CHR® - CLEAN HEAT RECOVERING FROM EAF HOT FUMES INTO ELECTRIC ENERGY, WITH CONSEQUENT FUEL SAVING AND REDUCTION OF GREEN-HOUSE GAS EMISSION[1]

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Abstract

The paper shall present the way to recover the energy transferred by the fumes , approximately 20%-30% of the total energy input is lost with the primary fumes sucked from the EAF, to the cooling media by using a closed cycle working with an organic fluid (ORC) and produce Clean Electric Energy. The Organic Rankine Cycle (ORC) is a technology based on the exploitation of waste heat using a closed cycle working with an organic fluid. Using HWHP (Hot Water High Pressure) and a non-flammable fluid at medium pressure the design is simple and efficient. The advantages of this technology, compared to steam turbines, are based on: simple completely automatic machine, no O&M costs, choice of the right fluid to get the best heat recovery and conversion efficiency, no influence on the steel-making process, direct coupling with generator and grid, available for frequent start&stop cycles, good off-design performances, reduced delivery due to standard design.

Key words: EAF; Environment; Dedusting; Energy.

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1 INTRODUCTION

The cooling of EAF primary fumes (extracted from the fourth hole of the EAF roof) is a function performed by the equipment of the FTP (Fume Treatment Plant), which is fundamental to protect the fume duct system and the bag filter.

After the oxidation of the combustible gas contained by the fumes (carbon monoxide), which is completed with the entrance into the fume circuit of a large quantity of dilution air, the fumes have a temperature of 1,200°C-1,300°C. This temperature is unacceptable for a single-walled duct, thus, in a traditional design, water-cooled ducts are used for the conveying of the fumes and water-cooled panels are often used, instead of refractory-lined walls, in the post-combustion chambers.

The traditional cooling system transfers to the cooling water part of the sensible heat contained by the fumes, which is generally lost in the water cooling plant.

Approximately 25%-30% of the total energy requirement of the EAF is wasted with the primary fumes and this is why recovering part of this huge amount of energy is a design option which must be considered in modern electric steelmaking.

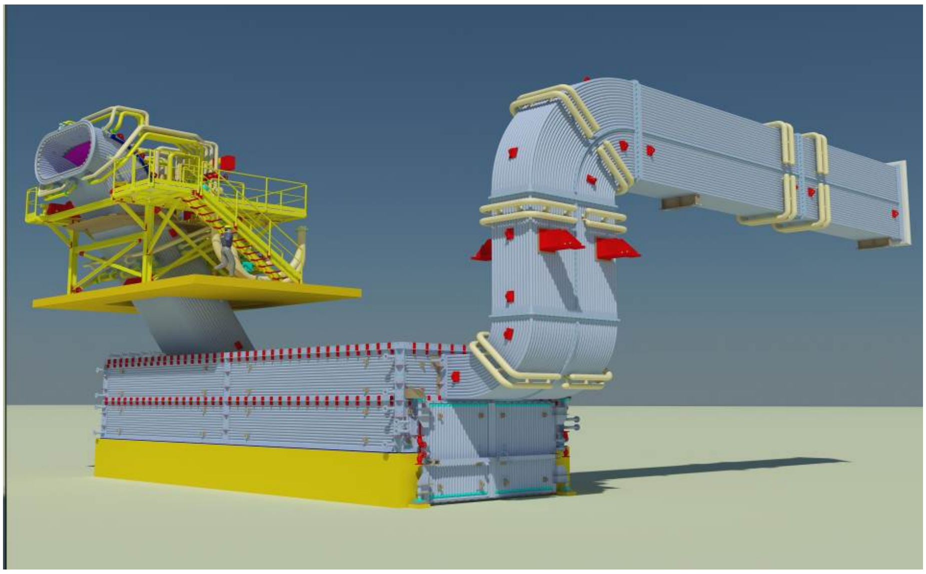

Figure 1. Cooled FTP components.

2 FTP COOLING SYSTEM

The process diagram shows a typical scheme used for the treatment of the primary and secondary fumes in electric steelmaking. Before entering the bag filter, the primary fumes sucked from the EAF are cooled by various equipment's which are installed in series:

- fourth hole elbow duct;
- mobile duct;
- cooled components of post-combustion chamber;
- cooled fume duct;
- natural heat exchanger (hairpin cooler);
- dilution with secondary fumes.

