NATIONAL BUREAU OF STANDARDS REPORT

6367

A STUDY OF THE CAUSES OF FAILURE OF THE BURNERS AND UPPER AIR TUBES IN THE ARMY TENT STOVE

by

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and
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Report to
Mechanical Engineering Division
Headquarters,
Quartermaster Research and Engineering Command
Natick, Massachusetts

U. S. DEPARTMENT OF COMMERCE
NATIONAL BUREAU OF STANDARDS

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to
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ABSTRACT

A study of the causes of failure in the vaporizing pot burners and upper air tubes used in the M1941 Army tent stove was made for the Quartermaster Research and Engineering Command. A group of pot burners made of low carbon steel except for the low fire ring and combustion ring were operated until failure occurred by oxidation and other groups having some components of stainless steel and some of low carbon steel in various combinations were operated for a period of 3000 hours at a firing rate above the recommended value for the stove. New upper air tubes from three procurements of commercial tubes by the QMR&E Command, others from an experimental batch cast by the QMR&E Laboratory, and others cast by the NBS foundry; and used upper air tubes submitted by Jeffersonville Quartermaster Depot as having been discarded, were subjected to prolonged operation at normal and excessive firing rates and to extreme thermal shock conditions to determine the factors causing the prevalent deformation of the tubes by bending that had been reported in field use. The tests showed the desirability of using stainless steel in the vaporizing pot burners for the combustion ring, the burner support ring, the low fire ring, the air casing, and the wall of the pot above the low fire ring to resist oxidation at high temperature. It was further shown that the commercial upper air tubes could be operated in excess of 4000 hours at firing rates up to 24 ml/min without deformation. Three tubes deformed by bending after operation at firing rates of 35 ml/min or higher for periods ranging from a few hundred hours to 3000 hours. At this firing rate the center of the tube operated at a temperature between 1300°F and 1400°F which is near the transformation temperature for gray cast iron. All the deformed tubes were eccentric between inner and outer surfaces, but not all the eccentric tubes used for the tests deformed. Microstructures of the deformed tubes indicated that the thinner side of the deformed tubes might have reached a higher temperature than the thicker side. A discussion of the possible causes of deformation is included and some recommendations regarding composition of the upper air tubes, materials for the burner pots, and oil control valve design have been made.

I. Introduction

At the request of the Quartermaster Research and Engineering Command, Natick, Massachusetts, a study was made of the Flame Spreader (Upper Air Tube) of the vaporizing pot burner in the Army tent stove M1941 to determine the cause of reported deformation of this component in field use. The gasoline-burning M1941 tent stove is used for space heating in temporary and semi-permanent military housing over a wide geographical area. Failure of the upper air tube incapacitated the stove and contributed to the destruction of the pot burner, thus multiplying the problems of immediate replacement in the field. It had been reported that the stock upper air tube of the M1941 tent stove did not have a service life commensurate with that of the stove burner.

The objectives of this study were as follows:

(1) To determine by laboratory tests of the stove, the service life of four groups of upper air tubes supplied by the Quartermaster Research and Engineering Command, using three firing schedules, and

(2) With the guidance obtained from these results and from metallurgical tests, to determine and recommend material or materials for the upper air tube that would yield a satisfactory service life, taking into consideration the following factors:

(a) Producibility by either large or small foundries;

(b) Probable availability of materials under the restrictions of wartime;

(c) Machinability of the part; and

(d) Cost

After completing the laboratory tests outlined above and after obtaining information on the availability of castings from a group of small and medium-sized foundries, the study was extended to include the following three tasks:

(1) To operate twelve pot burners with selected components of stainless steel and low carbon steel for a period of 3000 to 4000 hours at high fire;

(2) To operate twelve upper air tubes representing a range of chemical composition proposed by the National Bureau of Standards for a period of 2000 to 3000 hours. These specimens were to be cast in the experimental foundry of the National Bureau of Standards; and

(3) To make appropriate metallurgical examinations of the pot burners and upper air tube specimens at the beginning and periodically during the life tests.

II. Description of Test Specimens

The upper air tubes used for the tests came from the following sources.

(1) Twelve tubes were sent initially from the Quartermaster Research and Engineering Command at Natick, Mass. These were commercial samples from three different batches of upper air tubes procured during recent years under the existing specifications.

(2) Five new tubes from a group cast at the QMR&E laboratories for experimental purposes.

(3) Twenty-five used tubes furnished by the Jeffersonville Quartermaster Depot on request, as representing tubes that were no longer satisfactory for use.

(4) Thirty-six new tubes of three different compositions cast at the National Bureau of Standards experimental foundry to represent a range of carbon and silicon content.

The shape of the upper air tube is shown by the vertical cross section in Fig. 1. It was 7 1/8 inches high; the vertical column was about 1 1/2 inches in diameter; and the flame spreader at the top was 3 inches in diameter and 3/4-inch in vertical dimension. The sidewalls of the tube were about 3/16-inch thick. The holes near the top of the center column were 1/4-inch in diameter and the slot in the cap was 9/32-inch wide. Four cast pins connected the top of the cap to the remainder of the tube. The base of the tube was bored to provide a good fit over the air inlet tube in the center of the oil burner pot.

Twenty four experimental pot-type burners were submitted for the latter part of the study. Various combinations of low carbon steel and stainless steel components made of two thicknesses of sheet metal were fabricated to provide six burner styles. The combinations and identification of the six styles are summarized in Table 1. It will be noted that the air casing was of 18 gage low carbon steel in all styles, and that the low fire ring, combustion ring, and burner support ring were of 20 gage stainless steel in all styles. The other three components varied in material or thickness in the various styles.

III. Test Apparatus and Procedure

The operational tests were conducted in a special building designed to incorporate specific fireproof and explosion-proof features. Except for wood doors, the structure employed only galvanized sheet steel and cement asbestos board components.

The building was about 50 feet long and 16 feet wide with walls 10 feet high and a sloping roof reaching to a height of 13 feet at the ridge. An 8-foot space at one end was created by a floor-to-roof metal dividing partition and metal exterior walls to serve as an observation room. The two side walls of the testing space were made of cement asbestos boards lightly secured to the framing so an internal explosion could be readily relieved. The end wall was of metal. An opening 8-in. high was left both at the floor level and eave height to provide copious ventilation. A 2-foot wide opening was left at the ridge and this opening was covered with a hood 1 foot above the roof.

Table 1

MATERIALS OF CONSTRUCTION OF EXPERIMENTAL OIL BURNERS

IDENTIFICATION OF BURNER	GROUP MARKING	FLOOR AND SIDEWALL BELOW LOW FIRE RING	SIDEWALL ABOVE LOW FIRE RING	LOW FIRE RING	COMBUSTION RING	BURNER SUPPORT RING	AIR CASING	BURNER SHIELD
Style 1	1-2 1-3 1-1	Steel .0478 (18 Ga.) Thick	Corr. Res. Steel .0312 (22 Ga.) Thick	Corr. Res. Steel .0375 (20 Ga.) Thick	Corr. Res. Steel .0375 (20 Ga.) Thick	Corr. Res. Steel .0375 (20 Ga.) Thick	Steel .0478 (18 Ga.) Thick	Steel .0359 (20 Ga.) Thick
Style 2	2-2 2-3 2-1	Steel .0478 (18 Ga.) Thick	Corr. Res. Steel .0375 (20 Ga.) Thick.	"	"	"	"	Steel .0359 (20 Ga.) Thick
Style 3	3-2 3-3 3-1	Corr. Res. Steel .050 (18 Ga.) Thick	Corr. Res. Steel .0312 (22 Ga.) Thick	"	"	"	"	Steel .0359 (20 Ga.) Thick
Style 4	4-2 4-3 4-1	Corr. Res. Steel .050 (18 Ga.) Thick	Corr. Res. Steel .0375 (20 Ga.) Thick	"	"	"	"	Steel .0359 (20 Ga.) Thick
Style 5	5-2 5-3 5-1	Corr. Res. Steel .050 (18 Ga.) Thick	Corr. Res. Steel .0312 (18 Ga.) Thick	"	"	"	"	Corr. Res. Steel .0375 (20 Ga.) Thick
Style 6	6-2 6-3 6-1	Corr. Res. Steel .050 (18 Ga.) Thick	Corr. Res. Steel .0375 (20 Ga.) Thick	"	"	"	"	Corr. Res. Steel .0375 (20 Ga.) Thick

Fig 1

The large floor space was divided into three equal areas, approximately 14 ft by 16 ft, by two 4 ft by 8 ft sheets of galvanized sheet steel serving as radiant shields between adjoining sections. These shields were supported lengthwise 8 inches above the floor, as shown in the foreground in Fig. 2, allowing a passageway 4 ft wide at each end of the shields.

