RP129

RELIABILITY OF FUSIBLE TIN BOILER PLUGS IN SERVICE

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ABSTRACT

In cooperation with the Steamboat Inspection Service a study has been made of the reliability of fusible boiler plugs of the type installed in ships boilers under the jurisdiction of the Inspection Service. It has been found that under certain conditions fusible plugs would not operate due to the formation in service of a refractory oxide replacing the tin in the fire end of the plug. Apparatus is described in which plugs may be tested under simulated service conditions. The results of examination and tests of 184 plugs returned from service indicated that 10 per cent of all plugs in service would not operate when and if required. Recommendations regarding specifications and design of plugs to eliminate this dangerous condition are made.

CONTENTS

I. INTRODUCTION

The general rules and regulations provided by the Board of Supervising Inspectors of the Steamboat Inspection Service of the Department of Commerce require that every boiler under their jurisdiction other than boilers of the water-tube type shall be fitted with at least two fusible plugs. These are fitted at various places into the boiler either in the flues, tubes, or combustion chamber, in such a position that they are about 1 inch or more above the dangerous low water level with one end on the fireside and the other end on the waterside.

The fusible plug in its usual form consists of a bronze casing, having an external pipe thread, filled from end to end with a fusible metal or metal composition depending upon the temperature at which it is desired to have it function. As long as the water level in the boiler is maintained above the level of the plugs the temperature of the fusible metal remains below its melting point, but if the water in the boiler falls much below the level of the plug local heating occurs, the fusible filling of the plug melts and is blown out.

Plugs for use in marine boilers are generally of two types, known as an inside or outside type. This distinction is based on the manner in which the fusible plug is placed in the boiler. The inside type of plug is so designed that it is screwed into the boiler shell from the inside of the boiler, whereas the outside type is screwed into the boiler shell from the outside. Photographs of both types are given in Figures 1 (*a*) and 1 (*b*).

On August 19, 1925, a disastrous boiler explosion occurred on the steamer *Mackinac* near Newport, R. I.

The Bureau of Standards is responsible for the testing of the quality of the tin filling of fusible boiler plugs made to meet the specification requirements of the Steamboat Inspection Service. Accordingly, the latter was requested to submit plugs from the exploded boiler in order to determine their condition and, if possible, whether they had failed to function properly, thereby contributing to the cause of the disaster. Under date of August 31, 1925, two plugs were submitted by the Steamboat Inspection Service which were said to have been taken from the boiler of the *Mackinac*. Examination of these two plugs was made and detailed report submitted to the Steamboat Inspection Service on November 4, 1925.

This examination showed that one of the two plugs was in good condition, that it still met the specification requirements after approximately four months of service, and that it would have functioned had it been heated to the melting point of tin previous to the explosion. The second plug, however, showed evidence of serious deterioration in service.

Special apparatus was devised, described in detail later in this report, in which a plug can be subjected to steam pressures at elevated temperatures simulating service conditions. This plug was tested in this apparatus and although subjected to steam pressure at a temperature of about 340° C. it did not "blow out." It, therefore, probably would not have functioned in service had it been called upon to do so.

A plug in this condition obviously constitutes the very dangerous condition of a false security. In view of this fact, it was believed desirable to investigate in some detail the condition of plugs when removed from service.

In a previous report Burgess and Merica [1] showed the effect of small amounts of impurities, especially zinc, on the reliability of the fusible plugs. It was shown with 0.3 per cent zinc, and probably less, in the tin of the plug that a progressive oxidation occurred from the water end outward eventually forming an interlocking "network" throughout the tin of the filling. This network, due to its high melting point and relative strength, acts to prevent the proper functioning of the plug and so constitutes an actual source of danger rather than safety. As a result of this work the specifications of the Steamboat Inspection Service were changed so as to require that the tin in the filling should contain not more than 0.1 per cent lead and zinc, respectively, and a total impurity content of not more than 0.3 per cent.

In a somewhat later report Gurevitch and Hromatko [2] pointed out some of the precautions necessary in manufacture to prevent contamination of the tin in order to meet the rigid specification requirement that the tin filling shall not contain more than 0.3 per cent total impurity. It was shown that the tin should be poured into the casing at as low a temperature as possible in order to avoid contamination by solution of copper and zinc from the casing if made

[1] Burgess, G. K., and Merica, P. D., An Investigation of Fusible Tin Boiler Plugs, B. S. Tech. Paper No. 53; 1915; Ind. and Eng. Chem, 7, No. 10, p. 824; 1915; Trans. Am. Inst. of Metals; 1915–1921.

[2] Gurevitch, L. J., and Hromatko, J. S., Tin Fusible Boiler Plug Manufacture and Testing, Trans. Am. Inst. Min. and Met. Engrs., 64, p. 227; 1920.

of brass and of copper only if made of bronze. To avoid the danger of contamination with zinc, it was recommended that only bronze, with little or no zinc, should be used for the casing material.

The Steamboat Inspection Service requires that plugs shall be renewed at each annual inspection except in cases where plugs were installed or renewed not more than six months prior to annual inspection, in which case they may be allowed to remain until the next following annual inspection or for a period not to exceed 18 months.

It is often noted when plugs are removed after service that the tin in the fire end has been melted out and rather often the space is found to be partially filled with a hard material resembling oxide.

Burgess and Merica noted this in some of the plugs they examined. They suggested that the cause for the tin filling merely melting out at the fire end and leaving no oxide in some cases and being oxidized and remaining in place in other cases was probably due to variations in operating conditions of the boilers, to variations of the kind of coal used, and also possibly in the devices used by engineers in charge to stop up leaky plugs. One instance was cited by them in which plaster of Paris had evidently been used to stop a leaky plug.

The question obviously arises whether the presence of the oxide crust often noted in plugs, sometimes after only a few months' service, would prevent proper functioning. The present investigation was planned to answer this question by actually subjecting plugs in the laboratory to the steam pressures and temperatures at which they are expected to function. The Steamboat Inspection Service was requested to cooperate by sending to the Bureau of Standards plugs removed from service by their inspectors, together with as complete a history as possible of their service records. A total of 184 plugs was examined or tested, the details of which are given in this report.

II. TESTING APPARATUS

Special equipment was designed for the purpose of testing these plugs in the laboratory under simulated service conditions. The apparatus used for the so-called "blow-out" tests is shown in Figure 2 and is illustrated diagrammatically in Figure 3. A pressure of over 200 lbs./in.^{2} and simultaneous temperature of over 300° C. can be obtained. In general, for reasons of safety, the pressure was kept low.

The essential difference between the functioning of a plug in this apparatus and under service conditions is that in service the fire end is undoubtedly at a higher temperature. In the apparatus it is always approximately at the same temperature as the steam or "inside" end. It is believed, however, that this difference would not affect the results, since the functioning of the plug is dependent only upon the melting of the tin, and the manner in which the heat is applied would make little difference.

All plugs were tested in the apparatus with the pressure on the same (large) end as in service.

The pressure gauge was installed only in the later tests. That steam pressure was present throughout any one test was always indicated by slightly opening a safety valve on the top of the boiler. This was always done at the end of any test in which a plug failed to blow.

The temperature of the plug was determined in some cases by inserting a thermocouple in the casing, as indicated in Figure 2. A temperature difference of as much as 80° C. was noted in one instance between the temperature of the steam in the pressure chamber and the temperature of the casing of the plug; the latter was always cooler. In general, however, the temperature difference was much less than this. The difference noted depended largely upon the rate of heating. In case a plug did not blow, the temperature of the pressure chamber was maintained a sufficient length of time to permit a more even distribution of temperature to be established. Also, in all cases where a plug failed to blow, except as noted in Table 1, the tin was found to have been melted during the test which proved

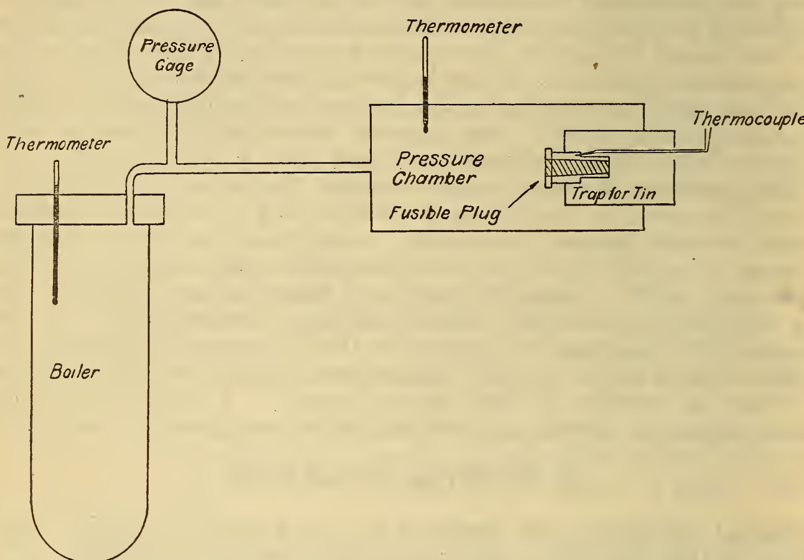

Figure 3.—*Schematic representation of testing apparatus shown in Figure 2*

that a temperature greater than the melting point of the filling had been reached.

