Babcock Power

Technical Publication

Dry Bottom Turbo® Furnace Test Results

by

P. J. Hunt
Manager
Results Engineering
RILEY POWER INC.
a Babcock Power Inc. company
(formerly Riley Stoker Corporation)

Presented to
Committee on Power Generation Association
of Edison Illuminating Companies
September 14, 1977
Minneapolis, Minnesota

RPI-0776-H

DRY BOTTOM TURBO® FURNACE TEST RESULTS

by

P. J. Hunt, Manager of Results Engineering
RILEY STOKER CORPORATION
WORCESTER, MASSACHUSETTS

The Riley Dry Bottom Turbo Furnace is a unique furnace design whose chief innovations are a venturi-like cross-section in the lower furnace and downward firing diffusion type directional flame burners. Figure 1 is an illustration showing the principal feature of the Turbo Furnace; i.e. the venturi-like contour. When used in combination with the directional flame burners, this contour produces a diffused flame pattern with gradual propagation through a long path of travel. Because combustion is gradually completed in the lower furnace area, both the lower and upper furnace walls are subsequently free from ash or slag deposits. Combustion is also completed with flame temperatures in a range desirable for minimum fixation of atmospheric nitrogen, resulting in low NO_x emissions.

Figure 2 is a closeup of a directional flame burner. This burner has the ability to change combustion air direction by the manipulation of vane type dampers located at the burner throat. This provides controllability of flame pattern in order to suit a variety of furnace conditions and combustion requirements.

Another advantage inherent in the Turbo Furnace is even burner spacing, which both minimizes flame impingement on furnace walls and provides an even heat release across the furnace width. This results in more uniform superheater and reheater metal temperatures across the unit, than those found in front or opposed wall burner furnaces, in general.

Most of Riley's Turbo Furnace test results have been accumulated on slag tap, wet bottom designs. However, we have sold 25 of the modern dry bottom types, with three of the larger utility type currently in operation. These units are:

1. City Utilities of Springfield
   Unit #1
   Springfield, MO
2. Interstate Power Company
   Unit #4
   Lansing, IA
3. South Carolina Public Service Authority
   Unit #2
   Georgetown, SC

Test Data in varying degrees of depth have been gathered on these units and are presented below.

Unit Descriptions

City Utilities of Springfield (Unit #1), Interstate Power Company (Unit #4) and South Carolina Public Service Authority (Unit #2) are shown in elevation views in Figures 3, 4 and 5 respectively. Aside from actual operating conditions, there are some major differences between the three units. Springfield and Interstate are single pass designs requiring gas recirculation (Springfield) or excess air (Interstate) for steam temperature control. South Carolina utilizes a two pass design which involves using

