

“LCTR-Series”

Laminar Continuous Taylor Reactor



 **Laminar**

- 
-
- 1. Introduction**
 2. Technology
 3. Advantage
 4. Application

Introduction

Laminar is the world's first manufacturer of the Taylor Reactor.



Established	August 20th, 2010
President	Mr. Jong-Pal Hong
Location	SeongNam, GyeongGi-do, South Korea
Certification	CE, ISO 9001/14001
Patent	S. Korea : 21 patents registered Overseas : 12 patent registered (USA, EU, Japan, Taiwan)



CE



CE

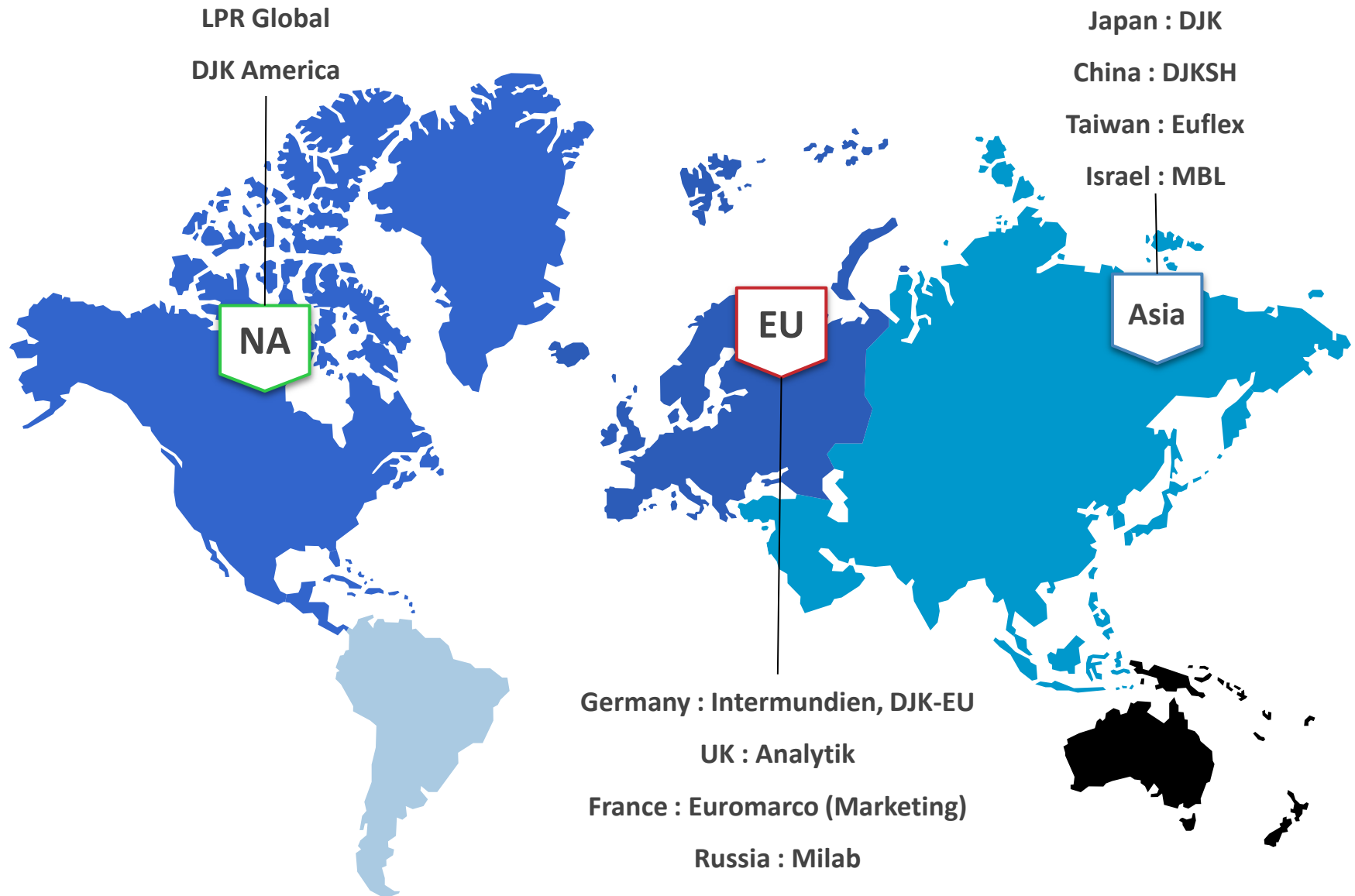


Patents (US, EU, Japan, Taiwan, Korea, etc)

History

2010	Established
2011	Established R&D Center & Factory Commercialized the manufacturing equipment of LIB
2012	Certified ISO 9001/14001 Sold a pilot-scale reactor(50 Lit.) to LG Chemical
2013	Started exports to Japan Commercialized the manufacturing equipment of Nano materials
2014	Commercialized the manufacturing equipment of Graphene Oxide Capital increase invested by Samho Green Investment Co., Ltd. Certified CE mark
2015	Exported a commercial-scale reactor to Japan Capital increase invested by POSCO Exported a reactor to USA
2016	Exported a reactor to France
2017	Exported a reactor to Germany & Saudi Arabia
2018	Exported a reactor to China & Taiwan
2019	Distributor agreement with Analytik (UK) Commercialized high-temperature and high-pressure reactor
2020	Commercialization of oxide-based solid electrolyte manufacturing equipment
2021	Cumulative sales exceeded 100 units
2022	Exported a reactor to UK and Sweden Commercialization of Prussian blue manufacturing equipment for sodium batteries
2023	Demo room installed in Germany Exported a reactor to Poland

Distributor



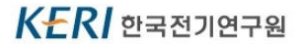
User List

◆ Company

<p>Battery</p>		
<p>Bio</p>		<p>Food</p>
<p>Fine chemical</p>		<p>Graphene</p>
		<p>Etc</p>

User List

◆ Research Institute

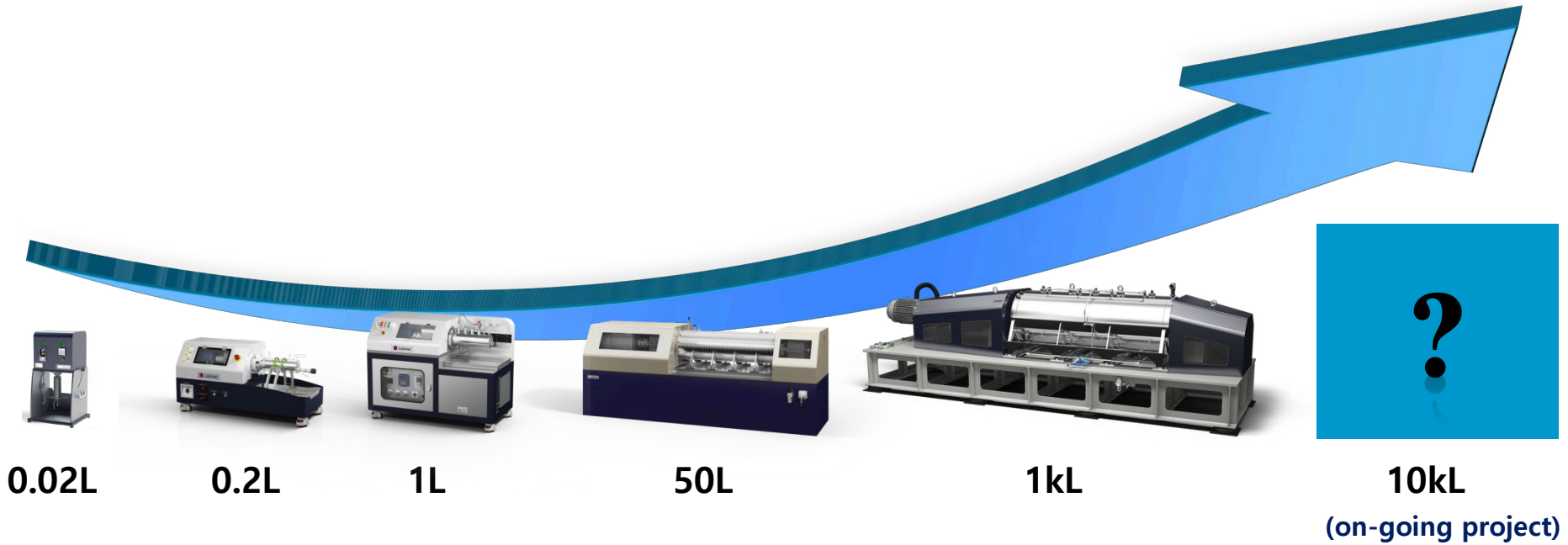


◆ University



Product Line

◆ Sustainable development for scale-up



Specifications

1. Working Volume : 0.02 L (20 mL)
2. Permissible Temperature:
 - General : Max 90 °C
 - Special : Max 600 °C
3. Agitation speed
 - General : Max 1500 rpm
 - Special : Max 5000 rpm
4. Material
 - General : SUS316L
 - Special : Fluorine-coating, Hastelloy-C, Inconell, etc.



Specifications

1. Working Volume : 0.1, 0.2 L (100, 200 mL)
2. Permissible Temperature:
 - General : Max 90 °C
 - Special : Max 600 °C
3. Agitation speed
 - General : Max 1500 rpm
 - Special : Max 5000 rpm
4. Material
 - General : SUS316L
 - Special : Fluorine-coating, Hastelloy-C, Inconell, etc.



Specifications

1. Working Volume : 1 L
2. Permissible Temperature:
 - General : Max 90 °C
 - Special : Max 600 °C
3. Agitation speed
 - General : Max 1500 rpm
 - Special : Max 3000 rpm
4. Material
 - General : SUS316L
 - Special : Fluorine-coating, Hastelloy-C, Inconell, etc.



Manual type



PLC type

Specifications

1. Working Volume : 5, 10, 50 L
2. Permissible Temperature: Max 90 °C
3. Agitation speed : Max 1200 rpm
4. Material
 - General : SUS316L
 - Special : Fluorine-coating, Hastelloy-C, Inconell, etc.



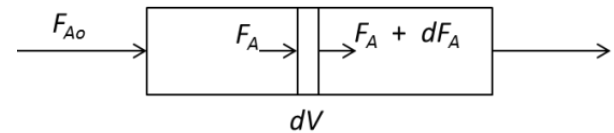
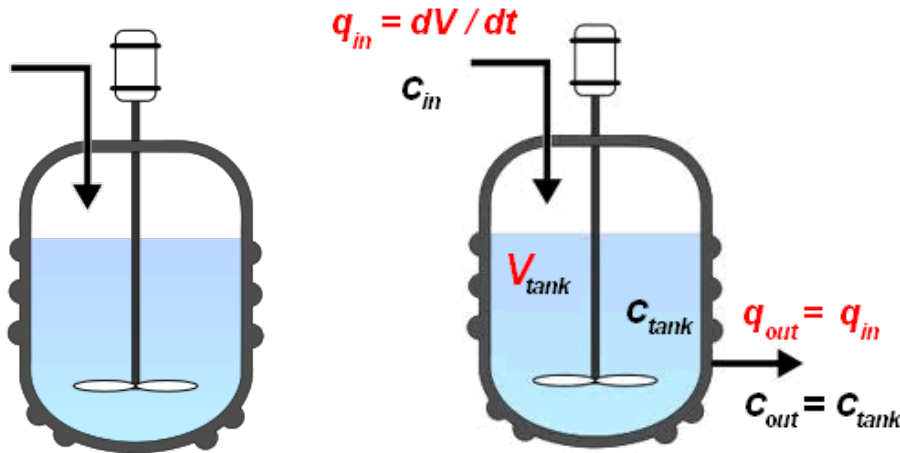
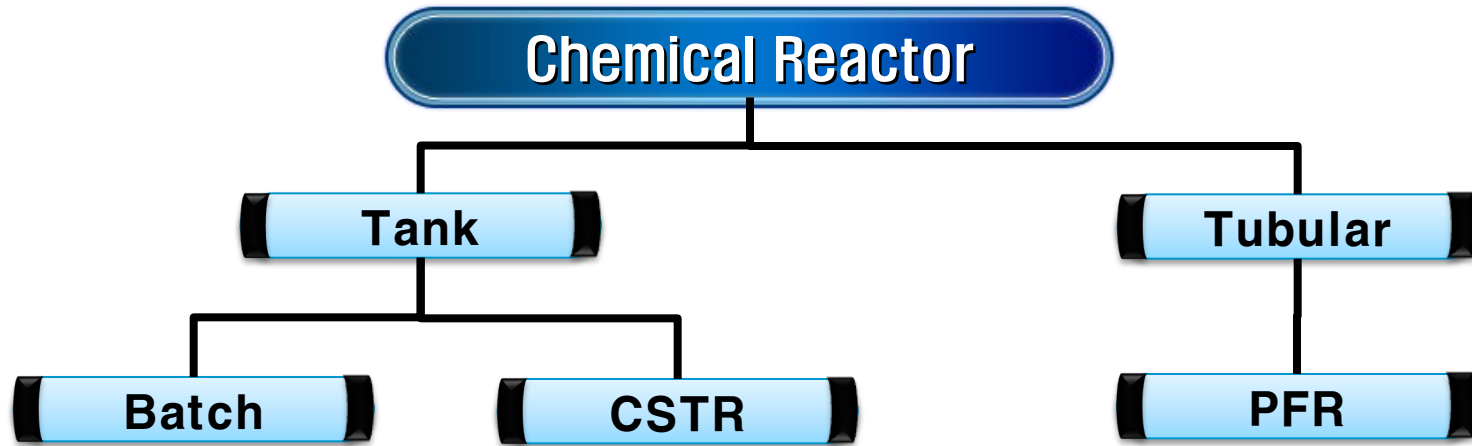
Specifications

1. Working Volume : 100, 500, 1000 L
2. Permissible Temperature: Max 90 °C
3. Agitation speed : Max 300 rpm
4. Material
 - General : SUS316L
 - Special : Fluorine-coating, Hastelloy-C, Inconell, etc.



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1. Introduction
 - 2. Technology**
 3. Advantage
 4. Application

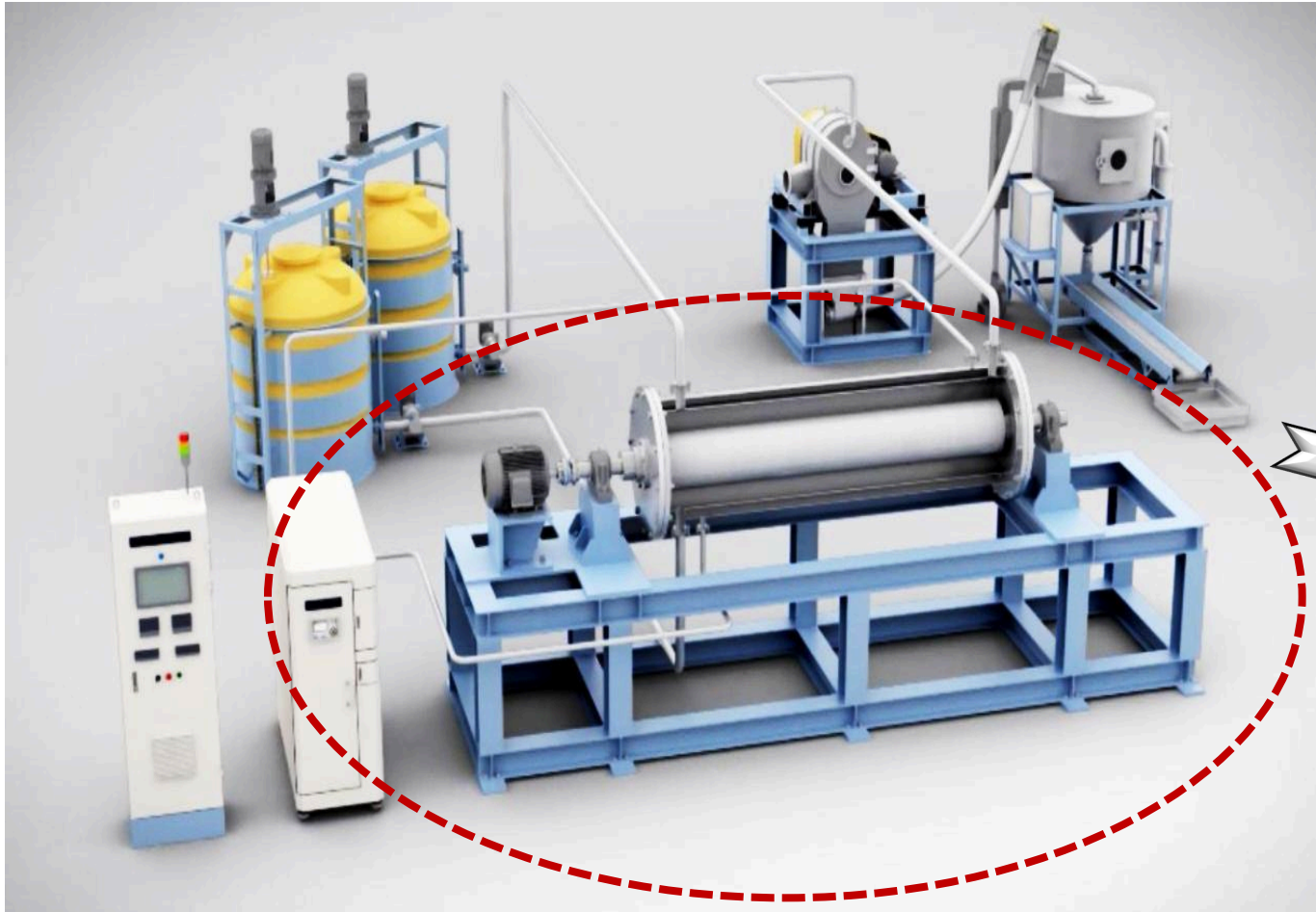
Type of Chemical Reactors



Manufacturing process

◆ Manufacturing process by chemical reaction

Inject solutions -> **Mixing (Chemical Reaction)** -> Solid-Liquid separation -> Dry -> Packing

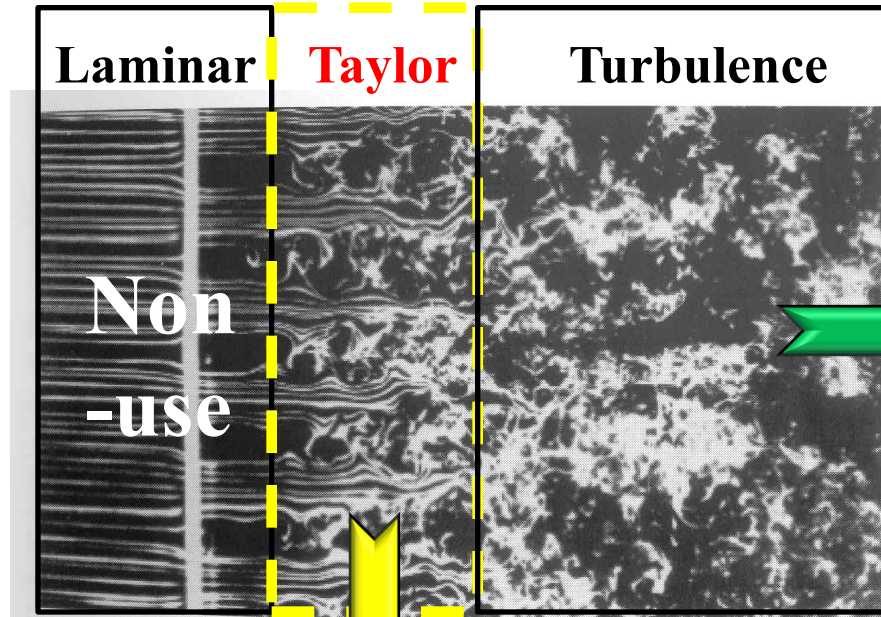


Able to produce
high-density powder



Taylor Flow

◆ Types of fluid flow



Conventional type



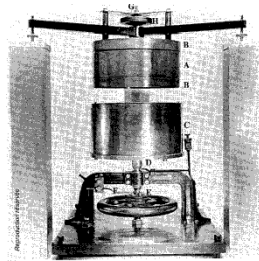
Laminar Reactor

History of Taylor Flow



**Maurice Marie
Alfred Couette**

- Physicist
- Viscometer
- Heat Engineering



[viscometer]