III. RESULTS OF TESTS

The results of all tests, together with available service data, are given in Table 1. The plug number is that assigned to the plug on receipt from the Steamboat Inspection Service. The heat number is the original number given by the manufacturer. The "condition" is that indicated by inspection on receipt in the bureau laboratory. The data on ships from which plug was removed, type of boiler, boiler pressure and length of service are those given by the inspectors of the Steamboat Inspection Service.

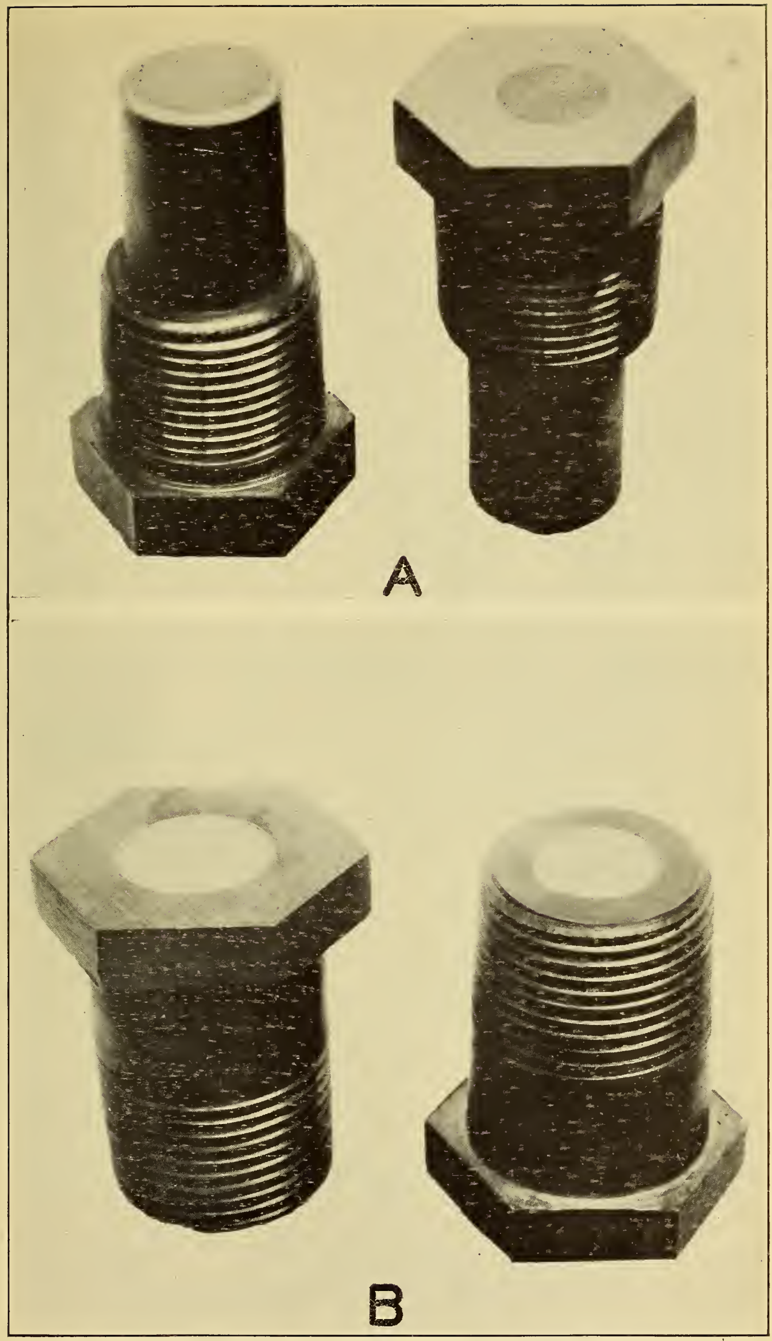

FIGURE 1.—*Fusible tin boiler plugs*

A, Outside type; *B*, inside type.

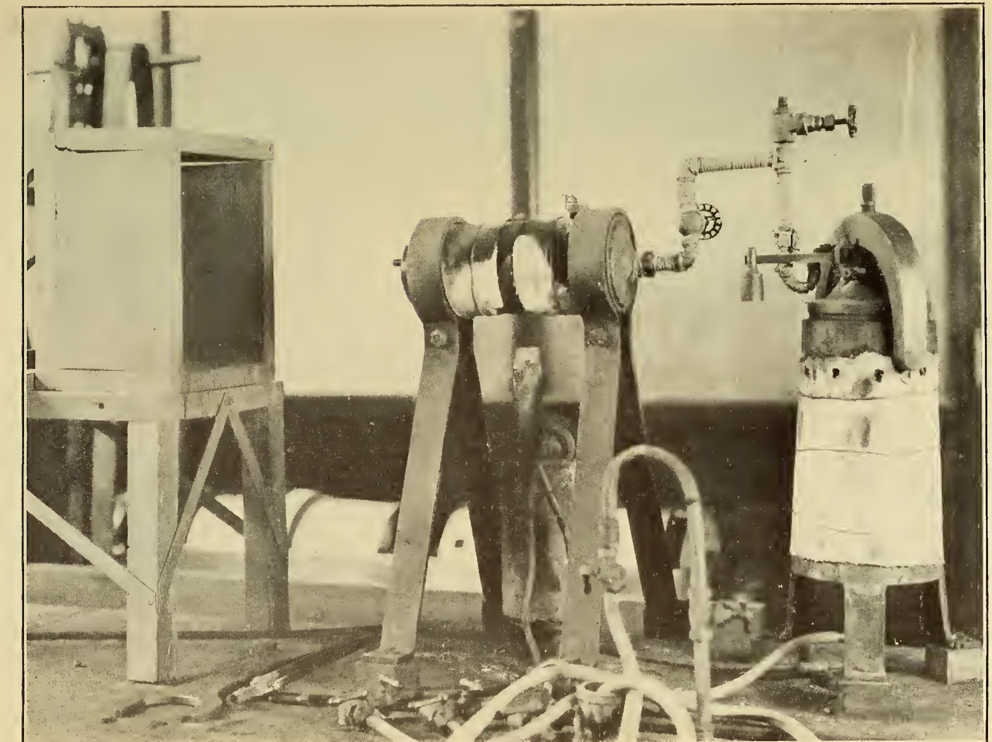

Figure 2.—*Apparatus used for testing boiler plugs under simulated service conditions*

