

Predictive Modeling

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(material from Maha Hajmeer)

Predictive microbiology provides objective means for evaluating the effect of processing operations on microbial growth, and shelf life and safety of food products. It is a possible alternative to traditional or rapid microbiological methods. Additionally, predictive microbiology and HACCP can be complementary concepts.

Understanding the factors influencing the growth of microbes (i.e., microbial ecology) is a key issue in controlling microbial proliferation; especially pathogens. The growth of microorganisms in foods is affected by a large number of variables (depending on the microorganism and environment). Examples include temperature, pH, sodium nitrite (NaNO_2), sodium chloride (NaCl), and presence of gaseous atmosphere. Understanding the effect of various variables (alone or in combination) on the growth of microorganisms is essential in evaluating their survival potential and identifying factors important in controlling their existence and minimizing potential risks.

Growth Curves

In a non-limiting nutrient environment bacteria will reproduce and increase in number. Bacterial growth curves relate the change in the number of microorganisms with time as influenced by a set of intrinsic and extrinsic parameters (or conditions) that dictate the growth, survival, and control of desirable and undesirable microorganisms in food systems.

Studies of the growth kinetics of microorganisms are usually carried out experimentally using laboratory growth medium (growth curve studies).

Growth curves are valuable in explaining some trends observed in processing operations, and assist in assessing methods for improving the overall process effectiveness and risk assessment.

If the logarithm of the density (count) of bacteria is plotted against time, a characteristic curve such as that shown in Fig. 1 results. This curve represents an environment desirable for bacterial growth, and is characterized by four main phases:

1. The **lag phase** (region 1) that encompasses the lag time in which the cells are adjusting their physiology and biochemistry to exploit the environment in which they find themselves.
2. The **exponential (log) phase** (region 2) where the cells grow in their environment as rapidly as possible and at a relatively constant rate.
3. The **stationary phase** (region 3) where the reproduction rate = death rate. The accumulation of waste metabolites leads to some reduction in the growth rate of the microorganisms.
4. The **death phase** (region 4) where a further increase in the accumulation of toxins increases bacterial lysis, and the rate of cell death exceeds the rate at which the cells divide.

Studying the growth kinetics (parameters characterizing growth/survival curves) and response of bacteria provides information that can be used to predict the microbial safety or shelf life of food products.

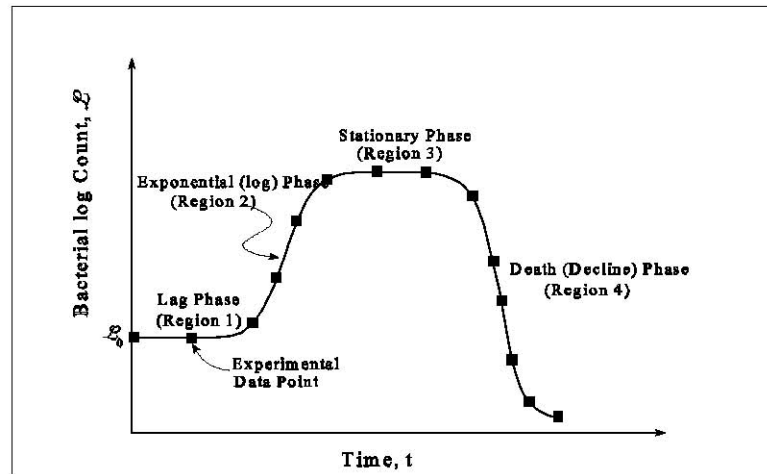


Fig. 1 Schematic of a typical growth curve showing the four phases.

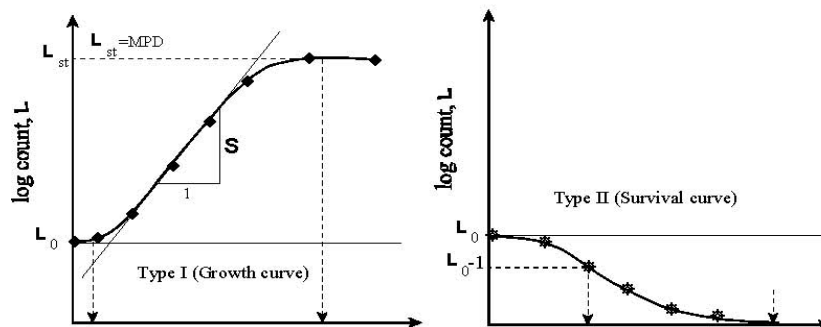


Fig.2 Schematic of growth curve (Type I) and survival curve (Type II) showing the various phases.

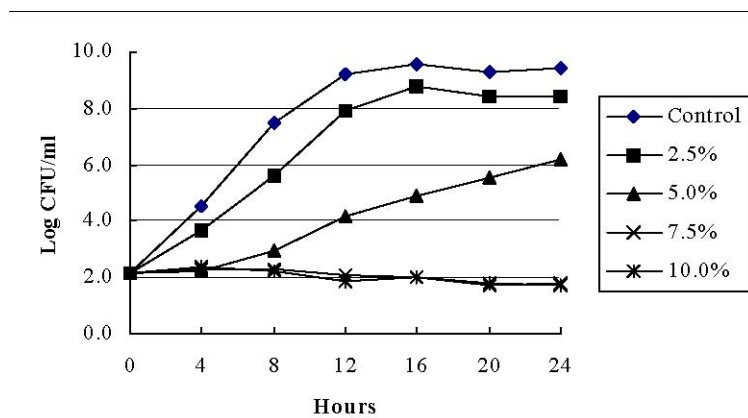


Fig.3 Growth of *Escherichia coli* O157:H7 over time at different concentrations of NaCl.

