THE GLASS INDUSTRY

A Method for Improving Regenerative Furnace Efficiency

A Method for Improving Regenerative Furnace Efficiency

By R.J. NAVEAUX and J.J. SHEA
Toledo Engineering Co., Inc.
Toledo, Ohio

This report on an effective system of combustion control and heat recovery was presented at the 42nd Annual Conference on Glass Problems held at the Univ. of Illinois

THE regenerative furnace was first invented by Robert Stirling in 1816 and was applied to glass melting by Fredrick Siemens. When we compare the details of the original invention with the furnace design practices of today, we must conclude that little change has been made in the original concept.

It has been only since the late 1960s, when fuel costs started to climb, that efficiency became a priority concern. Then, with the oil embargo in the 1970s and the resulting energy crisis in the United States, intensive efforts were made to improve the efficiency of regenerative furnaces.

This paper will focus on an economic improvement that can be adapted to existing furnace installations or incorporated into new furnaces. We will concentrate on large side port-type furnaces since all of our studies to date have been centered around them.

The Basic Regenerative Furnace

Fig. 1 shows a plan-view of a typical regenerative furnace. The flue connection is on the end of each regenerator, and both the waste gas and the combustion air pass through this connection. These regenerators come in many different sizes and shapes, but all of them have as their main function the preheating of the combustion air to save fuel. They do this by transferring the heat in the exiting waste gas to refractory bricks stacked in a checkerboard fashion inside each regenerator. The bricks, in turn, give up their heat to the incoming combustion air on about a 15-minute reversing cycle. This process goes on night and day, every day, for 5, 6, or 7 years, and even up to 10 or 12 years.

Most regenerators could stand improvement, especially from an efficiency point of view. It wasn't until recently that many segments of the glass industry in the United States addressed the fuel shortages and rising fuel prices and concentrated on fuel economy in their melting operations. We became "fuel economy conscious" very quickly as fuel costs started to escalate, and we can be assured that fuel costs will continue the upward trend. Some forecasters say that natural gas could go to $12 per thousand cubic feet by the year 1990.

Fig. 1 Conventional Regenerative Furnace (PLAN)

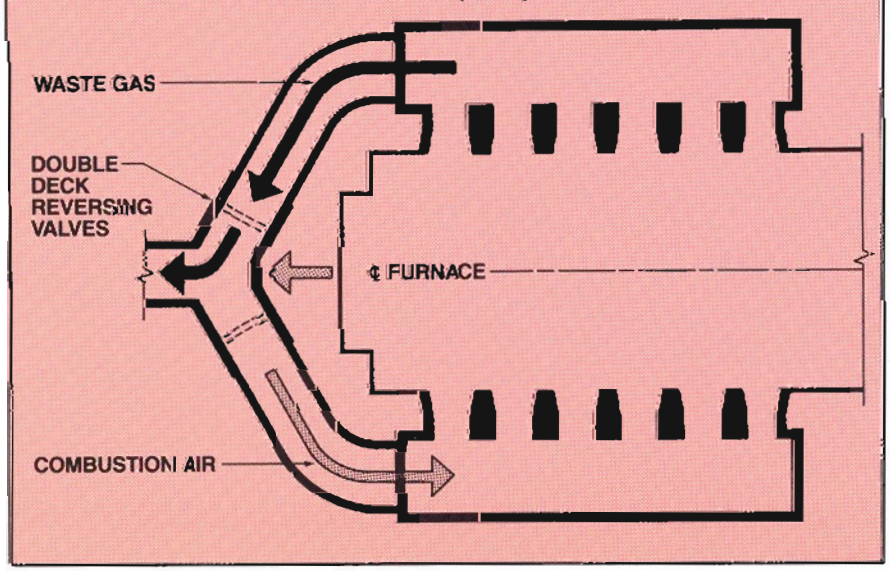
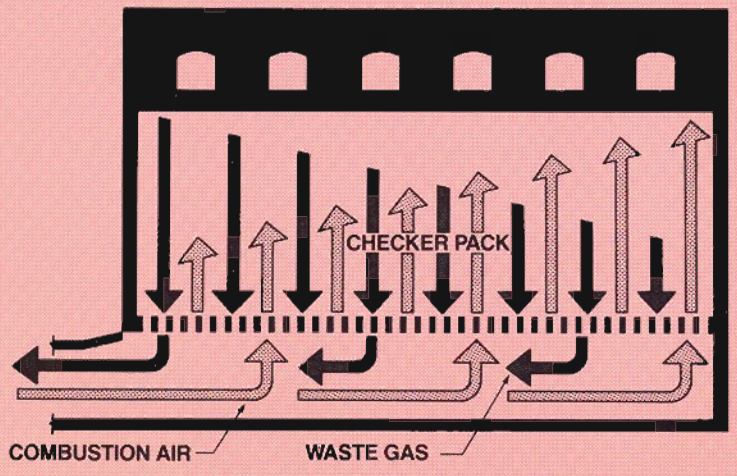