Each of these three spaces was divided into four cells by supporting a piece of sheet metal four feet square on each side of a square center post leaving a clearance of 8 inches between the floor and the lower edge of each sheet. This division of the floor space provided twelve cells each with a gross floor area of 7 ft by 8 ft. When one of the specimen stoves was supported 8 inches above the floor and one foot from the sheets affixed to the center post in each cell, it was radiantly shielded from each of the other eleven stoves. The stovepipe of all twelve stoves terminated inside the structure just beneath the ventilating cap at the ridge of the roof. The compartmentation of the building can be seen in Fig. 2. Fig. 3 illustrates one of the stoves mounted in the corner of one of the twelve cells.

A battery of twelve float valves mounted on the outside of one of the sidewalls metered the fuel to the twelve stoves. Fuel was supplied to these float valves through a single line from a storage tank located some distance away and at a higher elevation to provide gravity feed of the fuel. A solenoid valve and shut-off valve, was located upstream of each float valve in that order. An additional solenoid valve was located in the main fuel line. A vertical burrette was connected to a tee in the fuel line between the float valve and solenoid valve for each stove. These burrettes could be filled from the supply line and then isolated from the supply by the shut-off valve. By allowing the burrettes to empty through the float valves the rate of fuel supply to each stove was measured independently. Four of the float valves were controlled by a time clock which energized rotary actuators to alternate the fuel supply rate between high and low rates. The fuel metering system and rotary actuators are shown in Fig. 4.

The interior of the structure was equipped with six photoconductive cells sensitive to the flicker of a hydrocarbon flame, such that each pair of adjacent stoves was monitored by one cell. When the unsteady flame of the burning gasoline was viewed

Fig 2

Fig 3

Fig 4

by one of these cells it actuated a relay to close the solenoid valves in all of the fuel supply lines.

The fuel used for the tests was an 80-octane leaded gasoline.

IV. Two Thousand Hour Operational Test of Upper Air Tubes

The twelve commercial upper air tubes received from the QMR&E Command representing three procurements under existing specifications were operated for 2000 hours or more using three different firing schedules. The identification numbers of the twleve stoves and the twelve tubes are shown in Table 2.

Four of the stoves were operated continuously at a high fire fuel rate of 24 ml/min, four others were operated continuously at a low fire fuel rate of about 8 ml/min, and the remaining four were cycled every 2 hours between these two rates of fuel flow. The fuel rate for each stove and upper air tube is shown in Table 2 along with the total duration of the test.

Table 2

Stove number	Air Tube number	Fuel Rate ml per min	Total hours burned
1	23926-10	24	2173
2	23926-6	24	2176
3	23926-4	24	2238
6	23926-8	24	2261
8	22981-10	8-24	2008
9	23926-3	8-24	2034
10	23926-11	8-24	2054
11	23926-12	8-24	2181
13	23926-9	8	2161
16	23926-5	8	2067
24	23926-1	8	2154
30	24490-8	8	2222

At the end of 150, 750, 1550, and 2000 hours of operation, the tubes were removed from the stoves for inspection and measurement for deformation. At none of these inspection periods was any visible deformation noted nor did any of the measurements show a change from those recorded before firing. The jig used for determining whether or not any deformation had occurred is shown in Fig. 5.

During these tests the measured temperature at midheight of the tube averaged about 1150°F during high fire operation (24 ml/min) and about 950°F during low fire operation (8 ml/min).

Tubes numbered 23926-10, having operated continuously on high fire; 23926-3, having operated under a cycling condition; and 23926-1, having operated continuously on low fire, were removed from the stoves after the 2000-hour test for crystal analysis by the Mechanical Metallurgy Section. Two used tubes from the group received from the Jeffersonville Quartermaster Depot and 1 new tube from the group of five received from the QMR&E Command were also included in the crystal analysis study.

The microstructures of these six specimens indicated the following conclusions:

(1) The variation in the decomposition of the steadite and pearlite constituents of the cast iron from the bottom to top of the tubes indicated that they had been heated in a temperature gradient with the highest temperature at the top of the tube.

(2) None of the specimens had been heated to the transformation temperature as indicated by the absence of pearlite patches in the microstructure of the top portions of the tube.

(3) The two tubes from Jeffersonville Quartermaster Depot with unknown operational history appeared to have a thermal history not unlike that of the specimens tested at the National Bureau of Standards.

(4) Heating of portions of two of the tubes to 1500°F for one hour followed by air cooling and quenching of alternate specimens further substantiated the con-

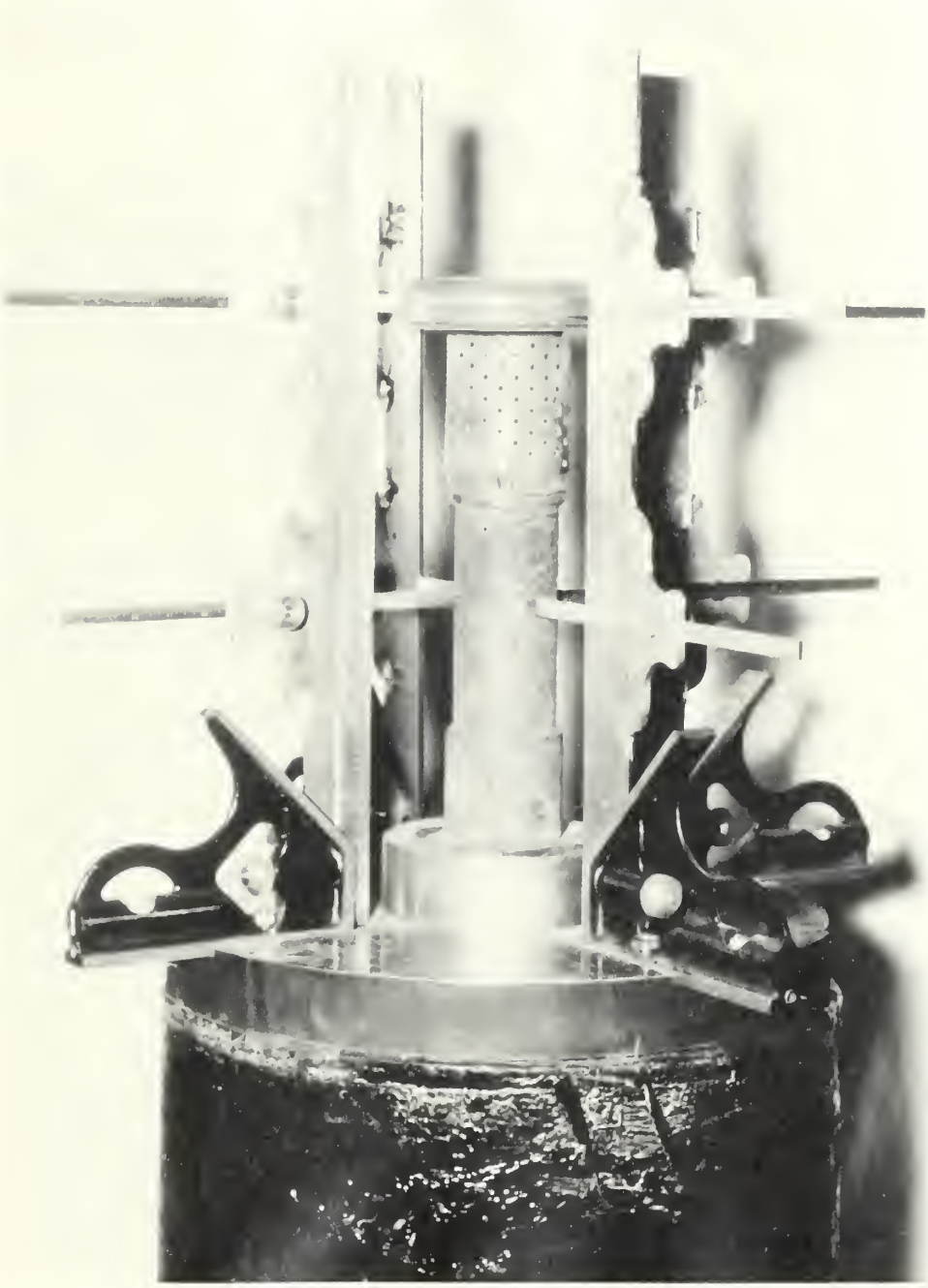

Fig 5

clusion that the tubes had not been heated above 1450°F during testing or use.

