Symposium On Condensing Heat Exchangers

Proceedings, Vol. 2

PROCEEDINGS:
VOLUME II

SYMPOSIUM ON
CONDENSING HEAT EXCHANGERS

March 3-4, 1982

Atlanta Marriott Hotel, Downtown
Atlanta, Georgia

SYMPOSIUM SPONSORS

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Forword

This proceedings volume contains manuscripts of 23 papers presented at the second of two combined symposia held at Atlanta, Georgia, March 2-4, 1982:

SYMPOSIA ON

I. PULSE-COMBUSTION APPLICATIONS

and

II. CONDENSING HEAT EXCHANGERS

The topics of pulse combustion and condensing heat exchangers are of current interest because these combined technologies offer opportunities for developing high-efficiency fuel-utilizing equipment for many applications in the residential, commercial, and industrial sectors.

This proceedings volume, Volume II, includes papers that relate to heat exchangers designed to recover a portion of the latent heat of the water vapor formed in the combustion process; they are applicable to equipment fired by either conventional power burners or pulse-combustion systems. The papers relate to heat-exchanger concepts and performance, corrosion resistant materials, venting of flue gases, condensate disposal, codes and standards.

Applications include use of condensing heat exchangers in conjunction with furnaces for space heating and boilers for generation of steam or hot water for use in space heating or industrial processing.

Pulse-combustion systems are designed with fuel-firing equipment intended to take advantage of the phenomena of combustion-driven pulsations. These systems are of special interest because of their potential in firing efficient heating equipment having compact heat exchangers, including those operating in the condensing mode. Papers on Pulse-Combustion Applications presented at the first symposium are contained in Volume I.

Intended as forums for exchanging significant information between researchers and manufacturers, the two symposia were organized as part of ongoing programs for efficient energy utilization by the sponsoring organizations: the Gas Research Institute, the U.S. Department of Energy (through Brookhaven National Laboratory), and Battelle-Columbus Laboratories. Trade associations cooperating in the symposia were the Gas Appliance Manufacturers Association, American Gas Association, Hydronics Institute, American Boiler Manufacturers Association, and Industrial Heating Equipment Association.

The technical program for the Symposium on Condensing Heat Exchangers was arranged by David W. Locklin and David A. Ball of Battelle-Columbus Laboratories.

Papers presented at the combined symposia provide an international perspective on these topics—with authors representing equipment manufacturers and research organizations from the U.S., Canada, United Kingdom, Denmark, Israel, Netherlands, Sweden, Switzerland, and the U.S.S.R. Total attendance was 312 for the combined symposia; 240 attendees were from the U.S., 19 from Canada, and 53 from overseas countries.

Symposia Publications:

ABSTRACTS of papers at both Symposia
GRI-82/0009.1

PROCEEDINGS, VOLUME I.
Symposium on Pulse-Combustion Applications
GRI-82/0009.2

PROCEEDINGS, VOLUME II.
Symposium on Condensing Heat Exchangers
GRI-82/0009.3

Information on availability and price of these publications can be obtained from:

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SYMPOSIUM ON CONDENSING HEAT EXCHANGERS

March 3 and 4

Paper Number

Note: Paper 6 was withdrawn

SYMPOSIUM PAPERS

STUDY OF MATERIALS TO RESIST CORROSION IN CONDENSING GAS-FIRED EQUIPMENT

O.O. SCHAUS and T. LAHTVEE

Canadian Gas Research Institute

SUMMARY

This paper presents the summary of the results of a research project sponsored by the Gas Research Institute of Chicago. The purpose of the study was to determine which materials would resist the corrosive conditions produced when flue gases from natural gas-fired equipment were cooled to temperatures which would cause a portion of the moisture contained therein to condense. Series 300 stainless steel samples showed excellent resistance to corrosion under these conditions. Type 430 stainless showed limited weight loss but cracked in weld affected areas, however, type 430 stainless modified with small amounts of titanium did not demostrate this cracking problem. Aluminum products showed moderate resistance to this type of corrosion but developed deep pits at localized points which might restrict its life in this type of service. Copper and copper alloys were somewhat less resistant to attack than aluminum but did not pit to any major degree. Lead and lead alloys showed some resistance to corrosion but suffered substantial weight loss during testing. Most plastic materials were resistant to the condensate produced from condensing gas-fired equipment but have temperature limitations specific to each type of polymer.

