by plastometer tests appear preferable for gasification by the Lurgi process. Coals 268 and 270 appeared to have the most desirable properties and were studied extensively by this method of complete gasification.

Coal DSC2 from Greene County, Pa., is high-volatile A bituminous in rank and has a high sulfur content. This coal was used for experiments on the desulfurization of coal. Its plastic properties are typical of high-volatile A bituminous coals.

In a special series of four tests, 500°, 400°, and 300° C. chars were made from a Texas lignite and blended with various asphalt binders in the proportion of 85:15 of char to binder for plasticity determinations. Only slight fusion was shown by any of the blends. The 400° C. char with a heavy asphalt binder showed the most fusion, giving a resistance of 0.9 pound-inch in the Davis plastometer test.

A revolving drum for automatically graphing the resistance of a coal sample as it develops during the Davis plastometer test was devised and installed. After some adjustments were made in the gears and pulleys, the automatic recorder proved quite satisfactory and has been in continued use since early in the year.

## Swelling Properties of Coal During the Coking Process

Bureau of Mines equipment for testing the swelling properties of coal during coking includes two vertical-slot ovens and a sole-heated oven, all electrically heated. The large vertical-slot oven uses a steel retort that holds 350 pounds of coal. The small vertical-slot oven requires no retort, as its heated surfaces are silicon carbide; the chamber holds 17 pounds of coal. These two vertical ovens are operated at constant volume, and the pressure exerted on the movable wall is measured. This pressure is the maximum to be expected on coke-oven walls. The sole oven is charged with 40 pounds of coal and is heated only at the floor. It is operated at a constant pressure of 2.2 pounds per square inch, and the percentage of expansion (or contraction) of the original thickness of coal charge is taken as the characteristic expansion index of the coal. Most duplicate tests in the sole-heated oven give expansion results that agree within 1 percent or less. This oven is useful for comparing different coals but does not show the maximum pressure to be expected on coke-oven walls.

Results from the small vertical oven are not reported at this time, as different test procedures and heating schedules are being used to determine the effect of these factors upon the maximum wall pressures and to develop a procedure that gives good agreement between duplicate tests. Thirty-nine tests were run in this small vertical oven during the year, and many data have been accumulated that may lead to a standard test procedure and correlation of results with either the large vertical oven or the sole-heated oven. One coal blend tested gave maximum wall pressures that correlated with the time required for the center of the coal charge to reach approximately 100° C. This time was less than 1 hour for the slowest heating rate or lowest wall temperature at charging. Other coals or blends may not show this same susceptibility to a slight change in heating rate or wall temperature at charging. For this particular coal blend, the effect of the heating rate through the preplastic range seems to have considerable effect upon the maximum wall pressures when the plastic layers meet. Table 20 gives the expanding properties of the coals tested during the year in the sole-heated oven and the large vertical oven.

A new sample of Pocahontas No. 3 coal (c75) for blending purposes was received. This coal was tested in the sole oven and expanded an average of 21.7 percent as compared with a sample from the same mine received and tested in 1942, which expanded an average of 24.4 percent.

It has been suggested that Beckley coal be used to augment the diminishing supply of low-volatile coals. As there are frequent occurrences of steep dips and rises in the Beckley bed, with thin coal on the crests of the rises and thick coal in the bottom of the dips, six special samples for expansion tests were taken from various parts of the mine in addition to a carbonization sample. Blends of 20 and 30 percent Beckley bed coal with 80 and 70 percent, respectively, of Pittsburgh-bed coal, did not show dangerous expansion pressures in the large vertical oven. However, the 30:70 blend was tested at a bulk density of 49.88 pounds per cubic foot and gave a maximum wall pressure of 4.4 pounds per square inch. High bulk densities using the 30:70 blend probably would give dangerous expansion pressures. Two sole-heated oven tests were made on Beckley coal with oxidized samples. After 18.4 days of oxidation at 100° C., the expansion was lowered to 3.6 percent. A dry sample oxidized for 8.2 days (and water equivalent to the normal moisture content of the coal then added) expanded 30.0 percent, or almost twice the expansion of the unoxidized sample of normal moisture content.

