PRACTIAL APPROACH IN CONTROLLING FLUE GAS EMISSION

by

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SYNOPSIS:

Over the years, there has been growing concerns in climate change and environmental risk due to Green House Gas (GHG) emissions. Iron and steel industry remain as one of the largest energy consuming sector in Asia that accounts for more than 20% of the overall energy consumption. To reduce and control GHG emissions, regulators will impose stricter air pollution and energy efficient targets for the iron and steel industry. This creates a strong motivation for companies to improve their processes, shift to lower carbon substitutes, and enhanced energy efficient technologies.

Effective management of air borne emissions can be achieved by systemic approach with emphasis on prevention, containment and treatment. Process optimization, energy assessment, industry bench-marking and usage of new technology are the four main pillars that can be used to define potential reduction in energy usage and flue emissions. These objectives can work hand in hand with energy conservation and cost reduction that provides commercial attractiveness to any iron and steel company.

This paper will discuss the practical approach on air emission assessment and potential waste gas heat recovery process that has been adopted in the industry.

Keywords: Flue Emissions, Air Emission Assessment, Process Optimization, Energy Conversation, Energy Efficiency.

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Introduction

Air pollution is recognized as one of the leading contributors to global warming, climate change, acid rain and impact of human health that results in economic losses. Iron and steel making remains as one of the major pollutive and energy-consuming industries. The industry accounts for more than 20% of the overall energy consumption and 6 % of world CO_2 emission [1-2]. Regulators continue to impose stricter air pollution standards, and energy-efficiency targets with the growing environmental concerns. It is a certainty that iron and steel industries in ASEAN countries will embrace the same control standards.

Flue gases are gases exiting to the atmosphere as a discharge from combustion processes (e.g. oven, furnace, boiler, burner, incinerator). In the iron and steel making context, flue gas refers to the exhaust gas produced in the combustion process for reduction, oxidation and pre-heating operation which mainly consist of N_2, H_2O, O_2, CO_X, NO_X, SO_X, dust, and oxides of metals.

Table 1 summaries the key air pollutants (excluding CO_2) and respective maximum allowable levels in ambient air across the regions.

Country / Region	PM10 µg/m3 24 hour	PM10 µg/m3 1 year	PM2.5 µg/m3 24 hour	PM2.5 µg/m3 1 year	CO mg/m3 1 hour	CO mg/m3 8 hour	NO_2 µg/m3 1 hour	NO_2 µg/m3 24 hour	O_3 µg/m3 8 hour	SO_2 µg/m3 24 hours	SO_2 µg/m3 1 year
European Union	50	40	-	25	-	10	200	-	120	125	20
Indonesia (2010)	150	-	65	-	30	-	400	150	-	365	60
Japan	100	-	35	15	-	23	-	113	-	104	-
Malaysia (2020)	100	40	35	15	30	10	280	70	100	80	80
Philippines (2015)	150	60	50	25	35	10	-	150	60	180	80
Singapore (2020)	50	20	25	10	30	10	200	-	100	50	15
Thailand	120	50	50	25	34	10	320	-	240	300	100
Vietnam (2013)	150	50	50	25	30	10	200	100	120	125	50
United States (Pri & Sec)	150	50	35	12/ 15	40	10	100	-	140	140	30
World Health Organisation (2005)	50	20	25	10	30	10	200	40	100	20	-

Table 1. Summary of Air Emissions Quality Standard

Flue gas from iron and steel making processes contain huge amount of acid gases of halogens and sulfur, that are volatilized upon combustion. Other by-products like slag and dust also contain harmful substances. Excessive exhaust heat has negative impact on the environment as well. Impact of these harmful by-products can be reduced by applying "clean" approaches that emphases on prevention, containment and treatment. Process optimization, energy assessment, industry bench-marking and usage of green technology are the four main areas to address issues on energy-reduction and improving emission levels.

Materials and Methods

Most iron and steel plants are designed with adequate gas cleaning equipment and air-pollution control systems. However, these equipment and systems are often designed with the initial production throughput which eventually changes or increases over the years. For such situation, the off-gas system capacity may not be sufficient to cope with the higher demand. The ever-stricter environmental control has brought about new requirements that are not initially considered, nor stringent. As the operating time of the flue-handling system proceeds, parts and equipment are coming near the end of their useful life. Such plants are normally expected to continue running after 20 years in operation.