The complete report of the Mechanical Metallurgy Section on these six tubes is attached as Appendices I and II.

V. Thermal Shock Tests

In the opinion of metallurgists at the National Bureau of Standards the conditions most likely to produce change in crystal structure and deformation of the tubes are extremely high operating temperatures and thermal shock. Therefore, a series of tests were performed involving higher firing rates and sudden heating and cooling operations. For this series of tests six of the original group of twelve commercial tubes, four additional used tubes from the Jeffersonville Quartermaster Depot, and two of the group of five tubes cast at the QMR&E Command, were used in the twelve stoves.

Two of the stoves, No. 2 and 10, were operated at the same firing rates as during the first 2000-hour test as controls. The upper air tubes in the other ten stoves were subjected to more severe temperature and thermal shock conditions. These may be summarized as follows:

(1) Five were operated continuously at a firing rate of 65 ml/min producing a temperature on the upper air tubes in the range from 1300°F to 1400°F. Five others were put on intermittent operation alternating between a firing rate of 65 ml/min for 1 1/2 hours and chilling in the freezing compartment of a refrigerator at -5°F. After 50 hours of such operation the firing rate was reduced because the fire was being extinguished by soot accumulation in less than 24 hours at a fuel rate of 65 ml/min.

(2) The high fire fuel rate was reduced to 40 ml/min for about three days and then to 35 ml/min at which setting smoking of the stoves was imminent. The same stoves were operated continuously as before and the same stoves were operated cyclically as before, except that the tubes in two of the latter group were chilled in solid CO_2 for about 80 cycles of the total 250 cycles

instead of chilling in a refrigerator at -5°F throughout the test. The ten stoves were operated at a fuel rate of 35 ml/min for periods ranging from 200 to 400 hours.

(3) The tubes in four stoves were heated for one hour at a firing rate of 35 ml/min and then quenched in water at room temperature.

(4) The four-inch stovepipe on one stove was replaced with six-inch stovepipe by connecting it to the opening for the stove lid on the top of the stove, and the firing rate was increased to 80 ml/min. The temperature of the upper air tube was not increased, however, by increasing the size of stovepipe and increasing the firing rate from 35 ml/min to 80 ml/min.

The only damage to the upper air tubes caused by this series of tests at high firing rates or by exposing them to thermal shock occurred when the heated tubes were quenched in water. The cap on one tube broke off after 4 quenchings; a second, after 7 quenchings; and a third was full of hairline cracks and about to break after 13 quenchings.

VI. Failure of Vaporizing Burner Pots

At the conclusion of the thermal shock tests described above, six of the twelve vaporizing burner pots had failed by oxidation. The remaining six burner pots were fitted with upper air tubes and operated at a fuel rate of 35 ml/min, until all the burners had failed. All twelve burners failed in the same way by oxidation of the low carbon steel in the sidewalls of the burner between the upper row of air holes and the top flange of the burner. Fig. 6 shows one of the pot burners after failure. The zone of oxidation was at the upper edge of the portion of the burner shown at the left in the photograph.

The total hours of operation of each of the twelve stoves prior to failure is summarized in Table 3.

Fig 6

Table 3

Summary of Vaporizing Pot Burner Life

Stove Number	Hours of Burner Operation
1	2677
2	4457
3	2747
6	2757
8	2331
9	2245
10	4094
11	2455
13	2662
16	2570
24	3417
30	2514

Stove No. 2 was operated continuously at a fuel rate of 24 ml/min during the entire life of the burner and stove No. 10 was alternated between high and low fuel rates of 24 ml/min and either 8 or 12 ml/min, respectively, during the entire burner life. All the other stoves and burners were operated for periods of time at fuel rates ranging from 35 to 65 ml/min.

At the time of failure of all of the burners, several of the commercial upper air tubes and one of the used upper air tubes from Jeffersonville Quartermaster Depot had been operated for an extended period. These operational periods are summarized in Table 4. No deformation had occurred in any of the upper air tubes at this time.

Table 4

Stove Number	Tube Number	Hours of Tube Operation
2	23926-6	4457
6	G*	1493
10	23926-11	4094
13	23926-9	2938
16	23926-5	2852

* Used tube

VII. Chemical Composition of Upper Air Tubes

The chemical composition of several of the upper air tubes used for the tests was determined for comparison with the purchase specifications used by the Quartermaster Research and Engineering Command and for correlation with the operational test results. The chemical composition in percent by weight specified by the QMR&E Command in procurements during recent years was as follows:

Total carbon----------3.00 - 3.60
Silicon----------1.80 - 2.50

The sum of total carbon and silicon shall not exceed 5.5 nor shall the silicon at any time be less than 1.80.

Phosphorous----------0.60 max.
Sulphur----------0.10 max.
Chromium----------0.30 - 0.60
Manganese----------0.60 - 1.00
Nickel----------0.00 - 2.00

The chemical determination for carbon, phosphorous, and sulphur and the spectrochemical determination of manganese, silicon, nickel, and chromium for six upper air tubes furnished for the tests are summarized in Table 5. The first three specimens listed in the table were commercially procured upper air tubes furnished by the QMR&E Command and the last three; A, J, and P, were used specimens furnished by the Jeffersonville Quartermaster Depot. The first three tubes were samples from different procurements purchased under the specified chemical composition shown above.

Table 5

Tube	Percent C	Si	P	S	Cr	M_n	N_i	Hrs. burned
1 (23926-10)	3.39	1.9	0.27	0.12	0.12	0.45	0.07	2173
8 (22981-10)	3.52	1.8	.40	.12	.5*	.46	.03	2280
30 (24490-8)	3.46	1.8	.30	.11	.5*	.66	.7*	2222
A (Jeffersonville)	3.37	1.9	.29	.13	.12	.70	.07	----
J (")	3.51	1.9	.41	.11	.5*	.73	.05	--+280
P (")	3.46	1.9	.32	.11	.09	.66	.06	----

* Approximate values. Suitable cast iron standard samples not available (Steel standards used).

In this group of upper air tubes those numbered 1, 8 and 30 had been operated at controlled firing rates under the following respective conditions: continuous at 24 ml/min; in two-hour cycles alternating between 8 ml/min and 24 ml/min; and continuously at 8 ml/min. The operational histories of tubes A, J, and P were unknown except that tube J had been operated at NBS for 280 hours at high firing rates (35 to 65 ml/min). These six tubes represented at least four, and perhaps six, different procurements of upper air tubes. All six tubes met the specified requirements on carbon, silicon, phosphorous, and nickel. All had slightly more sulphur than the maximum specified and some were deficient in chromium and manganese. None of the tubes was visibly deformed and all measured true in the special jig at the time of the chemical analysis.

A review of known specifications for cast iron for this duty led the Mechanical Metallurgy Section to suggest that Class I or II castings of Type B as described in ASTM Standard Specification A319-53 covering Grey Iron Castings for Elevated Temperatures for Non-Pressure Containing Parts would probably withstand the thermal shock and temperature requirements of this application. Thereupon, inquiries were sent to twenty-five foundries, distributed over all sections of the country, asking if they could furnish castings having the composition shown in Tables 6 and 7 below and in the quantities typical of previous military purchases. The composition shown is within the range of the requirements for Class I and II, Type B, castings of ASTM Specification A319-53 and is similar to the currently used specification except that it raises the upper limit of the carbon, silicon, and sulphur contents a little.

Table 6

Element	Percent by Weight
C	3.20 - 3.70
Si	1.80 min.
P	0.60 max.
S	0.12 max.
Cr	0.41 - 0.65
Mn	0.40 - 1.00
Ni	0.00 - 2.00

The allowable silicon content in relation to the various permissible carbon contents was further prescribed as shown in Table 7.

