Transforming Bottom Ash Into Fly Ash in Coal Fired Power Stations

MAR – MAGALDI ASH RECYCLING: Fiume Santo Project Experience

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ABSTRACT

The article describes the operational experience of the first installation of the Magaldi Ash Recycling (MAR) system. The system was installed at a 2x320 MW PC fired power plant in Fiume Santo (E.ON.). The MAR system is a recycling process that transforms bottom ash to fly ash by returning the dry bottom ash to the boiler combustion chamber.

Bottom ash is removed from beneath the boiler using a MAC® (Magaldi Ash Cooler) System. This system extracts and cools the bottom ash, and then the ash is conveyed back to the coal feeders, where it is mixed with the coal, milled and reintroduced into the furnace. The MAC® system is a proven technology with more than 100 installations worldwide, on boilers generating more than 35,000 MW.

The effects of reinjection of bottom ash will be discussed including the results of the analysis. The benefits of the MAR system for the study power station are remarkable, and can be summarized by the following achievements:

- Conversion of all bottom ash into saleable fly ash
- Complete elimination of costs associated with bottom ash disposal
- LOI (Loss On Ignition) content reduction in fly ash due to dilution effect.
- Fly ash is in compliance with international standards.
    - *In EU these are EN 197-1:2000/A3:2007 for cement and EN 450 1:2005/A1:2007 for concrete (LOI ≤ 5% and fineness ≤ 40% by mass as oversized particles on a 0.045 mm mesh sieve when wet sieved).*
- Environmental benefits occur from mixing fly ash with cement, thereby reducing the production of cement and leading to a decrease in CO_2 emissions that would have been produced without using fly ash as a "type II addition" (approximate reduction of 0.9 tons of CO_2 for each ton of fly ash used)

Patents related to the system are the following:

- "Steam generating system and method for discharge of ash" International Patent N° EP 471055 B1, priority IT 1955490 of March the 2nd 1990
- "Integrated system for the extraction of heavy ash, conversion thereof into light ash and reduction of unburned matter", Application Number PCT/EP 2005/007536, priority IT MI 2004 A 001371 of July the 9th 2004

1. INTRODUCTION

The bottom ash systems of units 3 and 4 at the Fiume Santo Power Plant were retrofitted with MAC (Magaldi Ash Cooler) dry bottom ash systems in 2003. The conversions were done to take advantages of the many benefits this technology has to offer including zero water usage, reliability, low maintenance and the possibility to sell bottom ash with fly ash to the cement industry. The retrofit included a supply of a pressure system to convey pulverized bottom ash to the existing fly ash storage silo.

- The design of the MAR system included utilizing this existing pneumatic system for conveying of the bottom ash

1.1. Boiler Characteristics

The Units 3 & 4 at Fiume Santo power plant are each rated at a nominal 320 MW_e. The boilers are equipped with tangential burners at. 6 (six) burner levels and are fed by positive pressure Raymond XRP783 coal bowl mills. The coal mills are identified with the letters "A" thru "F" preceded by the Unit number.

1.2. Fuel Characteristics

Both Units are currently fed with pulverized coal however in the near future they will be up-graded for the co-combustion of coal and biomass. The maximum biomass feed rate will be 10 t/h, or approximately 5% of the total boiler thermal input.

The coal has a medium to high ash content (e.g. South-African) with an average LHV of 6,000 kcal/kg, while the biomass LHV is around 4,000 kcal/kg.

1.3. Total Combustion Air

The total combustion air rate is on average equal to 1,200 t/h.

1.4. Bottom Ash Data

1.4.1. Density

The bottom ash density is assumed to be 700 kg/m^3 for volume calculations and 1,400 kg/m^3 for structural calculations.

1.4.2. Size Distribution

The bottom ash grain size distribution downstream the MAC system is not constant and is dependent on the secondary mill pulverization efficiency. The assumed ash grain size distribution is: 10.54% < 1.18 mm and 100% < 5.0 mm. Each mill has a maximum capacity of 12 t/h.

1.4.3. Flow Rate

The maximum bottom ash rate is estimated to be 1.84 t/h @ MCR, assuming a maximum ash content in the coal of 16% and a bottom / fly ash split of 10% / 90%. Allowing for the sootblowing cycle (nos. 3 times per day), the maximum bottom ash rate is 3.0 t/h.

The following table summarizes the main fuel data and the ash rates.

FUELS & ASH DATA			
Imported Coal Rate at MCR		t/h	115
Coal	Ash	%	12.0
		%	16.0 *(max)*
	Net Calorific Value	kJ/kg	25,000
Ash	Total Rate	t/h	~ 18.4
	Bottom Ash Rate	%	10
		t/h	~ 1.84 *(normal)*
		t/h	6 *(sootblowing)*
		t/h	9 *(design)*
Roller Mill	Type	-	Raymond
	Number	-	6 *(one in stand-by)*
	Overpressure	mmH_2O	300 *(normal)*
	Coal Rate	t/h	40 *(nominal)*
		t/h	32 *(max set)*
		t/h	23 *(normal)*
Ash Recycling	Number of Mill	-	4
	Bottom Ash Rate x Mill	t/h	0.46
	Mill Rate Increase	%	2.0 *(normal)*

Table 1: Fuel and Ash Data

2. MAR SYSTEM: TECHNICAL SPECIFICATION (FIUME SANTO PROJECT)

The MAR system is comprised of the following equipment:

- “Pneumatic Conveying System” with basalt lined pipes, feeds the reception bins installed at 18m elevation by a diverter valve.
- “Reception bins”, temporarily store bottom ash to be recycled. Those bins are loaded from the top by a dedicated valve. The bin venting is directly connected to the combustion chamber at 35m elevation. Each bin is provided with two separated discharge ducts, one per single coal mill.
- “Vibro-feeders”, feed ash into the coal mills. The ash feed rate is automatically adjusted to the corresponding coal feeder rpm.
- “Pneumatic Knife-gate Valves”, installed at each vibro-feeder discharge point.
- “Pneumatic Ball Valves”, installed on each bin venting in order to seal the reception bins from the combustion chamber.

