Solutions for R&D to Design

Differences between Batch and Continuous Operations

January 31, 2010

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Introduction

Batch operation and continuous operation are often selected according to production volumes, but equipment performances may differ depending on the unit operations. Laboratory experiments are conducted in batches, and when plants are made continuous, it is necessary to fully consider how the results obtained in batches will change when operations are made continuous.

In this presentation, we will discuss reaction and evaporation operations, which often lead to different results in batch and continuous operations.

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Example 1: Reaction

Reactor Volume Required to Achieve Same Conversion

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Comparison Method

We would like to calculate the reactor volume to achieve a given conversion, considering the first order reaction A→B. The following equation holds, assuming that the inlet concentration is A_0, the outlet concentration is A_e, the reaction rate constant is k, the batch reaction time is t_B, and the one-stage CSTR residence time is t_C.

Batch Reactor $$\frac{A_e}{A_0} = e^{-kt_B}$$

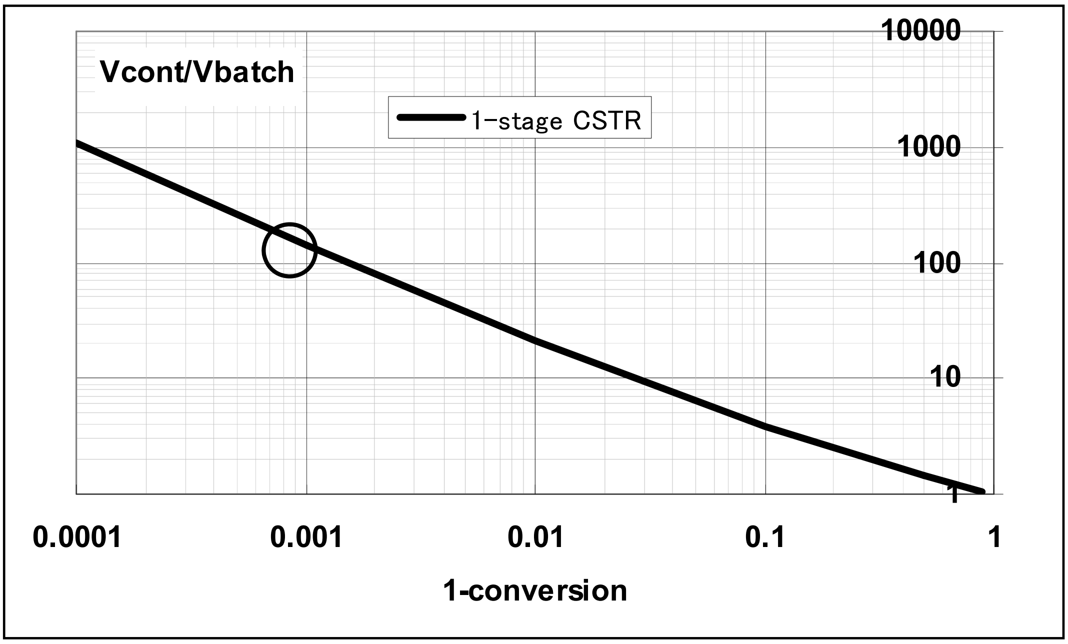
1-Stage CSTR $$\frac{A_e}{A_0} = \frac{1}{1+kt_C}$$

Ignoring the feed and discharge time of the batch reactor, the ratio of the reaction times (residence times) can be regarded as the ratio of the required reactor volumes. Assuming that the batch reactor volume is V_B and that the one-stage CSTR volume is V_C, the following equation is obtained.

$$\frac{V_C}{V_B} = \frac{kt_C}{kt_B} = \frac{\dfrac{1}{(A_e/A_0)} - 1}{\ln(A_e/A_0)}$$

Therefore, the ratio of the required reactor volumes can be calculated by giving the conversion (1-A_e/A_0).