Fig. 2

Conventional Regenerator

Showing Combustion Air and Waste Gas Flow (ELEVATION)



A most prominent cause of low efficiency and high fuel usage in a regenerative furnace is related to the uneven distribution of both the hot waste gas and the combustion air across and through the checker pack, thereby not utilizing all the checkers uniformly. This creates overheating of some checkers and underheating of others. The furnace is forced to operate at higher levels of excess oxygen in order to get the air required to the proper ports for efficient combustion. The element in the system that creates these poor efficiency conditions is the flue connection at the end of each regenerator. This fact can be explained by the fluid dynamics of the exiting waste gas and entering combustion air movements through these end connections.

Fig. 2 shows, in elevation, the extreme lack of gas flow symmetry that exists in this type of system and clearly indicates that the waste gas tends to favor the flue connection as it is being pulled by the furnace draft system to the flue. This causes overheating of checkers on the flue end and underheating of checkers on the opposite end. Then, when the system is reversed, the cold combustion air rushes in through the end connection and the air, because of its momentum, tends to favor the end opposite the flue, making it difficult to get the air needed for good combustion at all ports.

In addition to contributing to low energy efficiency, these conditions have been known to shorten campaign life by overheating some rider arches, causing them to collapse.

Various schemes have been tried to create uniform gas flow through the checkers; e.g., sloping the floor under the rider arches and varying the flue size within the checker pack down the length of the regenerator. Other schemes have been tried with varying degrees of success. In most cases, the improvement favored either the waste gas or the combustion air distribution and rarely satisfied both flow conditions.

At some point in time, the compart-

Fig. 3

Compartmented Regenerators

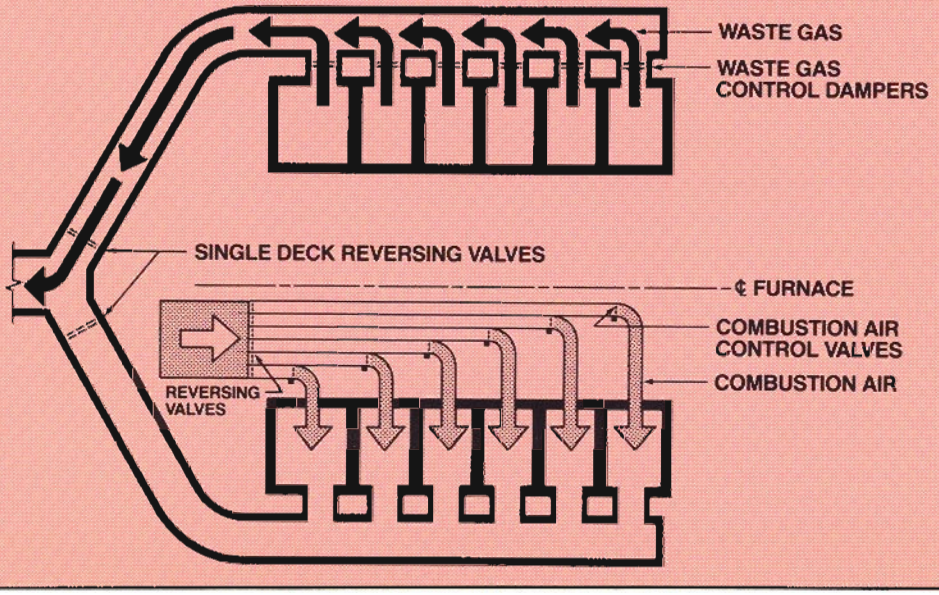
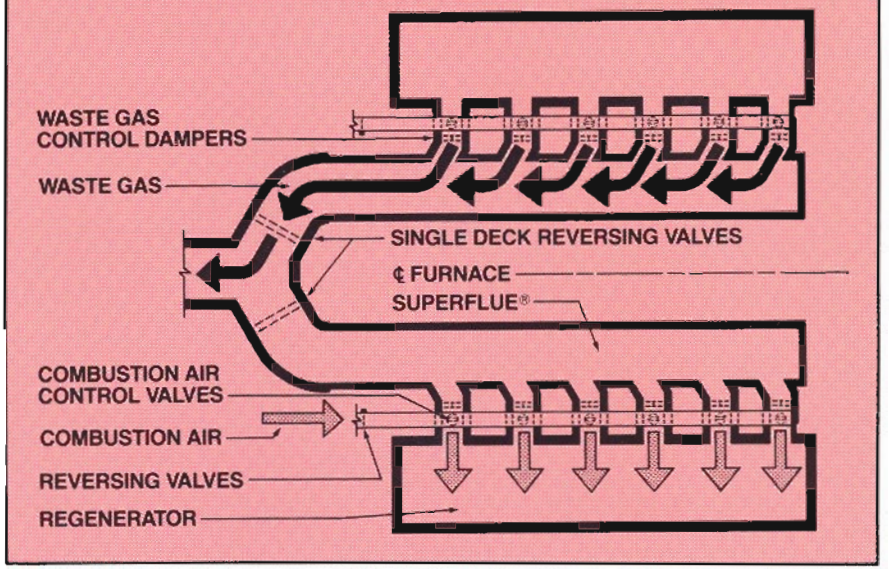


