Ethylene Oxide Emission and Elimination:

Overview of pollution control technology evolution

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1. Introduction

Ethylene Oxide (EO) is used for sterilizing materials and products that would be damaged by traditional methods involving heat, moisture, or radiation. It is commonly used to sterilize medical equipment and poses health risks to workers and communities surrounding sterilization facilities according to the US Environmental Protection Agency (EPA). The sterilizing atmosphere depends on an alkylation reaction that prevents microorganisms from reproducing with gas concentrations are typically 400-600 mg EO per liter of vessel volume. When the sterilization cycle is complete, the gas is removed from the chamber by a vacuum pump. While EO scrubbing is similar to conventional gas scrubbing, a longer residence time in the scrubbing unit is required because of mass-transfer and reactivity constraints. The EPA latest draft risk assessment, released Nov 2020, provided a route to tighten regulations on ethylene oxide releases from sterilization facilities. Thus, the need for a more efficient scrubber system for EO removal is critical.

The Clean Air Group LLC (known as CR Clean Air Group, or CR CAG) has been working on EO applications for over 40 years, with a substantial amount of installed and operating units and a deep bench of engineering expertise.

2. Current standard EO scrubber design

The major scrubber system used for EO removal is divided into two main categories, wet scrubber system and dry bed filtration system. For wet scrubber, a single-stage packed tower, with high-performance packing was sufficient to remove up to 99.99% of the EO. This is followed by a reactor vessel, solution feed tank and recirculating pump and if required a heat exchanger. CR CAG has installed multiple units of this nature for over 40 years, and can point to a track record of < 1 ppm efficiency.

Scrubbing solution flows counter-currently down the towers, while off gas rises. A mist eliminator at the top of the packed bed prevents entrained liquids from escaping with the vent gas. After the reaction is complete, the effluent with up to 40% glycol is diverted to a holding tank for further disposal.

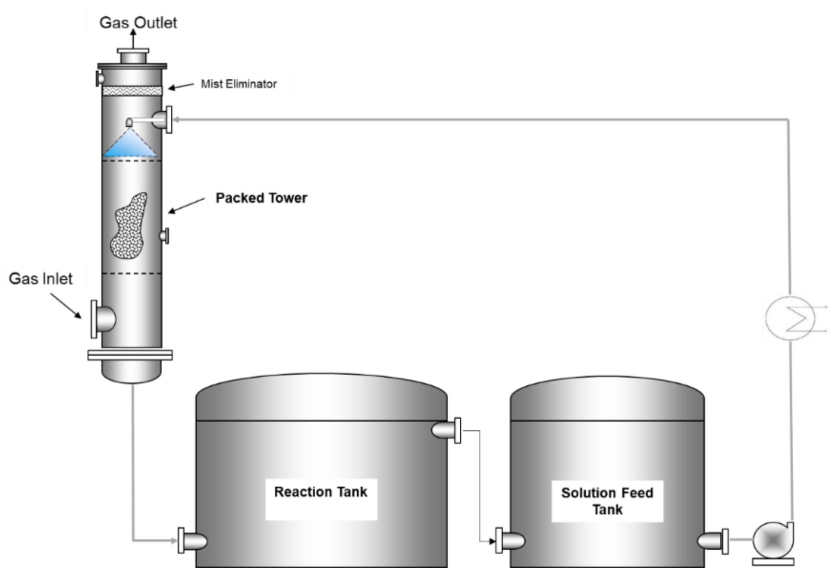

Figure 1: schematic for the EO wet scrubber system design

The size of the packed tower is in direct correlation of total inlet gas flow (ACFM) regardless of the EO concentration. The packing size and bed depth is selected based on removal efficiency required and tower diameter. The size of the Reaction Tank is based on the absorption of EO in the solution, and its subsequent hydrolysis to ethylene glycol (a common antifreeze compound). Reaction rate is a function of temperature and the presence of a catalyst such as sulfuric acid. Energy consumption is minimal. The final product is an ethylene glycol solution containing a small amount of acid which needs to be neutralized and recycled with a frequency depending on gas composition and operation length.

Another type of scrubber for EO removal is the dry bed sorbent-based system. It is mainly designed to accommodate high volume gas with low concentrated EO. It is often used as a polish scrubber at the end of a scrubbing system. The simplicity of the dry bed system provides a cost-efficient alternative to the wet scrubbing system. The packing materials consist of high efficiency chemical reactants that is capable of safely destroying EO and leaving no hazardous or toxic by-products. The biggest drawback for such system is the frequent change-outs (depending on the total load of EO amount) of the reactants and neutralization and disposal of such materials in non-hazardous landfills. This can get cumbersome and expensive.

