A NEW INCENTIVE: PAYBACK COSTS OF ENVIRONMENTAL CONTROL IN THE MELTING SHOP BY ADDING HEAT RECOVERY SYSTEMS

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ABSTRACT

The high cost of fuel and environmental control systems make heat recovery a viable approach to reducing fuel use and costs in foundry melting operations. Although heat recovery systems are relatively new for this application in this country, they have been in use for some time in other countries where their practical use has been demonstrated.

Heat recovery has great potential for all foundry melting operations, but in particular, electric arc, gas-fired,and cupola furnaces. There are a number of arc furnace exhaust hood methods; the hood method most amenable to heat recovery is direct evacuation. Gas temperatures from the products of combustion of gas-fired furnaces are very high and quite stable which is an advantage for heat recovery. Heat recovered from cupolas can be put to a variety of uses including heating the blast air, preheating the afterburner combustion air, and providing a hot air curtain at the charge door. Heat recovery rates and payback analyses are presented for the furnace heat recovery systems described.

HIGH COST OF EMISSION CONTROLS

The control of airborne dust and fume is as important in the melt shop as in any other production area of the foundry. Free silica, metallic oxides including lead, various other particulates and carbon monoxide are present in the melting shop environment in varying degrees of concentration, according to metallurgy and practice. Melting furnaces, holding furnaces, alloying stations, open ladles, and metal troughs are some of the many sources of pollutants that require control devices in order to maintain an acceptable working environment in the melting shop.

The high cost of installing these necessary control devices is making many foundries limit production or make major changes in production methods, in order to reduce the cost of emission control systems. Some foundries that can't afford emission control systems are closing their doors.

JUSTIFICATION FOR HEAT RECOVERY

One way that the costs of emission control systems can be justified or even totally recovered is if waste heat can be recovered and utilized effectively.

In the past, fuel was cheap and plentiful and waste heat recovery was not considered. There were many justifiable reasons why heat recovery was not practical on emission control systems, in particular, high installation expenses, more troublesome and risky equipment to operate and maintain, and poor payback. Well, those days are gone! Every single BTU of waste heat recovered and reused today means energy conservation at a time when energy is becoming scarce and very expensive. Heat recovery is now affordable, practical, reliable, and has in many cases, excellent payback economics. For example, a discharge stack emitting a constant gas flow of 25,500m^3/hr (15,000 cfm) at 426°C (800°F) will have a waste heat rate of 376,000g-cal/sec (5,367,000 BTU/hr). If only 60% of that heat were recovered and used effectively, a savings of $9.70 per hour could be realized. Based on an 8-hour day, 5 day week, 50 week operation, the savings would total $19,400.00 per year on that one stack alone.

Heat recovery systems applied to emission control systems on melting furnaces and other similar sources of waste heat have been used successfully for a long time in foundry applications in Europe, Australia, and Japan. Constant improvement over the years has resulted in a very high degree of reliability and practical operation.

To which sources of waste heat can recovery be applied? Any stack emitting a gas flow at temperatures higher than 65°C (150°F) has potential for heat recovery.

Emission control systems in the melt shop, curing ovens, annealing and heat treating furnaces, in short, any process where heat is present is a candidate. And the method is not just limited to situations where emission control systems are used.

The following sections of this paper will discuss the control of emissions and heat recovery methods for three types of furnaces that have the greatest potential for heat extraction: electric arc, gas-fired, and cupola furnaces. Only air-to-air heat exchangers will be discussed here, although heat recovery is not limited to this technique.

ELECTRIC ARC FURNACES

Electric arc furnaces are second only to the cupola as major producers of air pollution in the foundry. In order to provide the required air quality in the melt shop, as well as to clean up the emissions to the outside environment, the arc furnace requires an emission control system properly designed to capture all the particulates and gases generated during the various furnace operations, i.e., charging, melting, refining,and tapping.

The emission control systems will vary greatly according to the metallurgical practices and melt shop layout. The types of exhaust capture hoods in common use fall into the following categories:

1. Direct evacuation.
2. Sidedraft or roof hood.
3. Booth and enclosure.
4. Canopy.
5. Any combination of the above.

Of all of the above exhaust methods, direct evacuation has by far the greatest potential for heat recovery due to the higher temperature of the gases emitted. Sidedraft and roof-type capture systems may also have good potential, depending on the design of the hood and the exhaust rate required to capture the emissions generated by the furnace.

