Summary

This document describes the headlines of the Pulverizing Air Dryer technology, a patented non-thermal drying process. It shows the main characteristics of the process, together with its excellent energy performance, and thus outstanding operational costs. The Pulverizing Air Dryer technology opens and enables access to a wide variety of wet biomasses and waste streams, which have not been explored as a source for generation of sustainable energy. Compared to thermal drying, the non-thermal PAD technology reduces operational costs by 70-80%, lowers investments by 60%, requires minimal to no flue gas treatment and is able to reduce moisture content and particle size to less than 10% and 200 micron, respectively.
Executive Summary

The Pulverizing Air Dryer (PAD) is a novel technology for drying and pulverization of wet biomass streams from different origins to the desired degree of moisture content as well as to the required particle size. It is a non-thermal drying system, that saves up to 80% of energy costs compared to any actual thermal reference.

The US-based Company WhirlAway Drying Systems LP holds an exclusive license of the PAD technology based on several patents. BioValor Europe B.V. has been awarded a sublicence which provides the exclusive rights to market, sell and operate the PAD technology in Europe.

The main differentiators of PAD to thermal drying are:

- PAD reduces the energy consumption for drying wet streams by 80%
- In general, the PAD technology consumes 80-130 kWh electrical per ton of separated water. Degree of consumption varies per type of biomass.
- PAD dries to the required degree of dry content and at the same time reduces the material to the desired particle size.
- The return on investment for a 5 ton per hour (intake) is always between 1 and 3 years.
- The product shows on average of 15% more heating value because of the lack of loss of volatile organic components during drying.
- The PAD meets and does not exceed US and EU air emission limits.

The investment cost for the PAD solution is dependent on the type of feedstock and the requested quality of the final product. A 5 ton per hour (intake) PAD unit will vary between €900.000 and €1.000.000, delivered on site, excluding construction and external implement add-ons, such as material handling, housing, connections and foundation.

The operational cost on average is between €7,00 to €10,00 per ton incoming wet material for utilities and maintenance. It mainly depends on the degree of the incoming moisture content of the incoming material, the desired quality of the final product and the price for electricity. The maintenance cost is minimal as the process runs at nearly ambient temperature. It consists of very few moving parts and easily replaceable sleeves inside the cone abuse areas. More specific information can be provided after process analysis, the desired feedstock and the current plant specifications.

PAD meets and exceeds environmental emission standards easily as proven by Interpoll laboratories, Inc, who independently analyzed performance of the PAD at Heartland Grain Fuels facility in Huron, South Dakota, USA.
Pulverizing Air Dryer

Introduction

Thermal drying of wet biomasses such as wood, manures and sludges is a cost and energy intensive process for generating solid fuels or for disposal of waste streams. The economic viability for drying waste streams without use of residual heat is low, and the process often is politically driven or functions as reduction of landfill or transportation costs.

The industry has constantly been on the lookout for better drying solutions in order to create more value by a more positive overall mass and energy balance. Incremental improvements have been realized over many years but there was never created a real step change technology such as the Pulverized Air Dryer technology. For the evaporation of water, the minimum amount of energy has always been based on heat, which is approximately 2.2 MJ per kilogram of water.

The Pulverized Air Drying technology (PAD) is a non-thermal drying of wet feedstock, and separates water from the feedstock solids rather than evaporating the water. It therefore reduces the operational costs substantially.

Even more, the mass and energy balance is increased so significantly that the ecological contribution of the PAD technology as part of any total integrated solution will turn many waste-to-energy projects into viable and profitable investments.

The Technology

The raw material is combined with a proprietary feeder arrangement into a high velocity air stream. The raw product accelerates to high speeds before reaching the first cyclone in line where initial pulverizing takes place by application of shearing forces with angular impact, and subsequently centrifugal separation of wetted air and dried matter. As the raw material passes through subsequent cones of larger sizes, the pulverized product gives up its moisture until its discharge from the final conditioning cone. Auxiliary air is furnished along the line to aid in the drying process. The high velocity air increases in temperature, but does not raise the temperature of the raw product to create any detrimental changes to the end product. A finalizing cyclone stage for severe product diminishment is optionally installed.

Main Differentiators to Thermal Drying

PAD reduces the energy consumption for drying wet waste streams by 80% due to the reduced energy costs and other operational and maintenance costs.

- In general, the PAD technology consumes 70-80 kWh per ton of separated water. In most cases of thermal drying, this power consumption is less than the required power consumption of thermal dryers, excluding the use of thermal heat.
- PAD dries to the required degree of dry content and at the same time reduces the material to the desired particle size.
- PAD is a stand-alone solution from a thermal standpoint: it is not bound to residual heat availability.
- The product shows on average 15% more heating value because of the lack of loss of volatile organic components.
- Due to lower operational costs and decreased investment of 60%, the return on investment is between 1 to 2 years.