TABLE 1.—*Data regarding fusible plugs tested in "blow-out" apparatus*

A. PLUGS THAT FUNCTIONED

Plug No.	Manufacturer	Heat No.	Diameter filling (outside)	Type of plug	Ship	Firing	Time in service	Boiler pressure	Condition of plug	Results	Results of test (temperature of steam at failure) [1]	Pressure of steam at failure
			Inches				*Months*	*Lbs./in.²*			° *C.*	*Lbs./in.²*
1	A	175	1/2	I					Good	Blew	224	
2	A	170	3/8	O	Albert H. Hill		12	200	About 1 inch melted out of fire end	do	248	
4	A	212	5/16	O	Nora	Oil	12	220	About 3/16 inch melted out of fire end	do	240	
5	A	212	5/16	O	do	do	12	220	About 1 1/4 inches melted out of fire end	do	244	
6	A	212	5/16	O	do	do	12	220	About 1 inch melted out of fire end	do	239	
7	A	212	5/16	O	do	do	12	220	1 1/8 inches melted out of fire end	do	255	
8	A	212	5/16	O	do	do	12	220	Fire end corroded; head almost gone	do	222	
9	A	190	1/2	I	Walter Franks		12	70	Good	do	242	
10	A	152	1/2	O	do		12	70	1/2 inch melted out of fire end	do	217	
11	A	131	1/2	I	Tug Dixie		12	150	Fire end slightly corroded and burned	do	234	
12	A	131	1/2	I	do		12	150	do	do	239	
13	A	195	3/8	O	Sun Oil (tanker)		11	190	1 inch melted out of fire end	do	248	
14	A	195	1/2	O	Tug Shirley Keller		12	125	7/8 inch melted out of fire end	do	245	
15	A	195	1/2	O	do		12	125	do	do	244	
16	A	194	5/16	O	Federal		12	155	Fire end slightly corroded; water end pushed in about 1/4 inch.	do	250	
17	A	208	3/8	O	W. W. Mills		11	210	Fire end slightly corroded	do	262	
18	A	211	5/16	O	Edenton		14	210	1 3/16 inches melted out of fire end	do	241	
19	A	211	5/16	O	do				1 1/2 inches melted out of fire end	do	250	
20	A	209	3/8	O	City of Philadelphia		10	190	5/8 inch melted out of fire end	do	253	
21	A	211	5/16	O	Henry S. Graves		11	220	1/4 inch melted out of fire end	do	250	
22	A	211	5/16	O	do		11	220	1 inch melted out of fire end	do	246	
23	A	211	5/16	O	do		11	220	1 3/8 inches melted out of fire end	do	243	
24	A	211	5/16	O	do			220	Fire end slightly melted out	do		
26	A	215	5/16	O	Atlantic	Oil	10	210	do	do	249	
27	A	216	5/16	I	Sagadahoe		12	190	Fire end slightly pressed out	do	218	

[1] Figures in parentheses indicate temperature of plug as indicated by thermocouple in the bronze casing.

TABLE 1.—*Data regarding fusible plugs tested in "blow-out" apparatus*—Continued

A. PLUGS THAT FUNCTIONED—Continued

Plug No.	Manufacturer	Heat No.	Diameter filling (outside)	Type of plug	Ship	Firing	Time in service	Boiler pressure	Condition of plug	Results	Results of test (temperature of steam at failure)	Pressure of steam at failure
			Inches				*Months*	*Lbs./in.²*			° *C.*	*Lbs./in.²*
28	A	216	5/16	O	Sabatowan		12	190	Fire end slightly burned	Blew	245	
29	A	216	5/16	O	do		12	190	do	do	248	
30	A	209	5/16	O					Fire end slightly melted out; water end slightly pressed out.	do	217	
32	B	101	15/32	O	L. P. Smith		3	140	1¼ inches melted out of fire end	do	254	
33	B	96	15/32	O	Joseph Medill		8	170	1 9/16 inches melted out of fire end	do	243	
34	B	96	15/32	O	do		8	170	1⅞ inches melted out of fire end	do	251	
35	B	96	15/32	O	do		8	170	1⅛ inches melted out of fire end	do	217	
36	B	106	½	O	Wm. A. Field		4	154	1⅝ inches melted out of fire end	do	215	
37	B	101	½	O	Alex. C. Dinkey		8	170	1¼ inches melted out of fire end· head corroded.	do	245	
38	B	106	15/32	O	Harvey		2	150	1⅛ inches melted out of fire end	do	254	
39	B	106	15/32	O	do		2	150	1 inch melted out of fire end	do	250	
40	B	106	½	O	Wm. A. Field		4	154	1½ inches melted out of fire end	do		
41	B	96	15/32	O	Joseph Medill		8	170	1¾ inches melted out of fire end	do	248	
42	B	96	15/32	O	do		8	170	1⅛ inches melted out of fire end	do	246	
43	C	288	⅜	I	Northland	Coal	12	180	Fire end slightly corroded	do	217	
45	C	288	⅜	I	do	do	12	180	Slightly melted out in fire end	do	245	
46	C	288	⅜	I	do	do	12	180	do	do	258	
47	C	189	9/16	O	Federal No. 2		12	155	⅝ inch melted out of fire end	do	240	
48	D	170	½	O	William J. Olcott		8	170	⅞ inch melted out of fire end	do	257	
49	D	173	½	O	Douglas Houghton		8	210	1¾ inches melted out of fire end	do	255	
50	D	161		O	Wm. A. MacGonagle		11	180	⅛ inch melted out of fire end; head almost burned off	do	243	
51	D	173		O	Thomas Lynch		8½	170	2¼ inches melted out of fire end; head badly corroded.	do	245	
53	D	171	½	O	Henry Phipps		9	170	1½ inches melted out of fire end; badly corroded.	do	244	
54	D	171		O	do		11	170	Head burned off; one-half gone from water end.	do		
55	D	161		O	Wm. A. MacGonagle		11	180	Head badly corroded; 1¼ inches only of filling left.	do		

56	E	65	5/16	O	Ocean City Ferry (tug)		12	150	¾ inch melted out of fire end	do	253	
57	E	42		I	Alice		12	110	Excellent	do	213	
58	E	97	⅜	I	Curtis Bay		12	150	Good	do		
59	E	97	½	I	F. C. Latrobe		3	72	Excellent	do	253	
60	E	88	½	I	Louie		12	120	Fire end slightly pushed out	do	247	
61	E	97	5/16	I	Wilson		12	190	Excellent	do	243	
62	E	88	7/16	I	Little Nora		12	240	Fire end slightly pushed out	do	240	
63	E	98	½	O	F. C. Latrobe		1	72	Excellent	do	260	
64	E	90	½	O	Annapolis		4	80	do	do	247	
65	E	97	5/16	I	Nelson		12	190	Fire end slightly bulged out	do	213	
66	E	74	5/16	I	Chickasaw		12	200	Good	do	244	
67	E	78	½	O	Annapolis		4	80	do	do	203	
68	E	97	5/16	I	Nelson		12	190	do	do		
69	E	77	½	O	Annapolis		4	80	do	do		
70	F	58	½	O	Paulsboro		12	215	1 1/16 inch melted out of fire end	do	231	
71	G	57	5/16	I	Middlesex		13	130	Fire end slightly bulged out	do	248	
72	G	57	5/16	I	do		13	130	⅝ inch melted out of fire end	do	213	
73	G	56	5/16	O	State of Maryland	Coal	2	185	1 inch melted out of fire end	do	253	
74	G	56	5/16	O	do	do	2	185	Good	do	258	
75	G	56	5/16	O	do	do	2	185	⅞ inch melted out of fire end	do	251	
77	G	56	5/16	I	Middlesex			130	Fire end slightly bulged	do	225	
78	G	56	5/16	I	do			130	do	do	254	
81	H	181	5/16	O	Melville Dollar	Oil	12	210	1 inch melted out of fire end	do	213	
83	I	109	½	I	Erastus Wells		12	150	Good	do	260	
84	I	103	½	I	do		12	150	Fire end slightly bulged out	do	240	
85	I	106	½	I	Bold Eagle		12	198	do	do	256	
86	I	106	7/16	I	do		12	198	Fire end slightly melted out	do	259	
87	I	106	½	I	Gladys	Coal	12	140	Fire end slightly bulged out	do	260	
88	I	103	½	I	Alabama		12	184	5/32-inch melted out of fire end	do		
89	I	102	½	I	Perryville		7	148	Good	do	240	
93	E	93	5/16	O	A. Brooke Taylor	Coal	8	150	⅝-inch melted out of fire end	do		
94	E	115	½	O	Ridgewood	do	2	125	1¼ inches melted out of fire end; removed because leaking.	do		
95	E	115	½	O	do				1½ inches melted out of fire end; leaking.	do		
96	A	229	5/16	O	McKeesport		12	210	⅞ inch melted out of fire end	do		
97	A	229	5/16	O	do		12	210	1⅜ inches melted out of fire end	do	260	
98	A	229	5/16	O	do		12	210	1⅛ inches melted out of fire end	do		
99	A	265	5/16	O	Wytheville		12	210	do	do		
100	A	265	5/16	O	do		12	210	1 9/16 inches melted out of fire end	do		
101	A	265	5/16	O	do		12	210	1¼ inches melted out of fire end	do		
105	E	84		O	A. Brooke Taylor	Coal	12	150	Melted out of fire end for considerable distance.	do	240	