The following flow-diagram shows in detail the bottom ash recycling system adopted for Fiume Santo power plant.

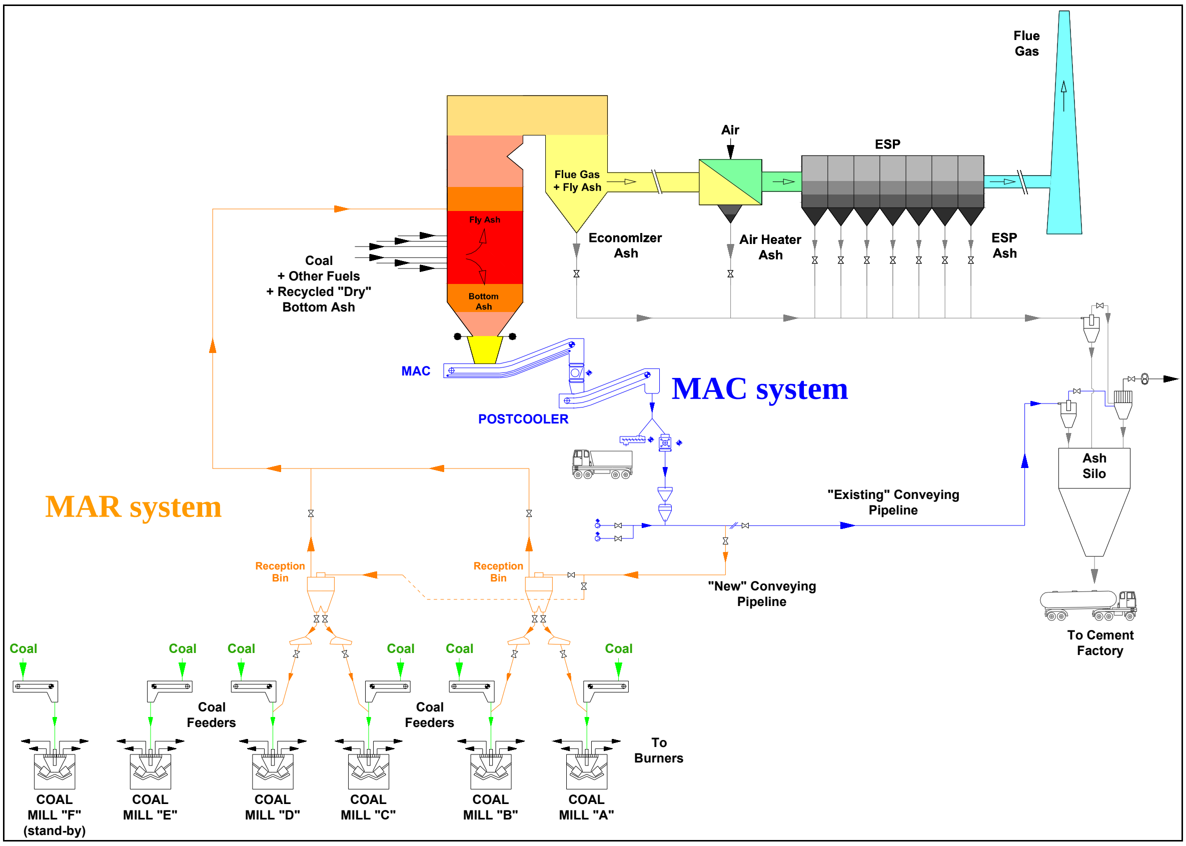


Figure 1: MAR System Flow-Diagram

2.1. *Pneumatic Conveying System*

The pneumatic conveying pressure system was installed in 2003 downstream of the MAC® "dry" bottom ash extraction system. In order to recycle the pulverized bottom ash a new conveying line was installed to convey the ash to the reception bin.

The control system can specify one of two operating modes:

1. Pulverized bottom ash conveyance to the fly ash silo for final mixing and storage (no longer in compliance with international standards).
2. Pulverized bottom ash recycling to the combustion chamber by the MAR system, in order to transform bottom ash and not to consider it as a simple waste from the combustion process.

In case of the recycling line is selected, bottom ash is pneumatically conveyed as far as the reception bin at 18m elevation.