Table 7

Class	Carbon %	Silicon %
I	3.50	1.80 - 2.70
	3.70	1.80 - 2.10
II	3.20	1.80 - 2.70
	3.40	1.80 - 2.10

Sixteen foundries cooperated with replies, in some cases adding their own remarks, as follows:

Foundry	State	Availability	Remarks
Colorado Fuel & Iron Corp.	Colorado	Yes	None
Emmaus Foundry & Machine Co.	Penn.	Yes	Add .4-.5 N_i .2-.3 M_o
Kirkland-Weathers Foundry Co.	Alabama	Yes	Exception requested 0.75 P
Inland Foundry Co.	Idaho	Yes	Chemistry too complicated
Taylor and Fenn Co.	Conn.	Yes	Suggested nodular iron
R. D. Cole Mfg. Co.	Georgia	No	No reason
Yale & Towne Mfg. Co.	New York	No	Do not make castings anymore
General Metals Corp.	California	Yes	----------
Duncan Foundry & Machine Works Inc.	Illinois	No	Do not produce castings
Indiana Foundry Corp.	Indiana	Yes	----------
Macaulay Foundry Co.	California	Yes	----------
Sterling Mfg. Co. (Kirsch Foundry Inc.Wisc.)	Nebraska	Yes	Suggest stainless steel
U. S. Pipe & Foundry Co.	Alabama	Yes	----------

Foundry	State	Availability	Remarks
A. G. Williams Co.	Ohio	Yes	----------
Sterling Casting Co.	Indiana	Yes	----------
Gulf Star Foundries	Texas	No	Too large quantities

After completing the survey of foundries for availability of castings it was agreed between the sponsor and this Bureau that 12 upper air tubes of each of three chemical compositions falling within the range of ASTM Specification ASTM 319-53 would be cast in the foundry of the National Bureau of Standards for further tests. The three compositions were as follows:

Table 8

Element	Type 1	Type 2	Type 3
C	3.20 - 3.30	3.40 - 3.50	3.60 - 3.70
Si	2.50 - 2.70	2.20 - 2.30	2.00 - 2.10
P max	0.6	0.6	0.6
S max	0.12	0.12	0.12
Cr	0.5	0.5	0.5
M_n	0.5	0.5	0.5
N_i	0.3	0.3	0.3

The three compositions were selected to cover a range of carbon and silicon contents. The compositions are similar to that now in use by the Quartermaster Research and Engineering Command except that the sum of the carbon and silicon is higher and the permissible maximum sulphur content is slightly higher in these three compositions.

Analysis of the finished castings showed the following compositions for the three types. It will be noted that the carbon content was lower and the silicon content was higher in each case than the selected range.

Table 9

Element	Type 1	Type 2	Type 3
C	3.13	3.06	3.29
Si	2.8	3.2	2.4
P	0.50	0.045	0.56
S	0.040	0.013	0.051
Cr	0.40	0.24	0.36
M_n	0.64	0.53	0.80
N_i	0.3	0.3	0.3

VIII. Deformation of Upper Air Tubes

While awaiting completion of the experimental upper air tubes by the NBS foundry, twelve of the vaporizing pot burners composed of different combinations of low carbon steel and stainless steel components were operated for approximately 1000 hours using the original twelve stoves and a selection of the original commercial and used upper air tubes. The identification of the tubes used for this period is shown in Table 10. The fuel burning rate was 33 ml/min for half of the specimens and 38 ml/min for the other half of the specimens.

Table 10

Stove Number	Tube Identification*	Hours of Operation
1	B	1045
2	2(23926-6)	1059
3	E	1091
6	T	1063
8	F	1016
9	M	968
10	10(23926-11)	1082
11	L	1090
13	G	959
16	D	1087
24	N & C	789 & 188
30	J	624

* Tubes identified with a capital letter were used tubes received from the Jeffersonville Quartermaster Depot.

During this period three of the upper air tubes deformed by bending in the column below the cap. Two of these are shown in photographs 7 and 8. One of the tubes that deformed was from the original group of twelve commercial specimens submitted by the QMR&E Command and was identified as No. 2 and also as 23926-6. It had been operated for 4457 hours at a firing rate of 24 ml/min followed by a period of 1059 hours at a firing rate of 35 ml/min for a total of 5516 hours. It deformed at the higher firing rate.

A second deformed specimen was identified as tube 13-G and was a used tube received from Jeffersonville Quartermaster Depot with unknown history of use. It was operated during these tests for a period of 2951 hours at a firing rate of 35 ml/min and deformed during this period. The third specimen which deformed, identified as specimen 30-J, was a used tube received from Jeffersonville Quartermaster Depot. It was operated for several hundred hours during these tests at a firing rate of 38 ml/min. In addition to being bent, tube J had increased in height by about 1/4-inch during the tests at this firing rate. This is not the same J specimen chosen for chemical analysis, as reported in Section VII of this report.

These three tubes were studied by the Mechanical Metallurgy Section to determine whether or not the microstructures were similar to those for tubes studied earlier.

The horizontal sections of the three tubes showed that the inner and outer surfaces were circular, but not concentric. The vertical sections of tubes No. 2 and 13-G showed that the axis of the bend was in line with the section of minimum and maximum wall thickness with the minimum wall thickness occurring on the convex side of the bend. These sections are shown photographically in Appendix III, which is the complete report of the Mechanical Metallurgy Section on these 3 tubes.

The microstructures of tubes No. 2 and 13-G near the bend showed that the pearlite in these sections was completely decomposed indicating that these tubes had been operated at higher temperatures than those previously examined but that they had not reached the transformation temperature. There were differences in the microstructure on the thin and thick sides of these two specimens near the bend that could be explained if the tempera-

Fig 7

Fig 8

ture of the thin side had been slightly higher than that of the thick side and was near 1450°F.

The photographs in Appendix III show that the layer of iron oxide on the inside of the tube increased in thickness progressively from the bottom to the top of the tube. There was little oxide on the exposed outer surface of the tube, probably because the tubes were cleaned at regular intervals during the test.

The reason for the deformation of these tubes could not be positively established from the operational tests and the metallurgical studies, but a theory is advanced in the Section on Discussion and Conclusions which is generally supported by the observed results.

Horizontal sections of four additional tubes, specimens T, 3, 10, and 30, were made and photographed to show the degree of eccentricity of the inner and outer surfaces, the thickness of wall section, and the thickness of the oxide layer on the inner surface. None of these four specimens was deformed.

IX. Tests of Experimental Cast Iron Tubes

Upper air tubes cast in the NBS foundry were placed in the twelve experimental burner pots containing stainless steel and low carbon steel components as summarized in Table 1 replacing those tubes that had been in the pots for about 1000 hours of operation.

The new tubes were of the three different compositions reported in Table 9 and were labeled Types 1, 2, and 3.

Four tubes of Type 1 were placed in four pots such that 2 tubes were operated at a fuel rate of 33 ml/min in style 1 and 2 pots and 2 tubes were operated at a fuel rate of 38 ml/min in style 1 and 2 pots.

Four tubes of Type 2 were placed in four pots such that 2 tubes operated at a fuel rate of 33 ml/min in style 3 and 4 pots, and 2 tubes operated at a fuel rate of 38 ml/min in style 3 and 4 pots.

Four tubes of Type 3 were placed in four pots such that 2 tubes operated at a fuel rate of 33 ml/min in Style 5 and 6 pots, and 2 tubes operated at a fuel rate of 38 ml/min in Style 5 and 6 pots.

The following table gives the stove number, the pot style number, the firing rate, the upper air tube number and the number of hours each tube operated in the pot and stove. In some cases more than one tube was used in a particular stove.

Table 11

Stove No.	Pot Style No.	Firing rate ml/min	Type of Tube	Hours of Operation*
1	1	33	1	2055
6	1	33	1	2064
2	2	38	1	694
				453
3	2	38	1	2078
10	3	33	2	1140
8	3	33	2	561
				454
11	4	38	2	316
9	4	38	2	595
				486
13	5	33	3	1106
24	5	33	3	2077
16	6	38	3	2023
30	6	38	3	2046

* Less than 2000 hours of operation indicates that the tube or tubes in that stove and pot exfoliated. Other tubes were placed in the pots for the remainder of the 2000-hour test period.

The tests of the experimental upper air tubes cast by the NBS foundry were continued for slightly over 2000 hours. During this period none of the tubes failed by bending; but six tubes of Type 2, two tubes of Type 1, and one tube of Type 3 failed by exfoliation at the base. The appearance of these exfoliated tubes is shown clearly in Fig. 1 of Appendix IV. A spectrochemical analysis of the exfoliated region showed a lead content of 0.05 to 0.5 percent, probably attributable to the leaded gasoline used

as fuel. Microstructures of the exfoliated region showed considerable slag penetration and voids. The 2 tubes of Type 1 that failed, had operated for 453 and 694 hours, respectively; the one tube of Type 3 that failed, had been fired for 1106 hours; and the 6 tubes of Type 2 failed after firing periods ranging from 316 to 1140 hours.