TABLE 1.—*Data regarding fusible plugs tested in "blow-out" apparatus*—Continued

A. PLUGS THAT FUNCTIONED—Continued

Plug No.	Manufacturer	Heat No.	Diameter filling (outside)	Type of plug	Ship	Firing	Time in service	Boiler pressure	Condition of plug	Results	Results of test (temperature of steam at failure)	Pressure of steam at failure
			Inches				*Months*	*Lbs./in.²*			° *C.*	*Lbs./in.²*
106	E	84		O	A. Brooke Taylor	Coal	12	150	½ inch melted out of fire end	Blew	276 (235)	
107	E	125		O	Ridgewood	do	6	125	do	do	264 (230)	
108	E	115		O	Pioneer	do	12	100	Melted out half length of plug; loose crust in fire end.	do	283 (235)	
110	E	116		O	Ridgewood	do	6	125	Melted out half length of plug; loose crust.	do	310 (230)	
111	D	174		O	Wm. A. MacGonagle	do	8½	180	Heavy crust; water end covered with scale.	do	275 (244)	
115	I	116		I	Gladys	do	12	140	Fire end slightly melted out	do	289 (230)	
116	I	116		I	do	do	12	140	Fire end considerably swelled out	do	300 (245)	
117	A	265		O	Wytheville		8		One-third length of filling melted out	do		144
118	A	265		O	do		8		One-half length of filling melted out	do	269 (233)	105
119	A	265		O	do		8		Crust	do	280 (238)	158
120	A	265		O	do		8		One-fourth length of filling melted out	do	277 (232)	135
121	A	265		O	do		8		One-half length of filling melted out	do	280 (232)	120
122	A	265		O	do		8		do	do	289 (235)	150
123	A	265		O	do		8		Crust fire end	do	285 (231)	70
125	A	265		O	do		8		do	do	286 (230)	100
126	A	265		I	Nelson	Oil	15	190	do	do	282 (233)	125
127	A	220		I	do	do	15	190	do	do	283 (238)	100
129	E	97		I	do	do	15	190	do	do	287 (236)	95
130	E	97		I	do	do	15	190	do	do	288 (236)	98
131	E	97		I	do	do	15	190		do	272 (237)	140
132	G	54		I	do	do	15	190	Crust fire end	do	271 (237)	104
133	G	54		I	do	do	15	190	do	do	281 (235)	100
134	E	63		I	J. H. Riehl	Coal	12	100	do	do	277 (228)	96
135	E	115		O	Howard W. Jackson		12	60	One-fourth length of filling melted out; crust fire end.	do	280 (224)	95
136	E	115		O	do		12	60	do	do	280 (228)	120
137	A	265		O	Micheal Tracy	Coal	4	175	Crust fire end	do	286 (228)	125
138	A	229		O	Cape Cod		12		One-third length of filling melted out; crust in fire end.	do		

139	A	265		O	F. J. Williams	Oil		220	Crust fire end	do	288 (229)	100
140	Unknown			O			8		One-half length of filling melted out of fire end; crust fire end.	do	293 (231)	100
141	do			O	Tug boiler			High pressure	do	do	282 (234)	140
147	do								One-half length of filling melted out; crust in fire end.	do	315 (246)	40
148	D	84							One-half length of filling melted out of fire end; crust fire end.	do	290 (231)	110
149	D	186					2		One-third length of filling melted out of fire end.	do	280 (232)	72
151	D	178		O					Crust fire end	do	290 (224)	62
155	I	116		I	Alabama	Coal	12	184	do	do	260 (232)	40
156	I	116		I	do	do	12	184	do	do	267 (233)	80
159	Unknown			O	Q.-A. Gilmore	do	8	150	One-third filling melted out of fire end	do	298 (244)	86
161	D	178		O	do	do	8	150	do	do	275 (232)	100
165	A	265		O	Nueuo		12		Filling bulged out about 3/16-inch fire end.	do	268 (231)	35
168	Unknown									do	275 (231)	85
170	do			O					One-third filling melted out of fire end	do	282 (232)	24
184	do								One-third filling melted out of fire end; plug removed because of leaking.	do	285 (236)	70

B. PLUGS THAT DID NOT FUNCTION

3	A	212	3/8	O	Nora	Oil	12	220	Corroded slightly at fire end	Did not blow	263	
25	A	215	5/16	O	Atlantic	do	10	210	Tin slightly melted out of fire end; crust in fire end; water end slightly pushed in.	do	268	
31	A	212	5/16	O	Inca	Coal	12	190	3/4-inch melted out of fire end; crust in fire end.	(2)	255	
44	C	288	3/8	I	Northland	do	12	180	Crust in fire end	Did not blow	277	
52	D	173	1/2	O	August Ziesins	do	8	180	1/2-inch melted out of fire end; water end slightly depressed; head corroded and eaten away; crust.	do	(249)	
76	G	56	5/16	O	State of Maryland	do	2	185	Apparently satisfactory, although fire end slightly bulged out; crust became apparent after test.	do	260	
79	H	181	5/16	O	Melville Dollar	Oil	12	210	Apparently satisfactory, but crust became apparent after test.	do	(274)	
80	H	181	5/16	O	do	do	12	210	Same as above, but head slightly corroded.	do	(264)	
82	H	181	5/16	O	do	do	12	210	Fire end slightly corroded and bulged out.	do	(276)	
91	A	244	1/2	O	Mackinac	Coal	4½	142	7/8-inch melted out of fire end; head slightly corroded; crust in fire end.	do	337	

[2] Tin filling probably not heated to melting point of tin during test. "Infusible crust," however, was present, and plug probably would not have functioned had it been heated above melting point of pure tin.

TABLE 1.—*Data regarding fusible plugs tested in "blow-out" apparatus*—Continued

B. PLUGS THAT DID NOT FUNCTION—Continued

Plug No.	Manufacturer	Heat No.	Diameter filling (outside)	Type of plug	Ship	Firing	Time in service	Boiler pressure	Condition of plug	Results	Results of test (temperature of steam at failure)	Pressure of steam at failure
			Inches				*Months*	*Lbs./in.²*			° *C.*	*Lbs./in.²*
92	E	93	5/16	O	A. Brooke Taylor	Coal	8	150	½-inch melted out of fire end; head slightly corroded.	Did not blow	261	
102	E	122	½	O	General Mathews	do		158	5/16-inch melted out of fire end; fire end closed up solid with a reddish colored crust.	[2]	262	
103	E	122	5/16	O	Clay Foreman	do	12	150	2 inches melted out of fire end; crust in fire end.	[2]	259	
104	E	122	7/16	O	do	do	12	150	3/16-inch melted out of fire end; reddish crust.	Did not blow	260	
109	E	115		O	Virginia (ferryboat)	do	12	50	One-half length of filling melted out of fire end.	do	267 (232)	
112	D	174		O	Wm. A. MacGonagle	do	8½	180	Heavy crust; water end covered with scale.	do	304 (275)	158
128	A	220		I	Nelson	Oil	15	190	Crust in fire end	do	305 (276)	68
154	I	116		I	Alabama	Coal	12	184	do	do	271 (240)	114

[2] Tin filling probably not heated to melting point during test. "Infusible crust," however, was present, and plug probably would not have functioned had it been heated above melting point of pure tin.

Almost all of the plugs removed from service showed that the tin in the fire end had been melted out probably back of or close to the plane of the outside surface of the boiler where the cooling effect of the water surrounding the plug prevented melting.

For convenience all plugs that failed to "blow out" under test have been placed in one group (Table 1, B) and those that blew in another (Table 1, A).

It will be noted that the plugs were taken from many different ships. These included tugboats, cargo boats, ferryboats, and ships operating in the Great Lakes. This necessarily included both coal and oil fired vessels and high as well as low pressure boilers. The plugs were made by many different manufacturers and were of different sizes. It is believed, therefore, that the condition of the plugs tested represents a fair cross section of service conditions.

The data show that of the 150 plugs tested in the "blow-out" apparatus 13, or nearly 9 per cent, failed to blow out. Five other plugs (Nos. 3, 25, 31, 102, and 103) also failed to blow, but in these cases the tin was found not to have melted out. Chemical analyses after test showed that they met the specification requirements with the exception of plug 31, this being slightly higher in copper but not sufficient to affect the melting point materially. It is therefore highly improbable that these five plugs were heated to the maximum temperature indicated by the thermometer. A thermocouple had not been installed to measure temperature of casings during test at the time when these plugs were tested. However, as discussed later, a longitudinal section of these plugs showed the presence of an "infusible crust" in the fire end which would probably have prevented them from functioning at the temperature of melting tin. If this is true, the percentage of plugs that failed to function would be increased to 12 per cent. Another point that should be noted, however, is that toward the end of the investigation only plugs showing evidence of the "infusible crust" were tested, as it was believed that those showing no crust would function properly.

