Analysis of sugar attenuation with curve-fitting method and its application for industrial fermentation control.

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- Factors to control fermentation in practical brewing
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    - Pitching
    - Aeration rate
    - Transfer time, interval
    - Wort cooling temperature (=Start temperature)
    - Additives
  - During the fermentation
    - Temperature
    - Pressure

Background : Controlling fermentation in the industrial brewing

- Factors “at the beginning of” the fermentation
  -We’ve developed various methods and put them to practical use (2,000~5,000 HL).

“Ester control in practice” (Tajika, Brewing Summit 2014)
Our technology…
- Dual effect of oxygen consumption by yeast
  (T. Irie, EBC 2009)
- Ununiform fermentation
  (Y. Nakamura & H. Koizumi, WBC 2012)
- Amino acid addition to wort
  (Y. Tajika, Brewing Summit 2014)

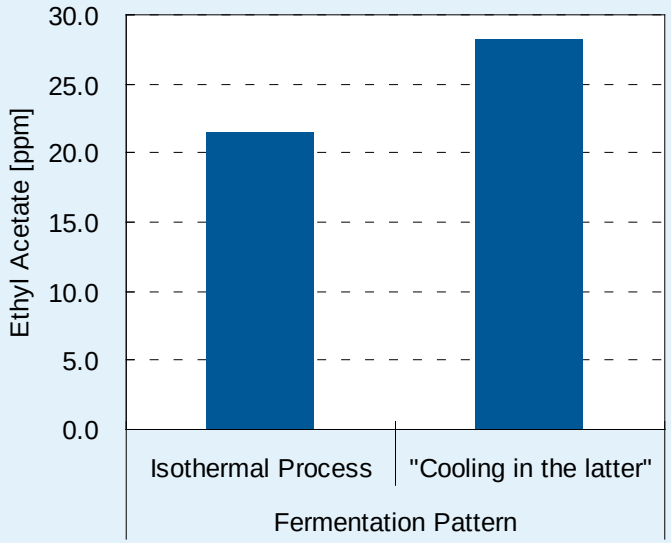
Background : Controlling fermentation in the industrial brewing

- Factors “during” the fermentation
  - We already have some knowledges “how to do” to control with temperature or pressure.

Example 1 : “Cooling in the latter” process for ester control

To prolong the stationary phase
and increase of the period of esterization

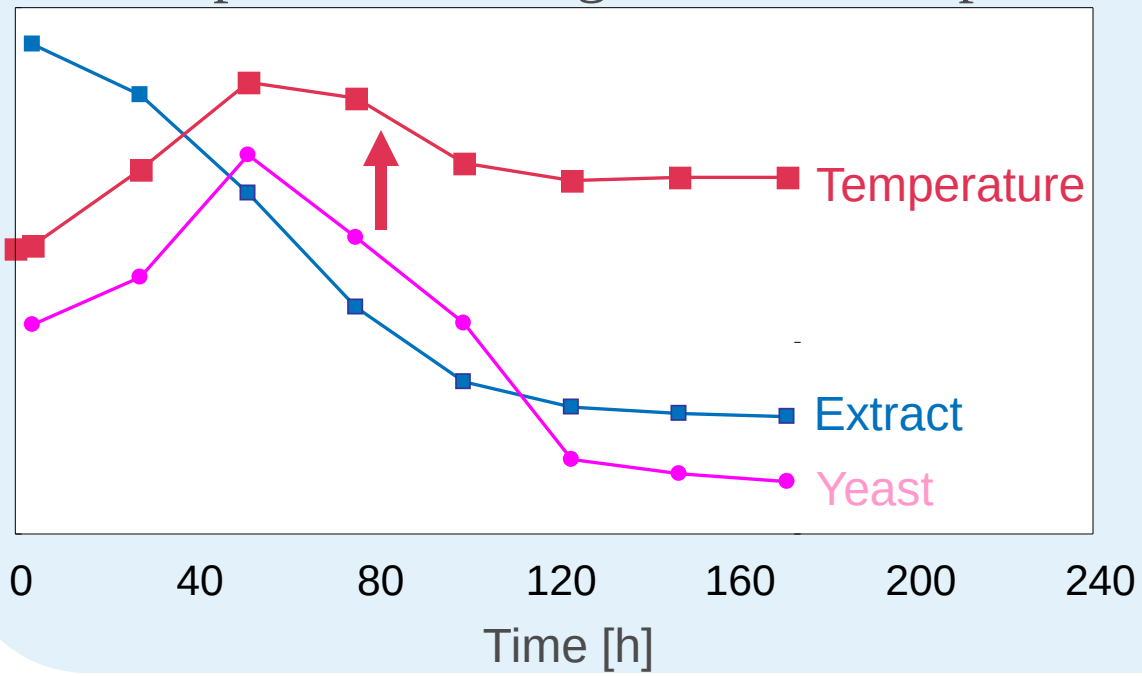
Ref. : “Isothermal Process”
17 ºC 6days
Test. : “Cooling th the latter”
17 ºC 3days + 15ºC 3days



- Factors “during” the fermentation

  …But we need more information about “when to do”.

Example 1: “Cooling in the latter” process for ester control



That should depends on the yeast growth phase…, but how to find it out?

- Factors “during” the fermentation
  - We already have some knowledges “how to do” to control with temperature or pressure.

Example 2 : Controlling Sulphury flavour

Knowledge

- Hydrogen sulfide has a peak in the log phase of yeast growth.
- Temperature control would be effective for yeast growth.

- Factors “during” the fermentation
  - We already have some knowledges “how to do” to control with temperature or pressure.

…But we need more information about “when to do”.

Example 2 : Controlling Sulphury flavour

Knowledge

- Hydrogen sulfide has a peak in the log phase of yeast growth.
- Temperature control would be effective for yeast growth.

For practical brewing

- When should we cool the fermentor on (and off) to suppress the sulphury flavour?

