B.9 CONDENSERS[1,2,24]

B.9.1 Background

Condensers are used to convert condensible components of a gas stream to the liquid phase, usually by reducing the temperature of the gas stream. Condenser efficiencies vary from 50 to 95 percent, and are dependent on the type of gas stream entering the condenser and on the condenser's operating parameters (e.g., coolant temperature). Gas stream properties such as the number of pollutants, chemical and physical properties of those pollutants, moisture content, particulate matter content, flow rate, and temperature all affect how well the condenser operates. Condensers can be classified as either contact condensers or surface condensers. In contact condensers, the exhaust gas comes into direct contact with the coolant. Contact condenser designs are similar to spray towers. In surface condensers, the coolant typically is circulated through a series of tubes around which the exhaust gas flows. No secondary pollutants are generated from the operation of surface condensers because the coolant flows through a closed system.

Condensation occurs when the partial pressure of the condensible pollutant in the waste gas stream is equal to its vapor pressure as a pure substance at the outlet gas temperature of the condenser. The waste gas stream is cooled by transfer of its heat to a refrigerant or coolant; the waste gas becomes saturated with one or more of its pollutants at the dew point or saturation temperature, and as the gas continues to cool, the pollutants condense. The temperature at which the gases condenses can be predicted from vapor pressure data for the pollutant and its mole fraction in the waste gas stream. The temperature required to achieve a given removal efficiency or outlet concentration depends on the inlet conditions of the waste gas stream.

The coolant used in a condenser depends upon the saturation temperature needed to condense the pollutants of interest in the gas stream. Chilled water can be used for condensation temperatures above approximately 40˚ to 45˚F, brines above 10˚ to 15˚F, and chlorofluorocarbons for condensation temperatures below −29˚F. Temperatures as low as −80˚F may be necessary to condense some streams. When such low temperatures must be achieved to reach the dew point for a particular pollutant, other components of the waste gas stream, such as water, can solidify and foul the heat transfer surfaces. In these instances a two-stage condensation system can be designed; the first stage removes moisture while the second stage is cooled to the lower temperature desired.

A condenser is designed for a maximum pressure and temperature. Normal operation of a condenser should include an outlet gas maximum temperature setpoint and a fixed inlet and outlet coolant/refrigerant temperature. The outlet gas temperature is a critical indicator of the efficiency of a condenser. Normal operation may also include a constant pressure differential across nozzles, tubes, etc. System pressures are important operating parameters that can indicate proper waste gas stream flow and coolant flow. The coolant flow rate should be checked on a regular basis to ensure that it is within design criteria. Several operating parameters may be used to indicate good operation of the condenser, including: outlet pollutant concentration of the most

volatile pollutant, inlet temperature of the waste gas stream, outlet temperature of the waste gas stream, temperature of the condensate pool, inlet temperature of the coolant, and outlet temperature of the coolant.

There are several common problems or malfunctions associated with condenser operation. Excessive flow rates may increase erosion of the device and may cause entrainment of liquids and PM in the waste gas stream. Fouling or plugging may occur on the shell, tubes, pipes, valves, and monitors; symptoms of fouling or plugging may include an increase or decrease in pressure, a performance decrease, hot or cold spots, and short-circuiting of flow patterns. Routine maintenance is an important component of proper condenser operation.

B.9.2 Indicators of Condenser Performance

The primary indicators of the performance of condensers are the condenser outlet VOC concentration and condenser outlet gas temperature. Other parameters that indicate condenser performance include coolant inlet temperature, coolant outlet temperature, exhaust gas flow rate, pressure differential across condenser, coolant flow rate, pressure differential across coolant recirculation system, and condensate collection rate. Each of these indicators is described below. Table B-9 lists these indicators and illustrates potential monitoring options for condensers.

Outlet VOC concentration. The most direct indicator of condenser performance in removing specific organic compounds from the exhaust stream is the concentration of those compounds at the condenser outlet; however, measuring concentrations of specific compounds may be impractical. For most applications, the most practical and direct indicator of condenser performance is the outlet VOC concentration.