A total of 184 plugs were received from the Steamboat Inspection Service and examined. Assuming that the five plugs previously discussed would not have functioned, the data indicate that approximately 10 per cent of the plugs examined would not have functioned in service. The average time in service of all of the plugs examined was 10 months.

The cause of the failure to function was evident in every case. It was always due to the presence of a hard "infusible crust" packed tightly in the fire end of the plug replacing some of the tin filling. In general, this deposit was apparent upon inspection, but in many cases, especially when the tin in the fire end had been melted out for an appreciable distance back into the plug, it was difficult to determine its presence, and in some instances a plug which was apparently in good condition failed to function in test because of it.

The appearance of this so-called infusible crust is shown in Figure 4 (plug No. 91). Figure 4 (*b*) shows the water end of plug No. 91 after test. It is evident that the tin melted during test and the plug would have functioned except for the obstruction which had formed in the fire end during service. This is typical of all plugs that failed to blow out in test.

In plug No. 25 (fig. 5) the tin did not melt out during test, thus indicating, as previously mentioned, that the plug itself was not heated above 232° C., the melting point of pure tin, but the hard deposit in the fire end would very probably have prevented its functioning even had the tin melted out. Similarly in plug No. 3 (fig. 6) the deposit in the fire end probably would have prevented proper functioning.

The cause of the formation of the deposit of "infusible crust" was not at first apparent. Chemical analyses of these deposits are given in Table 2, together with the composition of the tin filling after test in the "blow-out" apparatus.

It will be noted that in most cases the tin after test conforms to the specification requirements for new plugs except for the copper content. The increase in this element is without doubt due to "pick-up" of copper from the casing during test by the tin especially while molten.

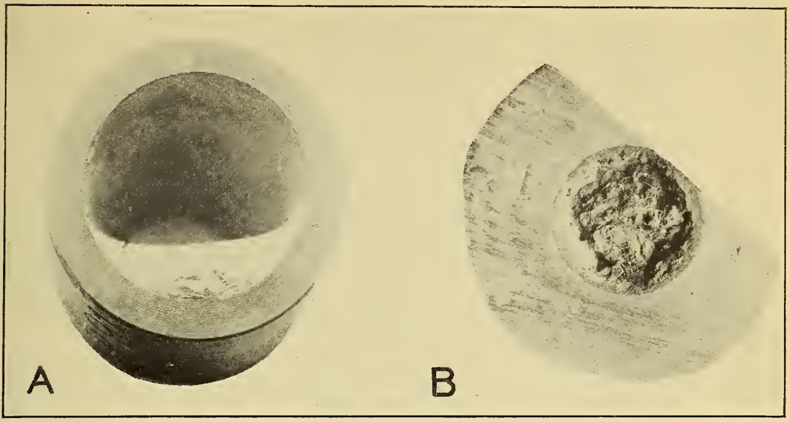

FIGURE 4.—*Plug No. 91 after test*

A, Appearance of water end filling melted during test but "infusible crust" in fire end prevented blowing; *B*, appearance of fire end showing "infusible crust" which had replaced filling during service.

FIGURE 5.—*Section of plug No. 25*

Note crust in the fire end.

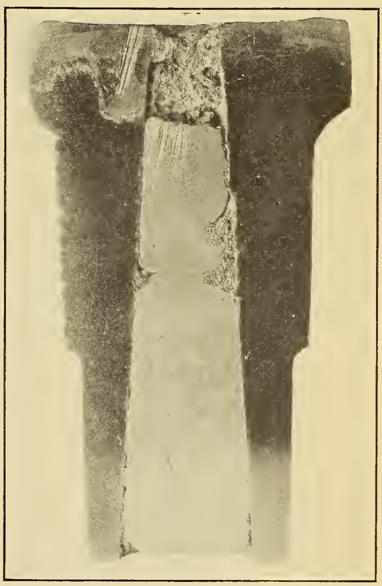

FIGURE 6.—*Section of plug No. 3*

Deposit in fire end would probably have prevented functioning.

TABLE 2.—*Composition of tin filling and "infusible crust" of plugs that did not function in test*

[n. d.=not detected]

Plug No.	Filling (water end)					Infusible crust (fire end)							Remarks
	Cu	Pb	Fe	Zn	Sn (by difference)	SnO_2 (by difference)	Cu [1]	Pb [1]	Fe [1]	Zn [1]	CaO [2]	SO_3	
	Per cent	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cen'*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	
3	0.12	0.06	<0.04	n. d.	99.78								
25	.29	.09	< .09	n. d.	99.53	44.0	4.0				22.0	30	Less than 0.1 per cent volatile matter.
31	.48	.10	< .05	n. d.	99.37								
44	.05	.07	< .03	n. d.	99.85								
52	.07	.02	< .04	n. d.	99.87	76.8	2.9	0.2	<0.1	n. d.	8.0	12.0	The $CaSO_4$ may be partially hydrated.
76	.63	.05	< .01	n. d.	99.31	93.85	5.9	.1	< .05	0.1			
79	.22	.27	< .05	n. d.	99.46								
80	.01	.09	< .03	n. d.	99.87	86.71	12.9	.09	< .10	< .20			
82	.15	.12	< .03	n. d.	99.70	80.85	18.4	.50	< .10	< .15			
91	.63	.08	< .01	n. d.	99.28	82.35	5.7	1.3	< .05	.5			SiO_2, 0.20 per cent.
92	.20	.09	< .02	n. d.	99.69	79.6	7.2	1.3	< .20	n. d.	n. d.	11.7	
102	.16	.10	< .02	n. d.	99.72	42.15	44.1	2.5	< .05		4.6	6.6	Crust from fire end of plug.
						86.35	2.8	.3	< .10	< .05	7.3	10.4	Crust from middle of plug.
103	.09	.11	< .02	n. d.	99.78	86.9	10.8	.7	< .2	n. d.	.6	.8	The $CaSO_4$ may be partially hydrated.
104	.18	.02	< .02	n. d.	99.78	94.25	2.2	.25	1.0		1.0	1.3	
109 [3]													
112	.7	.04	.10	n. d.	99.16	79.84	10.0	.04	.10	n. d.	4.0	6.0	Some MgO present probably a sulphate and carbonate.

[1] Present probably as oxides or other compounds, such as $CuSO_4$; not present as metals. [2] Present probably as $CaSO_4$ and $CaCO_3$. [3] Not analyzed.

Chemical analyses were also made of the tin blown out of many of the plugs that functioned properly. The results are given in Table 3. It is evident that, in general, the tin after test conforms to the specification requirements except for the copper content, which undoubtedly increased during test, as discussed later in the report. These data show that the composition of the tin filling does not change in service and that fusible plugs which are free from obstructions, such as the "infusible crust" previously described, may be expected to function when heated to the melting point of tin.

It was thought that the formation of the infusible crust might be associated with certain types of firing or boilers. From Table 1 (B) it is apparent that 12 of the plugs which did not function were used in boilers which were coal-fired and 6 which were oil-fired. Of the plugs that functioned (Table 1 (A), 15 were known to have been in oil-fired and 23 in coal-fired boilers. This indicates that the type of firing has no apparent relation to the formation of the infusible crust.

In Table 4 the plugs have been classified according to the permissible steam pressure of the ship's boilers. The plugs tested were principally from high-pressure boilers. It was, therefore, to be expected that a greater number of the plugs that failed to function would be from high-pressure boilers. The data do not indicate any relation between the crust formation and the pressure of the boilers in which the plugs were used. Data are not available regarding the positions from which the plugs tested were taken.