Coal blends were submitted by the Citizens Gas & Coke Utility, Indianapolis, Ind., to check the expansion of oil samples containing a high percentage of Pocahontas No. 3 coal. The first of these blends, coal 257, consisted of 49.5 percent Eagle coal from the border of Fayette and Raleigh Counties, W. Va., and 50.5 percent Pocahontas No. 3 bed coal from Raleigh County, W. Va. The second blend, coal 257A, consisted of 55.0 percent Eagle bed and 45 percent Pocahontas No. 3 bed coal. Blend 257A was received in the oiled condition; no unoiled samples were received. Both the oiled and unoiled blends were tested in the sole-heated oven and the large vertical oven. The large oven tests on the oiled samples all gave pressures greater than 4.4 pounds per square inch, or the limit of the gage. An attachment has since been added to the large vertical slot oven, so that pressures up to 5.0 pounds per square inch can be measured.

The 1.55 floats from two high-volatile A coals, Powellton and No. 2 Gas, were cleaned by a heavy-media process, and each sample was then blended with 20 and 30 percent Pocahontas No. 3 coal (c75). All of these blends were contracting in the sole-heated oven.

TABLE 20. - Expansion-test results

| Coal No. | Description | Sole-heated oven. Expansion at 55.5 lb. per cubic foot, percent | Large vertical-slot oven. Maximum wall pressure, lb. per square inch |
|---|---|---|---|
| c75 | 100 percent Pocahontas No. 3 bed | +21.7 | |
| 90 | 100 percent Beckley bed, carbonizing sample, third air course, first north, 150 feet inby No. 1 cross entry on right side | | |
| 90A | 20 percent Beckley bed and 80 percent Pittsburgh bed | +15.9 | 1/0.8 |
| 90B2/ | 30 percent Beckley bed and 70 percent Pittsburgh bed | - 3.6 | 1/3.4 |
| a902/ | Mine sample, first right off first north mains 200 feet inby | + 1.0 | |
| b902/ | Mine sample, fourth breakthrough between fourth right entries off eighth left | +13.9 | |
| c902/ | Mine sample, first breakthrough to right off No. 23 room off eighth left | 3/+12.6 | |
| d902/ | Mine sample, first west mains 300 feet past property line in right entry right rib | 4/+11.2 | |
| e902/ | Mine sample, No. 1 room first panel fifth north of eighth right 150 feet inby | +10.6 | |
| f902/ | Mine sample, No. 5 room off fifth left blind entry off No. 4 mains | +12.4 | |
| 906/ | 100 percent Beckley bed | + 9.0 | |
| 907/ | 100 percent Beckley bed | +30.0 | |
| 257 | 49.5 percent Eagle bed and 50.5 percent Pocahontas No. 3 bed | + 3.6 | 3.2 |
| 257 | 49.5 percent Eagle bed and 50.5 percent Pocahontas No. 3 bed (oiled sample) | + 2.1 | 5/4.4 |
| 257A | 55 percent Eagle bed and 45 percent Pocahontas No. 3 bed (oiled sample) | - .7 | 1/, 5/4.4 |
| 258 | 100 percent Powellton bed (1.55 floats) | -17.2 | |
| 258A | 80 percent Powellton bed and 20 percent Pocahontas No. 3 bed | - 5.3 | |
| 258B | 70 percent Powellton bed and 30 percent Pocahontas No. 3 bed | - .5 | |
| 259 | 100 percent No. 2 Gas and Peerless bed (1.55 floats) | -14.7 | |
| 259A | 80 percent No. 2 Gas and Peerless bed and 20 percent Pocahontas No. 3 bed | - 5.3 | |
| 259B | 70 percent No. 2 Gas and Peerless bed and 30 percent Pocahontas No. 3 bed | - 1.9 | |
| 280 | 100 percent Pocahontas No. 4 bed coal | +22.9 | |
| 2808/ | 100 percent Pocahontas No. 4 bed | +22.7 | |
| 2809/ | 100 percent Pocahontas No. 4 bed | + 6.2 | |
| 28010/ | 100 percent Pocahontas No. 4 bed | - 1.5 | |
| 281 | 100 percent Pocahontas No. 3 bed | +28.5 | |
| 28111/ | 100 percent Pocahontas No. 3 bed | +20.4 | |
| 28112/ | 100 percent Pocahontas No. 3 bed | + 2.6 | |
| 28113/ | 100 percent Pocahontas No. 3 bed | + .9 | |
| 28214/ | 100 percent Pocahontas No. 3 bed | +29.3 | |
| 28215/ | 100 percent Pocahontas No. 3 bed | 1/+29.8 | |