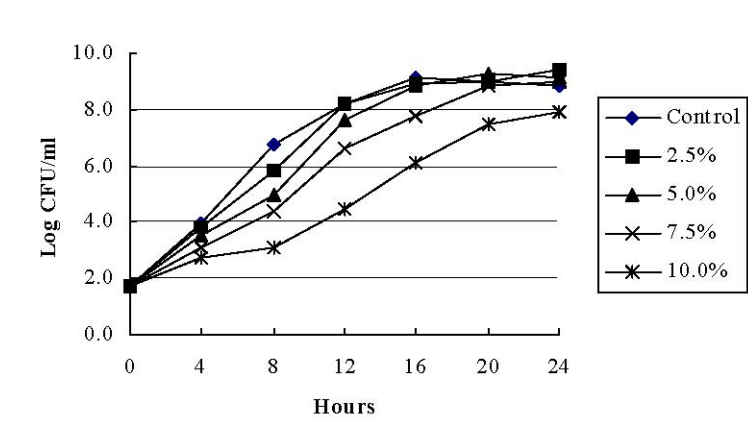


Fig.4 Growth of *Staphylococcus aureus* over time at different concentrations of NaCl.

Predictive Models

The use of simple kinetic parameters descriptive of the curves is one effective means in illustrating and quantifying the differences between curves and can enable simple comparisons between the various scenarios studied.

Growth models (predictive models) developed to fit experimental growth curves usually include a number of useful growth kinetic parameters: -Lag phase duration (LPD): The amount of time needed by the microorganisms to adjust to the growth environment. -Exponential growth rate (EGR): The speed by which the population doubles within the exponential phase.

- Generation time (GT): The time taken for the population within the exponential growth phase to double, also called doubling time. GT can be calculated from the maximum slope within the exponential phase ($GT = \log_2 2 / \text{slope} = 0.301 / \text{slope}$).
- Maximum population density (MPD): The highest microbial count pertaining to saturation phase.

The Modeling Process

The modeling process encompasses four main points:

1. Planning
2. Collection and analysis of data
3. Mathematical description of data (model development)
4. Validation and maintenance of model

Predictive Models Example on predictive models is the mathematical **modified** Gompertz equation

$$\text{Log}N = A + D e^{-e^{-B(t-M)}}$$

where A, B, D, and M are empirical constants, and t is time.

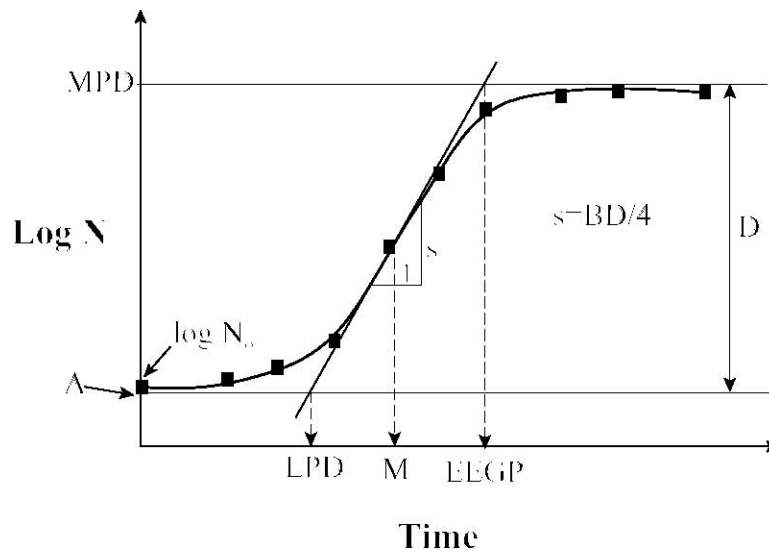
Kinetic Parameters

$$LPD = M - \frac{1}{B} (1 - e^{1 - e^{BM}})$$

$$EGR = \frac{BD}{e}$$

$$GT = \frac{0.301 e}{BD}$$

$$MPD = D + A$$



Examples of:

1. Predicting growth of *E. coli* O157:H7 under varying conditions.
2. Predicting growth of *S. aureus* under varying conditions.
3. Inactivation of *E. coli* O157:H7 in a meat system by irradiation.
4. Heat inactivation of *C. botulinum*.

URL address for Pathogen Modeling Program (PMP)

<http://www.arserrc.gov/mfs/pathogen.htm>

Applications of Microbiological Modeling

1. Hygienic efficiency of meat processing operations, cooling, transport, meat carton thawing
2. Shelf-life studies for meat, poultry and dairy products
3. Validity of regulations, check rationale for mandatory codes of practice
4. Microbial fermentation, finding optimum conditions for growth of desirable microbes (e.g., starter cultures)
5. Conditions for enrichment of target microorganisms in cultures
6. Process optimization and control
7. Product formulation
8. Education

HACCP AND PREDICTIVE MICROBIOLOGY¹

HACCP

1. Identify potential hazards and assess their severity at different stages of processing or operations.
2. Identify the Critical Control Points (CCP) where control measures need to be implemented.
3. Specification of control criteria and methods to ensure that a control has been achieved (when necessary).
4. Establish and implement monitoring procedures, and response measures to non-compliance situations.

Predictive Microbiology

1. Identify the microorganism(s) of concern.
2. Develop an understanding of the ecology of the microorganism to better identify the source and the likelihood of contamination.
3. Compare information with preset control specifications (i.e., accept/reject criteria).
4. Incorporate the available information into monitoring systems that indicate microbial proliferation.

¹ McMeekin, T.A., Olley, J.N., Ross, T., and Ratkowsky, D.A. 1993. Predictive Microbiology: Theory and Application. RSP, Taunton, England.