It is necessary to evaluate the emission gas quality and develop plans to ensure off-gas quality to meet environmental limits. It is important to understand the existing gas cleaning system capability, operating utilization rate, component conditions and the process variability so that the right measures can be applied accordingly. The following approach describe in Figure 1 can be used to evaluate the current emissions level and existing gas cleaning system efficiency.

Figure 1. Off-gas Evaluation Approach

Process Alignment

Process alignment is to determine which processes are contributing to the overall emissions and what are the major components involved in the current off-gas cleaning system. It is necessary to identify the end to end off-gas flow path for all operating conditions. Test locations can be defined for meaningful data collection which will contribute to an accurate study. Major gas cleaning system components consist of:

- Primary process-gas collection system (e.g. hoods, water spray, ducting, etc)
- Secondary fume collection system for fugitive emissions
- Electrostatic Precipitator (ESP)
- Scrubber and Absorption Tower
- Baghouse and Filtration system
- Cooling Tower
- Draft Fan System
- Stacks

Data collection (off-site)

It is important to obtain complete information for a comprehensive analysis. Besides process and operational monitors, relevant plant's design data and a questionnaire will be compiled as detailed as possible. This allows formulation of field-test plan with all required parameters to be verified, respective operating conditions, actual locations, frequency of records and duration of test. A good test plan is the key to a successful assessment. It must be aligned between user and tester.

On-site Observation & Data Collection

To ensure data, process and operating condition accuracies, site visits and real time data collection are necessary before final analysis take place. Multiple-point data collection of off-gas flow rate, velocity pressure, static pressure, temperature measurements, operation logs and gas samples are carried out. Gas analysis (e.g. CO, CO_2, O_2, NO_x, SO_x) will be carried out at the test locations.

Further discussions with operation, maintenance and environmental team are crucial to find out the current system shortcomings, issues and difficulties of solution options.

Data Analysis and Evaluation

Data collected at site, operational logs and actual ductwork measurements are used to evaluate the off-gas system condition, operation, capability, performance of the off-gas systems and related process equipment. Following activities are performed as part of the evaluation process.

- Computation of off-gas conditions generated from process equipment e.g. furnaces
- Develop mass and energy balance of the off-gas system using actual ductwork measurements and operating data
- Develop process flow diagrams to identify the off-gas system balances and measurements
- Develop flow distribution and static pressure profile to model the entire off-gas system including performance of all related equipment e.g. flow dampers, I.D. fans, ESP, baghouses, etc.

Data will be analyzed throughout the system, especially at critical locations to monitor for abnormal changes in pressure, temperature, flowrate and equipment throughput.

With the help of the computerized modeling, discrepancies can be identified by comparing the expected system performance under operating conditions with that of the design.

Conclusions and Recommendation

The objective of off-gas system evaluation is to understand the current emission situation and overall system efficiency. This will determine if there is a need to improve the current off-gas system and the related operation process. Often, underlying root causes for the deviations can be summarized as below.

- Excessive off-gas generation (over production or process change)
- Under capacity of off-gas system (system undersized)
- System inefficiency due to overall design issue (improper design)
- Sub-optimal performance (due to wear and tear, maintenance issue, damage, etc.)
- Under-sizing of off-gas system component e.g. hood, duct work, fans etc. (system partially undersized)

Recommendation to optimize off-gas system performance can be categorized into short-term improvements and long-term solution. Short-term improvements focus in quick result by optimizing existing system with minimal capital costs. Long-term solution will resolve the emissions control issue and improve the air quality standard to desire level for sustainable operation. Long-term solution may involve system modification to further improve off-gas system efficiency while considering future upgrading plans.

Computational Fluid Dynamics (CFD) modeling and comparative analysis can be developed for better understanding on the recommendations, operational effect and commercial feasibility. All these will help users to make appropriate decisions.

Besides targeting on off-gas system, other process controls can be tuned to reduce the chemical and energy input to achieve better emissions quality. The overall clean strategy is to adopt a low carbon, low energy and low chemical approach for sustainable operation. Fuel selection, heat sources, operational practice and waste heat recovery options can all be reviewed.