1/ Single test.
2/ Special expansion samples. 100 percent Beckley bed.
3/ Thick coal at bottom of slope.
4/ Thin coal at crest of slope.
5/ Not maximum wall pressure; unable to hold at constant-volume conditions.
Time oxidized in air at 100° C., days: 6/, 8.2; 7/, 18.4; 8/, 3.8; 9/, 9.0; 10/, 14.2; 11/, 5.0; 12/, 11.0; 13/, 13.1.
14/ Pillar sample containing up to 1/2-inch lump.
15/ Pillar sample crushed to pass 1/4-inch screen.

Although the chemical analyses, carbonizing properties, and plastic properties showed no significant differences for Pocahontas No. 3 and Pocahontas No. 4 bed coals, their expansion differed by 5.6 percent. Pocahontas No. 3 expanded more than the No. 4 coal, and its coke was slightly stronger. Prolonged oxidation of these two coals resulted in appreciable reduction in their expanding properties.

## Blending Properties of Coals

For a number of years it has been the practice in the Bureau of Mines Carbonization Laboratory to make blending tests on all coals included in the Survey of Carbonizing Properties of American Coals. All low- and medium-volatile coals have been blended with Pittsburgh-bed coal from the Warden mine, which has been chosen as standard, and high-volatile coals have been blended with a low-volatile coal considered as standard. Several low-volatile coals have been used, but Pocahontas No. 3, from Kimball, McDowell County, W. Va., has been used in most cases. Blending proportions were chosen arbitrarily, being 20 and 30 percent of the low-volatile coal with 80 and 70 percent of the high-volatile. Results of those blending tests have been published with other data on the coals in question, but up to the present, no attempt has been made to summarize the results and generalize on the effect of blending upon quality of the coke and yields of byproducts. The data have been collected and summarized in Report of Investigations 3936.[69] The following conclusions were reached as a result of the summary:

The results of BM-AGA tests at 900° C. of 12 low-volatile, 8 medium-volatile, and 26 high-volatile coals and their blends were analyzed to determine the effects of blending upon the quality of coke and yields of byproducts. The low- and medium-volatile coals were blended with 70 and 80 percent Pittsburgh-bed coal; 5 low-volatile coals were blended with various high-volatile coals in the same proportions. The relative coking power of the individual coals and their blends was determined by comparing the shatter and tumbler indexes of the cokes. The following conclusions as to results in the BM-AGA retort were made from this study:

1. The average coking power of medium-volatile coals equals that of low-volatile coals. This equality holds true if they are carbonized separately or as blends with Pittsburgh-bed coal.

2. The most strongly coking medium-volatile coals coke fully as well as the most strongly coking coal of any rank when carbonized separately.

3. The coking power of medium- and low-volatile coals generally indicates their value as blending coals, although anomalous results are sometimes obtained where different high-volatile coals are used. The coking power of binary blends correlates with that of the higher rank coal more closely when medium-volatile coals are blended.

4. Pocahontas No. 4, Pocahontas No. 3, and Beckley are satisfactory low-volatile coals for blending with high-volatile eastern coals. Blends

69/ See footnote 62.

containing Pocahontas No. 4 coal from No. 4 mine, Raleigh County, W. Va., yielded slightly stronger coke than similar blends containing Pocahontas No. 3 coal from No. 3 mine, Wyoming County, W. Va.

Hartshorne coal from the Quality mine, Sebastian County, Ark., is a very satisfactory low-volatile coal for blending with Henryetta coal from Oklahomas and Bevier coal from Kansas.

5. Blends of low-volatile coals yield more coke and less tar, light oil, and gas than blends containing equal proportions of medium-volatile coals. The yield of gas on the volume basis is approximately the same for blends of low-volatile and medium-volatile coals.

The above conclusions are made with respect to the coking conditions prevailing in the BM-AGA test retort. They are presented for the information of the coking industry in the hope that discussion and publication of results of plant operation will show how the results of the BM-AGA apparatus can be applied in the study of blending problems.

