Energy Technology 2011
Edited by: Neale R. Neelameggham, Cynthia K. Belt, Mark Jolly, Ramana G. Reddy, and James A. Yurko
TMS (The Minerals, Metals & Materials Society), 2011

WASTE HEAT REDUCTION AND RECOVERY OPTIONS FOR METALS INDUSTRY

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Keywords: Waste Heat Recovery, Energy

Abstract

Waste heat from industrial operations in metals industry represents 20% to 50% of the total energy used in most manufacturing plants. Reduction and recovery of waste heat offers the most attractive and cost effective method of reducing energy intensity for an industrial plant to meet corporate energy saving goals. It is possible to reduce or recover 30% to 60% of the available waste heat by using conventional and readily available technologies. Projects to reduce or recovery waste heat may offer less than 3 years payback to as short as a few months. This paper presents information on most commonly used methods for waste heat reduction and recovery in the metals industry operations. It describes the methods and use of analysis tools that would allow a user to estimate energy savings, CO2 or GHG reduction potential, and economic benefit and includes appropriate case histories.

Waste Heat Sources

Sources of waste heat abound with the metals industry. While the overall quantity of energy is high, the sources are distributed throughout a plant. The largest source within the metals industry is within furnace exhaust / flue gases. This includes the high temperature gases from burners in process heating such melting, calcining, and sintering operations. It also includes lower temperature gases from heat treat, dryers, and heaters. Lower temperatures are also found after post processed hot gases. This could include heat left after heat exchangers, regenerative systems, thermal oxidizers, and emission control systems. Other hot gases include air used in direct and indirect cooling.

While waste heat in form of exhaust gases is readily recognized, waste heat can also be found within liquids and solids. Waste heat within liquids includes things such as cooling water, heated wash water, and blow down water. Solids can be hot product at discharge after processing or reactions are complete. Indeed, not only is energy wasted in the hot metal that slowly air-cools, but additional energy may be used in providing air or water-cooling to increase the speed of cooling. Other waste heat sources are not as apparent and include things like hot surfaces, steam leaks, boiler blow down water, etc. Table 1 and Figure 1 show several major sources along with the temperature range and characteristics of the source.

There are different characteristics of waste heat that must be understood to engineer the best solution. As an example, for exhaust gases we need to know the availability of waste heat. Is it continuous, cyclic or intermittent? What is the temperature and how does that vary over time? What is the flow rate and does it vary? Is the gas at a positive or negative pressure and does this vary? What is the gas composition? To design a dependable heat exchanger, we need to know potential problems from the gases. What type of contaminants? Particulates might include carbon-soot but also could be particles of the product (either metals or non-metals). What type of moisture is in the gases that may form sludge? How corrosive is the gas? Do any combustible gases remain?

Heat source	Temperature Range (Deg. F.)	Characteristics
Furnace or heating system exhaust gases	600 to 2000	Varies
Gas (combustion) turbine exhaust gases	900 to 1100	Clean
Recip engines		
Jacket cooling water	190 to 200	Clean
Exhaust gases (for gas fuels)	900 to 1100	Mostly clean
Hot surfaces	150 to 600	Clean
Compressor after-inter cooler water	100 to 180	Clean
Hot products	200 to 2500	Mostly clean
Steam vent or leaks	250 to 600	Mostly clean
Condensate	150 to 500	Clean
Emission control devices - Thermal Oxidizers etc.	150 to 1500	Mostly clean

Table 1. Temperature Range and Characteristics for Industrial Waste Heat Sources

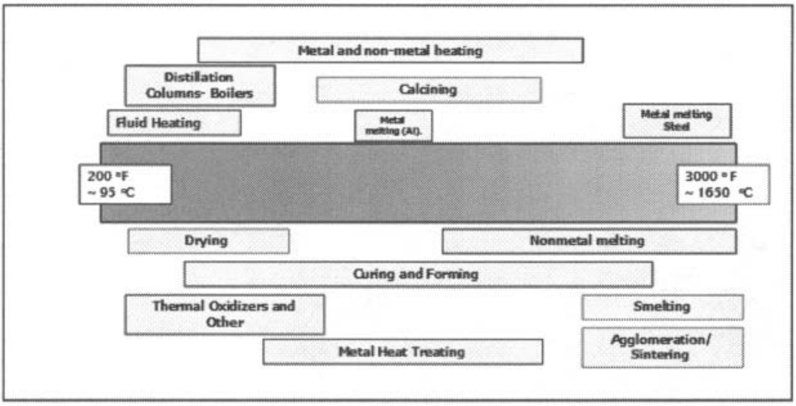

Figure 1. Temperature Range for Industrial Waste Heat Sources

Exhaust gases are typically a highly concentrated source of energy. As can be seen in Figure 2, recoverable heat can vary from 25% to as high as 45% even for relatively low temperature exhaust gases of 400-1400° F [200-760° C].

