Process Control

The Requirement for Process Control

Microbial activity is optimal when

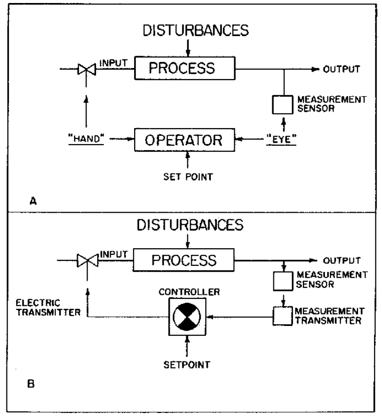
Environmental conditions in bioreactor =
environmental requirements of the cell

The cell's environmental requirements are generally within a narrow range. This means that adjustments are required to maintain conditions within the band.

Adjustments are made via process control
This enables the assurance of a desired environment.

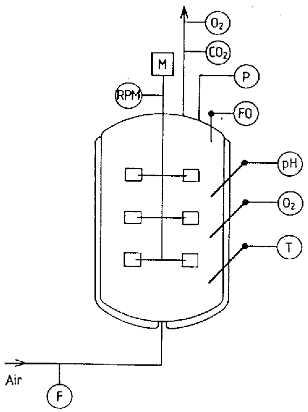
Process Control

Process control is a term which describes the implementation of a policy for operating a process.
The usual implementation of the policy is through a control loop



Representations of feedback control loops
(A) Manual control (B) Automatic control

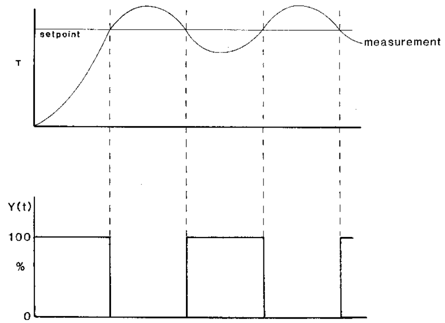
Main Controllable Process Parameters



F =Flow; FO =Foam; P =Pressure; RPM = Revolutions per minute T = Temperature; M = Motor

Automatic Feedback Control

1. On/Off Control



- Oscillatory
- Improved with "pause-pulse"
- Appropriate only for "fully on" or fully off" actuators
- Still commonly used

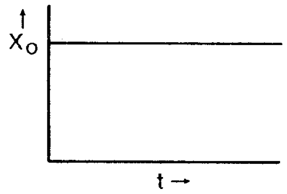
Automatic Feedback Control

2. Modulated control

a. Proportional control

Output of the controller is proportional
to the deviation between set-point and

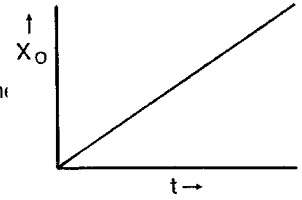
- Set-point "Offset" is a feature



b. Integral control

Output of the controller is determined
by the integral of the error signal overtim

- Time delay is a feature

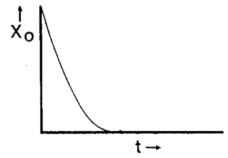


Modulated Control

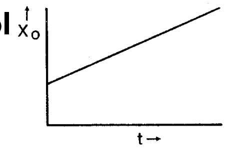
c. Derivative control

Output of the controller is determined by
the rate of change of the error signal.

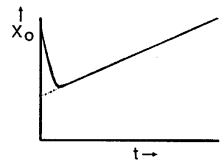
- No corrective action if error is constant.



d. Proportional Integral (PI) control



e. Proportional Integral Derivative (PID) control



In-Line Sensors

1. Physical process variables

a. Gas flow rate
Rotameter

b. Pressure
Pressure gauge

c. Reactor hold-up
Weight balance or hydrostatic pressure

d. Impeller speed
Tachometer

e. Foam
Conductivity probe

In-Line Sensors 2

2. Chemical process variables

a. pH
pH probe

b. Dissolved oxygen
Dissolved oxygen probe
Mass spectroscopy

c. Carbon dioxide
Mass spectroscopy

In-Line Sensors 3

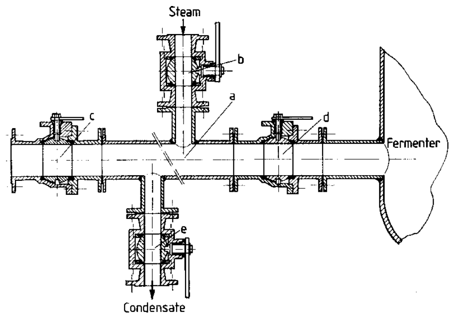
3. Biological process variables

Biomass
Turbidimetry
Light scattering
Particle counting

Off-Line Sensors

All the chemical process variables specified previously can be measured off-line

To preserve the axenicity of the reaction, aseptic sampling must be available

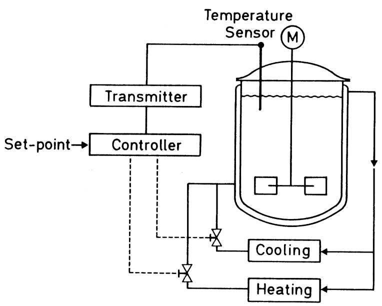


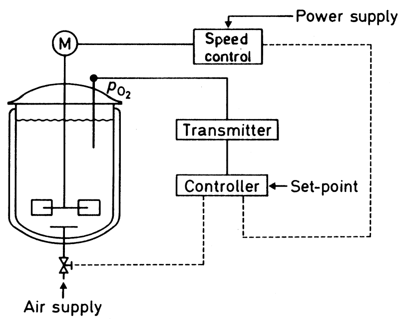
Steam-sterilizable fermenter sampling port

Control Systems

Two examples

1. Temperature
2. Dissolved oxygen





Use of Computers in Fermentation

Computers may be used for

1. Automated data logging
Unattended collection of data

2. Real-time data analysis
Derivation of process parameters from raw data

On-line Determination of Process Parameters	
Chemical	**Physical**
Cell density	Volumetric mass transfer coefficient
Oxygen uptake rate	Apparent viscosity (in non-Newtonian media)
Carbon dioxide evolution rate	
Respiratory quotient (RQ)	
Heat evolution rate	
Substrate utilization rate	

Use of Computers in Fermentation

3. Process control and optimization

Tasks

1. Simple monitoring; on/off control of operating steps e.g. filling, discharging, sterilizing
2. Sequencing of operating steps in batch and fed-batch processes (process automation).
3. Control of individual process parameters.
4. Control of entire process (process optimization).

Process Optimization

Examples of computer-controlled strategy in aerobic fed-batch culture of yeast (Onken & Weiland, 1985)

Control Tasks	Control Strategy
Optimal cell growth; suppression of ethanol formation	Control of nutrient feed (molasses, NH_3) via RQ based on constant C/N ratio in biomass
Maximum productivity; suppression of ethanol formation	Control of substrate feed via RQ; constraints for RQ and oxygen uptake
Maximum yield of biomass	Constant cell and substrate concentrations via time-optimal substrate feed
Time-optimal feed during start-up and exponential growth	Model for dynamic behavior