TABLE 10.6 Approaches to Monitoring and Control of the Chemical Environment

Approach	Possible measuring devices and compounds monitored	Comments
1. Insertable probes	pH electrode; H^+	Special design to facilitate repeated autoclaving; protein fouling of diaphragm can be a problem; pH probes used extensively
	Redox electrodes; redox potential	Measurement fairly reliable; interpretation and use of information often difficult
	Ion-sensitive electrodes; NH_3, NH_4, Br, Cd, Ca, Cl, Cu, CN, F, BF_4, I, Pb, NO_3, ClO_4, K, Ag, Na, S, SCN	Cross-sensitivity major problem; drift and calibration can be troublesome; response time can be slow; sterilizability is often poor
	O_2 probes, either galvanic or polarographic; pO_2	Measure partial pressure of O_2, not O_2 concentration; slow response; drift, fouling, and recalibration during extended fermentations can be a problem; O_2 probes widely used and extremely important
	CO_2 probes; activity of dissolved CO_2	CO_2 is known to have important physiological effects, but relating these effects to dissolved CO_2 is difficult
	Fluorescence probes; NADH	Commercially available to monitor intracellular concentrations; fouling is potential problem
	Biosensors (use enzymes, antibodies, organelles, or immobilized whole cells for chemical reaction with physicochemical probes to measure resulting change, e.g., pH); wide range of compounds potentially detectable, (e.g., glucose, glutamic acid, ammonia, acetate, ethanol formate, cephalosporin, penicillin)	Sterilizability, enzyme cost, cofactor regeneration, usable lifetime are all constraints on utilization of such probes; high level of development activity will lead to at least partial solution of these problems
2. Exit gas analyzers	Paramagnetic analyzer (O_2); thermal conductivity or long-path infrared analyzers (CO_2)	These instruments are specialized for measurements of these specific gases; important in fermentation balances; sample conditioning important
	Flame ionization detector; low levels of organically bound carbon, especially useful for volatile organics such as ethanol or methanol	Flame ionization measures total hydrocarbon; automatic process gas chromatography equipment available to separate into individual compounds
	Mass spectrometer; O_2, CO_2, volatile substances (can also be used on liquid streams)	Highly specific, rapid, and accurate; expensive; has not been used for complex molecules; depends on gas phase for volatile compounds

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