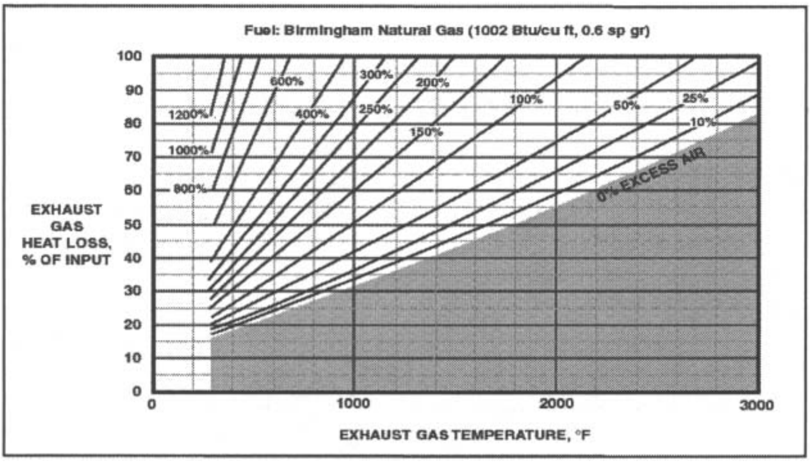

Figure 2. Exhaust Gas Heat Loss vs. Temperature

Options for Waste Heat Use

There are multiple options for waste heat within a plant. Each option should be evaluated for the given situation.

Reduction – This first option should always be evaluated is to make sure the least amount of heat is wasted by the process. There are many ways this can be done with exhaust gases. Examples include: proper air / fuel ratio, better control of temperatures, and positive furnace pressure. The entire plant process should be studied. For instance, there is waste heat within the metal after casting that is lost to the air. However, it may make sense to transfer product quicker to the next process such as heat treatment.

Leaks are another major source of reduction. Wall and opening losses may include enclosing the furnace better, better insulation, and reducing charging time. Reducing these losses reduces the waste heat within the ambient air. Steam leaks are another obvious source that should be reduced or eliminated.

Recycling – It is normally best to use the energy from waste heat within the source itself. This includes combustion air preheating, load or charge preheating, and make-up air or water preheating.

Recovery – Options for using waste heat should be evaluated for other systems within the plant. This includes heating water, steam generation, and plant air (HVAC) heating. Other options include cascading, i.e. the use of waste heat in lower temperature processes.

Recovery-Electrical – A subset of recovery is to use waste heat for power conversion or electricity generation. This tends to be the least efficient use due to inefficiencies in power generation at this time. However, recent advances in the area are promising.

The potential energy savings varies both due the source and the method of use. Table 2 shows several options with the range of energy savings. Please note these numbers for temperature and savings are for typical applications. There are lots of exceptions. Use this with care!

Method	Temperature range (Deg. F.)	Energy savings potential (%)	Typical Applications
Combustion air preheat			
Recuperators	1200 to 1600	10% to 30%	Furnaces, ovens, thermal oxidizers, heater, kilns etc.
Regenerators	1000 to 1800	10% to 40%	
Load/Charge preheating	600 and higher	5% to 25%	Furnace, ovens, kilns etc.
Internal heat recycling	300 to 1000	10% to 20%	Ovens, dryers etc.
Make-up air heating	200 to 1000	10% to 25%	Ovens, dryers, air heaters etc.
Water heating	150 and higher	3% to 7%	Heat treating operations, metal coating, ceramic kilns, etc.

Table 2. Energy Savings Potential

Waste Heat Recycling

The advantages of waste heat recycling are many. These include:

- Compatible with process demand and variations in operating conditions. For instance, at high fire more waste heat is available from the flue when more heat is needed for combustion air.
- Can be used as retrofit for existing equipment. Systems can be added as long as sufficient room in available.
- Relatively easy and inexpensive to implement. Typical payback periods vary from one to three years. These paybacks tend to be better than other alternative energy sources.
- Heat recovery: 30% to 90% of the waste heat.
- Implementation cost: $30,000 to $75,000 per MM Btu recovered heat (includes normal installation). This is very much site and size specific.
- Application temperature range: Typically it ranges from 400 ° F [200° C] and higher and depends on specific process conditions.