INTRODUCTION

Problems relating to the corrosion of heat exchangers in gas-fired residential furnaces have plagued the industry for the last thirty years. Many investigations of this problem have been carried out and an interesting number of theories regarding the causes have been formulated. An analysis of published data and viewing of a large number of damaged units leads to the conclusion that in practically all cases the corrosion is caused by the condensation of the moisture contained in the flue gases on the colder areas of the heat exchange system and a subsequent acidic attack on this area. In a few cases where halogenated hydrocarbons or chlorine compounds were employed in the area of the furnace, an accelerated rate of attack was noticed due to the formation of additional acid gases from the halogen which were subsequently absorbed in the condensate.

The Canadian Gas Research Institute has done a considerable amount of work in this area over the past few years particularly on the determination of methods of preventing heat exchanger failure due to corrosion. An assessment was made of the composition of the condensate produced and a thorough analysis of metal samples corroded by condensate was made. The amount of sulfur and nitrogen contained in the corroded metal samples was surprisingly high and it appeared that the condensation and evaporation experienced during the furnace cycle resulted in a substantial concentration of the sulfurous and nitrous acid formed during gas combustion. This concentrated acid in combination with certain products of combustion and contaminants in the atmosphere represent a potent corrosive agent.

As attempts are made to improve the efficiency of gas furnaces, lower flue gas temperatures are attained aggravating the corrosion problem even more and when the flue gas temperatures are deliberately lowered below their dew point, as in ultra high efficiency equipment, a substantial deviation in materials of construction is required to prevent complete disintegration of the heat exchange system in a very short period of time. Limited experience was obtained when the Pulsamatic boiler, which condensed the moisture in the flue gases, was introduced in Canada in 1961 and this equipment showed that even highly alloyed materials such as cupronickel caused problems due to corrosion of heat transfer surfaces.

BACKGROUND INFORMATION

The first part of this investigation was an extensive background study of systems involving condensation of flue gas moisture or related processes which could cause parallel occurrences. This involved a detailed study of the literature and discussion with parties who had experience in similar situations. The only condensing systems from which we were able to obtain direct information was the Pulsamatic boiler system developed in Canada in 1961 by Lucas Rotax Company of which approximately one thousand were installed in homes and many are still operating. The initial condensing components of these units were made of copper but this corroded rather badly and was later replaced by cupronickel alloys which exhibited better performance than copper but still showed substantial corrosion. Efforts were also made in the early 1950s to use so-called chimney condensers in oil-fired applications but corrosion of the copper and fouling made these experiments short lived.

Computer and manual searches were carried out on the various abstracts and other reference data, including an extensive manual study of the principal corrosion journals. Little was found which dealt directly with deliberate cooling of flue gases below their dew point but references were found relating to corrosion problems and materials used in other heat transfer applications where attacking species were similar to those found in flue gas condensate.

The problems of flue gas corrosion of metals was examined in the 1930s when a number of investigators (1,2,3,4) studied the rapid deterioration of boiler economizers and flue connectors. The proposed solutions were to increase temperatures to keep all surfaces hot, insulation of exterior surfaces and the application of protective coatings. Studies were also carried out on what constituted the corrosive elements in the flue gases by analysing the corrosion products (5,2,1,6,7,8). The results pointed strongly to sulfur and it was concluded that sulfurous or sulfuric acid caused the problems. It should be remembered that the sulfur content of the gas at that time was much higher than that encountered today.