The tests showed the superiority of Type 1 and 3 tubes as compared to Type 2 tubes. It is probable that the superior quality of Types 1 and 3 is dependent on differences in chemical composition and microstructure. Differences in cooling rate of the castings would also affect the microstructures. It will be noted that the highest incidence of failure occurred in the Type 2 tube with the highest silicon content and the lowest phosphorous content. Conversely, the fewest failures occurred in the Type 3 tubes with the lowest silicon content and the highest phosphorous content. These relative frequencies of failure may or may not be significant but it is known that high carbon and/or silicon contents decreases the growth resistance of ordinary gray irons while phosphorous will resist growth and oxidation to some extent.

The composition of the Type 3 tubes approximated most nearly the composition of the commercial and used tubes submitted for the initial tests of this study. These comparisons can be made from the data in Tables 5 and 9.

The complete report of the Corrosion Section on the examination of the exfoliated tubes is attached as Appendix IV.

X. Tests of Twelve Experimental Vaporizing Burner Pots

The twelve new vaporizing burner pots were installed in the twelve stoves and operated for 3000 hours. These burner pots were fabricated in six different styles using some components of low carbon steel and the remainder of stainless steel of one or the other of two thicknesses of sheet metal. The combinations of stainless steel and low carbon steel parts in the several styles are summarized in Table 1. Fig. 9 is a photograph of one of the burner pots when new.

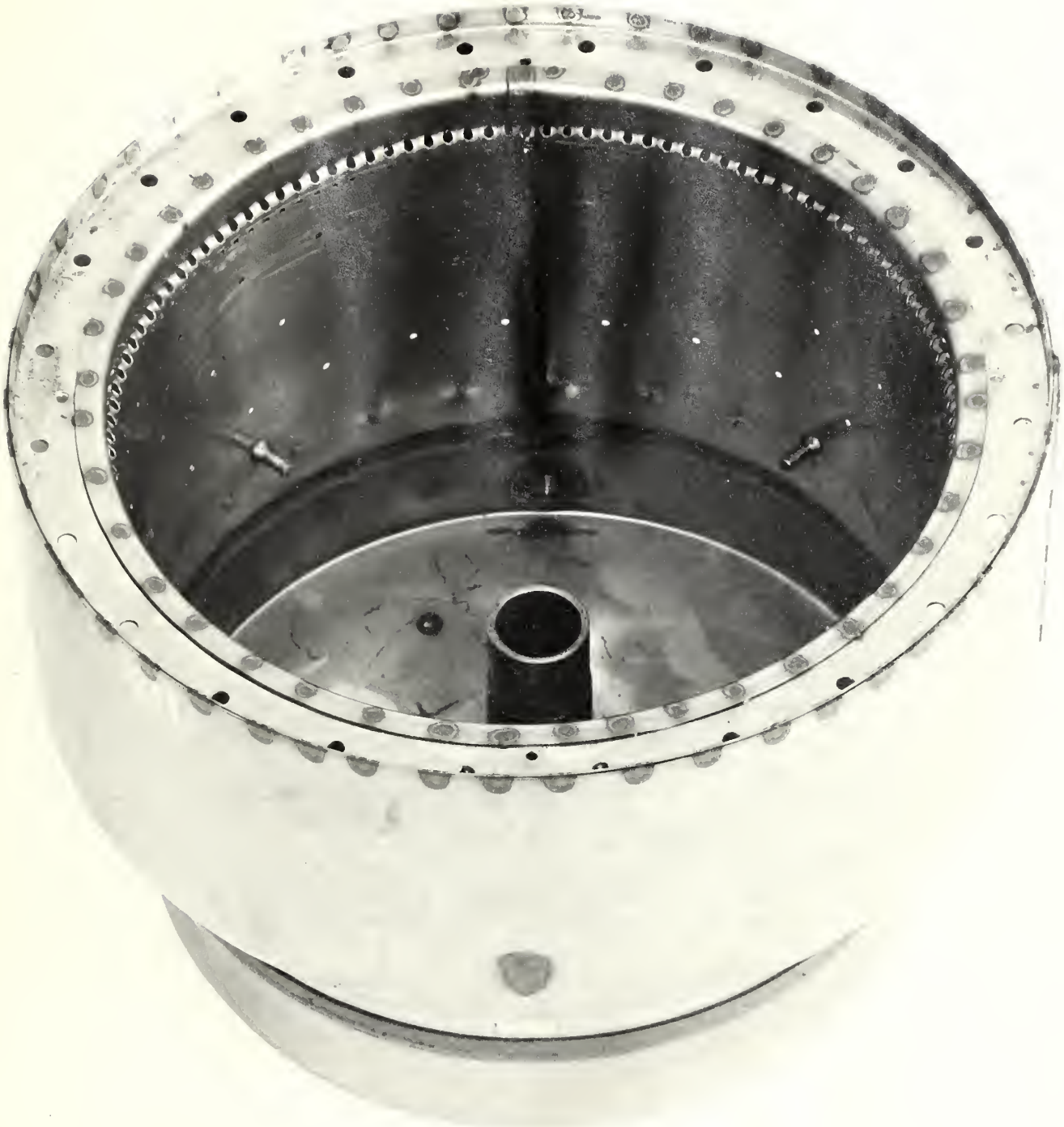

Fig 9

Two burner pots of each style were operated for 3000 hours with the firing rate set at about 33 ml/min for one of each style and at 38 ml/min for the other of each style.

The burners were examined for corrosion at the end of 500, 1000, 1500, 2000, and 3000 hours of operation. Those that appeared to be damaged the most were removed from the stove for careful inspection at each interval. At the 500-hour and 1000-hour inspections there was little visible change in the appearance of the burners. After 1500 hours of operation the upper edge of the low carbon steel air casing on both style 6 burners had buckled in some places between the spot welds that held it to the burner support ring. All twelve burners showed signs of scaling and oxidation of the low carbon steel air casing.

At the end of 2000 hours of operation both Style 2 burners and one Style 6 burner had holes in the upper edge of the air casing. All remaining parts in all twelve burners were in good condition.

At the end of 3000 hours of operation, which was the conclusion of the tests, the low carbon steel air casings had all suffered noticeable deterioration ranging from partial separation near the support ring to complete oxidation of the steel. All other components of the burners were in good condition. Fig. 10-16 inclusive show the nature of the deterioration of the air casings. The numbers below the burners are the corresponding stove numbers and can be used to identify the styles of the burners by referring to Table 11. Fig. 11 shows a style 2 burner and Fig. 13 a style 4 burner before cleaning and reveals the carbon deposits near the air holes on the inside walls of the burner and the considerable amount of soot and scale that had fallen into the burner. Fig. 15 shows a style 6 burner fully assembled after cleaning and Fig. 16 shows the same burner with the combustion ring, low fire ring, and upper air tube removed to indicate the condition of the interior.

The analysis of the air casing material at the end of the test is reported in Appendix IV as determined by a metallographic examination.