Fig. 4 The Superflue®



mented regenerator scheme of individual chambers within the checker pack was devised. Each regenerator is divided into separate chambers at each port. Fig. 3 shows a plan-view of this type regenerative system. In this design, the waste gas and the combustion air leave and enter the regenerator through side connections. This type regenerator design has been more prevalent in Europe than in the United States. This can probably be attributed to the fact that the Europeans encountered high fuel cost problems long before the 1973 embargo. Also, this type design may have been developed to enable a section of the checkers to be replaced "on the run" when a checker plugging problem occurred.

The compartmented design solved the distribution problem as long as the furnace was fired close to the design fuel gradient, but it created other problems. First, it is more expensive to build than a conventional regenerator. Second, if a compartment becomes plugged, that compartment and port are out of commission until the plugging problem is corrected. Third, if one looks closely at the division walls, it can be seen that these walls occupy valuable space that could contain additional checkers which would add about 10% to 15% to the heat transfer surface. This added checker surface could provide an increase of about 50°F to 75°F to the air preheat temperature. Fourth, the amount of the regenerator that serves each port is fixed by the original design, and it is not uncommon to fire a furnace with a different fuel input gradient than originally planned; this results in an inefficient operation. However, while this design solved the fuel/air ratio distribution problem by totally controlling the air and fuel to each port, it added greatly to the initial cost and to the costs of equipment and instrumentation and of upkeep.

To summarize, most regenerative furnaces of the end connection variety can stand some improvement in efficiency. If existing furnaces are to be improved or new ones are to be built, they should probably be provided with an improved regenerative system or the regenerators should be compartmented. However, the compartmented-type regenerator is relatively expensive and has need for improvement; therefore, it is only natural that an effort be made to come up with something new.

The SUPERFLUE System

Design Features—This brings us to the SUPERFLUE system, which is a patented[1] scheme for improving regenerative furnace performance. Fig. 4 shows a plan view of this type system. The waste gas exits the regenerator chamber and the combustion air enters the regenerator chamber through side connections in a similar manner as in the compartmented design, but without division walls to separate the gases at each port. Each side connection has its own manually controlled damper, and by positioning these dampers, even distribution of both the exiting waste gas and the incoming combustion air can be achieved. An important advantage of this scheme is that once the individual dampers are adjusted, it is not

(1) U.S. Patent No. 4,174,948 — "Manifold Inputs and Outputs for Furnace Regenerators," by R.O. Bradley, H.J. Knighton and R.J. Naveaux, Nov. 20, 1979, assignor to Toledo Engineering Co., Inc.