## Bureau of Mines-American Gas Association (BM-AGA) Apparatus and Procedure

Apparatus and methods used in the Bureau of Mines-American Gas Association carbonization-test procedure were described in Bureau of Mines Monograph 5,70/ published after completion of the first 30 coals to be tested. Ninety coals have now been tested by the BM-AGA methods and gradually, over a period of 16 years, minor modifications in apparatus and procedure have been introduced as experience gained indicated. Radical changes have not been adopted, because any radical departure from procedures originally devised would interfere with comparisons of new test data with those already collected. Apparatus and procedure now used are described in Technical Paper 685,71/ issued during the year. The main improvements made in apparatus were (1) use of the electric furnace exclusively for heating the retorts (dispensing entirely with the gas furnace), (2) provision of water jackets for the light-oil scrubbers, in which the temperature is controlled automatically at 5° C., (3) better instrumentation, and (4) provision for studying the expanding and oxidizing properties of coals. Procedures have been modified only as to minor details in the interest of higher precision, and some tests have been added to give more complete information. For example, water displacement of the retorts is determined before and after carbonization tests. These tests show whether the coal expands strongly enough to deform the retorts and indicate roughly whether the coal is strongly or

70/ Fieldner, A. C., and Davis, J. D., Gas-, Coke-, and By-Product-Making Properties of American Coals and Their Determination: Bureau of Mines Mono. 5, 1934, 164 pp.

71/ Reynolds, D. A., and Holmes, C. R., Procedure and Apparatus for Determining the Carbonizing Properties of American Coals by the Bureau of Mines-American Gas Association Method: Bureau of Mines Tech. Paper 685, 1946, 35 pp.

moderately expanding. Coals that do not expand strongly enough to deform the retorts should give no trouble in a byproduct oven unless charged at higher densities. More attention is now paid to the density of charge in the retorts, because charge density strongly influences expansion and physical properties of the coke to some extent.

## Bulk-Density Research

The extent of packing coal particles (that is the bulk density of the coal) in coke-oven charges has a marked influence upon the behavior of the charge during coking. Fluctuations in the bulk density of coal cause varying charges per oven with resultant uneven plant operation and poor quality of coke output because of under- or over-coking of the charge. Excessively low bulk densities can cause fluxing of the brickwork of the oven walls when the ovens are being operated at the maximum flue temperature. Excessively high bulk densities can cause generation of excessively high pressures, which distort and damage the brickwork of oven walls.

A new test method,72/ called the dropped-coal method was developed by the Bureau of Mines for predicting the average density of coal in coke-oven charges, so that coke producers could have a reliable method for guidance in their effort to produce larger quantities of higher-quality coke in existing equipment. Figure 23 gives a comparison of actual bulk densities with those obtained by the new dropped-coal method, the standard A.S.T.M. method, and the cone method. The average density in the oven is the base or zero line in this illustration; the plotted points show how far samples of various oven charges deviated from the bulk density of the actual oven charge when the samples were tested by the various methods. In the ranges studied, the dropped-coal method developed by the Bureau followed the oven results with great fidelity, regardless of moisture content, oil treatment, or fineness of crushing of the coal, whereas previously existent methods were found to vary widely from the desired behavior. These studies confirmed the opinion of many operators that the older test methods did not give results that paralleled actual oven bulk densities closely enough to allow the use of correction factors. The complete report on this work gives detailed data on the comparative tests and also covers general aspects of bulk-density control as well as factors influencing the packing behavior of coal in full-scale ovens and test containers.

## Gasification of Subbituminous Coal and Lignite

Research and development work on gasification of lignite and subbituminous coal in externally heated alloy retorts was continued on the small pilot plant at Golden, Colo., and on the commercial-size pilot plant at Grand Forks, N. Dak. The large plant was operated 1,400 hours during the year to produce 16,000,000 cubic feet of various grades of water gas from natural lignite.

72/ Auvil, H. S., Schmidt, L. D., and Graham, H. G., Control of Bulk Densities in Coke Ovens: Studies of Precision and Application of Various Testing Methods: Bureau of Mines Rept. of Investigations 3935, May 1946, 21 pp.