2

Fig 10

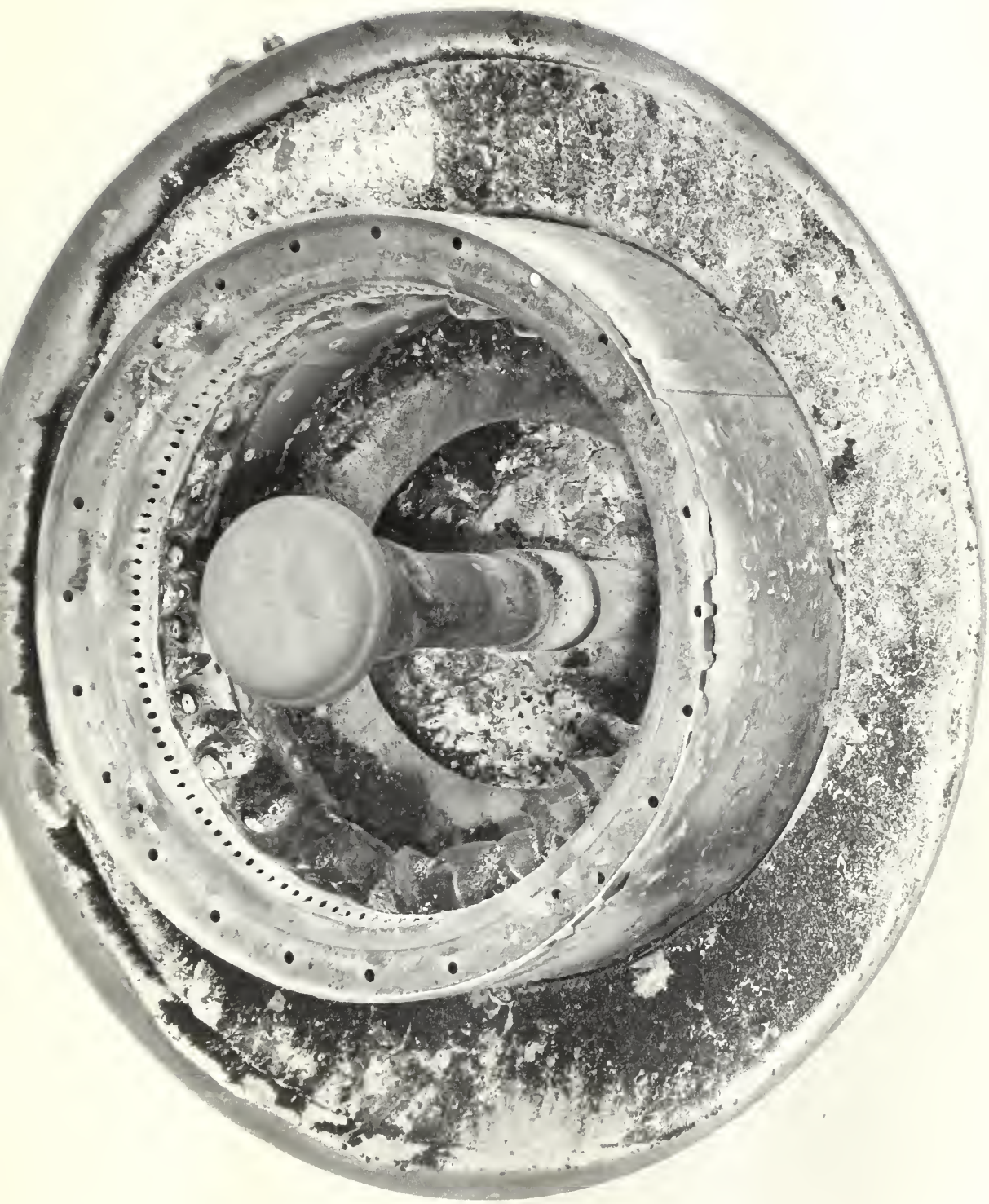

Fig 11

9.

Fig 12

11

Fig 13

24

Fig 14

Fig 15

Fig 16

XI. Discussion and Conclusions

The burner pots with low carbon steel sidewalls were found by test to have a life of less than 3000 hours when fired for any appreciable length of time at 35 ml/min or higher. One such pot lasted for 4457 hours when operated steadily at a firing rate of 24 ml/min and another lasted 4094 hours when operated cyclically at firing rates of 8 and 24 ml/min. Ten other specimens failed after operating from 2245 to 3417 hours of which 2000 hours employed firing rates of 24 ml/min or less. The average life of all twelve burners was 2910 hours. All of the burners failed similarly by complete oxidation and separation of the metal in the sidewall of the pot between the top row of air holes and the top rim of the pot.

Twelve experimental burners containing stainless steel components and low carbon steel components in various combinations were in good condition at the end of 3000 hours of operation at firing rates of 33 or 38 ml/min except for the air casing which was made of low carbon steel for all specimens. This component oxidized at the upper edge where it was welded to the burner support ring to the extent that separation occurred for distances of a few inches in some cases and fully half the periphery in other cases. The entire air casing component suffered from severe oxidation and scaling. These tests showed that the floor of the pot, the sidewall of the pot below the low fire ring, and the burner shield under the floor could be made of low carbon steel, but that all other components of the burner should be made of austenitic corrosion resisting steel in order to obtain a satisfactory burner life. Based on these test results, burners of this construction would probably have a useful life twice as long as the low carbon steel burners used for the initial tests in this investigation.

The tests of twelve commercial upper air tubes, twelve or more used tubes that had been discarded as unserviceable, and several other new experimental tubes cast at the QMR&E Command indicated the following conclusions:

(a) The commercial tubes could be operated in excess of 4000 hours with continuous firing at a rate of 24 ml/min or on intermittent high and low fire of 24 ml/min and 8 ml/min, respectively, without deformation.

(b) Operation of the stoves at firing rates of 35 ml/min or higher produced temperatures on the upper air tubes at midheight in the range from 1300°F to 1400°F, which approached the transformation temperature of gray iron and usually accelerates the growth of ordinary gray iron by graphitization.

(c) All of the used tubes functioned as well as the new tubes submitted as test specimens. None of the used tubes were deformed as received.

(d) Three tubes deformed by bending after operating at a firing rate of 35 ml/min for periods of time ranging from a few hundred hours to about 3000 hours. One of these tubes was a tube from commercial procurement that had been operated during the tests for more than 4400 hours at a firing rate of 24 ml/min and for more than 1000 hours at 35 ml/min, whereas the other two were used tubes whose usage was unknown prior to their submittal here. The inner and outer surfaces of all three of the bent tubes were eccentric relative to each other resulting in thinner metal on one side than on the other. The observed differences in the microstructure of the thin and thick portions of the tube near the bend could be explained if the temperature in the thin section was a little higher than that in the thick section and if the temperatures were at or very near the transformation temperature. However, a number of other specimens that were eccentric did not deform.

(e) The oxidation of the cast iron in the upper air tubes continues throughout the life of the tubes; it progresses faster at higher temperatures; and it progresses more rapidly at the middle and top of the tubes than at the base where the temperature is lower. The iron oxide remains on the inside of the tube and becomes thicker and thicker whereas it is likely to be scraped or brushed off the exterior during cleaning operations.

The observations summarized above and other experience during these tests suggests the following hypothesis regarding the cause of bending in the upper air tubes.

At the firing rates recommended for these stoves the gray iron in the upper air tubes will oxidize progressively with time, with more rapid oxidation occurring in the upper half of the tube because of the higher temperatures produced there. Eventually any gray iron tube would fail after sufficiently long usage from this progressive oxidation. However, when a tube is eccentric because the sand core and sand mold were not concentric during the casting process, failure is likely to occur earlier because the amount of unoxidized metal is always less on one side than on the other. The oxide that forms on the inside of the tube probably has a thermal conductivity of the order of 1/20 of that of the cast iron itself and therefore, insulates the cast iron from the cooling effect of the air stream moving upward inside the tube. Furthermore, the thin side of an eccentric tube cannot conduct heat to the cooler base as rapidly as the thick side. Thus, under the fluctuating temperature conditions that exist in such a burner the thin side of an eccentric tube would attain a somewhat higher temperature than the thick side during a temporary rise in the surrounding gas or flame temperature. Since the tendency of cast iron to "grow" as a result of graphitization increases progressively in the temperature range from 900°F up to the transformation temperature of 1400°F, more or less, variations in temperature between the two sides of an eccentric tube could produce deformation. The tendency to deform would probably increase with the amount of eccentricity, with increased firing rates, and with increasing thicknesses of oxide on the inside of the tube.

In our opinion most of the results observed during this investigation support the above hypothesis. The principal contradictory considerations are, (a) that not all of the eccentric tubes deformed even though some were extensively oxidized and (b) that the expected differences in temperature that would develop between the thin and thick sides of an eccentric tube because of differences in heat conduction to the base, would be relatively small.

The upper air tubes of three compositions cast at the NBS foundry did not fail by bending in 2000 hours of operation at firing rates of 33 and 38 ml/min, but did fail by exfoliation at the base. No specific reason for the exfoliation was found by chemical analysis or from the microstructures. All three of the compositions were higher in silicon content than the other tubes used for the tests and the incidence of failure by exfoliation increased with increase in silicon content. Whereas

a direct cause and effect relationship was not established between these two factors, it is known that increasing the silicon content in gray iron increases the rate of growth of the iron at elevated temperatures. In general, the performance of the experimental tubes cast at the NBS foundry is considered inferior to that of the other specimens used in the investigation.

Inasmuch as the commercial and used tubes employed for these tests exhibited fairly good resistance to bending and typically contained sulphur ranging from 0.11 to 0.13 percent it is suggested that the permissible sulphur content in the specifications be raised to 0.12 maximum which agrees with the limit specified in ASTM Standard A319-53 for gray castings for this type service. In view of the relatively good performance of the commercial and used tubes used during these tests in which the sum of the carbon and silicon ranged from 5.26 to 5.41 percent, as compared to that of the experimental tubes cast at the NBS foundry in which the sum of these two components ranged from 5.69 to 6.26 percent, it is recommended that the limit of 5.5 percent for the sum of these two elements be retained in the specification. It is further recommended that the specification limit the permissible eccentricity of the tubes. A suggested limit is that the difference in wall thickness at opposite ends of any diameter not exceed 1/32-inch in the middle third of the tube length.

