prevention of onstream failures and unwanted shutdowns, involves such techniques as creep measurement, radiography, and magnetic permeability.

P.A. Ruziska
Exxon Chemical Co.
and
D.L. Bagnoli
Esso Research and Engineering Co.
Florham Park, N.J.

Although the single "best" method is not yet available for non-destructive inspection of HK-40 tubing used in steam reformer furnaces, all methods now being utilized provide useful information and will aid in detecting "bad tubes." None, however, provide a *clearcut* indication that any given tube will not fail before the next turnaround.

This article discusses the merits and the limitations of currently used techniques. These methods include the circumferential growth (creep) technique, radiography, and magnetic permeability measurements. A number of other proposed techniques will also be covered: television scanning of inside surfaces, eddy current flaw detection, and ultrasonics.

Tube inspection, as defined here, is intended to identify tubing to be retired in advance of an onstream failure. A single tube failure and resultant unplanned unit shutdown can cause a loss in production amounting to several hundred thousand dollars. This potential economic loss, coupled with the possibility for additional mechanical damage to the unit as a result of the upset, can justify the expense of a comprehensive and regular furnace tube inspection program.

Some steam reformers are designed to permit onstream tube isolation by means of clamping inlet and outlet pigtails. With such a system, the incentive for avoiding an onstream failure of a tube is considerably reduced. However, non-destructive testing can still be of value in identifying tube replacements for a regular turnaround tube retirement program.

A review of the primary failure mechanism of HK-40 reformer tubes is in order. It has been well documented that the primary cause is creep-rupture *(1, 2)*. The stress profile in the reformer tube wall results in the initiation of fissuring somewhere between the inner wall and midwall, and not at the outer wall. Fissures propagate in both directions. Actual experience, together with analytical techniques for estimating the effets of creep, can be used to obtain an approximate relationship between crack size and remaining life.

Actual samples taken from steam reformers illustrate this mechanism. As shown in Figure 1a, the first signs of creep voids can be seen, with approximately one-fourth tube life consumed. Figure 1b represents a condition of approximately 50% life consumed. These life estimates were developed through creep tests on actual field samples and comparing remaining life with metallographic evidence of creep damage. Finally, Figure 1c illustrates a level of cracking occupying something under one-fourth wall thickness, with less than 25% remaining life estimated. An effec-

Figure 1a. Creep voids (arrow) can be seen in the tube wall between midwall and inner wall, with 3/4 tube life remaining. Mag. 50X.

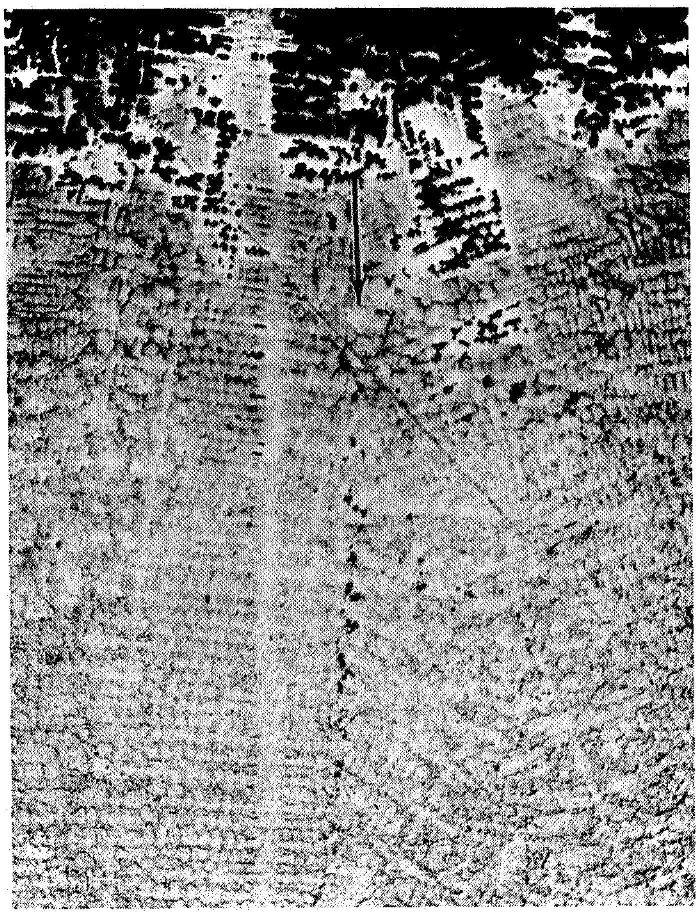


Figure 1b. Creep voids aligned and linking to form creep fissures (arrow) between inner wall and midwall represent approximately 1/2 tube life. Mag. 25X.

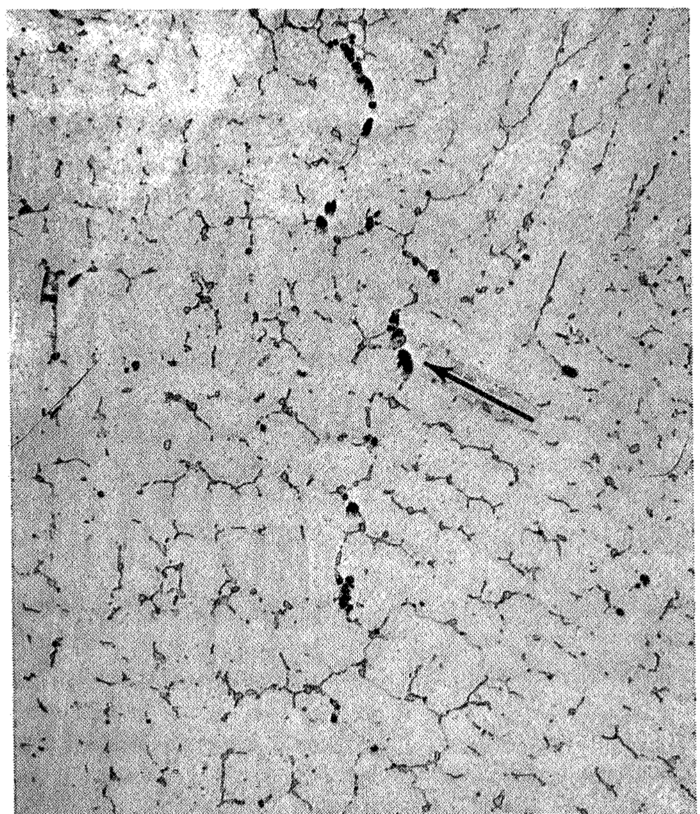


Figure 1c. Large creep fissures between midwall and inner wall are present with as much as 1/4 of the tube life remaining. Mag. 15X.

tive nondestructive testing technique could be based on the detection of cracks, the size of which would indicate imminent failure.