TABLE 3.—*Composition of tin from filling after test of plugs that functioned*

[n. d.=not detected]

Plug No.	Chemical composition					Plug No.	Chemical composition				
	Cu	Pb	Fe	Zn	Sn (by difference)		Cu	Pb	Fe	Zn	Sn (by difference)
	P. ct.	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*		*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*
1	0.65	0.02	<0.04	<0.04	99.25	30	0.94	0.06	<0.03	<0.04	98.93
2	.65	.19	< .04	n. d.	99.12	32	.04	.02	< .03	n. d.	99.91
4	.22	.06	< .04	n. d.	99.68	33	.06	.11	< .03	n. d.	99 80
5	.76	.36	< .03	n. d.	98.95	34	.13	.40	< .02	n. d.	99.45
6	.27	.07	< .03	n. d.	99.63	35	.29	.11	< .04	n. d.	99.56
7	.45	.12	< .04	n. d.	99.39	36	.38	.06	< .03	n. d.	99.53
8	.22	.26	< .04	n. d.	99.48	37	1.44	.06	< .02	n. d.	98.48
9	.42	.03	< .08	< .04	99.43	38	.20	.09	< .03	n. d.	99.68
11	.29	.05	< .07	< .06	99.53	39	.01	.01	< .03	n. d.	99.95
12	.28	.06	< .02	n. d.	99.64	41	.19	.11	< .03	n. d.	99.67
13	.60	.34	< .04	< .10	98.92	42	.44	.03	< .02	n. d.	99.51
14	.37	.09	< .02	n. d.	99.52	43	.03	.10	< .03	n. d.	99.84
15	.38	.03	< .03	n. d.	99.56	45	.01	.02	< .03	n. d.	99.94
16	.19	.02	< .03	n. d.	99.76	46	.04	.09	< .03	n. d.	99.84
17	.75	.20	< .03	n. d.	99.02	47	.33	.03	< .05	n. d.	99.59
18	.25	.11	< .04	n. d.	99.60	48	n. d.	.02	< .02	n. d.	99.96
19	.39	.12	< .04	n. d.	99.45	49	.08	.09	< .03	n. d.	99.80
20	.82	.06	< .03	n. d.	99.09	50	.09	.05	< .03	n. d.	99.83
21	.76	.22	< .03	n. d.	98.99	51	.18	.12	< .03	n. d.	99.67
22	1.14	.14	< .05	n. d.	98.67	53	.46	.25	< .03	n. d.	99.26
23	.39	.08	< .04	n. d.	99.49	54	.04	.03	< .02	n. d.	99.91
24	1.91	.09	< .04	n. d.	97.96	55	.03	.02	< .02	n. d.	99.93
26	.71	.23	< .03	n. d.	99.03	56	.36	.15	< .02	n. d.	99.47
28	.85	.19	< .05	n. d.	98.91	57	.19	.12	< .02	n. d.	99.67
29	.25	.03	< .05	n. d.	99.67	58	.12	.10	< .03	n. d.	99.75

TABLE 3.—*Composition of tin from filling after test of plugs that functioned*—Contd.

[n. d.=not detected]

Plug No.	Chemical composition					Plug No.	Chemical composition				
	Cu	Pb	Fe	Zn	Sn (by difference)		Cu	Pb	Fe	Zn	Sn (by difference)
	P. ct.	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*		*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*
59	0.80	1.10	<0.06	n. d.	98.04	81	0.47	0.18	<0.03	n. d.	99.32
60	.32	.09	< .02	n. d.	99.57	83	.37	.12	< .07	n. d.	99.44
61	.06	.16	< .05	n. d.	99.73	84	.17	.02	< .05	n. d.	99.76
62	.15	.04	< .01	n. d.	99.80	85	.69	.25	< .07	n. d.	98.99
63	.25	.09	< .03	n. d.	99.63	86	.14	.05	< .03	n. d.	99.78
64	.37	.07	< .04	n. d.	99.52	87	.05	.02	< .03	n. d.	99.90
66	.24	.07	< .01	n. d.	99.68	88	.22	.04	< .02	n. d.	99.72
67	.51	.17	< .02	n. d.	99.30	89	.50	.19	< .09	n. d.	99.22
68	.35	.17	< .02	n. d.	99.46	90	.25	.03	< .02	n. d.	99.70
69	.24	.06	< .01	n. d.	99.69	93	.90	.09	< .02	n. d.	98.99
70	.05	.03	< .03	n. d.	99.89	94	.14	.05	< .02	n. d.	99.79
71	.13	.21	< .05	n. d.	99.61	95	.10	.05	< .02	n. d.	99.83
72	.55	.11	< .06	n. d.	99.28	96	.26	.04	< .02	n. d.	99.68
73	.20	.15	< .03	n. d.	99.62	97	.93	.18	< .02	n. d.	98.87
74	.40	.05	< .03	n. d.	99.52	98	.27	.04	< .02	n. d.	99.67
75	.48	.10	< .04	n. d.	99.38	99	.18	.04	< .02	n. d.	99.76
77	.01	.02	< .03	n. d.	99.94	100	.22	.03	< .02	n. d.	99.73
78	.18	.27	< .04	n. d.	99.51	101	.36	.04	< .02	n. d.	99.58

It is of interest to note that of the total of 18 plugs that failed to function in the tests 15 were outside plugs and only 3 inside plugs, a ratio of 5 to 1. The ratio of outside to inside type of plug of all of the 150 plugs tested was less than 3 to 1, thus indicating that the inside type of plug is less liable to deterioration from the formation of the infusible crust. This may be due to the fact that the length of the inside type of plug is, in general, less than the length of the outside type, and in service the projection of the inside type of plug beyond the boiler shell into the fire chamber is less. Consequently, there is less danger of the tin melting and permitting the formation of the crust, as described later. These data are rather too few to allow drawing any general conclusions, but they indicate the desirability of having in all plugs the least possible length of projection of the fire end beyond the boiler shell into the fire chamber.

Chemical analyses of the infusible crusts indicated that they were chiefly stannic oxide (melting point 1,127° C.) with oxides of other metals present and in some instances a surprisingly large percentage of calcium sulphate (melting point 1,360° C.). As previously mentioned, in many of the plugs removed from service the tin had been melted out of the fire end. In cases where no crust was formed, the plug functioned properly. In other cases the tin or part of it was replaced by the dangerous oxides noted.

The general rules and regulations of the Steamboat Inspection Service require that "fusible plugs shall be so fitted that the smaller end of the filling is exposed to the fire and shall be at least 1 inch higher on the water side than the plate or flue in which they are fitted." Under these conditions it would be expected that any

TABLE 4.—*Classification of plugs that functioned and that did not function according to steamer boiler pressure*

BLEW OUT AT OR BELOW MELTING POINT OF TIN UNDER STEAM PRESSURE

[Steamer boiler pressures—pounds per square inch]

70 or less	80	100	110	120	125	130	140		150	155	170	180	190		200		210	215	220 and greater		Unknown pressure
9 10 59 63 135 136	64 67 69	134 108	57 62	60	14 15 94 107 110	71 72 77 78	32 87 115 116	11 12 38 39 56 58 83	84 89 93 105 106 159 161	16 36 40 47	33 34 35 37 41 42 48 51 53 54	43 45 46 50 55 88 111 137 155 156	13 20 27 28 29 61 65 68 73	74 75 126 127 129 130 131 132 133	2 66 85 86	17 18 19 26 49 81 96 97 98 99	100 101 117 118 119 120 121 122 123 124 125	70	4 5 6 7 8 21	22 23 24 62 139	1 30 95 109 138 140 165 168 170
TOTAL THAT FUNCTIONED																					
6	3	2	2	1	5	4	4		14	4	10	10	18		4		21	1	11		9
FAILED TO BLOW WHEN HEATED TO MELTING POINT OF TIN UNDER STEAM PRESSURE																					
109							91		103 104 92	102		44 52 112 154	31 76 128				25 79 80 82		3		
TOTAL THAT DID NOT FUNCTION																					
1							1		3	1		4	3				4		1		

molten tin in the fire end of the plug would run out. This occurs in the majority of cases. In fact, it is probable that the tin filling is melted out of the fire end after very few days or hours of service.

If the tin should not run out but remain in the plug in a molten condition, it probably would rapidly pick up copper from the casing and also might readily oxidize and finally fill up the fire end with the "infusible crust" noted. In order to determine the validity of this hypothesis, one end of a fusible plug was closed with a copper plug. A heating coil was wound around the casing and the entire plug heated to a temperature above the melting point of tin for approximately three months. The tin filling was left open to the air and was stirred about once a day with a glass rod. It was apparent that the tin was oxidizing and a hard infusible crust similar in appearance to that found in used plugs eventually formed. The appearance of the crust formed is shown in Figure 7 (*a*). A longitudinal section of the plug is shown in Figure 7 (*b*). It is evident that particles of the oxide had been stirred into the molten tin, and in time the oxide would have completely replaced the pure tin at least at this end of the plug.