Outlet gas temperature. The temperature of the gas exiting the condenser is a key indicator of condenser performance. The temperature necessary to achieve a specific outlet concentration of a compound can be determined based upon engineering principles. Increases in outlet temperature can indicate a problem with the condenser, such as plugging, or an increase in process gas temperature as it enters the condenser. In either case, removal rates are likely to decrease as condenser outlet temperature increases.

Coolant inlet temperature. The temperature of the coolant as it enters the condenser provides a good indication the condenser is operating as designed. If the incoming process gas stream flow rate and temperature do not vary significantly, coolant inlet temperature can be a reliable indicator of condenser performance. However, if the process gas stream characteristics vary, coolant inlet temperature is not a good indicator of condenser performance. Generally, increases in coolant temperature are likely to result in decreased organic removal from the process exhaust stream.

Coolant outlet temperature. Coolant outlet temperature, together with the coolant inlet temperature and coolant flow rate, affect the degree of heat transfer from the inlet gas stream to the coolant. The heat transfer rate provides a good indicator of condenser performance.

However, by itself, this parameter would be a less reliable indicator of condenser performance than other parameters (outlet VOC concentration, condenser outlet gas temperature). The coolant outlet temperature should be monitored in conjunction with other coolant parameters; coolant outlet temperature must be compared to the coolant inlet temperature and flow rate to determine heat transfer and the rate of organic compound removal.

Exhaust gas flow rate. Exhaust gas flow rate determines the gas residence time within the condenser. Higher flow rates result in shorter residence times and less cooling of the inlet process gas stream; higher gas flow rates affect the heat transfer equation. Consequently, the level of organic removal (or the efficiency) would likely decrease with increasing exhaust gas flow rate.

Pressure differential across condenser. An increase in pressure differential (resistance to flow) across the condenser is an indication of fouling, plugging, or obstruction of the flow paths around the condenser tubes; as a result, condenser effectiveness would diminish. Fouling would decrease the heat transfer rate from exhaust gas stream to coolant. Pressure differential across the condenser should be maintained within design range. Changes in pressure differential are likely to be gradual over time.

Coolant flow rate. The coolant flow rate affects the rate of heat transfer from the incoming process exhaust gas to the coolant. Decreases in coolant flow rate are likely to result in decreases in organic removal rates. This parameter is of limited use as an indicator of condenser performance unless coolant temperatures also are measured.

Pressure differential across coolant refrigeration system. Increases in the pressure differential through the refrigeration system are an indication of plugging of the tubes and can result in a decrease in coolant flow rate. Decreases in coolant flow rate would adversely affect condenser performance.

Condensate collection rate. The rate at which condensate is collected from the condenser provides a direct measure of the rate of organics removal from the process exhaust gas stream. This parameter is a useful indicator of condenser performance only if the process gas stream characteristics (flow rate, temperature, concentrations of organic constituents) do not vary significantly, or if process input data (i.e., usage) are being used in conjunction with the condensate removal data to conduct a material balance and calculate control efficiency or emission rate.

Periodic inspection. An annual inspection of the internal surfaces of the condenser should be performed to check for fouling or corrosion of condenser surfaces.

B.9.3 Illustrations

The following illustrations present examples of compliance assurance monitoring for condensers:

9a: Monitoring outlet gas temperature.
9b: Monitoring inlet coolant temperature, outlet coolant temperature, coolant flow rate, and condensate collection rate.

