

## Control of VOCs emissions by condenser pre-treatment in a semiconductor fab

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### Abstract

The performance of a modified design of local condensers to pre-treat a variety of volatile organic compounds (VOCs) emitted from the stripping process of a semiconductor fab was tested in this study. The reaction temperature of the condensers was controlled at around 10 °C, it is relatively higher than the traditional condenser reaction temperature. Both VOCs and water vapors were condensed and formed liquid films. This resulted in an enhancement of the VOCs removals, especially for VOCs of high boiling points or solubility. This can help to prevent the follow up zeolite concentrator from damage. The performance of the integrated system of condenser/zeolite concentrator could, therefore, remain highly efficient for a longer operation time. Its annualized cost would also be lower than installing the zeolite concentrator only. © 2005 Elsevier B.V. All rights reserved.

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### 1. Introduction

The exhaust gas from semiconductor manufacturers has characteristics of high-flow rate with a variety of VOCs emitted at low concentrations [1]. Besides, the boiling points of VOCs may vary over a wide range from less than 50 °C to over 200 °C. They are usually treated by regenerative adsorption/desorption devices such as the rotary zeolite concentrators to increase the VOCs concentrations. Then, the concentrated VOCs are further treated by incineration devices. The initial operation efficiencies of zeolite concentrators in terms of total hydrocarbon (THC) emitted from semiconductor fab are well above 90% in laboratory tests [2–6] and field operations [7,8].

But when high boiling-point VOCs are treated during desorption process, they tend to gradually occupy the adsorption sites and deteriorate the performance of an adsorber [4]. The installation of condensers before a VOCs adsorber to

condense the high boiling-point VOCs may be an effective method to prevent the decreasing of VOCs removal efficiency. However, limited information is available in the literature for the integrated process of condensers plus a zeolite concentrator.

In general, condensation involves a refrigerator to lower the temperature of the exhaust gas until it is below the dew point. And the removal is performed by the condensation of gaseous VOCs on the chilled parts of the condenser. The modules of a VOCs condenser system usually include the dehumidification module and the refrigerator module [9]. Dehumidification is performed to reduce the moisture and prevent the detrimental icing effects that would otherwise occur when the VOCs exhaust is cooled to a temperature below 0 °C in the VOCs condensation section. Besides, a dehumidification pretreatment is also beneficial for the purpose of VOCs recovery.

Zeiss and Ibbetson [10] showed that the successful application of condensation technology depended on two factors—low temperature capability and a high vapor phase concentration of VOCs. And it is known that the condensa-

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tion of VOCs is a proper technique to decrease the emission level for single compound, high concentration and low gas flow rate VOCs at below 0 °C. But whether a condenser is suitable to treat VOCs exhaust that has the characteristics of multiple compounds, low concentrations and high gas flow rate at the temperature of above 0 °C has rarely been studied.

The practical performance of a condenser in reducing low VOCs concentrations has not been sufficiently understood. In order to keep the condensers with economical performance, this study proposes a modification on the traditional condenser design. Both condensation and liquid absorption were effective in the condensers to enhance the removals of VOCs.

## 2. Experiments

The design of condensers for such purposes is slightly different from the traditional ones operated under ultra-low temperatures. The ice water inside the tubes and fins type coil was operated at 10 °C, thus the moisture can condense and form a liquid absorption film that enhances the condensation of some hydrophilic VOCs. With the design of dual effect (condensation plus film absorption) of the condensers employed herein, it is expected that not only the VOCs removal efficiency can be increased but also the power consumption cost can be reduced as compared to the traditional condensers.

Table 1 presents the operating parameters of the condenser set in this study. The indoor temperature of the location of condensers was maintained at around 22–23 °C dry bulb (db). The VOCs emitted from the stripping process were at temperatures of 35–60 °C before inlet to the condensers. The outlet temperature of the VOCs stream was around 10–14 °C and the water content in the condensed solvents was about 40–50% by weight.