3. Common Application Challenges

There are several limitations exist to pose challenges to the EO scrubber design. They include extremely high/low flow, catalyst/absorbent selection, extremely low EO concentration.

a. Extreme inlet flow rate

Some process conditions have extremely high or low inlet gas velocity which requires the regular designed scrubber with size either too small or too large. This will cause the whole project to be impractical due to cost or space constraints. A new design needs to be applied and integrated into the original system to address the constraints. Under extremely low flow conditions, CR Clean Air has deployed "bubble scrubber" technology to significantly reduce the scrubber size and operation cost. Under extremely high flow conditions, an additional equipment (such as a rotor concentrator system) can be used to remove excessive inert carrier gases, which leads to an increase of scrubbing efficiency.

b. Catalyst selection

The most commonly used catalyst for EO conversion is sulfuric acid which is the most cost-efficient choice for the application. However, this water-soluble catalyst cannot be separated by the finished effluent with ethylene glycol. This process requires constant acid make up and post treatment with caustic which increases the chemical usage of acid and caustic. The elimination of such processes can lower the operation cost as well as capitol cost via removal of meter pumps and pH monitoring. A solid catalyst which can be filtered at the discharge of the reaction tank can remains active for a long period of time with proper agitation.

c. Extremely low EO concentration

In some cases, the client only requests to eliminate ppm level of EO but with high total gas flow. It is not appliable to a traditional wet scrubber. A sorbent-based capture tower can be used to address such application. However, the major issue for this is the use of non-regenerable sorbent materials. The disposal of such materials can cause negative impact on the environment.

4. CR CAG efforts to develop next generation of scrubbers

CR CAG latest development of next generation of EO scrubbing system is to solve some of the above-mentioned challenges including extreme gas velocity and low EO concentration.

CRCAG bubble scrubbers for EO which can address the ultra-low gas velocity and EO concentrations. Such design provides a cost-effective approach to deal with flow rate between 1 to 250 cfm with EO removal efficiency between 90 to 99.9 %. The system has many advantages compared to a regular packed tower scrubber system, such as: simpler, less overall sizing, lower operational cost, and less maintenance required.

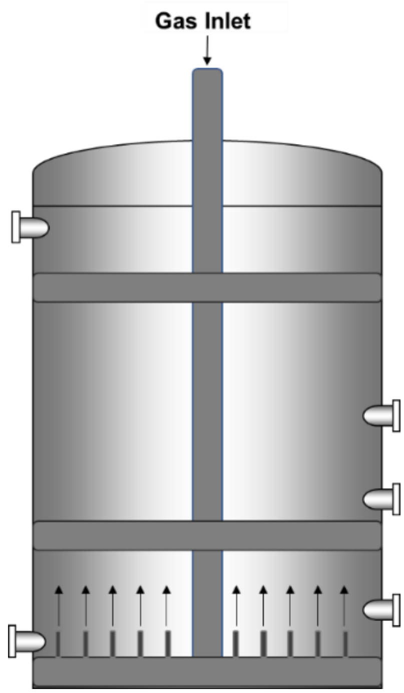

Figure 2: CR CAG “bubble scrubber” schematic

Regenerable packed tower scrubber system utilizes a dual-function catalyst/sorbent material to address the issue of high gas flow with low EO concentration applications. The scrubber provides three major advantages compared to the benchmark wet scrubbers and dry scrubbers.

1. Reactive absorption (RA) of EO to EG at the packing surfaces
2. Easy regeneration via water
3. Compact sizing of the setup

Such system offers not only the advantages of a wet scrubber which is under continuous operation but also the advantages of a dry scrubber which has a simpler setup with a smaller sizing. In addition, the proposed sorbent bed is regenerable so there is no disposal issue compared to a traditional dry sorbent scrubber.

Another plausible route to address the challenge of extremely high inlet flow with low concentration of EO is the combination of a rotor concentrator and a bubble scrubber. A rotor concentrator is mainly designed for VOC captures which utilizes various types of zeolites as sorbent materials. The adsorption/desorption cycle is achieved by temperature swing processes. Here CR CAG applies this technology for the purpose of concentrating the EO. Then the highly concentrated EO gas stream with significantly reduced total air flow will be sent to our proprietary bubble scrubber for EO removal.

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