A substantial amount of work was carried out in the late 1930s and early 1940s on the causes of deterioration of metal chimneys used with gas-fired equipment (2,7,1). Schnidman (2) and fellow investigators working for AGA investigated the problem for about twenty years and published numerous articles on methods and materials to prevent chimney corrosion problems. They concluded that the corrosion was caused by sulfuric acid which was catalyzed from the sulfurous form by the various oxides of nitrogen. Even though they found the condensate from the flue gases to contain 0.015% nitric acid, they felt its role was secondary in the corrosion process. Likewise, most investigators (8,9,10) felt the CO_2 played a minor role in corrosion even though small amounts of carbonates were found in corrosion deposits.

The various investigators (10,11,15) examined a number of materials and coatings in an effort to find corrosion resistant substances. Their findings can best be summarized by looking at the various classes of materials and results reported.

Iron and Steel Products

Ordinary carbon steel has been found to be universally unsatisfactory for condensing flue gases and could only be used when the temperature was well above the condensation point. Considerable work has been done examining low alloy steels, that is with about 2% alloying metal. Corten which contains small amounts of manganese, copper, silicon and chromium was found to be 4 to 6 times as resistant as mild steel. Similar improvements were reported for Mayari R, HT50 and Yoloy. In spite of the improvement, the rate of corrosion of these materials was found to be unsatisfactory. Low alloy cast irons showed parallel results to the low alloy steels.

Aluminum Products

Aluminum and aluminum alloys are reported as showing good resistance to condensing flue gases and condensate. Alloy 2S, 3003 and 5052 are reported to be quite resistant to attack but showed a tendency to form deep pits. On the basis of these studies, the aluminum lined type B vent for gas-fired equipment was developed.

Copper Products

Pure copper was found to be uniformly attacked by the condensing gases resulting in substantial weight loss. Alloying with zinc gave some improvement but dezincification was found to take place on extensive exposure. Several cupro nickel alloys were examined and while increasing nickel improved performances, chemical attack was found to occur on all alloys tested.

Stainless Steels

A wide variety of stainless steels were evaluated by different investigators. 18 Cr and 13 Ni containing molybdenum gave good corrosion resistance. Type 316 and 309 were reported as being resistant to condensate attack as was Type 430 but intergranular attack was reported on some 300 series alloys.

High Alloys

Investigators examined some highly alloyed metals such as Hasteloy C276, Carpenter 20 and Inconel. These metals exhibited good resistance but were no better than the lower alloyed stainless steels.

Coatings

A wide variety of coated metals were examined by numerous authors (16,17,18). Aluminized steel, aluminum sprayed steel, alonized steel and several other aluminum coated steels were reported. Marked improvements over mild steel are shown but coating durability over longer test periods caused subsequent failures. Numerous ceramic and porcelain coatings were tested and while the coatings exhibited good corrosion resistance, all subsequently failed due to attack at points of imperfection in the coating. Teflon and nylon were also employed as coatings with good results, however, temperature limits restricted their usage. Lead coatings were widely tested with mixed results.

EXPERIMENTAL EQUIPMENT

In order to evaluate various materials, two special pieces of apparatus were constructed. The cyclic condensing equipment which is shown in Figure 1 was developed to study the effects of condensing conditions on various materials.