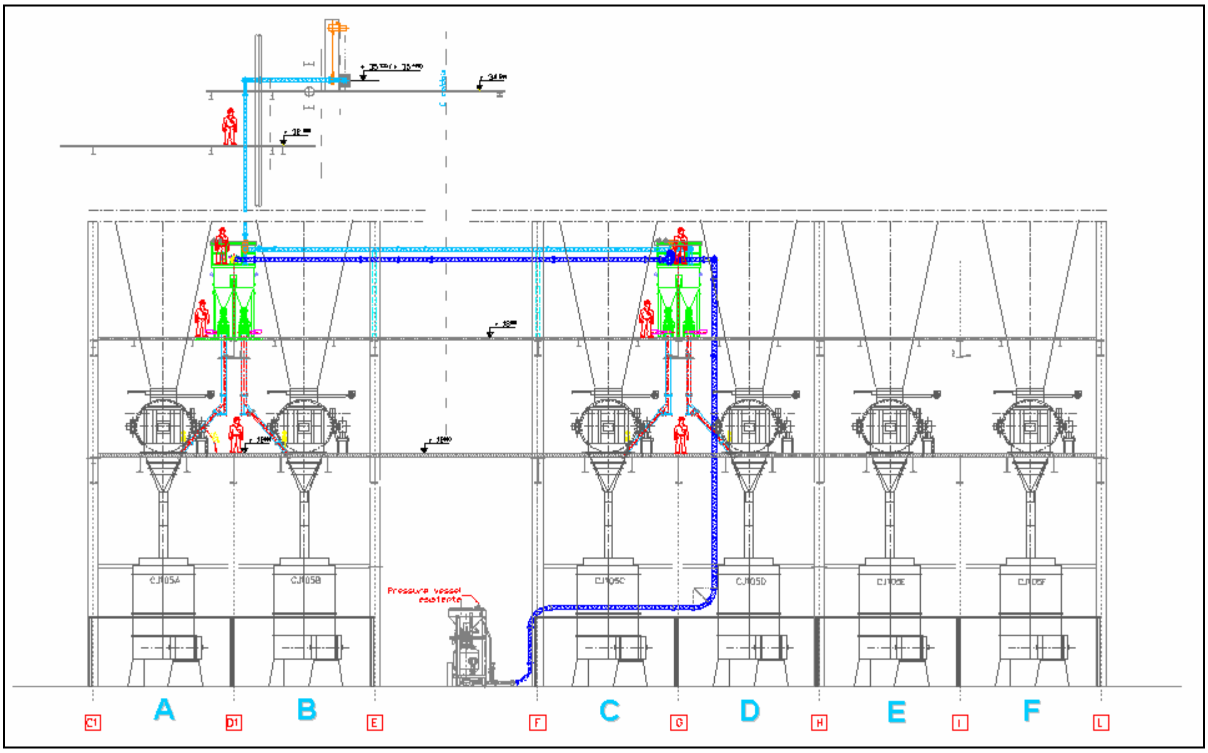


Figure 2: Conveying Pipe Route

2.2. Reception Bins

In each reception bin the course ash settles to the bottom while the finest particles are conveyed by the transport air directly to the combustion chamber. Bottom ash is extracted from the reception bins by tubular vibro-feeders, and discharged directly in the coal mill feeding hoppers. A single reception bin serves 2 coal mills, therefore it is necessary to install two vibro-feeders for each reception bin. Each Reception Bin is provided with a bursting disc for pressure relief and 4 level probes for control purposes.

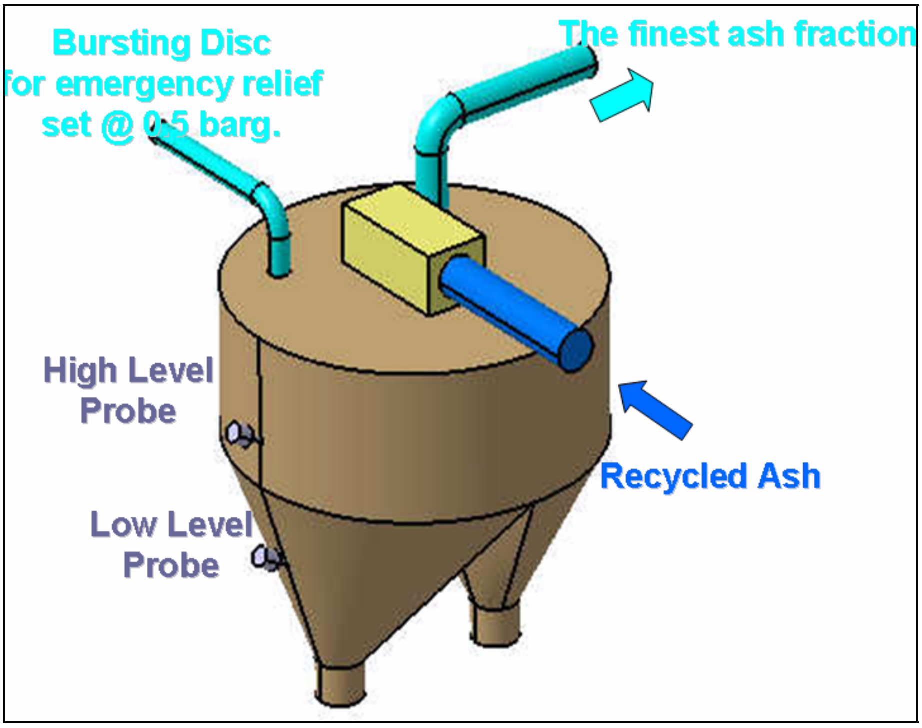


Figure 3: Reception Bin

The reception bins also provide a bottom ash classification ensuring that only the fines will directly be injected into the combustion chamber.

2.3. Reception Bin Venting

For each reception bin, the conveying air is fed in the boiler through an existing inspection door installed at 35m elevation. The pipe cross section is chosen to ensure the following:

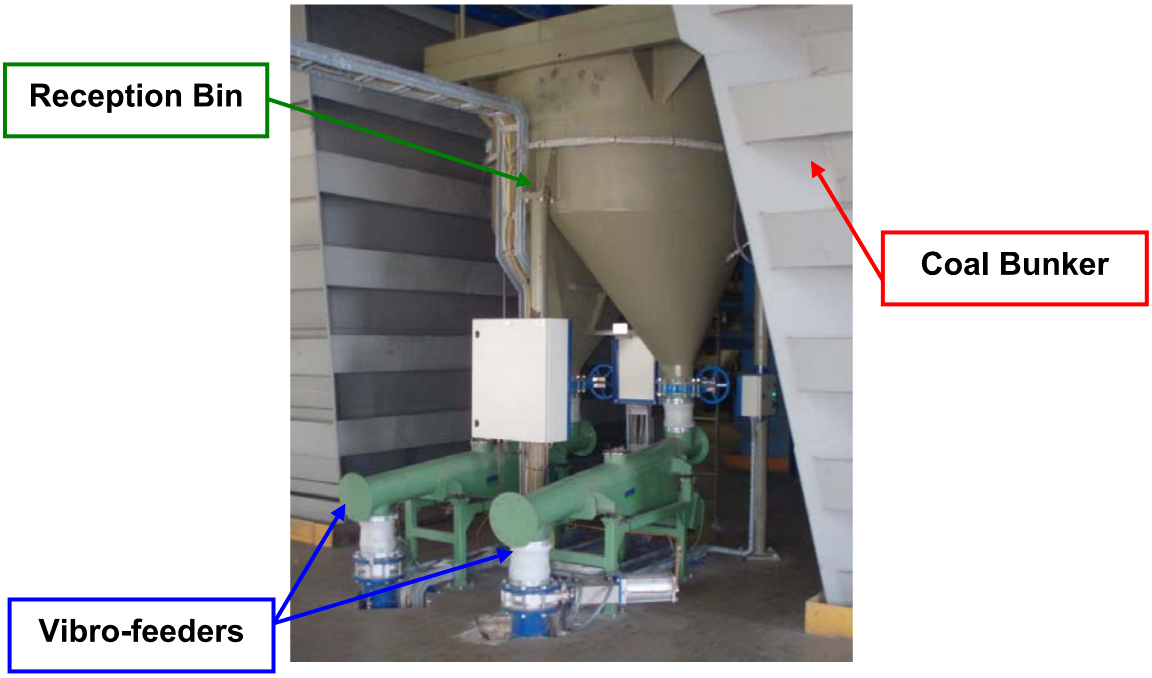
- The high velocity necessary to avoid ash settlement in the pipe
- A suitable inlet velocity for the combustion chamber