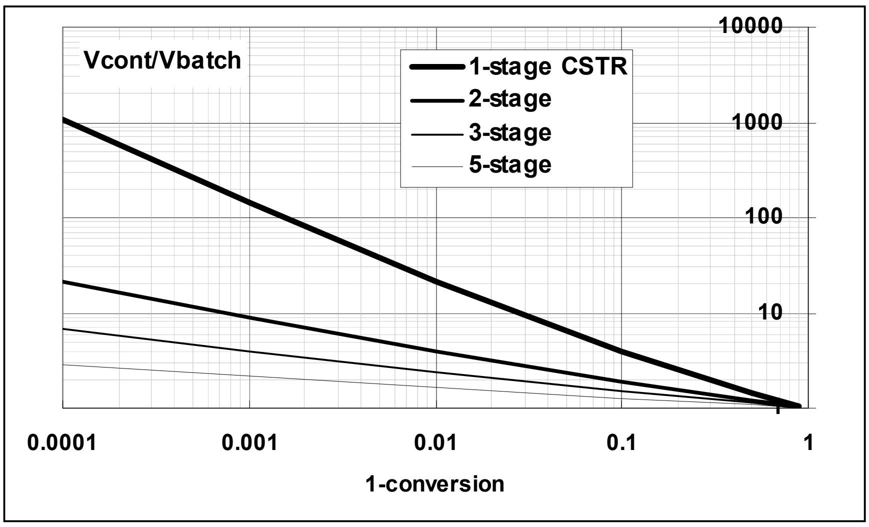
Ratio of One-Stage CSTR to Batch Reactor Required Volumes



To operate with a conversion of 99.9%, the one-stage CSTR requires a volume that is 140 times the volume of the batch reactor. A batch reactor is often used when a high conversion is required.

However, it is possible to approach the performance of the batch reactor by use of a multistage continuous process.

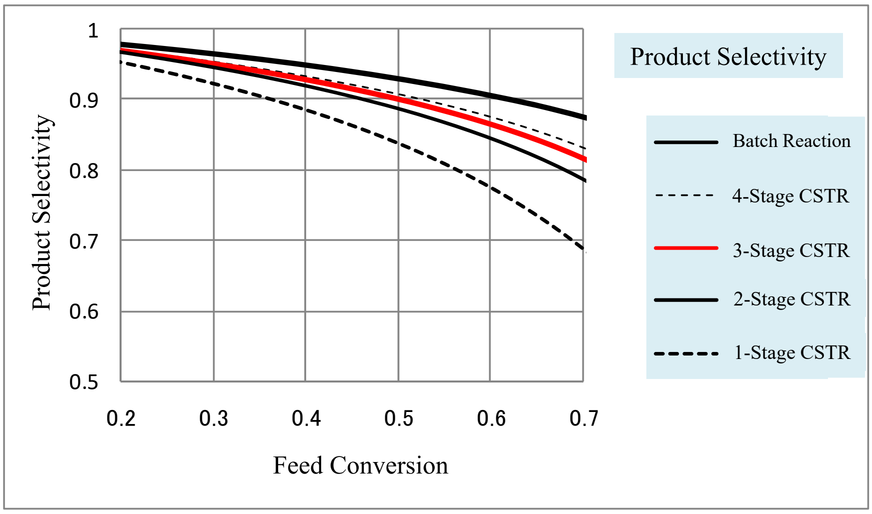
The ratio to the batch reactor volume can also be calculated in the case of an equal volume multistage CSTR by giving the conversion.



The multistage structure reduces the volumetric ratio to 9 (for 2 tanks), 4 (for 3 tanks), and 2 (for 5 tanks) times the batch volume in order to reach the targeted 99.9% conversion.

In a polymer reactor controlling a molecular weight distribution, there may be more than 10 stages but for other industrial applications the number of stages is approximately 5 in practice. For this reason, batch reactions are often adopted for reactions requiring a high conversion (in particular, in the case of fine chemicals, when raw materials remain, quality problems often arise).

