# Individual Based Modelling of Bacterial Cultures. A Lag Phase Study.

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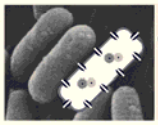

**Research Group:**
**"Modelling and discrete simulation of biological systems"**
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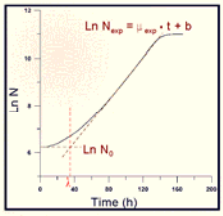
*INDISIM is a program based on an IbM (Individual based Model). INDISIM enables the study of the evolution of a bacterial culture based on the individual behaviour of the bacteria, over a period of time in a specific environment, in wich space and time are discrete. "Eigen experiments" controlling all the elements of the system can be done [2]. It's an interesting methodology to study the temporal evolution of complex systems. In particular, it is a good tool to study the lag phase in microbiological systems. The study of lag phenomena is specially important in food microbiology [5].*

The **lag phase** is the initial growth phase of a bacterial culture after inoculation, during which cell number remains relatively constant prior to exponential growth but total biomass increases [4]. During this period of time bacterial cells modify themselves in order to take advantage of the new environment and initiate exponential growth.




It can be characterized by lag-parameter $\lambda$, which gives the length of this phase as described in the figure [1].

$$\lambda = \frac{\ln N_0 - b}{\mu_{exp}}$$

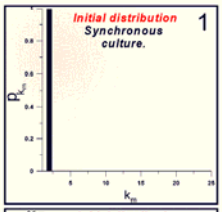
**In this work it has been considered that the lag phase can be caused both by**

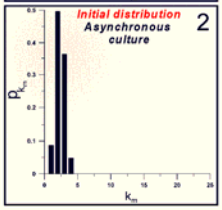
- $\alpha$ → **the need to reach a certain mean cellular biomass and mass distribution**
- $\beta$ → **the metabolic adaptation to a new medium by means of synthesizing new enzymes according to that**

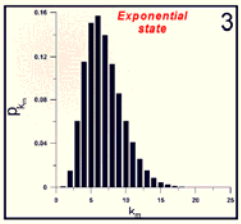
***These cases have been studied separately with INDISIM.***

## $\alpha$

To study the distribution of cells biomass, 25 discrete intervals of biomass with the same width are considered; the number of bacteria in each interval is counted to finally obtain the normalized distribution. The evolution of two different cases has been studied.




1 Initial mass distribution for a synchronous inoculum — 1 $\frac{\bar{m}_{t=0}}{\bar{m}_{repr}} = 0.233$

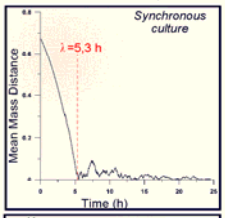
2 Initial mass distribution for an asynchronous inoculum — 2 $\frac{\bar{m}_{t=0}}{\bar{m}_{repr}} = 0.275$

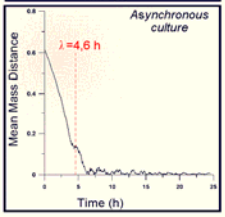
3 Mass distribution of the culture in the exponential phase: maximum diversity distribution [3] — 3 $\frac{\bar{m}_{exp}}{\bar{m}_{repr}} = 0.720$

**DISTANCES DEFINITION**
Two distances have been defined to study the evolution of the mean mass and the mass distribution, and their relationship with lag-parameter. The third one takes into account both of them.

*Mean Mass Distance*

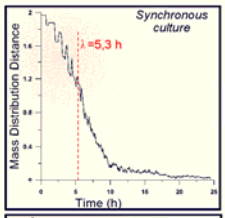
$$D_{\bar{m}}(t) = \frac{\left|\bar{m}(t) - \bar{m}_{exp}\right|}{\bar{m}_{exp}}$$

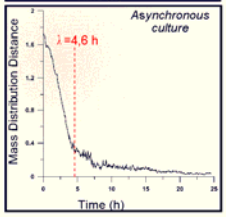



*Mass Distribution Distance*

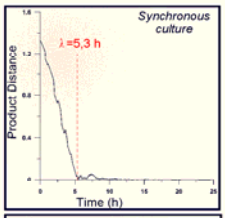
$$D_{p_k}(t) = \sum_{k_m=1}^{25} \left| p_{k_m}(t) - p_{k_m,exp} \right|$$

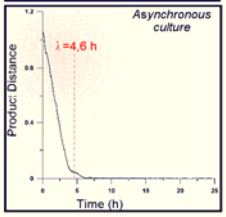



*Product Distance*

$$D(t) = D_{\bar{m}}(t) \cdot D_{p_k}(t)$$

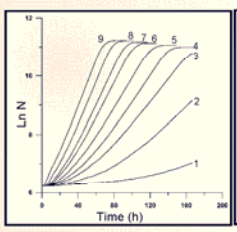


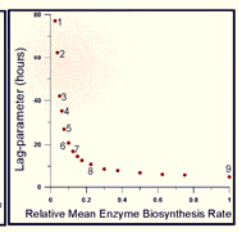




It has been proved that lag phase has a dependence in the mean mass of the culture and its cellular biomass distribution, as it is shown in the Product Distance graphics. **The Exponential Phase begins when the value of Product Distance is under 0.04.**

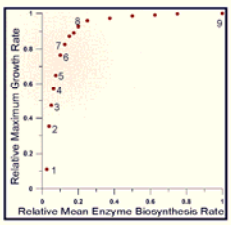
## $\beta$

The bacteria need to synthesize enzyme in order to grow and reproduce. With an asynchronus culture, and with an initial mean biomass corresponding to exponential growth, it has been tested the relationship between *Relative Mean Enzyme Biosynthesis Rate* and *Lag-parameter*, as you can see below.




**It has been shown that the lag phase is related to the enzyme's generation velocity.**




When the Enzyme Biosynthesis is slow, the growth is not exponential and the growth rate is not constant.

**INDISIM allows the improvement of the knowledge of the microbial cultures behaviour.**
**It has been proved that IbM is a good tool to study lag-phase phenomena.**

[1] J. Baranyi, T. A. Roberts, Int. J. Food Microbiol. **23**, 277-294 (1994)
[2] M. Ginovart et al., J. theor. Biol. **214**: 305-319 (2002)
[3] J. Wagensberg et al., J. Phys. Chem. Solids **49**: 695-700 (1998)
[4] S. Cooper, Encyclopedia of Molecular Cell Biology and Molecular Medicine. Ed. R. Meyers,Wiley-VCH. (2004)
[5] I. A. M Swinnen et al. Int. J. Food Microbiol. **94**:137-160 (2004)