Technical Bulletin

Common Problems Facing Torrefaction Technology Developers

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There are several common problems that torrefaction technology developers are experiencing. The following addresses two of these problems, both of which were disclosed by one torrefaction technology developer after a recent demonstration run at his plant:

1. **The line recirculating the torrefaction gases (which provides heat to the reactor) can accumulate tar (condensed VOCs), clogging the line and creating a problematic and dangerous situation.**

2. **VOCs end up being entrained with the torrefied biomass exiting the reactor thereby increasing the overall concentration of VOCs in the final product.**

Mark Leonhardt, the Chief Technology Officer of ATS, explains below how ATS TorreCat™ Catalytic Oxidation Technology can address these issues:

> For some time now I've been portraying these problems as significant issues and trying to inform others about how catalytic oxidation of the torrefaction gases is a solution which eliminates these issues. I have many years of chemical plant operating experience and the problems are the same. These issues will occur anytime you are dealing with a vapor close to its dew point that could contact a "colder" surface and, as a result, condense. I have experienced this in many different applications.
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> The issues with condensing vapors in torrefaction go beyond just gumming up the works with tars and oils. Acids are very corrosive when they are allowed to condense on metal surfaces (this is also accelerated by higher temperatures). Although the organic acids are not as strong as the inorganic acids such as HX, HNO_3 and H_2SO_4, formic and acetic acids are the strongest of the organic acids and are both present in the torrefaction gases. Since the torrefaction processes do not require pressure vessels, they are designed and built with thin-walled ductwork and equipment which has almost no corrosion allowance. I fully expect that beyond the short-term issues of frequently gumming up the ductwork

and equipment, there will also be a longer-term issue in which operators will experience significant corrosion in those areas of their equipment. Although upgrading alloys is one solution to corrosion, it is expensive. I fully expect that carbon steel will not last long in this environment without the use of our technology.

In an attempt to address the problem described in ISSUE #1, heat tracing of the recirculation line (and related equipment) would be considered standard industry practice (absent the use of catalytic oxidation). However, there are still significant issues that I have experienced throughout my career when dealing with a variety of similar streams. And these issues become more significant as the equipment is scaled up larger and larger, so that what may not be problematic at pilot or demonstration plant scale could be a serious problem at commercial scale. The issue is that as the equipment gets larger, it becomes more and more challenging to ADEQUATELY heat trace and insulate all the surfaces and "heat sinks" that are present and keep them above the condensation temperature. The heat tracing and insulation must also be meticulously maintained. Any failure in a heat tracing circuit will be problematic. Also any damage to insulation, especially if it is allowed to get wet, will be problematic. You would be amazed at how often pipes are used to stand on, or they get bumped into and insulation gets crushed or damaged or the cover gets bumped off or removed and not replaced in a timely fashion. At a minimum this requires a very high level of operating discipline. You can design all you want into a plant, but ultimately you are not the one that operates them. In some applications we actually use double-walled or "jacketed" pipe where hot oil or steam is on the jacket to ensure that wall temperatures are maintained on 100% of the surfaces that the process could contact. From a cost standpoint, this would obviously not be practical or feasible in a torrefaction plant.

Almost all of the torrefaction designs that I have seen recycle some of the torrefaction gases to the reactor and essentially operate with VOCs (tars and oils) at or near their dew points. This is obviously problematic since any slight cooling will result in condensation and even if it is not enough to experience fouling it will almost certainly result in localized corrosion. **So here is where the beauty of our technology comes in**. Because the oxidation catalyst allows complete VOC destruction to occur at very low residual oxygen levels, we are left with a hot, inert, low-oxygen flue gas that can be reused directly in the reactor. This not only allows a "purge" of the reactor to occur, but also significantly dilutes the concentration of all of the VOCs in the torrefaction reactor off-gas, significantly lowering the dew point of each component. This makes our process much more forgiving and significantly reduces the chances of VOC condensation. Since we also quickly mix this gas with more clean, inert gas for heating and dilution, the VOC concentrations are more in the ppm range than in the percent range. I cannot emphasize enough the importance of this. It seems that almost everyone has disregarded and downplayed this concern until they have actually experienced it themselves.

One last thought before I go on to ISSUE #2. This can also be a significant safety concern. If the VOCs are condensing and collecting somewhere in the system and are then all of a sudden swept into the furnace or thermal oxidizer, this can lead to an explosion or at the very least an over-temperature situation. Our technology dramatically reduces the possibility that these situations will occur.

Regarding ISSUE #2, this is another area where our technology shines. First of all, the VOCs have to migrate out of the biomass particles. This is a mass-transfer/diffusion process that is driven by, among other things, the concentration gradient of the VOCs. Therefore, having a concentration of VOCs outside of the particle as close to zero as possible will help maximize the diffusion rate. Shortening the distance with a smaller particle size can help, but there is nothing that we can do to change the diffusivity of the particle. Therefore, other than changing particle size (which has other implications) the only "knob" we have is reducing the VOC concentration outside of the particle. Our technology does that by using the inert catalyst flue gas in the process. With our technology, the reactor vapor space has a significantly lower VOC concentration than reactors that either recycle some of the VOC laden torrefaction gas or even once-through operations that don't provide any inert dilution gas. With our technology, this same process is then employed in the cooler since we are again sweeping with a clean, inert gas. The initial stages of the cooler are still hot enough that torrefaction is still occurring and therefore producing VOCs. The torrefied biomass must first be cooled to "quench" or stop the reaction and then to further allow for the remaining VOCs to diffuse out of the particle while being swept away by the counter-current inert gas flow.

These are very important and problematic issues that are addressed by ATS TorreCat™ Catalytic Oxidation Technology.