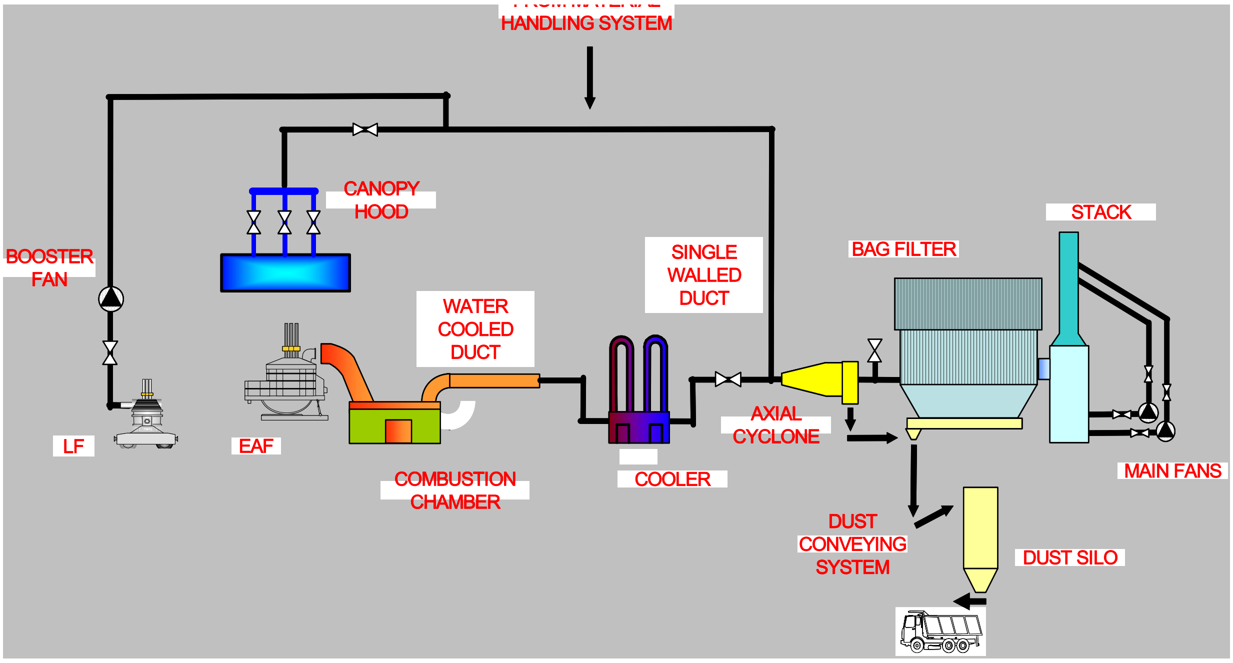

Figure 2. Typical scheme used for the treatment of the primary and secondary fumes in electric steelmaking.

The components of the plant which traditionally are water-cooled with a pipe-to-pipe design (fume ducts and post-combustion chamber) can be built to resist an internal pipe pressure much greater than atmospheric pressure in order to be cooled by hot water.

Figure 3. Cooled fume duct system.

3 HEAT CONTENT OF EAF FUMES

The following table provides the heat balance of a modern EAF charged with scrap:

Table 1. Heat balance of a modern EAF charged with scrap

ENERGY INPUT	kWh/tls	ENERGY OUTPUT	kWh/tls
Electric energy	410	Liquid steel enthalpy	385
Fuel gas / oil	53	Slag enthalpy	74
Coal (charge + injected)	149	Fume heat loss	194
Electrodes	14	Water heat loss	70
Chemical reactions	131	Electrical loss	21
Metallic charge enthalpy	-	Other losses	14
TOTAL INPUT	757	TOTAL OUTPUT	757

Assuming a liquid steel production of 70 tph, the thermal power given to the primary fumes is approximately 15 MW. This value shows that the potential energy to be recovered is significant and there is no wonder that various heat recovery systems have been developed, such as scrap pre-heaters.

Scrap pre-heating systems are not always seen favorably, due to their additional investment cost and maintenance; in addition some environmental issues have been associated with this solution, in particular when the scrap is heavily contaminated by organic materials.

Concerning the use of hot water in the circuit of the hot fumes, this is an option already applied for corrosion issues, and can be easily improved to be used for feeding ORC turbines.

