**TABLE 10.5** Monitoring and Control of the Physical Environment

| Parameter | Measuring devices(s) | Comments |
|---|---|---|
| 1. Temperature | Resistance thermometer or thermistor | Thermistors are used when small size and rapid response are required |
| 2. Pressure | Diaphragm gages | Pressure is regulated by a simple back-pressure regulator in gas exit line |
| 3. Agitator shaft power | Wattmeter or strain gages | Strain gages are used in bench or pilot-scale equipment |
| 4. Foam | Rubber-sheathed electrode | Mechanical foam breakers are self-regulating; sensor is used to activate solenoid valve to release antifoam agent |
| 5. Flow rate (gas) | Rotameters or thermal mass flow meter | Position of rotameter float is converted to an electrical signal; controller manipulates flow valve |
| 6. Flow rate (liquid) | Magnetic-inductive flow meters or change in weight of additional vessels determined by load cell | Magnetic-inductive meters are good for viscous fluids or fluids with high level of particulates; controller can manipulate flow valves |
| 7. Liquid level | Load cells to measure amount of liquid in vessel. Liquid height, conductivity sensors; capacitance probes; ultrasound | Liquid height is a function of gas sparge rate and gas hold-up; foam can complicate measurement |
| 8. Viscosity | Rotational viscometers | On-line measurement is difficult; broths with high solids content present special problems |
| 9. Turbidity (to indicate cell mass) | Photometer (either as a probe into the reactor or in a slip stream) | Many problems: fouling and interference from gas bubbles and suspended solids |

with sufficient turbulence to help keep it clean. Although the use of multiple probes would be desirable, the increased risk of contamination often argues against it. Even with accurate probe response, the interpretation of that response in a large fermenter must be done carefully.

Since many fermentations require extensive periods for completion (2 to 20 days), it is important that probe response be stable for extended periods. Industrial fermentation broths contain many proteins and other organics that have a significant tendency to adsorb onto surfaces. Many microbes also have a strong tendency to adhere to surfaces. Thus, *probe fouling* in an extended fermentation is a constant problem. Drift is a problem in some probes, and recalibration *in situ* is not always possible. If sterility is to be maintained, the removal and replacement of probes is practically impossible. In some cases, special designs allowing some back-flushing are possible. However, the quality of information available tends to decrease as the length of a fermentation cycle increases.

Exit-gas measurements, particularly with mass spectrometers, are of increasing interest. Advances in building robust process instruments at lower cost have made this a more attractive proposition, particularly when such an instrument can be used for several fermenters (e.g., using a computer-controlled switching manifold). The main limitation on exit-gas analysis is that only volatile components can be monitored.