Case study

The retrofit of a 3-stage acid EtO scrubber to Trevi's Smart scrubber technology



Figure 1. *Assembly of Trevi's EtO scrubber at our manufacturing partner's facility.*

BACKGROUND

Ethylene oxide (EtO) is a colorless, highly reactive gas widely used for the sterilization of medical equipment and materials. While its reactivity makes it highly effective as a sterilant, EtO poses a severe occupational and environmental hazard. It is classified as carcinogenic and mutagenic, and forms explosive mixtures with air. Consequently, EtO emissions are subject to stringent regulatory limits worldwide.

Regulatory limits vary by jurisdiction; in several places, facilities must demonstrate very high removal efficiencies and/or meet outlet concentration limits of 1 ppmv or lower. In practice, many operators aim for destruction and removal efficiencies (DRE) exceeding 99.99% to provide an adequate safety margin and minimize health risks to workers and surrounding communities.

PROJECT CONTEXT

At a partner facility, improved operational safety required an upgrade of the existing EtO abatement system. To address this, Trevi NV (Belgium), a global environmental engineering company specializing in air, water, and energy solutions, was appointed.

The partner for whom the project was executed is an industrial distributor of specialty gases, including EtO, serving medical sterilization and chemical-industry clients. The partner facility handles cylinders containing pure EtO, as well as EtO diluted with CO_2 or N_2. As part of routine logistics, empty or spent cylinders are depressurized between deliveries, generating EtO-containing exhaust streams that must be treated prior to atmospheric release. At the partner facility, an existing 3-stage sulfuric acid scrubber (a Trevi system installed in 2018) was retrofitted towards

Trevi's Smart wet scrubber EtO technology (SwEtO). The original scrubber had met applicable emission limits based on site compliance monitoring, prior to the Smart upgrade.

The Smart wet scrubber replaces corrosive liquid acids with water as the scrubbing liquid and a Smart catalyst system, eliminating the need for acid handling and storage, reducing corrosion and operational complexity, and thereby improving overall operational safety while maintaining high EtO DRE.

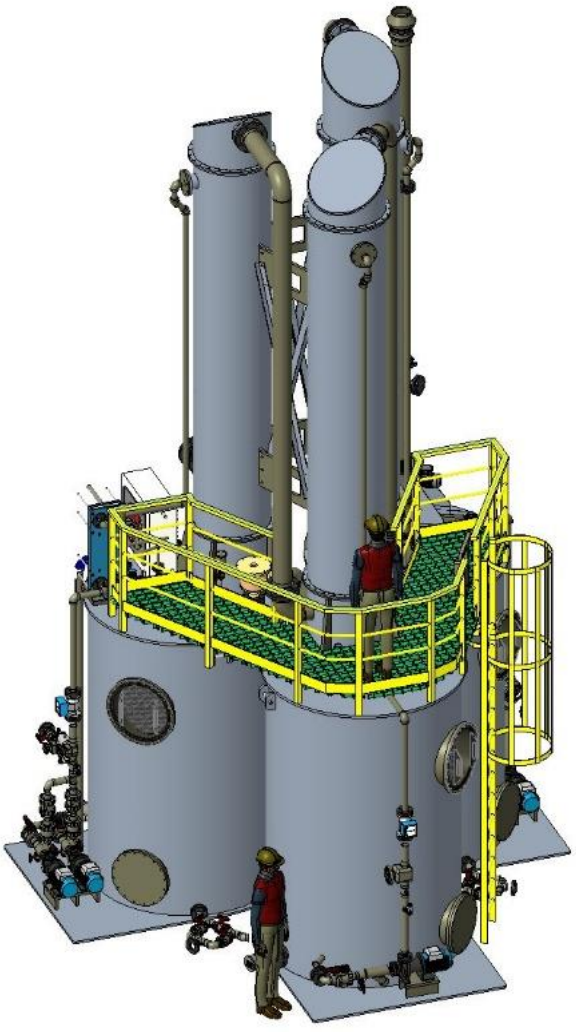


Figure 2. *Triple stage Smart EtO scrubber.*

EXECUTIVE SUMMARY

Gas-phase EtO concentrations were verified using gas chromatography, with flame ionization detection for higher concentration ranges and a plasma emission detector (GC-PED) for trace-level measurements, with a practical quantification limit for the latter of approximately 2 ppbv.

The Smart wet scrubber installed at the facility is a 3-stage packed-bed wet scrubber that uses only water and a Smart catalyst to hydrolyze ethylene oxide into ethylene glycol. Inlet EtO concentration spikes of up to approximately 20% by volume (200 000 ppmv) were reduced to outlet concentrations below 1 ppmv, with a median value around 0.1 ppmv. This corresponds to EtO destruction and removal efficiencies exceeding 99.9999%.