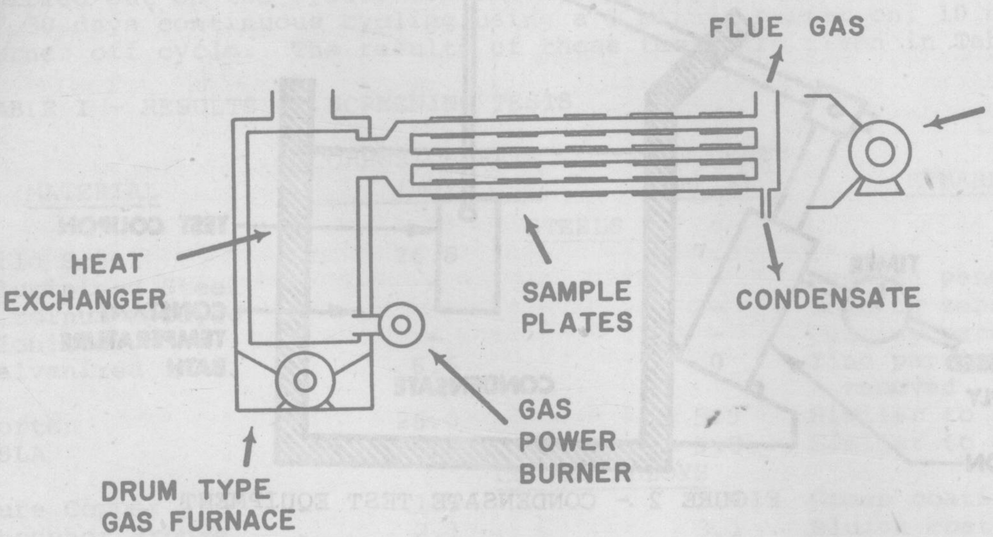

FIGURE 1 - CONDENSING CORROSION APPARATUS

In this apparatus, 6" x 6" sheets of the material to be tested are bolted to the upper and lower sides of the hollow rectangular tubes shown in the drawing. The furnace is then put into operation and flue gases pass through the tubes and contact the test samples. Cold air is blown over the outside of the tubes by a blower at such a rate as to cause substantial condensation at the exit end of the tubes. The furnace is then cycled at a rate of 5 minutes on and 10 minutes off to give maximum corrosive effect.

After a specific period of operation, the specimens are removed, polished and examined for weight loss and signs of pitting or other deterioration.

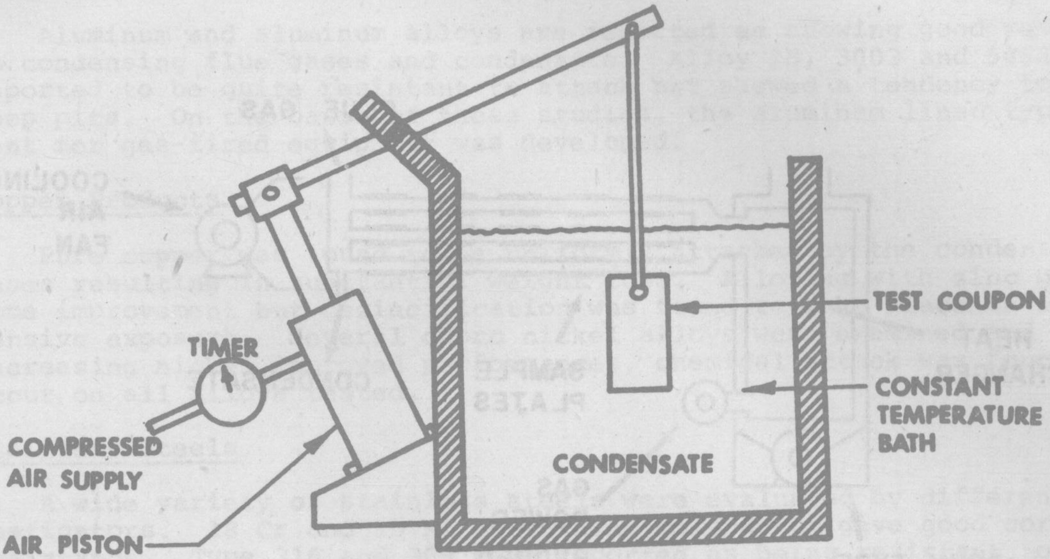

FIGURE 2 - CONDENSATE TEST EQUIPMENT

In the second apparatus shown in Figure 2, samples of test materials are intermittently submerged in fresh furnace condensate maintained at 110°F. The cycle followed was 5 minutes submerged and 10 minutes removed. This cycle simulates furnace operation during a period of cold weather. After specified periods of time, samples are removed, cleaned and examined for weight loss, pitting and other signs of corrosion. Each type of test includes samples containing welds, sharp bends and crevices to ensure that stress or crevice attack type of corrosion was being evaluated. Figure 3 shows a sample plate with attachments.