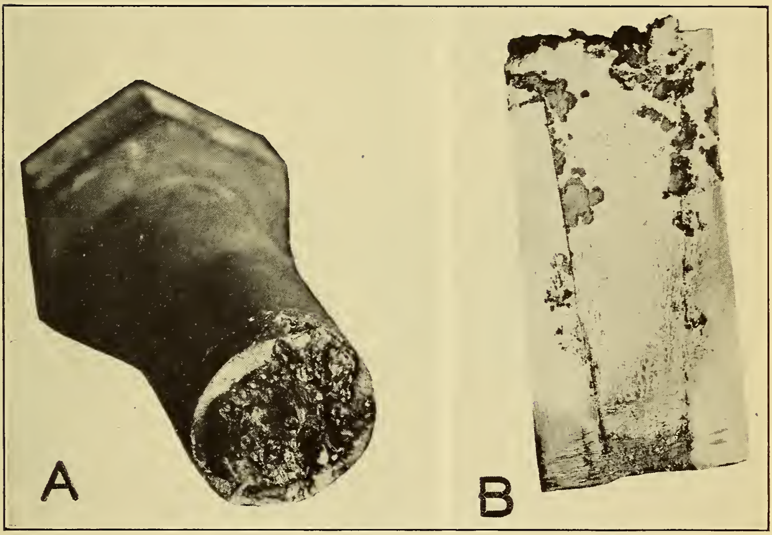

Figure 7.—*Infusible crust produced in plug in laboratory*

A, Shows oxide crust in end of filling; *B*, longitudinal section through filling.

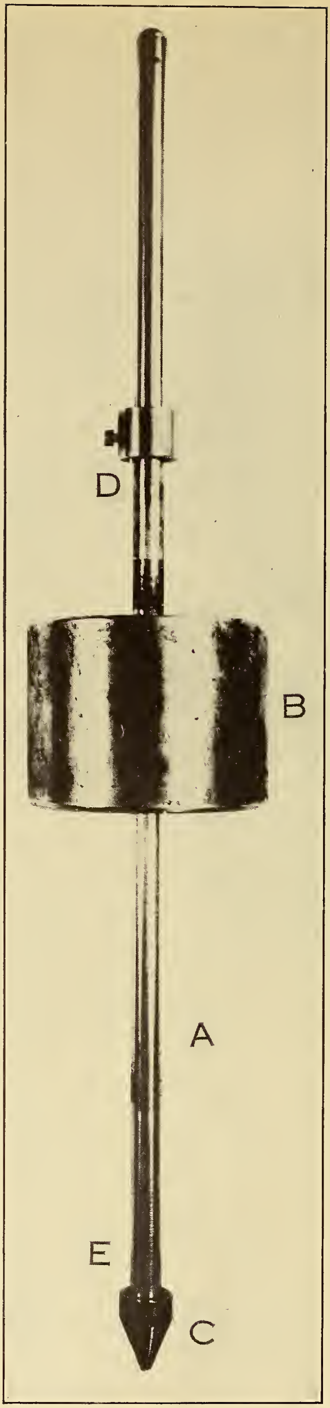

FIGURE 8.—*Device for testing tightness of filling*

The composition of this crust and filling was found to be as follows:

Crust.—Copper, 5.8 per cent; lead, 0.1 per cent; iron, 0.05 per cent; zinc, 0.10 per cent; SnO_2, remainder.

Filling.—Copper, 48.2 per cent; lead, 0.8 per cent; iron, 0.05 per cent; zinc, not detected; tin remainder.

It will be noted that the copper content of the tin has attained a very high value with a consequent raising of the melting point of the filling to approximately 650° C., considerably above that of pure tin. This, of course, is a very extreme condition, but emphasizes the importance of preventing molten tin from remaining in the plug.

An analysis was also made of the casing, which was found to have the following composition: Copper, 83.1 per cent; lead, 4.1 per cent; iron, 0.05 per cent; zinc, 6.8 per cent, and tin, 5 per cent; Ni, 0.20 per cent.

It is of interest to note that no zinc was found in the tin. Probably zinc was taken up by the tin while molten from the casing but was rapidly oxidized and so passed into the crust.

The validity of the theory of the formation of the crust is further confirmed by the statement of Inspector Hunter (letter of March 4, 1927, to the Supervising Inspector General, Steamboat Inspection Service) based on personal observation in service that it sometimes happens that "the tin does melt on the fire end and does run down, but does not entirely run out." He believes that this happens "more often in boilers operated under a high pressure forced draft." The reason for the tin not running out is the presence of obstructions, such as ash deposited in the plug in service after a small amount of the tin has melted and run out. Andrews, in a discussion of a paper by Warner,[3] has pointed out the necessity of frequent cleaning of fusible plugs to insure their proper operation.

In this investigation several plugs that failed to function had an appreciable percentage of calcium sulphate in the fire end intimately mixed with the oxides. The fact that the $CaSO_4$ was intimately mixed with the oxides indicated that it could not have been placed there as a filling to stop up a leak but probably was deposited gradually from the water in the boiler during service.

Plug No. 25 offers an explanation. A longitudinal section is shown in Figure 5. Examination indicated that the tin filling of this plug was not in intimate contact with the casing at all points, and a thin layer of $CaSO_4$ was found between the casing and the filling. Apparently the filling was not tight when placed in service or for some reason became slightly loosened in service and a slow leak developed. Calcium sulphate is one of the chief constituents of hard waters. It is readily conceivable that as the water leaked through the filling and reached the fire end of the boiler it evaporated and left a small deposit of the salts contained in the boiler water. Although the actual quantity of $CaSO_4$ in water is small, the total amount carried through the plug and deposited in the fire end could become sufficient to build up the crust noted over the period of 10 months that this plug was in service.

A confirmation of the possibility of this transfer of a salt from the boiler water to the fire end of a plug was given by plug No. 112. This plug when returned from service had a similar appearing deposit of scale on both the water end and the fire end. A sample of this scale

[3] Andrews, E., Some Causes for the Failure of Fusible Plugs, Power, 69, p. 65; Jan. 8, 1929.

was scraped from the outside of the casing near the water end and the composition was found to be as follows: CaO, 8.4 per cent; MgO, 10.4 per cent; $Fe_2O_3(Al_2O_3)$, 2 per cent; Cu, 6 per cent; SO_3, 18.4 per cent; CO_2, present; insoluble matter, present.

It will be noted (Table 2) that the "infusible crust" in the fire end contained appreciable amounts of CaO and MgO. Apparently water leaked through the plug, and on evaporation at the fire end left the deposit of CaO and MgO, which became intimately mixed with the oxidized tin and copper. In fact, the presence of water or water vapor at the fire end may accelerate the oxidation. The conclusion is obvious that a plug showing any indications of a leak should be removed from service.

The present specifications for fusible plugs do not require any definite composition for the casings. Gurevitch and Hromatko [4] recommended that only a bronze with little or no zinc should be used for the casing material in order to avoid the possibility of contamination of the tin with zinc. In order to determine what is being used at the present time, chemical analyses were made of 31 of the casings returned from service. The results are given in Table 5. It appears that the recommendations as to use of a low zinc bronze casing is, in general, being followed.

TABLE 5.—*Composition of casings of plugs returned from service*

Plug No.	Chemical composition			
	Cu	Sn	Pb	Zn
	Per cent	*Per cent*	*Per cent*	*Per cent*
44 [a]	85.8	7.0	1.8	5.36
90	85.3	7.6	1.9	5.06
82 [a]	87.5	4.6	4.8	2.99
79 [a]	85.6	5.2	7.0	2.12
80 [a]	87.5	4.7	4.8	2.89
24	86.4	7.7	2.0	3.76
31 [a]	87.6	7.6	1.8	2.95
32	83.5	6.1	2.2	8.15
25 [a]	86.4	7.6	1.8	4.15
40	82.1	7.0	3.2	7.65
48	90.0	5.6	3.8	.55
3 [a]	86.0	6.7	1.3	5.94
53	87.5	6.9	5.0	.47
27	86.0	6.4	1.8	4.75
68	84.9	2.5	4.9	7.45
55	87.3	6.2	2.7	3.74
88	86.4	10.3	2.8	.45
93	85.3	2.0	4.3	8.15
96	87.3	6.7	1.2	4.75
87	85.1	9.6	4.9	.35
98	87.1	6.5	1.8	4.55
99	85.6	7.1	1.6	5.65
100	87.1	6.8	1.1	4.90
101	86.4	7.3	1.4	4.80
102 [a]	83.7	3.8	4.7	7.50
103 [a]	84.7	3.7	4.9	6.38
104 [a]	84.8	4.8	6.4	3.7
95	82.0	4.5	4.9	7.0
92 [a]	81.2	3.0	7.5	8.07
94	85.1	3.9	4.4	6.28
Average	84.95	5.89	3.48	4.30
Minimum	81.2	2.0	1.1	.35
Maximum	90.0	10.3	7.5	8.15

[a] Plug did not function in test after service.