4 HOT WATER TEMPERATURE FUME COOLING

Because all fume treatment plants for EAF must include cooled components, the simplest approach for recovering the fume heat is to make a beneficial use of the energy transferred by the fumes to the cooling media.

An alternative or supplementary option is the insertion of an Heat-Exchanger/Economizer after the water cooled ducts, in this way it’s possible to avoid the installation of air coolers or quenching towers; this solution allows to recover the large amount of heat available at relatively low temperatures, not recoverable directly by water cooled panels.

Usually, cooling water enters the water-cooled parts at a temperature of 30°C and exits at around 50°C, a temperature which is too low for economical heat recovery, except for particular situations, such as the on-site requirement of large quantities of heat for other industrial uses. Some plants uses high temperature cooling water, approximately 120°C, to improve the lifetime of the ducts preserving from corrosion and reducing the thermal stresses. High temperature cooling water of FTP components is the solution to this problem, because heat can be transferred more efficiently keeping the traditional FTP layout arrangement with a proved solution.

5 ORGANIC RANKINE CYCLE (ORC) TURBINES

As previously mentioned, recovered energy can be used to feed an ORC turbine to produce electric power. In general, Rankine cycle is a cycle that converts heat into work. The heat is supplied externally to a closed loop.
The Organic Rankine cycle (ORC) is named for its use of an organic, high molecular mass fluid with a liquid-vapor phase change curve, or boiling point, occurring at a lower temperature than the water-steam phase change. The fluid allows Rankine cycle heat recovery from lower temperature sources such as biomass combustion, industrial waste heat, geothermal heat, solar ponds etc. The low-temperature heat is converted into useful work, that can itself be converted into electricity.
This means that, by using the heat from the Fumes Treatment Plant, it's possible to obtain electric power.

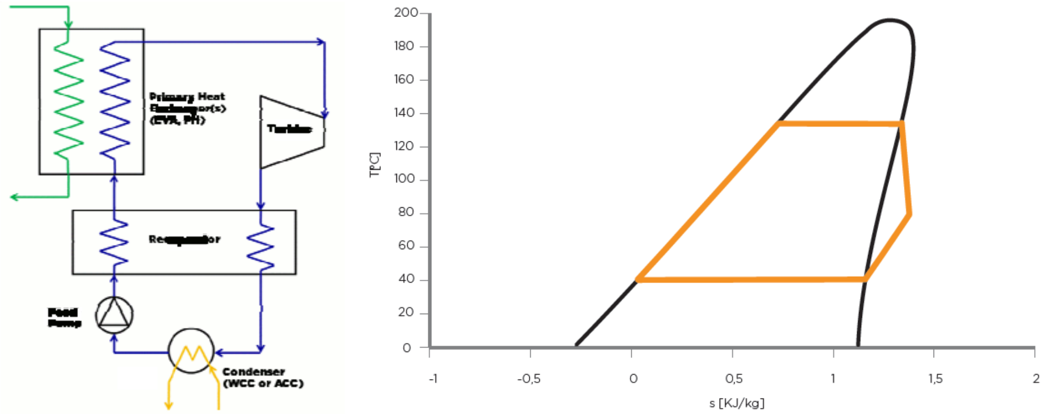

Figure 3. Organic Rankine Cycle (ORC) turbines.

The advantages of this technology, compared to steam turbines, are based on:

- simple completely automatic machine;
- no O&M costs;
- choice of the right fluid to get the best heat recovery and conversion efficiency;
- direct Coupling with generator and grid;
- suitable for frequent start&stop cycles;
- good off-design performances.