Independent of any inspection technique, adequate control of furnace tube metal temperatures must be stressed. The importance of tube temperature control is illustrated in Figure 2. If a tube is operated much above its prescribed design limit, rapid failure can be anticipated (no matter what the condition of the tube at a previous turnaround inspection).

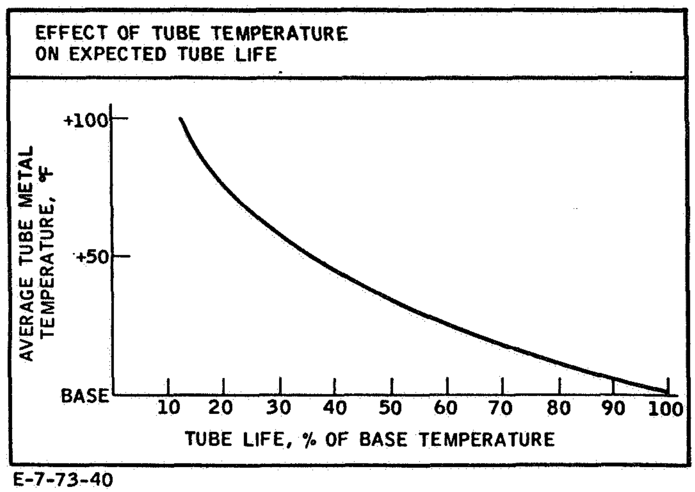


Figure 2. Effect of tube temperature on expected tube life.

On the other hand, due to the significance of temperature as a factor governing tube life, Figure 2 may lead to the erroneous conclusion that failures can be predicted on the basis of tube temperature records. In actual fact, although failures are more likely to occur in the hotter areas of the furnace, this phenomenon cannot be considered as a feasible alternative for non-destructive tube testing at turnaround.

There are several reasons why temperature measurement alone is not sufficient to predict tube life. Tube temperatures vary considerably during normal operation due to changes in furnace load or condition of the catalyst. Furnace upsets, or burner impingement, can also cause short-term temperature excursions. Prediction of tube life from temperature measurement alone would require highly accurate readings, plus would require some means for averaging the effects of temperature changes.

This is not an insurmountable problem. New developments in pyrometry may provide accurate temperature-recording ability. Average tube metal temperatures can also be determined metallographically, using techniques such as observing changes in carbide distribution and type if the proper standards are available *(3)*, or if a correlation can be established between available standards and the actual long-term exposure properties encountered in field samples. Some authors even report success in conducting this type of analysis on in-place catalyst tubes *(4)*.

However, even accurate data on average tube temperature history is still not sufficient to predict remaining life. Other factors such as the way tube temperatures have been cycled, as well as the original HK-40 casting properties, will affect remaining life sufficiently to make predictions from temperature alone highly unreliable. In addition, there are the possibilities of corrosion or weld failures which also would not be anticipated by tube temperature readings.

Ideal inspection method has several characteristics

An ideal steam reformer tube inspection method would have the following characteristics:

● Of primary importance is the ability to measure a tube condition indicative of failure within the space of time normally allotted for operation until next turnaround. For purposes of this discussion, we will define this as 10,000 hr.

● The technique should be conducted from and on the outside wall of the tube, with catalyst in place.

● A 100% scan of the full length of each tube should be possible within a reasonable time period, and for reasonable cost.

The key question is: what does one measure as a reliable indication of limited remaining life? Aside from checking for actual outside surface cracks or tube ruptures, a number of inspection methods have been used in the industry to detect imminent failure:

● Circumferential growth (or creep) measurements.

● Radiography for detection of internal fissures which have not yet reached the outside surface.

● Increase in magnetic permeability resulting from corrosion at the tube inside surface.

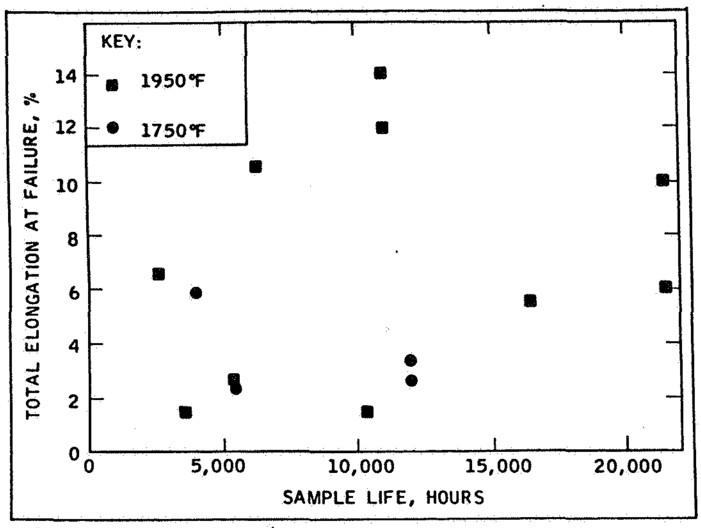
The remainder of this article will discuss the merits and limitations of each of these methods, based upon the present state of technology.

Circumferential growth (creep) technique has some problems

Survey data which indicate that the predominant mode of HK-40 reformer tube failure is creep-rupture leads one to consider that creep measurements would be the most obvious choice for measuring reformer tube deterioration. However, a number of problems have been encountered in applying this technique to HK-40 reformer tubes:

● It has been reported that the amount of creep (or strain) experienced at failure varies with the conditions under which the tubes have been operated *(5)*.

● Measurement techniques commonly employed in the past did not permit a practical way of obtaining a 100% scan along the tube length having sufficient accuracy to detect bulging in the amounts of interest.