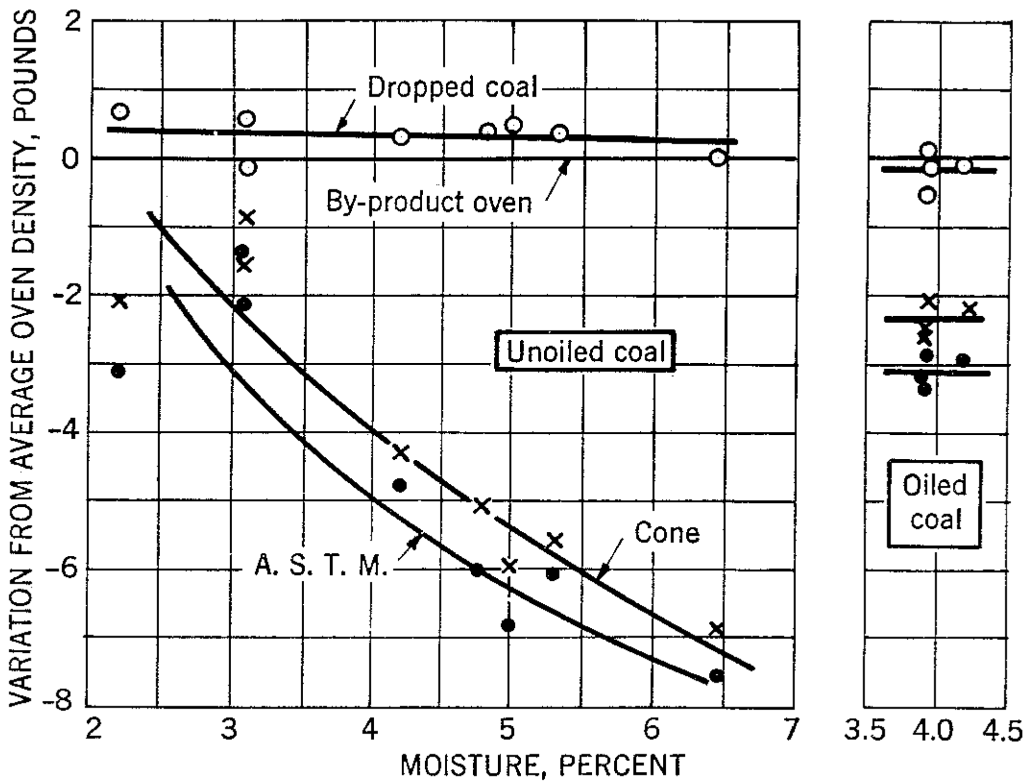


Figure 23. - Comparison between test results and the average density in byproduct ovens at various moisture levels. Oiled and unoiled coals.