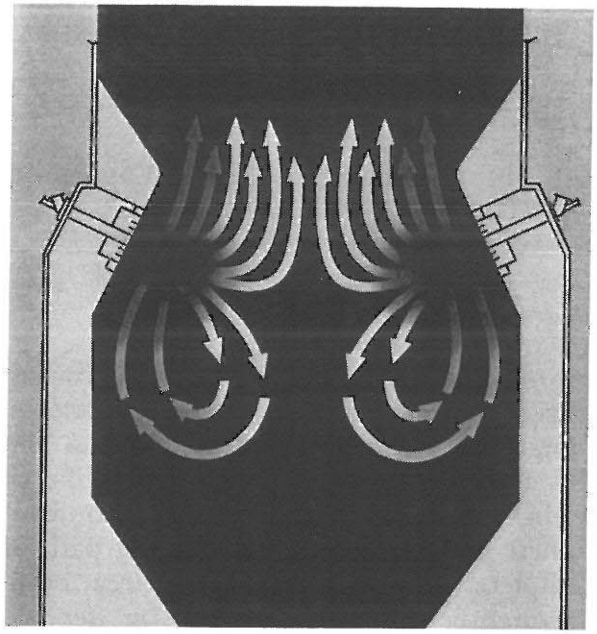

Figure 1 Turbo Furnace Venturi Shape and Flame Pattern Diagram

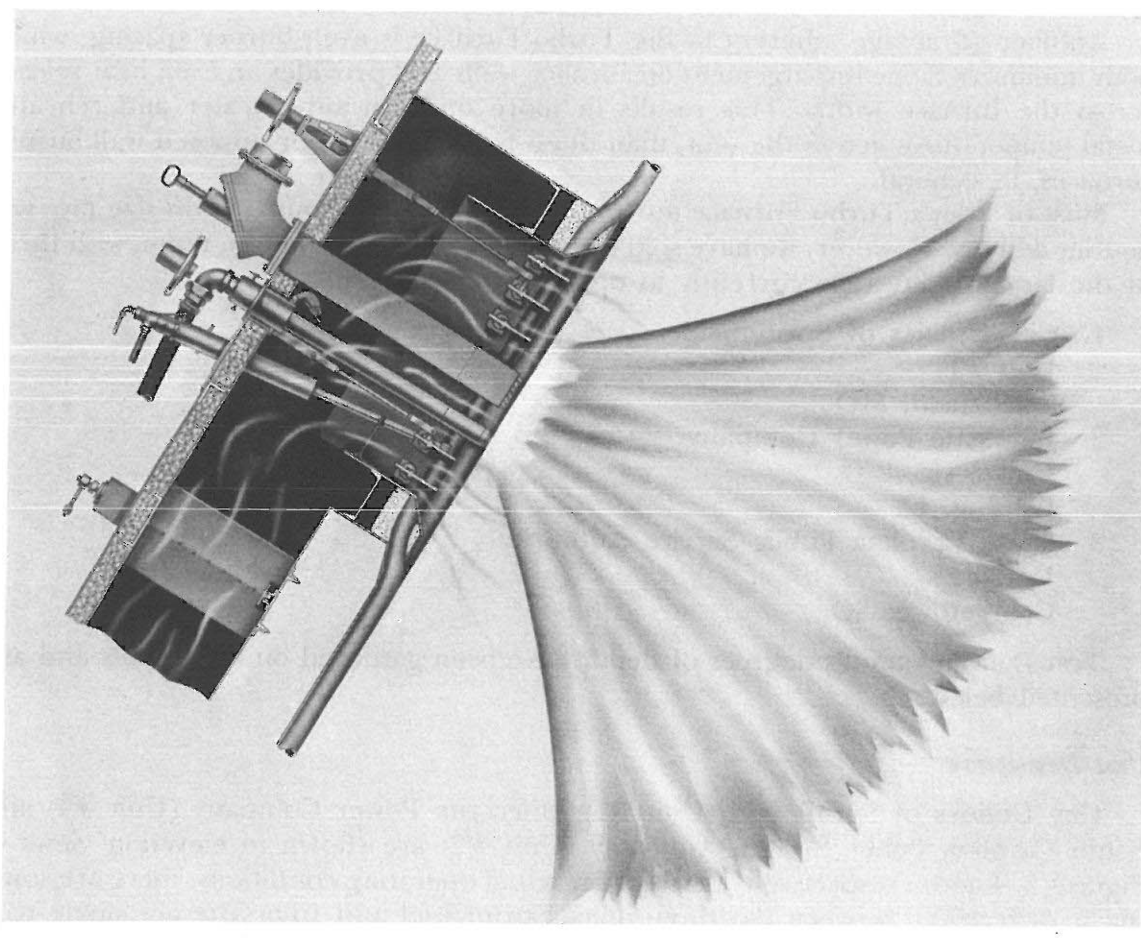