Heat exchanger



HISTORY

1900

1950

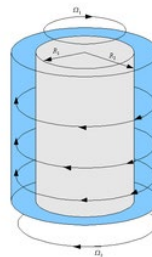
1980

2010



**Geoffrey Ingram
Taylor**

- Physicist
- Mathematician
- Fluid dynamics
- Wave theory

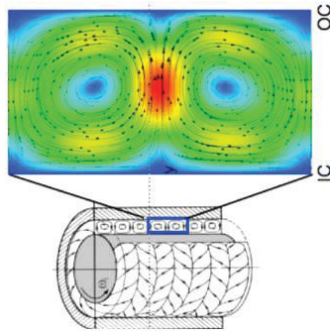


Chemical Reactor

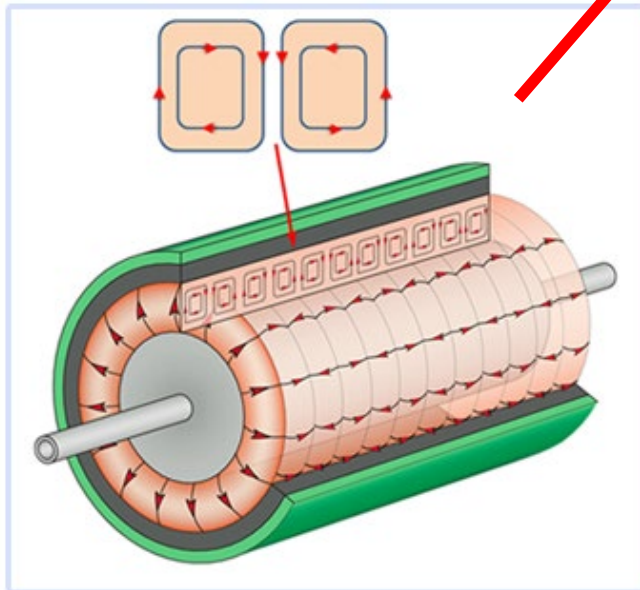
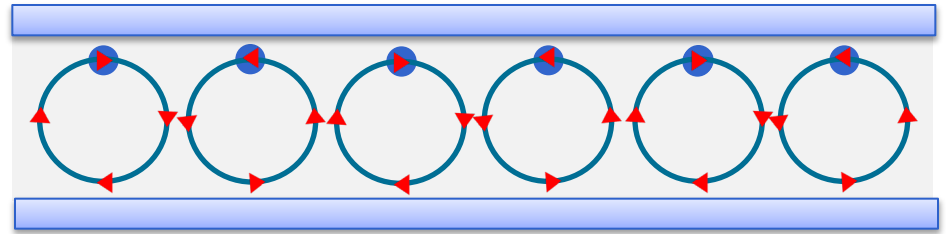


Taylor Flow

• Ring pair



• Taylor flow



$$Ta = \left(\frac{d}{R_1} \right)^{1/2} \frac{\omega_1 R_1 d}{\nu}$$

ω_i : angular velocity of the rotor (rad/s)

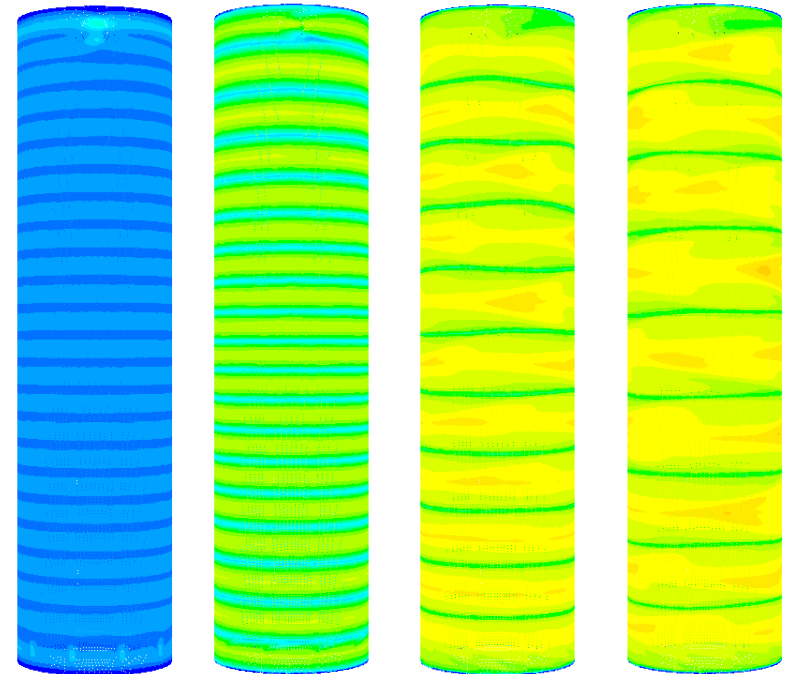
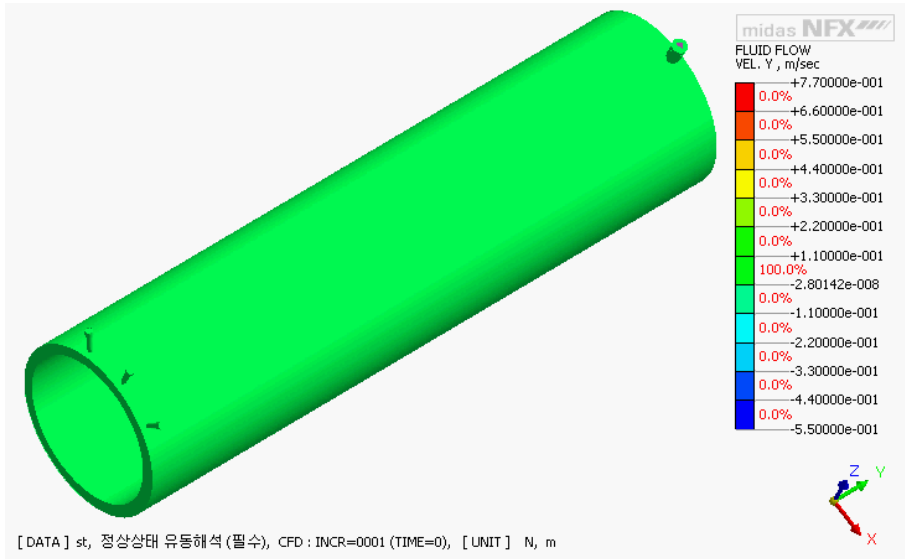
ν : kinematic viscosity (m²/s)

R_i : rotor radius (m)

d : width of the annular gap (m)

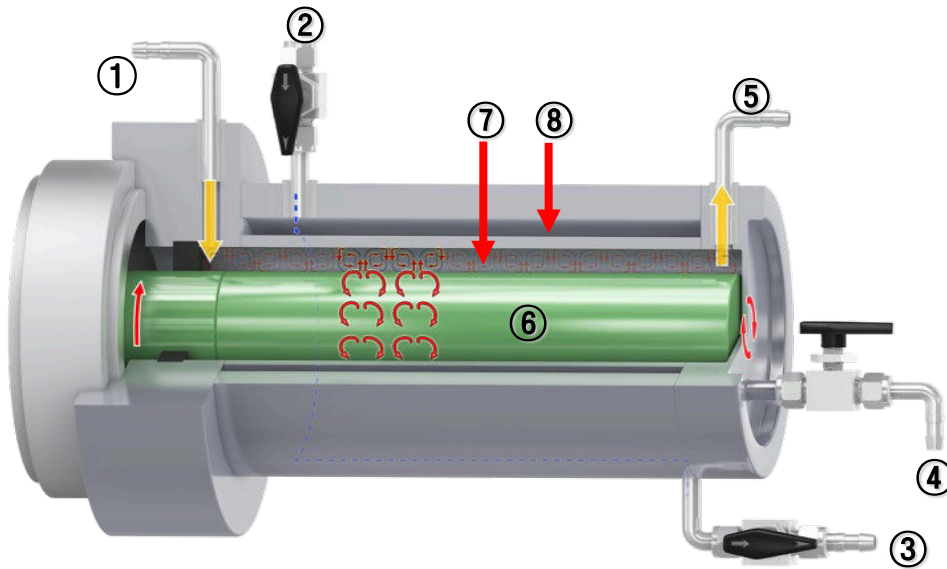
Taylor Fluid Flow: CFD

- Contour of velocity magnitude



Ta (rpm)	2,016 (2.7)	2,879,080 (100)	289,726,287 (1,000)	2,591,007,081 (3,000)
Number of annulus	24	19	11	9

Taylor Chemical Reactor



① Feeding Port

② Temp. Control Outlet

③ Temp. Control Inlet

④ Drain

⑤ Reactants Outlet (Slurry)

⑥ Agitation Bar

⑦ Reaction Area

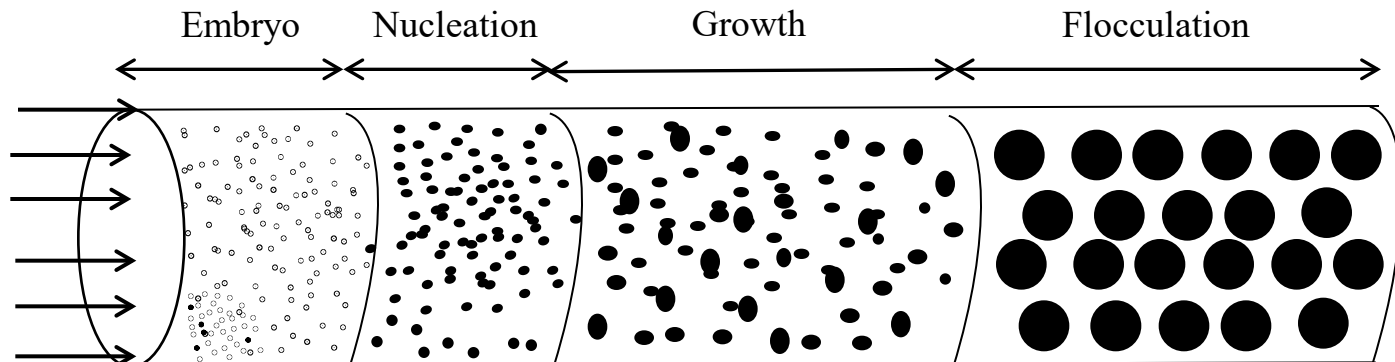
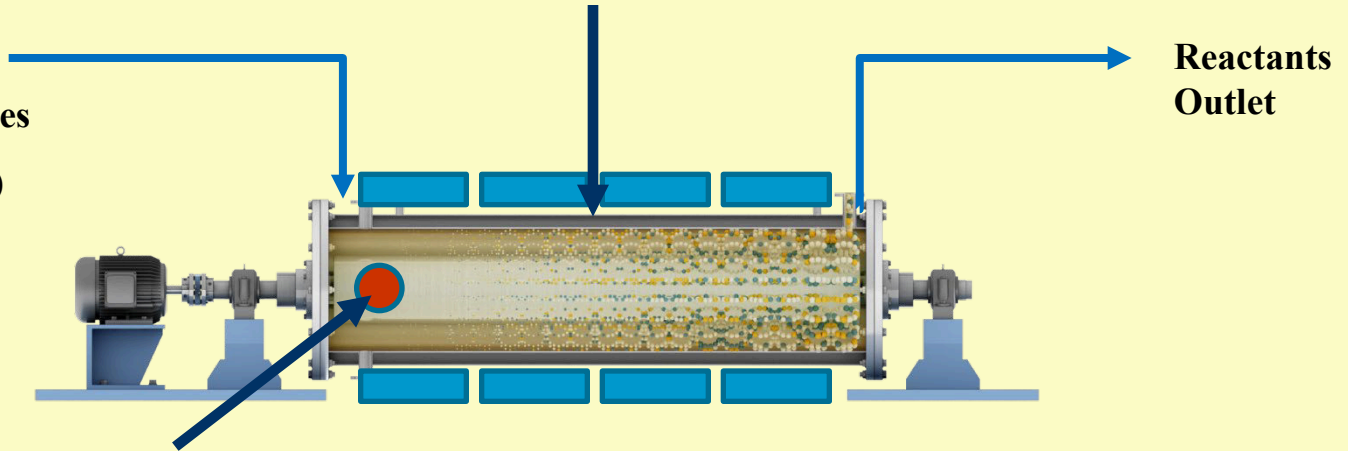
⑧ Reaction Solution

Temperature Control Area

Option & Particle formation process

- Feeding port (more than 1)
- Feeding of 3 phases (solid, liquid, gas) materials

Middle port (more than 1)
→ dual particles manufacturing (Concentration gradient)



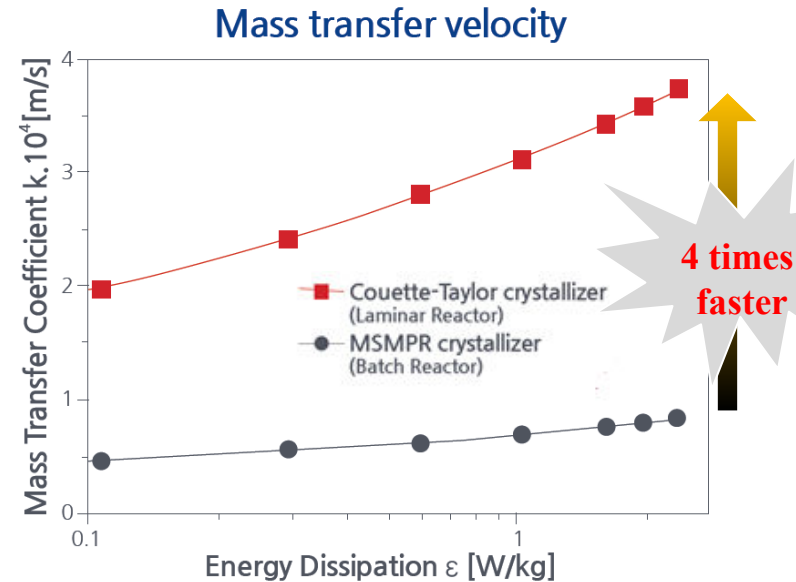
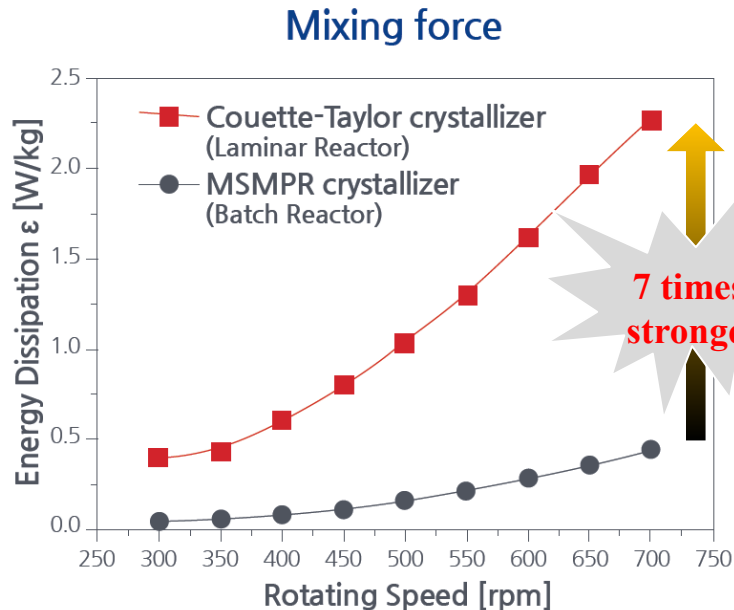
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Summary

TIME	COST
	
	
QUALITY	CONTINUITY

Advantage 1. Time reduction

◆ Comparison data on flow characteristic between Laminar reactor and Batch



Nguyen-Anh TUAN, Jeong-ki Kang, Jong-Min Kim, Sang-Mok CHANG, Choul-Ho Lee, Woo-sik KIM, “Drowning-out Crystallization of Guanosine 5-Monophosphate(GMP) in Continuous Couette-Taylor Crystallizer”, 8th International Conference on Separation Science and Technology, Karuizawa, Japan, (Oct 2-4, 2008)

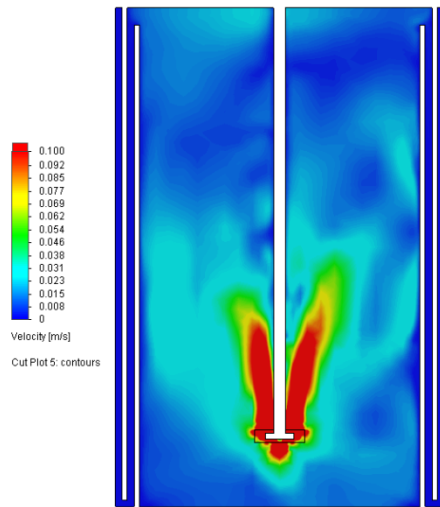
■ Comparing to Batch-type reactor.

- * Laminar Reactor has **7 times stronger mixing power** (Criteria : 400 rpm)
- * Laminar Reactor has **4 times faster mass transfer speed** (Criteria : ϵ : 0.4 W/kg)

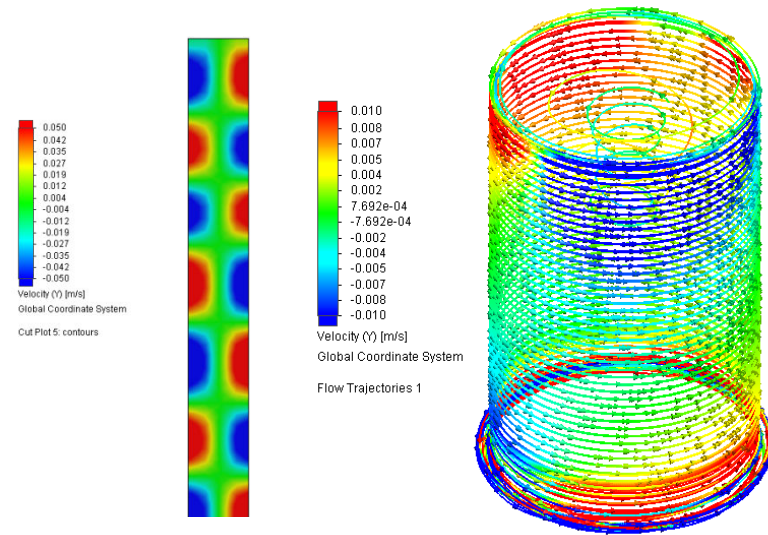
Advantage 2. High-purity

◆ Reduce the creation of impurity by uniform mixing

Conventional Reactor



Laminar Reactor

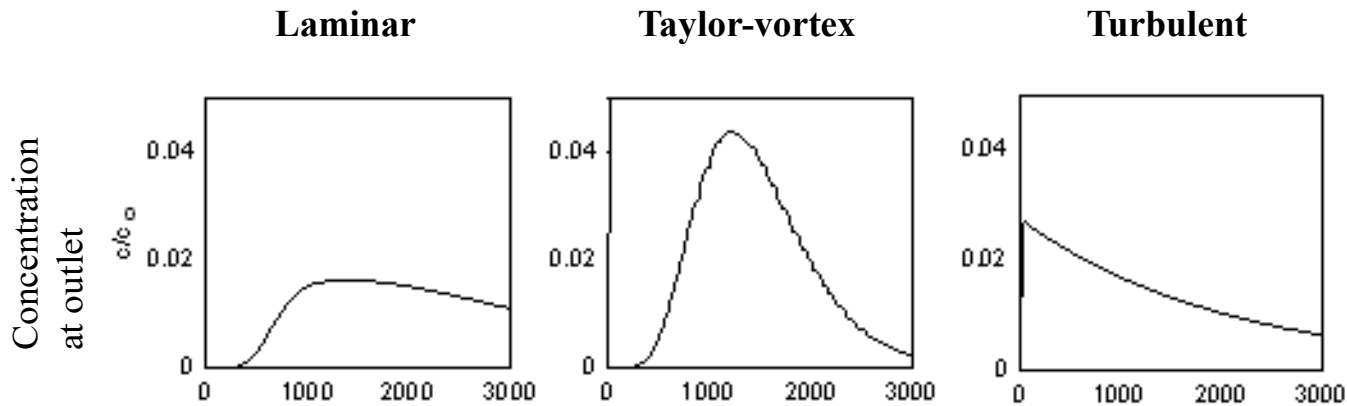


[CFD, Computational Fluid Dynamics]

Division	Material	Conventional Reactor	LCTR
Food	GMP (Guanosine-monophosphate)	97 %	99.9 %
Petrochemical	DMTP (Dimethyl Terephthalate)	51.5 %	98.2 %

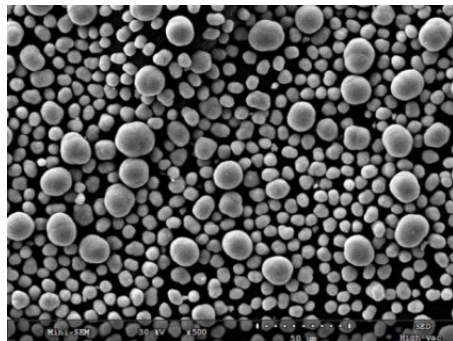
Advantage 3. Uniform properties

<Demonstration of mixing>

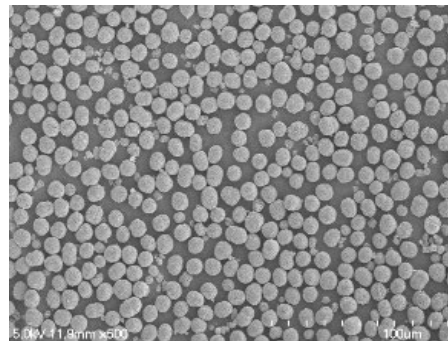


From : A. Syed and W.-G Fruh (2003). Journal of Chemical Technology and Biotechnology 78, 227-235

