MAP® – MAGALDI ASH POSTCOMBUSTOR

Post-combustion of carbon residues from biomass / RDF co-firing during dry ash removal

Fulvio Bassetti¹, Daniele Coppola¹, Daniele Ricci¹, Osvalda Senneca², Alberto Carrea¹

¹ Magaldi Power S.p.A., Via Irno 219, 84135 Salerno (Italy);
² Istituto di Ricerche sulla Combustione, Consiglio Nazionale delle Ricerche, P.le V. Tecchio 80, 80125 Naples (Italy)

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ABSTRACT

In some countries, as in the EU, current regulations provide incentives to promote co-firing of biomass / RDF with coal. Both the co-firing of biomass and RDF (Refuse Derived Fuel) as well as the conversion to 100% biomass combustion are under technical and economical evaluation. Operators are looking for ways to improve plant performance and lower both the environmental and economic impact. The grinding and firing systems of the existing coal-fired plants are not designed for those co-fuels. Any deterioration of the combustion performance would reduce the power output and increase ash disposal costs by increased content of combustion residues. Moreover, operating problems may occur at existing wet ash removal systems because of changes in ash properties (e.g. floating on water surface). The application of air cooled ash removal, with simultaneous and controlled post-combustion of unburned residues on the conveyor belt, enlarges the furnace and maintains combustion efficiency even with different fuel qualities. In addition the plant efficiency can be increased through heat recovery. This new ash removal technology supports operators and plant manufacturers in their efforts to make conventional coal plants more flexible and more efficient. For example when co-firing biomass, grinding power can be reduced and combustion completed during ash removal on the conveyor. Combined ash removal and post-combustion systems are successfully operating at ENEL Fusina Power Plant #3 & 4 (2 x 320 MW) and RWE Gersteinwerk Power Plant #K (770 MW), each with RDF co-firing, and at Plzenska Teplarenska Power Plant #3 & 4 (2 x 60 MW) co-firing biomass and RDF.
1. INTRODUCTION: DRY BOTTOM ASH HANDLING

In the last 25 years it has been widely demonstrated that a mechanical system can be used to extract bottom ash from large coal-fired boilers in a dry condition. Wet technology uses water to quench bottom ash generated by the boiler. It was and is still based on two main methods: Water Impounded Hopper (WIH) systems and Submerged Chain Conveyors (SCC). But growing concerns about water scarcity, environmental regulations, Wet Bottom Ash System (WBAS) reliability, and increasing awareness of the overall cost savings due to dry system, are some of the reasons why utilities are selecting the dry ash handling technology.

As an alternative option to the conventional wet systems, the MAC® system is a well proven and unique technology for the dry extraction of bottom ash from pulverized coal-fired (PCF) boilers. With hundreds of installations worldwide since 1980s, the MAC® Magaldi Ash Cooler is the world’s leading dry bottom ash handling system for utility and industrial boilers, of any size and burning any type of solid fuel.

![Picture 1: A MAC® System Installation in Mexico.](image)

The MAC® system is normally made of:

1. A mechanical seal, to connect the boiler to the MAC® system, allowing free furnace expansion.
2. A refractory-lined hopper, or a transition chute, between the furnace and the MAC® extractor.
3. A set of bottom doors, normally open. If necessary, the doors can be closed to store ash in the hopper when minor maintenance is required in the downstream equipment or in case of a sudden large ash fall (due for instance to sudden drop in temperature of the membrane walls).
4. The MAC® extractor that is the heart of the system. Its key component is the Magaldi Superbelt®, in stainless steel version, completely enclosed in a steel casing, suitable to ensure a safe operation, admit a limited amount of cooling air into the system and avoid dust dispersion to the environment. A scraper conveyor removes the fine residuals from the bottom of the casing.

5. A primary crusher for size reduction of large ash lumps and, if required, a hydraulic pre-crusher in case of very big ash clinkers.