[4] See footnote 2, p. 2.

There is no apparent reason why a rigid specification for the composition of the casing should be set except possibly a maximum zinc content. No data are available regarding the maximum zinc content that might be present and not contaminate the tin in service. There is no apparent relation between the zinc content of the casing and the failure of the plug to function as evidenced by the data in Table 5. Plugs having a casing with a low zinc content (No. 31), and also with a relatively high zinc content (No. 92) both failed to function in the "blow-out" test for reasons previously stated. On page 16 data are given which show that tin in a casing containing 6.8 per cent zinc, even when kept molten in the casing for three months, does not show an increase in zinc content, such zinc as it may pick up being rapidly oxidized and so passed into the crust.

It is evident that casings having a composition within the limits shown in Table 5 are satisfactory.

IV. SUMMARY

A series of tests has been carried out to determine the reliability of fusible plugs after about six months to one year of service. Special apparatus was devised with which it was possible to test fusible plugs under known steam pressures and temperatures simulating service conditions.

A total of 184 plugs which had been removed from service in various types of steam vessels were examined and 150 of them tested. Approximately 10 per cent of all plugs examined did not function when heated under steam pressure to the melting point of tin. The average length of service of these plugs was 10 months. One plug removed after only 2 months' service failed to operate. All other plugs tested that did not function had been in service at least 8 months. The maximum length of service permitted by the Steamboat Inspection Service is 18 months.

The plugs were removed from vessels of various types with low and high pressure boilers, coal and oil fired, and were made by several different manufacturers. They were, therefore, quite representative of the condition of all plugs in service.

While the total number of plugs tested was small relative to the total number in service, their representative character indicates that the same percentage of those that failed in tests in the laboratory would fail to function in service—namely, about 10 per cent. However, it should be noted that the regulations of the Steamboat Inspection Service require, in general, that at least two plugs shall be installed in all boilers under their jurisdiction. This appears to be a desirable precaution, since the probability of both plugs failing to function would be very small.

The cause of failure of the plugs to function was found in every case to be due to the presence in the fire end of a so-called "infusible crust" which had replaced the pure tin originally present. Chemical analysis showed this "infusible crust" to be chiefly stannic oxide intimately mixed with oxides and sulphates of copper and lead. In some instances an appreciable quantity of calcium sulphate was present and in one instance a small amount of magnesium carbonate or sulphate.

The formation of the "infusible crust" in some cases was believed to be due to the melting of the tin in the fire end and its being prevented from dropping out due to the presence of ash or other obstructions. The tin then apparently oxidizes, together with some of the copper from the casing, eventually replacing the tin in the fire end with a hard mass of very high melting point. In other instances the formation of the crust was found to be due to a small leak in the plug, permitting boiler water which may contain appreciable amounts of calcium and magnesium sulphates and carbonates reaching the fire end. Here it would be evaporated but leave a small deposit of the dissolved salts. Over a long period of time these deposits apparently become appreciable and eventually form a hard compact mass in the fire end.

The danger of the presence of an obstructing material forming in a plug during service which might prevent its functioning is evident.

V. GENERAL CONSIDERATIONS AND RECOMMENDATIONS

As a result of this investigation it was established that an appreciably large number, possibly 10 per cent, of plugs in service may have deteriorated after six or more months' service in such a manner that they probably would not function if called upon to do so.

The deterioration is the gradual development of a hard "infusible crust" in the fire end replacing the tin. This infusible crust consists principally of oxides of tin and copper and ash. In some instances salts common to boiler waters were found in the fire end believed due to a small leak in the plug.

The presence of this crust in the fire end constitutes a potential source of danger because of the false sense of security offered by a supposedly reliable safety device. Every effort should be made to eliminate the causes.

Engineers responsible for boilers equipped with fusible plugs should inspect the fire end at every opportunity. If there is at any time any evidence of a leak, the plug should be immediately replaced. All foreign matter, such as oxides, scoria, or any matter other than the tin, should be immediately removed. Leaky plugs are probably due to lack of proper bonding of the tin filling to the bronze casing.

Ford, in his discussion of the paper by Gurevitch [5] and Hromatko, emphasized the necessity of pouring the tin into the casing at a temperature sufficiently low, such that the tin freezes in less than one-half minute, so as to prevent solution by the molten tin of copper from the casing. However, if the temperature of pouring is too low the tin does not stick to the casing. At intermediate temperatures the tin may become only partially bonded to the casing, but sufficiently so to pass unobserved and yet develop a small leak in service.

Gurevitch and Hromatko showed that copper decreases the melting point of the tin to a minimum of 227.1° C. at the eutectic composition of 1 per cent copper. With increasing copper content the melting point increases rapidly.

There is no evidence that the presence of up to 1 per cent of copper in tin causes or promotes any deterioration that might in any way prevent the proper functioning of the plug in service. The principal cause of loose fillings (leaky fillings) is too low a temperature of

[5] See footnote 2, p. 2.

pouring. A low pouring temperature is used to avoid contamination with copper. The present requirements of the Steamboat Inspection Service permit a maximum impurity content of 0.30 per cent which includes the lead and iron normally present in tin. The manufacturer is thus forced to pour at a low temperature in order to keep the copper within specification requirements and yet at a temperature sufficiently high to obtain tight fillings. By permitting a higher copper content in the specification requirements, a higher pouring temperature could be used and so insure tighter fillings less liable to leakage. The Bureau of Standards has accordingly recommended to the Steamboat Inspection Service that the permissible copper content be increased to 0.5 per cent and the total impurity content to 0.7 per cent; the maximum limits of lead and zinc to remain as at present at 0.1 per cent each.

Coincident with this recommendation it has been emphasized that requirements as to tightness of filling should be written into the specifications. A loose filling is often detected by striking it on the small end with a punch and hammer. If loose, the filling will slip partially, sometimes entirely, out of the casing. A plug having such a filling should be rejected and the entire heat suspected.

The punch and hammer test is rather indeterminate due to differences in weight of hammer and force of blow that may be used by different persons. To insure greater uniformity, the device shown in Figure 8 was developed and has been used quite satisfactorily in routine testing of plugs. It consists of a slide rod *A* and a 2-pound weight *B*. In testing the tightness of a filling the point *C* is placed against the small end of the tin filling and weight *B* permitted to drop through the distance *d–e*, of 6 inches. Three such blows will generally indicate whether the filling is loose by forcing it to slide partially out of the casing.

The present regulations of the Steamboat Inspection Service permit the small end of taper in a fusible plug to "be countersunk not more than one-fourth of an inch in depth and width." When such a countersink is present, the tin in that portion of the bore acts to prevent a filling, even if loose, from being driven out. It is believed, therefore, that this countersink should not be permitted.

The looseness or tightness of a filling is directly related to proper alloying of the tin filling with the casing. It is often noted in melting out fillings of plugs submitted for test for chemical analysis of the tin filling that the tin of the filling has not alloyed with the casing as evidenced by areas showing the bare surface of the casing. Obviously, the bore of a casing showing this condition was not properly cleaned or tinned before pouring in of the filling. It is believed that all plugs from any heat should be rejected in which a plug shows such evidence of lack of bonding of the tin with the casing.

The data are too few to support specific recommendations regarding modifications in design of plug. It appears desirable, however, that the projection of any plug beyond the boiler shell into the fire chamber should be a minimum. This should be readily obtainable in the inside type of plug by so fixing the position of the threads on the casing such that, when placing it in position, the fire end can be forced but a short distance beyond the outer surface of the boiler sheet. In the outside type of plug the relation of the position of the threads to the head (fire end) of casing should be designed such that in placing the plug in position the head will go in as nearly flush with the outside surface of boiler sheet as possible.

VI. ACKNOWLEDGMENTS

The authors wish to express their appreciation for the indispensable cooperation and interest of the Steamboat Inspection Service and to R. D. France for valuable assistance in conducting the tests.

WASHINGTON, June 22, 1929.