Wet Scrubbers for Gasifier Gas Cleaning

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ABSTRACT

Concern for global climate change coupled with high oil prices has generated new interest in renewable energy sources. Many innovative companies are working to commercialize these sources using gasification to convert waste to energy and fuels. Gasification is a thermal conversion process which produces synthetic gas (syngas). With proper cleaning, syngas can be used to fuel an internal combustion engine (ICE) to drive a generator, and produce electricity. Waste heat is recovered from the system to improve the overall plant efficiency.

During gasification, various pollutants may be produced depending on the type of gasification process and the make-up of the waste feedstock. The feedstock can vary from biomass, municipal solid waste (MSW), to even medical or hazardous waste. The pollutants involved can include large to sub-micron particulate matter, tars, and acid gases. A key challenge to commercializing gasification is designing a syngas cleaning system that removes pollutants to a level that is tolerated by the ICE (or fuels and chemical production system) and also meets emission standards. This paper will discuss different approaches to tar removal and control strategies for the various pollutants.

INTRODUCTION

Concern for global climate change coupled with high oil prices has generated new interest in renewable energy sources. Many innovative companies are working to commercialize these sources using gasification to convert waste to energy.

A key challenge to commercializing a gasification plant is designing a syngas cleaning system to remove the pollutants to a level that is tolerated by the ICE and that meets emission standards. Each application is unique and depends on the type of gasifier, and feedstock material. Tar formation in the gasification process is one of the more challenging elements for the syngas cleaning system. There are two common tar management approaches regarding syngas cleaning:

1. Thermal Tar Destruction Systems
2. Tar Removal Systems

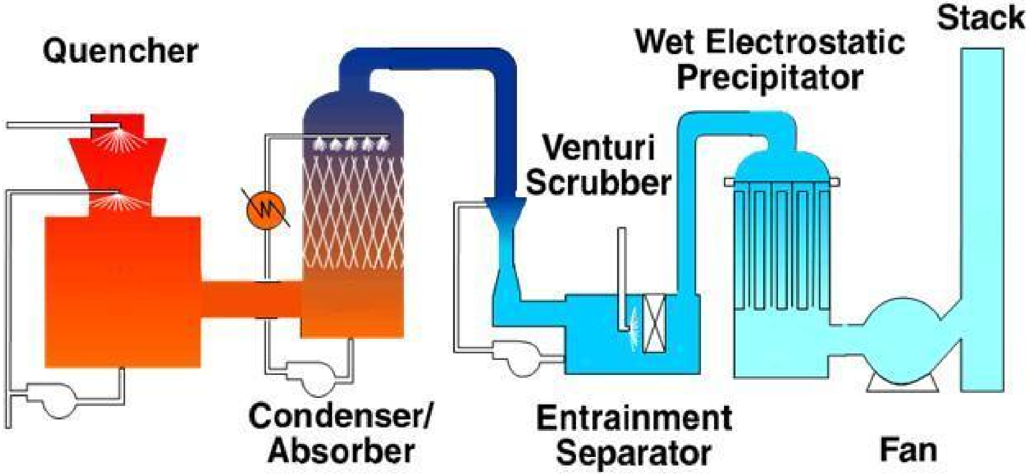
Decisions regarding which approach is used are generally made by the technology developer of the gasification process. In this context, thermal tar destruction is considered to be part of the gasification process. This paper will discuss control strategies downstream of the gasifier for both approaches. Data from a pilot scale system is presented to demonstrate the performance for a tar removal system.

THERMAL TAR DESTRUCTION SYSTEMS

In this approach, the syngas passes out of the gasifier and through thermal tar destruction process that operates at a high temperature. This greatly simplifies the gas clean-up, as it eliminates the need for tar removal in the syngas cleaning system. The trade-off, however, is lower energy content of the gas. Typical non-tar pollutants when gasifying MSW, medical, or hazardous waste feedstock are particulate, HCl, SO_2, and H_2S. The syngas clean-up downstream of the thermal tar destruction process is achieved with proven, reliable scrubbing technologies, similar to systems that have been used on many conventional industrial gas cleaning systems. The syngas cleaning system also reduces the moisture content in the gas using a cooling tower and heat exchanger.