6 CHR ®-CLEAN HEAT RECOVERY

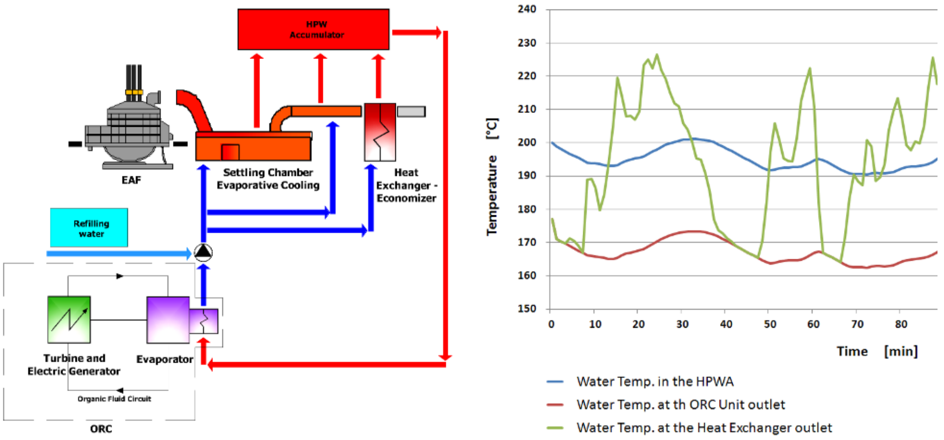

Figure 4. CHR ® - Clean Heat Recovery.

All EAF fumes treatment plants must include a cooling system. The simplest approach for fumes heat recovery is to use proved solutions like hot water cooling jointly with ORC turbines. In particular, the cooling water that flows in the cooling panels, in the cooled duct and economizers can be directly stored in a reservoir (HPWA). The reservoir has the function to guarantee a continuous energy feeding to the ORC turbine.

7 FIRST REALIZATION

First *Danieli* CHR®- Clean Heat Recovering plant will be installed at ABS (Italy) within 2013. Actually, at ABS, EAF primary fumes (extracted from the fourth hole of the EAF roof) are cooled by water cooled panels and by a FDC (Forced Draft Cooler).

At ABS the FDC will be replaced by a pressurized hot water recovery system. In this way use of FDC cooler fans is not necessary resulting in an additional electric energy saving. This solution is suitable in case of revamping in existing plants without significant layout modifications.