Fig. 5 Superflue® Feasibility Requirements

- % Fuel Per Port
- % Combustibles/O_2 Per Port
- Temperature At Rider Arches Per Port
- Total Fuel Per Hour
- Pull Rate (TPD)
- Regenerator Length And Width
- Height Of Checker Pack
- Checker Flue Size And Setting

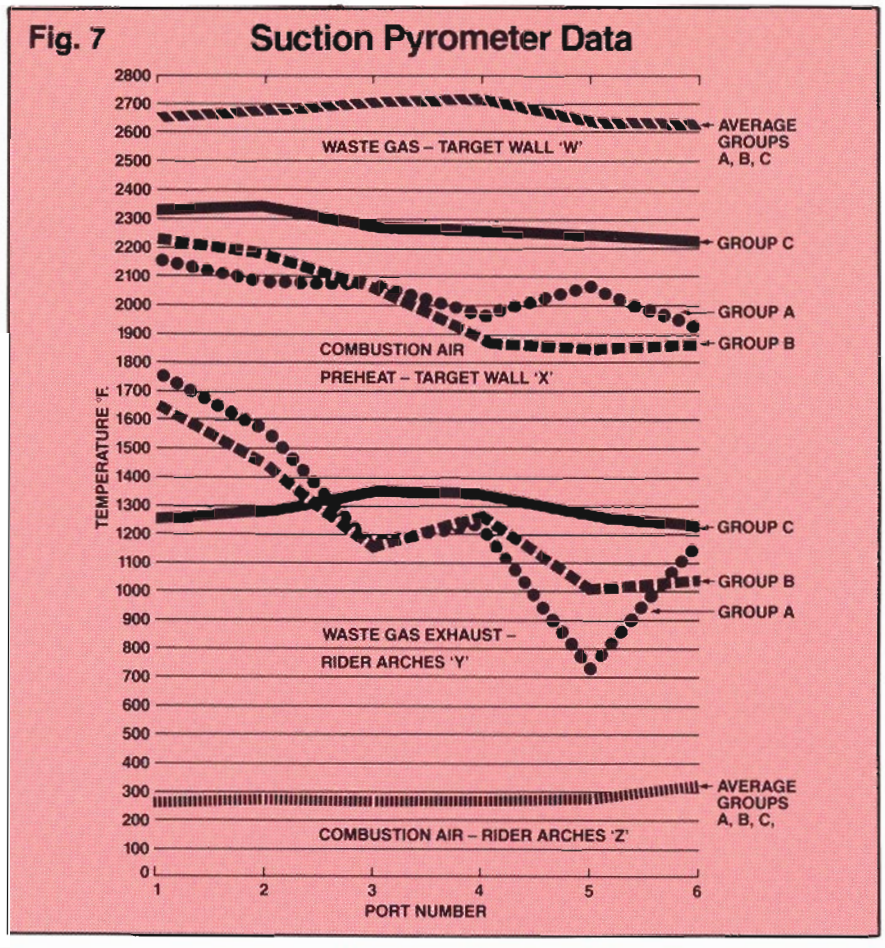
necessary for them to be moved until major changes in pull rate, firing distribution, etc., are encountered.