The other capture methods normally require large exhaust rates, which tend to reduce the gas temperatures to below the desired minimum for heat recovery [65^oC (150^oF)].

Since most emission control systems on arc furnaces utilize a baghouse (fabric filter), the gas must be cooled below the limiting temperature of the fabric before entering the baghouse. Cooling is usually accomplished by introducing ambient air using a bleeder damper until the desired temperature is reached by mixture. The ideal location for the heat exchanger is upstream of the bleeder damper.

Figure 1 illustrates a hypothetical gas temperature record for two identical arc furnace operations at a steel foundry using different exhaust methods. Furnace A is equipped with a direct evacuation control system; furnace B uses a sidedraft hood control system. The exhaust rate for furnace A is 20,500^{3}m/hr (12,000 cfm) and for furnace B is 44,100m^3/hr (26,000 cfm).

GAS FIRED FURNACES

Gas fired furnaces, e.g., rotary, reverberatory, open hearth, and crucible furnaces,have tremendous potential for heat recovery.

The control method for these furnaces is normally direct venting of the products of combustion from the melting chamber, with additional canopy or sidedraft hoods to control fume from charging and tapping operations.

The gas flow temperatures from the products of combustion are very high, and in most cases, quite stable. The exhaust volumes from the other hoods are used for dilution cooling of the gas stream to filtering temperatures.

The heat exchanger should be located in the hot gas stream from the melting chamber. This should not present any problems with most types of furnaces, however, in a crucible furnace the port venting the products of combustion must be ducted, and this ductwork must allow the furnace to tilt for pouring.

The higher quantity of heat that can be extracted from these furnaces can be used for many purposes, but, particularly important, the combustion air

