



*FutureMetrics™ LLC*

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A 6-page excerpt from the 186-page

## ***FutureMetrics Report:***

### **Thermal Treatment of Biomass**

#### **Solutions for Coal Substitution in Power Generation and Metallurgy**

The full report is available from the [FutureMetrics website](#).

**This document contains parts of the report's  
section on chemical oxygen demand (COD)  
from outdoor storage runoff.**

#### **Why is this important?**

The typical maximum limits for discharge, <120 mg/L, are significantly lower than what is observed from torrefied and steam exploded pellet leachate.

As this excerpt from the report shows,  
discharged water treatment costs can be optimized.

See [HERE](#) for a summary of typical regulatory limits.



**Some paragraphs, charts, and values are not included in this excerpt.**

**The full report contains the full content of this section.**

## Chemical Oxygen Demand of Leachate from Outdoor Storage of Black Pellets

Over the past several years the high Chemical Oxygen Demand (COD) in leachate from black pellet piles outdoors has come into focus as an issue that cannot be ignored.

In this section we discuss this topic and explore potential mitigation options.

The best choice depends on the specific situation and the costs involved. Although there is no one-size-fits-all solution initially, the problem can be addressed. The key factors determining the COD active fraction in the treated biomass are:

- The feedstock
- The severity and the sequence of the treatment
- The process (washing/leaching)
- The pile management
- The runoff management.

We will discuss the approximate composition of the COD-active substances and quantify the problem. We have researched the cost-optimal treatment options for a given pile geometry, precipitation pattern, and COD-active concentration range. For that treatment method (could be one or several of EGSB, MBBR, PAC/BAC)\*, we estimated CAPEX and OPEX ranges. We discuss our conclusions and suggest an approach to mitigate the problem.

### What causes Chemical Oxygen Demand in Runoff?

Both upgrade paths, torrefaction and SE [steam explosion], thermochemically or hydrothermally degrade primarily the hemicellulose in the wood fiber. Most of the reaction products are carried out of the solid biomass via the torr gas or the blow steam. Some remain in the solids. Most of these residuals are water-soluble. The predominant soluble species are

- Hemicellulose breakdown products: oligomeric carbohydrates (sugars, fractured hemicellulose molecules)
- Organics: (acetic acid, propionic acid, formic acid, fatty acids, resin acids)
- Aldehydes, Ketones, Furans: (furfural, HMF)
- Small quantities of phenols

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\* See the Glossary in the full paper for the definitions of acronyms.



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These compounds will partially dissolve in water that falls on the storage pile as rain or snow and will be carried away in the runoff. Runoff with high COD levels is harmful to bodies of water because it reduces the amount of dissolved oxygen naturally present. These processes make the oxygen-depleted water less suitable for fish and other marine life.

### How Big is the Problem?

The extent of the problem depends on several factors:

- The inherent amount of leachable COD-active content in the product.
- The structure and maintenance of the pile
- How often and how much precipitation and how much melting snow occurs
- What mitigation, if any, is being used?

Since chemical conversions are temperature sensitive, the severity of the treatment should be carefully considered. The fact that torrefied and SE biomass resist biological decay indicates that some reaction products may not be easily accessible to traditional remedial (digestion) processes. Testing the behavior of leachate is highly recommended to ensure the effectiveness of the intended remedial process.

### Precipitation Model

For conservative estimates of runoff, the ranges are from 35% to 50% of the rain received. For a steeper angle of repose and a “crusty” surface of the pile, the runoff is estimated at 50-70%. This correlates with shallower penetration depth. We use XX% in our model.

Since typical SE and torrefied pellets are much smaller than coal lumps, we assume hard-crust pile behavior for pellet piles, with most runoff occurring as surface runoff.

The water penetration depth reported for torrefied pellet piles is 5-15 cm. During extended storm events, the penetration could reach up to 15 cm.