Picture 1: ***Bin Venting Connection to the Combustion Chamber***

2.4. Vibro-Feeders

Four vibro-feeders are used in the system. The control system adjusts the recycled ash rate as a function of the actual coal feed rate in the combustion chamber. This control system maintains a fixed ash to coal ratio at the coal mills.

After the coal mill pulverization, the mixture is conveyed by the primary air to the coal burners and then injected in the combustion chamber where the pulverized bottom ash is transformed into fly ash.



Picture 2: Reception Bin View

3. FUNCTIONAL DESCRIPTION

The MAR system uses the existing pneumatic conveying pressure system installed downstream for the MAC system for “dry” bottom ash handling. Utilizing new pipe routing the bottom ash is be directed to the reception bin at the 18m elevation.

During start-up operations the system is operated in manual mode in order to ensure a minimum ash level in the reception bins. This minimum level must be maintained in order to ensure the separation between the positive pressure equipment (coal feeders and mills) and the negative pressure of the combustion chamber.

The ash level in the reception bins is generally kept constant by 2 low level probes. The reception bin loading is controlled by 2 high level probes.

Each reception bin has two unloading points with dedicated vibro-feeders for bottom ash feeding of the coal mills. Regulated by the control system, the ash feed rate to the coal mills is a function of the corresponding coal feeder speed (rpm).

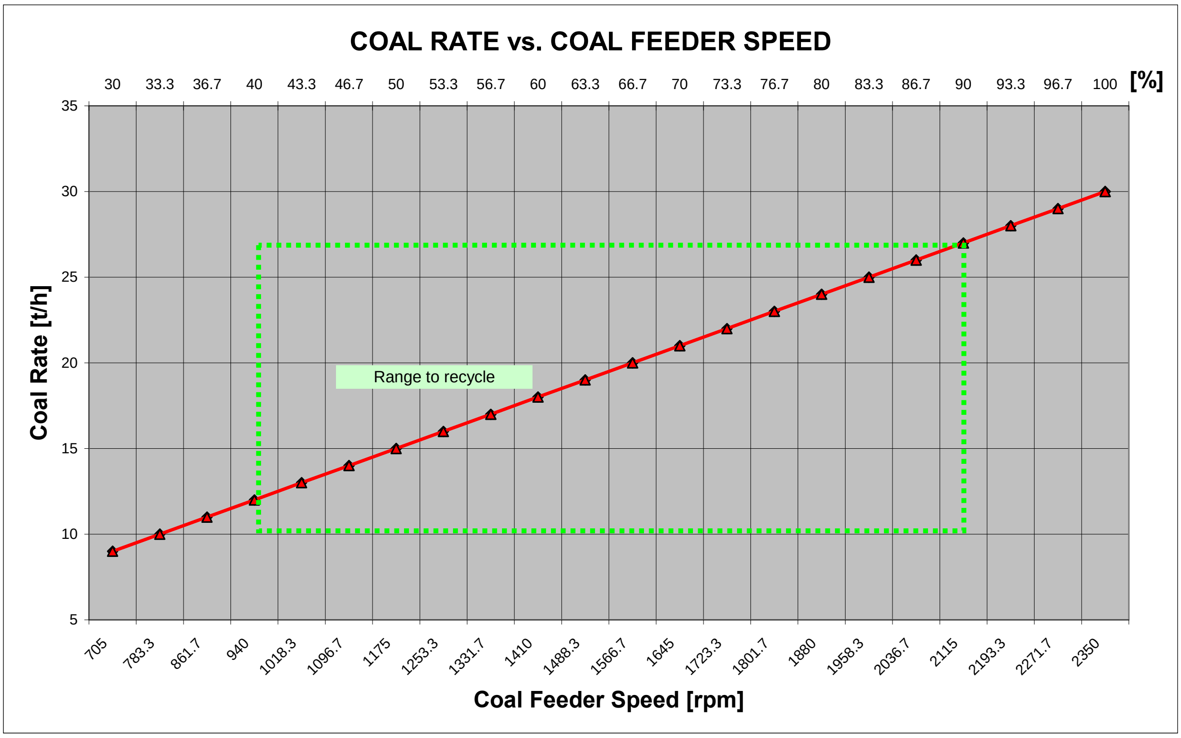


Figure 4: ***Coal Rate vs. Coal Feeder Speed***

The above figure provides the coal feeder characteristic curve and the operating range for bottom ash recycling (40 - 90%). Each coal mill has a nominal capacity of 40 t/h while the maximum coal rate is set at 30 t/h, with a corresponding 2,350 rpm on the coal feeder drive shaft. The characteristic curve is “linear” in shape, as shown in Fig.4. If “$Q_{i,coal}$” is the coal rate [t/h] and “N_i” the “i-th” coal feeder speed [rpm]:

$$\dot{Q}_{i,coal} = \frac{15}{1{,}175} \times N_i$$

The distribution of the total bottom ash rate to be recycled “$Q_{tot,ash}$” depends on:

- Number of available reception bin
- Number of available coal mills (from “A” to “D”)

and it is directly proportional to the coal feeder speeds:

$$\dot{Q}_{i,ash} = \dot{Q}_{tot,ash} \times \frac{N_i}{\sum_{i=1}^{k} N_i}$$

where “k” depends on the above mentioned parameters. For example, in the case where both reception bins and all coal mills (“A” to “D”) are available, the parameter “k” is equal to 4.In case where only one reception bin and one coal mill is available, “k” is equal to 1 and it is not possibility to recycle bottom ash.