6. A secondary conveyor, or Postcooler, to take the crushed ash to a storage silo, while extending the cooling effect. The Magaldi Ecobelt® is the most appropriate conveyor for that purpose.

In the MAC® system, ash cooling is carried out by ambient air, naturally drawn into the system by the furnace negative pressure. A limited amount of ambient air enters the system through accurately sized inlet valves located along the system. The system is designed to maximize the counter-current bottom ash cooling. Following the air/ash heat exchange, sensible heat from the ash is effectively transferred to the air.

One of the most important effects related to the use of the MAC® dry bottom ash technology is its impact on boiler efficiency. When the MAC® system is used instead of a WBAS, overall efficiency improvement of the boiler has been demonstrated, primarily because of the use of air as the ash cooling medium rather than water. High temperature air creates an oxidizing atmosphere inside the system, that promotes reduction of the unburned carbon contained in bottom ash. Flame radiation through the boiler throat is not lost into the water, as in conventional systems, but is also recovered. As a result, cooling air enters the furnace through the boiler throat at quite a high temperature, recovering a significant amount of energy in the form of ash sensible heat.
ash chemical energy from unburned particles and boiler radiation flux through the throat.

![Figure 2: Counter-Current Ash Cooling in the MAC® System.](image)

The MAC® system, compared to conventional wet systems, can improve the boiler efficiency by a factor in the range 0.1÷0.6%, depending on coal properties and ash rates, calculated within the framework of “ASME PTC 4-2008”.

The main benefits related to the MAC® system are listed below:

- Zero water usage. No water treatment systems required.
- Performance at the highest level of reliability and safety. No risk of boiler shutdown.
- Damage-tolerant design of conveyors, based on the Magaldi Superbelt® technology, ensuring continuous ash removal, low wear, low power demand, long service-life, low O&M costs, safe operation, high system dependability.
- Boiler efficiency improvement, due to recovery of energy from unburned fuel in bottom ash, ash sensible heat and flame radiation through boiler throat. Coal consumption savings and CO₂ emission reduction.
- Improved quality of bottom ash (dry and low-carbon). Maximum potential for valuable ash marketing.
- Effective environmental risk mitigation. No need for bottom ash storage ponds.

Further, where profitable because of the local ash market or high disposal costs, dry bottom ash can be recycled back to the boiler using the Magaldi Ash Recycling (MAR®) system. This way all ash leaves the boiler as fly ash, thus eliminating completely the issue how to manage bottom ash.
2. BIOMASS / RDF CO-FIRING WITH COAL: TECHNOLOGICAL ISSUES

Power generation from coal is primarily based on pulverized coal-fired boilers. In some countries, as in the EU, current regulations provide incentives to promote co-firing of biomass / RDF with coal.

![Picture 2: Variety of Co-Firing Solid Fuels.](image)

However there are still technological issues that need to be addressed to improve the reliability and the availability of power plants operated under co-firing conditions. Among them, inaccurate control of the co-fuel feed particle size may negatively affect the residence time of coarse biomass / RDF particles, which have a tendency to fall down from the feeding points together with bottom ash and to increase the carbon-in-ash levels. The maximum size of biomass / RDF particles is therefore a key-parameter that can adversely affect the combustion process.

Most biomass fuels and RDF are difficult to ground to a size suitable to burn completely in a PCF boiler. Grinding biomass or RDF is an expensive and energy-intensive process. Specific energy requirements can vary based on equipment and feedstock conditions. Grinding costs determine the extent to which biomass and RDF can be economically pulverized. This issue needs to be addressed in order to define the relationship between the maximum particle size, type of biomass / RDF and the economics of pulverizing the co-fuel.

The next figure shows the experimental results for grinding a type of biomass, i.e. palm kernel shells (PKS), obtained using a hammer mill equipped with two different round-hole screens:

- Case 1 - 4 mm screen size (green line).
- Case 2 - 6 mm screen size (red line).