B.9.4 Bibliography

TABLE B-9. SUMMARY OF PERFORMANCE INDICATORS FOR CONDENSERS

Parameters	Performance indication	Approach No.	1	2	3	4
		Illustration No.	**9a**	**9b**		
		Example CAM Submittals	**A3**			
		Comment	✔		✔	✔
Primary Indicators of Performance						
Outlet VOC concentration	Direct measure of outlet concentration. Most direct indicator of condenser performance; can be monitored continuously or periodically.					X
Outlet gas temperature	Indicates if gas is being cooled to/below dew point of target compounds; indicator of level of condensation. Too high indicates condensation to the level expected will not occur; increase in outlet temperature may indicate plugging or fouling problems.		X		X	
Other Performance Indicators						
Coolant inlet temperature	Indicates that condenser is meeting inlet design parameters. Good indicator of performance if inlet gas temperature and flow rate do not vary; increase in coolant inlet temperature indicates organic compound removal rate will be lower.			X		
Coolant outlet temperature	If coolant inlet and outlet temperature and flow rate are measured, indicates level of heat transfer from inlet gas stream. By itself, would be less reliable indicator of performance than other parameters; decrease would indicate decrease in organic compound removal rate (i.e., heat transfer to the coolant is not occurring).			X	X	
Coolant flow rate	Affects heat transfer rate. Decrease indicates decrease in condenser performance; parameter is of limited use without coolant temperature data.			X		
Condensate collection rate	Organic compound removal rate. Useful indicator of condenser performance only if process gas stream characteristics do not vary, or if used in conjunction with material balance.			X		

TABLE B-9. (Continued)

Parameters	Performance indication	Approach No.	1	2	3	4
		Illustration No.	9a	9b		
		Example CAM Submittals	A3			
		Comment	✔		✔	✔

Comments:

- Approach No. 1 corresponds to 40 CFR 60, subparts G (HON), M (Perchloroethylene Dry Cleaning, R (Gasoline Distribution), U (Polymers and Resins I), W (Polymers and Resins II), Y (Monhe Tank Vessel Loading), DD (Offsite Waste and Recovery), EE (Magnetic Tape), HH (Oil and Natural Gas), DDD ( ), III ( ), JJJ (Polymer and Resins IV), MMM (Pesticides), NNN (Wool Fiberglass), OOO (Polymers and Resins III), RRR ( ), SSS ( ), VVV ( ), and 40 CFR 63, subpart M (Perchloroethylene Dry Cleaning) requires both inlet and outlet gas temperatures for condensers on washer units.
- Approach No. 3 corresponds to 40 CFR 61, subpart FF.
- Approach No. 4 corresponds to 40 CFR 60, subpart DDD, III, NNN, and RRR; 40 CFR 61, subpart FF; and 40 CFR 63, subpart G (HON), R (Gasoline Distribution), U (Polymers and Resins I), Y (Manhe Tank Vessel Loading), DD (Offsite Waste and Recovery), HH (Oil and Natural Gas), MMM (Pesticides), OOO (Polymers and Resins III); 40 CFR 63, Subpart EE (magnetic tape) requires both inlet and outlet VOHAP concentration.

[EE - inlet & outlet VOHAP concentration.]

CAM ILLUSTRATION
No. 9a. CONDENSER FOR VOC CONTROL

1. APPLICABILITY

1.1 Control Technology: Condenser [072, 073, 074]
1.2 Pollutants
Primary: Volatile organic compounds (VOCs)
1.3 Process/Emissions Unit: Coating, polymer manufacturing, distillation units, equipment leaks, air oxidation units, miscellaneous reactors, pharmaceuticals

2. MONITORING APPROACH DESCRIPTION

2.1 Parameters to be Monitored: Outlet gas temperature.
2.2 Rationale for Monitoring Approach: Condenser outlet gas temperature affects removal efficiency; an increase in outlet gas temperature indicates decreased removal efficiency.
2.3 Monitoring Location: Outlet vent of condenser.
2.4 Analytical Devices Required: Thermocouples, RTDs, or alternative methods/instrumentation as appropriate for specific gas stream or specific equipment design; see section 4.2 (Temperature) for additional information on devices.
2.5 Data Acquisition and Measurement System Operation
- Frequency of measurement: Hourly, or recorded continuously on strip chart or data acquisition system.
- Reporting units: Degrees Fahrenheit or Celsius (°F, °C).
- Recording process: Operators log data manually, or recorded automatically on strip chart or data acquisition system.

2.6 Data Requirements
- Baseline outlet gas temperature measurements concurrent with emissions test;
- Calculations indicating outlet gas temperature necessary to achieve compliance; or
- Historical plant records on outlet gas temperature measurements.