E-8-73-2

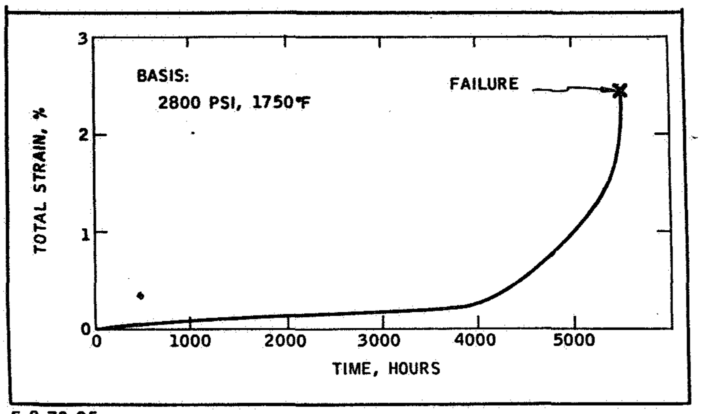
Figure 4. HK-40 laboratory creep tests.

The typical creep curve for HK-40 material is shown in Figure 3. This is based on laboratory testing, and shows a typical long-term flat portion (second-stage creep) followed by a steeply rising portion (third-stage creep) as the material approaches actual failure. In Figure 3, failure occured at 2% total elongation. It is difficult, however, to identify a consistent value of final elongation at failure. The degree of scatter encountered in our lab test program is shown in Figure 4. The results indicate that a maximum strain value of about 2% might be reasonable for the data at 1750°F., which is more typical for steam reformer tubing. It would be helpful to see what the final elongation values would be in the range of tube life encountered in commercial reformers.

Yet, there have been a number of acutal plant cases reported where creep measurements have been correlated with tube failure. For instance, one Exxon Chemical Co. ammonia unit operated for an extended period of time after creep in excess of 2% was detected on a number of tubes, and failures were reported which correlated with the tubes having the high creep values. This was a naphtha feed unit, top-fired design. Creep values measured during the first two years were consistently below 1%. After three years service without any tube failures, a number of tubes showed in the range of 2% to 3-1/2% creep. Presumably, the tube deterioration was caused by temperature excursions, which were partly due to coking problems. Five months after this inspection, the first tube failure occurred.

Until the furnace was retubed 18 months later, a total of 11 onstream failures were experienced and 4 additional tubes were replaced, based on creep in excess of 4%. Of the 11 tubes which failed, 9 failed due to weld-joint cracking and only two failed longitudinally in the non-welded area. At the time of retubing, a few tubes were found with what seemed to be an unusually high amount of creep, in the order of 7%.

There is no disputing the fact that creep measurements provide important information concerning the state of



E-8-73-25

Figure 3. Typical HK-40 strain curve.

metal deterioration. However, at present, the creep method locks a definitive and reliable creep value for tube retirement. A better criterion for tube retirement might be to plot reformer tube creep readings as was done in Figure 3, and retire a tube when creep rate accelerates. Again, however, there are no definitive commercial plant data regarding the remaining life of a tube when creep rate does accelerate (i.e., whether it is in the range of 10,000 hr. required for assuring against failure unitl next turnaround).

Full tube scan provides effectiveness

In any case, in order for creep measurements to be effective, a full tube scan having an accuracy in the range of ±0.01 in. on diameter is required. In addition, a reference scan on the tube as-supplied is important because such a tube may have a diameter variation of as much as 1/16 in. Recent developments in instrumentation may provide this ability.

An interesting technique appears to be a recent development by Canadian Industries Ltd. *(6)*. CIL offers an electronic tube caliper which fits around the tube, and can scan full tube length propelled with a winch and cable attached to an aluminum mast. With this device, it is reported that about 4 hr. would be required to scan 42 tubes (no scaffolding required, catalyst in place). Tube dimensions are indicated on a recorder output, which also provides a permanent record of the tube scan. Accuracy is reported to be ±0.005 in.

Circumferential creep measurements, utilizing an effective scanning device such as the one described above, can be of value for identifying the *worst* tubes. Based upon the present state of this technology, we cannot propose any definitive retirement criteria. However, this by no means cancels the effectiveness of the method. One could log the creep readings and retire select tubes showing either an acceleration of creep, or simply those having the highest creep values. These tubes can then be subjected to metallurgical analysis and the findings used to revise as necessary the previous retirement criteria. We would propose initially to retire those tubes which reach creep valves in the range of 1-2%.

Radiographic techniques finds cracks or fissures

Radiography perimits location of cracks or large fissures. Radiography has a finite sensitivity, which means that cracks must be sufficiently large in order to be detectable. The primary question to be asked is whether the crack size detectable by radiography will produce failure in 10,000 hr. But, we have found the situation can be even more complex than this. Crack "size", as related to detection by radiography, can refer to crack width or crack length.

Regarding the question of remaining tube life once fissures have formed, our reformer tube stress analyses have allowed us to estimate that a crack size of one-third wall thickness would cause failure in approximately 10,000 hr. Consequently, if the radiographic technique could detect cracks of at least this size, it would seem to have value in assuring reliable tube operation until next turnaround.

Dalton reports in a paper on reformer tube radiography

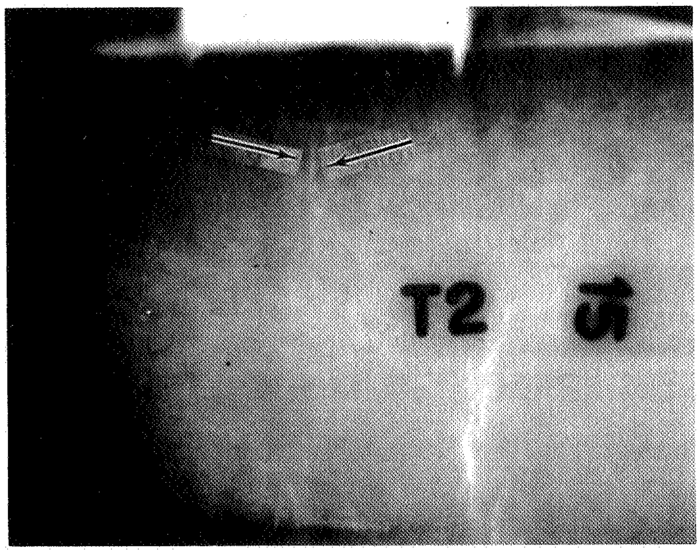


Figure 5. Radiograph of tube showing several creep fissures. Arrow locates creep fissure which represents "minimum" detectability.

