Coflore® RTR Flow Reactor vs Batch Manufacturing

Technical Note: An Energy Consumption Comparison

Summary

When compared to an equivalent batch process, the Coflore® RTR requires 27 times less peak heating and 5.9 times less peak cooling than for an equivalent batch process.

Introduction

The Coflore Rotating Tube Reactor (RTR) has a 100 L capacity that is capable of processing countless reactor volumes without interruption. For a 10-minute residence time, the RTR can generate 14.4 m3 of material within a 24-hour period.

The productivity of an Coflore RTR is comparable to a 3000 imperial gallon (13.6 m^3) batch reactor performing one batch per day. The following technical note will calculate and illustrate the possible power savings with respect to heating, cooling, and electrical demand.

Assumptions

- Heating is supplied by 3 BarG steam with condensing jackets.
- Cooling water supplied at 10 °C and is raised to a maximum of 40 °C by cooling processes.
- The frame of reference for utility requirements is with regards to the heat transfer streams (-X kW implies heating, +Y kW implies cooling).
- A 3000 gallon batch vessel has a heat transfer surface area of 25.2 m^2 when filled to the nominal capacity.
- The heat transfer surface area decreases linearly with fill percentage.
- Heat transfer coefficients of 316 W/m2 K and 185 W/m^2 K have been taken for heating and cooling processes, respectively.
- It was assumed that no heat losses occur in either batch or flow
- It was assumed that heat capacity is invariant with respect to temperature.
- No enthalpies of mixing were accounted for.
- Total volume and enthalpy were assumed to be a sum of pure component volumes and enthalpies
- Electrical power demand is based on the motor rating rather than the real load
- No margins of error have been applied

Estimation of Heating, Cooling, and Electrical requirements in Batch

Step 1: Heating of reagent A in water from 10 °C (storage temperature) to 80 °C

Step 2: Dropwise addition of reagent B to the reactor. Reagent B is added at 10 °C and instantaneously reacts exothermically. The reactor temperature of 80 °C is maintained during the addition

Step 3: Cooling of the reactor vessel contents from 80 °C to 25 °C

Step 4: Heating of an aqueous CIP fluid from 10 °C to 80 °C

Step 5: Reactor contents are stirred for 2 hours with no change in temperature or reaction

Step 6: Cooling of the reactor vessel contents from 80 °C to 25 °C

The six process steps outlined require a total time of 20.6 hours based on the assumptions laid out. This allows for 3.4 hours in the batch sequence for fluid transfers, draining of the jacket when changing utility media, as well as a time contingent.

Estimation of Heating, Cooling, and Electrical requirements in the Coflore RTR

In the Coflore RTR, a residence time of 10 minutes will produce 14.4 m^3 of product within a 24-hour period. In order to convert the same reaction performed in batch to continuous production:

- Reagent A in water is continuously fed into the RTR at 80 °C
- Reagent B is continuously fed into the RTR at 10 °C

The reactor is supplied with cooling water onto the jacket and the process temperature at the outlet is maintained at 80 °C. -12.8 kW (heating) are generated from the heats of reactions. -1.9 kW (heating) and +2.3 kW (cooling) are generated from the enthalpic change in the compounds and raising the temperature of reagent B, respectively. In total +12.4 kW (cooling) is required to the RTR to maintain the outlet temperature at 80 °C. To run the RTR for 24 hours, there is an electrical power demand of 52.8 kWh. It should be noted that -41.8 kW of heating are required to heat the stream reagent A in water from 10 °C to 80 °C, prior to addition to the RTR. +33.3 kW of cooling are required to cool the reactor product stream from 80 °C to 25 °C.

Since the RTR is a continuous flow reactor, the net utility requirements can be further reduced with heat integration circuits. By using the warmed cooling water from the reactor, and the reactor product stream, the reactor feed can be partially heated. By taking the total cooling demand of +45.7 kW, and the total heating demand of -41.8 kW, the theoretical minimum net utility demand is +3.9 kW of cooling. Reaching the theoretical minimum net utility demand is inherently impossible but a well-designed heat integration network can provide significant savings.