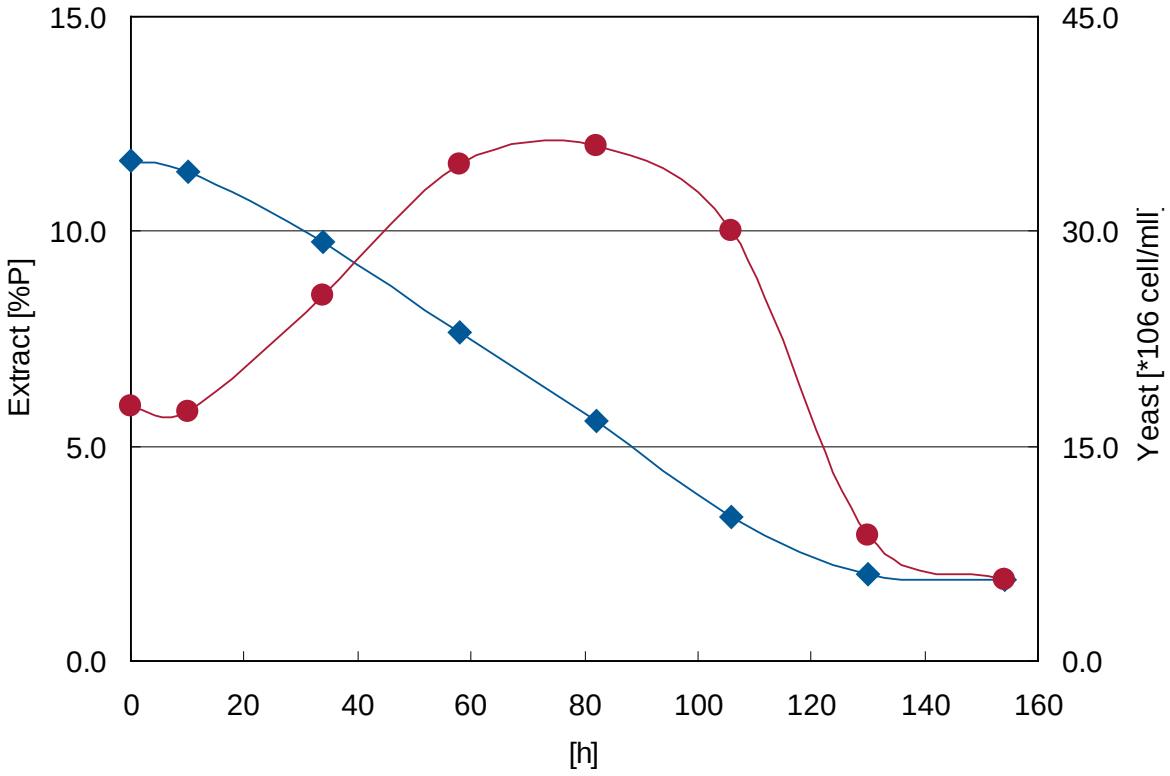
Background : Hypothesis

- How to find out the appropriate time to control?
  with high reliability… without additional effort…

Background : Hypothesis

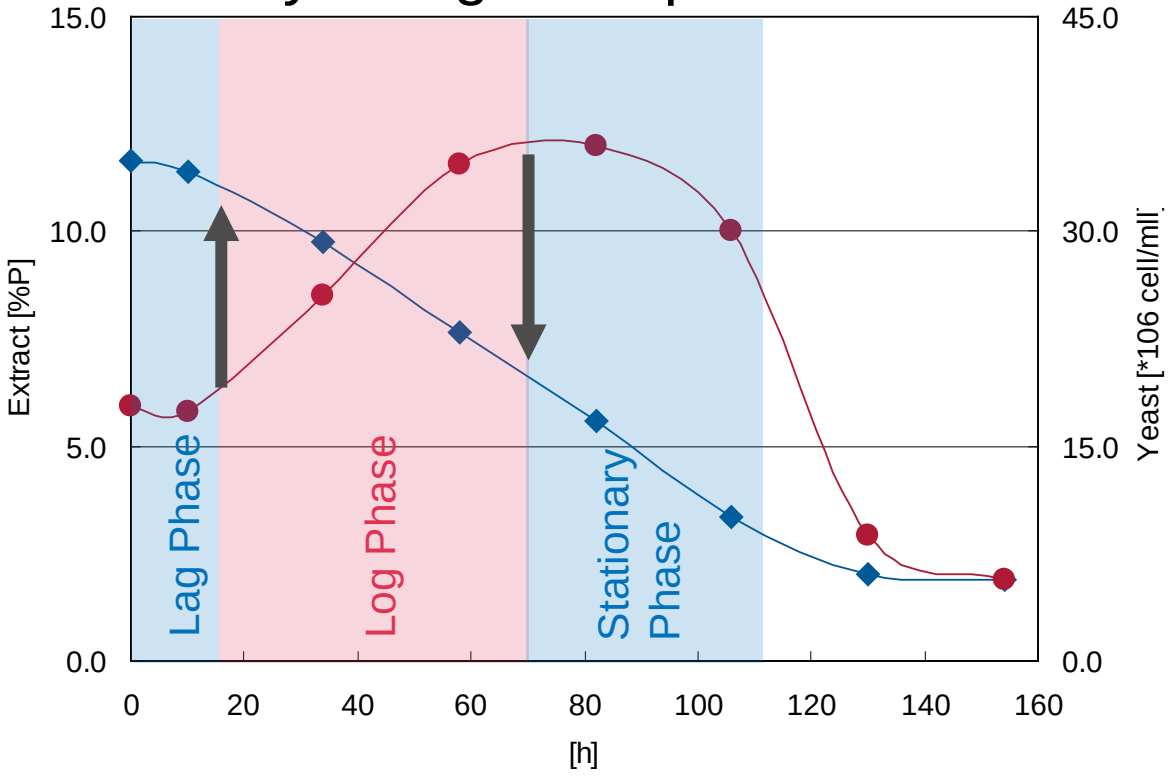
- How to find out the appropriate time to control?
  with high reliability… without additional effort…

- ”Information extraction” from daily data.



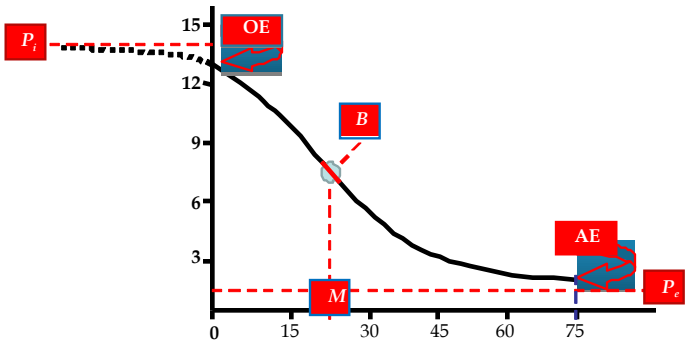
Background : Hypothesis

- Attenuation describes sigmoidal curve and its rate would reflect the number of yeast.
- The changing point of the curve would suggest borders between yeast growth phases.