Measured byproduct formation closely matched stoichiometric expectations, with approximately 1.4 kg of ethylene glycol formed per kilogram of EtO treated. Compared to conventional sulfuric acid scrubbers, the Smart wet scrubber achieved equivalent or superior abatement performance while eliminating acid handling and hazardous waste streams. The primary liquid byproduct is a concentrated ethylene glycol aqueous solution.

Potential OPEX reductions versus acid scrubbing are site-specific and depend on chemical, waste-handling, and utility costs. The partner's installation demonstrated robust performance under variable flow conditions, fully consistent with design expectations.

SYSTEM DESCRIPTION AND CONFIGURATION

SCRUBBER CONFIGURATION

The Smart wet scrubber consists of three packed-bed scrubber towers, constructed from polypropylene (PP), installed in series and operated in counter-current mode. EtO-loaded gas enters the bottom of the first tower and flows upward against a downward-flowing liquid film over the packed bed material. Each stage provides intensive gas–liquid contact in the absorption column and catalytic hydrolysis of EtO in the Smart catalyst reactor. A demister downstream of the final stage captures entrained droplets to prevent liquid carryover.

At the partner facility, the retrofit reused the existing scrubber infrastructure while replacing the acid liquor and installing a Smart catalyst reactor for every stage.

OPERATING PHILOSOPHY

Each stage operates with a high liquid-to-gas (L/G) ratio to ensure efficient mass transfer and reaction kinetics. Water is continuously recirculated separately within each stage. As ethylene glycol accumulates in the recirculating liquid, a controlled purge is initiated when the glycol concentration in the first-stage solution, where glycol concentrations are highest, reaches a preset threshold.

The aqueous glycol solution from the first stage scrubber is extracted towards a storage tank and replaced with the aqueous solution from the second stage scrubber. Similarly, the second stage scrubber solution is replaced with

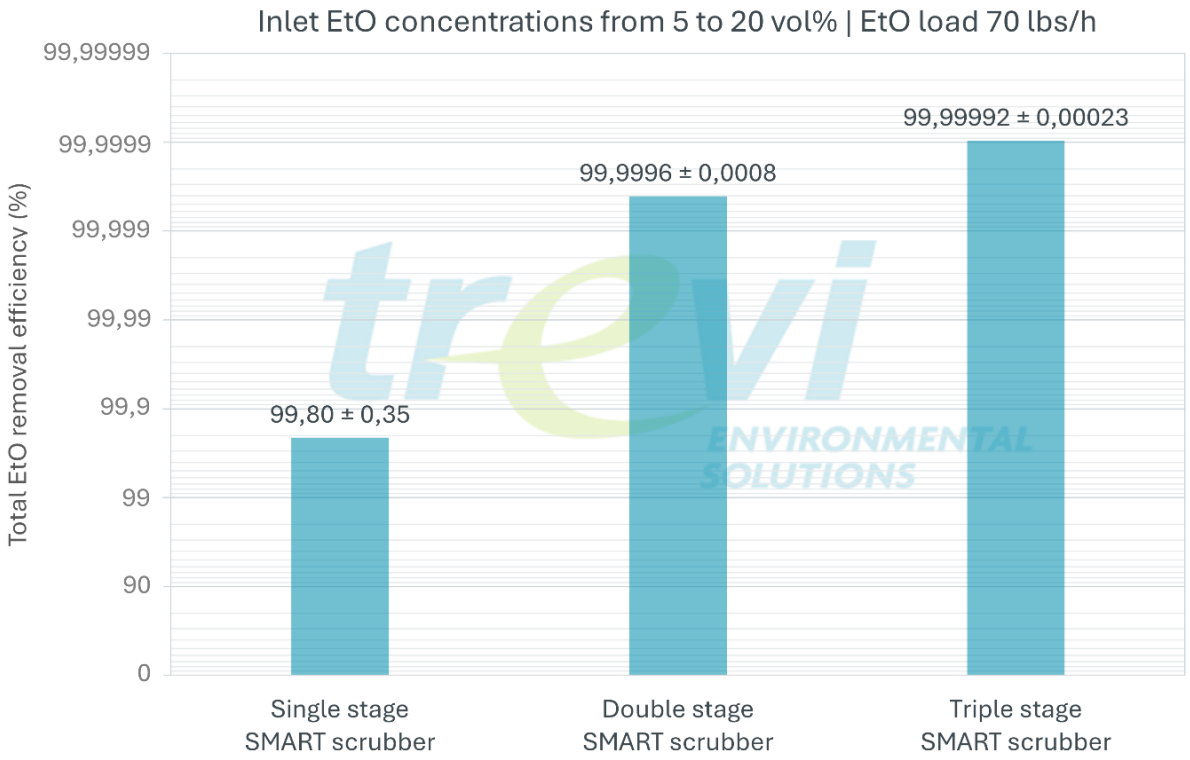


Figure 3. *The measured DRE of the Smart wet scrubber after stage 1 (Single stage), after stage 2 (Double stage) and after stage 3 (Triple stage).*

the third stage scrubber solution, after which fresh make-up water is added to the third stage scrubber. This approach is done in an automatic way and maintains stable system performance while preventing excessive glycol buildup.