Figure 2 Riley Directional Flame Burner

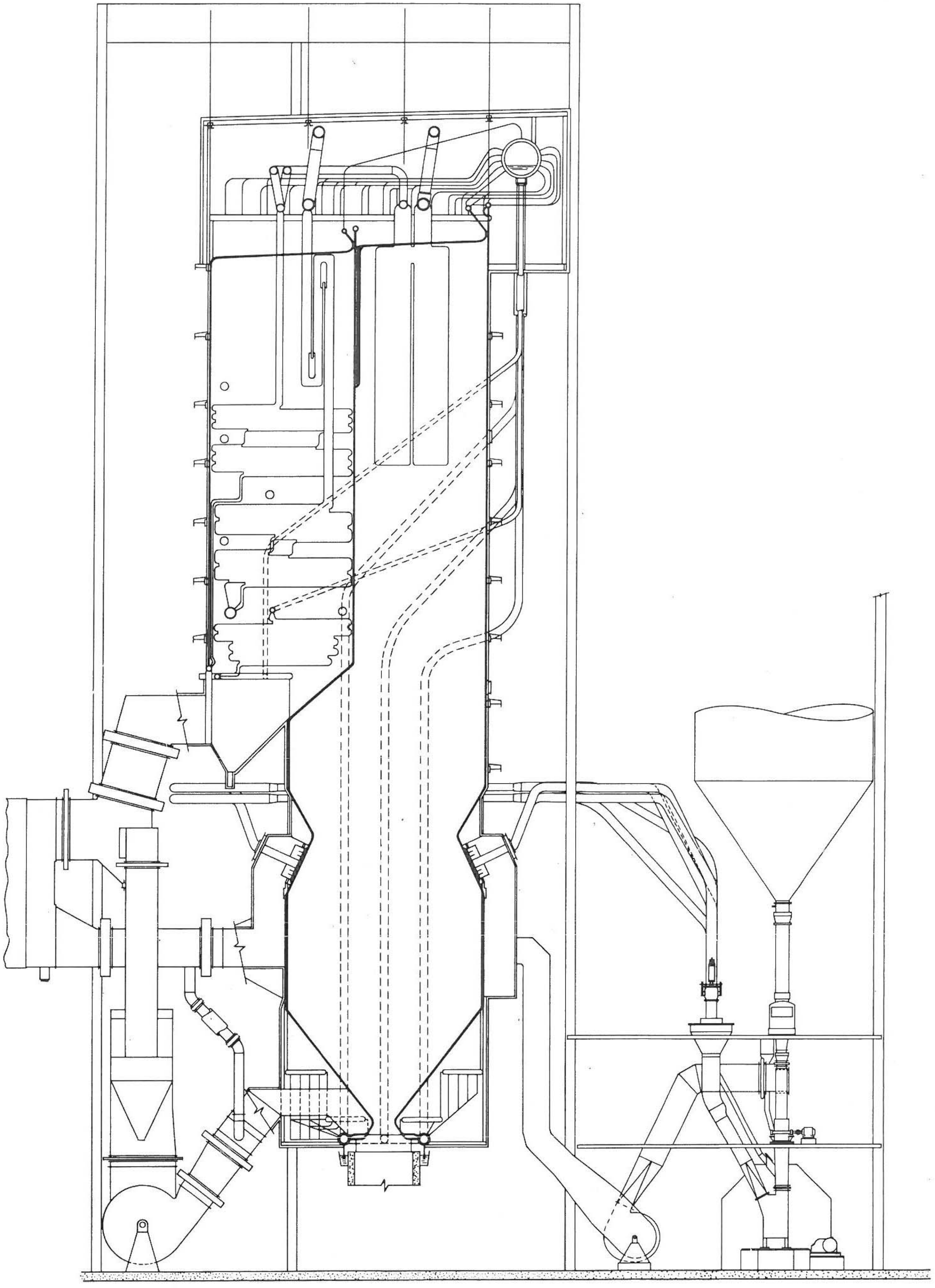

Figure 3 City Utilities of Springfield, Southwest Power Station, Springfield, Missouri