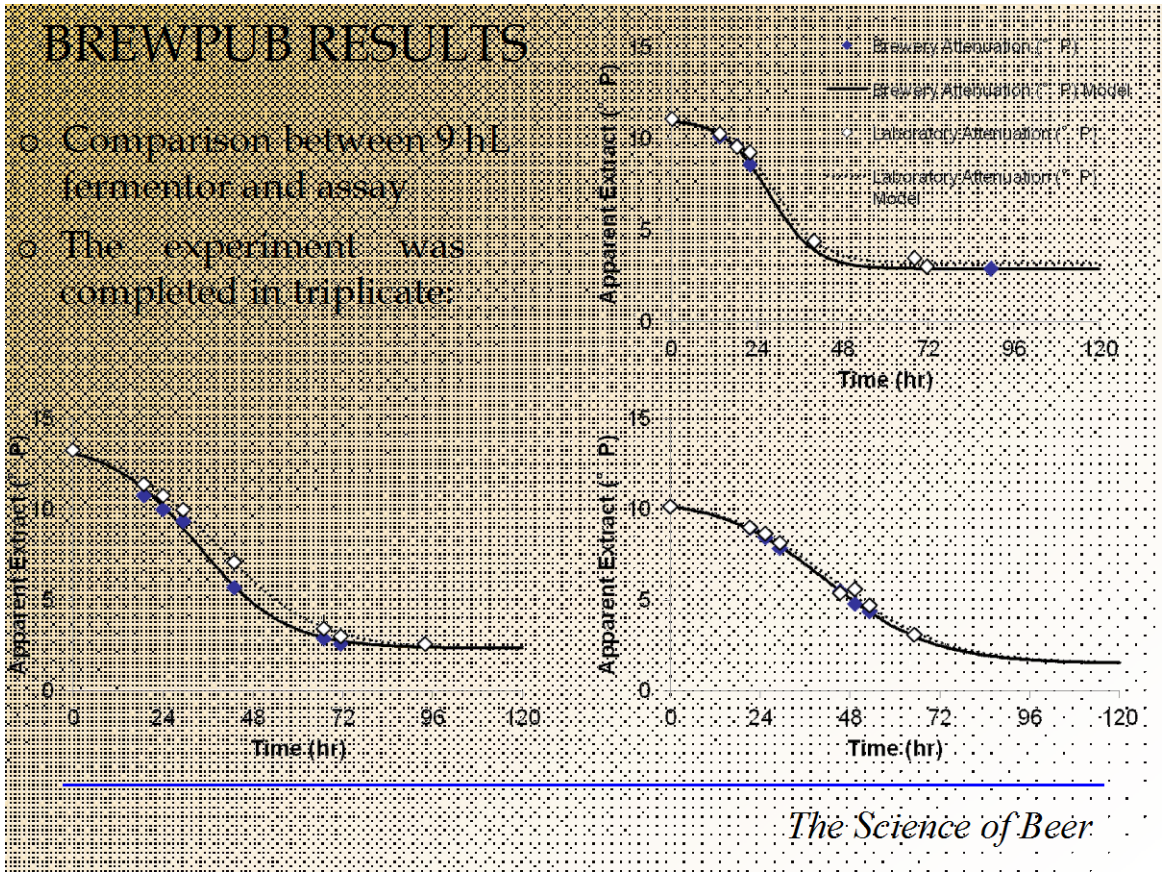
Background

- Curve fitting to apparent extract with sigmoidal function (MacIntosh, ASBC2011)



Logistic Curve

$$P(t) = P_e + \frac{P_i - P_e}{1 + \exp\{-a(t - M)\}}$$



The Purpose of the study

- In this study, we examined curve-fitting method to analyze the attenuation data in beer fermentation.

- By this method, we tried to obtain information about appropriate time to control fermentation.

- We investigated whether this method would be useful for analyzing and controlling fermentation even in the industrial brewing(2,000~5,000HL).

Methods：Curve fitting with apparent extract

- Least-square method with Solver add-in on Microsoft Excel®

- 4-parameter sigmoid curves

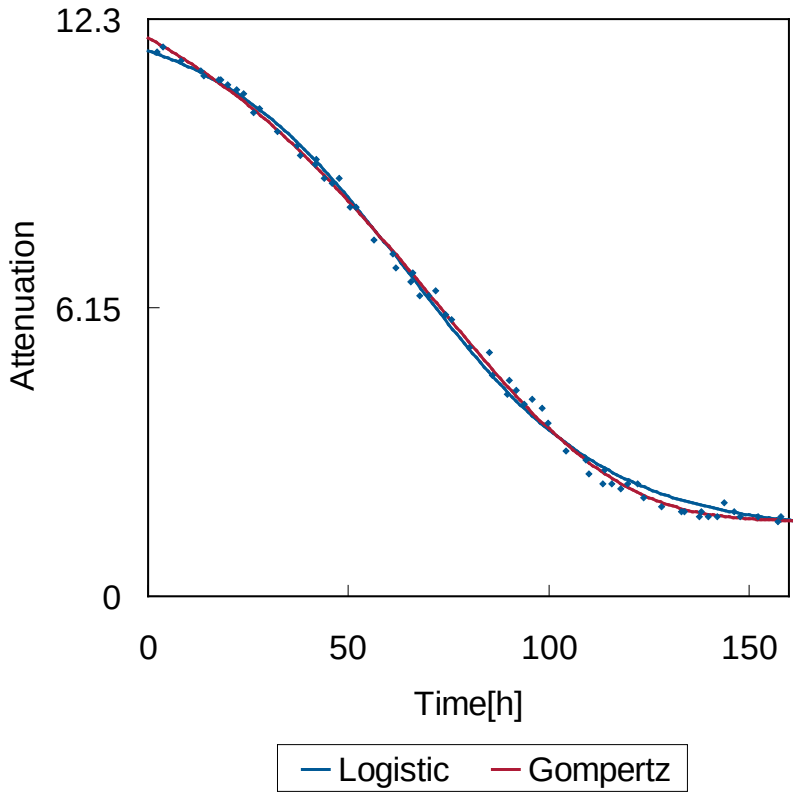
Logistic function

$$P(t) = \frac{K}{1+\exp\{a(t-b)\}} + d$$

Gompertz function

$$P(t) = K \cdot a^{\exp(bt)} + d$$

P : apparent extract [%P],
t : fermentation time [h],
K,a,b,d : Parameters



Methods：Curve fitting with apparent extract

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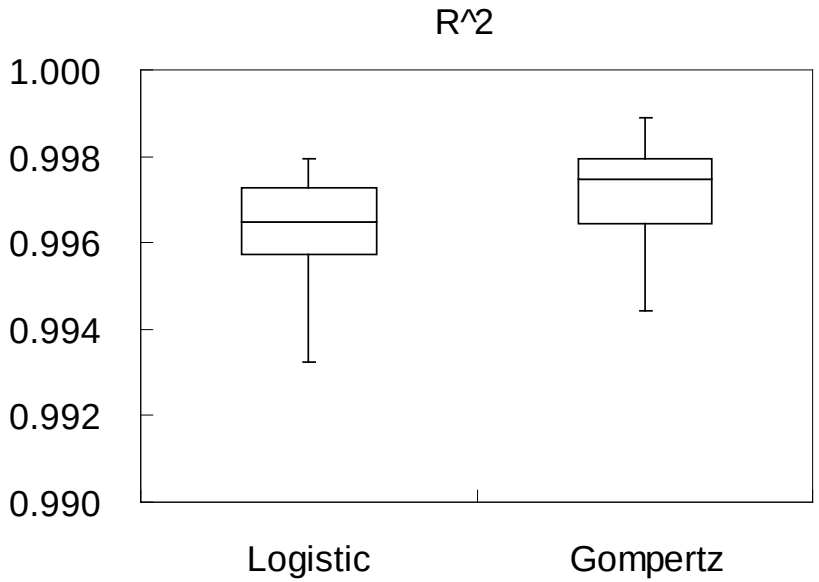
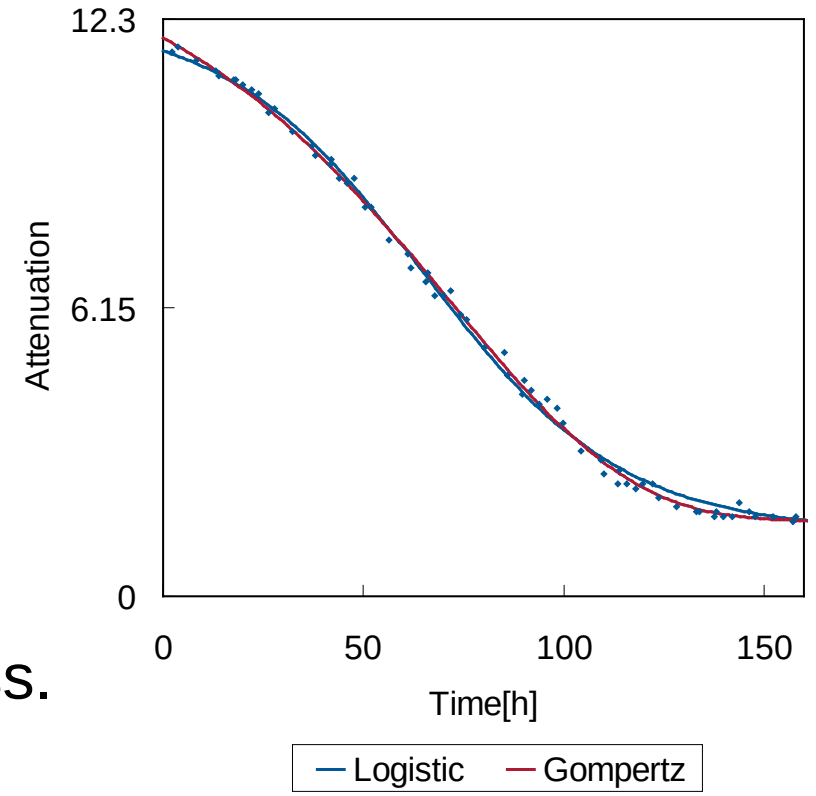