REACTION CHEMISTRY AND CATALYST FUNCTION

The Smart wet scrubber relies on the catalytic hydrolysis of ethylene oxide at ambient conditions:

$$C_2H_4O + H_2O \rightarrow HO–CH_2–CH_2–OH$$

In this reaction, ethylene oxide first transfers from the gas phase into the scrubber liquid (water) through gas–liquid mass transfer in the absorption column, after which it reacts with water to form ethylene glycol, a non-hazardous, biodegradable liquid. While the reaction is thermodynamically favourable, it proceeds slowly in the absence of catalysis.

The Smart catalyst present in the scrubber tank accelerates the hydrolysis sufficiently to achieve near-complete conversion within minutes under ambient temperature and pressure, before the scrubber liquid is recycled to the packed bed column.

OPERATION AND PERFORMANCE

DESIGN BASIS AND RESIDENCE TIME

The system of the partner is designed to treat a gas flow up to approximately 600 m³/h with inlet EtO concentrations of approximately 20% by volume and higher, while providing sufficient contact time in each stage to ensure complete conversion.

AMBIENT OPERATION

The Smart wet scrubber operates at near-atmospheric pressure and ambient temperature, typically between 20 and 40 °C. Pressure drop across the 3-stage scrubber unit is approximately 14 mbar at maximum gas flow. A cooling system (heat exchanger) is provided in the first stage to control the heat released by the hydrolysis reaction. No preheating, burners, or thermal oxidation units are required. In cold climates, the system can be insulated or heat-traced, and a heater can be installed if required, while still operating without the high external heating required as for thermal or catalytic oxidation.

MONITORING AND ANALYTICAL METHODS

Inlet and outlet EtO concentrations were measured using gas chromatography-flame ionization detection (GC-FID, detection limit 1 ppmv). GC-FID was used for higher concentration ranges, while plasma emission detector (GC-PED, detection limit 2 ppbv) was employed for trace-level measurements near the regulatory limit. Calibration was performed using certified EtO standards. During representative multi-hour trials outlet concentrations consistently remained below 1 ppmv during the measurement periods. Measured DRE over the triple stage Smart scrubber were 99.99992 ± 0.00023% under tested conditions, ensuring outlet concentrations were well below regulatory requirements.

BYPRODUCT HANDLING AND MASS BALANCE

Captured EtO is converted to ethylene glycol. The theoretical yield of ethylene glycol from EtO hydrolysis is approximately 1.409 kg per kg of EtO reacted. Measured glycol concentrations in the recirculating liquid closely matched this theoretical value, confirming complete conversion. Once glycol concentrations reached a predefined setpoint (e.g. 30%), a controlled bleed-off is initiated according to the process described previously. The automated liquid changeover process requires less than 60 minutes and the scrubber remains in operation during the purge/refill cycle, ensuring continuous EtO abatement. The glycol-containing effluent is non-hazardous under applicable local classification and does not require neutralization, unlike spent sulfuric acid streams from conventional acid EtO scrubbers.

CATALYST STABILITY AND MAINTENANCE

Full-scale operation of the 3-stage unit commenced in August 2024. Over the observation period, no indications of catalyst loss were observed and no catalyst replacement was required. Routine maintenance was limited to inspection of pumps, valves, and instrumentation. The replacement of sulfuric acid with water as a scrubbing liquid removed corrosion-related maintenance and drastically reduced hazardous waste handling requirements as the byproduct is a dilute antifreeze solution. Overall operating costs are primarily associated with electricity consumption for pumps and blowers. The system requires no onsite combustion, thereby avoiding combustion-related NO_x emissions and direct CO_2 emissions at the point of abatement.

CONCLUSIONS

The full-scale Smart wet scrubber installed at the partner facility demonstrates reliable, ultra-high-efficiency abatement of ethylene oxide using a safe, water-based catalytic process.