Figure 1 shows a process arrangement for a gasifier designed with thermal tar destruction. Hot flue gas from the gasification reactor is first cooled to saturation in an evaporative quencher. The inlet gas temperature varies with the type of gasifier (fluid bed, fixed bed, etc.) and downstream equipment and can be as high as 2,200°F for systems without an upstream waste heat boiler. For system with a waste heat boiler, the inlet temperature will be in the range of 300°F to 400°F. The saturation temperature can typically range between 150°F to 185°F, depending on the specific gasifier design and feedstock.

Figure 1: Syngas cleaning process arrangement



The quencher is designed as a low pressure drop Venturi. It both quenches the gas and collects large particulate. After the quencher, the gas passes through a packed bed condenser/absorber for acid gas removal and sub-cooling. In this step, any HCl or SO_2 in the gas stream is neutralized using a caustic solution. Although not considered a particulate removal device, the condenser/absorber will remove between 10% to 15% of the inlet particulate. H_2S removal can be achieved with a second packed bed scrubber using caustic or a scavenger reagent. Alternatively, H_2S can be removed downstream of the syngas cleaning system using a media bed, such as sponge iron.

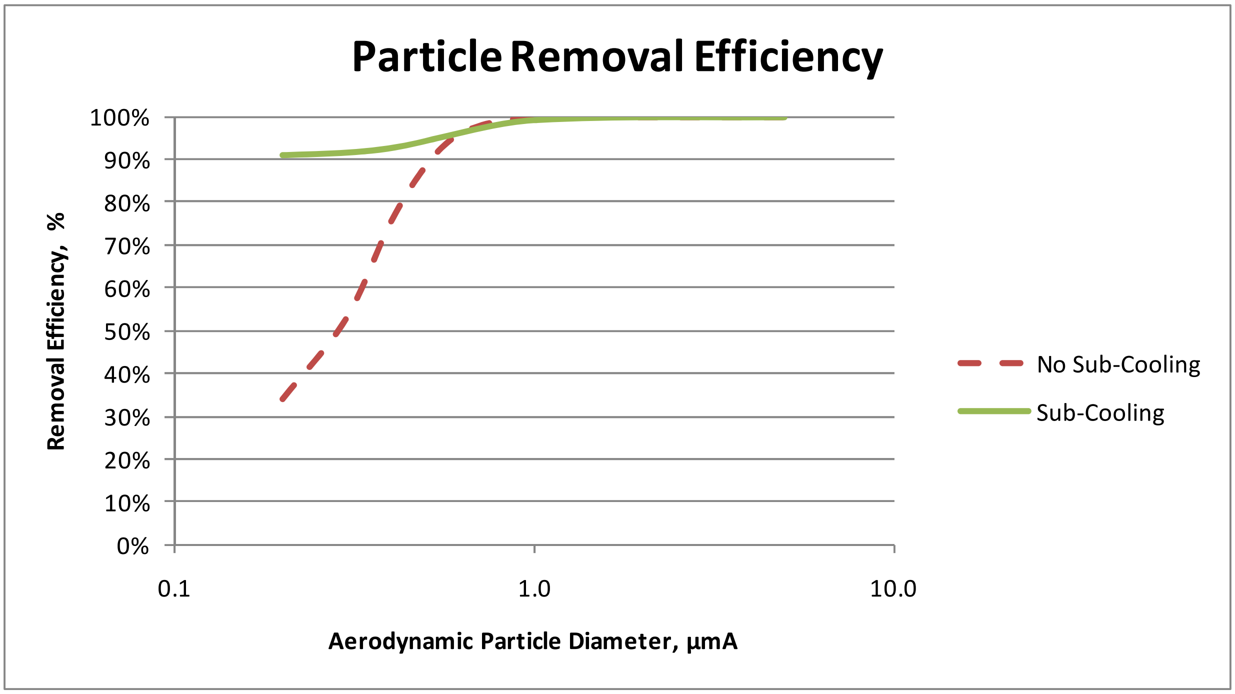
The final process step is removal of the remaining particulate in the gas stream with a Venturi scrubber. Water condenses on particles due to sub-cooling in the condenser/absorber, causing their mass and diameter to increase, and enhancing particle removal. As a result, particulate entering the Venturi is less than 3 microns, and this allows the particles to be collected at a lower pressure drop.