Energy required per ton of ground PKS increases from 16 kWh up to 30 kWh when reducing the screen size respectively from 6 mm down to 4 mm. Ground PKS results to be just slightly finer, while the hammer mill capacity decreases by 25%.
Allowing for the above premises, it is clear that coarser biomass / RDF can lead to both capital cost reduction and grinding energy saving of co-fuel screening and pulverizing system. In that case it is required a strong integration between the boiler and the dry ash extraction system in order to promote and control the conversion of unburned carbon residues.

3. MAGALDI ASH POSTCOMBUSTOR: PROCESS MODELING

Occurrence of extensive ash post-combustion has been frequently recorded in plants equipped with the MAC® (Magaldi Ash Cooler) proprietary technology. This finding led to the idea that design and operation of the MAC® system could be optimized in order to promote effective carbon post-combustion at the same time as bottom ash extraction, with the ultimate target of reducing the carbon-in-ash levels below the threshold required for ash reuse.

The goal was that of upgrading the MAC® technology into a Magaldi Ash Postcombustor (MAP®), by combining “dry” ash extraction and afterburning of residual carbon. The patented MAP® system had to be configured as a system integrated with the boiler:

- reducing the restrictions on the co-fuel size distribution and mixing conditions;
enhancing the robustness of the plant with respect to the nature and properties of the co-fuel and the boiler load fluctuations.

**Picture 3:** Evidence of Post-combustion in the Magaldi Dry Bottom Ash Systems.

For the above reasons MAGALDI, together with Istituto di Ricerche sulla Combustione (CNR Naples), has set up a mathematical model to describe the fate of ash particles during their fall-out from a boiler, co-firing biomass / RDF with coal, and during the subsequent dry extraction.

**Figure 4:** Average Ash Temperature Profile in the Magaldi Ash Postcombustor.
The model effectively addresses the complexity related to the broad variability of the particle sizes of bottom ashes, which requires careful description of transient heat transfer phenomena within a granular bed of polydisperse material. The model predicts temperature and carbon conversion profiles in the granular bed for each class of particle sizes as a function of the operating conditions. The possibility to implement the dry ash extraction system based on a belt conveyor so that it can be operated as an ash afterburner is proven.

4. MAGALDI ASH POSTCOMBUSTOR: THE INSTALLATION IN GERMANY

4.1. Power Plant Technical Data

In April 2010 MAGALDI received a technical tender specification for the installation of a dry ash handling system for the Unit #K (770 MW combined cycle) at Gersteinwerk power plant in Werne (Germany). Block #K of Gersteinwerk PP is equipped with an upstream gas turbine and a PCF boiler that has been in operation since 1974. The 770 MW output is composed of 112 MW from the gas turbine and 658 MW from the opposite-fired boiler. This heat input to the boiler is in turn 90% from coal and 10% from co-firing of RDF (Refuse Derived Fuel).

4.2. Project Description

Due to problems encountered by the existing wet system (submerged chain conveyor type) since the start of RDF co-firing in 2004, MAGALDI had been in contact with the power plant owner. A plant for the RDF preparation is located next to the power plant. RDF is transported to the boiler house through a pipe conveyor, distributed to two pulverized coal burner levels and pneumatically injected into the combustion chamber. The use of RDF led to an increased accumulation of unburned residues in the wet system. In fact, because of the RDF quality (mainly plastics), a proportion of RDF was falling directly down to the water bath under the boiler throat, leading to two undesirable effects:

- Floating of unburned particles with gradual accumulation in the water bath and consequent problems, both operating and safety, in removing this material.
- Strong increase (up to 30%-35%) of the loss-on-ignition (LOI) in bottom ash, well above the 5% threshold to avoid a very expensive management of bottom ash.