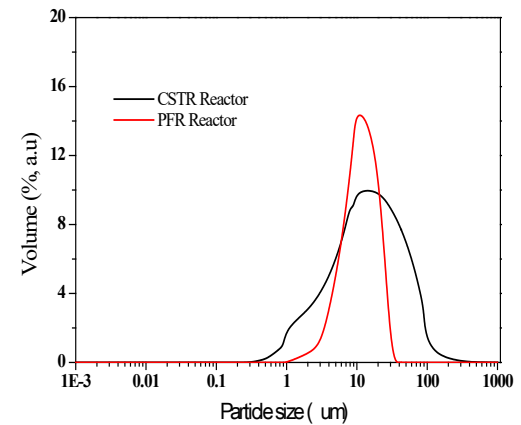
<LIB Data>



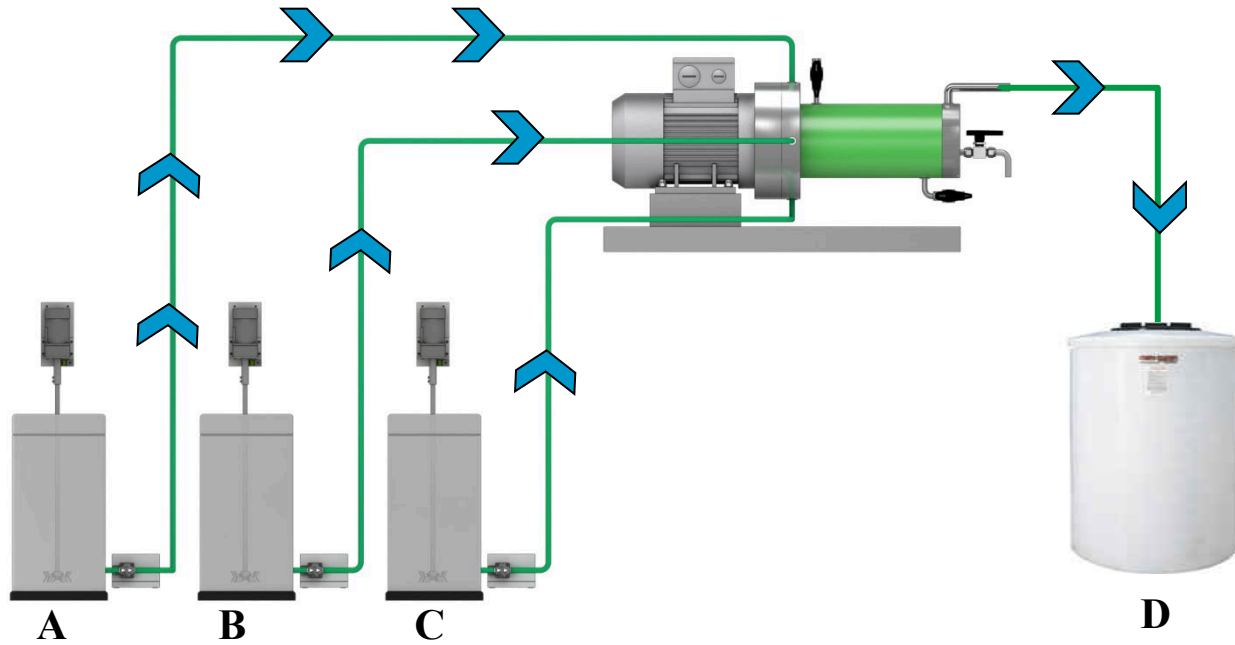
[CSTR]



[LCTR]



Advantage 4. Continuous production



Input = Output
(A+B+C) (D)

Advantage of Laminar Reactor

By making the best use of advantages from tank and tubular type ones, the most ideal reactor was invented.

Able to produce high-purity materials under the continuous production system



[Tank-type]



[PFR]



[Laminar Reactor]

Advantages of Tank-type reactor

1. Easy to use
2. Mixer
3. Easy to check the synthesis process

Advantages of PFR

1. Able to produce high-purity materials
2. High repeatability
3. Easy to produce nano materials

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1. Introduction
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 4. **Application**

Application fields

◆ Industries where high-performance chemical reactor is needed:



Dye, Surfactant

Fine Chemical

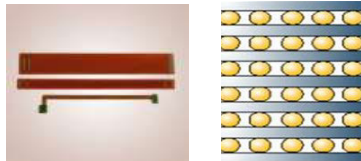


Bio/Drug



Drug, Enzyme, Protein

Electronic materials



Semiconductor, Display materials
Secondary battery materials

LCTR-series

Food



Amino acid,
Functional Food materials

Environment



Recover high-priced materials
Enhance the quality of water

Petrochemical



TPA Isomer separation

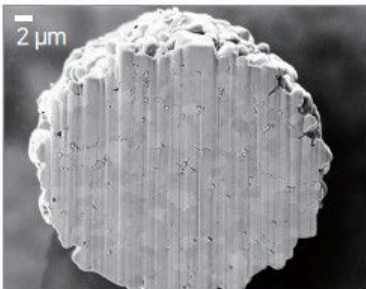
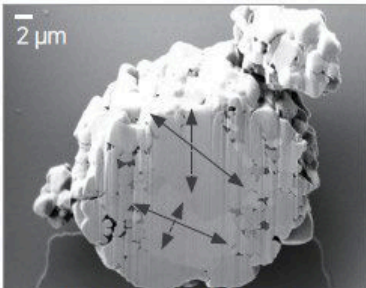
*Numerous literatures have been showing
the efficiency of Taylor Flow in chemical processing.*

- **Emulsion polymerisation** (Kataoka et al., 1995; Wei et al., 2000)
- **Catalytic** (Cohen and Maron, 1990)
- **Photochemical** (Haim and Pismen, 1994; Forney and Pierson, 2003)
- **Electrochemical** (Coeuret and Legrand, 1981)
- **Enzymatic reactions** (Iosilevskii et al., 1993; Giordano et al., 2000b)
- **Cell cultivation** (Haut et al., 2003)
- **Precipitation** (Jung et al., 2000; Judat et al., 2004)
- **Focculation for wastewater treatment** (Grohmann et al., 1981)
- **Dynamic tangential and membrane filtration** (Schwille et al., 2002; Lee and Lueptow, 2004)
- **Microparticle classification** (Ohmura et al., 2005)
- **Liquid—liquid extraction** (Baier et al., 2000; Forney et al., 2002)
- **Exfoliation** (Woo Seok Yang, 2015, Carbon)

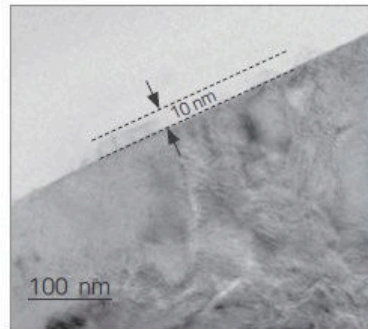
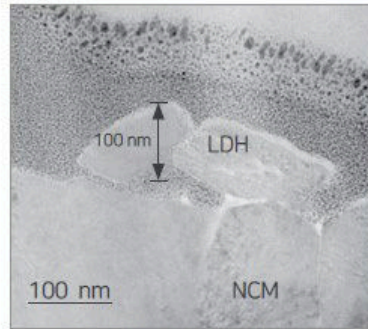


Summary

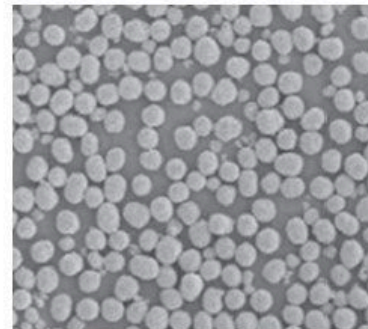
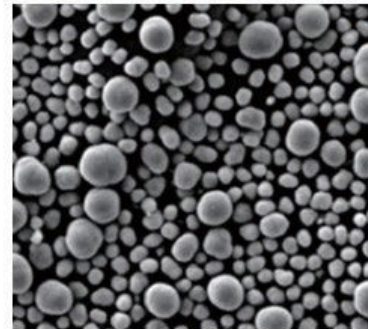
High density



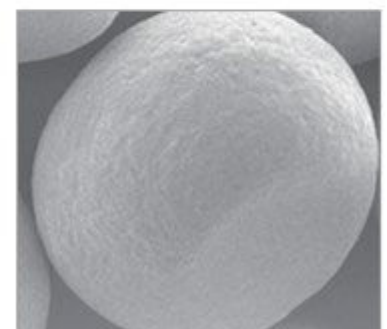
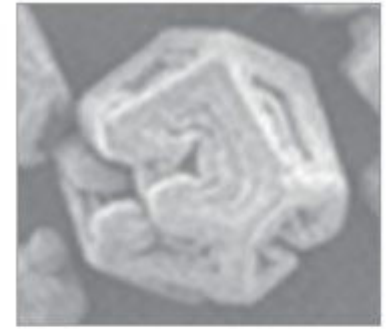
Coating



Uniform particle size

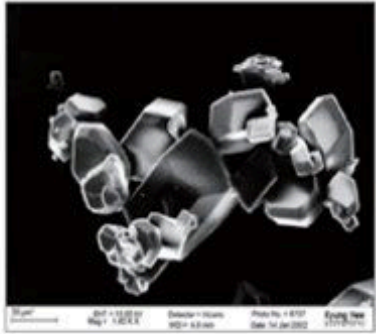


Spherical particles

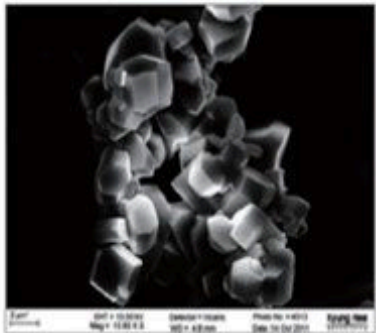


Summary

Time reduction

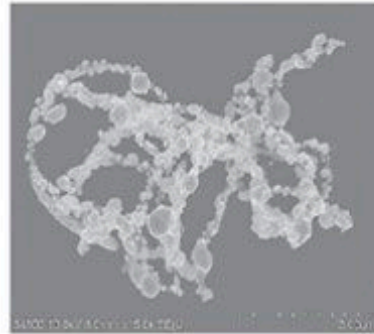


CSTR : 93 hr



LCTR® : 20 min

Nanocomposite

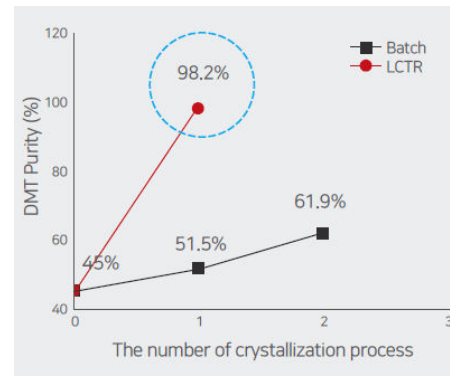


CSTR



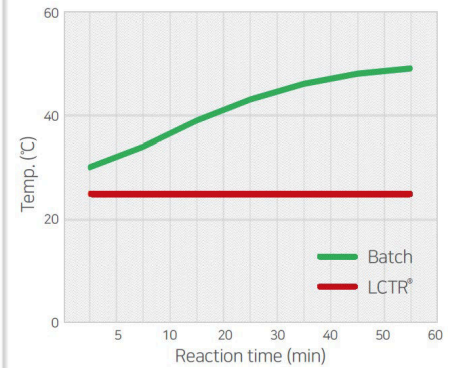
LCTR®

High purity



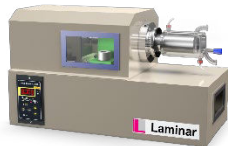


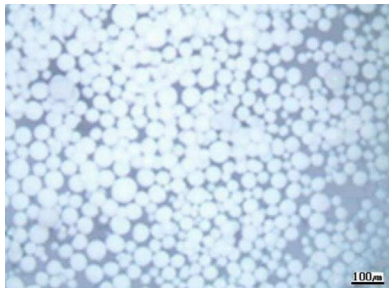

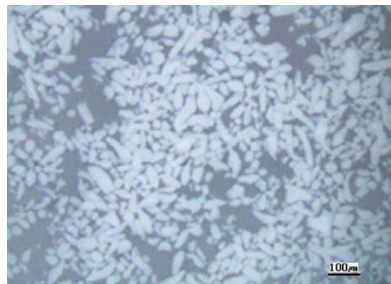
	Batch	LCTR®
Raw material (DMT) Purity	45.0%	
1 time	51.5%	98.2%
2 times	61.9%	

Exothermic reaction



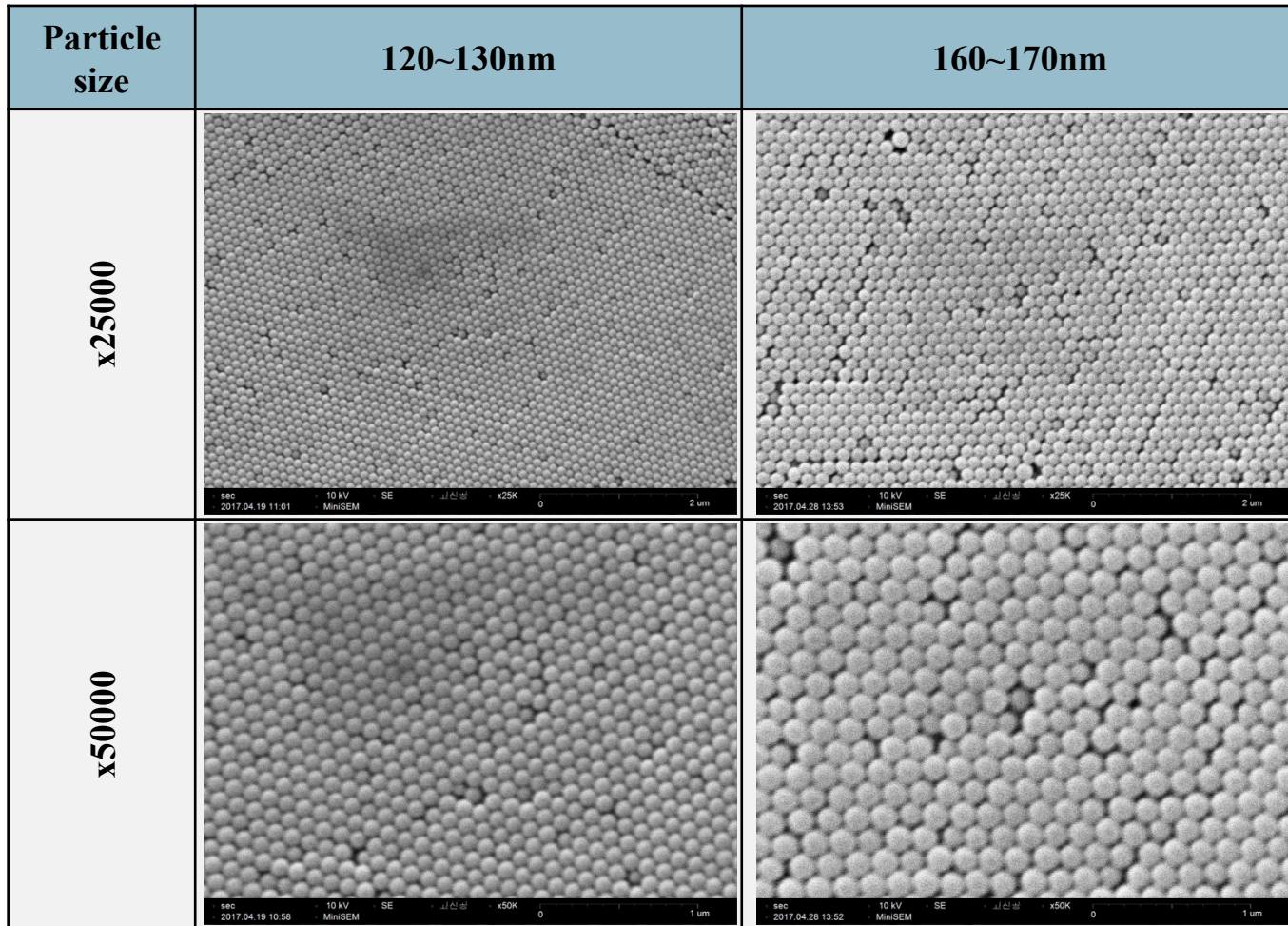
Zirconia bead (Emulsion polymerization)

Result: Continuous mass production

Division	Taylor reactor	Vibration mill	Homogenizer
Equipment			
Bead particle size (μm)	40~60	50~130	20~100
Spherical rate (%)	95	89	85
Particle size distribution	1.2	3.6	4.2
Yield (%)	95	83	78
Particle shape			

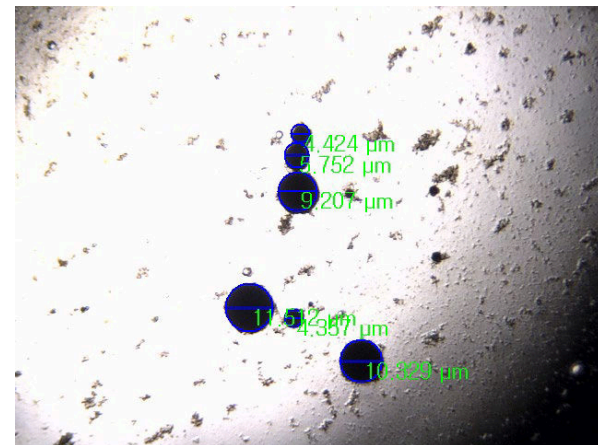
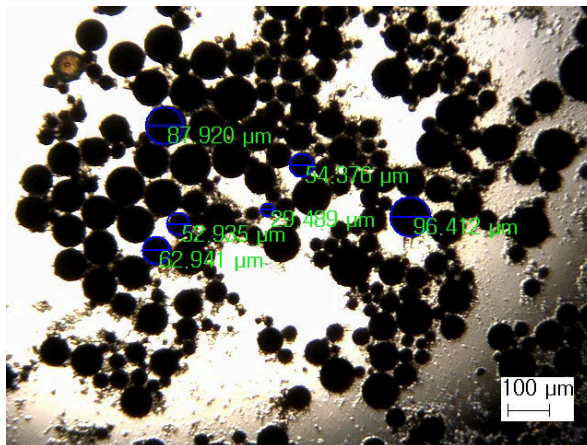
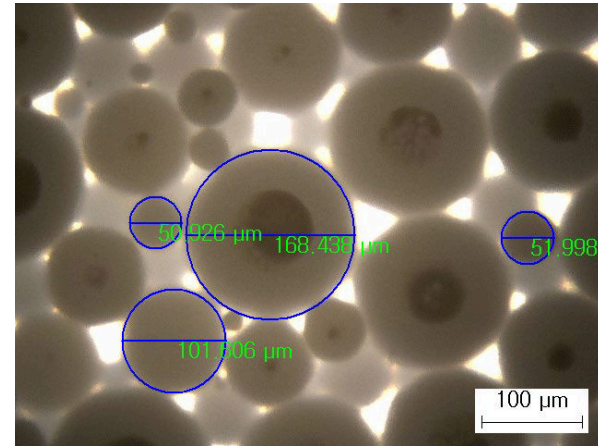
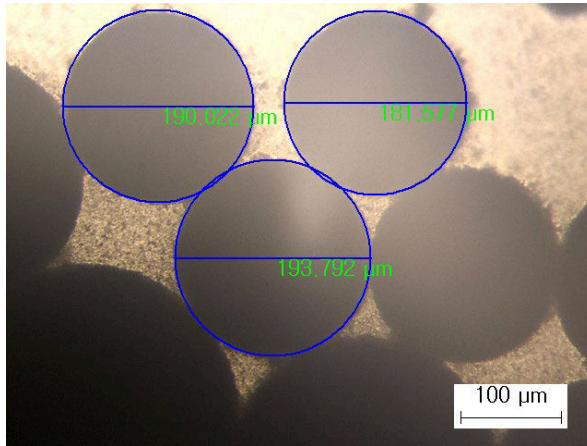
Polystyrene (Emulsion polymerization)