2.7 Specific QA/QC Procedures
- Calibrate, maintain, and operate instrumentation using procedures that take into account manufacturer's specifications.

2.8 References: 1, 2.

3. COMMENTS

3.1 Data Collection Frequency: For large emission units, a measurement frequency of once per hour would not be adequate; collection of four or more data points each hour is required. (See Section 3.3.1.2.)

CAM ILLUSTRATION
No. 9b. CONDENSER FOR VOC CONTROL

1. APPLICABILITY

1.1 Control Technology: Condenser [072, 073, 074]
1.2 Pollutants: Volatile organic compounds (VOCs)
1.3 Process/Emissions units: Coating, polymer manufacturing, distillation units, equipment leaks, air oxidation units, miscellaneous reactors, pharmaceuticals

2. MONITORING APPROACH DESCRIPTION

2.1 Indicators Monitored: Inlet and outlet coolant temperatures, coolant flow rate, and condensate collection rate.
2.2 Rationale for Monitoring Approach
- Inlet coolant temperature: Affects removal efficiency; an increase in the coolant temperature decreases removal efficiency; demonstrates that coolant is at design temperature.
- Outlet coolant temperature: Gives an indication of removal efficiency; a decrease in the outlet coolant temperature decreases removal efficiency.
- Coolant flow rate: Affects the heat transfer rate.
- Condensate collection rate: Demonstrates that VOC component is being removed by the condenser; a decrease in collection rate indicates a decrease in removal efficiency.

2.3 Monitoring Location
- Inlet coolant temperature: Front end heads.
- Outlet coolant temperature: Rear end heads.
- Coolant flow rate: Front end heads.
- Condensate collection rate: Condensate pool.

2.4 Analytical Devices Required
- Inlet coolant temperature: Thermocouples, RTDs , or alternative methods/instrumentation as appropriate for specific gas stream or specific equipment design; see section 4.2 (Temperature) for additional information on devices.
- Outlet coolant temperature: Thermocouples, RTDs , or alternative methods/instrumentation as appropriate for specific gas stream or specific equipment design; see section 4.2 (Temperature) for additional information on devices.
- Coolant flow rate: Liquid flow meter or other flow device; see section 4 for more information on specific types of instruments.
- Condensate collection rate: If measured by weight, use of a scale or other weight monitor; if measured by volume, use of a flow meter, tank level indicator, or visually observing changes in the level of the condensate pool tank.

2.5 Data Acquisition and Measurement System Operation
- Frequency of measurement: Hourly, or recorded continuously on strip chart or data acquisition system.

- Reporting units:
  - Inlet coolant temperature: Degrees Fahrenheit or Celsius (°F, °C).
  - Outlet coolant temperature: Degrees Fahrenheit or Celsius (°F, °C).
  - Coolant flow rate: Gallons per minute (gpm) or pounds per hour (lb/hr).
  - Condensate collection rate: Weight or volume units (pounds, kilograms, liters, gallons, etc.).
- Recording process: Operators log data manually, or recorded automatically on strip chart or data acquisition system.

2.6 Data Requirements

- Baseline coolant temperature measurements, coolant flow rate, and condensate collection measurements concurrent with emission test;
- Calculations indicating outlet gas temperature necessary to achieve compliance, baseline outlet gas temperature measurements concurrent with coolant temperature measurements, coolant flow rate, and condensate collection rate; or
- Historical plant records on coolant temperature, coolant flow rate, and condensate collection rate measurements.

2.7 Specific QA/QC Procedures

- Annual process review to determine process or materials changes that could affect the initial determination of condensation parameters.
- Calibrate, maintain, and operate instrumentation using procedures that take into account manufacturer's specifications.

2.8 References: 1, 2.

3. COMMENTS

3.1 Data Collection Frequency: For large emission units, a measurement frequency of once per hour would not be adequate; collection of four or more data points each hour is required. (See Section 3.3.1.2.)

3.2 Use of these control device parameters are appropriate for process systems where the process vent gas stream characteristics (flow rate, temperature, VOC concentration) are consistent over time.