**Comparison to Thermal Drying**

<table>
<thead>
<tr>
<th></th>
<th>Steam</th>
<th>Gas</th>
<th>PAD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Power Consumption</td>
<td>kWh/t</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Steam Consumption</td>
<td>t/t</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gas Consumption</td>
<td>m³/t</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Power Consumption</td>
<td>PJ/year</td>
<td></td>
<td>0,047</td>
</tr>
<tr>
<td>Steam Production</td>
<td>PJ/year</td>
<td>0,270</td>
<td>0,000</td>
</tr>
<tr>
<td>Gas Consumption</td>
<td>PJ/year</td>
<td>0,000</td>
<td>0,171</td>
</tr>
<tr>
<td>Total Consumption</td>
<td>PJ/year</td>
<td>0,294</td>
<td>0,194</td>
</tr>
<tr>
<td>CO₂ Production</td>
<td>t/year</td>
<td>15,837</td>
<td>10,474</td>
</tr>
</tbody>
</table>

Assumptions and explanation:

- electricity production @ 40% yield
- steam production 90% yield
- CO₂ calculations based on CH₄ equivalents.
- specific consumption numbers (kWh/t, t/t, m³/t) related to water
- calculations based on drying 78% m.c. to 15% m.c.

**Technical Specifications**

The design of the PAD technology is simple and comprehensive, as shown in the figure below. In summary, the technical details and performance indicators are:

- Three installed hot air blowers, 160 kWe each, and depending on the feedstock quality, product specifications and throughput. Numbers for a 5 ton per hour unit.
- Air dosage 4,700 Nm³/hr per installed blower
- The installed number of stages is dependent on feedstock and product requirements (4/8 cyclones)
• The moisture content is reduced by 8% to 15% per stage (see throughput specs).
• The material is pulverized down to 200 micron, if required.
• The input size for the feedstock is 20-50 mm maximum.
• The required space for the PAD is 400 m$^2$, 8 meter in height.

The degree of drying and throughput are dependent on the quality of the feedstock, initial moisture content and required moisture content of the product. Any solution is engineered to the customer’s specification, starting from a single line of 5 ton per hour, dried from 30% dry matter to 85% dry matter.

Blue lines indicate solid flows. Red lines depict air streams, containing the intermediate solid flows. From the green lines, the exhaust gas streams, it shows that each separation stage emits air to the open. Also, each stage is fed with auxiliary air to maintain air velocity and air-to-solid ratios.

**Emissions**

Because external heat from various hydrocarbon sources is not part of the process, the emissions from the process are proved to be significantly below allowable international pollution levels.

The US based company Interpoll Laboratories conducted an extensive air emission measurement campaign (report #3-19268) for the PAD at the Heartland Grain Fuels Ethanol Facility in Huron, SD. The particulate determinations were performed in accordance with EPA methods 1-5, CFR Title 40, part 60, Appendix A (revised July 1 2003). The overall synopsis is presented here, and it was concluded that the results are three fourths under the US EPA requirements before any emission cleaning. The US EPA standards are comparable to the EU legislative emission requirements.

<table>
<thead>
<tr>
<th>Component</th>
<th>Measured (3 runs average)</th>
</tr>
</thead>
<tbody>
<tr>
<td>PARTICULATE</td>
<td></td>
</tr>
<tr>
<td>(mg/Nm$^3$, dry)</td>
<td>6.35</td>
</tr>
<tr>
<td>(g/hr)</td>
<td>5.44</td>
</tr>
<tr>
<td>SPECIATED VOC’S</td>
<td></td>
</tr>
<tr>
<td>(ppm,dry)</td>
<td>less than 25.02</td>
</tr>
<tr>
<td>(kg/hr)</td>
<td>less than 1.04</td>
</tr>
</tbody>
</table>
Sulphur and nitrogen components were non-detectable. Because external heat from various hydrocarbon sources is not part of the process, the emissions from the process are proved to be significantly below allowable international pollution levels.

**Experience and References**

The PAD Technology was operated, demonstrated and tested on several locations across the US. All data was gathered during long term testing campaigns on-site with average campaign duration of 2-3 months during 12 hours per day operations. All bullet points are based on a single line system.

- 55 to 65% moisture content DGS at 3.5/5 tons per hour input, dried to less than 12% moisture content
- 55 to 65% moisture content feedlot manure sludge at 4/7 tons per hour range, dried to less than 20% moisture content
- 65% moisture content paper mill sludge at 6 tons per hour range, dried to less than 25% moisture content
- 60 to 65% moisture content dairy-manure sludge at 4/7 tons per hour, dried to less than 25% moisture content
- 30 to 35% moisture content wet sand at 8/12 tons per hour, dried to less than 10% moisture content.

References can be provided on request. Currently, a 5-10 ton per hour unit is at operations at Marietta OK, US.

**Operational and Maintenance Costs**

For the calculation of the operational cost, it is estimated that the price for one kWh is €0,12. In the case of drying a feedstock from 30% dry matter to 80% dry matter, the drying cost for a 5 ton per hour unit is per ton of feedstock as follows:

<table>
<thead>
<tr>
<th>Commodity</th>
<th>Cost (€)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Power</td>
<td>5,25</td>
</tr>
<tr>
<td>Maintenance</td>
<td>2,25</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>7,50</strong></td>
</tr>
</tbody>
</table>

Operational costs are to be completed with additional costs for personnel, infrastructure and others.

**IPR Position**

The intellectual property position for the Pulverized Air Dryer technology is internationally protected by several patents. This position will be updated and completed over time by additional patents, covering future developments to the technology.


Unit Availability

Models are available with a throughput of 1, 5 and 10 ton per hour (wet based).

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