It follows that in the case where both reception bins are available, the following operating conditions can occur:

- One (1) coal mill unavailable: bottom ash recycling by 3 coal mills.
- Two (2) coal mills unavailable: bottom ash recycling by 2 coal mills (this configuration should last as short as possible in order to reduce the coal mill wear phenomena).
- Three (3) coal mills unavailable: bottom ash recycling is not possible.

The automation system ensures the bottom ash recycling will be performed according to one of the three conditions detailed above.

Based on these conditions the bottom ash rate for the coal mill is adjusted by regulating the flow from the corresponding vibro-feeder. Once calculated the bottom ash rate to be recycled “$Q_{i,ash}$”, a suitable control signal is sent to the vibro-feeder.

The next figure shows a typical vibro-feeder characteristic curve.

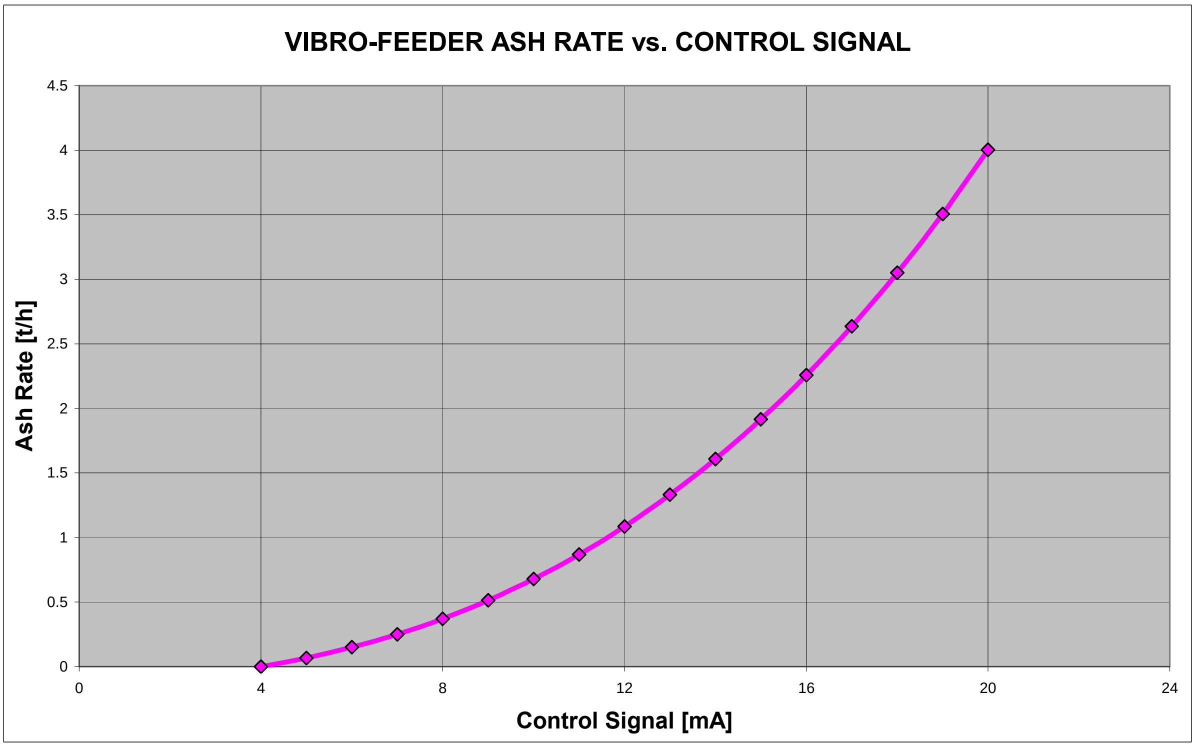


Figure 5: Vibro-feeder Ash Rate vs. Control Signal

4. OBJECTIVES AND FINAL RESULTS

After the MAR system installation in Fiume Santo power plant, some experimental activities have been carried out with the following objectives:

- Evaluation of Coal mill wear
- Fly ash (produced with MAR system in operation) certification in compliance with the European standard EN 450-1:2005/A1:2007

4.1. Coal Mill Wear

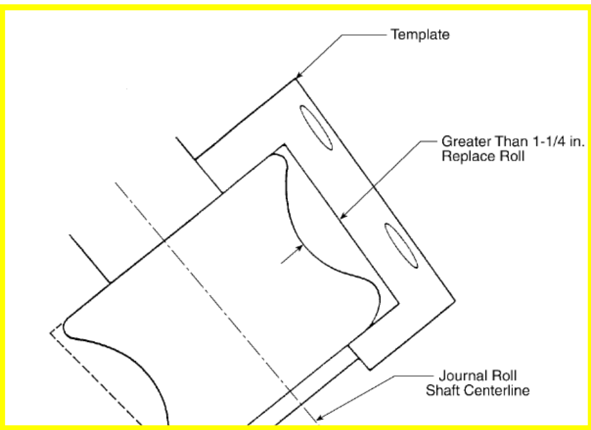
As indicated in § 1.1, each boiler is provided with six (6) Raymond XRP 783 coal bowl mills at positive pressure (one in stand-by) and a tangential firing system.

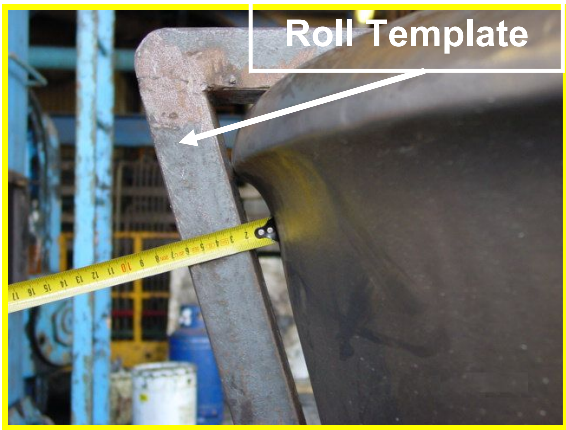
The coal mills are indicated with the letters from “A” to “F” (one in stand-by) preceded by the Unit number. Mills “A” thru “D” are involved in the ash recycling; coal mills “A” and “B” are equipped with “standard” rolls while “C” and “D” are equipped with “regenerated hard-facing” rolls. The coal mill “E”, which pulverizes only coal, is provided with “standard” rolls and will be used as the reference (control) mill.