Target : Continuous process, Uniform particle size



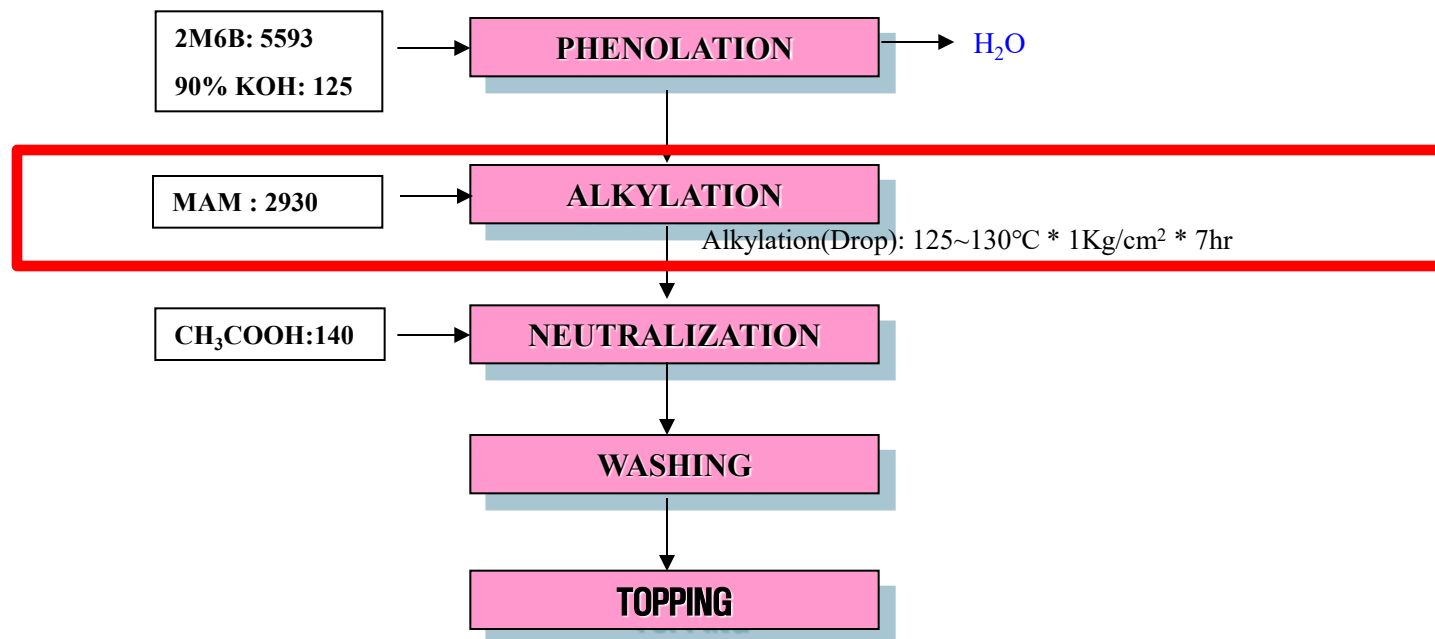
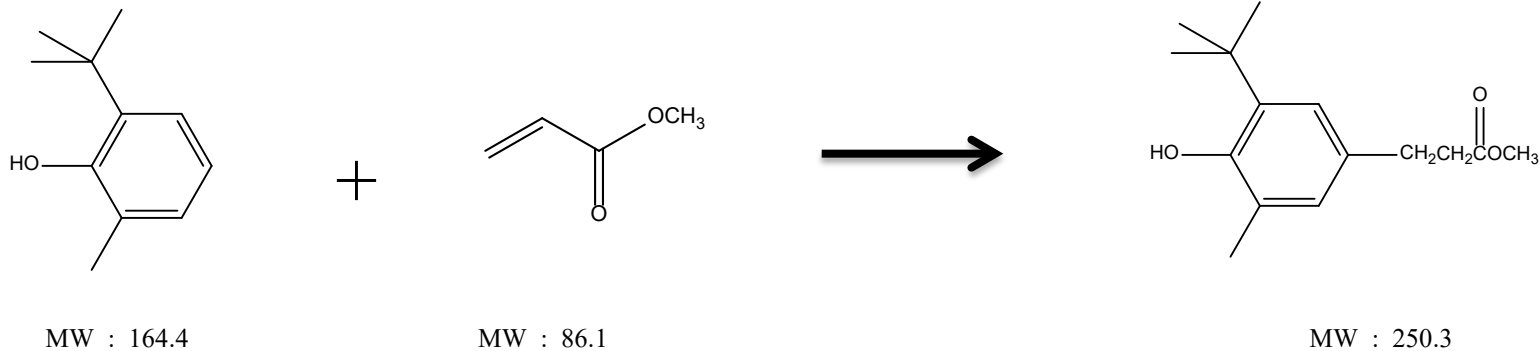
Oil + Water (Emulsion polymerization)

Target : Particle size control



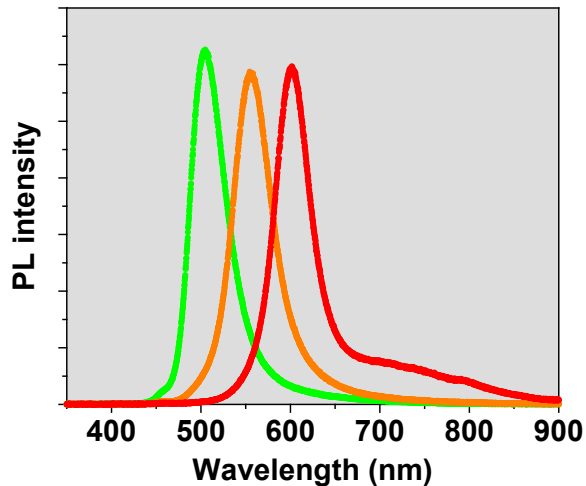
Alkylation

Target : Continuous process



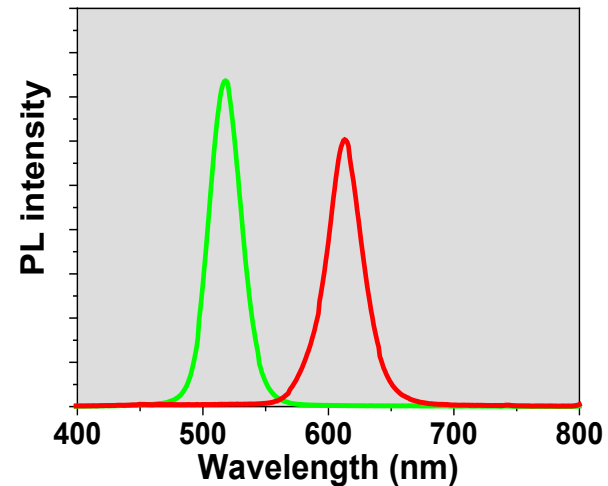
Quantum dot (Core-shell process)

Target : Continuous process, Uniform particle size



▪ InP/ZnS

- Wavelength : 505, 540, 605nm
- Line width : 46-48nm
- Efficiency : > 50%

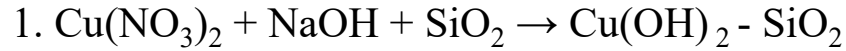


▪ CdSe/ZnS

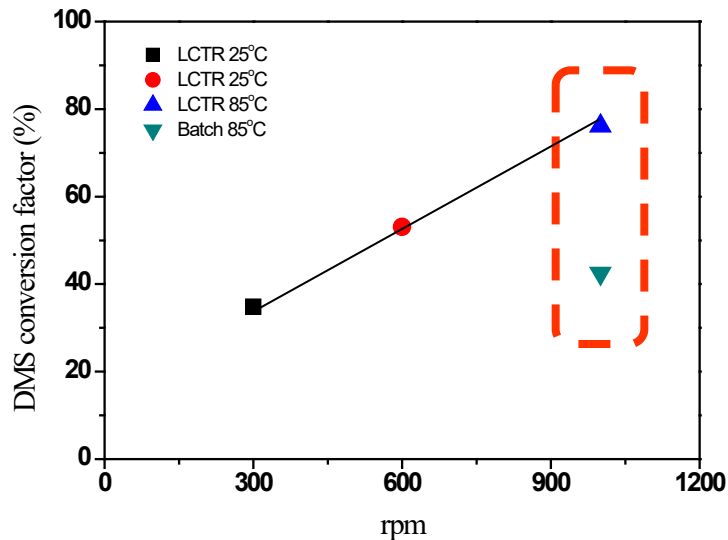
- Wavelength : 510, 620nm
- Line width : 26-35nm
- Efficiency : > 80%

Catalyst (Core-shell process)

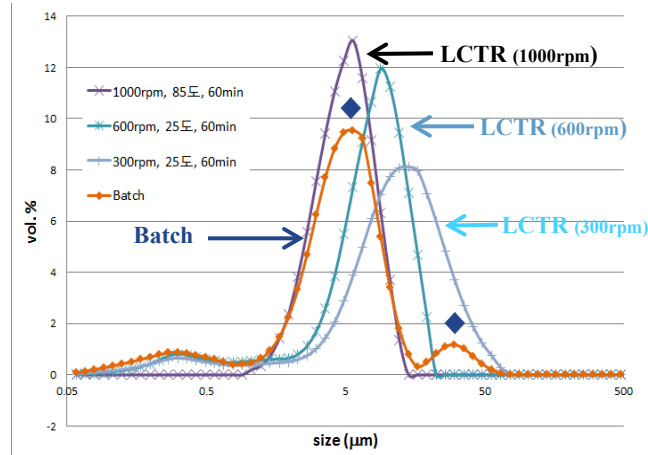
Goal: Small particle size, improved DMS conversion



◆ DMS conversion ratio of CuO-SiO₂ catalyst



◆ Uniform particle size (Batch < LCTR)



	Batch	LCTR		
	1000rpm,85°C	1000rpm,85°C	600rpm,25°C	300rpm,25°C
DMS conversion ratio (%)	42.5	76.1	53.1	34.8
Particle size (nm)	28	13	24	30

* This study is an excerpt from Dr. Hwang Dong-won of the Korea Research Institute of Chemical Technology.

Metal Nano particle (Capping)

Result: Continuous mass production, increased yield, uniform size distribution, reproducibility

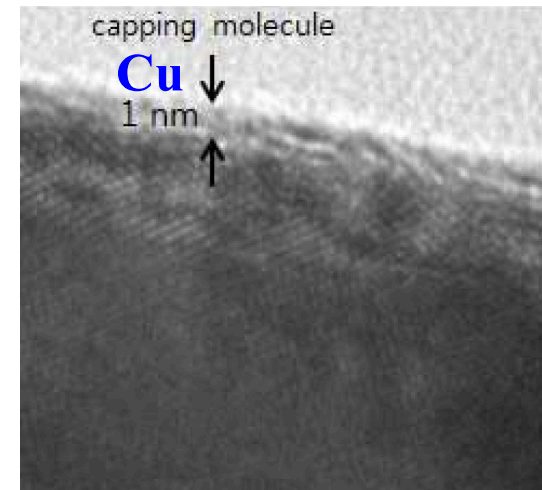
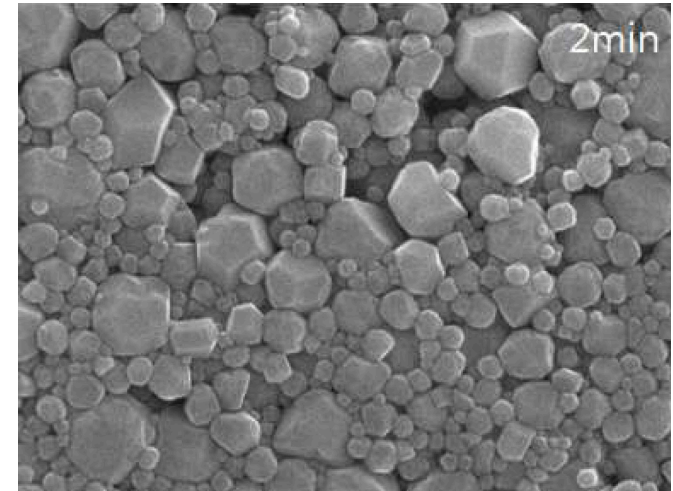
❖ **Experimental condition :**

1. **Agitation speed : 400~1000 rpm**
2. **Reaction temp : 100~350 °C**
3. **Reaction time : 1~5 min**

Division	Test 1	Test 2	Test 3
Reaction temp (°C)	130	155	125
Agitation speed (rpm)	600	600	800
Size uniformity (A_1/A_t) a)	0.6	0.1	0.8
Average particle size (nm)	100	100	5
Resistivity ($\mu\Omega \cdot \text{cm}$)	9	60	50

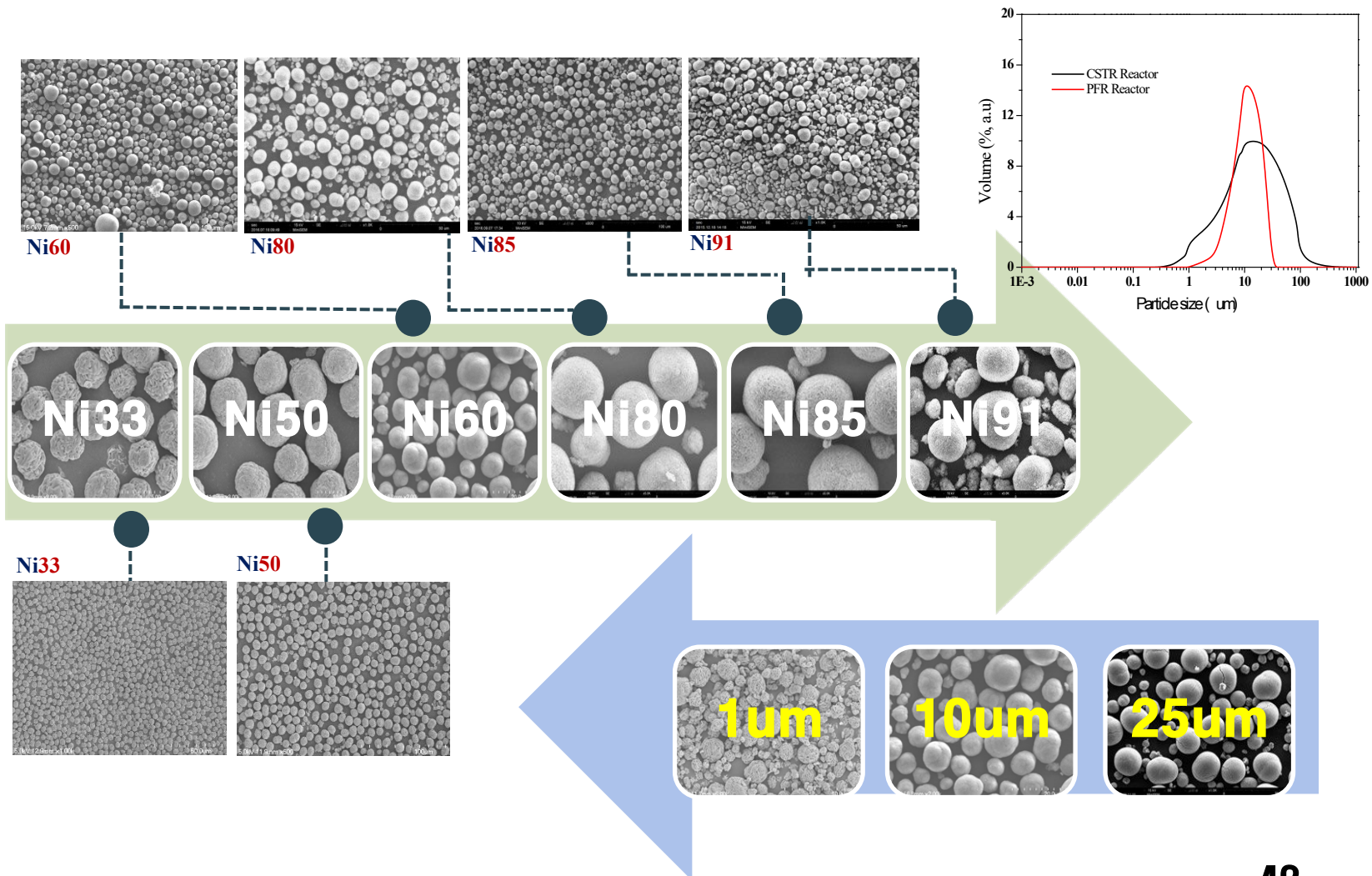
Closer to 1, uniform particle size distribution

(A_1 : Sum of area of smallest particle size, A_t : Sum of the areas of all peaks)



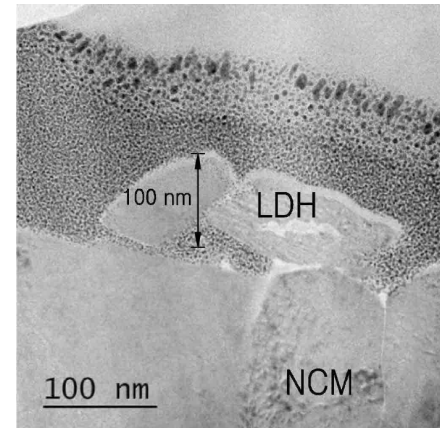
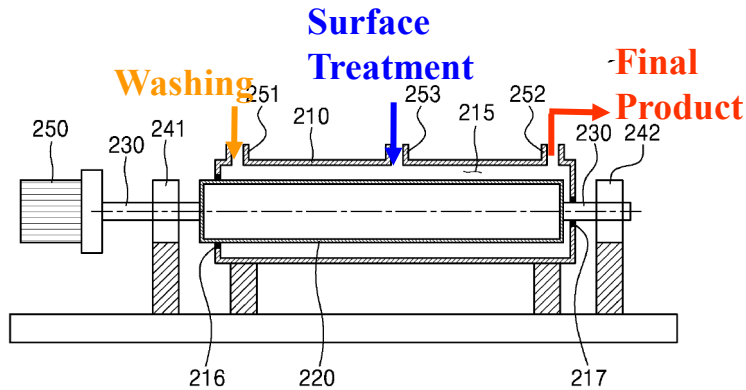
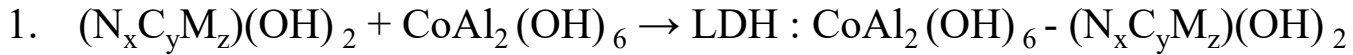
Li-ion Battery (Co-precipitation)

Target : Particle size control, Uniform particle size, Reduce cost

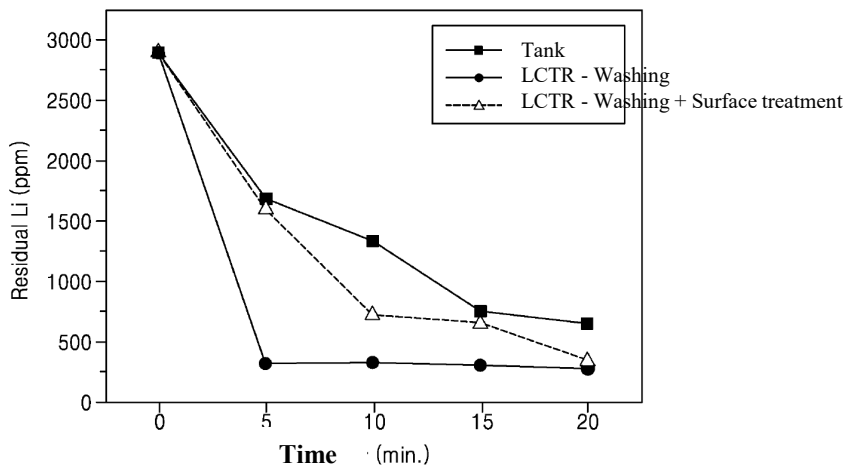


LIB (Washing & Coating)

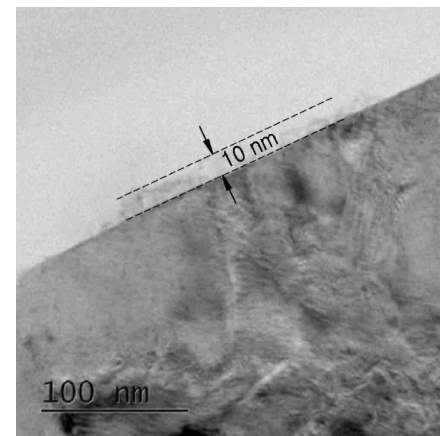
Result: LDH (Layered Double Hydroxide) Manufacturing, Thin Coating, Increased Charge and Discharge Efficiency