- Fuel selection: Possibility on usage of substitution fuels that has low carbon properties or carbon-free sources from conventional sources such as coal, coke and diesel. A diverse range of substitutable energy sources such as clean energy (i.e. bio-energy, bio-fuels & hydrogen energy) and renewable energy (i.e., solar & wind energy) can be used.
- Operational practices: Process optimization and sufficient operational training to ensure energy usage, process efficiency and product quality is optimized.
- Heat source management: A combination of equipment efficiency, energy efficiency and fuel selection to ensure process is controlled at optimum level.
- Waste heat recovery: Up to 50% of the energy input is lost as waste heat [3] in the form of hot exhaust gases, cooling water, heat lost from hot equipment surfaces and heated products. Reuse of waste heat can be an energy substitute option instead of purchased fuels or electricity.

Waste Gas Heat Recovery and Power Generation

Heat recovery provides the direct benefit of reducing energy consumption for any high temperature processes. Ability to generate electric power from heat recovery is a significant opportunity to reduce operating costs, as electricity costs are expected to increase significantly in the future to cover the costs of modern power plants.

In a typical off-gas heat recovery study, the key consideration is to evaluate the off-gas conditions and to determine which type of heat recovery technologies is suitable that would result in favorable returns on investment. Waste heat is recovered from off-gas indirectly by passing them through a gas tube exchange which heat energy is transfer for other application processes. General heat recovery applications are 1) to generate thermal heat for steam and hot water production; 2) to generate process heat for pre-heating and drying requirements and 3) to generate electricity for electrical power consumption.

For the purpose of this paper, investigation of applying Organic Rankine Cycle Heat Recovery and Power Generation gives great opportunities on low latent heat recovery applications between 50°C and 300°C.

Organic Rankine Cycle Heat Recovery and Power Generation

Organic Rankine Cycle (ORC) heat recovery is well established for low-grade heat recovery (temperatures between 50 and 300°C) but it has not been widely used in steel making applications. ORC is a thermodynamic cycle which converts heat into work. The working principle of the organic Rankine cycle is the same as that of the traditional Rankine cycle involving water and steam. However, the organic Rankine cycle uses a low boiling point organic fluid in place of water. Fluids typically used as ORC working fluids include standard commercial refrigerants as well as low boiling point hydrocarbons, such as Pentane, iso-pentane, and butane. The lower boiling point allows heat recovery from lower temperature heat sources such as industrial waste heat, geothermal heat, solar ponds, etc. where steam generation is not practical.

Key design considerations for ORC application include:

- Selection of ORC working fluid
- Heat exchanger design and materials of construction
- Air-cooling or water-cooling
- Power generation setup
- Optimization of heat recovery

The basic organic Rankine cycle system consists of a boiler, a turbine or turbo-expander with generator, a condenser, and a pump. The working fluid is pumped as a liquid to a boiler where it is evaporated through indirect contact with a hot heat transfer medium. The vaporized organic fluid leaving the boiler then passes through the turbine or turbo-expander. The gas expansion that occurs as the gas passes through the turbine generates shaft power which produces electricity in a coupled generator. The organic fluid exiting the turbine passes to a cooler/condenser which discharges the remaining heat and condenses the working fluid, which is collected in a receiver. The cooler/condenser can be air-cooled or water-cooled. Finally, the pump recirculates the condensed fluid back to the boiler to complete the cycle. The electricity generated from the ORC system is directed to a substation so that it can be distributed through the existing power supply system within the plant.

Heat is transferred to the ORC working fluid, either directly (one heat exchanger between waste heat and working fluid) or indirectly (one heat exchanger between the waste heat and an intermediate heat transfer medium such as thermal oil, and a second heat exchanger between the intermediate medium and the ORC fluid) – depending upon the characteristics of the waste heat source and other constraints. Typically, liquid waste heat streams are directly coupled to the ORC cycle, while gas waste heat streams are indirectly coupled.

In the case of direct exchange, the heat source is simply connected to the ORC heat exchanger which converts part of the heat into electricity, as previously described. As shown in Figure 2, direct heat transfer requires only one heat exchanger between the heat source and the working fluid.