The amount of unburned residues falling in the bottom hopper was evaluated by the plant operators ranging from 5 to 10% of the RDF feed rate to the boiler.
Due to the above reasons, in 2011 MAGALDI replaced the existing submerged chain conveyor with the MAP® System - Magaldi Ash Postcombustor. The project schedule was very tight as witnessed by the following milestones:\(^{(1)}\):

- Contract signature → 21 February 2011
- Boiler shut-down for revamping → 23 May 2011
- Boiler restart after revamping → 20 July 2011
- Start of RDF co-firing → 12 August 2011

4.3. **Background at Fusina Power Plant**

Since the start-up of RDF co-firing in 2004 at Fusina Power Plant in northern Italy, MAGALDI has gained very extensive experience. The Units #3 & 4 at Fusina PP, owned by the largest Italian electricity company, are each rated at a nominal 320 MW. The boilers are provided with tangential burners at 5 (five) burner levels. Both Units are currently fed with pulverized coal and RDF. The maximum RDF feed rate is 9 t/h, or 5% of the total thermal input to the boiler. The basic RDF analysis data are not untypical of those expected for RDF materials, with moisture contents up to around 15-20% and ash contents around 15-20%, both on an as fired basis.

Some modifications and instruments have been added to the MAC\(^{®}\) systems supplied in 1993 and designed at the beginning to handle bottom ash with a negligible UBC content.

\(^{(1)}\) During boiler shut-down the MAP\(^{®}\) system installation was performed together with other activities planned by the plant Owner.
Over the years MAGALDI has performed several test campaign at Fusina PP. Experimental results have been collected and analyzed, studying the feasibility to afterburn carbon residues in bottom ash and how to promote and control the post-combustion process. Those tests have demonstrated the good performance of the Magaldi Superbelt® under severe operating conditions.

4.4. New Challenges at Gersteinwerk Power Plant

The opportunity to replace the existing wet system (submerged chain conveyor type) with the dry MAP® system showed up in 2010 when the power plant owner submitted to MAGALDI a request for proposal for the installation of a dry ash handling system with controlled afterburning, as part of a wider Unit revamping (i.e. conversion to imported coal).
All process parameters and performance requirements were specified as reported in the tables below.

<table>
<thead>
<tr>
<th>Operating Condition</th>
<th>Bottom Ash Production [t/h]</th>
<th>RDF Unburned Residues [t/h]</th>
<th>Design Production [t/h]</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>2.1</td>
<td>1.1</td>
<td>3.2</td>
</tr>
<tr>
<td>B</td>
<td>5</td>
<td>1.1</td>
<td>6.1</td>
</tr>
<tr>
<td>C</td>
<td>50</td>
<td>-</td>
<td>50</td>
</tr>
</tbody>
</table>

**Table 1**: Bottom Ash and RDF Rates to the MAP® System.

<table>
<thead>
<tr>
<th>Performance Requirement</th>
<th>Threshold Limit Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Unburned material in bottom ash at MAP® system discharge</td>
<td>&lt; 5%</td>
</tr>
<tr>
<td>2. Final ash conditions at MAP® system discharge</td>
<td>Moisture: 10% (±2%) Temperature: &lt; 100 °C</td>
</tr>
<tr>
<td>3. Time allowed to evacuate the bottom hopper after 50 tons sudden fall</td>
<td>Max 10 hours</td>
</tr>
</tbody>
</table>

**Table 2**: Performance Requirements for the MAP® System.

The requirement #3 was not a problem, since the Magaldi dry bottom ash handling systems are usually equipped with hydraulic operated bottom valves as for the project discussed in this paper. An automatic sequence of opening bottom doors allows ash accumulated in the bottom hopper to be unloaded and restore the normal operating conditions. However, to avoid any possible combustion of RDF above bottom ash accumulated in the hopper, with consequent potential ash agglomeration, MAGALDI asked to stop the RDF feeding to the boiler in case of this event. The requirement #2 was again not difficult to comply with. This is one of the guaranteed parameters generally satisfied by the Magaldi dry bottom ash handling systems. The actual challenge was the requirement #1. Allowing for the “operating condition A” in the table no.1, the target of 5% maximum UBC content at system discharge leads to the values reported in the next table.