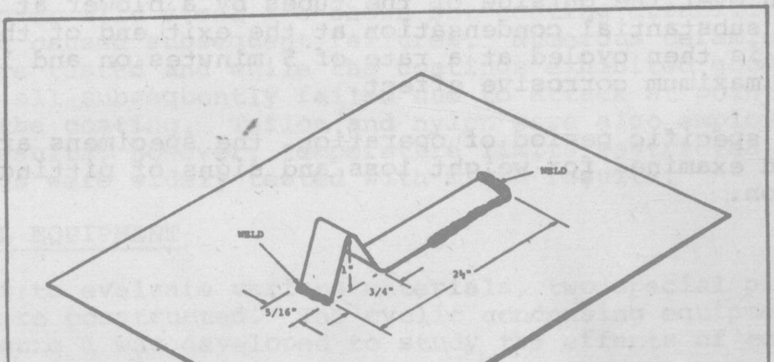

FIGURE 3 - SAMPLE PLATES

PRELIMINARY SCREENING OF MATERIALS

Before proceeding with long term cyclic testing of a large number of samples, short term tests of selected candidate materials were carried out on the cyclic condensing apparatus. These tests consisted of 30 days continuous cycling using a 5 minute burner on, 10 minute burner off cycle. The results of these tests are given in Table I.

TABLE I - RESULTS OF SCREENING TESTS

MATERIAL	CORROSION RATE (mpy)	PIT DEPTH (mils)	REMARKS
STEELS			
Mild Steel	26.5	7.8	
Aluminized Steel	-	-	Coating penetrated
Aluminum Sprayed	-	-	Coating separated
Alonized	-	-	Coating penetrated
Galvanized	6.6	0	Zinc partially removed
Corten	26.0	5.9	Similar to steel
HSLA	26.8	5.8	Similar to steel
COPPER ALLOYS			
Pure Copper	1.5	2.0	Green coating
Phosphor Bronze	2.1	3.1	Bluish coating
Beryllium Copper	2.0	2.8	Bluish coating
Aluminum Bronze	0.8	2.0	Slight pitting
Cupronickel 90/10	1.9	5.8	Green coating
Cupronickel 70/30	1.0	2.0	Green coating
ALUMINUM ALLOYS			
1100	0.5	5.9	Some pitting
1100 Anodized	0.7	.12	
3003	2.6	5.9	Some pitting
5052	0.3	9.8	Some pitting
6063	0.92	5.9	Some pitting
STAINLESS STEELS			
409	0.10	0.6	Rust colored surface
410	0.12	1.8	Similar to 409
430	Nil	3.9	
Nyby T	Nil	2.0	
Nyby MoT	Nil	Nil	
Nyby MONIT	Nil	Nil	
304	Nil	3.2	
316	Nil	2.4	
317	Nil	2.0	
Carp 20	Nil	3.1	
OTHERS			
Porcelain-Steel			Pits in coating
Enamelled-Aluminum	Nil	21.2	Heavy pitting
Epoxy-Steel	Nil	.05	Good
Teflon-Steel	Nil	.2	Rust in pits
Lead-Galvanized	5.26	.1	Weight loss
Nylon-Steel	Nil	Nil	Little attack
Titanium	Nil	Nil	Little attack

LONG TERM CYCLIC TESTING OF MATERIALS

On the basis of the preliminary screening tests, the following materials were selected for long term testing on the cyclic condensing apparatus: stainless steel types 304, 316, 317, 409, 430, Nyby T(430 + Ti), Nyby MoT (430 + Mo + Ti), aluminum bronze, anodized aluminum type 1100, type 6063 aluminum, lead coated copper, pure copper, epoxy coated steel, nylon coated steel, teflon coated steel and porcelain coated steel.