A full economic analysis for any potential project is needed. Energy savings can be calculated based on the average operating conditions using readily available equations, tables or calculators (see example of Table 3). However, savings will vary over time. Changes in conditions can change the savings. For a melt furnace, reduced utilization will reduce savings. Poor maintenance of the waste heat recovery system will definitely reduce savings but the total system must also be maintained. For instance, a poor furnace door seal may pull in cold air that will change the flue gas composition and temperature and reduce efficiency of the waste heat recovery system.

Savings - Use of Preheated Combustion Air		
	Current	New
Furnace flue gas temp. (F)	1,400	1,400
Percent O2 (dry) in flue gases	2.10	2.10
% Excess air	9.94	9.94
Combustion air temperature (F)	80	700
Fuel consumption (MM Btu/hr) - Avg. current	10.00	8.14
Available Heat (%)	58.00	71.29
Fuel savings (%)	Base	18.64%
No. of operating hours	8000	8000
Therms used per year (Therms/year)	800,000	650,843
Therms saved per year (Therms/year)	Base	149,157
Cost of fuel ($/Million Btu)	$ 10.00	$ 10.00
Annual savings ($/year)	Base	$ 149,157
CO2 savings (tons/year)	Base	873
Carbon equivalent savings (tons/year)	Base	238

Table 3. Calculator Energy Savings- Combustion Air Example

Savings can be obtained from more than just energy. Emissions may be reduced. Many times there will be a productivity gain. Hotter combustion air or product can reduce cycle times. There may be quality improvement as a benefit. For example, controls used within the new system may result in better temperature control. Other savings may include labor, waste disposal, and maintenance costs.

Of course, the full costs must be understood. Besides the main equipment, installation costs can be substantial. This includes engineering and labor along with auxiliary equipment such as burners, controls, and piping. Additional equipment can use energy that needs to be considered. For instance, preheating metal may require fans and blowers. Equipment may need to be relocated along with changes to the building roof or foundation. This new equipment will many times require permitting changes and charges for new discharge testing. Finally, the additional equipment may increase maintenance costs (ex. Valves or bed cleaning in a regenerative system).

Options for waste heat recycling include recuperators and regenerative systems. Recuperators are basically an air-to-air heat exchanger. These heat exchanges can be internal (self-recuperating) or external. Some external recuperators are within the flue while some are located away from the flue so that a controlled amount of gas (and heat) can be delivered to the heat exchanger. Recuperators are capable of handling up to 1600° F [875° C] flue gases while the recovery of the waste heat ranges from 30–60 %.

Regenerators or regenerative systems are capable of handling higher temperatures of up to 2400° F [1300° C] with a much better recovery of 50–80 % of the waste heat. For preheating combustion air, the unit is external. The hot gases heat a medium within the unit. After a short period of time, the system reverses. Cold air is then heated by the hot medium to be used as combustion air. .

Regeneration is perhaps the most efficient method of heat recycling. Energy Intensity (energy use per unit of production) can improve from 5–40 %. Production increases are typically seen. Other benefits might include a higher yield and improved product quality. However, the costs are also typically higher than a recuperator system.

Load or charge preheating offers another method of heat recycling. Usually charge preheating using flue gases requires use of an external preheater where the charge material is preheated to remove moisture (drying) and increase the temperature before charging it in a furnace or an oven. Charge preheating is limited by the available space, limits on material handling equipment and cost of installing and operating the preheating system. For preheating charge materials, required changes can be expensive. However, additional benefits include increased safety with dry charge materials, reduced melt times, and may increase the total capacity of the furnace.

Waste Heat Recovery

Waste heat can be recovered for use both within other processes within a plant or for neighboring plants and homes. The biggest issue for recovery is that the secondary processes must either be close to the primary process or an effective method to transfer the heat must be determined. Within fired systems, waste heat has been used for steam generation, hot water heating, plant or office heating (HVAC), and absorption cooling systems. When possible, heat can be cascaded to lower temperature heating processes or for reaction heat for endothermic processes. For instance, heat from a melting operation might be used in heat treatment or drying operations.

While direct use of the flue gases is preferred for better efficiencies, a heat exchanger may be required to transfer the heat to either 'cleaner' air or to a secondary heating medium. Waste heat recovery can be used as a retrofit for existing equipment with temperatures as low as 250° F [120° C] and higher. Heat recovery ranges from 10–75 % of the waste heat.

An important consideration of recovery is that the heat supply must be matched to the heat demand of the selected process. Recovery systems are moderately expensive to implement with highly variable costs due to the type of system and distance between the supply and demand processes. Table 4 shows example costs for systems. These costs are very preliminary and can vary by as much as 100%. DO NOT use the costs for economic analysis for site-specific cases. Typical payback varies from 0.5 – 5.0 years.