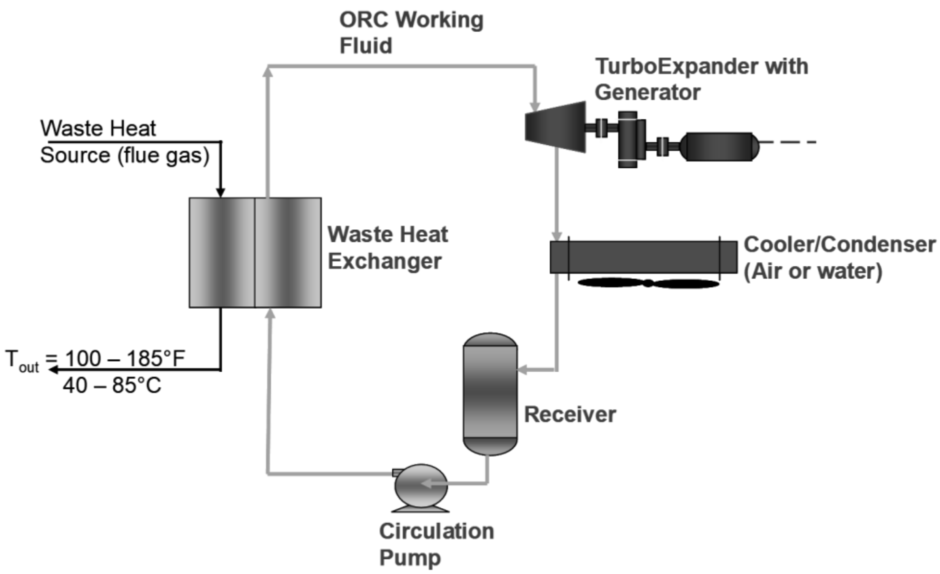

Figure 2: Organic Rankine Cycle with Direct Heat Exchange

When an indirect heat recovery scheme is employed, the heat source exchanges heat with an intermediate medium (typically pressurized water or a thermal fluid e.g. thermal oil, glycol, etc), and the intermediate loop feeds the heat to the ORC cycle. Figure 3 shows a simple process flow diagram utilizing indirect heat transfer between the heat source and the working fluid.

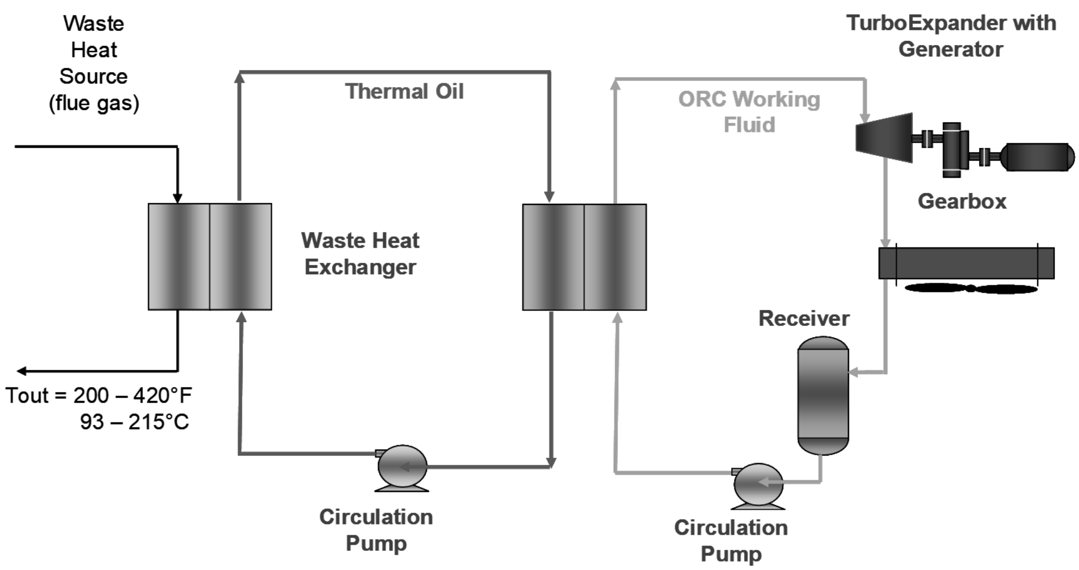

Figure 3: Organic Rankine Cycle with Indirect Heat Exchange

Table 2 summarizes the advantages and disadvantages of direct and indirect heat exchange configurations for ORC heat recovery.