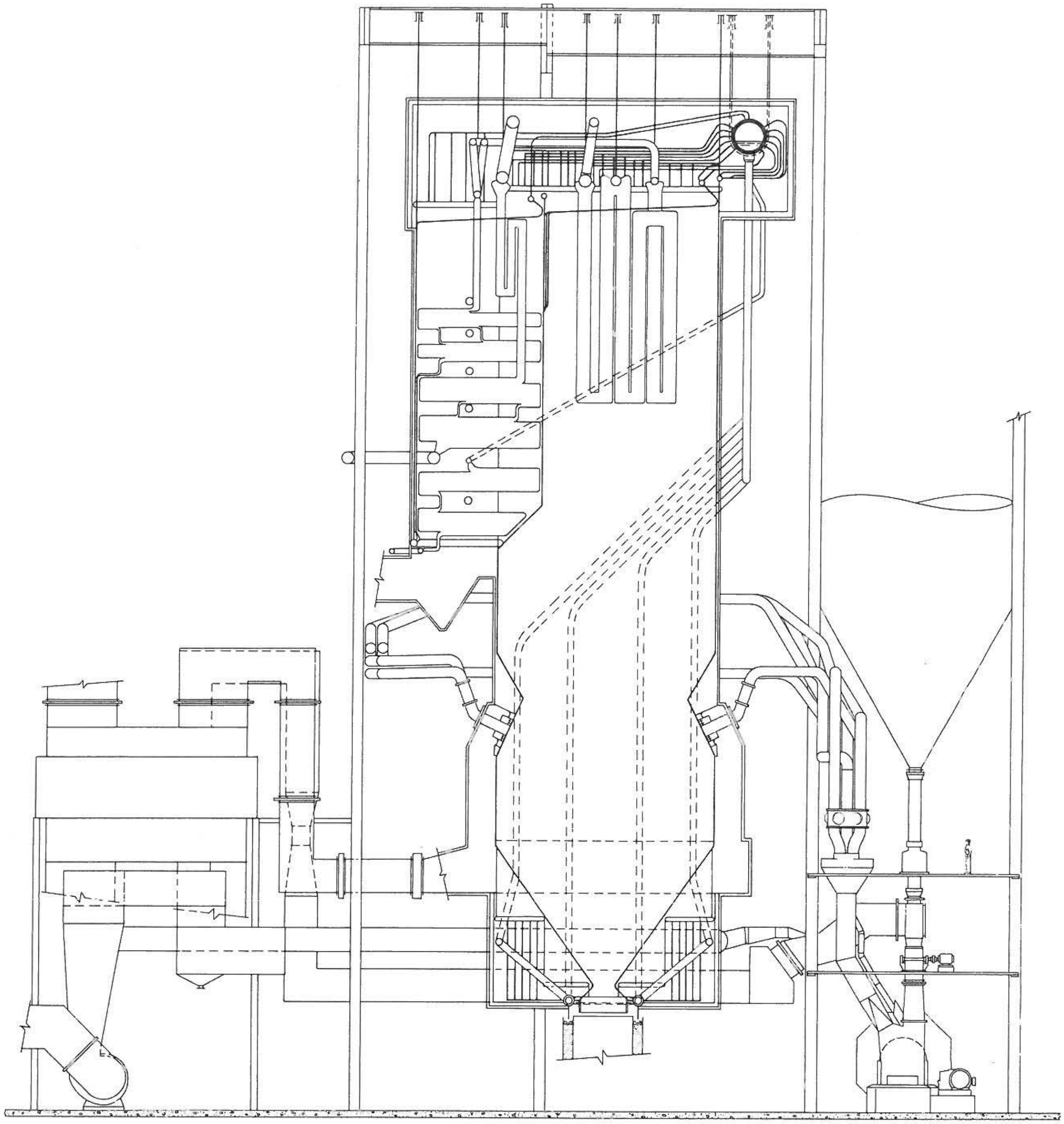

Figure 4 Interstate Power Company, Lansing Power Station, Lansing, Iowa

dampers in each pass capable of biasing or directing gas flow to either the superheater or reheater section for control of final steam temperature.

All three units fire coal only; Springfield and South Carolina a bituminous type, while Interstate uses Western sub-bituminous.

The table below gives more specific size and design parameter comparisons for each unit.

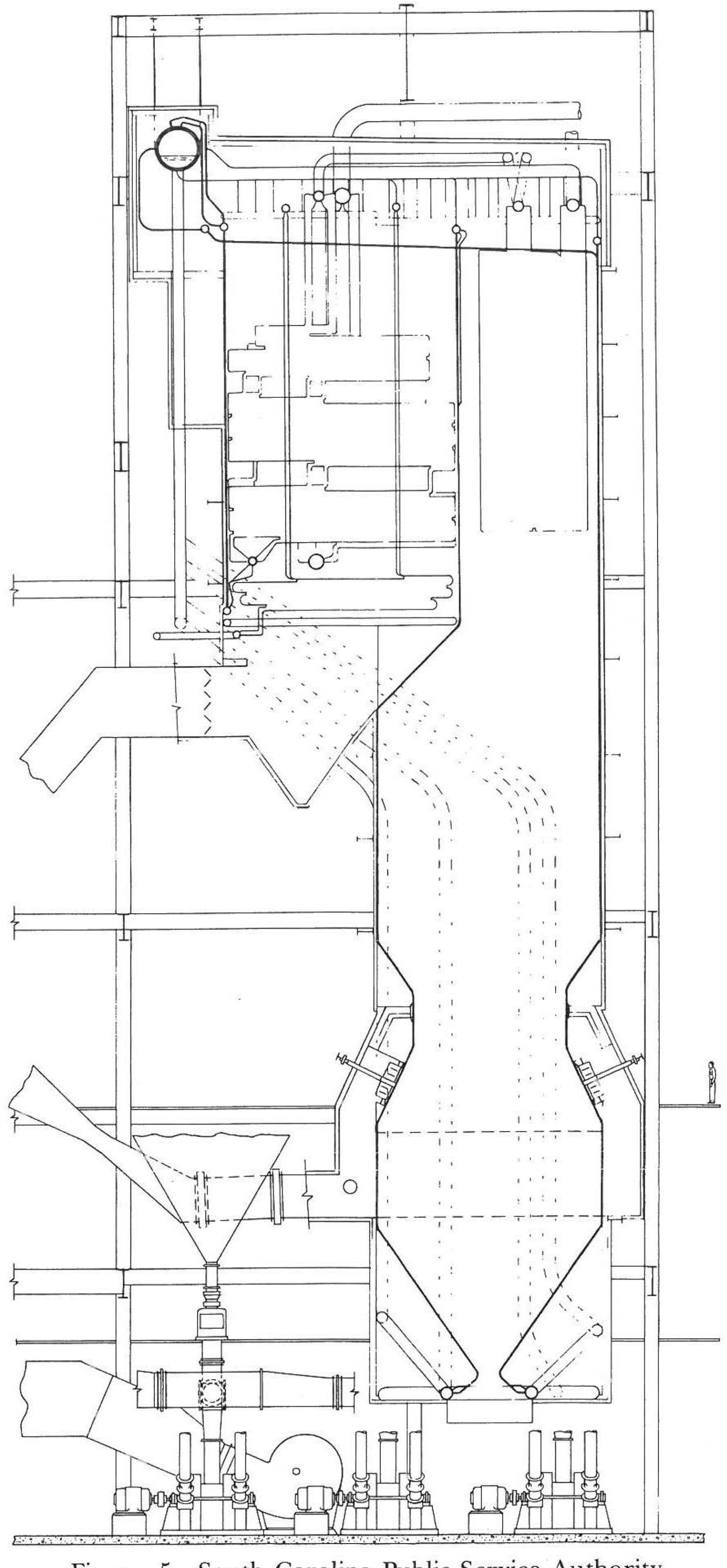

Figure 5 South Carolina Public Service Authority
Georgetown Steam Electric Station, Unit No. 2
Georgetown, South Carolina