(2) This not a mass flow rate [t/h] but a sudden fall of ash accumulated on the boiler membrane walls (due to change with and without gas turbine operation or sudden reduction of the boiler load).
The Low Heating Value (LHV) of the RDF residues was specified equal to 30.5 MJ/kg on average. All this led to a series of consideration that had to be taken into account in the design of the post-combustion system:

- **Post-combustion zone length**
  Whereas RDF falls over the entire length of the hopper and then also in proximity of the belt conveyor exit from the hopper, it is necessary to give RDF particles an appropriate residence time for the post-combustion. So, it is required to prolong the post-combustion zone outside the hopper, finding a suitable compromise between the belt conveyor speed and the ash thickness on the belt itself. This leads to two additional considerations:
  - Based on the Fusina PP experience the afterburning out of the boiler hopper is waning without boiler flame radiation. Therefore hot air, taken downstream the air heater, has to be added to extend the post-combustion outside the boiler hopper.
  - The extension of the post-combustion zone beyond the boiler hopper reduces the normal cooling zone. It is necessary to find a different solution for ash cooling down to an acceptable temperature before the first crushing stage.

- **Post-combustion heat release**
  The heat is totally released from the RDF combustion since coal ash presents a negligible UBC content. It amounts to more than 9 thermal MW, that means a different order of magnitude compared to 1-2 thermal MW that is the overall heat generally recovered in the MAC® system. Referring to the area of the belt conveyor under the boiler throat where RDF falls and burns, it amounts to 20 m² approx. Consequently the specific heat released in the MAP® system turns to be equal to 0.5 MW/m² approx. with peaks presumably quite higher. The Magaldi belt conveyor could be seen as a travelling grate as the ones installed under stoker grate boilers.

### Table 3: RDF Conversion through the MAP® System

<table>
<thead>
<tr>
<th>At Boiler Throat Level</th>
<th>At MAP® System Discharge</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Production [t/h]</strong></td>
<td><strong>Rate [t/h]</strong></td>
</tr>
<tr>
<td>RDF</td>
<td>1.1</td>
</tr>
<tr>
<td>Ash</td>
<td>2.1</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>3.2</td>
</tr>
</tbody>
</table>

The Low Heating Value (LHV) of the RDF residues was specified equal to 30.5 MJ/kg on average. All this led to a series of consideration that had to be taken into account in the design of the post-combustion system:
4.5. MAP® System Working Concept

All that required a complete rethinking of the basic design concepts of the MAC® system: a new system able to enhance and control the post-combustion process of a significant amount of unburned material, followed by the bottom ash cooling process, that is today the MAP® system.

To get an idea of what happens in both the MAC® and MAP® systems, we can ideally divide the process into three phases:

1. “post-combustion”, where the heat release from combustion of unburned residues is prevalent compared to the cooling;
2. “transition”, in which the two processes are more or less equivalent and there is no major change in temperature;
3. “cooling”, in which the combustion is more or less already completed and the cooling takes place.

This division is valid for both the MAC® and MAP® systems, however the zoning is very different, as depicted in the next figure.

![Figure 5: Process Zoning in the MAC® and MAP® Systems.](image)

The loss of the hopper as cooling zone can be a problem because in the hopper, where bottom ash is dispersed and offers a large contact surface to the heat exchange with cooling air that rises to the boiler, a significant fraction of heat is released. The MAP® system must be provided with an alternative cooling means based on need. This alternative system is constituted by a spray of water, however designed with the criterion of a complete evaporation of the sprayed droplets. This complete evaporation is guaranteed by control of the ash temperature at the crusher discharge: a temperature much higher than 100 °C in that point ensures the complete water evaporation, with steam rising to the boiler together with air. The MAP®, therefore, remains a system for ash post-combustion and cooling producing an absolutely dry product.
The cooling is then completed in the process downstream of the primary crusher. For the MAP® project at Gersteinwerk PP, ash cooling is completed by means of a secondary conveyor, i.e. the Magaldi Postcooler using ambient air naturally drawn into the equipment by the furnace negative pressure, and an ash conditioner, necessary to humidify bottom ash at the required moisture content.