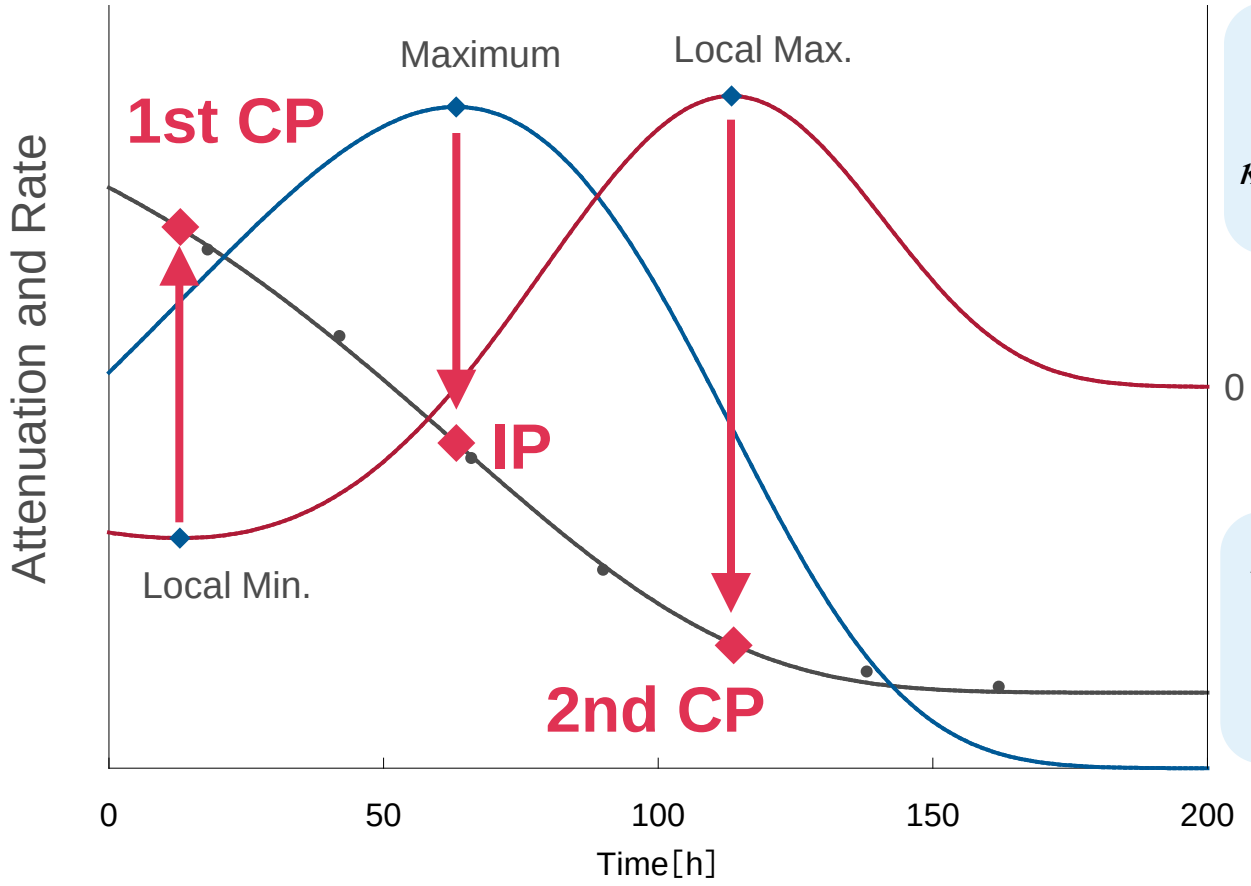


Gompertz shows better fittness.

Method : Changing points of fitting curve

- Maximum on attenuation rate : Inflexion Point (IP)

- Local extrema on curvature : Curving Points (CP)