	DESIGN PERFORMANCE AT MAXIMUM LOAD		
	City Utilities of Springfield	Interstate Power Co.	S.C. Public Serv. Authority
lb. stm./hr.	1,350,000	1,920,000	2,000,000
Operating pressure, psig	2,520	2,620	2,475
Final superheat °F	1,005	1,005	1,005
Final reheat °F	1,005	1,005	1,005
MW	200	290	300

Test Results

As yet, Springfield, Interstate and South Carolina have not been tested either extensively or equally. A comprehensive test program has been partially completed at Springfield and a limited amount of test information is available from both Interstate and South Carolina. We are currently preparing an elaborate test program at Interstate in order to verify preliminary information and establish a basis for refinements in our design standards for the dry bottom Turbo. However, the preliminary data collected to date allows us to discuss the following topics now:

1. NO_x emissions
2. Steam temperature flexibility (effect of directional vane manipulation)
3. Combustion efficiency
4. Slagging tendencies
5. Heat distribution
6. Furnace exit gas temperature (FEGT)

1. *NO_x*

NO_x emissions were measured at the economizer exit for 20 tests at Springfield. The results of the tests were averaged and a plot made in comparison to the unit guarantee values. The overall results show a margin of 18% existing between the 525 ppm guaranteed level and the actual or measured value of 430 ppm at 100% load. (See Figure 6.)

We can further extrapolate that if the testing had been conducted firing the design or guaranteed coal (1.44% nitrogen by weight vs. the 1.5 nitrogen present in the test coal), we would have obtained even lower NO_x emissions. The adjusted curve is identified by the dashed line on Figure 6 and results in a 22% margin, instead of the 18% actually achieved.

Note: Single test NO_x emissions have been measured at South Carolina and Interstate for full load firing. They show South Carolina at 435 ppm and Interstate at 400 ppm.

Based on the tests at Springfield, the Turbo Furnace *does* conform to Federal EPA limits on NO_x emissions. In fact, there appears to be a comfortable working cushion between what the units are now emitting and the maximum level allowed. Should current boilers be asked to conform to lower NO_x emission standards, the inherent Turbo Furnace leeway could be utilized, rather than making costly and or extensive furnace modifications.

2. *Steam Temperature Flexibility*

As previously noted, one of the advantages of the Riley directional flame burner is its ability to change the direction of the combustion air by the manipulation of vane

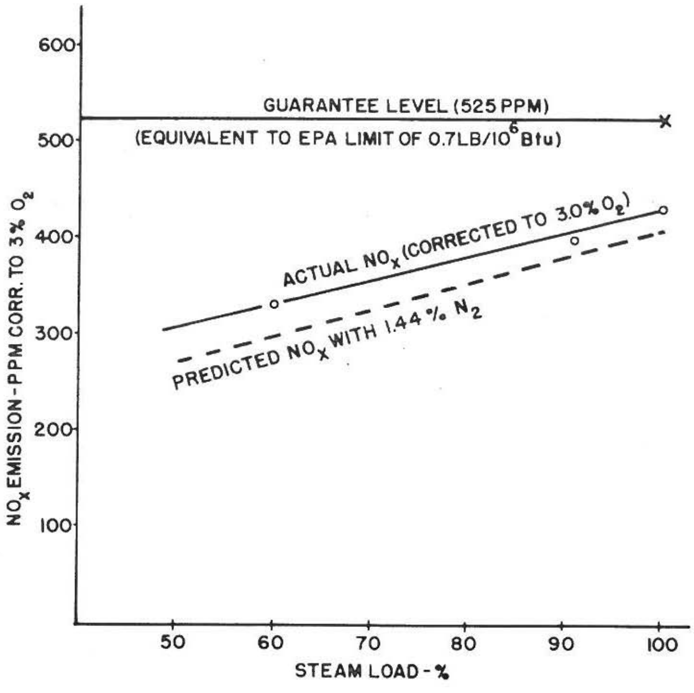

Figure 6 Actual and Guarantee NO_x Emissions vs. Steam Load

type dampers. There are ten separate operational positions, each capable of affecting combustion rate and location. (See Figure 7.) By altering the center of combustion, the rate of heat absorbtion in the furnace is increased or decreased, resulting in lower or higher final steam temperatures.

At Springfield, during maximum continuous load testing, it was noted that the final superheat temperature could vary as much as 72°F, and final reheat 58°F, by varying directional vane positions. Only seven of the ten possible directional vane positions were used in Springfield. For comparison purposes the actual temperatures were first "normalized" by taking into account differences in excess air, gas recirculation, elimination of desuperheater spray, etc., among the various tests. Figure 8 shows the overall effect on reheat and superheat "normalized" temperatures at the seven vane positions tested.

From the above, we can conclude that during periods of temporary changes in fuel, or even permanent switchovers, the directional vanes provide the flexibility necessary to offset changes in furnace performance without major costly furnace modifications.