(7) that he was able to detect cracks having a minimum of one-fourth wall size. He also reports reduced senstivity with catalyst in-place. Figure 5 shows results of some of our own laboratory radiograph studies on HK-40 reformer tube samples with internal fissures to determine what size cracks could be detected. Figure 5 shows a radiograph of the tube sample without catalyst. In addition to a pronounced fissure, there is a barely detectable fissure marked with arrows which we considered at the limit of detectability.

Both radiographs used a double-wall technique. The source, IR-192, was placed against the tube wall at three positions spaced 120° along the circumference. The measured senstivity was about 4%.

The tube was next sectioned at the plane indicated by the arrows in Figure 5 to determine actual crack size (this is shown in Figure 6. The crack found in the radiograph is acutally one-half wall thickness. The crack opening shown at the arrow made the defect visible to radiography. However, there are other cracks, about the same size, which did

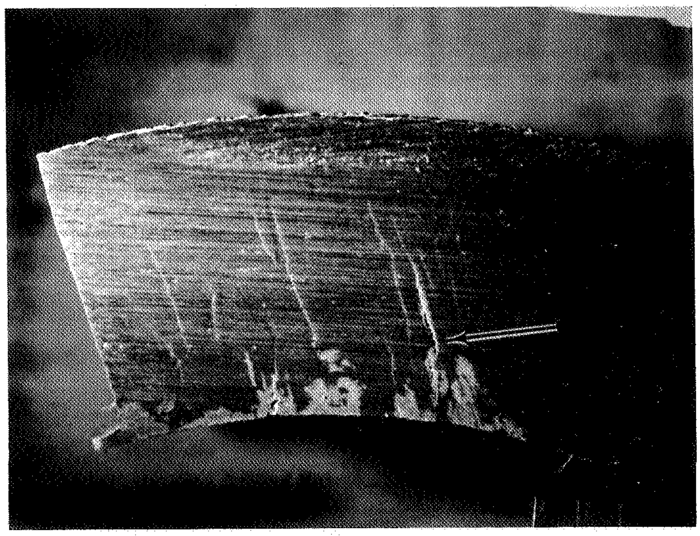


Figure 6. Cross-section of tube, made at location identified on radiographs in Figure 5. Arrow locates creep fissure which represents "minimum" detectability.

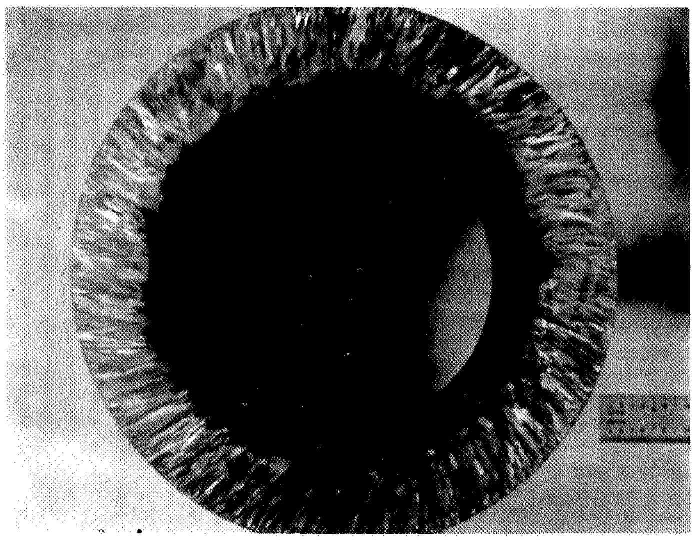


Figure 7. Columnar grain structure for sample examined in the previous figures. Note that cracks follow direction of columnar grains and are not radially oriented.

not show up in the radiograph at all. Note also the non-radial crack orientation. If these tight cracks were aligned in the direction of the beam, they could have been detected. An improvement in the technique seems to be indicated, which would take this directionality into account.

The reason for the crack alignment in a non-radial orientation appears clear (Figure 7). The cracking follows the orientation of the columnar grains, which are characteristic of centrifugally cast HK-40 tubing material. At present, we know of no radiographic methods which fully recognize this factor. Radiography in its present state may not guarantee detection of critical size cracks.

The final concern we have regarding radiography is that, based on present technology, it is not suitable for reformer tube scanning. Some other method is required to identify critical areas for radiography. Some furnaces have a definite hot zone (for instance, about four to five feet about burner level in Foster-Wheeler terrace-wall furnaces, as reported by Dalton). These hot zones could be selected for radiography. A better technique would be to scan the tubing using an electronic creep gage, or some other means, to pinpoint the worst areas (which may or may not be in the hottest zones). Then these areas could be examined with radiography to determine the extent of creep damage.

We believe improvements in the radiographic technique are needed to overcome the crack orientation problem reported above. If proper beam alignment can be provided, radiography seems to have sufficient sensitivity to assure detection of cracking indicative of limited life (even with catalyst in-place). However, due to the lack of scanning ability, we believe the application of the radiographic technique will probably be limited in any case. It could be considered as a back-up to a scan technique. It would then be employed to confirm scan indications provided, for instance, by the creep gage referred to above. Instead of removing tubing to assess whether a retirement tube condition has truly been reached, radiography of the worst zones would be conducted.

Another potential application is to check areas where severe temperature excursions were noted during operation; provided such areas are well-defined and are limited in number so they can be radiographed within the turnaround shcedule. Finally, radiography would be the method to use to check the condition of the welds:

Magnetic permeability measurement services are available

The HK-40 reformer tube scan technique most commonly employed is the measurement of magnetic permeability by a low-frequency, eddy current method. At least two companies offer this as a contract service. These systems can be designed to scan by using a pulley system operated from the furnace floor *(8)*.

However, considerable controversy has arisen regarding the significance of magnetic measurements to indicate remaining tube life. An increase in magnetic permeability occurs as a result of carburization or oxidation of HK-40. These corrosion phenomena are found on occasion *(9)*, due to factors which are not fully understood but are certainly related to the composition of the process stream and the tube inner wall porosity. In addition, when creep produces cracks which penetrate to the inside surface, a condition is formed which favors oxidation in the fissure *(10)*. Consequently, one might expect from a measurement of magnetic permeability an indication of not only the presence of corrosion, but also creep damage.