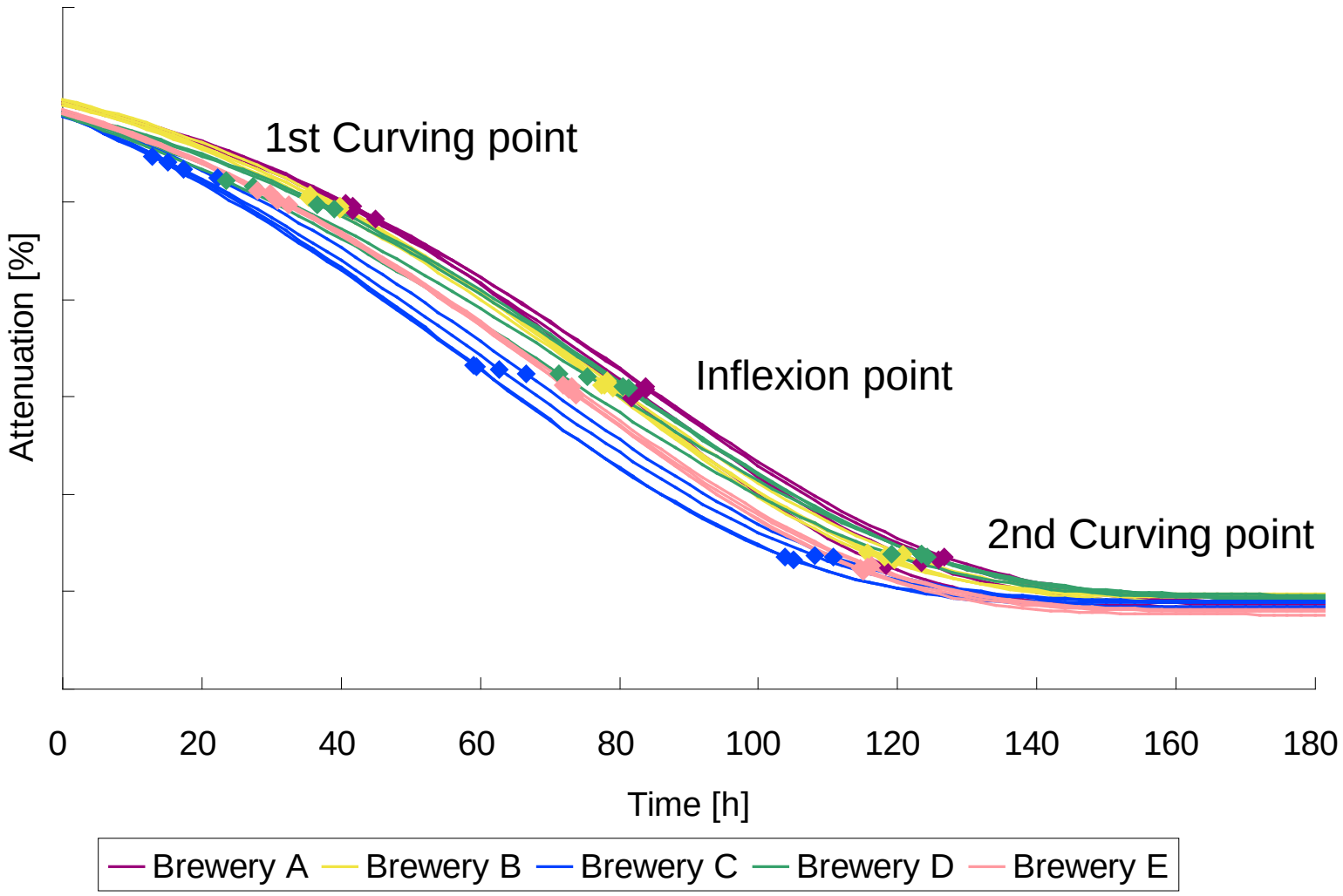
Curvature

$$\kappa = \frac{1}{R} = \left\{1+\left(\frac{dy}{dt}\right)^2\right\}^{-\frac{3}{2}} \cdot \left(\frac{d^2y}{dt^2}\right)$$

Attenuation Rate

$$v = \frac{dy}{dt}$$

Result：Fitting curves with changing points



Short summary

- We could find out the sigmoidal curve which would suit for our attenuation data.
- With this curve we could calculate changing points (Inflexion point and two curving points).
- The position of the points depends on breweries, regardless of brewing for the same brand.

Result : Cases of process improvement with curve fitting

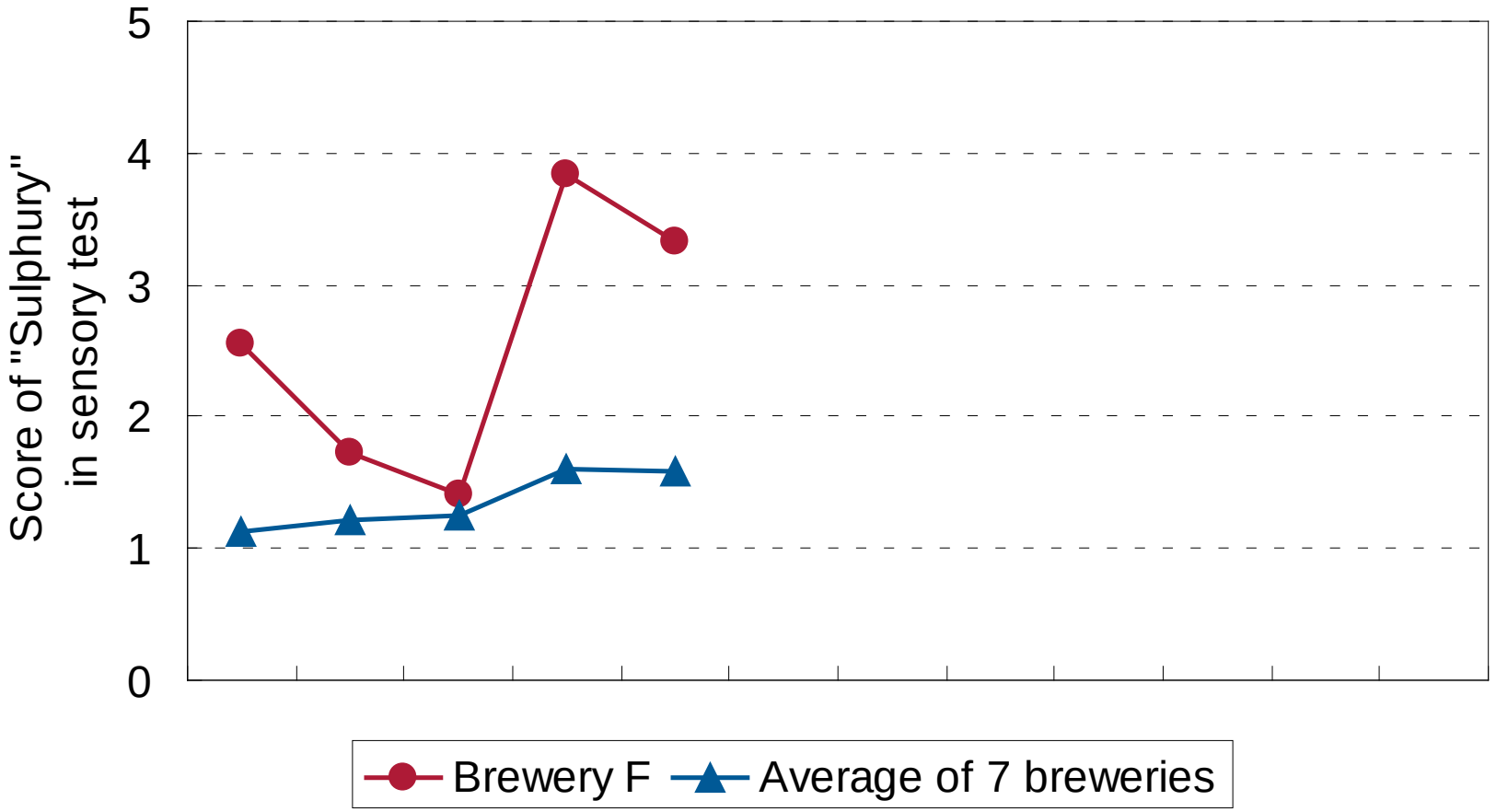
- We put this method into practical use to find out the appropriate time for temperature control to …

