Recuperation And Insulation In Glassmaking
An Overview

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Glass is expensive. The major expense involved is the continual and everlasting gas bill. How many of us at one time or another have been confronted with the specter of being shut down because of astronomical fuel costs and rapidly rising fuel prices?

For most small shops and university glass programs it is the largest single expense, and the most volatile. In the last ten years we have seen prices multiply by factors ranging from three to ten, depending on demographics.

What can be done about it? Raise the prices? There is a limit to that, and schools do not have the option. Shut down more often? This is counterproductive.

The solution is to find a way to use less fuel while maintaining the quality and quantity of the glass that is produced.

The rapid increase in fuel costs has not been matched by a rise in consciousness in ways to counteract the increase. Furnace building techniques are not generally stressed in schools. The typical response from working shops is to continue to use the furnace designs that have produced dependably in the past.

The problem demands a new awareness of and attitude toward the economics of glassmaking. The low esteem in which technical knowledge is held must be reversed. For many it is quite simply a matter of survival in glass.

The Furnace. This is the heart of any glass operation. First and foremost, the furnace must make quality glass. Secondly, it must be durable.

These have been the main considerations for years, and must remain so. Now we must learn to do it less expensively.

What are the essential characteristics of a glassmelting furnace? The furnace is basically a box with a burner going in and a flue going out. The purpose of the box is to contain the heat of the combustion gasses long enough to bring the furnace load to a desired temperature. The hot gasses then escape through the flue. The goal should be to maximize the use of the heat generated by the burner.

We know how the heat gets into the furnace. How does it get out?

There are only two ways it gets out. The first is by passing through the walls of the furnace to the outside. The second is by leaving with the exhaust gasses through the flue or other openings in the furnace. Let's first consider departure through the walls.

For years standard design generally has consisted of one course of hardbrick for the furnace liner backed up by a course of softbrick and maybe a layer of ceramic fiber. This is sufficient to contain the heat from the burner long enough to heat the furnace load. This and its close variations work to make good glass, but at what cost?

Consider the nature of insulating materials. Heat passes through a material at a given rate. The slower the rate, the better the insulating quality of that material.

A good way of looking at the relative qualities of insulating materials is to compare them to the insulating qualities of the standard heavy hardbrick. We can assign an arbitrary value to the insulating value of hardbrick. Call it "one." From this standard, we can denote the values of other materials using multiples of one for "equivalent inches of firebrick" (E.I.F.). Each material has an insulating value that can be expressed in terms of equivalent inches of firebrick. Fortunately there are tables for this. Refer to A.P. Green's, <u>Calculating Heat Transfer Through Refractory Walls.</u>

The following is an abbreviated table of the approximate insulating values of a number of different materials expressed in equivalent inches of firebrick.

Material	E.I.F
Heavy Firebrick	1.00
Heavy Castable	1.00
3000° Insulating Castable	2.92
2500° Insulating Castable	2.92
2200° Insulating Castable	4.80
2000° Softbrick	4.30
2600° Softbrick	3.70
2800° Softbrick	3.15
1900° Block Insulation	12.00
1600° Vermiculite Castable	12.00
2400° Ceramic Fiber	12.00

Let's examine the insulating values of the materials in the "standard" furnace mentioned earlier. Multiply the thickness of each material in inches by its E.I.F. then add the products to obtain the total
E.I.F.

Material	Thickness	E.I.F.	Product
One Course Hardbrick	4.5"	1.00	4.50
One Course 2600° Softbrick	4.5	3.60	16.20
	Total E.I.F.		20.70

Using the appropriate tables, we find that 20.7 E.I.F. translates to a heat loss of 840 BTU/Hr/Ft2 at 2400° furnace temperature. Let's add one inch of ceramic fiber:

Material	Thickness	E.I.F.	Product
One Course Hardbrick	4.5"	1.00	4.50
One Course 2600° Softbrick	4.5	3.60	16.20
Ceramic Fiber	1"	12.00	12.00
	Total E.I.F.		32.70

translating to a heat loss of 550 BTU/Hr/Ft^2 at 2400°. A one inch layer of fiber has cut the heat loss through the walls by 34.5%.

My furnaces were designed considering both the durability of the materials and their insulating values. Start with a 3000° hardbrick liner, consisting of splits mortared and stacked on edge. Back that up with two inches of 3000° insulating castable. Finish with seven inches of vermiculite castable.

Material	Thickness	E.I.F.	Product
3000° Splits	2"	1.00	2.00
3000° Insulating Castable	2"	2.92	5.84
Vermiculite Castable	7"	12.00	84.00
	Total E.I.F.		91.84

This translates to a heat loss of 200 BTU/Hr/Ft^2 at 2400°, a heat loss saving of 76% over the original standard construction. Insulation is cheaper than gas.

Preventing excessive loss of heat through the furnace walls is not the only way insulation saves energy. Most of the energy lost from a furnace leaves via the flue. Two thousand degree gasses leaving at the rate of fifteen feet per second carry fifty per cent more heat with them than gasses leaving at ten feet per second. In fact, savings here are much greater than savings through furnace walls. The calculations are rather esoteric, but put four or five inches of fiber around your furnace and watch your gas bill drop.

This brings us to the second way heat exits the furnace: Through the flue.

Consider a furnace set on cruise, holding at 1950°. It is in a state of equilibrium. It is losing heat at exactly the same rate as it is gaining heat. The temperature of the gasses as they enter the flue is 1950°. Depending on the insulation of the furnace, they are leaving at a faster or slower rate. Much of that heat can be recaptured and fed back into the furnace.