Figure 2 shows a comparison of modeling results for Venturi particle removal efficiency versus particle size for 2 different cases with sub-cooling and no sub-cooling. Both cases show that removal efficiency for particulate less than 3 microns is dependent on particle size.
That is because Venturi scrubbers collect particles primarily according to their aerodynamic size through inertial mechanisms between water droplet and particles in the Venturi throat. As particles get smaller in the submicron range, they are able to find slip streams between water droplets and avoid capture. Higher pressure drop can off-set this affect by increasing the differential velocity between the particles and water droplets.

The difference between the sub-cooling curve and no sub-cooling curve shows the increase in removal efficiency for various particle sizes. For instance, a 0.5 micron particle will be removed with about 60% efficiency without sub-cooling. That compares to greater than 90% removal with sub-cooling.

In some cases, the particle size distribution and the outlet emission requirements may exceed the capability of a Venturi scrubber. In this case, an additional particulate polishing step is required. This can be done using a wet electrostatic precipitator (WESP) or using re-heat and a filter. Care must be taken with using a WESP with gasifier gas, as the power supplied to the WESP is a potential source of ignition for the fuel syngas if sufficient oxygen is available.

Figure 2: Venturi scrubber particle removal efficiency comparison by pressure drop and sub-cooling



TAR REMOVAL SYSTEMS

Gasifier plants that do not use thermal tar destruction generally have lower outlet temperatures, but higher energy content in the syngas. The syngas contains tars which are more difficult to remove. Figure 3 shows the first stage impinger from the back half of a Method 5 train used to sample the gas from a biomass gasifier. The condensed tars can be seen in the water with some light tars floating on top and heavier tars settled to the bottom of the impinger.

Figure 3: Condensed tars shown in the 1st stage impinger from the back half of a Method 5 train used to sample the gas from a biomass gasifier.

The main challenge of tars relates to fouling that can occur in the process equipment from condensed tars and tar deposition. To overcome this challenge, the syngas cleaning system is designed to condense and remove tars in the first process step to keep them out of the downstream equipment. The objective of the tar removal section is therefore two-fold: 1) to get as much of the tars as possible in the condensed phase, and 2) to maximize tar collection and removal, particularly for tar droplets larger than 1 to 3 microns. Getting tars into the condensed phase early in the gas cleaning system keeps them from condensing in downstream process equipment which can result in fouling of recirculation lines, pumps, heat exchangers, and media beds. Removing tars larger than 1 to 3 microns prevents them from fouling equipment in places where they can impinge and deposit such as packing material, mist eliminators, or damper blades. The remaining condensed tars are micron or submicron in size and will not be easily collected by inertial impaction in the downstream equipment. Rather, they will pass through, as if they were gas rather than particles.

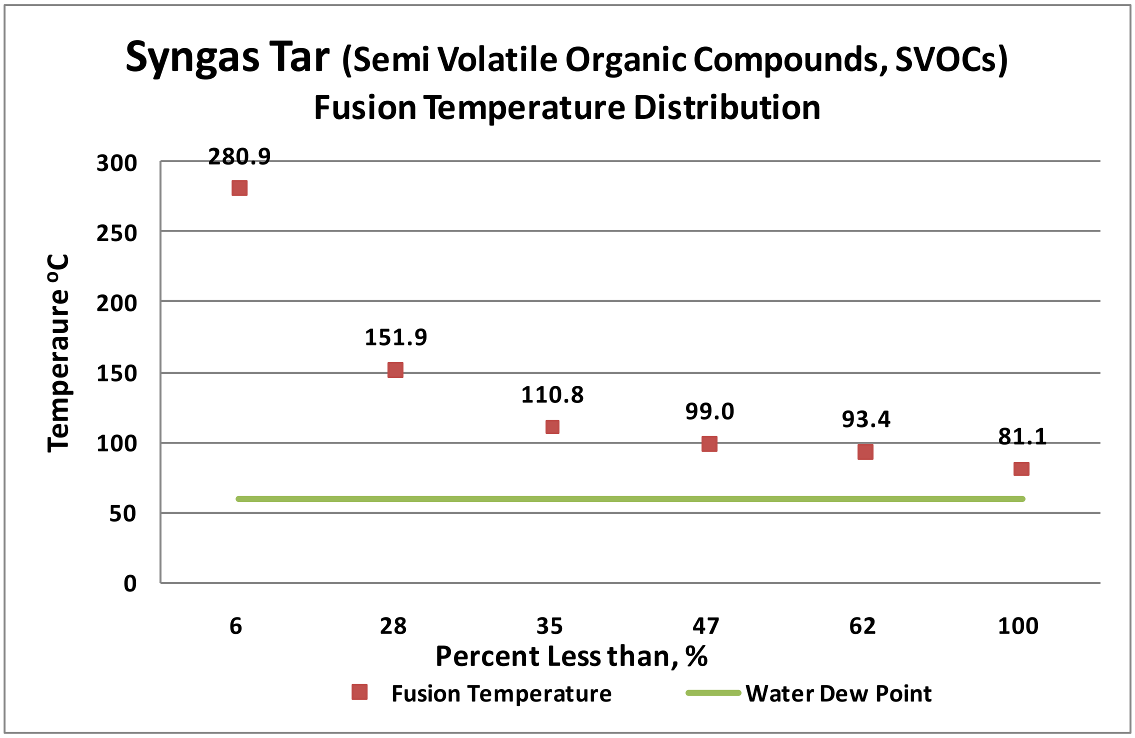
The syngas tar properties that relate to tar removal are complex and depend on many factors, including:

- Tar concentration and composition
- Vapor pressure characteristics
- Fusion temperature (melting point) distribution
- Phase change kinetics
- Solubility of tars in the recirculation medium
- Particle size distribution of condensed tars

These characteristics can vary greatly depending on the type of gasifier and the specific waste streams being converted to energy. The syngas tar properties can also influence the tar removal configuration. This can include things like the type of recirculation liquid (oil versus water), intermediate cooling temperature, pressure drop, or type of mist eliminator.

Figure 4 shows an example of one of these characteristics for a specific syngas. The curve shows the fusion temperature (melting point) distribution for several compounds which represent the bulk composition of semi volatile organic compounds (SVOCs) or tars. A compound at or below its fusion temperature with enough residence time will be a solid. A reference line shows the inlet gas water dew point. The fusion temperature distribution represented by Figure 8 suggests the bulk of the tar compounds will condense at temperatures at or above 80°C (176°F). This temperature is well above the water dew point temperature of 60°C (140°F). This type of curve can be used as a guide for determining an intermediate cooling temperature for condensing tars using an oil loop configuration.

Figure 4: Syngas fusion temperature profile.



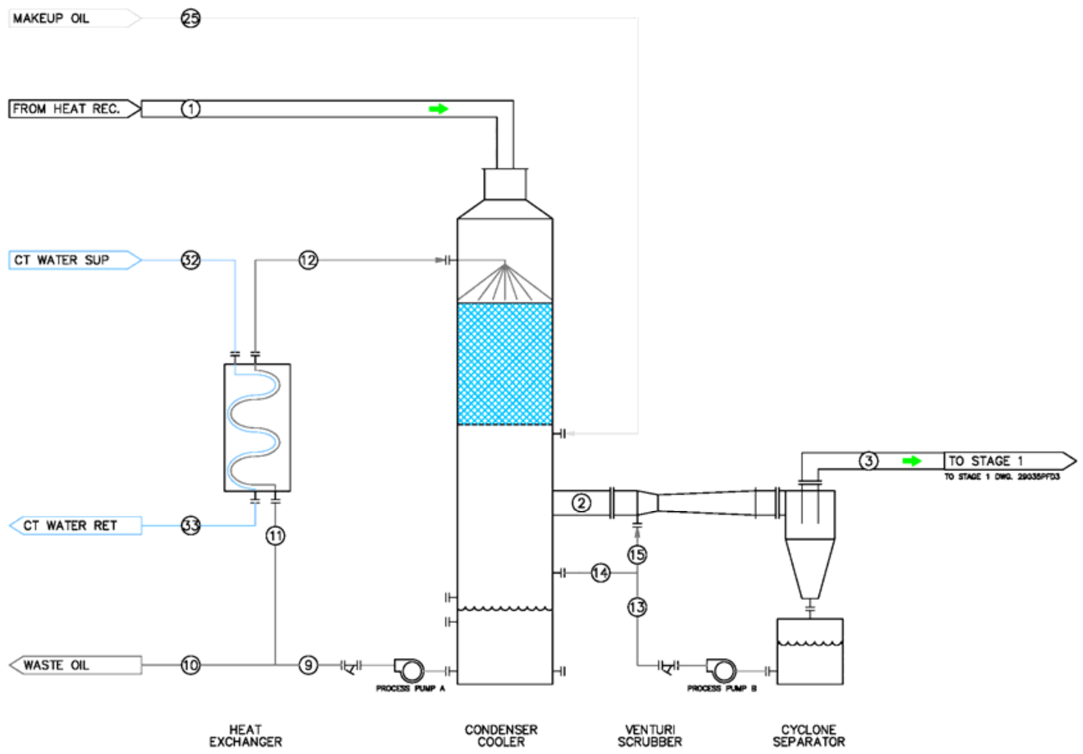
OIL LOOP TAR REMOVAL

When considering the tar removal design, there are several conditions that may be better suited for an oil loop configuration. These include:

