

Heat Evolution

We now wish to estimate the heat evolution during cell growth

Carbon Source + Energy Source + Nutrients \rightarrow Cells + Products + HEAT

To do this, we need to have the following data:

1. **Full Stiochiometry**
2. **Heat of Combustion of all Substrates, Products and Biomass**

The Heat of Combustion of Biomass can either be measured in a calorimeter or can be estimated:

19.68 kJ / g Biomass has commonly been used

Heat Evolution (Cont'd)

Obtaining the Heat of Combustion of a range of substrate and nutrients at the concentrations that are used in industrial fermentations is not routine. Sometimes it is necessary to estimate these using heat of formation from “functional group” estimations and / or heat of mixing data etc.

Heat Evolution (Cont'd)

Table 5.1 Heats of combustion for bacteria and yeast

(From J.-L. Cordier, B.M. Butsch, B. Birou and U. von Stockar, 1987, *The relationship between elemental composition and heat of combustion of microbial biomass*. Appl. Microbiol. Biotechnol. 25, 305–312)

Organism	Substrate	Δh_c (kJ g ⁻¹)
Bacteria		
<i>Escherichia coli</i>	glucose	-23.04 ± 0.06
	glycerol	-22.83 ± 0.07
<i>Enterobacter cloacae</i>	glucose	-23.22 ± 0.14
	glycerol	-23.39 ± 0.12
<i>Methylophilus methylotrophus</i>	methanol	-23.82 ± 0.06
<i>Bacillus thuringiensis</i>	glucose	-22.08 ± 0.03
Yeast		
<i>Candida lipolytica</i>	glucose	-21.34 ± 0.16
<i>Candida boidinii</i>	glucose	-20.14 ± 0.18
	ethanol	-20.40 ± 0.14
	methanol	-21.52 ± 0.09
	lactose	-21.54 ± 0.07
<i>Kluyveromyces fragilis</i>	galactose	-21.78 ± 0.10
	glucose	-21.66 ± 0.19
	glucose*	-21.07 ± 0.07
		-21.30 ± 0.10
		-20.66 ± 0.26
	-21.22 ± 0.14	

* Chemostat rather than batch culture: dilution rates were 0.036 h⁻¹, 0.061 h⁻¹, 0.158 h⁻¹ and 0.227 h⁻¹, respectively.

Heat Evolution (Cont'd)

There has also been shown to be a correlation between Heat Evolution and Oxygen Uptake – so if the Oxygen Uptake Rate can be calculated, then the Heat Evolved may be estimated. This is very useful since we have a method to calculate the oxygen uptake. This heat evolution is used to calculate the cooling requirements for a fermenter.

Heat Evolution (Cont'd)

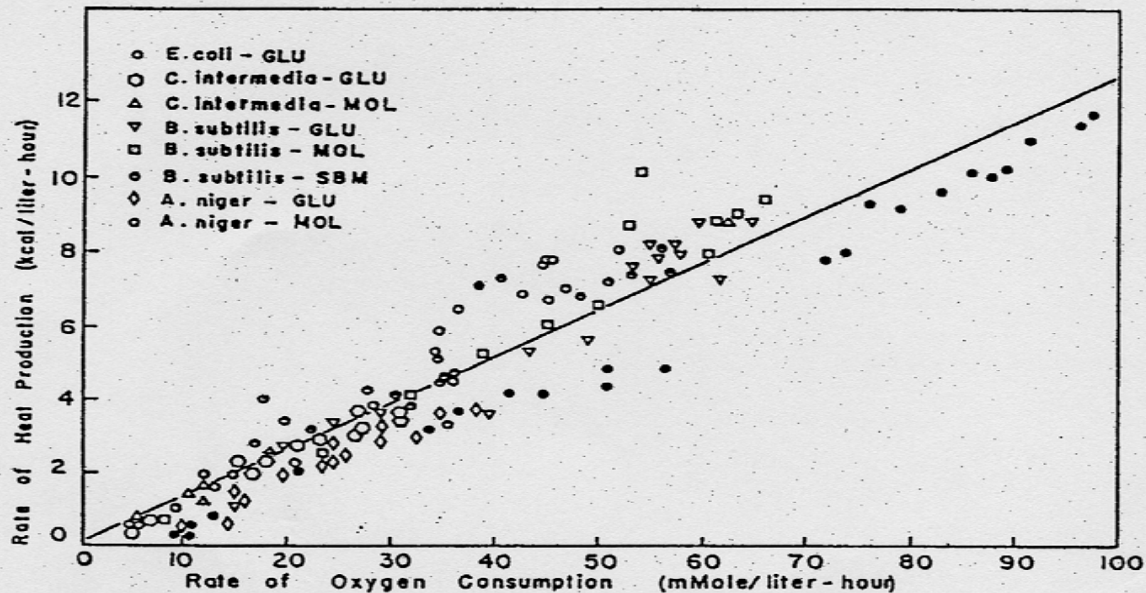


Figure 6.13 Correlation of heat evolution with oxygen consumption for a variety of microbial fermentations.

Heat evolution Q_f (kcal/liter-hr) has also been shown by Cooney et al. (1968) to be related to oxygen uptake rate (Q_{O_2} (m moles/l-hr)) via the correlation

$$Q_f = 0.12Q_{O_2} \quad (39)$$

This expression is generally valid and is shown in Figure 6.13 for a variety of microorganisms growing on different substrates.

Heat Evolution (Cont'd)

QO₂ is used to make ATP from NAD(H). NAD(H) is the major energy source in aerobic growth (much higher ATP comes from this source than from direct ATP production by substrate level phosphorylation). If we assume a fixed efficiency of ATP utilisation to make cell material, then we would expect a direct relationship between QO₂ and HEAT (which is the fraction of ATP not utilised for growth, which would also be a constant fraction of the ATP produced)

Heat Evolution (Cont'd)

The relationship should be seen as consistent with our previous studies on metabolism since:

If oxygen is uptaken, then NAD(H) is being regenerated to NAD⁺ ($Q_{O_2} = \alpha Q_{NAD(H)}$).

If NAD(H) is used then ATP is being made by some stoichiometry ($Q_{NAD(H)} = \beta Q_{ATP}$)

ATP is utilized by the cell at an almost constant efficiency of 30-32% ($Q_{ATP}(\text{used for cell growth}) = \gamma Q_{ATP}$)

Hence, the remaining ATP is wasted as heat ($Q_{ATP}(\text{used for heat generation}) = Q_{HEAT} = (1-\gamma) (Q_{ATP})$)

Consequently, we would expect there to be a relationship between specific oxygen uptake and heat evolution ($= Q_{O_2} * (\alpha Q_{NAD(H)} / Q_{O_2}) * (\beta Q_{ATP} / Q_{NAD(H)}) * (1-\gamma) * Q_{ATP}$)

=

$$Q_{O_2} * \alpha * \beta * (1-\gamma)$$

=

Q_{HEAT}

$$\text{Or } Q_{O_2} = \text{constant} * Q_{HEAT}$$