Excellent and detailed work on leaching and pile penetration was carried out by a team of researchers (Susan Weatherstone (E.ON), Nicklas Simonsson, Gerth Karlsson, Nader Padban (Vattenfall), Alex Adell (Topell), Pedro Abelha, Michiel Carbo (ECN). The SECTOR Deliverable 6.7 report provides a comprehensive examination of the effects of outdoor storage on torrefied pellets from Andritz.

Regarding leachate water analysis, the SECTOR researchers prepared the samples according to BS EN 12457-4:2002 and found that the COD of the samples ranged from 3860 mg/L for poplar pellets to 5,740 mg/L for spruce pellets.

We performed a similar test following the conditions outlined in EN 12457-4:2002, except that instead of a tumbler for agitation, we used an approved roll table, which rotated the sample bottles at 60 rpm. All other conditions stayed within the limits specified by EN 12457-4:2002.



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Our samples consisted of

- Torrefied Hardwood pellets
- SE Softwood pellets
- EFB SE -washed- pellets

We used 25 g of as received pellets (~5% moisture content), 250 ml of distilled water (vapor-distilled, 18 MΩ), and agitated the mixture at 20°C for 24 hours. We filtered the leachate and sent it to a certified environmental laboratory within the permissible time frame. The pH was measured and indicated that all samples were mildly acidic, with a pH range of 4 to 5. The laboratory performed COD analysis using the Hach Method 8000 (digestion/spectrophotometric).

We obtained the following results:

COD data	our Samples	SECTOR Deliverable 6.7	Third Party
	mg/L	mg/L	mg/L
Torrefied Hardwood	<b>2800</b>	-	-
Torrefied Poplar	-	3860	-
Torrefied Spruce	-	5740	-
Torrefied blend	-	-	2140
SE Softwood	<b>7100</b>	-	-
SE Blend	-	-	3030
SE EFB - washed	<b>1400</b>	-	-

Table 58: COD data from leaching tests

All the torrefied samples were from PAT pellets (Pelletization after torrefaction). Published data suggest that TAP (torrefaction after pelletization) show much better hydrophobicity . This phenomenon should be carefully examined to see how it could improve the COD active content of the runoff (Bergman P. e., 2005) (Ghiasi, 2014) (Manouchehrinejad, 2018) (Wang, 2020) (Yoshida, 2021)

Interestingly, both we and the third party observe higher COD with SE samples compared to torrefaction samples, which can be explained by the underlying chemistry and different treatment temperatures. SE shows a higher residue of resin acids, especially dehydroabiatic acid (30-35 µg/L vs. 5 µg/L for torrefied product), while torrefaction is richer in fatty acids, mainly o-methylpodocarpic acid (40 µg/L vs. 3 µg/L for SE).

Since the treatment temperatures are lower for SE, more of lower molecular weight reaction products may remain in the solids, while fewer do so during torrefaction. The torrefaction process is a thermochemical breakdown that typically occurs around 280-320°C, producing more volatile, low molecular



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weight gases (see Table 1) which are less likely to adhere to the solids. The remaining solids are nearly insoluble in water. Additionally, the water injection used for cooling in the torrefaction process also acts as a mild steam stripping method, resulting in a further reduction of oxidizable components.

We also observed that the EFB-based sample, prepared from EFB feedstock using SE with integrated leaching as a treatment, produced the lowest COD results. The data made us cautiously optimistic that there could be an economical pathway for that technology. It will depend on the actual cost proven with observable operations.

The approximate composition of COD-active leachate components is shown in Table 59

Low molecular weight organic acids (e.g. acetic, formic, propionic)	40%	Common torrefaction/SE products, from dehydration and decarboxylation of hemicellulose.
Aldehydes / ketones / furans	23%	Furfural, HMF, furans, pyrones, etc.
Phenolics / lignin degradation products	5%	Phenols, cresols, substituted phenols, not many at the mild torr /SE temperature
Oligomeric carbohydrates / oligomers	32%	Residual oligomers or partially degraded water soluble cellulose / hemicellulose fragments
Miscellaneous (nitrogenous compounds, small heterocycles)	1%	Negligible in woody biomass

*Table 59: Approximate composition of leachate from a torrefied or SE pellet pile*

As the actual composition can vary substantially and is highly dependent on feedstock and process parameters, it is necessary to test the actual leachate composition before selecting a treatment protocol.