- High inlet tar concentration.
- Tars that condense into a sticky solid rather than an oily liquid.
- High degree of condensed tars which don't mix well with water.

Under these circumstances oil may serve as a better choice for the initial recirculation medium to cool and condense the tars. That is because the condensed tars will be more soluble in an organic liquid and less prone to foul the recirculation lines, and the higher temperature reduces viscosity. Figure 5 shows the system arrangement for an oil loop tar removal section. Tar condensation and removal occurs in a downflow, co-current, direct contact condenser cooler followed by a Venturi scrubber and mist eliminator. It operates at temperatures above the water dew point for the gas. Direct contact with re-circulated oil is used in conjunction with a liquid cooling circuit to cool the gas to an intermediate tar condensation temperature. The intermediate cooling temperature is determined by evaluating the fusion temperature distribution in conjunction with vapor pressure data for the specific components. A horizontal Venturi scrubber and mist eliminator are installed downstream of the condenser cooler to collect and remove condensed tars and particulate. A waste oil stream purges the system of collected tars and particulate. The waste oil can be filtered for recycling back to the oil loop. The collected sludge is fed back to the gasifier for reprocessing.

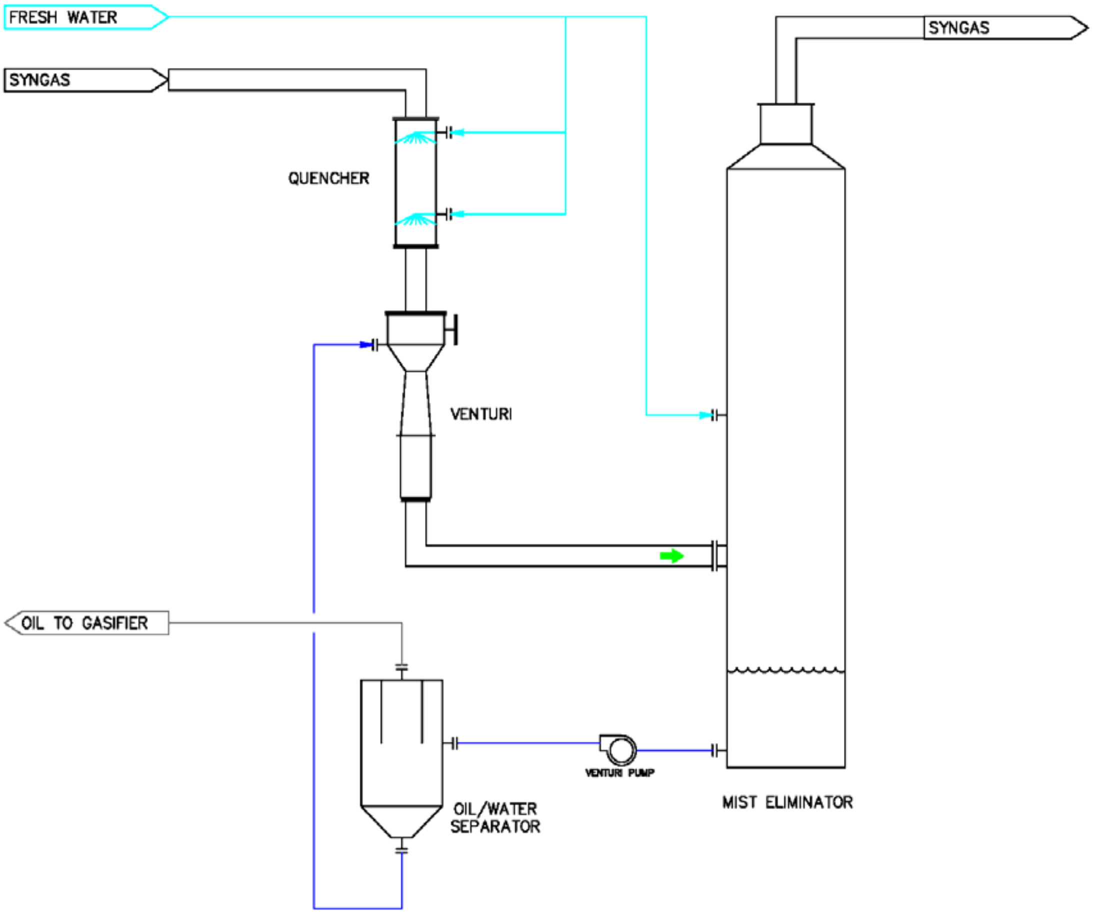
Figure 5: Oil Loop Tar Removal, Operating Above the Water Dew Point