Heat recovery system	Waste heat Temperature (F)	Typical applications	Typical installed cost
Steam generation	600^0 F and higher	Large furnaces with >25 MM Btu/hr. firing rate. Reheat furnaces, process heaters, glass melting furnaces etc.	$35 to $60 per 1000 lb. steam generation
Hot water heating	200^0 F and higher	Heating equipment of all sizes. Heat treating, reheating, forging, ovens, dryers etc.	$30,000 to $50,000 per MM Btu heat transferred
Plant or building heating	150^0F and higher	Mostly in cold climate areas. Can be used for medium to large size (5 MM Btu/hr. and larger size).	$25,000 to $50,000 per MM Btu transferred
Absorption cooling systems	300^0 F and higher	Low to medium temperature systems, large size furnaces, ovens, heaters etc.	$750 to $1500 per ton of refrigeration capacity
Cascading to lower temperature heating processes	800^0 F and higher	For gases from medium to large size systems supplying heat to lower temperature heating systems.	$40,000 to $100,000 per MM Btu transferred

Table 4. Heat Recovery Systems - Summary

A subset of heat recovery is the generation of electricity from the waste heat. The conventional systems use a steam boiler, steam turbine, and a generator. Other options are now available that can be used for lower temperature heat sources. These options include Organic Rankin Cycle (ORC), ammonia-water systems (i.e. Kalina, Neogen systems), Super Critical carbon dioxide systems and Thermo-Electric Generators (TEG). This area is a fast changing field and technologies, performance, and costs can vary significantly (Table 5).

To produce electricity, a continuous or predictable flow is needed from the heat source. Even a relatively moderate temperature source of at least 300° F [150° C] can be a possibility but a source above 600° F [315° C] is preferred. Currently for conversion to electricity, the waste heat source (either gas or liquid) must be relatively clean and free from contamination. Care needs to be taken to prevent the condensation of vapors within these units.

As mentioned before, conversion to electricity is less efficient so that it should only be used when the heat cannot be used directly within the process or other recovery methods are not practical within the plant. Try to avoid or reduce the use of supplementary fuel for power generation since this has negative effects on the overall economics. One time this might make sense is to reduce high costs from plant peak demand.

Comparison	Steam Rankine	Organic Rankine (ORC)	Ammonia (NH_3) - Water	CO2 Power Cycle
Source Temperature Range Deg. F.)	800 plus	200 to 500	200 to 800	400 to 1200
Working Fluid	Treated water	HCFCs or Hydrocarbons	Ammonia - water mixture	Caron Dioxide
Working Fluid Attributes	Requires treatment to reduce corrosion and mineral deposition	Limited temperature range, flammability, thermally unstable at higher temperature	Limited temperature range, corrosive, ammonia leaks	Non-corrosive, non-toxic, non-flammable, thermally stable
Conversion Efficiency (%)	20% plus	8% to 12%	8% to 15%	13% to 17%
Reported Cost ($/kW)	$600 plus	$2500 plus	$2500 plus	$2000 plus

Note: This is a fast changing field. The efficiency values highly dependent on the source temperature. Cost could vary significantly with size, supplier and incentives from several sources.

Table 5. Power Generation Comparison

Conventional steam turbine-generator option is the most attractive option for clean, contamination free waste heat at >800° F [425° C] temperature. At lower waste heat temperatures, there are three options available: ORC, ammonia-water based systems, and CO2 based systems. However none of these have long and proven history in industrial applications to offer economically justifiable power generation as of today. Waste heat-to-power projects are difficult to justify for <400° F [200° C] temperature waste heat, especially if the waste heat supply is not continuous and auxiliary energy is required.

Thermo-electrical systems are in early development stage and their use cannot be economically justified at this time except in special cases. The technology is being used for a temperature range of 400-900° F [200-480° C]. The reported efficiency has been less than 5% with a very expensive cost of >$5000 per kW. The technology will require considerable R&D and technology pilot demonstration before it can be used for waste heat-to-power applications

Conclusion

Four possible options should be considered and evaluated for use of waste heat from a heating system. For overall energy efficiency, these should be evaluated in this order.

1. Reduction – Heat should be used directly and efficiently within the process to minimize waste heat.
2. Recycle - Use waste heat within the process or system itself. This is the most economical and effective method of using waste heat.
3. Recovery - Use waste heat within the plant boundary. Options include use in plant utilities or use in other processes.
4. Recovery-Electrical - Waste heat to power conversion.

Technological changes have been rapid in this area to take advantage of the great potential in waste heat use as an 'alternative' fuel.