The dimensional inspection on the coal mill wear parts is scheduled to be performed every 2,000 to 2,100 operation hours, with a detailed inspection of the grinding rolls, the segmented grinding ring and the classifier. The following pictures show the grinding roll condition before and right after the observation period.

Picture 3: A Grinding Roll View Inside the Mill

At the end of each observation period, the dimensional deviation due to wear has been measured using a roll template. Additionally each grinding roll has been weighed in order to measure the amount of roll material loss.





Pictures 4 & 5: New Roll Template to Evaluate the Grinding Roll Wear

The next figures show the numerical results of the above mentioned experimental phase after one year and a half with the MAR system in operation.

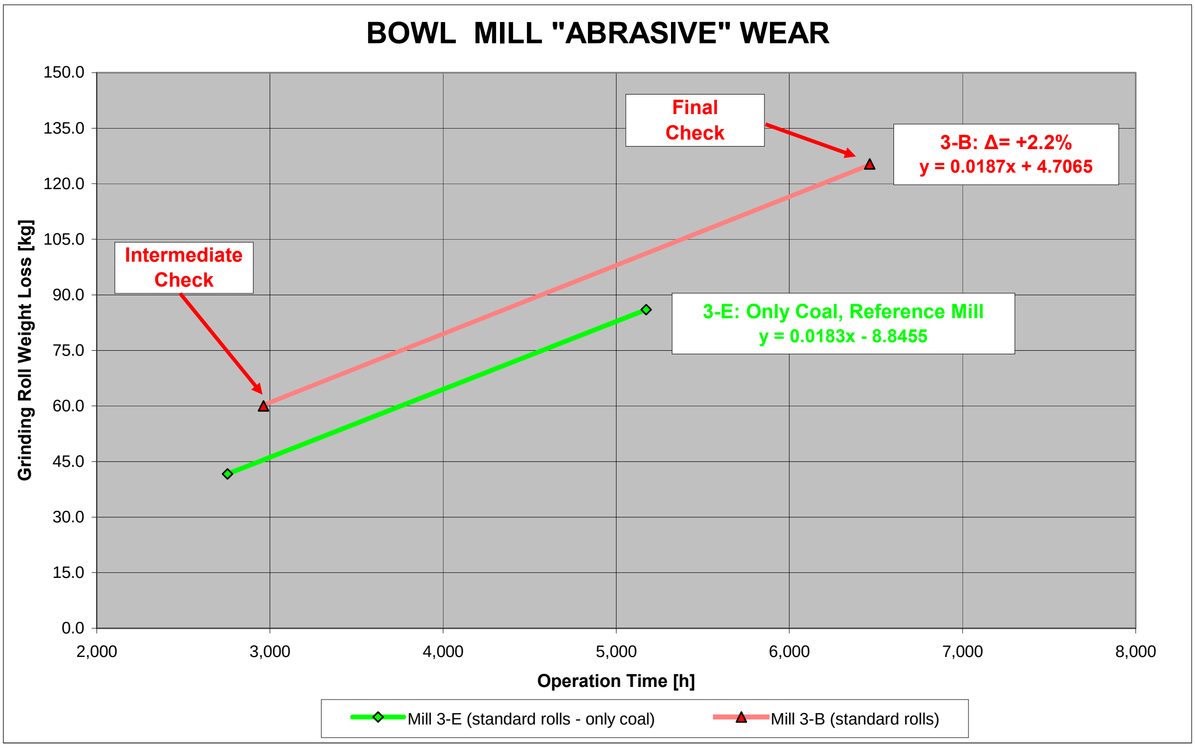


Figure 6: Bowl Mill "Abrasive" Wear Results (between the final check and the intermediate one on the mills provided with "standard rolls")

Note: the wear of the coal mill "A" is not shown in the previous figure as there were some technical issues on the machine.

Evaluating the time interval between the "final" check and the "intermediate" one, only a very slight difference was observed when comparing the coal mills "B" and "E" (both provided with "standard" rolls). Evaluating the corresponding weight loss over the same time results in a wear rate increase of only +2.2%. This wear rate deviation was observed with a bottom ash rate equal to approximately 1.0 t/h, or an ash to coal ratio of approximately 1.1% on each coal mill.

Earlier testing results from 2007 indicated higher wear rate and were based solely on dimensional measurements. Current testing utilizes weight differences to more accurately depict material being lost from the mills grinding rolls.

In addition to roll wear, inspections were carried out on the coal mill classifiers have shown no appreciable wear differences. The same observations were made of the boiler burners after the preliminary inspections in January, 2008.

4.2. *Fly Ash Certification*

The implementation of the MAR system had to also demonstrate there would be no impact on the fly ash properties due to the bottom ash recycling. All fly ash and recycled bottom ash in compliance with the European standard EN 450-1:2005/A1:2007 is recognized as a valuable product for cement and concrete industry.

Therefore, by utilizing the MAR system, bottom ash is no longer considered a coal combustion waste. It is now considered a beneficial product since it has been turned into fly ash.
In order to gain the mentioned product certification, in 2007 the power plant had to certify all manufacturing processes from coal ship unloading to fly ash delivery at the final customer (UNI EN ISO 9001, § 3.4.1; 3.4.2).

The manufacturing phases which were implemented and certified are the following:

- General direction activity
- Human resources management
- Infrastructure management
- Customer product specifications
- Product design and development
- Supply chain management
- Ship unloading operations
- Raw material handling and carriage to coal yard
- Raw fuel management
- Fly ash production
- Production process control
- Monitoring and measuring device settings
- Process measuring, analyzing and improving activities

The quality handbook details all procedures to gain the process certification. During the first three months the quality procedures led to perform chemical and physical analyses briefly shown in the following tables.