3. *Combustion Efficiency*

Combustion efficiency is the ratio of combustibles actually burnt to the amount originally present in the raw fuel. The amount of combustible unburnt, or carbon loss, can be determined by the percentage of carbon present with flyash in the precipitator, economizer and furnace ash hoppers.

Poor combustion efficiency can be caused by any number of factors. Some of the more noteworthy that we have come upon during our various tests are: unbalanced combustion air flow, broken or missing burner parts, poor mixing of fuel and air, or even less than design total air quantity available. In these cases the carbon percentage in the ashpit, CO readings in the furnace bottom, and precipitator carbon ash content will be higher than would normally be expected.

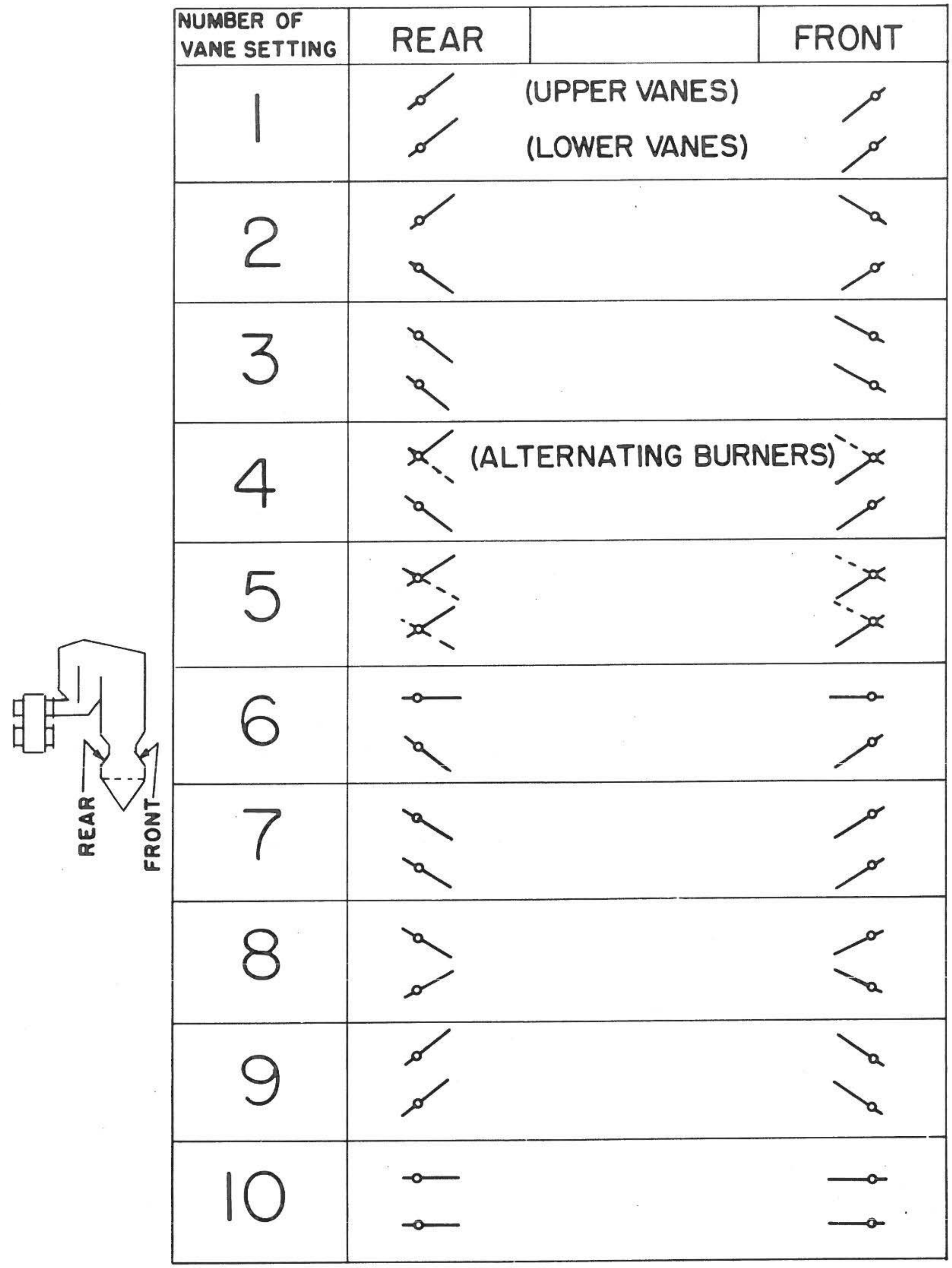

Figure 7 Burner Vane Settings

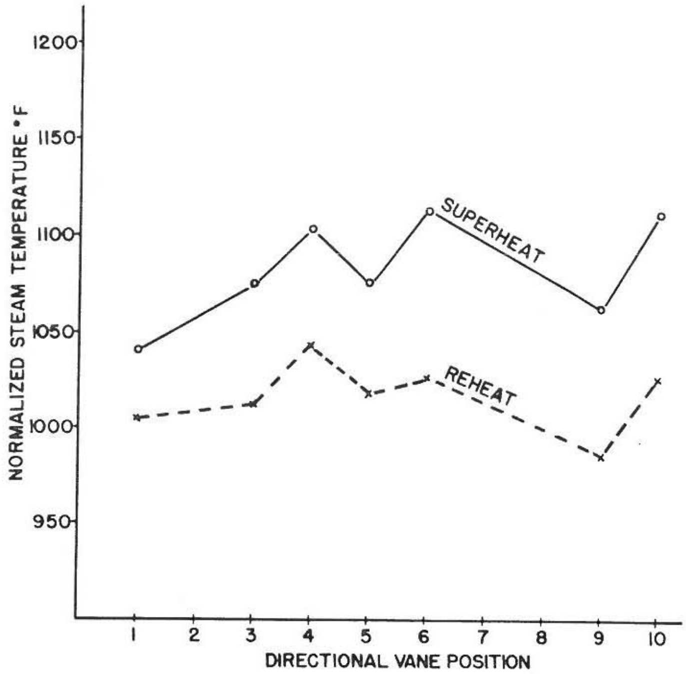

Figure 8 Effect on Final Steam Temperature of Directional Vane Position at 100% Load

The two dry bottom Turbo Furnaces we have tested to date show a very high degree of combustion efficiency. Our most recent sampling shows the following results:

	% CARBON OR COMBUSTIBLE IN FLYASH	
	Furnace Ash Pit	Precipitator Hoppers
Interstate	9.5	0.4
Springfield	1.7	3.4

The low carbon consistency in the furnace ash pit at Springfield may be attributed to the introduction of gas recirculation through the furnace hopper, thus maintaining the ash particles in suspension for a longer period of time, resulting in more complete combustion.

The effect on overall boiler efficiency can be calculated once the percentage of carbon in the ash pit is known. The net loss in overall boiler efficiency from our test measurements were:

Springfield	0.4%
Interstate	0.43%

From these results we conclude that combustion efficiency in the Turbo Furnace is *at least* equal to the conventional dry bottom furnaces, and preliminary investigations indicate better combustion efficiency is possible with the Turbo Furnace.

4. *Slagging Tendencies*

The following analyses are typical of the various coals being fired at Springfield, Interstate and South Carolina.

COAL ANALYSIS

	Springfield	Interstate	South Carolina
% C	66.80	47.81	66.32
% H	4.67	3.43	4.62
% N	1.40	1.05	1.41
% O	4.01	11.13	7.07
% S	3.54	0.42	2.07
% Ash	12.88	6.16	12.71