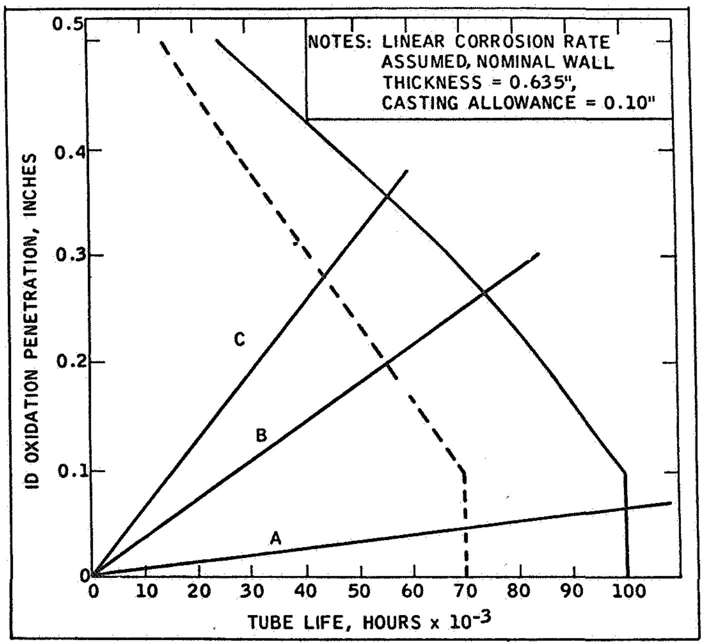
The question is: what order of remaining tube life exists when fissures have not only reached the inside surface, but have also oxidized sufficiently to be detectable via the low frequency eddy current method?

In our experience, we have seen critical sized cracks (defined as that predicted to cause failure in under 10,000 hr.) which may or may not have penetrated to the inside surface, depending upon tube geometry and stress considerations. This indicates that the potential for crack-induced oxidation may or may not develop. Plant experience with tube failures in less than one year after a magnetic scan appears to confirm this conclusion.

Let us review how magnetic permeability is used. A calibration curve is established. *(11)* Tubing exhibiting a "severe" increase in magnetic permeability would be selected for removal and evaluation. If oxidation only were of concern, one could develop an estimate of tube life as a function of oxidation rate, Figure 8. Note that no stress credit was taken for the 3/32-in. casting allowance, consequently any corrosion penetration value below 0.10 in. will not significantly affect tube life. The curve allows estimation of the reduction in tube life for penetrations in excess of 0.10 in., subject to the assumption of linear oxidation penetration. Note that the approach concerns only oxidation effects and does not relate to creep damage, which is the more usual cause of tube failure.

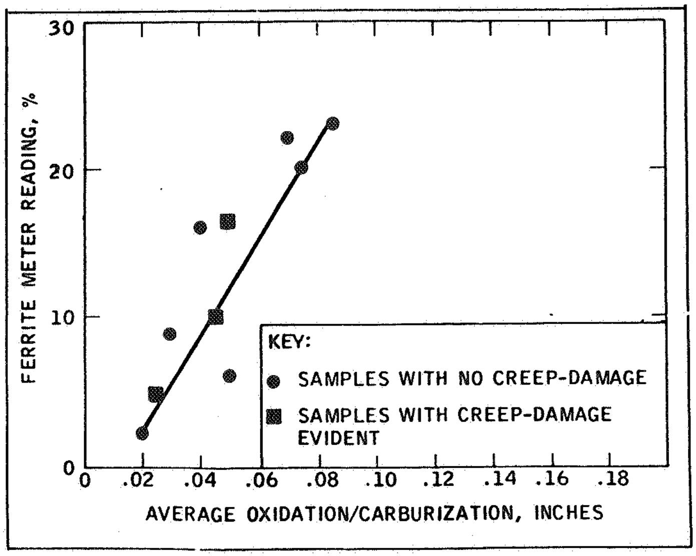
Evaluation tests were conducted

To assess whether measurement of magnetic permeability has any possible value at all for detecting creep damage, we evaluated a number of HK-40 reformer tube samples exhibiting severe creep damage. The results are summarized in Figure 9. The magnetic readings were taken from the



E-8-73-4

Figure 8. Effect of corrosion on stress analysis—simplified model.



E-8-73-3

Figure 9. Magnetism vs. penetration, in sound vs. marginal tubing.

inside surface, using a ferrite meter. A calibration curve was developed using samples showing various levels of oxidation and carburization on the inside surface, but which did not exhibit severe creep damage. The squares indicate those tubes which did exhibit pronounced creep damage (cracking). Note that the levels of magnetic permeability present in the tubes with cracks are well within the range of magnetic permeability exhibited by the tubes which are not in a condition of limited life. Some of the samples used are shown in Figure 10.

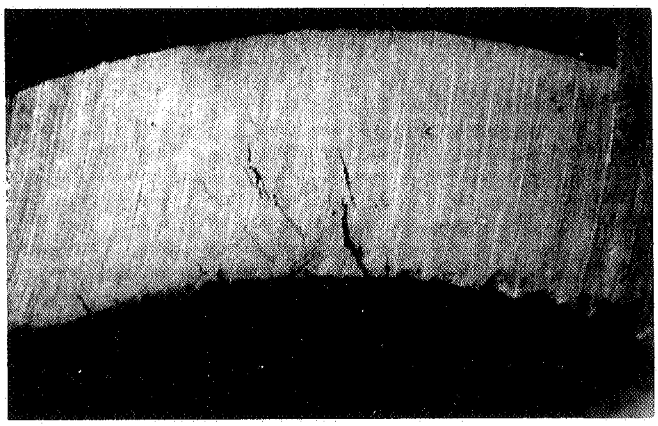


Figure 10a. Magnetic reading –20. No visible creep fissures.

Figure 10b. Magnetic reading –16. Visible creep fissures subsurface not oxidized.