Table 1  
Operating parameters of the condenser

Operating parameters	Value
Tube and fins type heat coil	330 mm ( <i>L</i> ) × 608 mm ( <i>W</i> ) × 457.2 mm ( <i>H</i> )
Total area of cooled surface for condensation (m <sup>2</sup> )	20
Total area of wetted surface for condensation (m <sup>2</sup> )	40
Maximum treated flow-rate by the condenser (SCMH)	3000
Maximum VOCs inlet concentration (designed value) (ppmv)	100
Superficial velocity of inlet VOCs flow (m/s)	1.0–3.0
Retention time of VOCs flow in the condenser (s)	0.11–0.33
Temperature of the fab (dry bulb) (°C)	22–23
Humidity of the fab (%RH)	40–45
Inlet temperature of VOCs laden air flow (°C)	35–60
Temperature of ice water chilling coil (°C)	10
Temperature of outlet VOCs flow (°C)	10–14
Water content of condensed VOCs (wt.%)	40–50
Cooling capacity (kJ/h)	51000–53500
Water condensed weight (designed value) (kg/h)	1.5

Fig. 1 presents the schematic of the stripping process of a semiconductor fab in Taiwan as well as its VOCs removal process including two parallel condensers and a zeolite concentrator/incinerator unit. The stripping process was composed of one strip step and three rinse steps. The wafer boat was immersed in the first strip tank at a temperature below 110 °C and then transferred to the rinse tanks. The VOCs exhaust emitted from the strip and the first two rinse tanks was introduced into the condensers and then sent to the zeolite concentrator/incinerator for final treatment. The condensed organic solvent was drawn into the daily tank. Because stripper and rinse solutions used in stripping process of the semiconductor industry were composed of several organic solvents so the constituents of exhausted VOCs were complicated. And the purity of organic solvents required by every manufacturing process was so high that the condensed VOCs could not be recycled for stripping and rinsing purposes again.

The concentrations of VOCs were measured at the inlet and the outlet of the condensers and the removal efficiencies of the two condensers were calculated. The VOCs concentrations were analyzed according to the USEPA TO-14A method [11]. The VOCs were sampled by stainless-steel tube sampling. The sampling tube drew a VOCs sample from the stream by the drop in pressure ( $\Delta p = 10^{-2}$  mmHg). The sample was then analyzed by GC/MS in the laboratory. The equipments for analyzing VOCs included a VOCs autosampler (Xontech, 911/912 systems), a Cryogenic Concentrator (Nutech, 3350A), a Gas Chromatograph (HP 5890 Series II) and a Mass Selective Detector (HP 5971 Series II) coupled with a GC column (Rtx-502.2, 60 m, 0.25 mm i.d., 1.4 μm f.m.). Furthermore, a continuous emission instrument (GC/FID detector) was installed at the pipe-end for on-line measurements of the THC removal efficiency.

## 3. Results and discussion

### 3.1. Analysis of VOCs emitted from the stripping process

Fig. 2 presents the dominant species detected by GC/MS during the stripping process of a semiconductor fab. The largest quantity of VOCs emitted during the stripping process was dimethyl sulfoxide (DMSO, 63%). Other major VOCs being detected included the dimethyl sulfide (DMS, 15%), isopropylalcohol (IPA, 11%), dimethyl disulfide (DMDS, 6%), 1-methyl-2-pyrrolidinone (NMP, 2%) and trace amounts of toluene, *N,N*-dimethyl acetamide, and acetone, etc. The total concentrations of VOCs emitted during the stripping process depended on the product yields and were varied from 16,000 to 42,000 ppbv.

The VOCs emitted from the stripping process are mainly due to heating and agitating steps in the first and second tanks as well as the rinsing step in the third tank. The compounds of DMS, DMDS, DMSO, NMP, and *N,N*-dimethyl acetamide were emitted when the stripper is heated and agitated, while

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