Pile management and water collection have a significant impact on the volume and COD-active load of leachate.

In our leaching experiment, the highest COD observation was 7100 mg/L of leachate from leaching 25 g of thermally treated pellets for 24 hours with agitation in a 10:1 water-to-solids ratio; the lowest was 1400 mg/L. The data suggest that, assuming the COD active matter was in equilibrium with the solution, the inventory of COD-active matter in our samples ranged from 15.4 to 78.1 g/kg of biomass. These figures may seem very high, but they are consistent with findings from other laboratories. In a precipitation-induced leaching event, only a part of the COD active inventory in the wetted layer gets mobilized.

In our model, we use the following conservative assumptions (complete text in the full report):

- “XXX YYY etc.”
- Penetration depth in the pile is YY cm.



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- Runoff fraction is ZZ%,
- Mobilization factor of XX%/event of the remaining COD inventory in the penetration layer.
- The pile is assumed to hold a maximum of XXX tonnes or YYY m<sup>3</sup>
- The pile consists of ZZ windrows or a contiguous “mesa” with  $h = X\text{m}$  and  $b = Y\text{m}$  and  $l = ZZZ\text{m}$
- The angle of repose is XX°

We assume a retention basin to collect the runoff water for XX% of the monthly precipitation (YYY L/m<sup>2</sup> of pile area). The pile area is assumed at XX,XXX m<sup>2</sup>, and the corresponding pile surface is YY,YYY m<sup>2</sup>.

We assume that rainfall occurs in XX storms evenly spaced over time, each producing ZZ.Z L/m<sup>2</sup>. If the runoff is processed at a rate of YYm<sup>3</sup>/h, the holding tank should have days of no flow for plant shutdown and sediment removal.

With the specified conditions, our WWTP (Wastewater Treatment Plant) model would include an...  
[full text in the report]

UV treatment will be unnecessary as there will be no microbial load in the leachate.

For conceivable COD scenarios, ranging from XXg/kg to ZZg/kg leachable COD active content, and the assumed model conditions, we estimate a CAPEX range of US\$M XX.X - YY.Y.

The OPEX range for treating the runoff under the model assumptions spans from US\$ XXX/day to US\$ YYY/day.

The CAPEX and OPEX ranges represent the low-cost assumption for the XXg/kg scenario as the lower figure and the high-cost assumption for the YYg/kg scenario as the upper end of the range.

### Comments and Conclusions

COD of runoff from outside storage piles of black pellets is a significant issue that needs to be addressed.

Since it is influenced by many factors, forming an interdisciplinary work group to analyze and design cost-optimized response plans may be more effective. The wide range of CAPEX and OPEX indicates numerous opportunities for optimization.

The factors that should be examined and analyzed for cost and contribution potential should encompass:

- Treatment variation (higher severity → more energy loss, less COD)
- TAP vs. PAT for torrefied pellets, TAP seems more hydrophobic
- Binders or additives to the pellets to reduce permeability
- Process modifications (washing, leaching steps → cost, energy loss, but significantly less COD).



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- Pile management (minimize surface area, no layering, hydrophobic top layer)
- Runoff management (high concentration first flush to treatment, low concentration secondary runoff to dilution)
- End-users will benefit from pile management measures, also by protecting the calorific value of the fuel.

Recognizing that numerous factors along the value chain affect COD, a collaborative approach appears to be the most effective means of achieving the desired reduction at the lowest possible cost.

Ignoring the problem or passing it along in the value chain is not a good strategy, as it will decrease market acceptance of the fuel to the detriment of all the stakeholders and the environment.