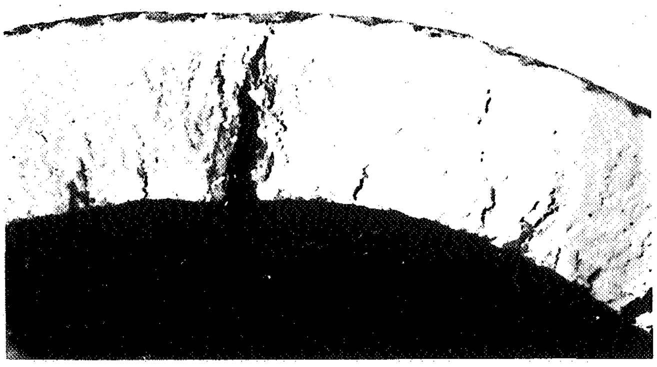


Figure 10c. Magnetic reading –5. Numerous inner surface fissures.

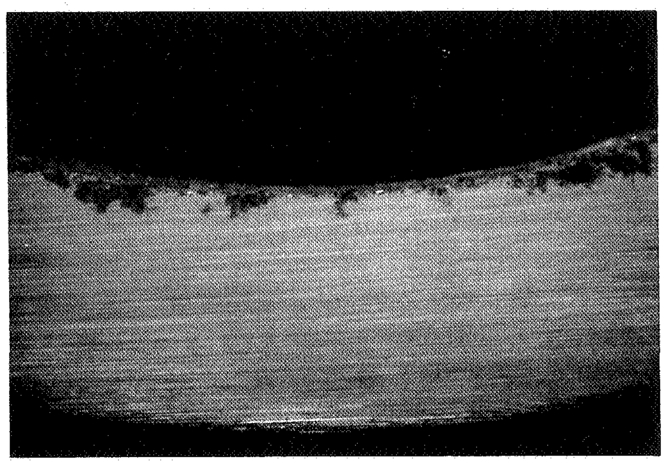


Figure 10d. Magnetic reading –10. Inner wall and midwall creep fissures.

Obviously, one must conclude that creep damage does not necessarily result in a sufficient increase in magnetic permeability to permit distinction of a bad tube from a satisfactory tube as part of a regular turnaround inspection program. Consequently, measurement of magnetic permeability will not provide a reliable indication of remaining life in tubing damaged by creep alone. There may be cases where one is fortunate enough to catch a tube on the verge of failure, having been in operation long enough at this state to produce sufficient oxidation in the fissures in order to allow detection. But, the technique does not seem to provide assurance of 10,000 hr. remaining tube life.

On the other hand, low-frequency eddy current methods do provide a convenient way to scan tubing for corrosion. There appears to be some value in conducting magnetic permeability scans for corrosion detection, coupled with a second method for creep damage. American Cyanamid Co. reported an unusually severe corrosion problem that was monitored successfully via measurement of magnetic permeability *(9)*. We ourselves have encountered a form of carburization attack similar to that reported by others *(12)* in a magnetic permeability scan, and we plan to continue monitoring that furnace by measurement of magnetic permeability.

When we talk of corrosion, we include both oxidation and carburization. In most cases, only oxidation is present. The depth of penetration appears to be related to surface porosity differences, plus being favored by increasing temperature. Oxidation rate probably decreases with penetration, inasmuch as we find few cases of serious sound metal loss in tubes exhibiting only oxidation. On the other hand, when carburization is present, oxidation of the carburized zone appears to proceed at a faster rate than oxidation of the base metal. Similarly, the degree of corrosion penetration in such cases is significantly greater than the typical oxidation pattern experienced in a normal furnace without carburization. Consequently, when carburization occurs, monitoring of carburization/oxidation penetration can be important for assessing remaining tube life.

Figure 11a shows the carburization/oxidation attack detected in an Exxon Chemical Co. Foster-Wheeler terrace wall unit, at the hot zone about six feet above lower burner level. This is a low-severity reformer design, which may have affected the carburization rate experienced here vs. that obtained in other units. Three tubes showing the highest corrosion indications were removed. Maximum depth of the carburization layer is 0.15 in., while the oxide penetration ranges from 0.08 in. average to 0.15 in. maximum penetration. Tube life at time of removal was 34,000 hr. Although some indication of creep voids were evident in the microstructure, remaining tube life independent of corrosion was estimated to be in excess of 30,000 hr.

We will monitor the progress of carburization/oxidation attack in this unit. A depth of oxide penetration which would cause us to retire additional tubing based upon loss of sound wall can be estimated (Figure 8).

A more difficult problem is to account for the effect of the carburized layer, which may also affect tube life. Carburization produces a change in the density of the material; the amount of change depending upon the amount of

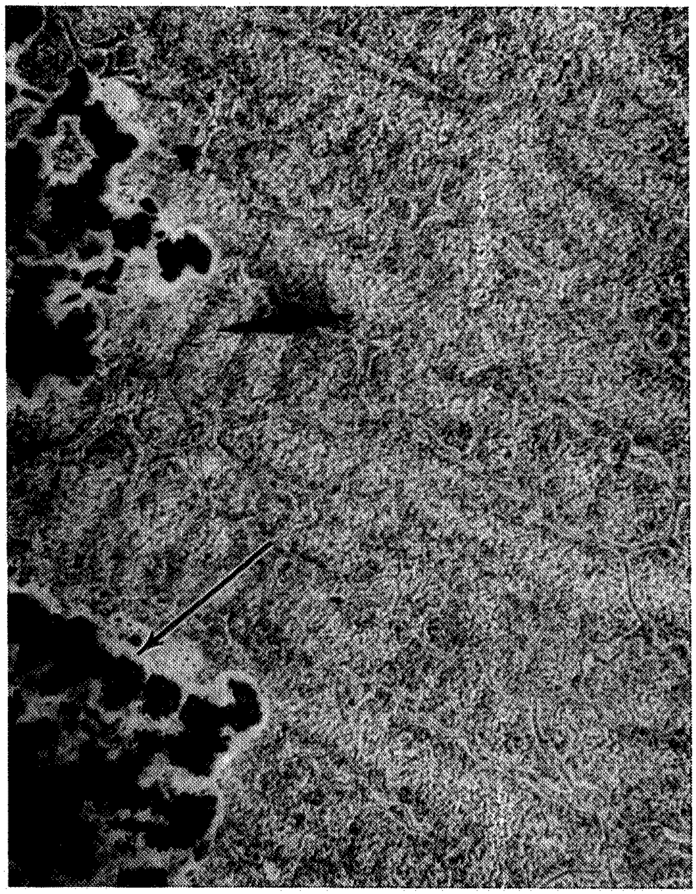


Figure 11a. Layer of carburization found in the Exxon Chemical steam reformer sample. Surface carbon measured at 2%. Arrow shows oxide layer. Mag. 100X.