<Tank type : 100 nm>



<Washing>

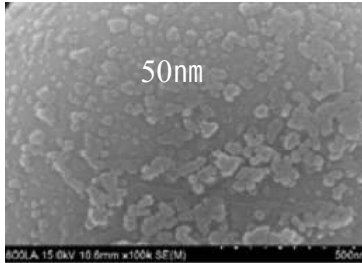
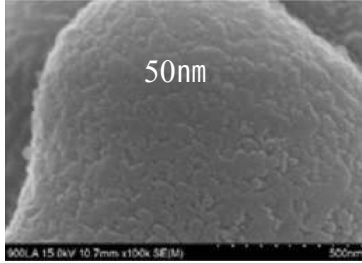
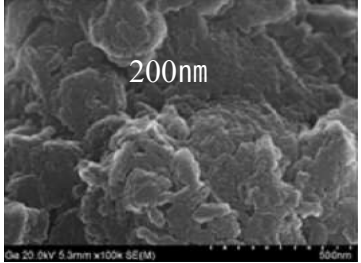
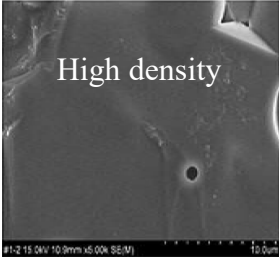
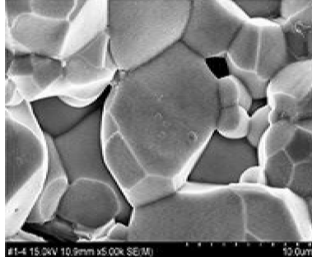


<LCTR : 10 nm>

All solid battery- electrolyte (Co-precipitation)

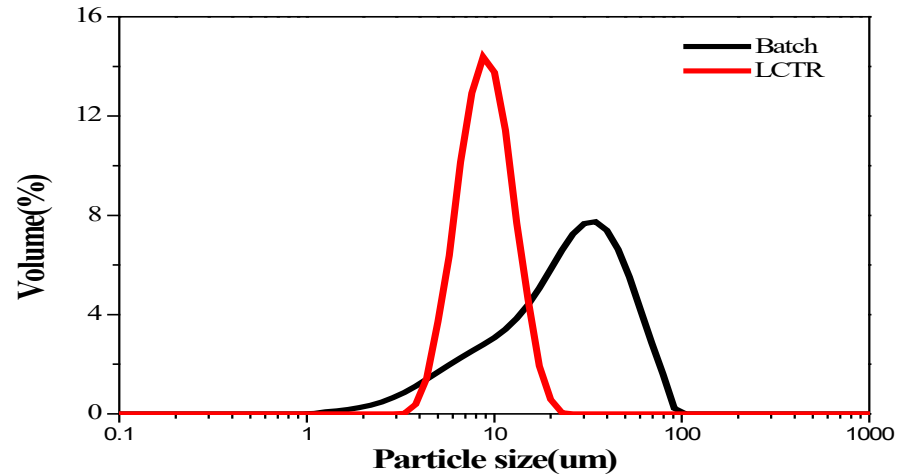
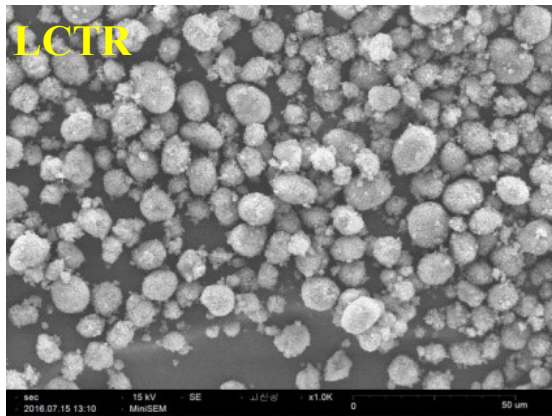
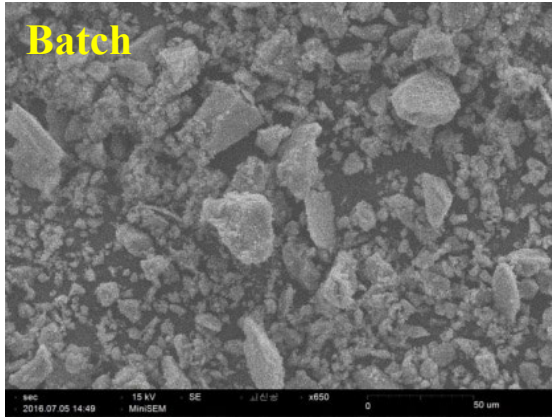
Result: Improved ion conductivity

Material : LLZO (Lithium Lanthanum zirconium oxide)

Division	Taylor reactor 1	Taylor reactor 2	Batch
LLZO Doping Composition and calcination temperature (°C)	Ga-0.2 mole (@900)	Ga-0.2 mole (@800)	Ga-0.2 mole (@900)
Impedance ($\Omega \cdot \text{cm}^2$)	94.38	161.30	459.34
Total ion conductivity (σ) (S/cm) at R.T	1.49×10^{-3}	1.31×10^{-3}	3.90×10^{-4}
Surface morphology			
Cross section of pellet			

Mn-Co Powder (Co-precipitation)

Target : Spherical shape, Particle size control (10 μm ↓)





	Batch	LCTR
Particle size (um)	30.2	7.3
Uniformity*	1.9	1.3

Particle size 4.1times↓, Uniformity 1.4times↑




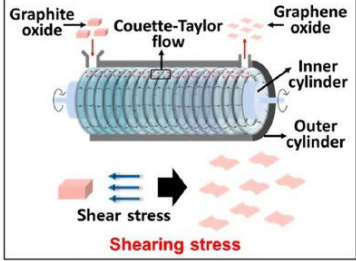
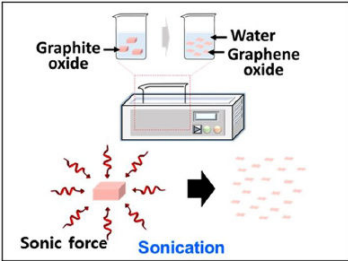
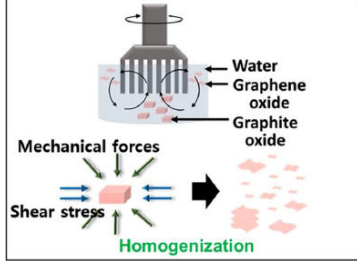
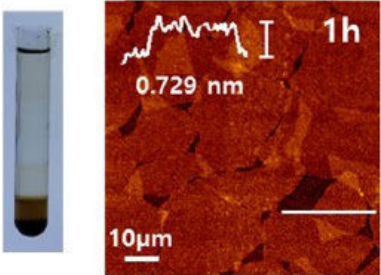
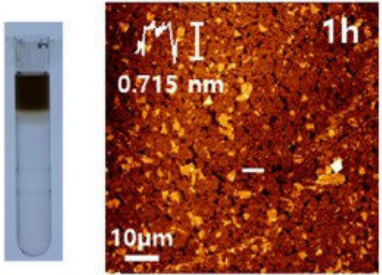
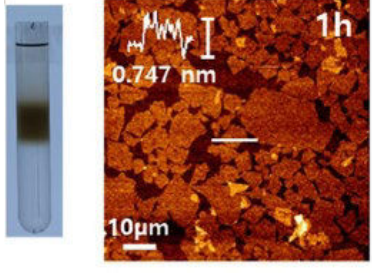
Graphene oxide (Exfoliation)

Target : Reduce cost, Continuous process

Contents	Batch	LCTR
Diagram		
Production process	Non-continuous	Continuous
Process Temp. (°C)	30	30
Recovery Rate (%)	70	95 ↑
Reaction Time (h)	Max 120	1 ↓
Production Cost (USD/g)	500	50

Graphene Oxide (Exfoliation)

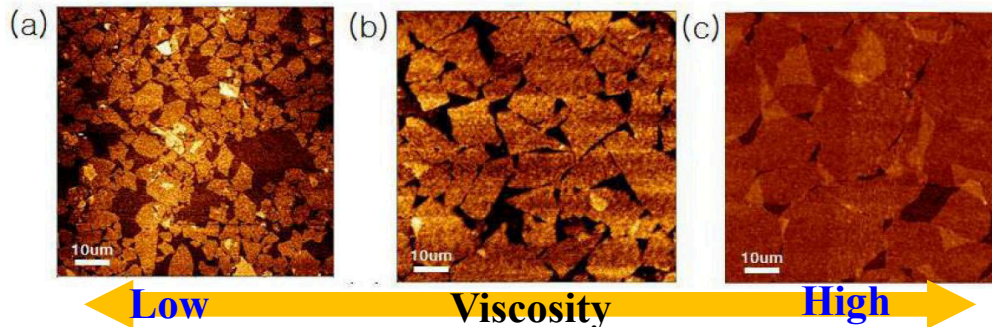
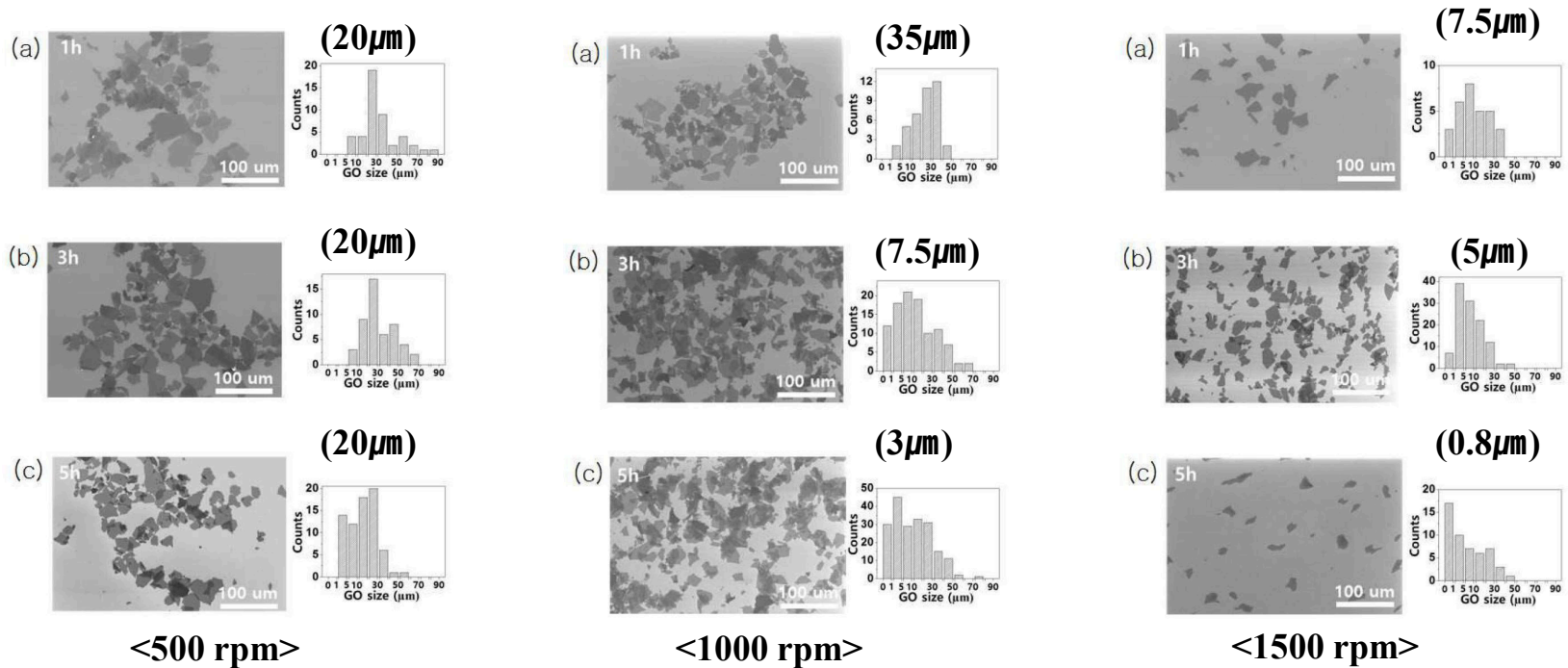
Result: As a result of experiments with GO on GtO, large-area exfoliation is possible using a Taylor reactor.

구분	Taylor reactor	Sonication	Homogenizer
Equipment			
Experimental Method			
Result			

* 본 연구결과는 전자부품연구원 양우석 박사님의 결과를 발췌하였습니다.

Graphene Oxide (Exfoliation)

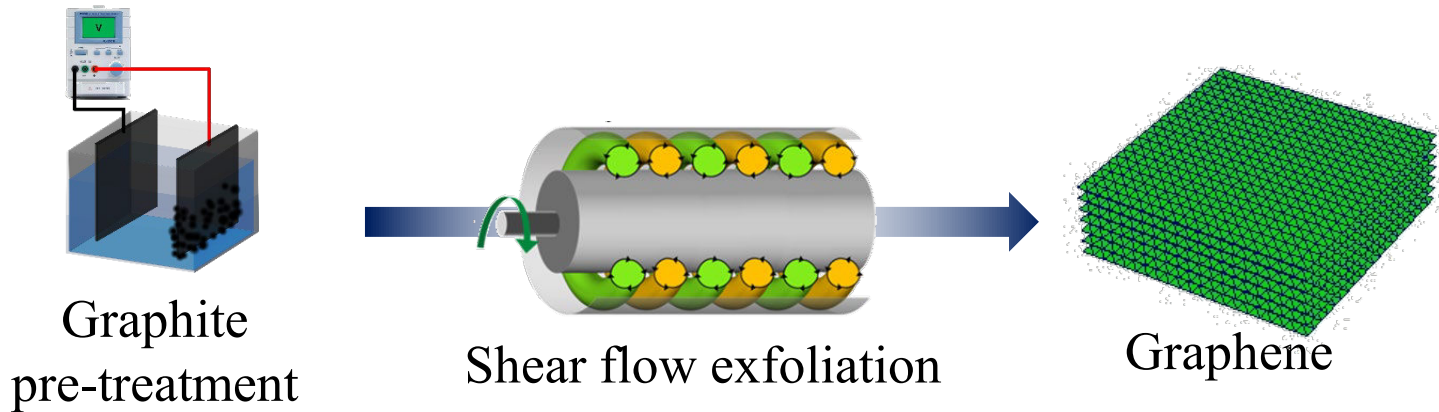
Result: Quality control in a short time, particle production with controlled particle size and size distribution



*This study is an excerpt from the results of Dr. Woo Suk Yang of the KETI.

Graphene (Exfoliation)

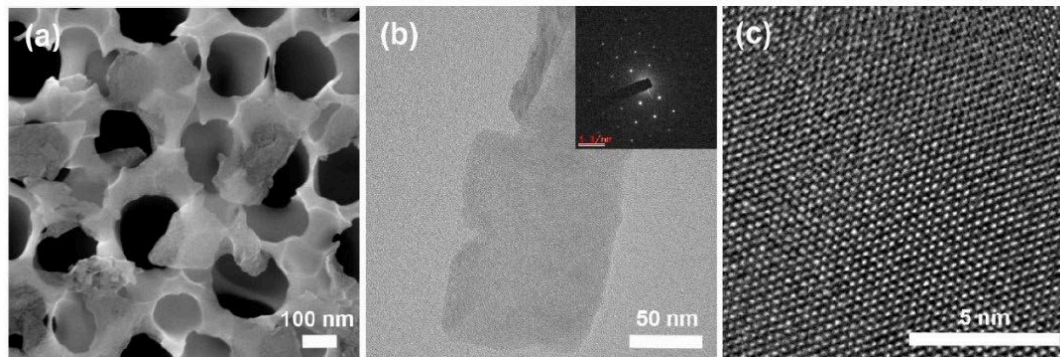
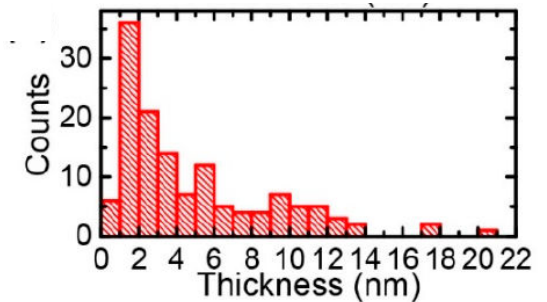
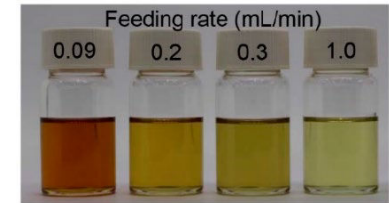
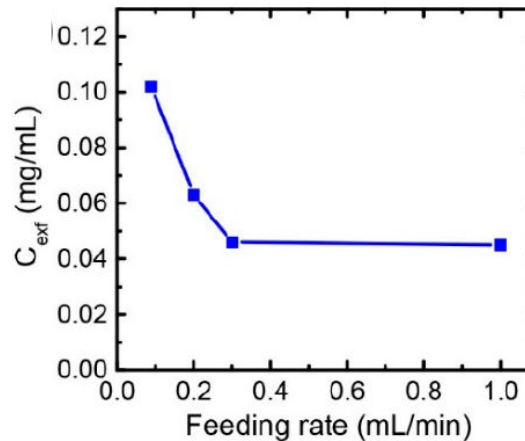
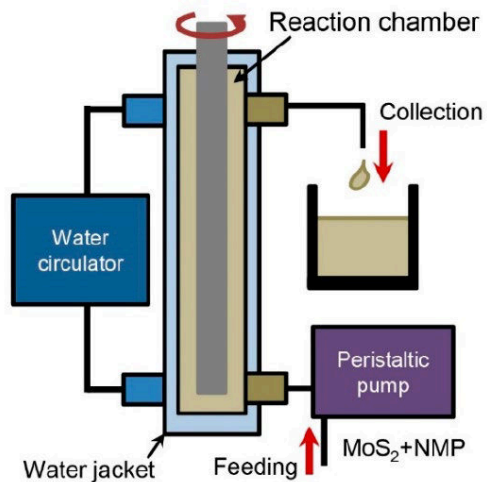
Target : Reduce cost, Continuous process, Improved yield



Contents	Batch	LCTR
Production process	Non-continuous	Continuous
Recovery Rate (%)	7	25
Reaction Time (h)	4	1

MoS₂ (Exfoliation)

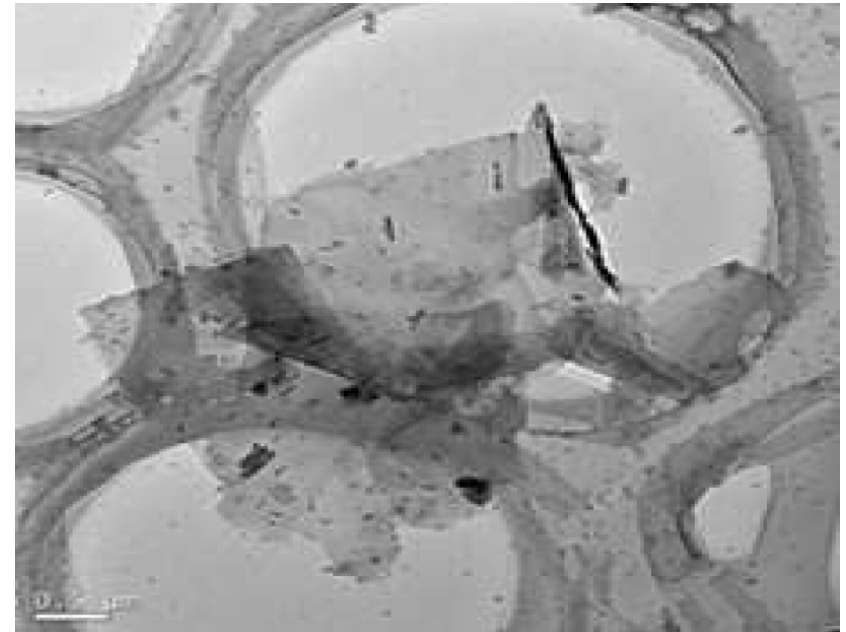
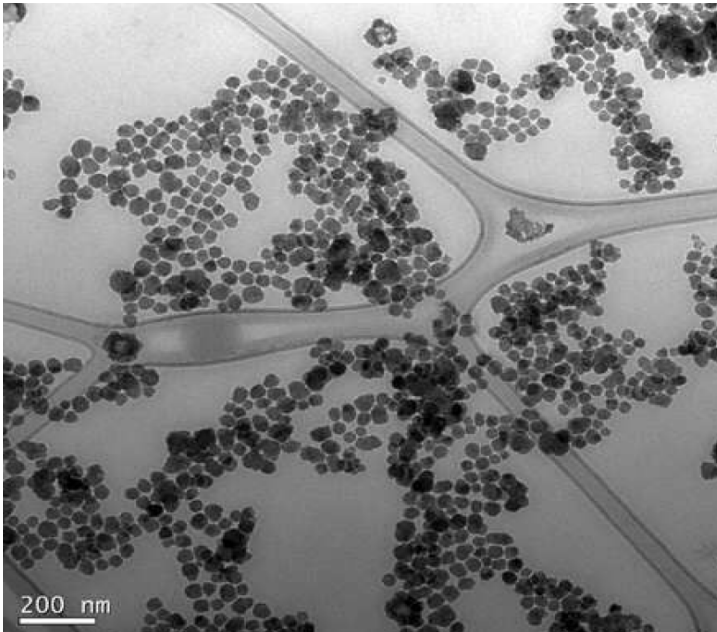
Target : Continuous process, Improved yield



- (a) SEM image of the exfoliated MoS₂ nanosheets placed on an anodic aluminum oxide (AAO) membrane;
- (b) TEM image of the exfoliated MoS₂ nanosheet; the inset shows the selected area electron diffraction (SAED) pattern for the MoS₂ nanosheet;
- (c) High-resolution TEM image showing the single crystalline structure without defects.