% Moist	6.7	30.0	5.8
HHV Btu/lb	12,064	8,253	11,832
Ash fusion temp. (I.D.-oxy)	2,180	2,120	2,550
Slagging Index	High/Severe	High/Severe	Low

The heat releases designed into these units reflect the slagging potential of the various coal types. None of the three units experienced more than an insignificant amount of dry ash accumulations, and there was no evidence of running slag in any one of the three.

Both Interstate Power and City Utilities of Springfield experienced some ash deposits which never reached a thickness of more than two inches. These deposits were self-limiting in both cases and were easily removed with wall blowers or steam load changes. In both cases the radiant superheater experienced some vertical buildup which was easily removed with soot blowers.

South Carolina's furnace remains completely clear of deposits. In fact, most oil fired units exhibit more furnace fouling than does this coal fired installation. The radiant superheater does accumulate 1-2 inches of ash deposits on the leading outer loop tubes. This buildup, which is only on some pendents, usually remains about 1-2 hours before shedding itself.

In most cases, Turbo Furnace walls will be free of slag/ash deposits. Where deposits do occur, they will be dry and self-limiting, shedding themselves during normal operation of the boiler.

5. *Heat Distribution*

In order to determine tube metal temperature profiles, thermocouples were attached to selected outlet superheater and reheater tubes across the width of the unit.

On all three units the temperature profiles or patterns were very similar. A typical data run, at 100% load, for City Utilities of Springfield is plotted in Figure 9. The plot shows the high temperature superheat outlet tube profile (the hottest and coldest tubes in pendents), the low temperature superheater outlet tube profile, and the high temperature reheater outlet tube temperature pattern.

The flat profiles are indicative of a uniform heat distribution across the unit width.

Because of the uniform lateral distribution of fuel and air into the Turbo Furnace, gas temperatures and flows entering superheater, reheater and economizer heating surfaces produce very level and balanced tubemetal temperature patterns. This will result in longer trouble-free life of the tubing material.