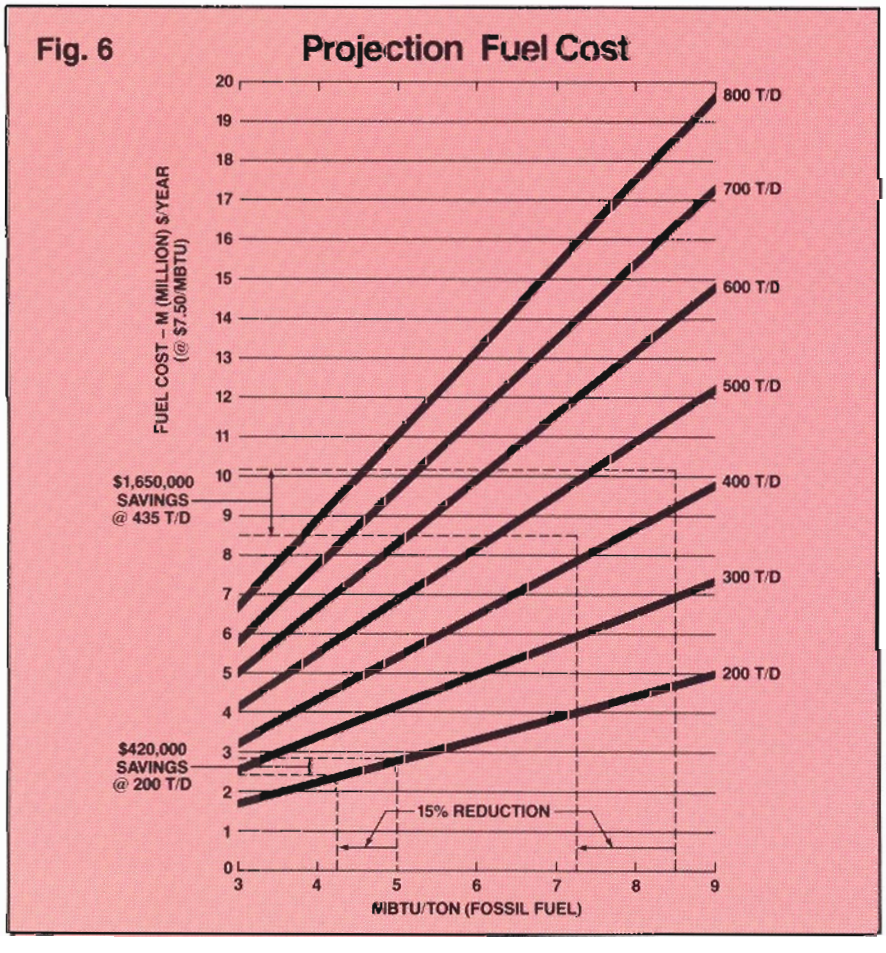
Another important advantage of this scheme is that each damper, both combustion air and waste gas, is, in effect, a "one way" damper. The combustion air and waste gas settings for firing to the right have absolutely no effect on the operation when firing to the left.

Many believe that it is not possible to significantly bias the amount of combustion air to each port of a box-type regenerator without division walls by controlling the amount of air that enters each connection below the rider arches. However, test data have shown that it can be done very successfully.

The SUPERFLUE system encompasses the total furnace firing and exhaust system. A proper design must take into consideration all facets; e.g., port design and shape, burner arrangement, combustion space, checkers and air preheat temperature, temperature losses, pressure losses, etc.

When this sytem is incorporated into a furnace design, the conditions that may have been considered as somewhat typical will change. Air preheats of 2300 °F and 2400 °F and above can be achieved and should be considered in the design.





The increased utilization of the heat transfer surface brought about by proper positioning of the dampers makes it possible to add additional checkers to attain these high preheat temperatures. There have been instances where the No. 6 port in a six-port furnace was blocked off and full utilization of the checker pack was still obtained. These higher preheat temperatures, along with the proper burner/port geometry, have resulted in natural gas flames that develop full luminosity.

Port sizing relationships, although very important, are not as critical in a SUPERFLUE system. This system can force the air and waste gas to achieve full utilization of the regenerators over a range of fuel input gradients. A conventional regenerator must depend on port size alone and, therefore, cannot accomplish this. A compartmented regenerator is restricted by the size of the compartment and, therefore, can accomplish this for only a limited firing range.

Operating Economics—A computer program that allows us to make a quick analysis of the improvements that could be expected with this system has been developed. The data required to make this analysis is shown in Fig. 5.

Capital costs and operating costs are always key considerations in any fur-

Furnace Efficiency

nace design. When this system is installed in an existing furnace, capital costs will vary considerably depending upon existing conditions. Of course, on a new furnace, only the premium capital costs need be considered. In most cases, the additional capital cost can be justified by the resulting reduction in operating costs. To get an idea of the cost savings potential, an increase in air preheat of 100°F represents a fuel saving of about 5%, and a decrease of 1% excess oxygen on a mass average basis represents a fuel saving of about 2%.