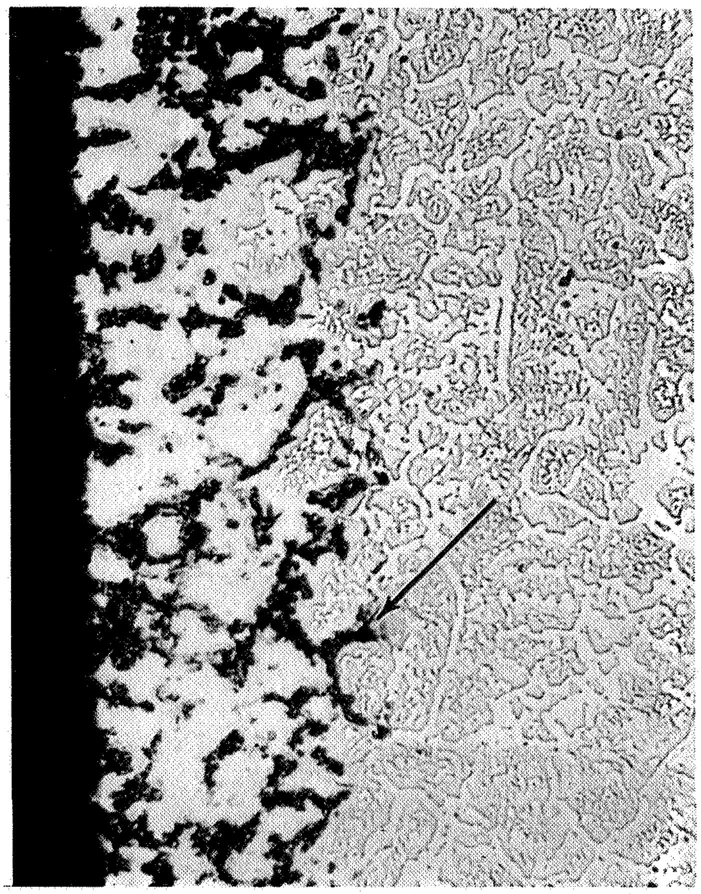


Figure 11b. Layer of carburization found in Exxon Chemical pyrolysis furnace sample. Surface carbon measured at 4%. Arrow shows oxide layer. Mag. 100X.

carbon absorbed in the matrix. The rate of change in density produces creep strain in the uncarburized layer which leads to an internal tensile stress, and could shorten life considrably. Our estimates show that a level of 4% carbon at the inside surface, such as shown in Figure 11b taken from an ethylene pyrolysis furnace, can greatly reduce tube life. In this case, creep strain resulting from the above mentioned change in density lowered tube life to a year's time.

In contrast, the steam reformer tube referred to above is shown in Figure 11a and contains a surface carbon of 2%. Here, the carburization stress does not affect tube life as greatly, and is not the overriding factor in determining tube life. For now we will retire tubes having the highest magnetic permeability in order to check the condition of the base metal for creep fissures. In any case, we would not like to continue to run with tubes showing in excess of about 0.20 in. penetration at the next turnaround inspection.

Measurement of magnetic permeability by a low-frequency eddy current scan technique can be recommended for detection of corrosion problems only. Most furnace tube samples examined indicate a small oxide layer at the inside surface, and this does not provide any cause for concern. Similarly, creep-rupture can occur without a significant change in magnetic permeability. For situations where carburization is occuring (or severe oxidation if this were to be encountered), magnetic permeability measurements would be valuable for monitoring the progression of attack. Tube sampling would be required to confirm the nature of the attack and verify remaining life.

Three other techniques proposed

Due to the fact that none of the previously described inspection techniques provides total reliability as of the present time, a number of additional techniques have been proposed:

- TV scan of tube inner wall.
- Eddy current flaw detection.
- Ultrasonics.

A TV scan of the tube inside surface is practical, and has been conducted on a few occasions. This technique may have application in certain isolated cases, but we do not consider it a generally applicable method for regular turnaround inspection programs. First of all, it requires catalyst removal. Secondly, the technique would only allow detection of corrosion or cracking on the inside surface. As we have shown, corrosion can be assessed more reliably via a magnetic permeability scan. Inside surface crack detection would certainly be of value. However, both our experience and calculations indicate tube life when cracking penetrates to the inside surface may be well below 10,000 hr. Consequently, this method would have little to offer compared with other available scanning techniques.

The eddy-current flaw detection technique uses a higher frequency than is employed for measurement of magnetic permeability. This permits direct detection of internal discontinuities, such as fissures. However, the non-homogeneous character of HK-40 grain structure produces a strong interference which masks the presence of cracking, unless the cracks are quite close to the surface. Consequently, it has not been possible to develop a successful eddy current flaw detection technique for cast HK-40 steam reformer tubes.

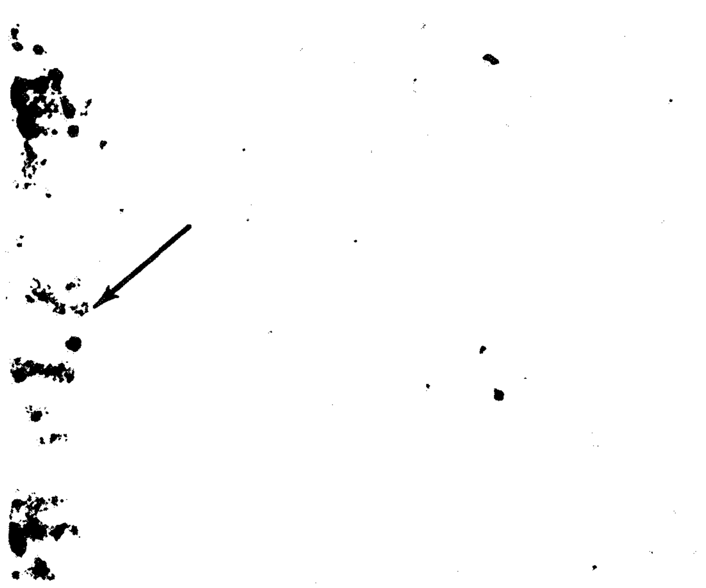


Figure 11c. Typical structure found at inner wall of steam reformer. No carburization present as indicated by normal low volume percent of carbides. Arrow shows oxide layer. Mag. 100X.