  Case (1) : Decrease sulphury flavour

  Case (2) : Increase ester aroma

Example 1 ：Control of sulphury flavour

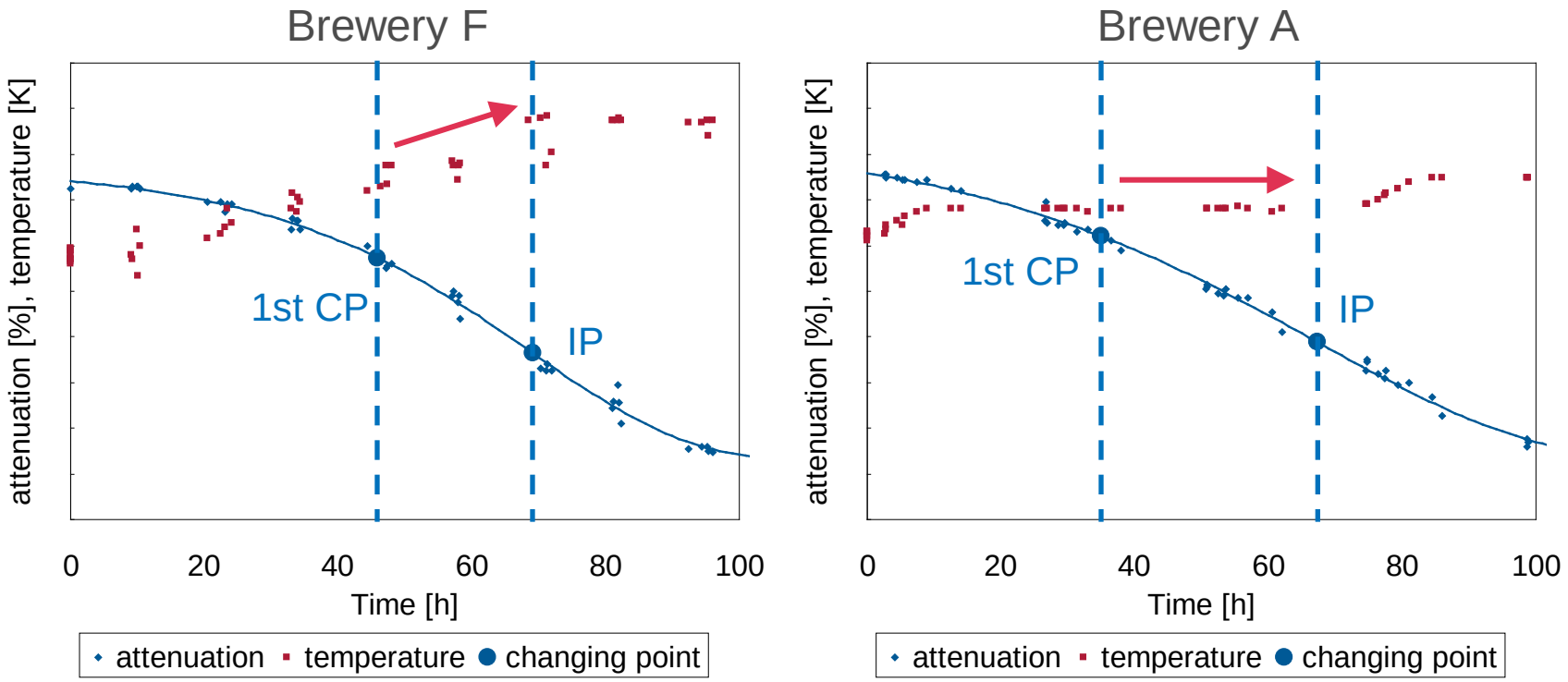
- Sensory test for monthly sample of Brand X



- Brewery F had higher score in sulphury flavour.

Example 1 ：Control of sulphury flavour

- Comparison in the relationship between temperature and “changing points”



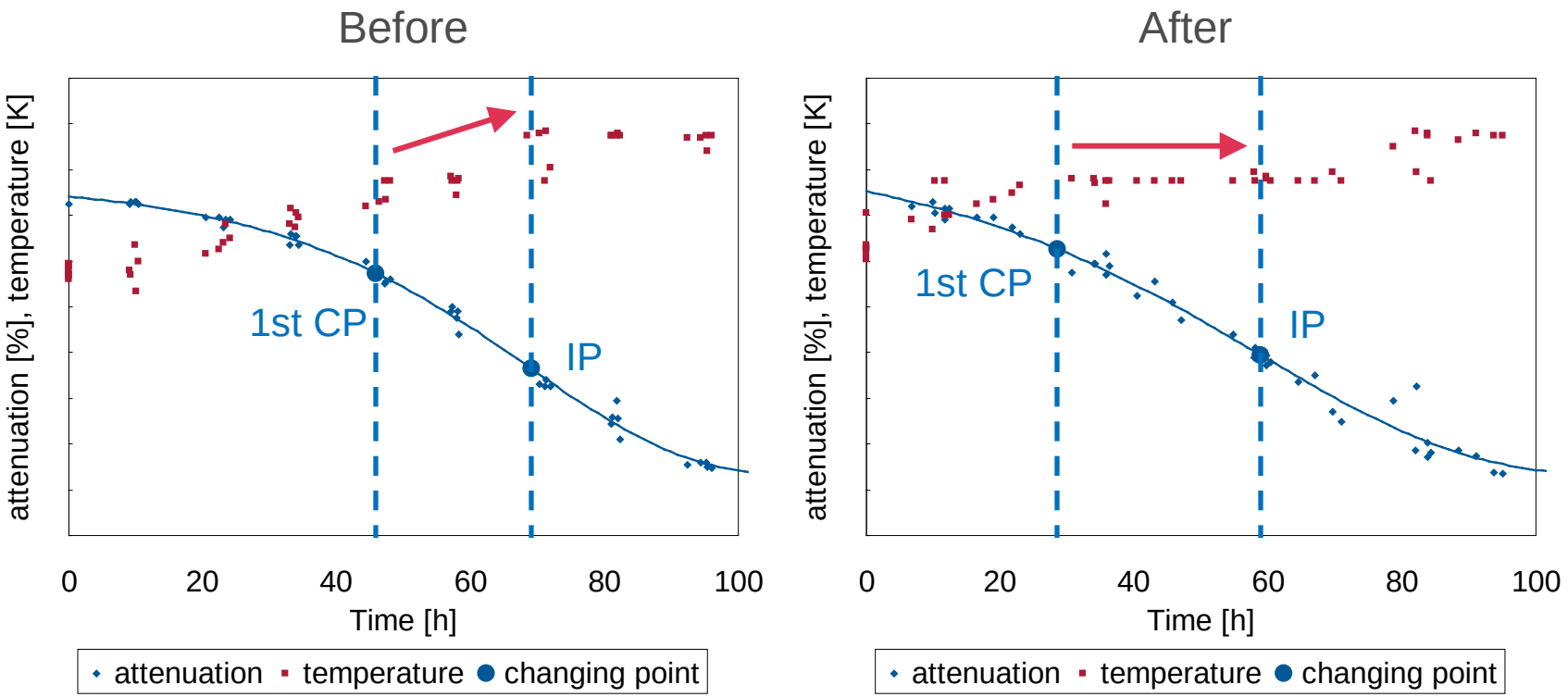
- Lower start temperature and later temperature increase
  : No temperature control at the “log phase (45-70h)”

Example 1 ：Control of sulphury flavour

- Change in temperature pattern on Brewery F

  Start temperature : Conventional value +1 ºC

  Temperature increase time : 60h → 72h (Inflexion point : 70h)



- Temperature control at the “log phase”