WATER LOOP TAR REMOVAL

While some syngas compositions will require an organic recirculation liquid, others will be suitable for a water loop configuration. Figure 6 shows the basic system arrangement. The syngas is first cooled to saturation in a vertical, downflow quencher using water. This is followed by a vertical Venturi scrubber to collect the condensed tars and particulate. After the Venturi scrubber, the syngas passes through a mist eliminator to remove the water droplets in the syngas. The Venturi scrubber recirculation water passes through a water-recycle unit to separate the oil from the water. The recycled water will be free of oils that either float or sink. The collected oils can be sent back to the gasifier.

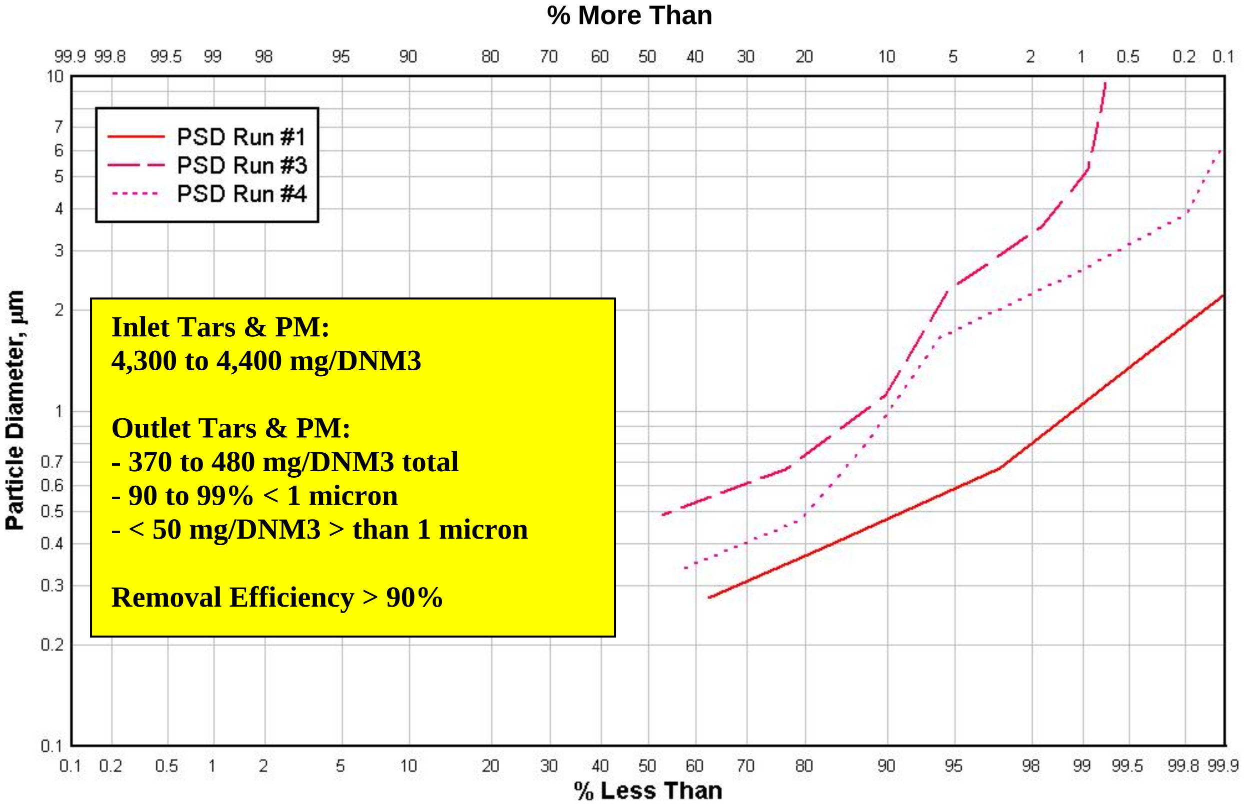
Figure 6: Water Loop Tar Removal



VENTURI PERFORMANCE

A Venturi scrubber and mist eliminator is used to collect particulate and condensed tars in the recirculation liquid in both the oil and water loop configurations. The performance will be similar in either configuration and is not dependent on the type of recirculation liquid. Rather, it will depend on particle size distribution and pressure drop. Figure 7, shows outlet particle size distribution data taken from a pilot scale oil loop system from a fixed bed, updraft gasifier. The overall particulate removal efficiency was 90%. The particulate remaining in the gas stream is predominately submicron. The data confirms that a Venturi scrubber is effective at removing roughly 90% to 99% of condensed tars and particulate larger than 1 micron and greater than 97% to 99.9% for sizes larger than 3 microns. The pictures in figure 8 illustrate the effectiveness of the Venturi scrubber. They show the inlet and outlet particulate sample probes from the pilot oil loop system. The inlet sample probe shows particulate and tars from the gas stream that impinged and were collected on the probe. The outlet particulate sample probe is relatively clean.

Figure 7: Venturi Scrubber performance for oil loop pilot test.



Inlet Tars & PM:
4,300 to 4,400 mg/DNM3

Outlet Tars & PM:
- 370 to 480 mg/DNM3 total
- 90 to 99% < 1 micron
- < 50 mg/DNM3 > than 1 micron

Removal Efficiency > 90%

Figure 8: Inlet and outlet particulate sample probes from a pilot Venturi scrubber syngas cleaning system operating on a biomass gasifier.

Inlet particulate sample probe before the Venturi scrubber.

Outlet particulate sample probe after the Venturi scrubber and condenser absorber.