The MAP® system in operation at Gersteinwerk PP is schematically represented by the following figure.

**Figure 6**: Flow Sketch of the MAP® System in Operation at Gersteinwerk PP.

**Picture 7**: The MAP® System at Gersteinwerk PP (Block #K).
5. THE GERSTEINWERK #K EXPERIENCE: PERFORMANCE AND RESULTS

5.1. Heat Recovery by the MAP® System

The integration between the boiler and the MAP® system allows for significant thermal energy recovery: for the Gersteinwerk project it has amounted to more than 9 thermal MW.

This number is in accordance with the findings of the power plant that has noted a surplus of electrical power generation up to 4 MW compared to the same operating conditions with the previous conventional wet system. In other words, keeping the boiler power output unchanged, this has led to a coal saving of 1.4 t/h approx. and consequent CO₂ saving. The air mass flow to the boiler through the MAP® system has been set equal to around 1.6% of the total combustion air.

The above results have been obtained considering the following design and measured data:

<table>
<thead>
<tr>
<th>Design Data</th>
<th>Measured Data</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Normal ash production = 2.1 t/h (~0.58 kg/s)</td>
<td>• Final UBC content &lt; 5%</td>
</tr>
<tr>
<td>• RDF unburned residues = 1.1 t/h (~0.31 kg/s)</td>
<td>• Final ash temperature ≈ 80 °C (upstream the mixer conditioning)</td>
</tr>
<tr>
<td>• Total production = 3.2 t/h (~0.89 kg/s)</td>
<td>• Final ash moisture ≈ 10% (at the MAP® system discharge)</td>
</tr>
<tr>
<td>• RDF residue LHV = 30.5 MJ/kg</td>
<td></td>
</tr>
<tr>
<td>• Ash temperature at boiler throat = 900 °C</td>
<td></td>
</tr>
</tbody>
</table>

Table 4: Design and Measured Data of the MAP® System at Gersteinwerk PP.

The UBC rate at system discharge has been calculated as follows:

\[
UBC_{OUT} = \left[ \frac{Ash Rate}{100\% - \% UBC_{OUT}} - Ash Rate \right] \approx 0.03 \text{ kg/s}
\]

Therefore, the heat recovery from post-combustion has been:

\[
HEAT_{UBC} = (UBC_{IN} - UBC_{OUT}) \cdot LHV_{RDF \ RESIDUES} \approx 8.4 \text{ MW}_t
\]

while the heat recovery from ash enthalpy has been:

\[
\Delta H_{ASH} = (H_{IN} - H_{OUT}) \approx 0.74 \text{ MW}_t
\]
The total heat recovered by the MAP® system has been evaluated as follows:

$$HEAT_{TOT} = (HEAT_{UBC} + \Delta H_{ASH}) \approx 9.2 \text{ MW}_t$$

5.2. *Water Saving by the MAP® System*

The MAP® system saves make-up water (from evaporation, entrainment and leakage), resulting in system simplification, power saving, O&M reduction and environmental respect.

The water saving\(^{(3)}\) for the Gersteinwerk project has amounted to 5,640 m\(^3\)/year approx.

The above result has been obtained considering the data reported in the table no.4 and the following assumptions\(^{(4)}\):

- Residuals moisture at the SCC system discharge: ≈30%.
- Amount of water evaporating in a wet system (SCC type): ≈20% (of residuals rate).