Fig. 6 shows the magnitude of the cost savings available. If a container furnace operating at 5 mill BTU/ton when melting 200 ton/day could be improved to operate at 4.25 mill BTU/ton, a savings of about $420,000 per year could be realized. Similarly, if a float furnace operating at 8.5 mill BTU/ton when melting 450 ton/day could be improved to operate at 7.25 mill BTU/ton, a savings of $1,650,000 per year is possible. To develop these figures, we used a gas cost of $7.50 per thousand cubic feet, which could be the average fuel cost for the next campaign.

Actual installation of the SUPERFLUE system on an existing furnace has resulted in a savings of about 12%. On new installations, where checker depth and length can be increased, it has been possible to reduce fuel consumption by about 17%. Savings like these must be given due consideration.

Operating Data—Six SUPERFLUE systems have been installed between 1977 and 1981. Each system has been a little different due to existing conditions, method of firing, tonnage pulled, size of furnace, and size of checker pack.

Fig. 7 shows a series of curves representing the data that has been taken on the furnaces with and without SUPERFLUE systems. We have divided the furnaces studied into three groups to represent the data more accurately. Temperature readings were taken with a modified Land SU4 Suction Pyrometer to obtain temperature readings that were not affected by radiation from surrounding surfaces.

Group A shows the conventional end flue-type regenerators with single span rider arches. Group B shows the conventional end flue-type regenerators with open center walls below the double rider arches. Group C shows the SUPERFLUE system, two of which are new and

Fig. 8

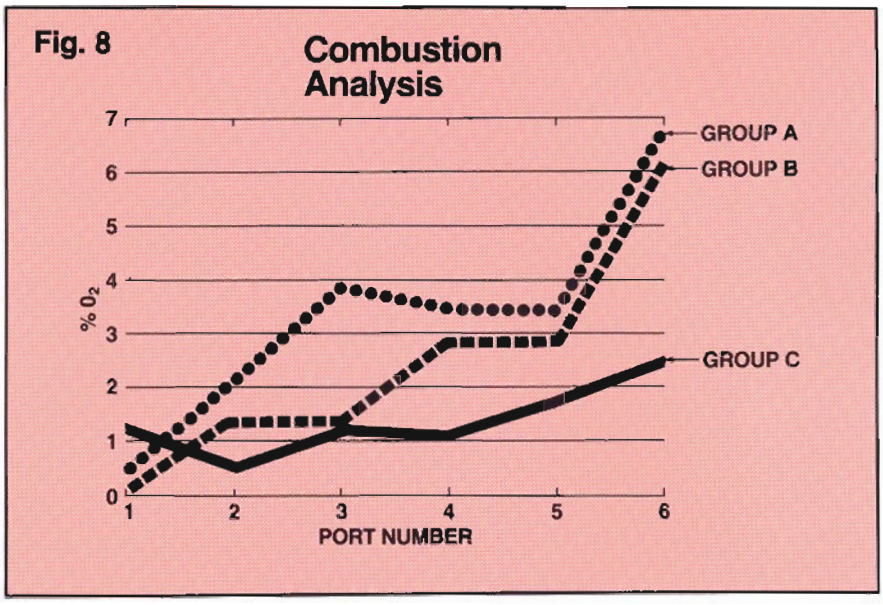


Fig. 9

Performance Analysis Data

	PORT	% CHECKER PACK UTILIZED	CALCULATED % WASTE GAS	CALCULATED % COMBUSTION AIR
GROUP A	1	20.1	23.2	15.4
	2	21.5	22.8	18.2
	3	13.1	13.0	14.3
	4	20.4	19.4	22.9
	5	21.0	17.7	25.0
	6	3.4	3.9	4.4
GROUP B	1	20.5	21.9	17.1
	2	19.9	21.1	17.8
	3	18.6	17.8	18.0
	4	17.7	17.5	19.0
	5	15.8	14.3	18.1
	6	7.5	7.4	10.0
GROUP C SUPERFLUE®	1	20.4	19.8	19.0
	2	21.8	20.5	21.5
	3	14.6	15.1	14.7
	4	20.9	21.5	21.8
	5	20.4	21.0	21.0
	6	1.9	2.1	2.0

Fig. 12

two are retrofit. All four have single span rider arches.

Unfortunately, we do not have any data on compartmented regenerators that we can publish.