Ultrasonics, in our opinion, offers the highest probability for a successful development of a new inspection technique. Ultrasonics, like radiography, permits detection of internal fissures. Reported efforts to employ ultrasonics to date have experienced similar problems to that described above for the eddy current flaw detection method. In other words, signal scattering caused by the coarse grain, non-homogeneous character of the HK-40 material masks the presence of cracks.

New developments in this field are likely. For instance, research in the area of improved resolution of crack vs. grain-caused responses. If ultrasonic techniques can be improved to permit critical size crack detection in HK-40 material, it is possible that ultrasonics will supplant radiography for HK-40 tube inspection due to the former's ability to scan tubing. If the ultrasonic method's crack-size sensitivity is significant enough to insure against failure in under 10,000 hr., creep measurements and the problem of defining retirement criteria may become an obsolete question. Finally, ultrasonics also measures wall thickness, and may be able to identify internal corrosion in the same scan. But, as of now, a suitable ultrasonic technique has not been proposed.

Summary

Based on the present state of reformer tube inspection technology, we believe the following will provide the most meaningful inspection program, for regular turnaround application:

- Creep scan, preferably utilizing a travelling caliper.

Retirement of tubes showing in excess of predetermined creep limit.

● Magnetic permeability scan (only needed on a regular turnaround basis if carburization or severe oxidation has been detected). Retirement of tubes showing in excess of predetermined corrosion indication.

● Radiography of tube welds (perhaps not every turnaround, but certainly if high creep values have been detected).

● Radiography of selected areas showing higher than average creep or magnetic permeability (can be considered as an alternative to removing tubes to check their condition visually).

Metallographic inspection of the condition of all retired tubes, at the location of the highest readings of creep, etc., is essential for updating or revising the retirement criteria for the next inspection program.

Further research in the area of reformer tube inspection methods is definitely recommended. Additional experience with creep measurements, especially correlation of the creep values with metallographic examinations, is needed to confirm whether a meaningful and reliable retirement creep value can be established. Alternatively, research in new areas, such as ultrasonics, may result in the development of a more direct measurement of a condition indicative of imminent tube failure. #

Literature cited

1. Salot, W.J., "Anticipating Reformer Tube Life in Normal Service," *Ammonia Plant Safety*, **14**, 119, AIChE Publication (1972).
2. Ciuffreda, A.R., and Greene, B.N., *Hydrocarbon Process.*, **51**, 113 (May, 1972).
3. Dillinger, L., etal., "Microstructures of Heat Resistant Alloys," Alloy Casting Institute (1970).
4. Ingram, A.G., and McCandless, J.B., *Hydrocarbon Process.*, **51**, 125 (April, 1972).
5. Tucker, A.J.P., etal., "Reformer Catalyst Discussion," *Ammonia Plant Safety*, **13**, 80, AIChE Publication (1971).
6. Quinlan, R.A., personal communiation, Canadian Industries, Ltd., Courtwright, Ontario, Canada (July, 1973).
7. Dalton, R.R., *Materials Evaluation*, 249, December, 1972.
8. Holloway, L.W., "Ammonia Reformers and the Tube Deviation Analyzer," *Ammonia Plant Safety*, **13**, 78, AIChE Publication (1971).
9. Gackenbach, R.E., and Shay, J.F., *Materials Protection and Performance*, 19, June, 1971.
10. Zeis, L.A., and Heinz, E., "Catalyst Tubes in Primary Reformer Furnaces," *Ammonia Plant Safety*, AIChE Publication (1970).
11. Holloway, L.W., and Kellum, G.B., "Evaluation of High Alloy Materials Used in Reformers and Pyrolysis Furnaces by Use of Magnetic Analysis Techniques," presented at 31st National Fall Conference, American Society for Non-Destructive Testing, October 18, 1971.
12. Roach, B.B., *Materials Evaluation*, 229, November, 1972.

BAGNOLI, D. L.

RUZISKA, P. A.

DISCUSSION

W.H. VAN MOORSEL, CF Industries, Inc.: You mentioned on several occasions where water had been associated with failures. Is this water carried over from the boiler and introduced as process steam?

RUZISKA: I mentioned one occasion in which the water came from a tube failure in a waste heat boiler downstream of the reformer furnace. This was a hydrogen plant, remember, so the transfer line ran straight into the waste heat boiler. On the other two occasions mentioned the water came from boiler carryover and entered the catalyst tubes with the process steam.

W.D. CLARK, ICI, Billingham, England: I would like to ask three questions. Firstly you referred several times to solution annealing of the HK40. Is this the 2300°F–1250°C treatment which we have found necessary and reported previously?

RUZISKA: I'm not sure of the exact temperature value, but it's in that range.

CLARK: Second. We at Billingham think very favourably of water jacketing these refractory lined heads. While you cannot then see early signs of trouble with the lining, you have very considerable protection against local insulation failure causing a burst. Have you used water jackets?

RUZISKA: The cases I described here did not employ water jackets. We have them on one or two plants, but we prefer to have the equipment exposed and painted with temperature sensitive paint. When we detect a lining failure, steam sprays are quite successful in protecting against a pressure wall failure. Where we have had a pressure wall failure, the reason was that we had not gotten the steam spray installed in time.

CLARK: We too have had trouble in places where it was difficult to install a water jacket and have found steam cooling a satisfactory temporary measure. From what you said I gather that you, like us, are not in favor of having a metal lining inside the refractory.

RUZISKA: That is correct.

J.M. BLANKEN—UKF—Holland: The reformed gas boiler of the Shellstar ammonia plant has about the same transition cone in the shell as you mention for the transferline.

The bottom of the shell is of carbon steel insulated on the inside, the top of the shell is of stainless steel insulated on the outside.

In between is a stainless transition cone.

The same cracks as you mentioned were found in the weld between transition cone and stainless steel top.