Summary Comparison

Table 2 shows the calculated summary of utility requirements for both the 3000 gallon batch reactor as well as the 100 L RTR. It can be seen that there are significant reductions in demand even without a heat integration network. Since the daily productivities shown in Table 2 are not equal, it is necessary to normalise the utility requirements to the daily productivity for each reactor. Table 3 shows the normalised utility requirements as well as the reductions ratio for scaling out a process.

Even without a heat integration network, the Coflore RTR requires 27 times less peak heating and 5.9 times less peak cooling than an equivalent batch process.

On top of the reduction in utility requirements, the RTR required less operating volume than the equivalent batch reactor. This can lead to additional energy savings such as reduced HVAC energy consumption by operating in a smaller building.

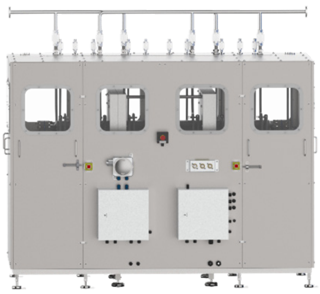
Footprint Size Comparison

Coflore RTR vs 3000 Gallon Batch Reactor

Dimensions:

Batch: H 5700 mm
W 2700 mm

RTR: H 2000 mm
W 2240 mm



Step	Utility Type	Peak Utility Power (kW)	Average Utility Power (kW)	Time (Hr)	Motor Power (kWh)
Step 1	Steam	-948	-670	1.4	20.8
Step 2	Cooling water		+242	1.1	16.4
Step 3	Cooling water	+256	+112	6.8	99.8
Step 4	Steam	-1065	-752	1.5	21.6
Step 5	None			2.0	29.4
Step 6	Cooling water	+256	+112	7.8	114.6
			Total	**20.6**	**302.7**

Table 1: Utility Demand Breakdown for each Step in the Batch Sequence

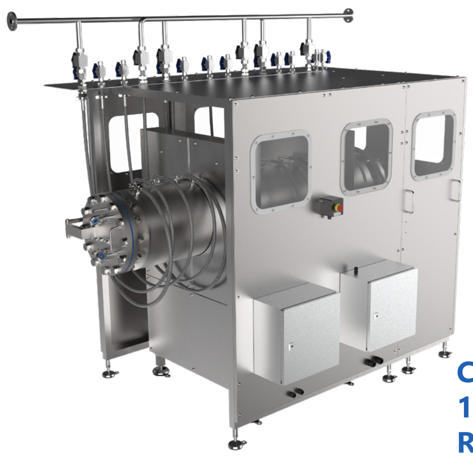
Utility Totals Comparison	3000 Gallon Batch Reactor	100 L RTR
Daily productivity (m^3/Day) (1)	13.6	14.4
Peak heating demand (kW)	-1065	-41.8
Average heating demand (kW)	-752	-41.8
Peak cooling demand (kW)	+256	+45.7
Average cooling demand (kW)	+112	+45.7
Electrical power demand (kWh)	302.7	52.8

(1) A residence time of 10 minutes in the RTR was assumed

Table 2: Summary of Utility Requirements for each Reactor

Utility Ratio Comparison	3000 Gallon Batch Reactor	100 L RTR	Reduction ratio
Peak heating demand per unit volume of product (kW Day / m^3)	-78.3	-2.9	27.0
Average heating demand per unit volume of product (kW Day / m^3)	-55.3	-2.9	19.0
Peak cooling demand per unit volume of product (kW Day / m^3)	18.8	3.2	5.9
Average cooling demand per unit volume of product (kW Day / m^3)	8.2	3.2	2.6
Electrical power demand per unit volume of product (kW Day / m^3)	22.3	3.7	6.1

Table 3: Normalised Summary of Utility Requirements for each Reactor



Coflore RTR 100 L Flow Reactor

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