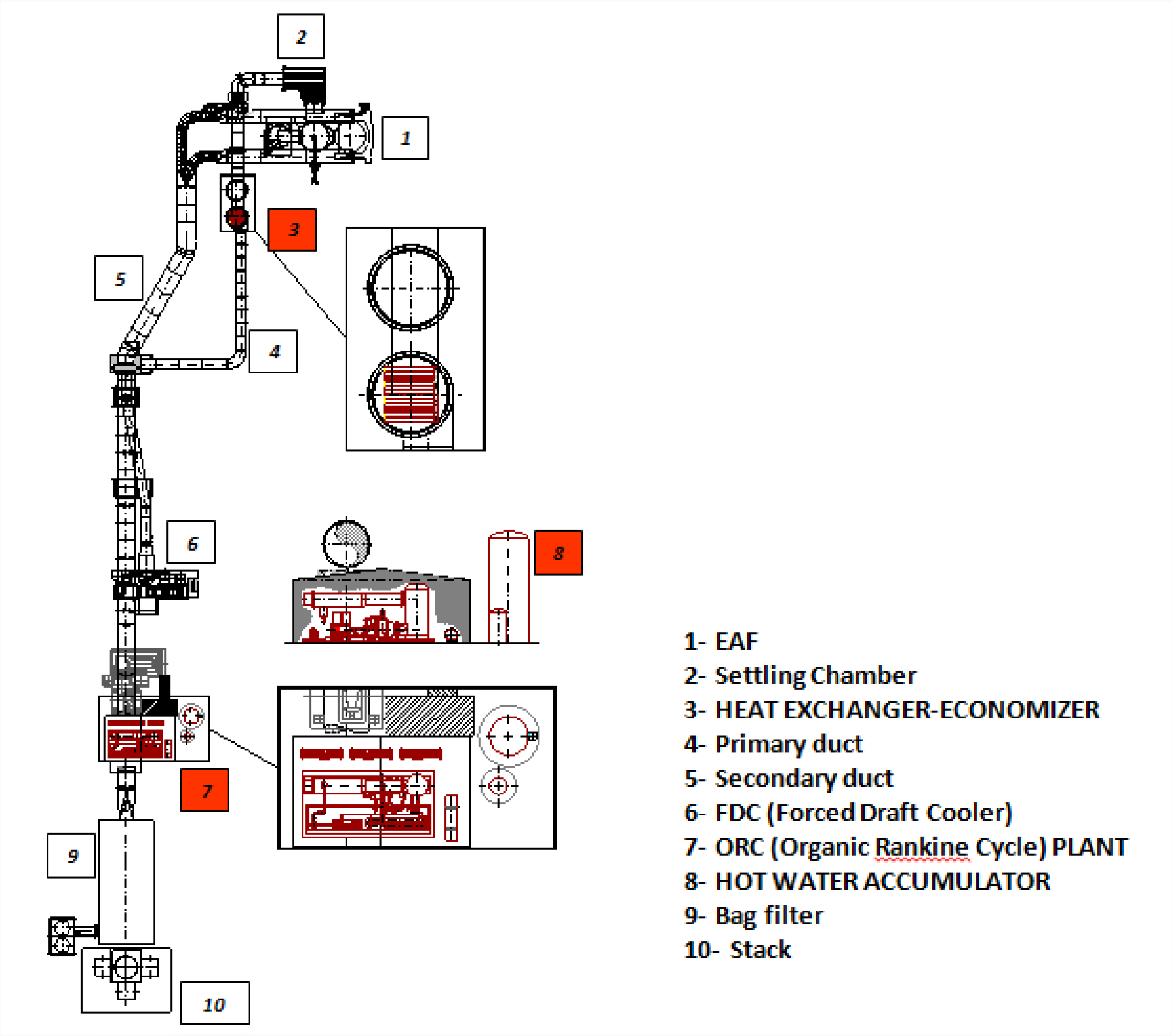

Figure 5. CHR® - Clean Heat Recovering future installation layout at ABS (Italy).

Hot fumes heat water up to 200°C; produced hot water, coming out from heat exchanger, is sent to an accumulator mainly for two reasons: first because melting process is discontinuous while ORC recovery plant performances are optimized in case of continuous energy feeding; hot water accumulator decreases temperature oscillations maximizing electric energy production; in addition a water storage guarantees a power supply in case of EAF power off.

8 SYSTEM INVESTMENTS AND PERFORMANCE

Table 2. ROI calculations based on EAF 50Tons,TTT 47 min

Power balance:		
Power at settling chamber inlet (Average	12 MWt	
Removed power from settling-combustion chamber (average)	6 MWt	
Electrical power at generator	1 MWe	
Energy balance		
Working hour per year	7200 h/y	
Energy recovered in 1 year	7200 MWhe/y	
Steelmaking productivity	70 tons/h	
NET Energy saving	15 kwh/tons	
Cost balance:		
Energy cost (average)	0.1 USD/kWh	
Energy yearly produced	7.560.000 kWh/y	
Energy cost Recovered	756.000 USD/y	
Environmental Benefit:		
CO2 saved	2300 t/y	
Green credits (Country by Country)	11-33 USD/MW	80000-200000 USD/y

In general, the quantity of recovered heat depends first of all on the size and melting profile of the EAF, which determine the design of the primary fume system. At ABS the target is to recover 5.5 MW of thermal power.

Table 3. CHR® - Clean Heat Recovering system performance

Power balance	
Removed power from Waste heat recovery	**5,5 MWt**
Nominal ORC power	**1 MWe**
Energy balance	
Energy recovered in 1 year	**5.760.000 kWhe/y**
Cost balance	
Energy cost (average)	**0.1 €/kWh**
Energy cost Recovered	**576.000 €/y**
White Certificates	**400.000 €/y**
Environmental Benefit	
CO2 saved	**2300 t/y**

In the conclusion, do not mention incomplete papers; new hypotheses may be shown whenever they are well justified; recommendations may be included. They should be precise and clear, and based on the objectives of the study.

Assuming a cost of electrical power amounting to 0.1 €/kWh, the estimated annual saving is approx.. 576,000 EUR, an amount surely sufficient to make attractive the additional cost of CHR®. The last raw of the table indicates the cut in the air emission of carbon dioxide, a dangerous green-house gas. If, instead of natural gas, oil fuel or coal, EAF off-gas are used to produce energy, a reduction of the CO2 emissions is obtained. Recovering part of the waste give also the opportunity the access to public financing. The amount of this financing for emissions reduction is variable country by country, and has a big contribution in the return of investment time. In green-field plants, energy recovered can reach values of 15 kWh/t-20 kWh/t of produced steel.

Steelmaking is an energy demanding industry which offers various opportunities to recover energy and waste heat recovery using hot water for electrical power generation via ORC turbines can well combine cooling efficiency, low maintenance and economic feasibility with environmental sustainability.