Complex Reaction Example



In the following complex reaction, B is the product. The batch reactor and CSTR were compared to see how the selectivity of B varies depending on the conversion of A.

$$A \rightarrow B$$

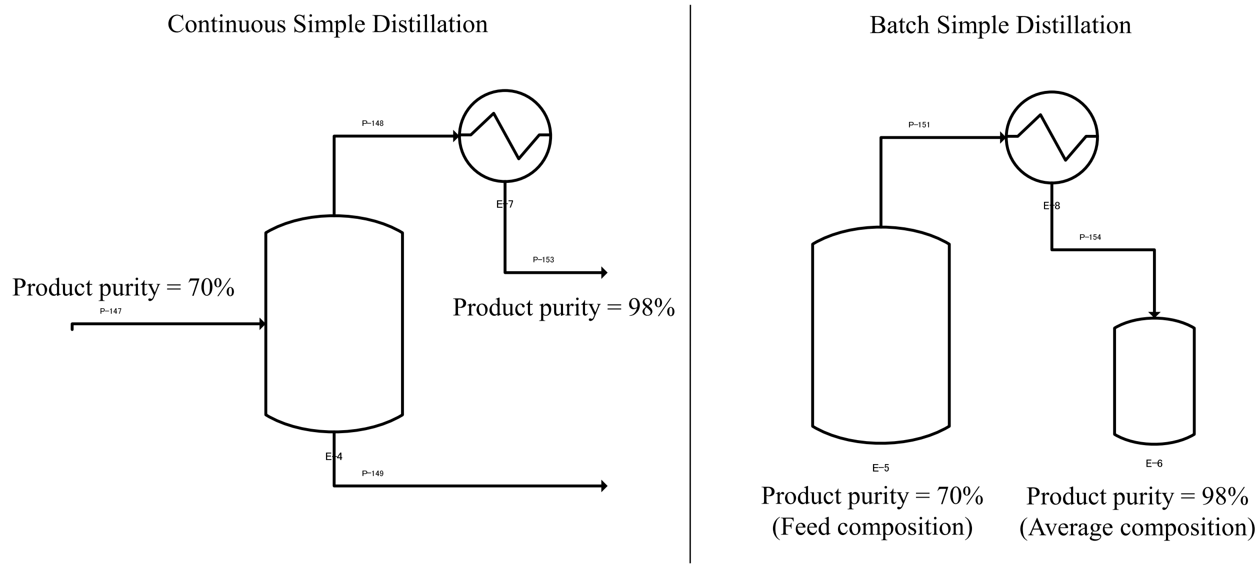
$$B \rightarrow C$$

$$B + C \rightarrow D$$

- It is possible to bring the selectivity closer to that of the batch reactor by increasing the number of CSTR stages, but it can be seen that this effect becomes limited after about 3 stages.
- For the same conversion, the product selectivity is lower in the CSTR so the load of the purification process will be increased. In order to obtain the same selectivity, the conversion must be kept lower in the CSTR, and the load of the raw material recovery process will be increased.
- As shown above, batch and continuous processes must be carefully compared when sequential reaction intermediates are transformed into products.

Example 2: Evaporation (Simple Distillation)