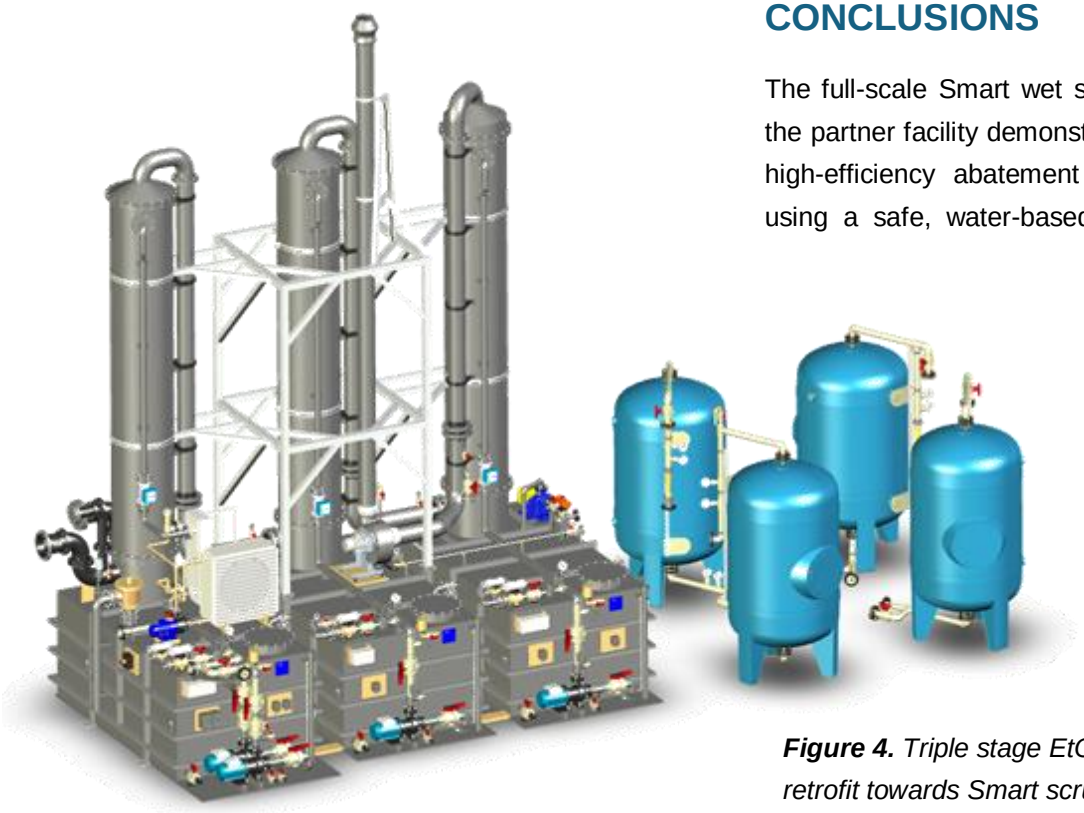


Figure 4. *Triple stage EtO scrubber after retrofit towards Smart scrubber technology.*

During the measurement periods, the 3-stage system consistently maintained outlet concentrations at or below the 1 ppmv compliance limit, corresponding to ultra-high destruction and removal efficiencies of 99.9999% under the tested conditions. Ethylene glycol formation closely matched theoretical expectations, confirming complete hydrolysis of EtO by the Smart catalyst. Compared to conventional sulfuric acid scrubbers and thermal oxidizers, the Smart wet scrubber delivers equivalent or superior performance while eliminating hazardous chemicals, combustion-related emissions, and high operating costs. This case demonstrates that existing acid EtO scrubber installations effectively can be retrofitted to Smart wet scrubber technology, enabling sterilization and gas-handling facilities to meet stringent EtO emission standards while reducing operational complexity, cost, and environmental impact. ■

COMPARISON WITH CONVENTIONAL TECHNOLOGIES

Compared to sulfuric acid wet scrubbers or thermal/catalytic oxidizers, the Smart wet scrubber (SwEtO) offers several key advantages:

ULTRA-HIGH REMOVAL EFFICIENCY

Three-stage Smart wet scrubber sustained ethylene oxide DRE of 99.9999%.

ACID-FREE OPERATION

Uses water as the scrubbing liquid and a Smart catalyst system, eliminating acid handling, corrosion, and hazardous acid waste.

AMBIENT TEMPERATURE OPERATION

No combustion, burners, or preheating required, resulting in low energy consumption and immediate start-up.

NON-HAZARDOUS AND BIODEGRADABLE BYPRODUCTS

The primary byproduct is an ethylene glycol–water solution, which is non-hazardous and biodegradable under applicable local classification and may offer potential for reuse or recycling depending on downstream specifications.

LOWER OPERATING COSTS

No chemical consumption, minimal labor (<4 hrs/month operating labor) and no fossil fuel use result in significantly lower OPEX.

OPERATIONAL ROBUSTNESS

Tolerates variable flows and concentration spikes without complex control strategies.

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