First, let's look at the basic characteristics of combustion in a gas burner system. In a pre-mix system gas and air are mixed, usually under pressure, and delivered to a burner where heat is applied to initiate combustion, the breaking of carbon-hydrogen and carbon-carbon bonds and the subsequent creation of carbon-oxygen and hydrogen-oxygen bonds, accompanied by a great release of heat energy. In a word, oxidation takes place.

To be effective, the combustion gasses must enter the furnace at a higher temperature than the interior in order to counteract the heat loss from the furnace. Oxidation of the fuel provides this heat. However, only about twenty per cent of the air being mixed with the gas is oxygen. In terms of combustion, the rest of the air is neutral, adding nothing to the reaction. In fact, it is a detriment, since all that air must be heated by the flame before it enters the furnace.

We could get rid of the air and use only oxygen. That would solve the problem, but would increase the cost drastically.

We could pre-heat the air, taking some of that burden off the oxidation reaction. Fortunately, there is a source of free heat to do the trick. All of that heat going out the flue is perfect for the job. All there is to do is capture it and return it to the furnace.

Running the flue gasses back through the burner does no good. There is no oxygen left in them with which to burn the gas. We need to move only the heat from the flue gasses to the incoming combustion air. For this we need a heat exchanger, or recuperator.

Basically, a recuperator is a device that sits in the chimney of the furnace, through which a blower forces the combustion air. The air picks up heat through the walls of the recuperator and delivers it to the burner.
The flame then delivers a higher percentage of its heat to the furnace and a lower percentage to the "baggage" air. Since more heat is being delivered per BTU of gas used, we can turn down the burner, thus saving gas.

Hot oxygen increases the efficiency of the oxidation process, releasing more heat to the furnace. Turn down the burner again.

Recuperation is a positive feedback system. The better things work, the better they will work. Consider two furnaces, both with recuperators, one more well insulated than the other.

One burner can be set lower than the other because of its additional insulation. Air is traveling more slowly through the recuperator,having more time to gain additional heat to return to the furnace. The flue gasses are moving more slowly also, allowing more heat to pass to the combustion air.

More heat is being returned to the furnace. Turn down the burner. The oxygen is hotter, producing more efficient combustion. Turn it down again. Turning down the burner itself, as a result of these conditions, slows down the passage of the air and exhaust, producing even more efficient heat exchange, more heat back to the furnace, and hotter oxygen. Turn down the burner again. This is positive feedback.

It also works in reverse. The less efficient the system is in the first place, the less efficiently it will work. The inefficiencies are compounded.

There are four major criteria to consider in designing and building a recuperator for a glass melting furnace:

•Durability. The material must be able to withstand extremely high temperatures and corrosive chemical attack dependably.

•Heat transfer qualities. The materials used must allow heat to pass through them quickly.

•Surface area. The more surface area exposed to the heat, the more heat passing to the combustion air.

•Burner characteristics. A nozzle mix burner system is required for use with high temperature air.

A material or combination of materials that satifies the first two criteria is needed. Stainless steel immediatly comes to mind. Metal passes heat readily, and there are grades of stainless that are rated at 2000° or more. While this is good, it still will not survive the extreme heat of a melt.

The exhaust gasses must be cooled somewhat before they reach the stainless steel recuperator. This can be accomplished by introducing cool air into the flue from the outside to dilute the exhaust gasses, or by placing the recuperator high in the stack to avoid the temperatures at the mouth of the flue. Both of these methods waste heat.

Other materials can be used that will withstand the heat of the furnace. Silicon carbide has excellent heat transfer qualities, and will withstand high temperatures and chemical attack. However, it needs to be thicker than stainless in order to maintain its structural integrity, thereby losing some of its heat transfer efficiency.

Both materials work well. Let's make them work better.

A primary recuperator using silicon carbide can be placed at the exhaust port. A secondary unit of stainless steel can then be placed on top of the primary unit. The silicon carbide unit will pass heat to the incoming combustion air thus cooling the exhaust enough for the temperature to fall below the service temperature of the stainless unit. Here we have the best of both worlds in one complete unit, the high heat resistance of silicon carbide, and the superior heat transfer qualities of stainless steel, while losing a minimum of exhaust heat.

Recuperative efficiency is directly related to the surface area through which heat can be exchanged. In general, this area should be maximized. The more surface area per volume of gasses, the greater the efficiency of heat exchange.

In reality, there may be some functional limits to these relationships, and to the physical size that can be accomodated. Consider an array of long pipes set in a matrix of given outside dimensions. A large number of small pipes has more combined surface area than a small number of larger pipes, and would theoretically make a better heat exchanger. A limit arises when the pressure drop over the system exceeds the ability of the air pressure source to deliver sufficient combustion air to the burner. The greater the surface area of the unit, the more friction and resistance to air flow.

If the spaces through which the exhaust gasses pass are too small, they can easily be further constricted by deposits of batch material and carbon on the heat exchanger, greatly reducing efficiency.

Larger pipes can be used to avoid these problems. The loss in surface area can be made up to a great degree by lengthening the pipes as much as possible, thus increasing the total surface area.

The fourth major criterion to be considered is the burner system. Since the combustion temperature of gas is about 1000°, a pre-mix system should not be used with pre-heated air. There is too great a chance of burn-back and explosion. The gas and the air should not meet until they are actually in the burner throat, effectively inside the furnace. This can be accomplished using a nozzle mix burner. Again, material considerations must be made due to the high heat of the combustion air and the higher flame temperatures associated with it. High temperatures alloys are available. Another solution is to use an all ceramic mixer-burner system to avoid the possible deterioration of the metal alloys.

Through using the procedures outlined above, by paying more attention to my furnace settings, and by keeping my furnaces tight I have cut my gas bill in half without sacrificing anything but a hot, noisy studio. The best thing about it for me is knowing I am again in control. The feelings of desperation concerning the gas bill are gone. I can buy a lot of beer with the savings.