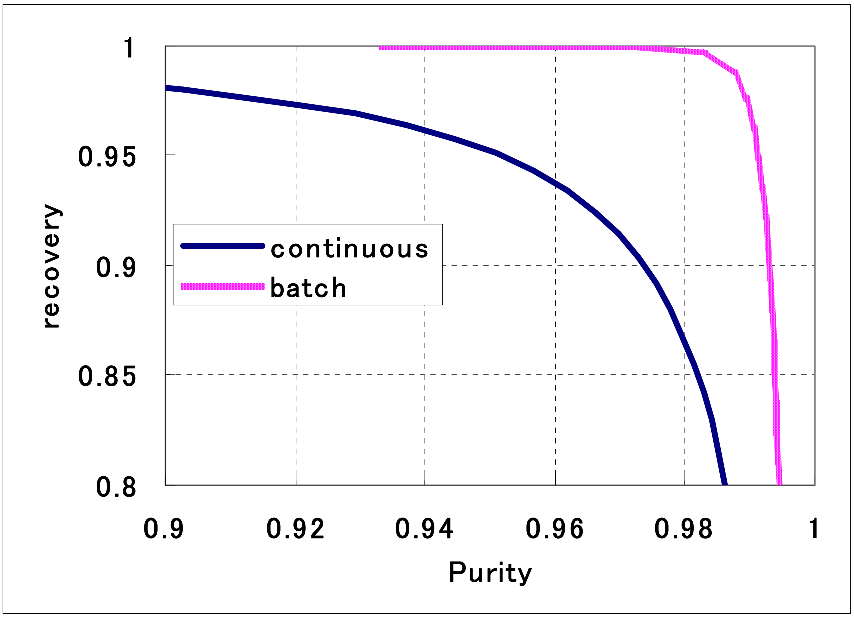
Recovery Ratio when Obtaining Distillates of the Same Purity



We want to remove tar from a product and obtain the product as a distillate. Product purity of the raw material is 70%, and the desired purity of distillate is 98%.

The relative volatility of product and tar is 150, therefore separation is quite easy.

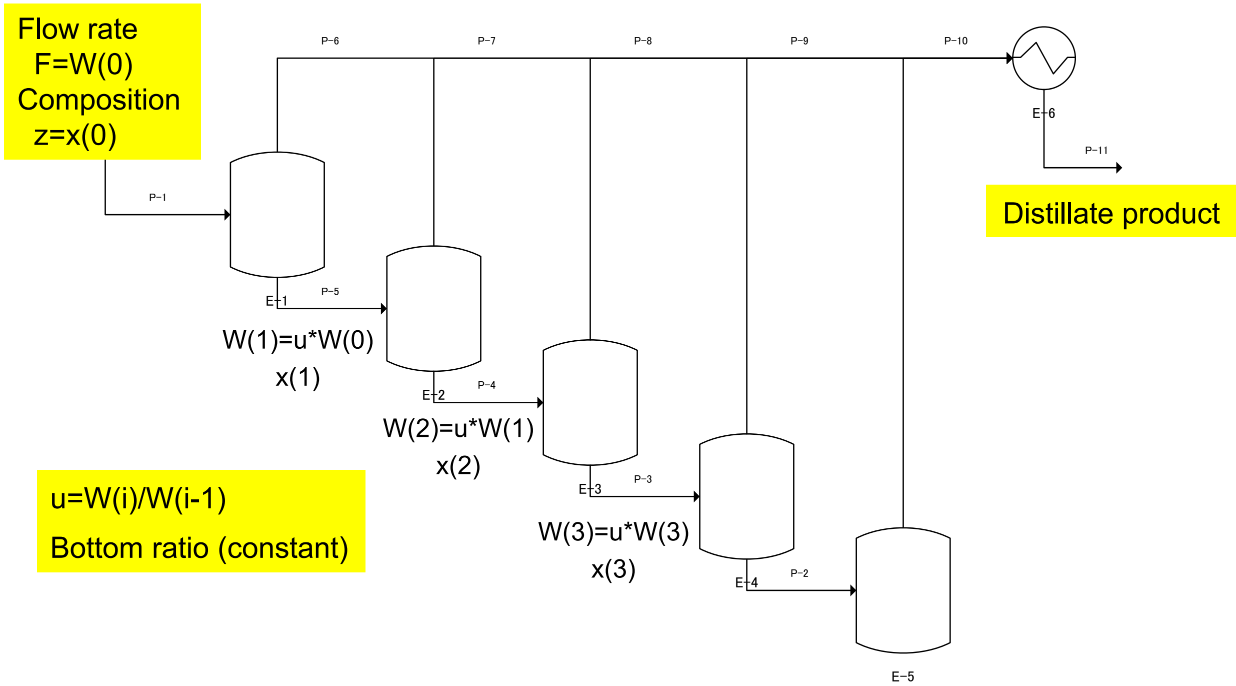
Product recovery ratios were compared under these conditions.