The top curve "W" shows the average waste gas temperatures at the target walls of Groups A, B, and C and is a representation of the temperature of the waste gases as they enter the checker pack.

The "X" group of curves shows the average temperature of the combustion air after it has been preheated by the checkers. Note the increase in temperatures and uniformity of the temperatures in Group C.

Since these are average temperatures, it should be pointed out that systems with more checkers achieve preheat temperatures of about 2400 °F, and with these preheats, optical temperature readings taken at the top of the checkers exceed 2500 °F.

The "Y" group of curves shows the average temperature of the exiting waste gases at the rider arch level after giving up their heat to the checkers. Again note the uniformity of the temperatures in Group C.

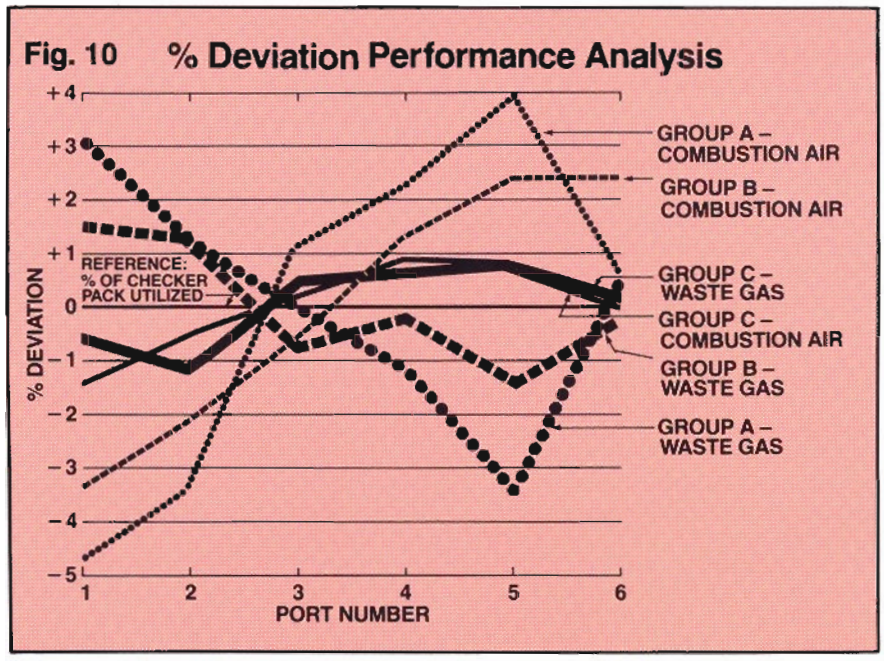
The lower curve "Z" is an average of the incoming combustion air temperature for all groups studied.

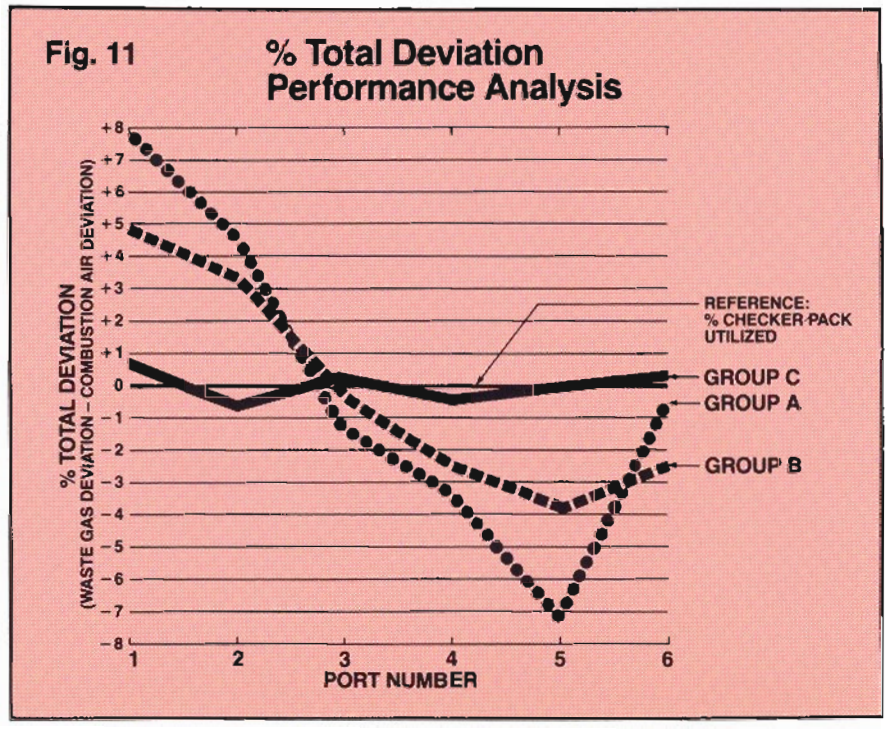
Fig. 8 shows the average percent O_2 (excess oxygen) present in the groups of furnaces studied. Note the flatter profile of Group C.