The water saving has been evaluated as follows:

$$\Delta \dot{Q}_{H_2O} = \left( \dot{Q}_{H_2O\, SCC} - \dot{Q}_{H_2O\, MAP} \right) \quad [m^3 / y]$$

where “ t° ” indicates the hours of operation per year.

The water consumption of the replaced wet system (SCC type) has been:

$$\dot{Q}_{H_2O\, SCC} = \left( \text{(Ash Rate} + \text{UBC Rate)} \cdot \left[ \frac{\% \text{Evap.} \cdot H_2O + \frac{\% \text{Re s.} \cdot H_2O}{1 - \% \text{Re s.} \cdot H_2O} \right] \cdot t^\circ \right) \approx 10,060 m^3 / y$$

Even if it is a small amount of water required to discharge bottom ash on an existing rubber belt conveyor, the water consumption of the MAP® system has been:

$$\dot{Q}_{H_2O\, MAP} = \left( \text{(Ash Rate} + \text{UBC Rate)} \cdot \frac{\% H_2O}{1 - \% H_2O} \cdot t^\circ \right) \approx 1,220 m^3 / y$$

Therefore, the overall water saving by the MAP® system installation has been:

$$\Delta \dot{Q}_{H_2O} = 8,840 m^3 / \text{year}$$

\(^{(3)}\) 5,000 hours of operation have been considered according to information received from the power plant.

\(^{(4)}\) Typical and conservative data for a submerged chain conveyor.
5.3. **Ash Disposal Cost Reduction by the MAP® System**

The MAP® system greatly reduces the bottom ash quantity delivered to the final destination and transforms it into a better quality by-product. For the Gersteinwerk project the reduction of the bottom ash quantity can be attributed to two different factors:

- The ash moisture at system discharge is reduced from 30% down to 10%.
- The unburned RDF residues conversion is up to 90%.

The reduction of the bottom ash quantity has been evaluated as follows:

\[
\Delta Q_{ASH} = \left( Q_{ASH,SCC} - Q_{ASH,MAP} \right) \quad [t/\text{y}]
\]

where "t°" indicates the hours of operation per year.

In case of the replaced wet system (SCC type), the bottom ash rate has been:

\[
\dot{Q}_{ASH,SCC} = \left( \frac{\text{Ash Rate} + UBC \text{ Rate}}{1 - \%H_2O} \right) \cdot t^o \approx 22,860 \text{t/y}
\]

In case of the MAP® system, the bottom ash has been shown to reduce considerably:

\[
\dot{Q}_{ASH,MAP} = \left( \frac{\text{Ash Rate} + UBC \text{ Rate}}{1 - \%H_2O} \right) \cdot t^o \approx 12,200 \text{t/y}
\]

Therefore, the overall ash rate reduction due to the MAP® system installation has been:

\[
\Delta \dot{Q}_{ASH} = 10,660 \text{tons/year}
\]

6. **CONCLUSIONS**

The MAP® system allows to improve plant performance and lower both the environmental and economic impact of the bottom ash management. Compared to conventional wet bottom ash systems, the MAP® technology provides the following benefits:

1. Water saving. No water treatment systems required.
2. Reduction of the bottom ash quantity delivered to the final destination.
3. Boiler efficiency increase, due to the energy gains obtained by the controlled post-combustion of high unburnt carbon content in bottom ash and by the recovery of ash sensible heat and furnace radiation. Coal consumption savings and CO₂ emission reduction.
4. Potential increase of co-fuel maximum particle size, leading to capital cost reduction of co-fuel screening and pulverizing system.

5. O&M cost reduction, both for co-fuel preparation system and for bottom ash extraction system.

6. Increased potential for sale of bottom ash (dry and low-carbon).

7. ACKNOWLEDGMENTS

The authors would like to thank everyone who contributed to develop this challenging technology for the controlled post-combustion of high unburnt carbon content in bottom ash.

8. REFERENCES