	Direct Heat Transfer	**Indirect Heat Transfer**
Advantages	i. Higher conversion efficiency of thermal energy to electrical energy ii. Lower waste heat outlet temperature can be achieved – i.e. higher heat recovery iii. Less equipment iv. Lower capital cost for single heat sources ($/kW)	i. Indirect heat exchangers designed for dirty gas streams ii. Process variability is dampened by thermal oil loop iii. Working fluid is completely separated from the heat source process – enhanced safety. iv. Thermal oils have a higher decomposition temperature and can therefore interface with hotter gas streams than the working fluid. v. Multiple heat sources can easily be tied to a single ORC system vi. Lower capital cost for multiple heat sources ($/kW) vii. Lower volume of working fluid required
Disadvantages	i. Direct heat exchangers not designed for dirty gas streams ii. Process variability is passed through to ORC system iii. Greater volume of working fluid required	i. Lower conversion efficiency of thermal energy to electrical energy Outlet temperature of the waste heat source will be higher – i.e. lower heat recovery. ii. Introduces additional material e.g. thermal oil. iii. More equipment iv. Higher capital cost for single heat source ($/kW)

Table 2: Comparison of Direct vs Indirect Heat Transfer ORC systems

As summarized in Table 2, there are several advantages for each type of heat transfer system. Typically, direct heat transfer configurations would be preferred for lower temperature clean gas streams with steady process flow conditions. Indirect heat transfer configurations would be preferred for higher temperature dirty gas streams, where gas conditions are variable, or where multiple heat sources could be tied to a single ORC system. Direct systems can achieve gas outlet temperatures of 40 to 85°C. Indirect systems using thermal oil as the intermediate heat transfer medium can achieve outlet gas temperatures of 95 to 215°C.

ORC units can typically produce enough power to be used to directly drive the ID fans of a system as well as some additional equipment. This results in lower installation, distribution, and metering requirements than would be required to put the power back on the grid. Figure 4 below shows the normalized heat recovery potential (kWt/Nm^3/hr) versus inlet gas temperature for various outlet temperature targets.