The float valves used on the stoves for control of the fuel flow rate permitted a flow rate upwards of 70 ml/min at their highest setting. The flow rate was further adjustable by turning a set screw in the top of the valve mechanism which was accessible through a hole in the adjusting knob. These flow rates are excessive because the burner will not admit enough combustion air for complete combustion at these operating conditions, the stoves extinguish themselves with soot and carbon accumulations, the upper air tubes attain temperatures of approximately 1400°F, and the stovepipes operate red hot and deteriorate rapidly. The life of the upper air tubes, the burners, the stovepipe, and the stove itself could be extended considerably if the float valves were designed for a maximum setting of about 30 ml/min which literally could not be increased in the field without boring out the orifice in the valve. It seems highly probable that the stoves will typically be operated at a maximum setting of the float valve in the field in cold weather. Thus, a fixed maximum setting more commensurate with a reasonable life of the stove and its components is recommended.

APPENDIX I

U. S. DEPARTMENT OF COMMERCE
NATIONAL BUREAU OF STANDARDS
Washington 25, D. C.

Interdivision Work
Order No. 10-676
Project No. 4885

NATIONAL BUREAU OF STANDARDS REPORT

on

Examination of

CAST IRON AIR TUBES

Submitted by

Division 10.3 (P. R. Achenbach)

By

H. C. Vacher
C. K. Speller
P. D. Sarmiento

Mechanical Metallurgy Section

UNITED STATES DEPARTMENT OF COMMERCE
WASHINGTON

NATIONAL BUREAU OF STANDARDS

Report

on

Examination of

CAST IRON AIR TUBES

Submitted by

Division 10.3 (P. R. Achenbach)

Reference: Division 10.3 Interdivision Work Order of 11/4/57, Requisition No. 10-676, Project No. 4885.

Identification of Tubes:

Tube	History
X	This tube was cast at Natick QMR&E Command with the composition shown in their specifications. It has not been fired.
A and H	These tubes were sent in from Jeffersonville Quartermaster Depot as no longer serviceable. They were purported to have been fired until they no longer performed satisfactorily.
1.	This tube fired with gasoline at NBS for 2170 hours at 24 cc/min firing rate, or high fire, at a temperature about 1150°F avg.
9.	This tube fired with gasoline at NBS for 2034 hours at 8 - 24 cc/min firing rate, or cycling fire, changing every two hours. About 1000°F & 1150°F.
24.	This tube fired with gasoline at NBS for 2154 hours at 8 cc/min firing rate, or low fire, at a temperature about 950°F avg.

Work Requested: Perform metallurgical examinations of six upper air tubes to determine changes in crystal structure and size and distribution of graphite inclusions. Examinations should be made at three sections on each specimen, viz. (1) at the base, (2) near mid-height and (3) near the top.

Nominal Composition: 3.3% to 3.6% carbon, 2.2% silicon, 0.6% manganese, 0.5% chromium, 0.8% nickel, 0.6% max. phosphorus, 0.1% max. sulphur.

Metallographic Examination: The metallographic specimens were cut from the tubes at locations indicated in Figure 1. Surfaces parallel to the tube axis were polished according to a procedure developed by Samuels (J. Iron and Steel Institute, Vol. 180, May 1955, p. 23). The polished surfaces were examined in the unetched condition and after etching with 1 percent nital. Definitions of the principal microconstituents that were in the microstructure are given in the appendix.

The size and type of distribution of the graphite flakes are shown in Figures 2 and 3. A comparison of the microstructures in Figure 2 with the graphite-flake size chart in the American Society for Testing Materials Standards 1955, showed that the longest flakes varied between size 5 (1/4 to 1/2 in. in length) and size 6 (1/8 to 1/4 in. in length). The shorter flakes were in the bottom portion of the tube. The comparison also showed that the distribution and orientations of flakes in tube X were a mixture of ASTM types A, B, and E. Types B and E predominated near the surfaces of the tubes whereas type A predominated in the interior. The size and type of graphite flakes did not vary appreciably from tube to tube as can be seen from typical microstructures in Figure 3.

Appreciable differences were observed in the microstructures of the top portions of the tubes. These differences were mainly in the pearlite and steadite structures and to some extent in the character of the boundaries of the graphite flakes.

The stable microstructure of gray cast iron at room temperature is graphite plus ferrite. It can be formed by very slow cooling from 1450°F or by reheating a meta or unstable structure for a prolonged period at temperatures below 1450°F. Graphitization, that is, the decomposition of the meta and unstable structure to form graphite and ferrite, is fastest around 1330°F. If the stable structure is reheated to temperatures above 1450°F austenite will be formed which on cooling at a rate approximating air cooling or in a sand cast mold, would form pearlite.

The pearlite and steadite microstructures shown in Figure 4 were typical of tube X and also typical of gray cast iron that had been cast in a sand mold. Typical microstructures of the top, midheight, and bottom portions of tubes A and 1 are shown for comparison in Figure 5. It can be seen that the pearlite and steadite constituents were in progressive stages of decomposition and spheroidization. The advanced stages at the top nearly approached the stable structure whereas the initial stage at the bottom corresponded to the structures observed in tube X. These structures indicated that the tubes had been heated in a temperature gradient in which the top of the tube had been at the highest temperature. The absence of pearlite patches in the microstructure of the top portions indicated that the highest temperature had not been above the transformation temperature, that is, 1450°F. The close similarity of the structures in corresponding portions indicated that the thermal histories of tubes A and 1 were similar.

The microstructures of the top and bottom portions of tube 9, shown in Figure 6, indicated that it also had been heated in a temperature gradient but that the highest temperature in the top portion had not been as high as in the tops of tubes A and 1.

The close similarity of the microstructures in corresponding portions and in the top and bottom portions of tubes H and 24, Figure 7, indicated that the tubes had similar thermal histories but that the

time at maximum temperature had not been sufficient to change the initial character of the pearlite and steadite constituents. Evidence that tubes H and 24 had been heated to elevated temperatures was shown by the formation of scale, see Figure 8.

Metallurgical examinations have indicated that tubes A, 1, and 9 were heated in temperature gradients in which the maximum temperature of the tubes was in the top portions, that the thermal histories of tubes A and 1 were similar, also that the thermal histories of tubes H and 24 were similar but that the maximum temperature was lower than that of tubes A, 1, and 9.

Appendix: Definitions of microconstituents:

Austenite: Austenite is a solid solution phase in which the face-centered cubic form of iron is the solvent. In ordinary gray cast iron austenite is stable between approximately 2500°F and 1450°F. The solubility of carbon in austenite at the austenite-iron carbide-ferrite eutectoid temperature, 1450°F, is approximately 0.85% and at the liquid iron - austenite - graphite eutectic temperature, 2150°F, it is approximately 1.5%. This silicon content of the gray iron is soluble in both the face-centered cubic and body-centered cubic forms of iron. Austenite is not ordinarily a microconstituent of gray cast iron at room temperature.

Ferrite: Ferrite is a solid solution phase in which the body-centered cubic form of iron is the solvent. The solubility of carbon at 1450°F is approximately 0.03%. Ferrite not associated with the ferrite in the ferrite-iron carbide eutectoid structure (pearlite) is sometimes referred to as "free" ferrite and is indicated by F in Figure 4. Ferrite is the matrix in the microstructure of slowly cooled gray iron.

Graphite: In gray iron graphite is in the form of flakes that appear in microstructure as dark bands, see Figure 4. The graphite flakes are part of the austenite-graphite structure that is formed in the freezing of the eutectic liquid.

Pearlite: Pearlite appears in the microstructure, see Figure 4, as an aggregate of dark (iron carbide) and light (ferrite) bands. Pearlite is formed in gray iron when it is cooled at an appropriate rate below the eutectoid temperature, 1450°F.

Steadite: Steadite results from the presence of phosphorus in the iron. As gray iron cools, a ternary eutectic structure consisting of austenite, iron carbide, and iron phosphide freezes about 1750°F. This subsequently decomposes into a "pseudo binary" iron, iron phosphide eutectic structure plus graphite. The boundaries of steadite generally are fluted because the phosphorus eutectic freezes after the austenite dendrites have formed.