6. *Furnace Exit Gas Temperature (FEGT)*

Units #1 and #2 at South Carolina Public Service Authority, Georgetown Station, have nearly identical furnace areas. Unit #1 is a rear fired unit, while Unit #2 is a dry bottom Turbo.

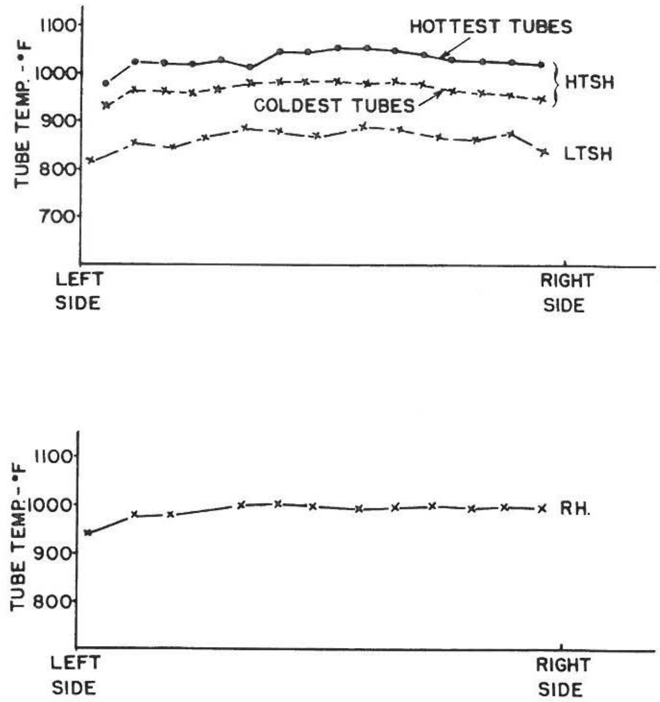

Figure 9 Tube Metal Temperature Profile—High Temperature Superheater, Low Temperature Superheater and Reheater

A comparison of furnace absorption rates between the two shows the furnace efficiency of the Turbo to be 3-4% higher than the rear fired unit.

Since furnace efficiency determines furnace exit gas temperature, the higher the efficiency the greater the heat absorption rate, thus the lower the furnace exit gas temperature for a given heat release. Figure 10 is a plot of FEGT vs. heat release.

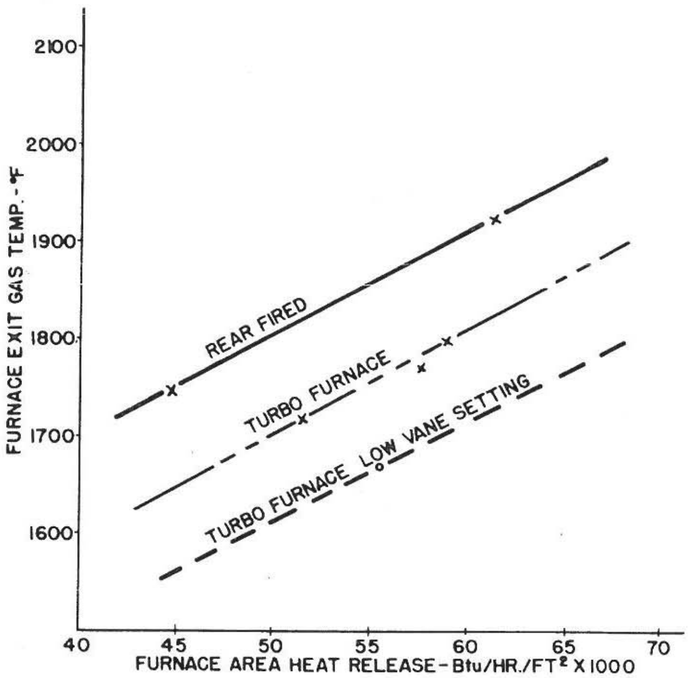

Figure 10 Furnace Exit Gas Temperature vs. Heat Release
Rear Fired Furnace vs. Turbo Furnace

Note that the Turbo has a FEGT 100-200°F lower than the rear fired unit depending upon the directional vane setting.

This means that smaller, less costly installations of the Turbo Furnace design, will have equal performance to units 10-15% larger in furnace size.

Summary

Although most of the data collected and results made to date have been obtained from the wet bottom Turbo, we are continuing to test the three dry bottom units currently in operation, and will be testing still more units as they are installed. However, from the data collected to date we have been able to confirm or conclude the following:

1. Present Turbo Furnaces can conform to lower NO_x emission standards without costly modification.
2. The directional flame burner allows flexibility in operation *if* significant fuel changes occur.
3. Turbo furnace combustion efficiency is *at least* equal to that of dry bottom furnaces.
4. Furnace slag deposits will be, on the whole, dry and self-limiting.
5. The balanced tube metal temperature patterns demonstrated in the Turbo furnace will give longer tube life.
6. The low furnace exit gas temperature in Turbo Furnaces will enable smaller units to perform as efficiently as units larger in overall furnace size.