To enable us to rate regenerators and assist us in determining the best system design, we have developed a method of analyzing the suction pyrometer data. Fig. 9 shows, in tabular form, the results of this analysis for the furnaces studied. These numbers are only a calculated representation of what really occurs in a regenerator, but they can be used to show the imbalance present and to compare or rate the systems.

The column titled "Checker Pack Utilized" is, in reality, the percent of fuel per port and approximates the amount of the regenerator that serves each port. Ideally, to achieve the full benefit of the checkers, the portions of the regenerator used by the waste gas and by the combustion air for each port should be equal to the amount of energy transferred each way.

Think of a regenerator with a SUPERFLUE system as having imaginary division walls that separate the sections of the regenerator served by each port. These imaginary walls have the ability to move in order to obtain the best possible utilization of the checker pack for any given operating conditions. We do not really know





where these imaginary walls are, but we do know that they can be moved with the SUPERFLUE dampers to obtain the best possible utilization of the regenerator.

The column in Fig. 9 titled "Calculated Waste Gas" shows the theoretical portion of the waste gas that is handled by the portion of the regenerator being utilized. A similar condition pertains to the "Calculated Combustion Air" column and the combustion air. A number higher than the "Checker Pack Utilized" indicates an overloaded condition, while a number lower indicates an underloaded condition. For example, Group A-Port No. 1 indicates that 23.2% of the total waste gas is using 20.1% of the regenerator and, correspondingly, 15.4% of the total combustion air is using 20.1% of the regenerator. This represents an overheating condition at port No. 1.

Although these calculations only approximate the actual conditions, they do provide a useful tool for comparing and evaluating systems.

Fig. 10 is a graphic representation of the values listed in Fig. No. 9. Each pair of curves, waste gas and combustion air, has been plotted to show the deviation from the "Checker Pack Utilized" values.

Fig. 11 is another graphic representation of these same values. In this chart, we plotted the total deviation between the calculated waste gas and combustion air. Note the uniformity of Group C.

Fig. 12 is a photograph that shows the balanced conditions that exist in SUPERFLUE-type regenerators. This picture was taken under the rider arches of a six-port float glass furnace where No. 6 port is blocked off. The purpose of presenting this picture is to demonstrate the uniformity of color (temperature). Those who are familiar with this size of regenerator are used to seeing changes in color (yellow to black) from end to end, and this picture shows what this system can do. Smaller regenerators usually do not show such extreme color difference, but even a temperature difference of only 300°F indicates a distribution problem that could be improved.

Conclusion

In conclusion, the SUPERFLUE system has made significant efficiency improvements to large capacity, side port, regenerative furnaces. Experience with the installations to date indicate that approximately a 17% fuel reduction has been achieved, and we hope to improve upon this on future installations. It has also provided other operational benefits, such as uniform rider arch temperatures, thus reducing the possibility of failure due to overheating. In addition to saving fuel, furnaces with these systems have provided improved glass quality and a better percent pack brought about by the more even and constant operation.

As fuel prices continue to increase, the SUPERFLUE system should prove beneficial to medium-sized side port regenerative furnaces and should even prove beneficial to end port furnaces. We hope to report on this aspect as well as provide an update on results from subsequent system installations in Part II, which will be presented in a future paper.

(Editor's Note: This article is based on a paper presented by Mr. Naveaux at the 42nd Annual Conference on Glass Problems held Nov. 10-11, 1981, at the University of Illinois, Champaign-Urbana.)

Reprinted from
THE GLASS INDUSTRY
February, 1982