APPENDIX II

U. S. DEPARTMENT OF COMMERCE
NATIONAL BUREAU OF STANDARDS
Washington 25, D. C.

Interdivision Work
Order No. 10-818
Project No. 4885

NATIONAL BUREAU OF STANDARDS REPORT

(Supplement)

on

Examination of

CAST IRON AIR TUBES

Submitted by

Division 10.3 (P. R. Achenbach)

By

H. C. Vacher
P. D. Sarmiento

Mechanical Metallurgy Section

APPENDIX III

NATIONAL BUREAU OF STANDARDS REPORT

No. 2

(Supplement)

on

Examination of

CAST IRON AIR TUBES

Submitted by

Division 10.3 (P. R. Achenbach)

by

H. C. Vacher
C. K. Speller

Mechanical Metallurgy Section

August 26, 1958

Interdivision Work Order
No. 10-50
Project No. 4885
August 1, 1958

NBS

U. S. DEPARTMENT OF COMMERCE
NATIONAL BUREAU OF STANDARDS

UNITED STATES DEPARTMENT OF COMMERCE
WASHINGTON

NATIONAL BUREAU OF STANDARDS

Report

Supplement No. 2

Examination of

CAST IRON AIR TUBES

Submitted by

Division 10.3
P. R. Achenbach and S. D. Cole

References: (1) Division 10.3 Interdivision Work Order No. 10-50, Project 4885.

(2) Division 8.3 report dated 2/10/58 on Interdivision Work Order No. 10-676, dated 11/4/57.

(3) Division 8.3 report dated 3/13/58 on Interdivision Work Order No. 10-818, dated 2/12/58.

Work Requested: Examine two upper air tubes to determine if the bend in the air tubes could be correlated with wall thickness and if the microstructures in different portions of the tubes were similar to the microstructures in the tubes described in two previous reports (Ref. 2 and 3).

Material Submitted: Three tubes were submitted: 13 G, 2 and J, all of which had been fired.

Examination: Tubes 13 G and 2 were cut so that the cut surfaces coincided with the plane of the bend, photographs 581709 and 581712, and then cut to show the cross sections near the top of the tube, photographs 581711 and 581715, and at the bend, photographs 581710 and 581716. These photographs show that the maximum wall thickness is on the concave side of the bend in tubes 13 G and 2.

Tube J was cut to show the cross sections throughout the length of the tube, photograph 581708. The sections showed that the outside and inside surfaces were cylindrical but were not concentric. The maximum wall thickness was on the concave side of the bend as in tubes 13 G and 2.

Specimens for metallographic examination were cut from tubes 13 G and 2 near the bottom and in the bent portion near the positions of maximum and minimum wall thicknesses. See photographs 581709 and 581712 for location and identification of the specimens. The microstructures were examined in the unetched and etched conditions at both low and high magnifications. They were photographed in the etched condition at 100 and 250 magnification.

The size and distribution of the graphite flakes in tubes 13 G and 2 were similar to that in the tubes described in the previous reports. This indicates that the cooling rates in the molds during freezing were approximately the same for all of the tubes examined. The pearlite in tube 13 G near the bottom was nearly completely decomposed, only a small amount of spherodized cementite remaining. This differs from the microstructure at the bottom of the tubes previously examined, Ref. 2, and indicates that the reheating temperatures were higher for tube 13 G. The pearlite in tube 2 at the bottom was similar to that in the tubes previously examined, that is, the pearlite was fine but resolved at X1000 with no indications of spherodized cementite. The microstructures of tubes 13 G and 2 near the bend were similar but both differed from that in corresponding locations in the tubes previously examined. In tubes 13 G and 2 the pearlite was completely decomposed. This was not the case in the middle portions of the tubes previously examined and indicates that the reheating temperatures were higher and the periods at the reheating temperatures were probably longer in tubes 13 G and 2.

The appearance of the graphite flakes in the thick wall section near the bend was different from that in the thin wall region in both tube 13 G and

tube 2. In the former the graphite flakes were thinner and the boundaries smoother than in the latter.

Discussion: The observed differences in microstructure between the thin and thick portions of the tubes could be explained if the temperature in the thin section was slightly higher than in the thick portion and at or very close to the transformation temperature, approximately 1450°F. It may, of course, be merely coincidence that the thin sides of the three tubes examined had been exposed to higher temperatures, due to non-uniform conditions of heating. It appears more probable that other factors influence the temperature distribution so that the thin sections are generally hotter. It seems possible that if the temperature in the furnace was fluctuating there would be a lag in the temperature of the thicker wall thus causing the maximum temperature in the thin side to be slightly higher than in the thick side, as indicated by the microstructure.

It has been established that graphitization of pearlite causes gray iron to expand or "grow". If the thin portion of the tube was hotter than the thick part, graphitization and growth would occur more rapidly, causing the tube to bend toward the thick side.

Summary: Sectioning of the tubes showed that the tubes had bent towards the thick side.

Metallographic examination showed that the bottom of tube 13 G had been heated to a higher temperature than the bottom of tube 2 and the ones previously examined. It also showed that the middle portions of tubes 13 G and 2 had been reheated to higher temperatures than the tubes previously examined. The appearance of the graphite flakes in the thick and thin sides of the tubes 13 G and 2 indicated that the temperature in the thin side was higher than the thick side and was probably approximately 1450°F.

A possible explanation for the bend in tubes 13 G and 2 is that the thin side grew at a faster rate than the thick side. This might result if the temperature in the furnace had fluctuated at or close to the transformation temperature, 1450°F.

U. S. DEPARTMENT OF COMMERCE
Lewis L. Strauss, *Secretary*

NATIONAL BUREAU OF STANDARDS
A. V. Astin, *Director*

THE NATIONAL BUREAU OF STANDARDS

The scope of activities of the National Bureau of Standards at its headquarters in Washington, D. C., and its major laboratories in Boulder, Colo., is suggested in the following listing of the divisions and sections engaged in technical work. In general, each section carries out specialized research, development, and engineering in the field indicated by its title. A brief description of the activities, and of the resultant publications, appears on the inside front cover.

WASHINGTON, D. C.

Electricity and Electronics. Resistance and Reactance. Electron Devices. Electrical Instruments. Magnetic Measurements. Dielectrics. Engineering Electronics. Electronic Instrumentation. Electrochemistry.

Optics and Metrology. Photometry and Colorimetry. Optical Instruments. Photographic Technology. Length. Engineering Metrology.

Heat. Temperature Physics. Thermodynamics. Cryogenic Physics. Rheology. Engine Fuels. Free Radicals Research.

Atomic and Radiation Physics. Spectroscopy. Radiometry. Mass Spectrometry. Solid State Physics. Electron Physics. Atomic Physics. Neutron Physics. Radiation Theory. Radioactivity. X-rays. High Energy Radiation. Nucleonic Instrumentation. Radiological Equipment.

Chemistry. Organic Coatings. Surface Chemistry. Organic Chemistry. Analytical Chemistry. Inorganic Chemistry. Electrodeposition. Molecular Structure and Properties of Gases. Physical Chemistry. Thermochemistry. Spectrochemistry. Pure Substances.

Mechanics. Sound. Mechanical Instruments. Fluid Mechanics. Engineering Mechanics. Mass and Scale. Capacity, Density, and Fluid Meters. Combustion Controls.

Organic and Fibrous Materials. Rubber. Textiles. Paper. Leather. Testing and Specifications. Polymer Structure. Plastics. Dental Research.

Metallurgy. Thermal Metallurgy. Chemical Metallurgy. Mechanical Metallurgy. Corrosion. Metal Physics.

Mineral Products. Engineering Ceramics. Glass. Refractories, Enameled Metals. Concreting Materials. Constitution and Microstructure.

Building Technology. Structural Engineering. Fire Protection. Air Conditioning, Heating, and Refrigeration. Floor, Roof, and Wall Coverings. Codes and Safety Standards. Heat Transfer.

Applied Mathematics. Numerical Analysis. Computation. Statistical Engineering. Mathematical Physics.

Data Processing Systems. SEAC Engineering Group. Components and Techniques. Digital Circuitry. Digital Systems. Anolog Systems. Application Engineering.

• Office of Basic Instrumentation.

• Office of Weights and Measures.

BOULDER, COLORADO

Cryogenic Engineering. Cryogenic Equipment. Cryogenic Processes. Properties of Materials. Gas Liquefaction.

Radio Propagation Physics. Upper Atmosphere Research. Ionospheric Research. Regular Propagation Services. Sun-Earth Relationships. VHF Research. Ionospheric Communication Systems.

Radio Propagation Engineering. Data Reduction Instrumentation. Modulation Systems. Navigation Systems. Radio Noise. Tropospheric Measurements. Tropospheric Analysis. Radio Systems Application Engineering. Radio-Meteorology.

Radio Standards. High Frequency Electrical Standards. Radio Broadcast Service. High Frequency Impedance Standards. Electronic Calibration Center. Microwave Physics. Microwave Circuit Standards.


NBS