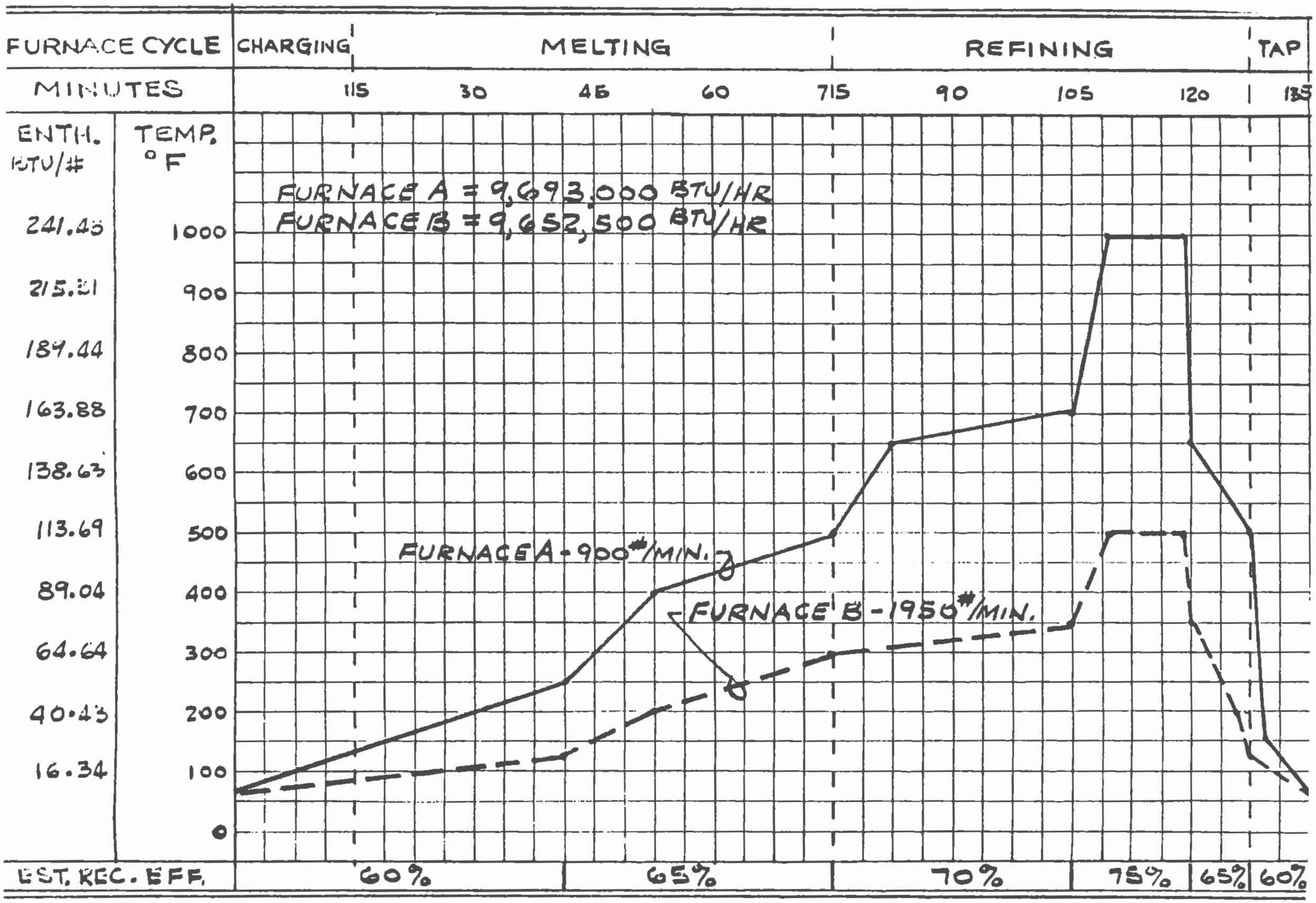

Figure 1. Hypothetical gas temperature records for furnaces with direct evacuation hood (A) and sidedraft hood (B).

for the burner equipment could be pre-heated. Pre-heated combustion air can result in as much as a 20% or more fuel savings. In most cases, enough heat is extracted from these furnaces to pre-heat the combustion air and have large amounts left over for other uses.

Figure 2 shows a schematic diagram for a heat recovery system on a rotary smelter application. The heat and cost savings analysis for this system is presented below:

Heat content of flue gases	165,000 $\frac{\text{g-cal}}{\text{sec}}$ (2,358,960 BTU/hr)
Predicted heat exchanger effectiveness	70%
Heat extracted	125,000 $\frac{\text{g-cal}}{\text{sec}}$ (1,651,260 BTU/hr)
Cost savings per hour @$1.19/10,000 g-cal ($3.00/mill. BTU)	$4.95
Cost savings per year (4,000 hrs)	$19,800.00
Est. cost of recovery system	$45,000.00
Payback period (at current cost)	2.27 yr.

THE CUPOLA

The cupola has been one of the most economical and reliable melting furnaces ever used. Its popularity is confirmed by its use time and time again on new foundry construction. However, because of increasing prices for coke and natural gas and the requirement of an emission control system, the economical advantage is being diminished almost daily.

The emission control system for the cupola can be technically complex and costly both to purchase and operate. I would like to comment on one area that is always forgotten in a cupola emission control system, and that is the control of metallic fume from the cupola forehearth area and pouring ladles. This fume normally ends up in the melting shop, adding considerably to the levels of respirable particulates. Localized hooding could easily take care of this problem, and if properly designed, the hooding may not require large exhaust volumes.

But let's talk now about heat recovery for the cupola. Heat recovery, is one way to reduce the operating cost of the entire cupola melting shop.

Because the quantity of waste heat is so great, the cupola waste gases can provide heat for, among other uses: hot blast tuyere air, pre-heat after-burner combustion air; hot air curtain at the charge door.