After the mist eliminator with either configuration, the syngas passes to the downstream process equipment which includes a packed bed condenser/absorber to neutralize acid gases and condense water vapor. The condenser/absorber sub-cools the syngas to approximately 38°C (100°F) using re-circulated water and a liquid cooling circuit. The syngas entering the condenser/absorber contains a residual concentration of submicron particulate and condensed tars. However, these are small enough to pass through the vessel without fouling the packing or mist eliminator elements. There will some gas phase tars that condense with the additional cooling in the condenser/absorber, but these are typically in relatively low concentration and are not enough to deposit and foul the recirculation line and heat exchanger. If required, the submicron particulate and condensed tars are collected in a final polishing step before sending the syngas to an IC engine.

CONCLUSION

With renewed interest in renewable energy sources, waste to energy conversion using gasification will play an increasing role in energy production. Tar formation during the gasification process is one of the more challenging aspects of commercializing the technology.

One approach for dealing with this issue is to thermally destroy the tars. This results in a lower energy content of the product gas, but eliminates the risk of fouling downstream process equipment. With this approach, the syngas clean-up can be achieved with proven reliable scrubbing technologies similar to systems that have been used on many industrial gas cleaning systems.

An alternative approach is to remove the tars from the syngas. This increases the complexity of the cleaning system, but preserves the heating content of the gas. The cleaning system is designed to condense and remove the tars in the first step in order to keep them out of the downstream equipment. This can be done with either an oil loop or water loop configuration depending on the syngas tar properties. Performance data demonstrates the capability to remove greater than 90% of the inlet tars and particulate, and greater than 97% to 99.9% for particulate and tars larger than 3 micron in size. The majority of the remaining condensed tars is submicron will pass through the downstream equipment without fouling. The problems associated with tar removal can be overcome by applying the right syngas cleaning system design.

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KEY WORDS

Tar removal, gasification scrubber, syngas cleaning system