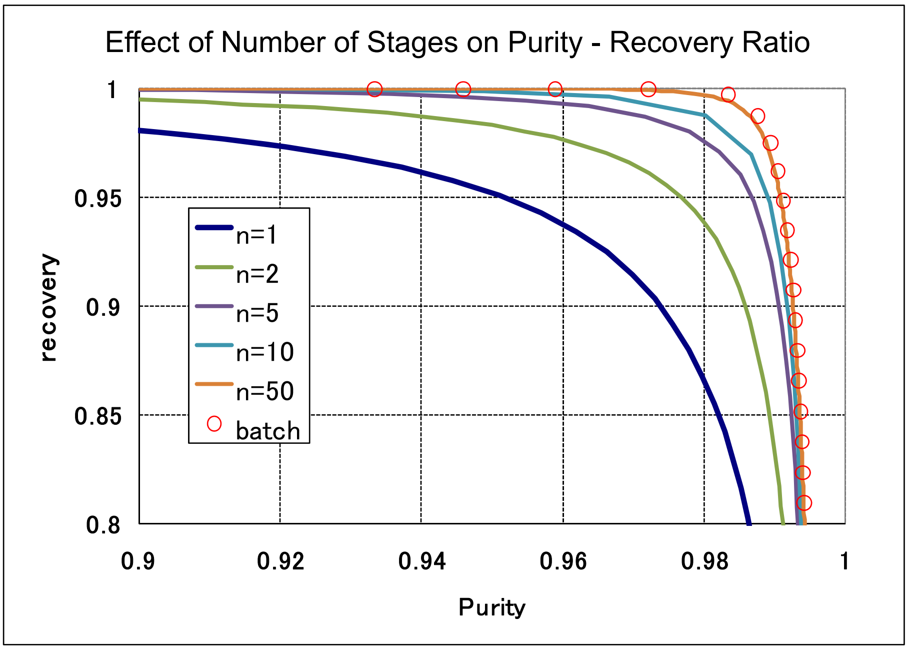


When the product purity is 98%, the recovery ratio of the batch column is nearly 100%, but it is 86% for continuous simple distillation. There is a big difference in recovery ratios.

Next, we examined how the result of the batch process could be approached by using multiple continuous stages.

Multistage Continuous Single Distillation





Continuous operation is not equivalent to batch operation unless the number of stages is increased considerably. Batch operation can be seen as a limit where the number of continuous stages has been increased to infinity.

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Example 3: Rectification

Number of Stages
Required for Two Component Distillation Separation

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Generally, separation is easier with batch distillation than with continuous distillation, as introduced in "Guidelines for the Number of Distillation Separation Stages" (Tips to Scale-up Design #0902).

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Conclusion

"Reaction Kinetics for Chemical Engineers" (Walas) states that "In modern industry with its great emphasis on mass production, the continuous process is highly favored. Because the continuous process is modern, because it lends itself easily to automatic control, and because it involves interesting design calculations, it possesses such a fascination for chemical engineers that the economic superiority of batch operations in some instances may be overlooked. A careful evaluation of both schemes must always be made." As pointed out, batch operation and continuous operation each have useful aspects.

In this paper, we compared batch operation and continuous operation only in terms of unit operation performances, but comprehensive comparisons including operability are also required before actually making a selection.

* "Reaction Kinetics for Chemical Engineers", Walas, S.M., McGraw and Hill p.82 (1959)