A heat recovery system on a cupola can bring other benefits beside reducing the gas and coke consumption. These benefits include:

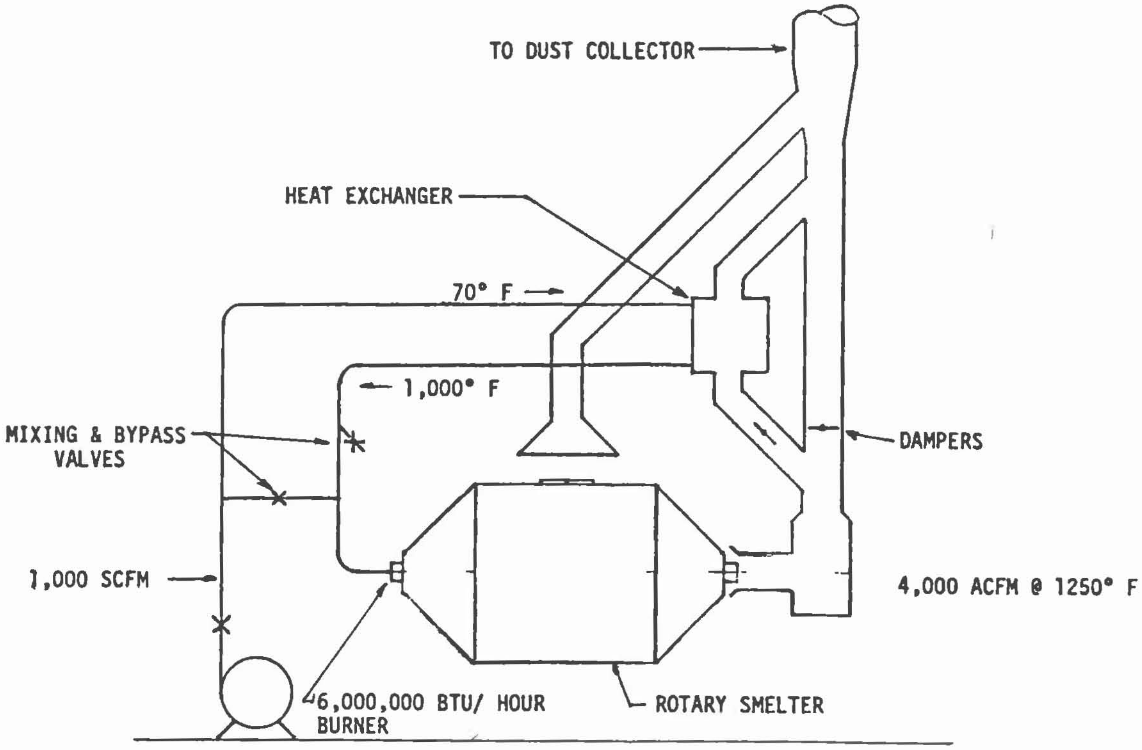

Figure 2. Heat recovery system on rotary smelter.