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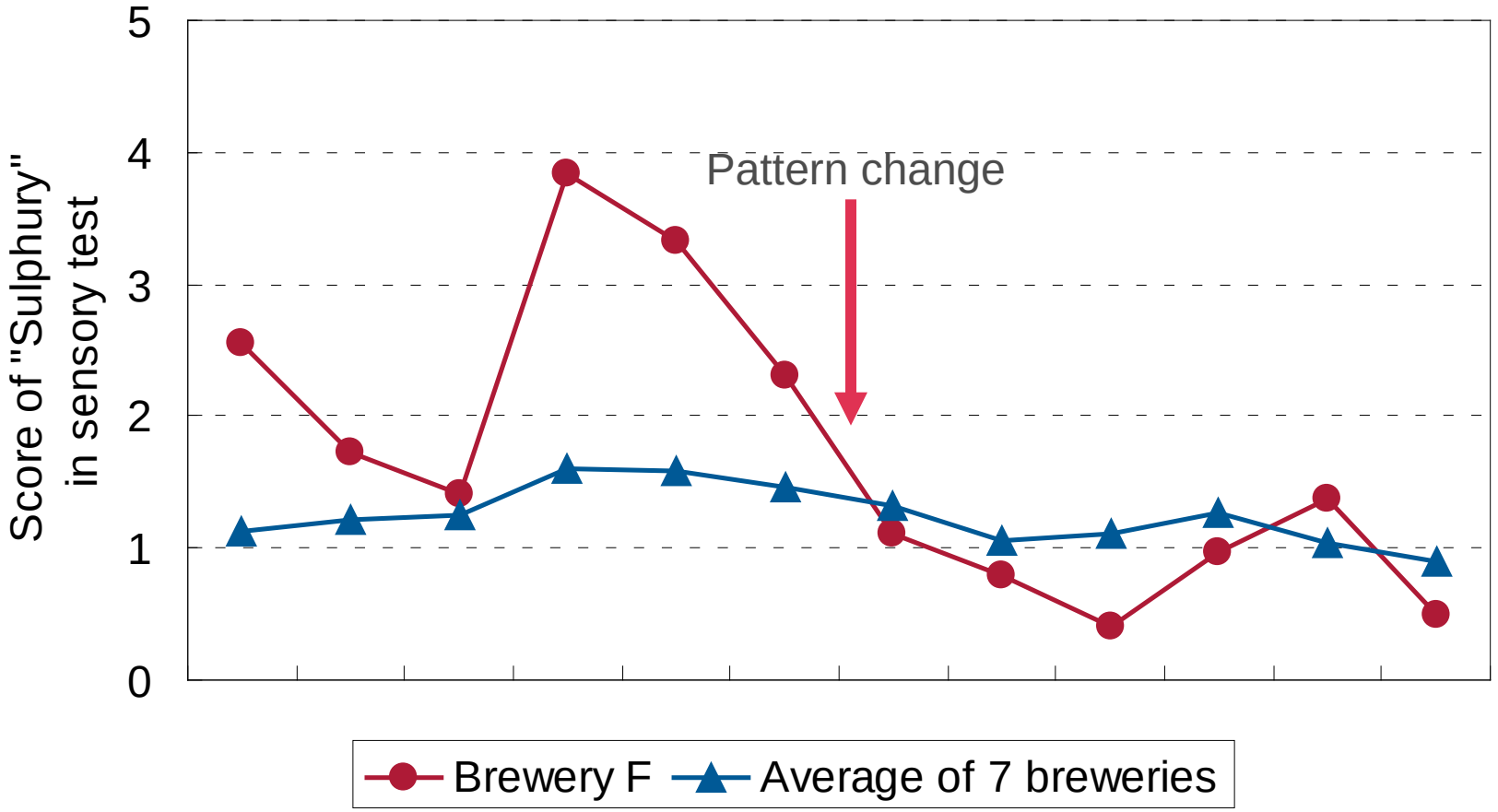

Result : Cases of process improvement with curve fitting

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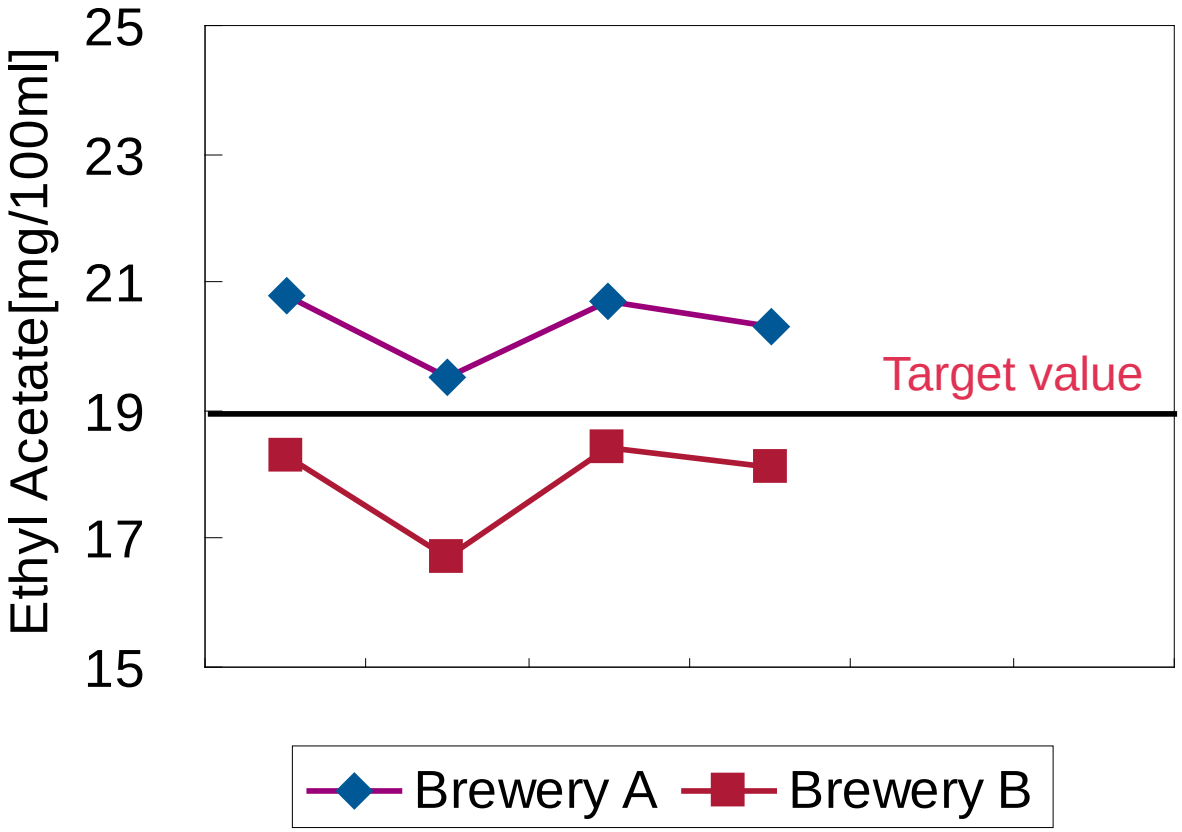
Example 2 ：Control of ester with temperature

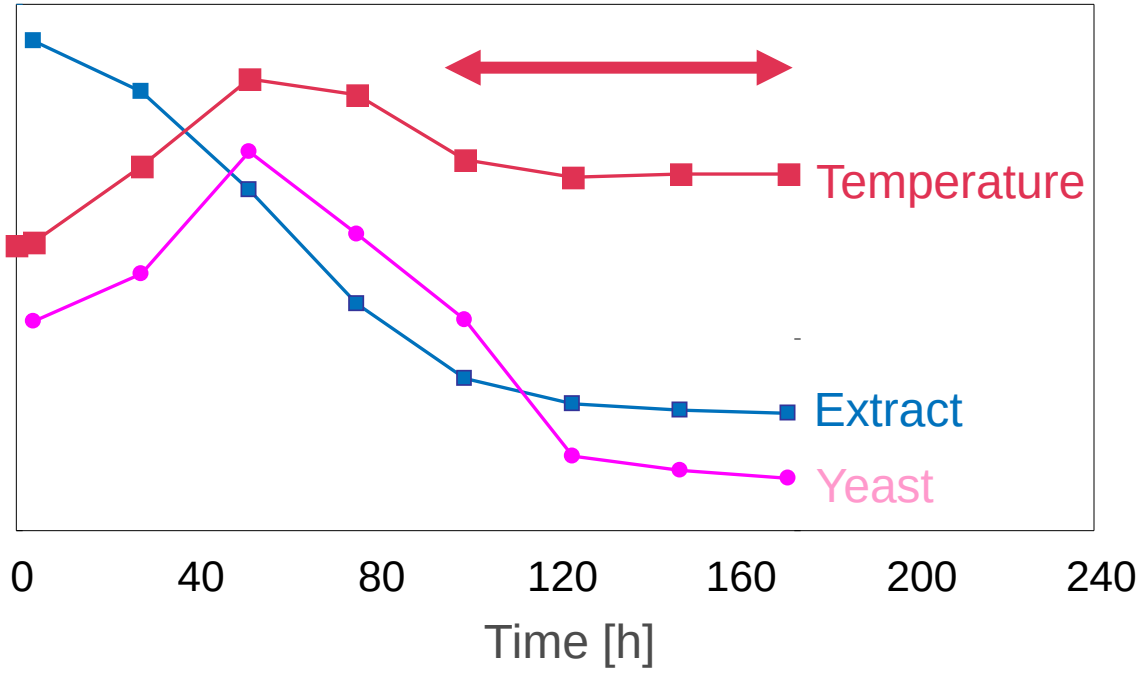
- Monthly data of brand Y



- The amount of ester in brewery A had never reached to the target value.