Graphene/Cu nano-partice (Nanocomposite)

Result: Metal particles are uniformly distributed on graphene within a short time

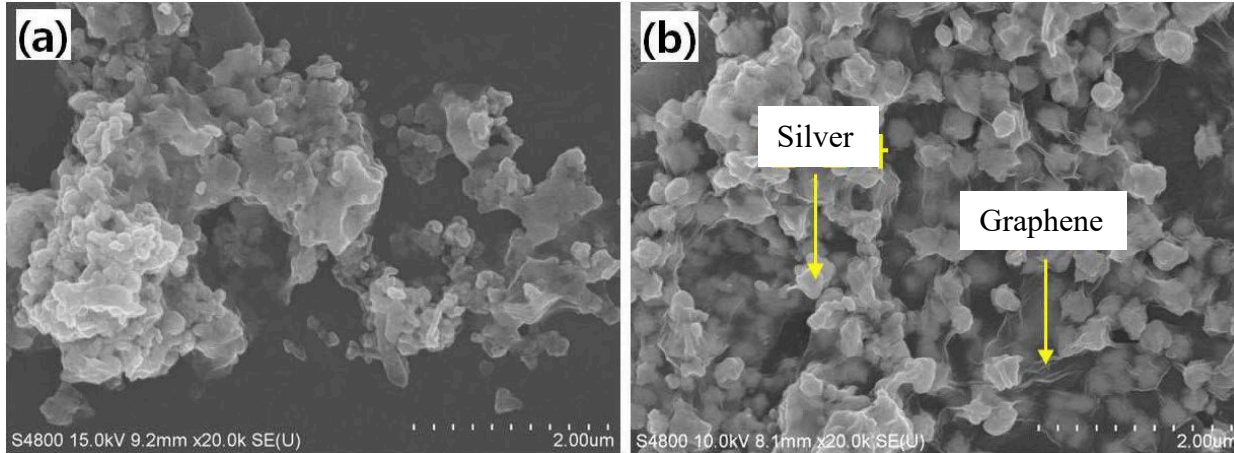


(a) : **Tank type**, Size = 50 nm, RT = 120 min (b) : **LCTR**, , Size = 10 nm, RT = 15 min

<Graphene/Cu>

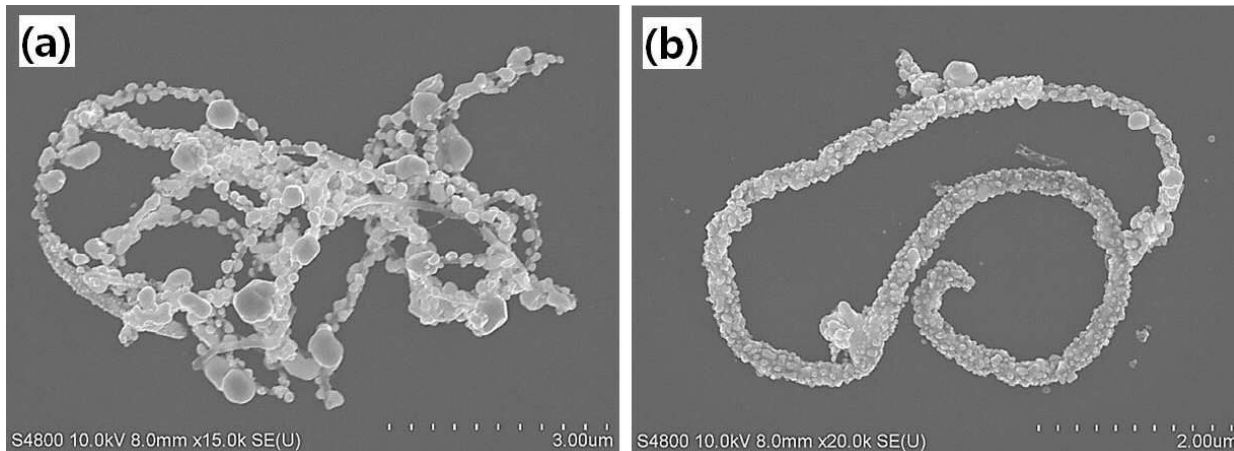
Carbon Nano-composite (Reduction)

Result: Synthesis of Silver Particles with Uniform Diameter and Preparation of Carbon Nanocomposites



(a) : Tank type
(b) : LCTR

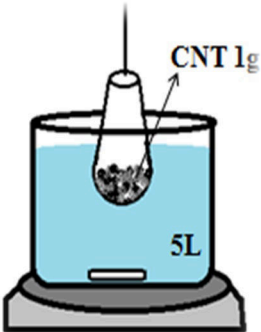
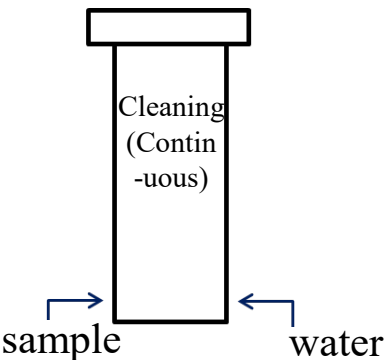
<Ag-Graphene : Uniform and not agglomerate>



(a) : Tank type
(b) : LCTR

<Ag-Nano fiber : Uniform >

CNT washing

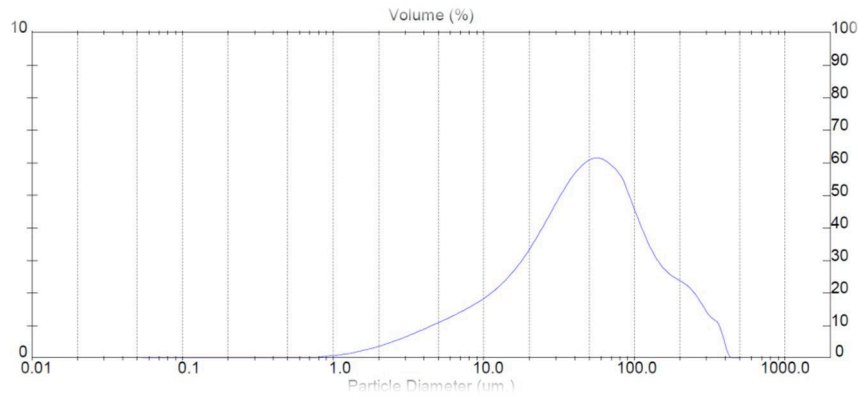
Contents	Dialysis process	Laminar Reactor
Diagram	 <p>A diagram of a dialysis process. It shows a beaker containing 5L of water. A dialyzer is suspended in the water, containing 1g of CNT. The dialyzer is connected to a tube that goes out of the beaker.</p>	 <p>A diagram of a laminar reactor. It shows a vertical tube with a cap at the top. The text 'Cleaning (Continuous)' is written inside the tube. Arrows indicate 'sample' input on the left and 'water' input on the right.</p>
Processing Time (h)	168	1.66
Consumption of water (L)	70	4
Production Process	Non-continuous	Continuous
pH values after washing	6	6

* Saving the processing time **by 99%**

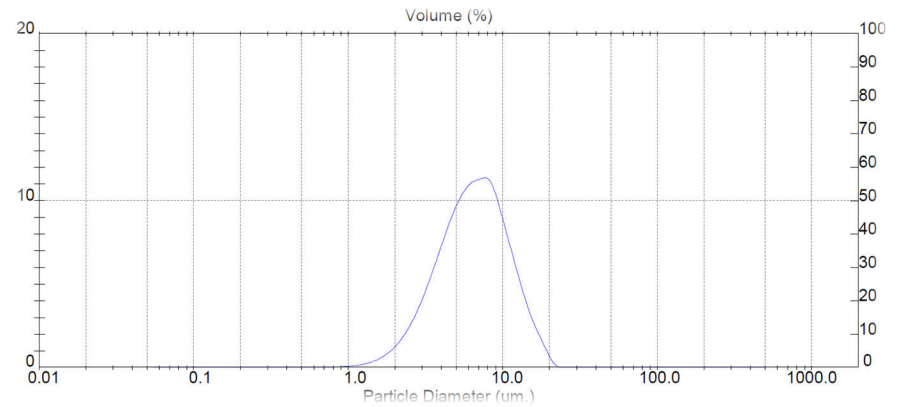
* Reduce the consumption of water **by 94.2%**

Ni powder (Hydrothermal)

Contents	Batch	LCTR
Reaction Time (h)	2	0.6
Particle Size (μm)	70.93	7.19
span	3.418	1.726
Production process	Non-continuous	Continuous



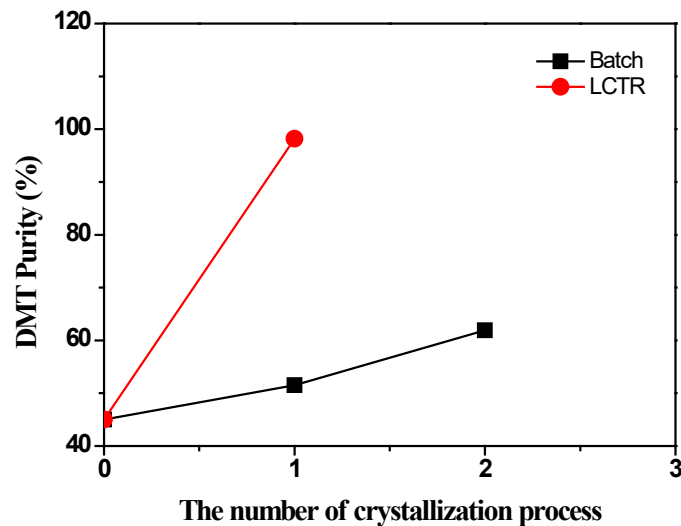
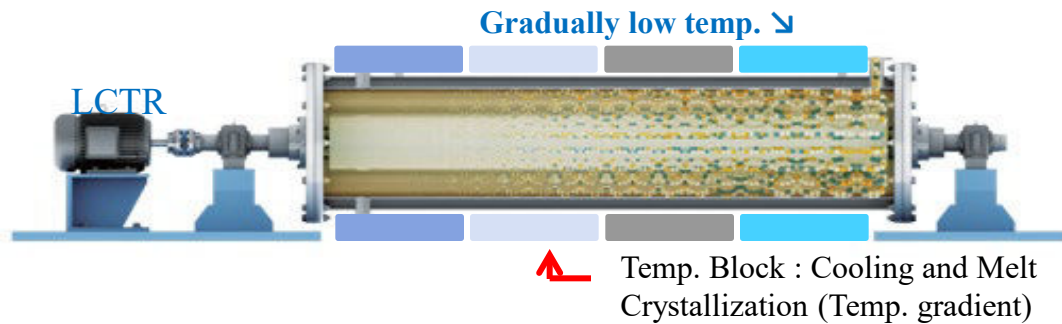
Batch reactor



LCTR

Dimethyl terephthalate (Melt crystallization)

Target : Isomer separation, Purity improvement (over 95%)

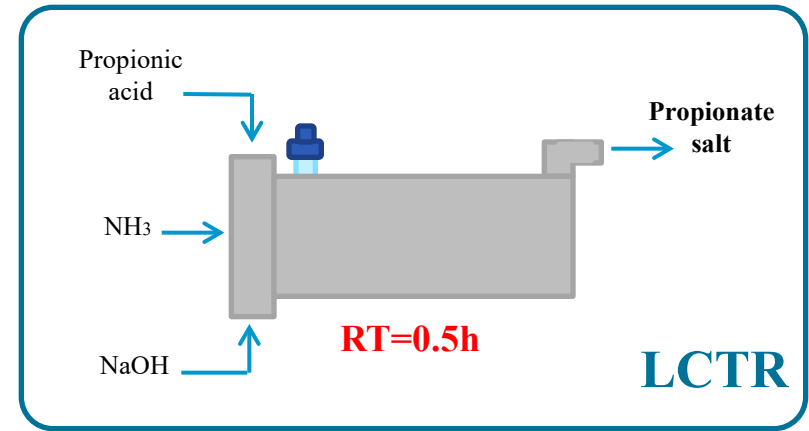
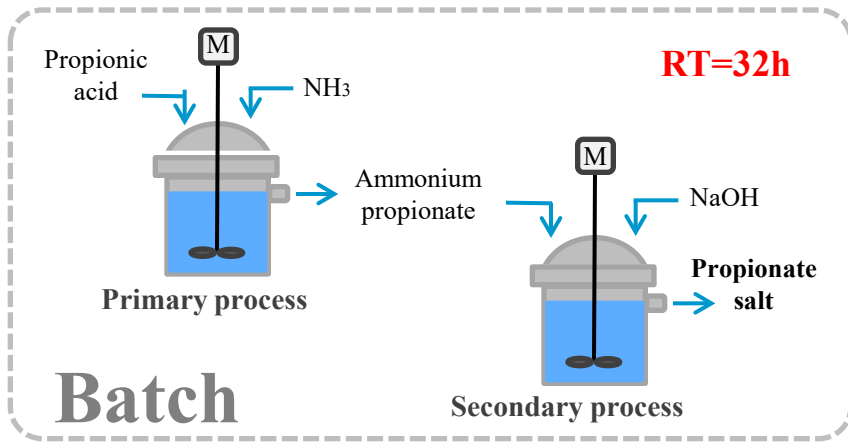


Purity change by the number of crystallization (%)

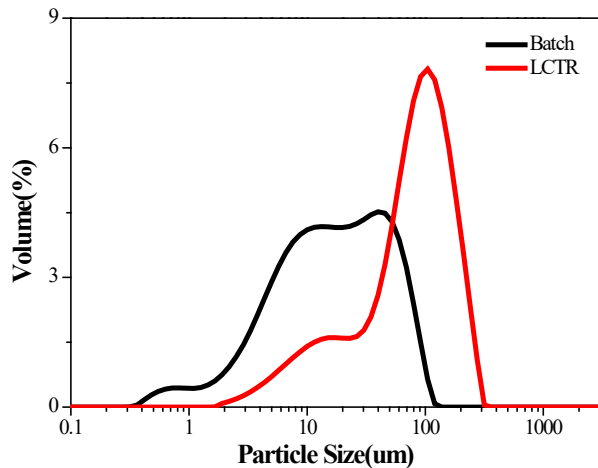
Number of repetitions	Batch	LCTR
Raw sample	45	
1 st	51.5	98.2
2 nd	61.9	

Propionate salt (Liquid + Gas, Crystallization)

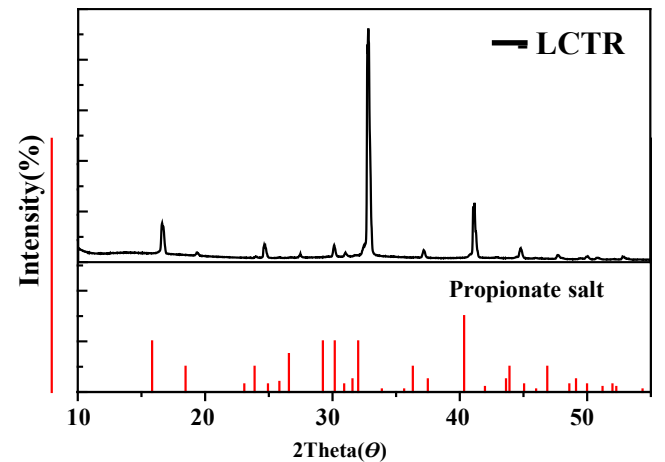
Target : Continuous process, Uniform particle size



◆ PSA



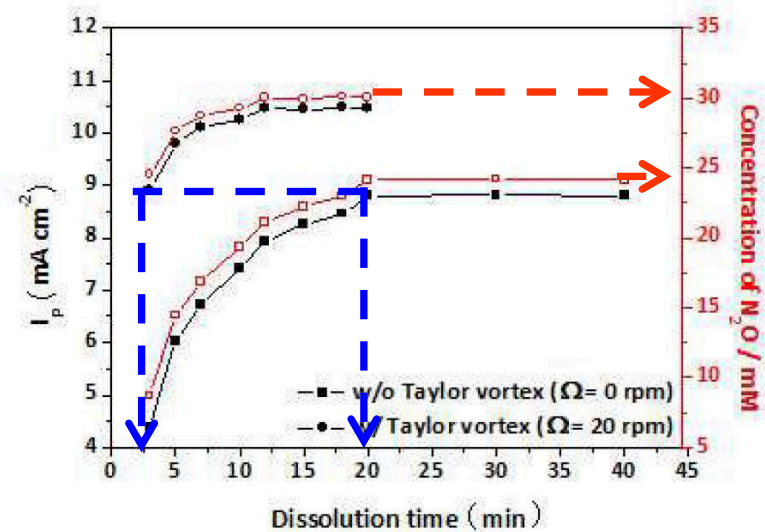
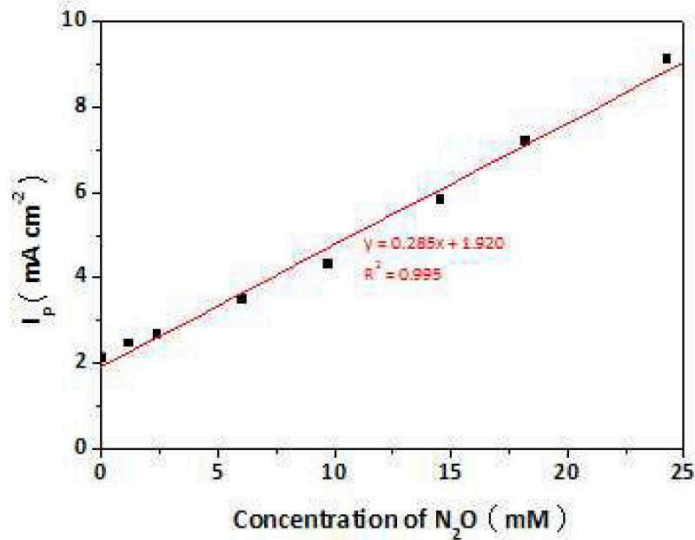
◆ XRD



N₂O Reduction (Electrolysis)

Result: Gas decomposition simultaneously reduce process time , Increase efficiency
Gas and electrolyte mixing

< Apply constant voltage or constant current inside and outside the reactor >

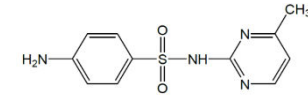


Division	Tank type	LCTR	Comparison
Reaction time (min)	20	2.5	8x increase
[N ₂ O] (mM)	23.8	30.1	23.9 % increase

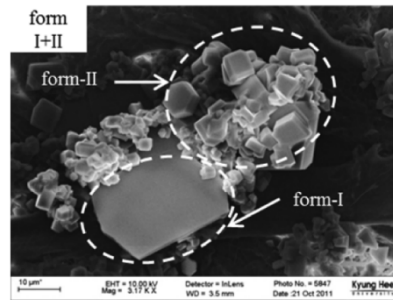
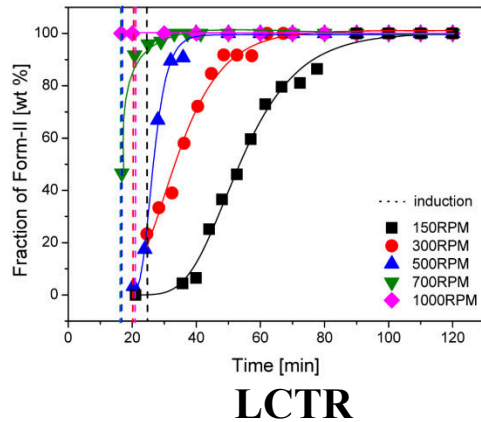
Pharmaceuticals (Drowning-out crystallization)

Target : Reduce cost

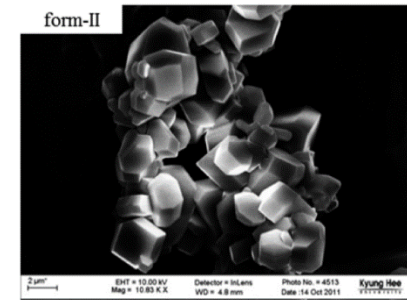
SMZ (Sulfamerazine)