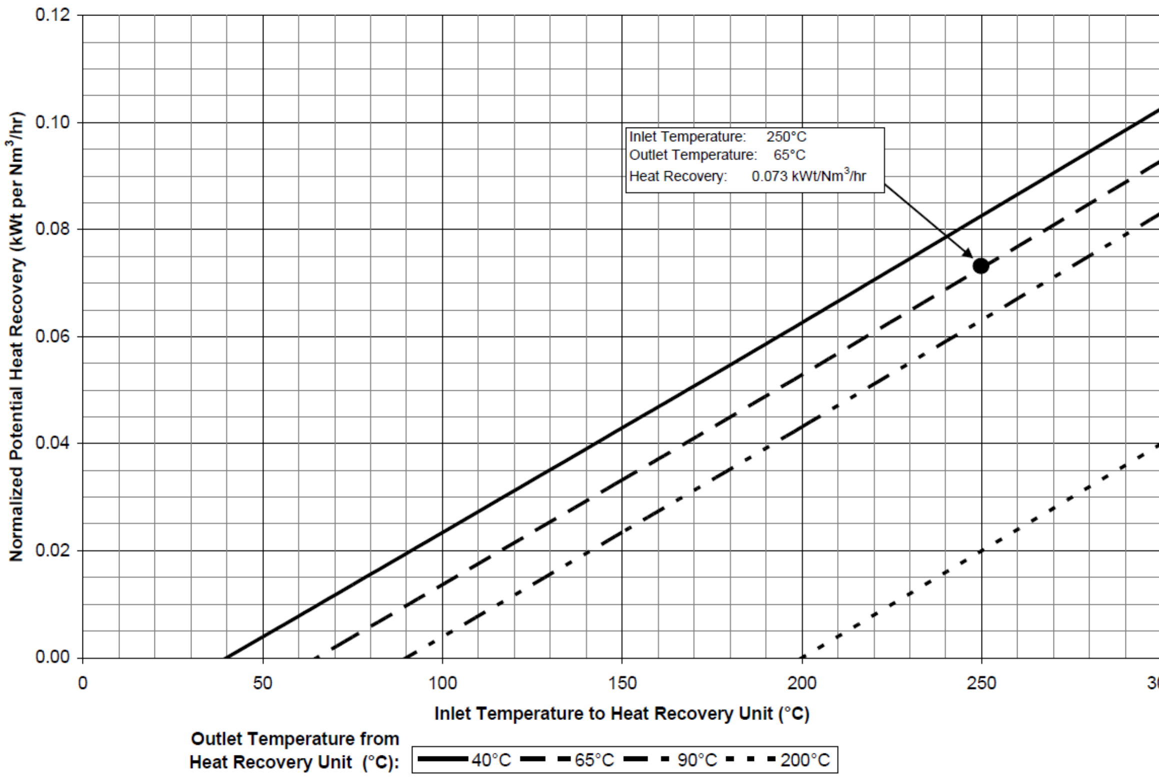

Figure 4 – Normalized Heat Recovery Potential for ORC Applications

Figure 4 above shows that off-gas entering at 250°C and exiting at 65°C could yield heat recovery of 0.073 kWt per Nm^3/hr of off-gas. An off-gas flow rate of 300,000 Nm^3/hr would thus allow 21,900 kWt (21.9MWt) of heat to be recovered.

ORC systems are well proven in low temperature heat recovery applications in geothermal and hydrocarbon refining applications. There are multiple ORC system vendors with decades of commercial experience supplying ORC systems. ORC systems are expected to have a capital cost in the range of $3000 to $4000 per kW of power production and can typically achieve 12% to 17% conversion of thermal energy to net power generation. Higher efficiencies could potentially be achieved for higher off-gas temperature applications.

While there are many benefits from waste gas heat recovery, there should be feasibility study on waste heat recovery system maintenance and potential changes in flue-gas characteristic as well.

Conclusions

In terms of overall flue emissions in iron and steel industry, energy consumption is the key factor as the production of fuels and energy indirectly adds to the total amount of emissions. It can be concluded that by reducing the overall energy requirement, it will lower the amount of flue gas emissions. Cullen et al. [4] calculate global mass flows through the steel supply chain from a range of data sources.

The supply chain shown in Figure 5 covers 95% of all steel production which accounts for up to 40% of the overall steel production costs that are spent on energy according to the World Steel Association [5-6].

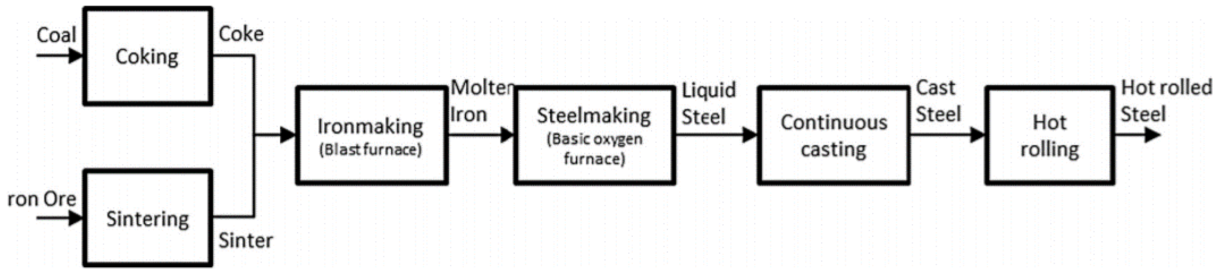

Figure 5. Upstream processes for iron and steel making

It is crucial for the industry to achieve high level energy efficiency with cleaner emissions. Recovering waste heat energy from various iron and steel making processes such as off-gas, molten slag and products is an effective solution to reduce energy consumption and carbon emissions.

With the significant global warming and environmental impacts, it is likely that stricter air pollution and energy efficient targets will be set for the iron and steel industry in near future. This creates a strong motivation for companies to improve their processes, shift to lower carbon substitutes, and enhanced energy efficient technologies. These objectives can work hand in hand with energy conservation and cost reduction that provides commercial attractiveness to any steel company.

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