CHEMICAL ANALYSIS SPECIFICATIONS [2]		
ELEMENT	**LIMIT**	**LIMIT DESCRIPTION**
Loss on ignition	Category A: < 5.0% by mass Category B: 2.0 ÷ 7.0% by mass Category C: 4.0 ÷ 9.0% by mass	ranging value
Chloride	0.10% (by mass)	maximum value as Cl^-
Sulfuric anhydride (SO_3)	3.0% (by mass)	maximum value
Free calcium oxide	2.5% (by mass)	maximum value
Reactive calcium oxide	10.0% (by mass)	maximum value
Reactive silicon dioxide	25% (by mass)	minimum value
Silicon dioxide (SiO_2), aluminum oxide (Al_2O_3) and iron oxide (Fe_2O_3)	Sum 70% (by mass)	minimum value
Alkalis	5.0% (by mass)	maximum value
Magnesium oxide (MgO)	4.0% (by mass)	maximum value
Soluble phosphate (P_2O_5)	100 mg/kg	maximum value

Table 2: Chemical Analyses [2]

PHYSICAL ANALYSIS SPECIFICATIONS [2]		
CHARACTERISTICS	**LIMIT**	**LIMIT DESCRIPTION**
Fineness	Category N: 40% oversize (by mass); ±10% variation limits from the declared value Category S: 12% oversize (by mass)	maximum value on a 0.045 mm mesh sieve
Activity index	75% at 28 days, 85% at 90 days	minimum values
Soundness	10 mm	maximum value
Density	±200 kg/m^3	Maximum deviation from the value declared by the producer

Table 3: Physical Analyses [2]

After the observation period a statistical results analysis was performed in accordance with the following specifications:

- Sampling by a third party (certification body)
- First quality audit by a third party (certification body) for process analysis
- Temporary certification based on declared results
- Certificate validation after further check
- Continuous monitoring activity for statistical analysis

An extensive analysis activity in compliance with the quality standards has demonstrated that the fly ash properties have not been influenced by the MAR system implementation.

The fineness of fly ash is expressed as the mass proportion in percent of the ash retained when wet sieved on a 0.045 mm mesh sieve (determined in accordance with EN 451-2:1996) and has to fall within the limits of the categories specified in EN 450-1:2005/A1:2007.

Figures 7 and 8 show the fineness and the LOI content monthly trends of the above mentioned activity before (April 2007) and after (May 2008) the MAR system implementation.

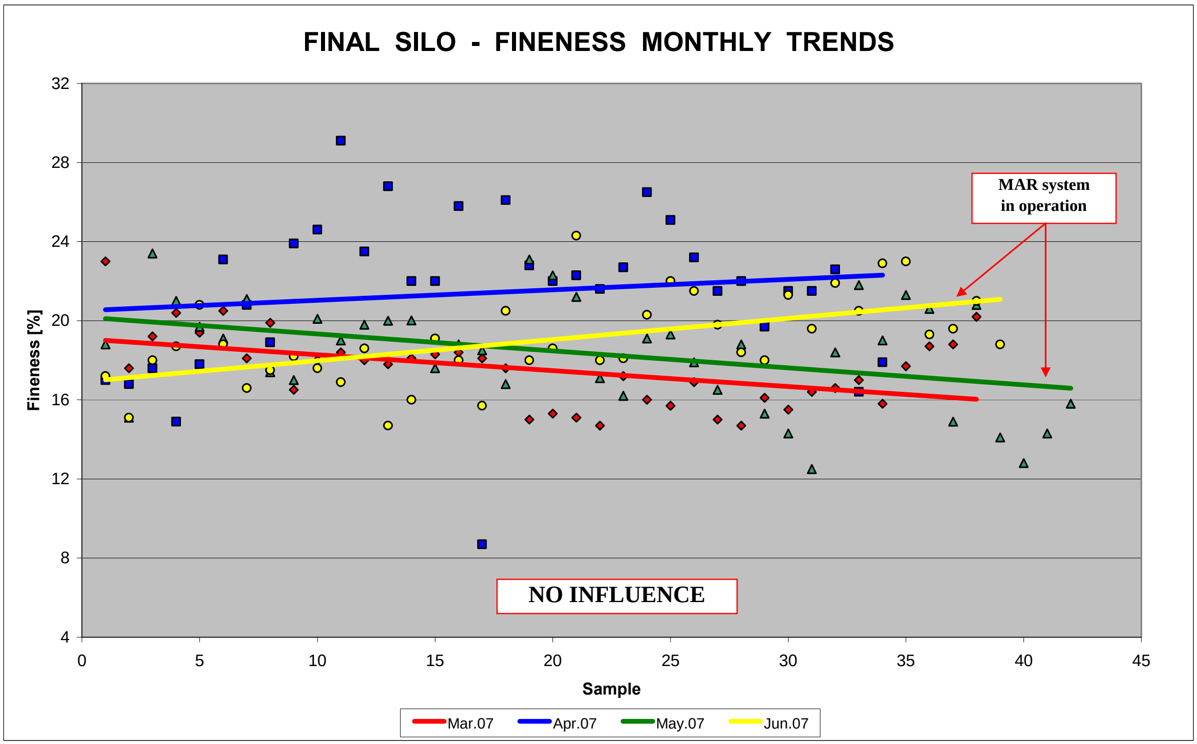


Figure 7: ***Fineness Monthly Trends*** ***(before and after the MAR system implementation)***