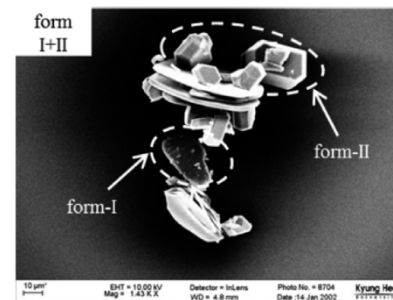
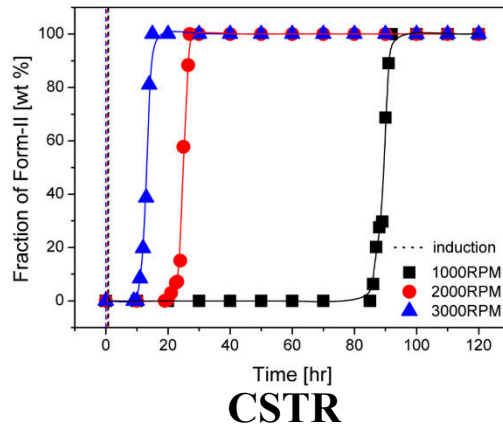
	CSTR	Laminar Reactor
Time	93 hours	20 min



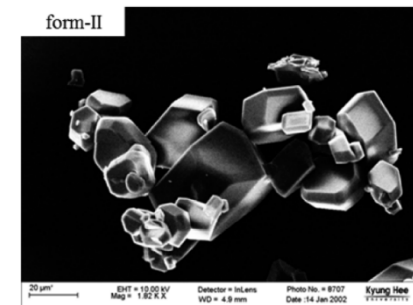
LCTR - 10min



LCTR - 20min



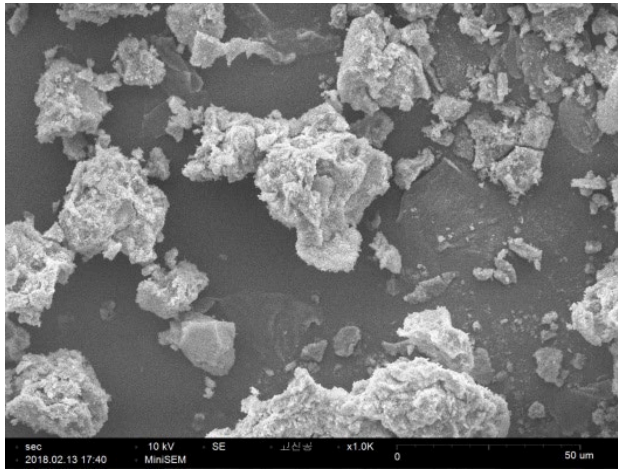
CSTR - 90 hr



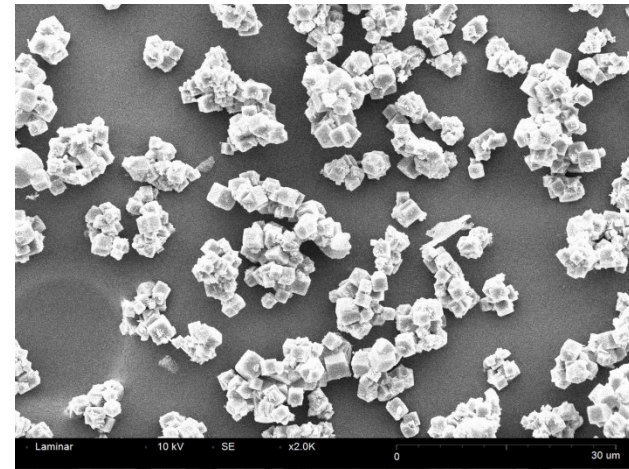
CSTR - 93 hr

Pharmaceuticals (Hydrothermal)

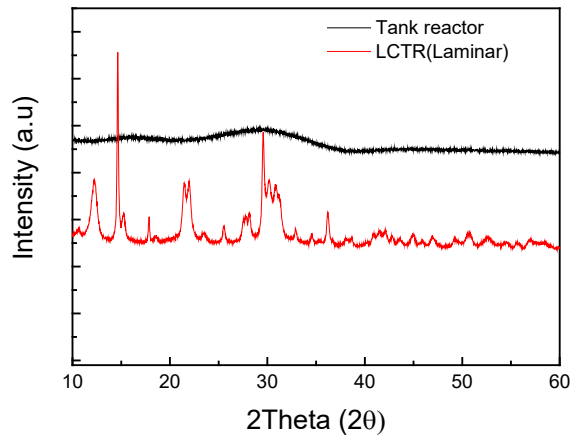
Target : Amorphous → Crystal (cubic)



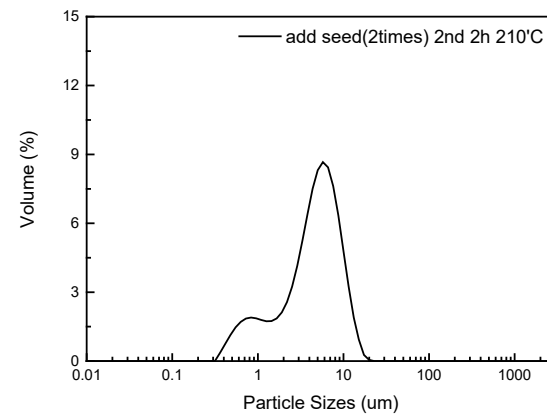
[Tank type reactor]



[LCTR reactor]



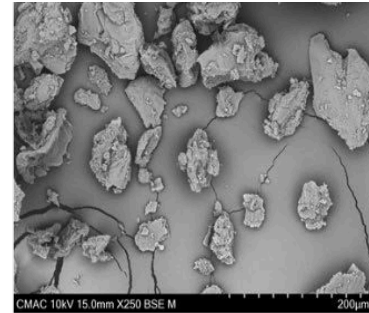
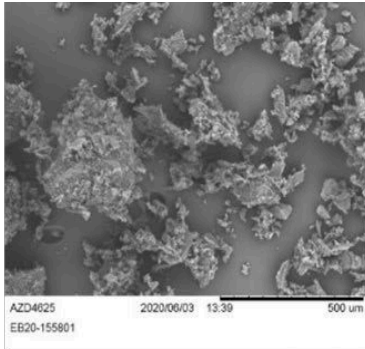
[XRD]



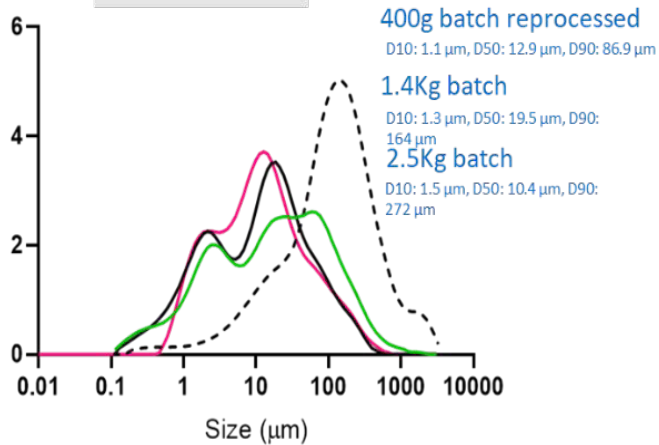
[Particle size distribution]

Pharmaceuticals (AstraZeneca)

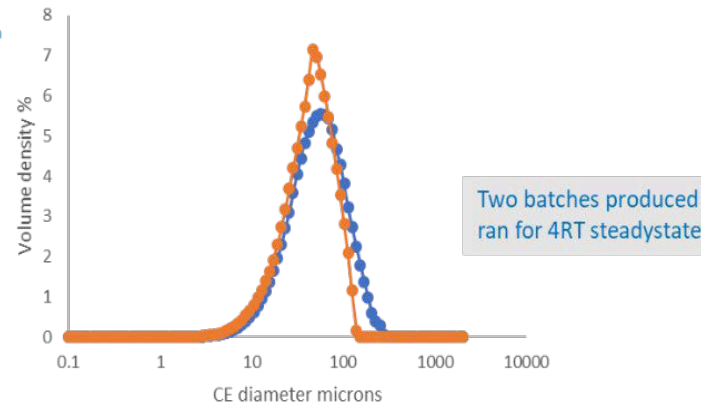
Target : Consistent product with improved flow ability, particle size, and span



Batch Process



Continuous process Laminar

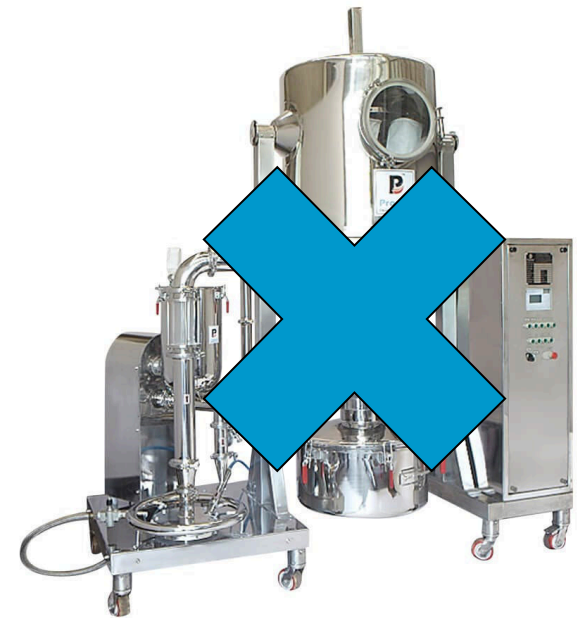
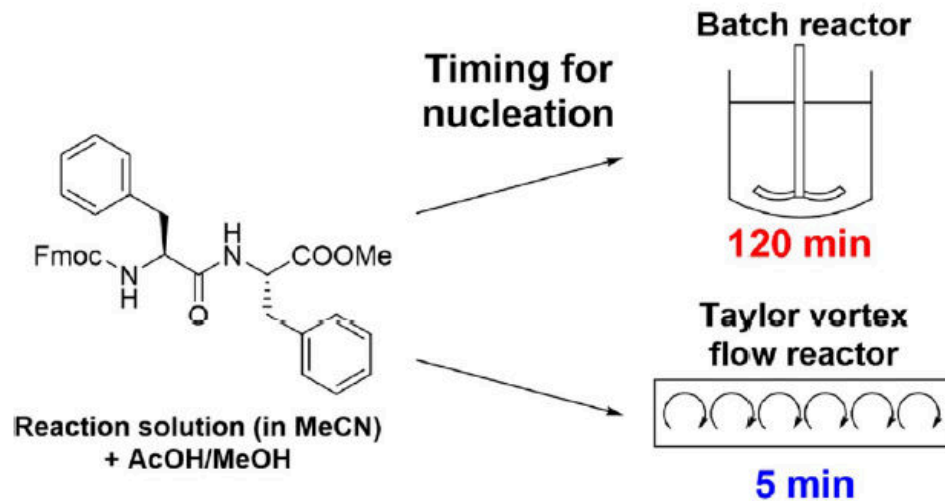


Pharmaceuticals (Shionogi)

Target : Particle size control

Advantages

1. Reduces nucleation time by a factor of 24
2. Enables the production of particles smaller than 10 μm , eliminating the need for a milling process



Jet mill

Target : Improve Nicotinamide Mononucleotide (NMN) delivery efficiency and bioavailability

Liposome Results

1. **Average Particle Size: 125.2 to 184.9 nm**
2. **Stability: Retained over 80% of its content after 180 days of storage**

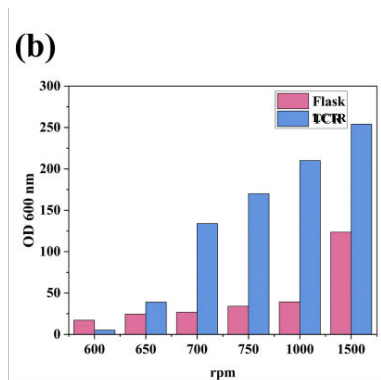


Fig 1. Comparison of liposomes produced using LCTR and flask according to rpm change

(Optical Density(OD) at 600 nm)

(a) 47000x, (b), (c) 65000x

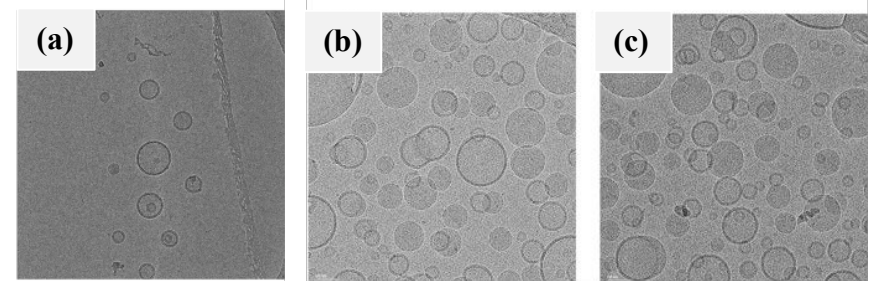


Fig 2. LCTR (a) 750 rpm, (b) 1000 rpm, (c) 1500 rpm

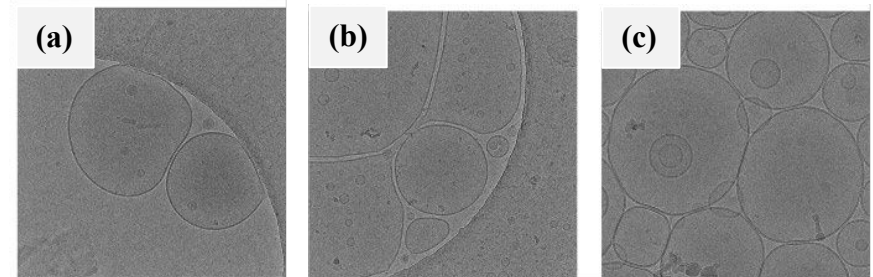


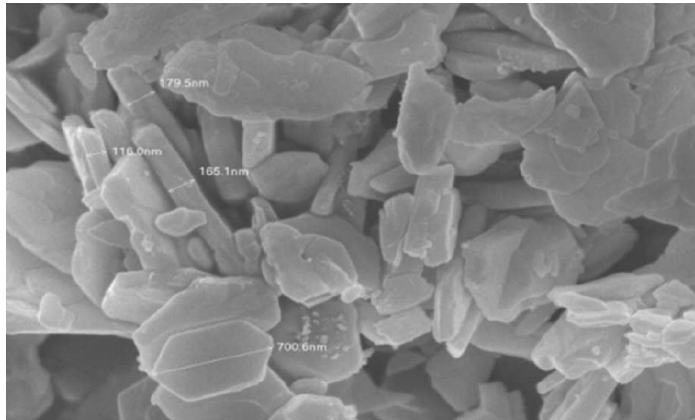
Fig 3. Flask (a) 750 rpm, (b) 1000 rpm, (c) 1500 rpm

Remaining NMN (%)	30 days	90 days	180 days
In aqueous solution	0.321 ± 0.0651^a	0.259 ± 0.520^a	0.213 ± 0.323^a
600 rpm	84.9 ± 0.372^b	68.3 ± 1.96^c	55.8 ± 1.37^d
750 rpm	85.9 ± 0.554^b	80.9 ± 1.32^c	80.2 ± 0.524^c
1000 rpm	90.3 ± 0.520^f	87.6 ± 0.121^g	87.0 ± 0.662^g
1500 rpm	91.6 ± 0.323^f	89.8 ± 0.233^f	89.4 ± 1.44^f

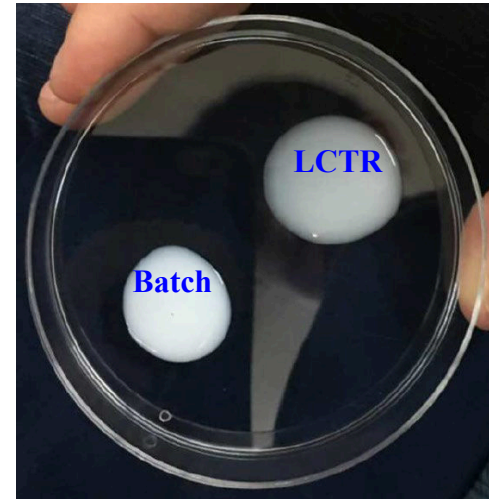
Fig 4. Stability Analysis of LCTR liposomes

Zinc pyrithione (Cosmetic)

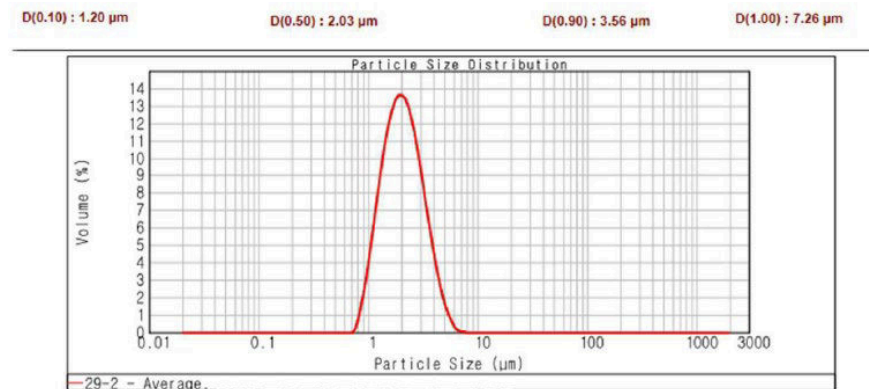
Result: Narrow particle size distribution, improved dispersion transparency



<Length : 3~7 μm , Thickness : 0.1 μm >



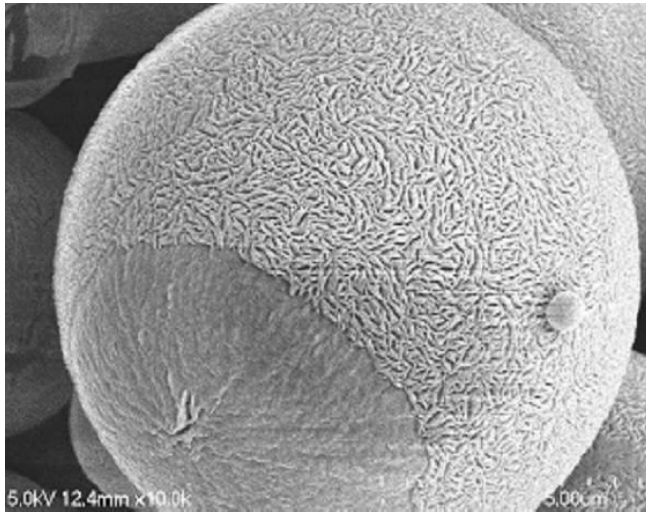
< Applicable to transparent products >



< Size reduction from 5 μm to 2 μm (provides wider surface area for sterilization activity) and uniform distribution >

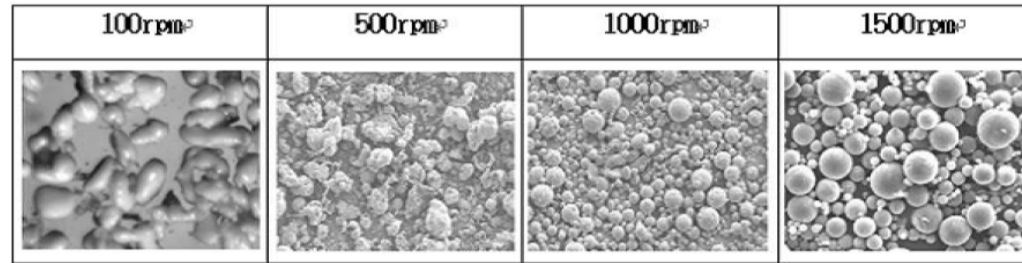
Biodegradable polymer microparticle (Bio, Pillar)

**Result: Easy to control the size and shape of biodegradable polymer microparticles,
Easy to mass production,**

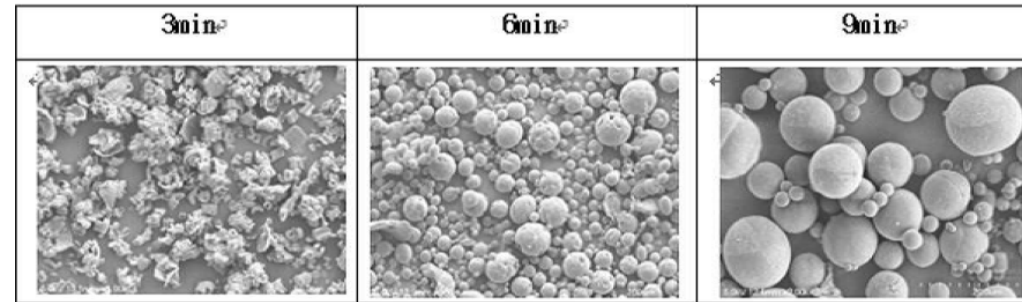


<Particle shape, 8 μ m>

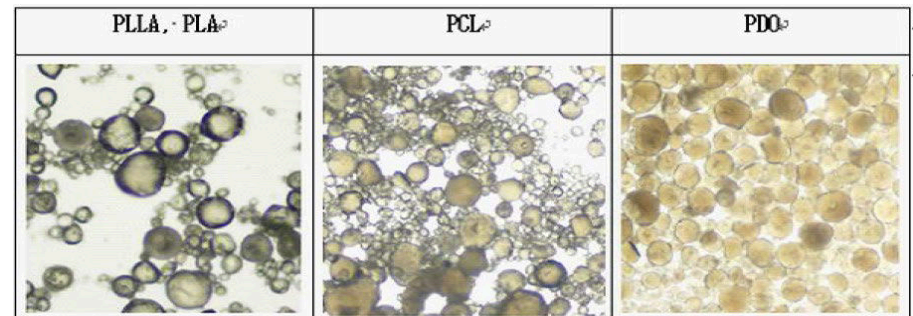
<Agitation speed>



<Reaction time>



<Polymer type>



* The results of this study are excerpted from Ultra-V

Food additive (Drowning-out crystallization)