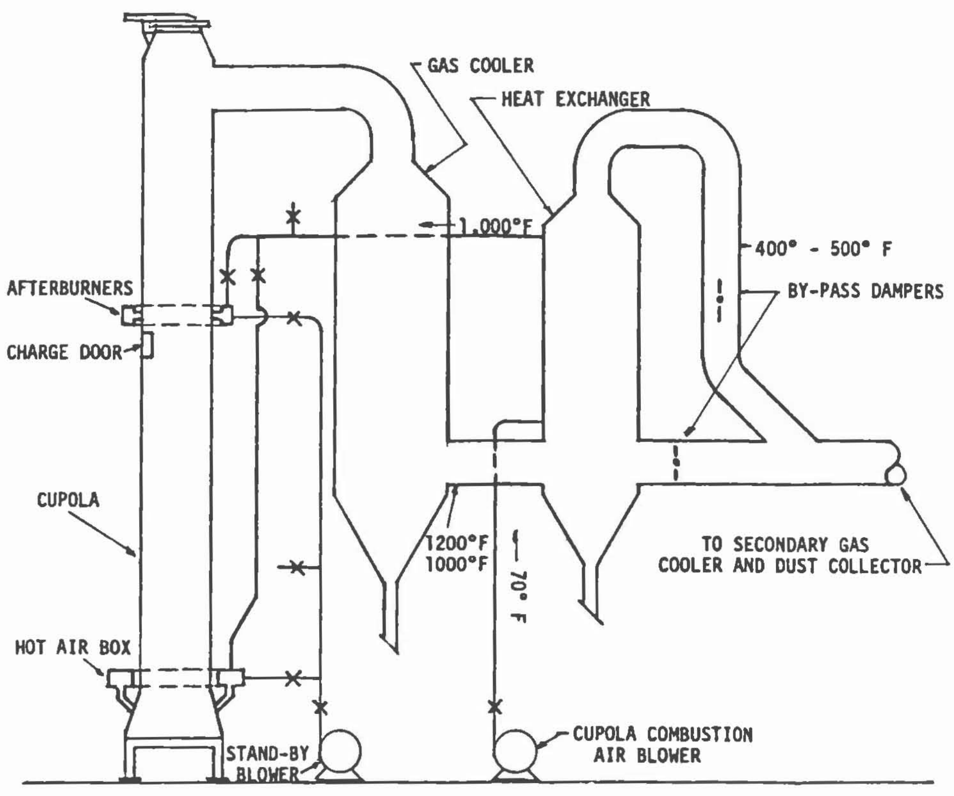

Figure 3. Heat recovery system on a 183 cm (72 inch) diameter cupola.

1. The high waste gas flow temperatures are maintained for a longer period of time. This is due to longer duct runs required to add the heat exchanger. This longer period of time at higher temperatures allows almost complete incineration of hydrocarbons. If a fabric filter is used as the dust collector, a lower resistance across the filter media is realized.

2. Since the heat exchanger will remove a great amount of heat from the waste gas flow, less water will be required for cooling to final filtering temperatures. This will lower the dewpoint of the gas flow, and a lower dewpoint may prevent condensation problems in the dust collector.

3. There will be better control of temperatures and gas flow in the emission control system. This, along with the other benefits listed above, will add to equipment life and refractory life.

Figure 3 shows a schematic diagram for a heat recovery system for a 183 cm (72 in.) diameter cupola. The payback analysis is presented below:

Cupola melt rate	10 metric ton/hr (11 TPH)
Coke usage (@8:1 ratio)	1250 Kg/hr (2750 lb/hr)
Tuyere air required	13,400m^3/hr (7900 SCFM)
Afterburner combustion air required	4,180m^3/hr (2460 SCFM)
Heat content of hot blast @ 537^{o}C (1,000^{o}F)	560,000 $\frac{\text{g-cal}}{\text{sec}}$ (133,715 BTU/min)
Heat content of afterburner comb. air	175,000 $\frac{\text{g-cal}}{\text{sec}}$ (41,638 BTU/min)
Coke use reduction	287 Kg/hr (632 lb/hr) (23%)
Gas use reduction	386m^3/hr (2271cfm)
Total savings [coke @ $178.00/metric ton (160.00/ton) and gas @ $0.117/m^3 (3.00/1000^{3}ft)]	$229,480.00 57.37/hr
Est. heat recovery system cost	$450,000.00
Payback period (4000 hr. operation)	2 yrs

THE HEAT EXCHANGER

The application of heat exhangers to dirty gas streams is not new. Heat exchangers on cupola waste gases are numerous and have proven very successful.

It is very important, however, that the limitations of heat exchangers are recognized and the application is thoroughly studied prior to any attempt at heat recovery. It is also very important that all the conditions of the waste gases where the heat exchanger is to be applied are known. The chemical composition, the temperature range, volumetric flow, and dewpoints are all factors that must be taken into account when designing the heat recovery system.

The type of air to air heat exchanger that is normally applied to contaminated gas streams is an opposed flow tube type or slot type, having the heat recovery surfaces countercurrent or parallel to the waste gas flow, depending on the construction of the heat exchanger. The heat exchanger must be designed to meet the following requirements.

1. Operate at high temperature.
2. Operate under high air pressures that are required for cupola blast or combustion air.
3. Able to expand and contract without difficulty as the temperatures change in the system.
4. Have some protection against wear due to abrasion at areas blasted by the dust laden gas flow.
5. Self cleaning or equipped with cleaning jets to blast away any material buildup on the heat transfer surfaces. (Material buildup will greatly reduce the effectiveness of the heat exchanger).

We must remember that the heat exchanger is only one part of the heat recovery system. The other components and the actual design of the system are equally important if the system is to operate successfully.

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