The long term tests consisted of cyclic exposure of the samples to condensing flue gases for a continuous period of up to six months. Samples were removed from the apparatus after 2, 4 and 6 months exposure, cleaned, weighed and examined for pitting, cracking or other types of deterioration. Removed samples were not returned to the test apparatus to avoid negating passive effects which may occur with certain materials. All tests included specimens with welds, sharp bends and crevices.

The results obtained from this series of long term tests are given in Table II and Table III.

TABLE II - LONG TERM CYCLIC TESTING (Condensing Flue Gas)

	RATE OF CORROSION (mpy)				
	EXPOSURE TIME (days)				
MATERIAL	30	60	120	180	REMARKS
304	nil	.008	.014	.008	
316	nil	.014	.010	.008	
317	nil	.003	.004	.001	
430	nil	.015	.010	.011	cracked at weld
Nyby T	nil	.006	.006	.003	
Nyby MoT	nil	.008	.010	.007	
Al Bronze	.785	.851	.715	.595	
An Alum	.880	.861	.555	1.120	white coating
Alum 6063	.765	.695	.547	.506	white coating
Pb on Copper	1.905	1.672	1.534	1.192	lead removed
Copper	1.554	1.168	1.716	.966	green coating
Type 409 SS	.243	.303	.371	.388	rusty appearance

Since one of the most problematic type of corrosive result is the formation of pits or highly localized penetration, all sample plates were examined for this type of attack. The results of this study are given in Table III.

TABLE III - SURFACE EXAMINATION (Condensing Flue Gases)

MAXIMUM PIT DEPTH (mils)

MATERIAL	EXPOSURE TIME (days) 30	60	120	180
304	3.2	1.6	1.6	1.8
316	2.4	0.2	0.2	0.2
317	2.0	nil	nil	nil
430	2.8	4.0	0.8	0.8
Nyby T	2.0	0.4	0.8	0.4
Nyby MoT	nil	0.6	0.8	0.2
Al Bronze	nil	3.2	3.2	7.5
An Alum	5.9	3.2	24.0	12.0
Al 6063	2.5	2.0	9.5	24.0
Pb on Copper	Lead removed from copper			
Copper	2.0	4.0	3.1	4.0
409 SS	5.5	6.4	9.8	6.5

To evaluate the ability of materials to withstand the condensate produced from condensing gas furnaces, the second piece of apparatus described was employed. Samples of materials were immersed in fresh condensate for 5 minutes and then removed and allowed to dry for 10 minutes. The condensate was maintained at 110°F. The results obtained are given in Table IV.

TABLE IV - CYCLIC CONDENSATE IMMERSION

CORROSION RATE (mpy)

MATERIAL	EXPOSURE TIME (days) 30	60	90	230
304	nil	nil	nil	nil
316	nil	nil	nil	nil
317	nil	nil	nil	nil
409	nil	nil	.008	.005
430	nil	nil	.008	.005
Nyby T	nil	nil	.008	.016
Carp 20	nil	nil	.016	.009
Titanium	nil	nil	.008	.006
Be Copper	1.42	1.82	1.80	1.73
Ph Bronze	1.67	2.14	2.08	1.75
Al Bronze	1.12	1.12	1.18	0.33
Copper	1.75	1.75	1.70	1.43
Cu Ni 90/10	2.05	2.54	2.38	1.78
An Al 1100	1.85	2.08	1.71	0.96
Alum 1100	1.65	1.55	1.26	1.12
Alum 3003	1.23	1.52	1.17	1.04
Alum 6063	1.14	1.23	1.13	0.93
Lead	0.28			2.90