Example 2 ：Control of ester with temperature

- “Cooling in the latter” to prolong the stationary phase



- Appropriate cooling leads increase of esters.
- Too early cooling could result in inadequate attenuation.

Example 2 ：Control of ester with temperature

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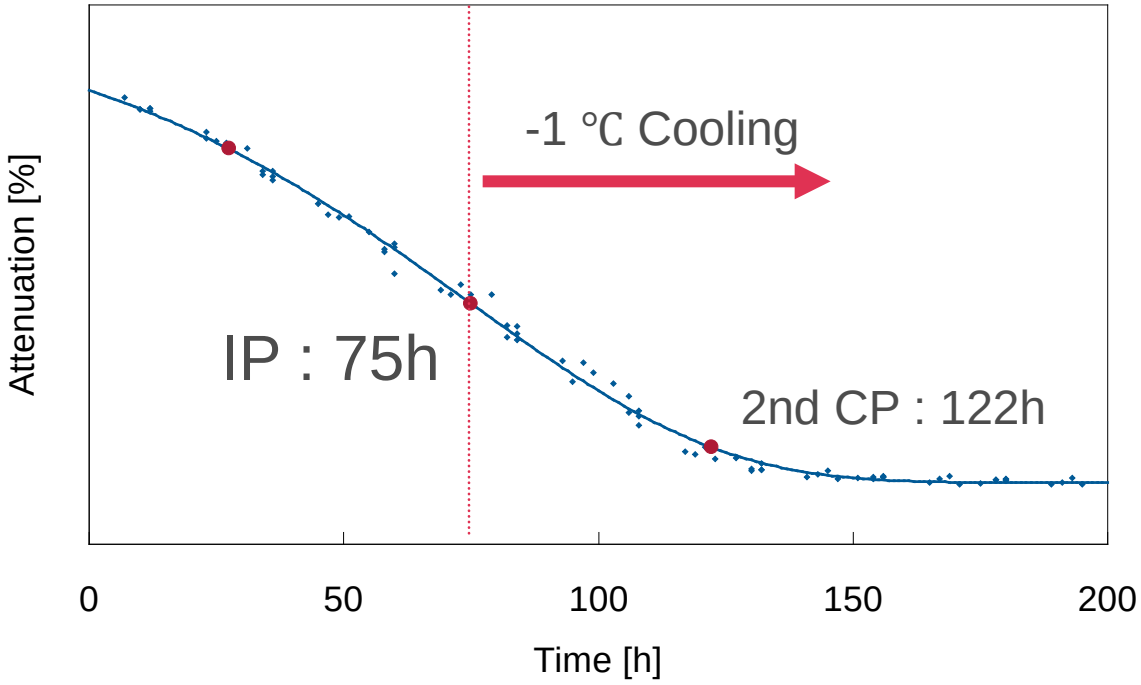

- Cooling after the Inflexion point
  (=start of the stationary phase)

Example 2 ：Control of ester with temperature

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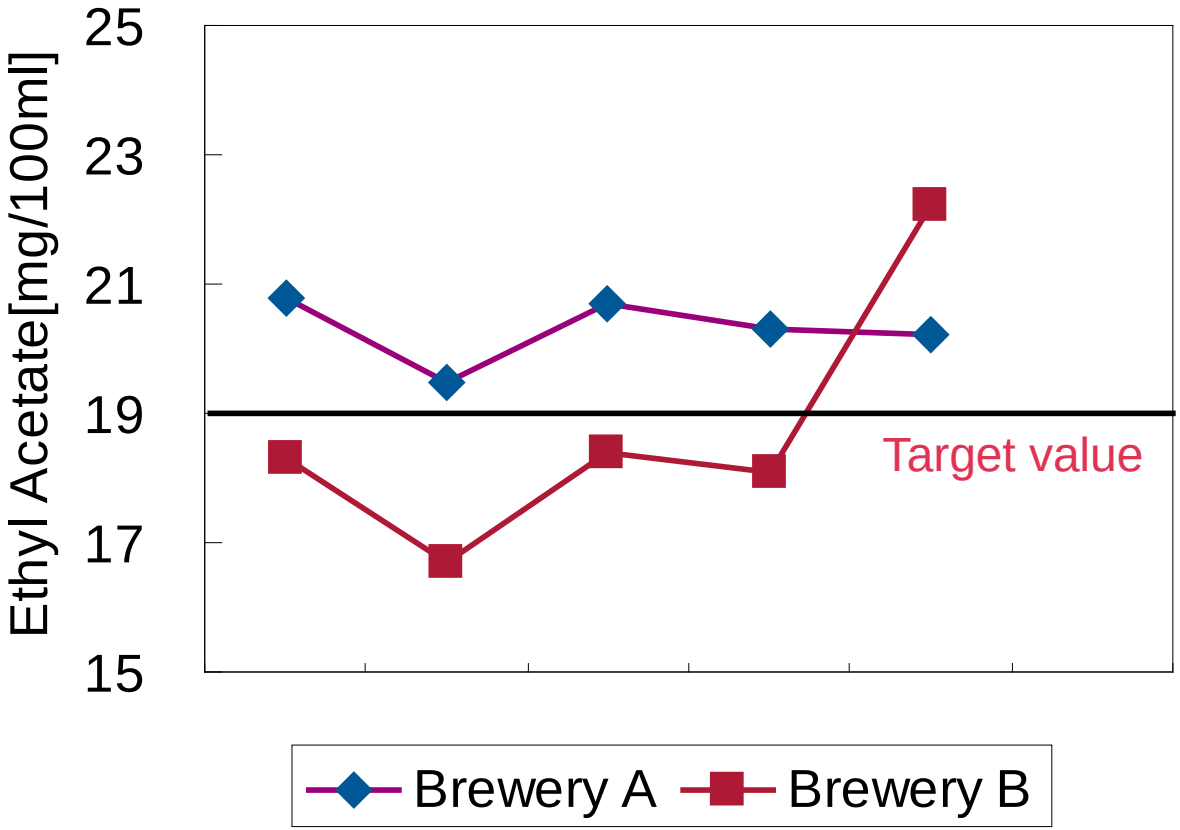

- The amount of ester in brewery A have reached to the target value.

Summery

- In this study, we examined curve-fitting method to analyze the attenuation data in beer fermentation.

- We could obtain the changing point with mathematical method, which would suggest the information about yeast growth phase.

- This method would help us to “when to do” the action to control fermentation, even in the industrial brewing.

Thank you for your kind attention!!

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