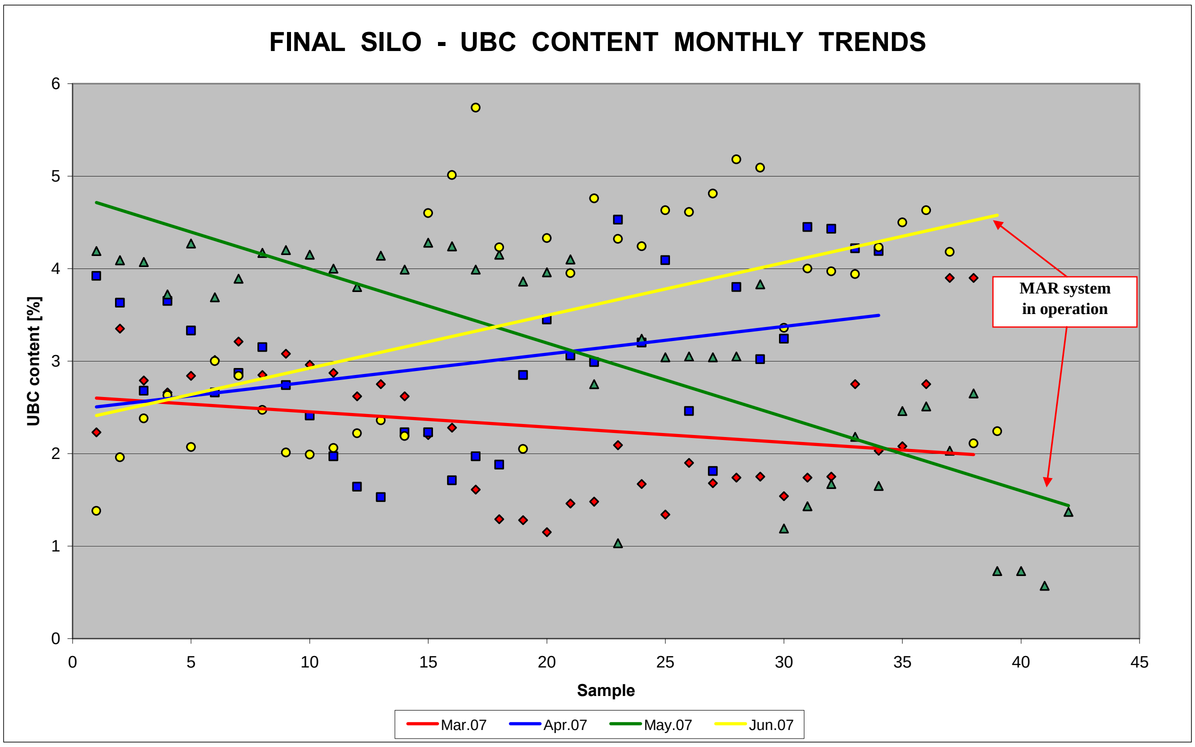
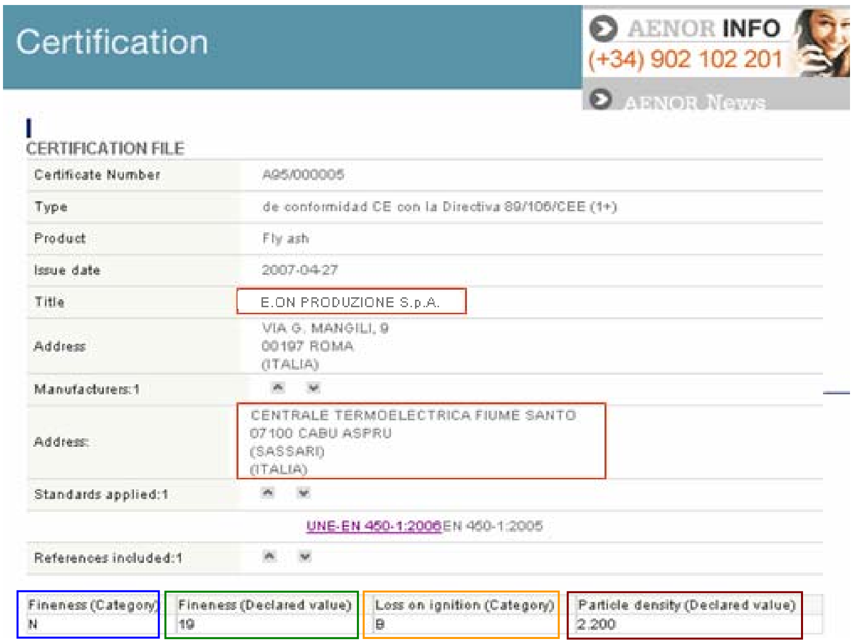


Figure 8: LOI Content Monthly Trends ***(before and after the MAR system implementation)***

In Figure 9, there is the fly ash certificate gained by E.On Produzione for Fiume Santo power plant in compliance with the European standard EN 450-1:2005/A1:2007.



Fly ash was marked with the following characteristics:

- Fineness: Category "N" (max 40% by mass > 0.045 mm).
- Fineness Declared Value: 19% (±10% variation limits).
- Loss on Ignition (LOI): category "B" (2.0 - 7.0% by mass).
- Particle Density: 2,200 kg/m^3 (±200 kg/m^3 variation).

Figure 9: ***EN 450-1:2005/A1:2007 Fly Ash Certificate***

5. CONCLUSIONS

The objectives set forth in section 4 have successfully been achieved with the following results:

1. The bottom ash recycling in the coal mills has proven to have a negligible impact on coal mill wear rate (+2.2% after one year and a half with the MAR system in operation).
2. The pulverized bottom ash conversion into fly ash increases the fly ash total quality. In fact, there is a LOI (Loss on Ignition) content reduction thanks to the dilution effect of bottom ash (~ 8% on average).
3. The bottom ash conversion into fly ash has no negative impact on fly ash properties leading to a bottom ash transformation from a coal combustion waste to a product suitable for sale to the cement industry
4. Fly ash production from the plant is increased with the addition of bottom ash recycling, certified CE in accordance with European standards, resulting in no-restriction of use or sales throughout EU Member States.

6. ACKNOWLEDGMENTS

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7. REFERENCES

[1] European Standard EN 197-1:2000/A3:2007 “Cement - Part 1: Composition, specifications and conformity criteria for common cements”.

[2] European Standard EN 450-1:2005/A1:2007 “Fly ash for concrete - Part 1: Definition, specifications and conformity criteria”.