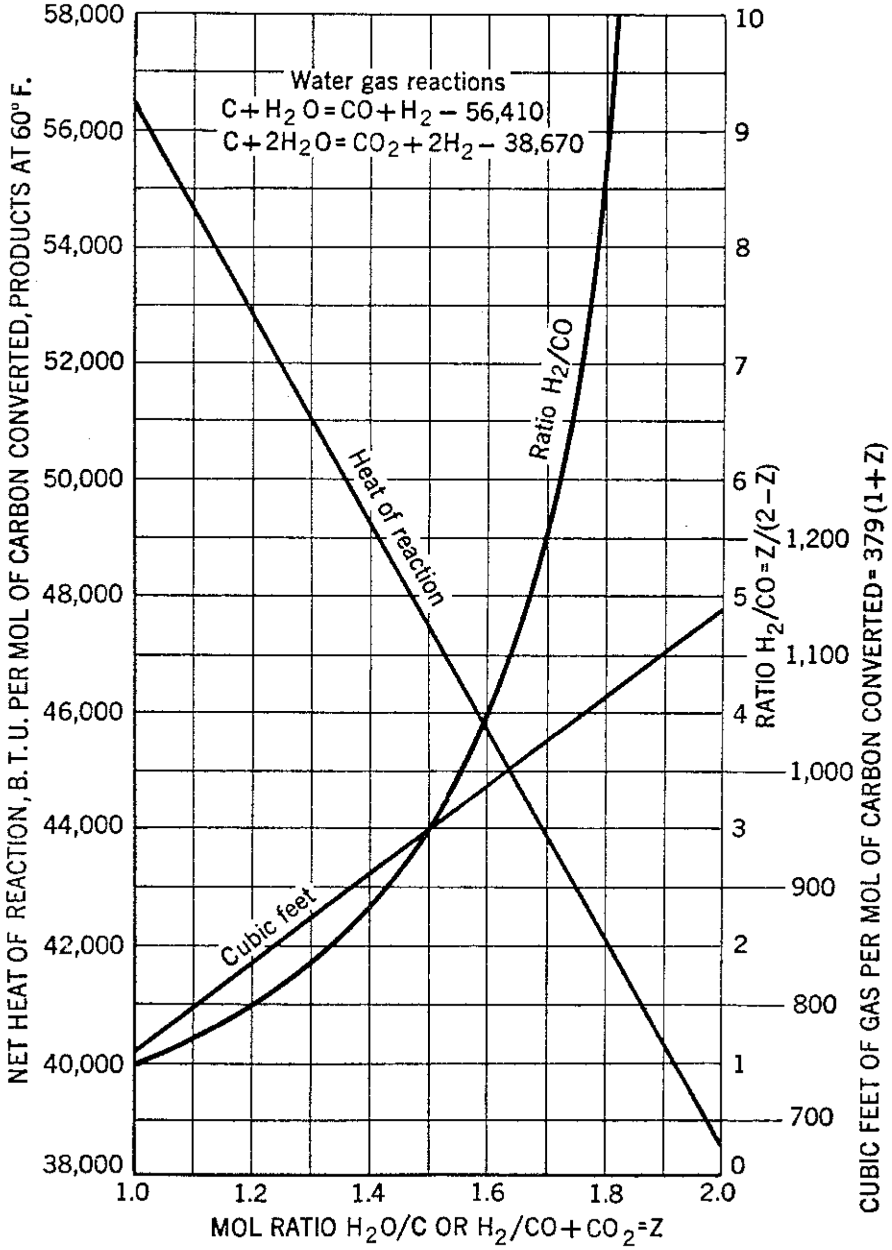


Figure 24. - Water-gas reactions.

Research work was conducted at Golden to obtain data on the mechanism of the reactions encountered when coal is converted to gas in an externally heated retort and to observe the factors affecting capacity of the retort. It was demonstrated that the rate of gas formation can be increased from 66 to 81 cubic feet per hour per square foot of heated surface by decreasing the width of the reaction zone from 2.75 to 2.0 inches. Further studies were made on control of the composition of water gas by variations in temperature and in the concentration of steam, and the physical and chemical properties of high-ash char residues were determined.

The composition of water gases from low-rank fuels can be varied over a wide range. Figure 24 shows the change in gas composition and heat of reaction as the concentration of steam is increased. In the process under investigation, the $H_2/CO+CO_2$ ratio in the water gas, designated by "Z," can be varied from 1.35 to 1.80 by adjusting steam concentration and temperature. An important objective of pilot-plant tests has been to work out the operating problems involved in making these different grades of water gas. If the water gas is to be used for the manufacture of industrial hydrogen, the value of "Z" should be 1.7 to 1.8, and a high concentration of steam and relatively low temperatures are employed in making the gas. On the other hand, if the water gas is to be used for making synthetic gasoline, which needs a gas having a $H_2/CO$ ratio of about 2.0, the apparent equilibrium or "Z" will be 1.3 to 1.5. Low steam concentration and relatively high temperatures are necessary for these conditions. The intermediate water gases that have an apparent equilibrium denoted by "Z" of 1.5 to 1.7 are the easiest type of gases to make in the externally heated retort, because the natural balance of hydrogen and carbon in the low-rank fuels favors this equilibrium at moderate temperatures. These intermediate gases probably will be useful as industrial heating gas. No tar is formed in this process, but the combined hydrogen appears in the final gas in the form of saturated gaseous hydrocarbons and illuminants.

The investigations during 1946 on the two pilot plants have solved many practical problems encountered in this new method of making water gas. The pilot plants were described in the 1945 report of research and technologic work on coal. It was found that both lignite and subbituminous coal will move freely through narrow reaction zones 2 inches wide. High rates of heat transfer through the metal wall in the range of 6,000 to 7,000 B.t.u. per hour per square foot were attained. It was further observed that the high-ash char residues are amenable to handling in simple mechanical and pneumatic devices. In the large plant, the unconverted char is removed continuously into a receiver and then extracted and transported from the machine by a gas jet, which conveys the char any desired distance from the generator. It was observed that operating problems increased as the concentration of steam was advanced.

The behavior of the alloy steel retort with respect to its life and cost is an important objective in operation of the plants. In the large plant, the vessel is 4 feet in diameter and 20 feet in length. It is suspended in a vertical furnace, which generates temperatures of 1,500° F. to