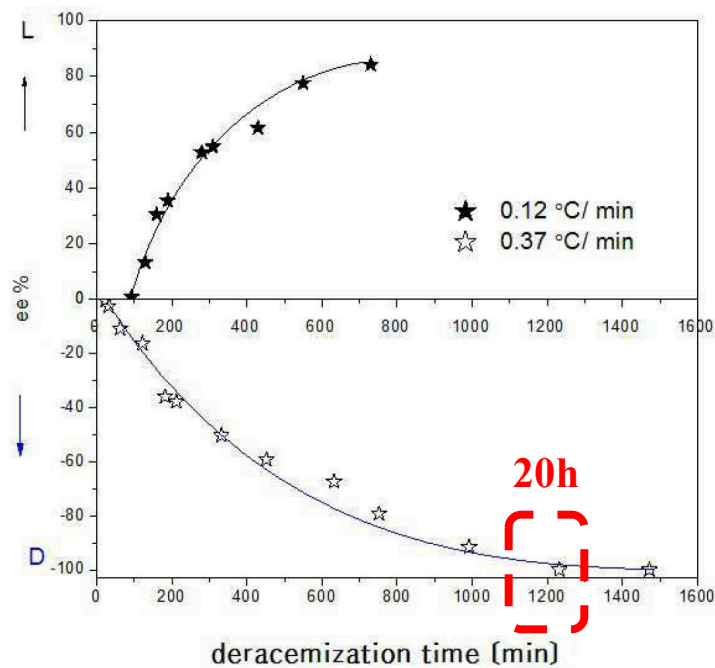
GMP

Contents	Batch	LCTR
Time	8~9 h	5 min
Energy consumption (TOE/ton)	25,200	15,200
Purify (%)	97	99.9
Crystallinity (%)	90	98
Volume (m ³)	21.0	0.27
Production process	Non-continuous	Continuous
Raw material cost on purification (USD/kg)	16	7

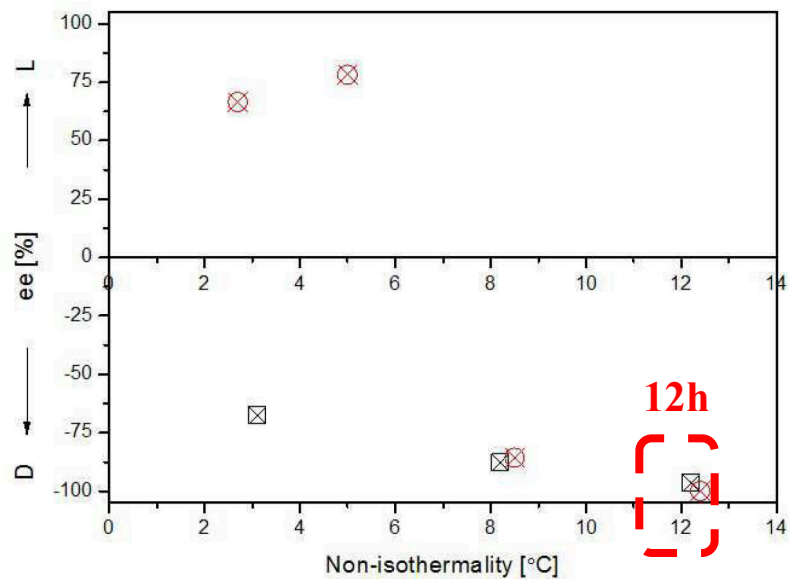
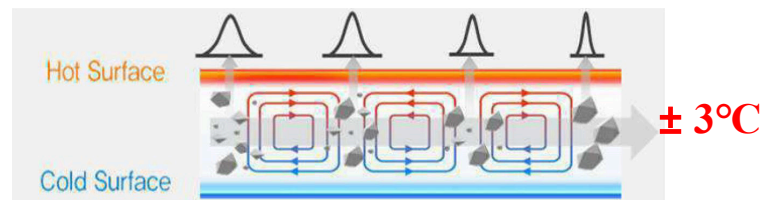


Enantiomer separation (Deracemization)

Result: Reduced separation time (150 h \rightarrow 12 h)



<Isothermal – Taylor flow>



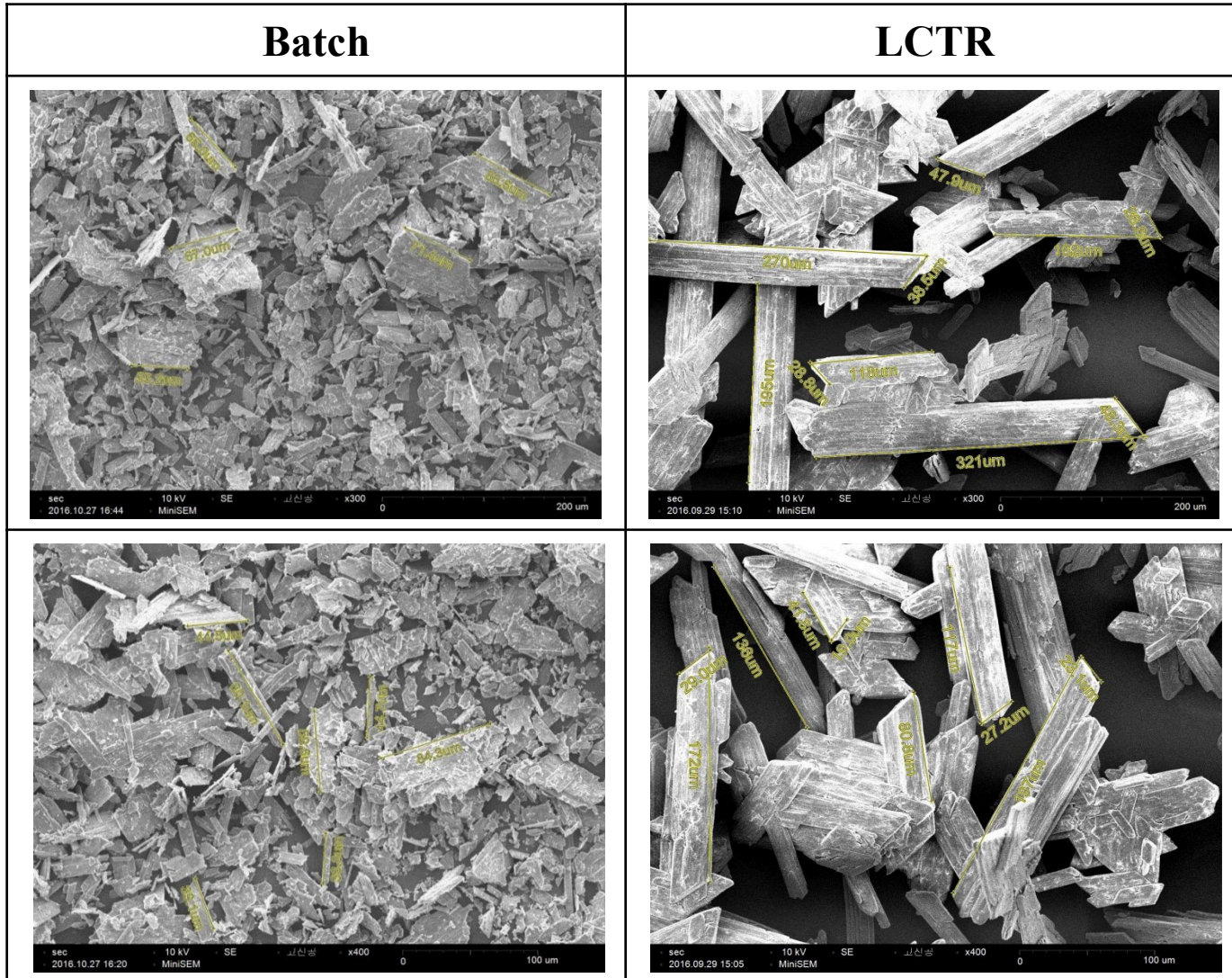
<Non-Isothermal – Taylor flow>

* ee : enantiomer excess value

* This study is an excerpt from Professor Kim Woo-sik of the Kyung Hee University.

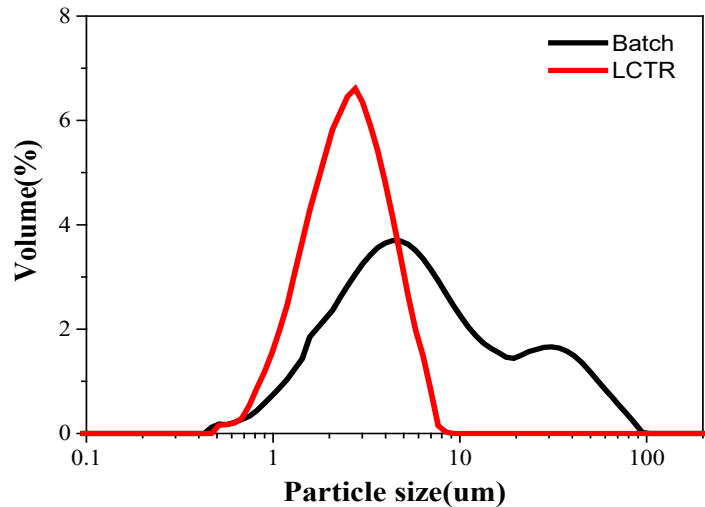
Calcium sulfate (Reaction crystallization)

Target : Particle shape control



Cobalt hydroxide (Reaction crystallization)

Target : Uniform particle size, Below 10 um

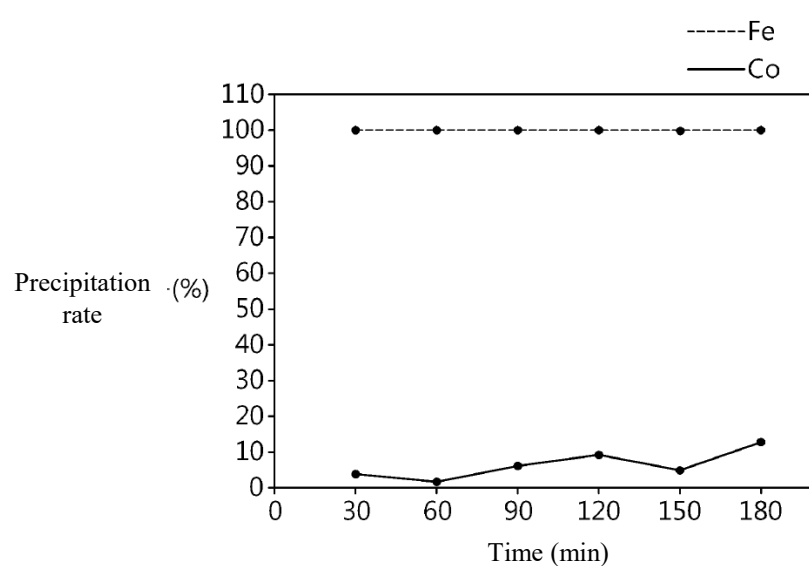


	Batch	LCTR
Particle Size	11.6	2.7
Uniformity*	5.8	1.6

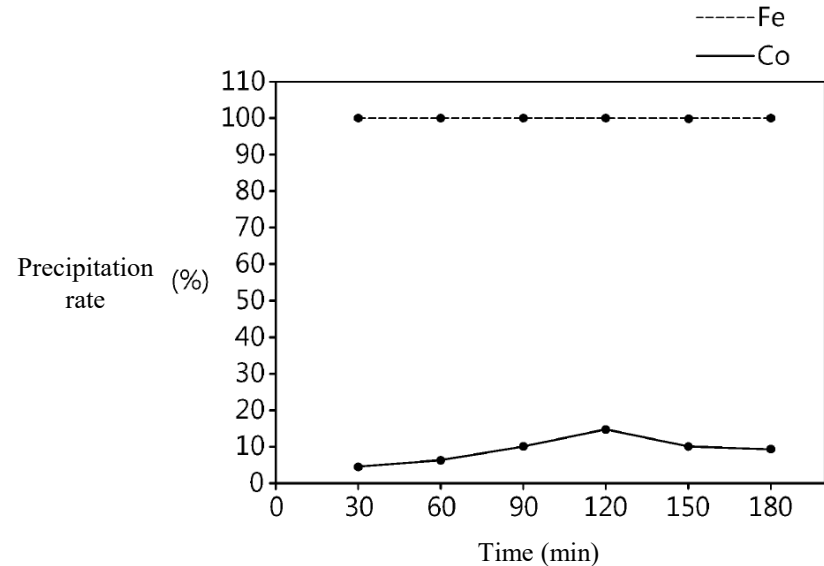
Uniformity(span) * : $(D_{90}-D_{10})/D_{50}$, The lower the value, the more uniform

Metal separation (Reaction crystallization)

Goal: Separating Fe / Co and crystalline particles



< Co ; 3 g/L, Fe : 30 g/L, pH 3.22 >



< Co ; 90 g/L, Fe : 9 g/L, pH 1.91 >

< Filtering Time (mL/min) >

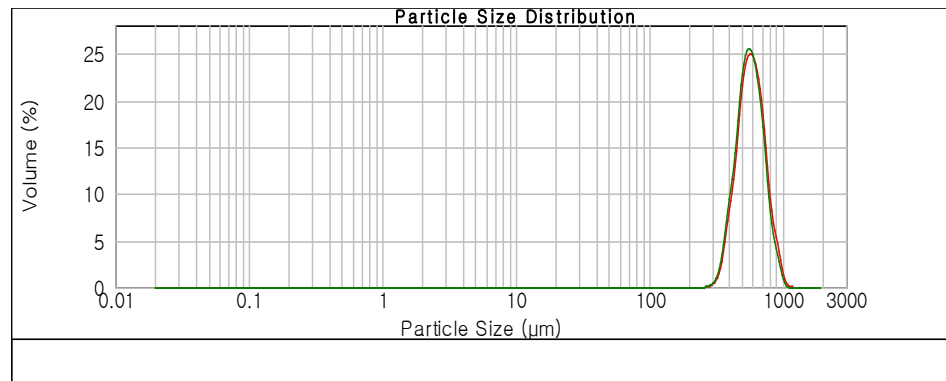
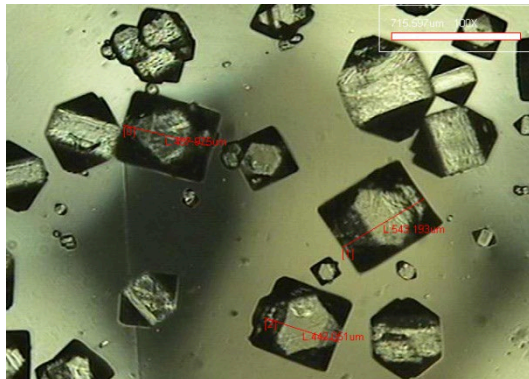
Batch	LCTR
2.4	64.5

32x increase

Recycling (Reaction crystallization)

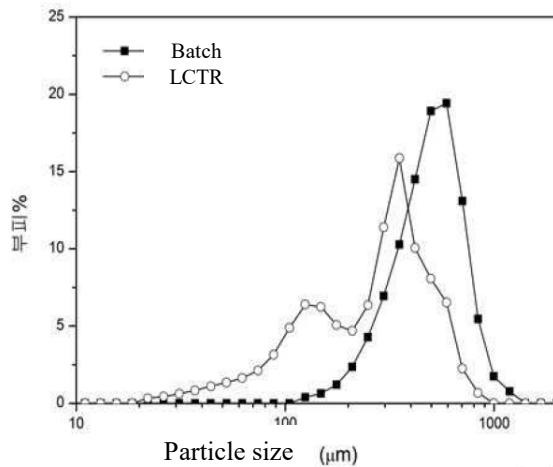
◆ $\text{NH}_4\text{H}_2\text{PO}_4$

Contents	Batch reactor	LCTR
Reaction Time (h)	3	0.5
Particle Size (μm)	300	500
Purity (%)	99.5	99.5
Recovery Rate (%)	80	85
Production process	Non-continuous	Continuous

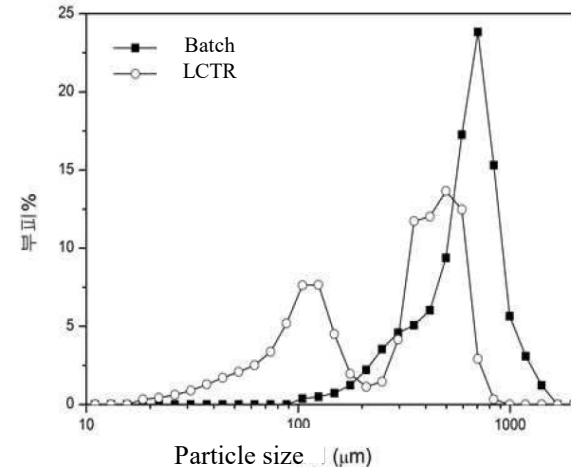


CO₂(g) recycling (Reaction crystallization)

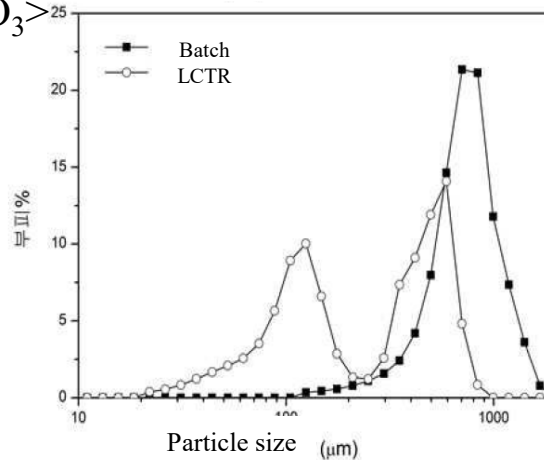
Goal: uniform particle size distribution, increase particle size



< 30 % KHCO₃ >





Particle size (μm)
< 35 % KHCO₃ >



< 40 % KHCO₃ >

OLED (Cooling + Drowning-out crystallization)

NPB materials

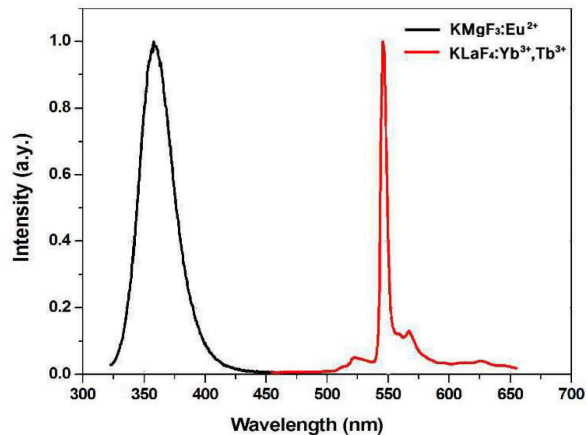
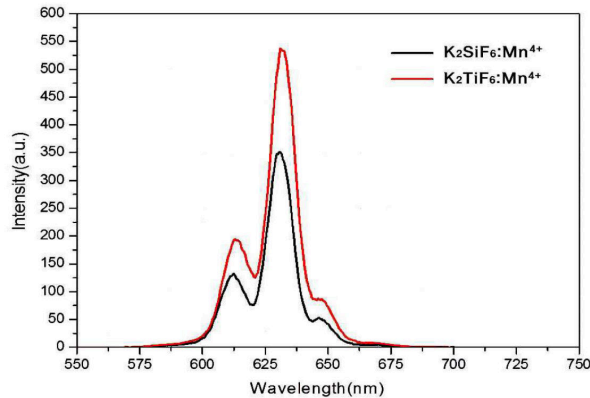
Contents	Sublimation	Laminar Reactor
Diagram		
Purification process	Dry method	Wet method
Purify (%)	99.95	99.99
Production process	Non-continuous	Continuous
Process Temp. (°C)	270~280	R.T
Pressure (Pa)	200	Atmospheric pressure
Purification Time (h)	12~24	6~12
Production Cost (USD/kg)	10,000	3,000

Phosphor (Precipitation)

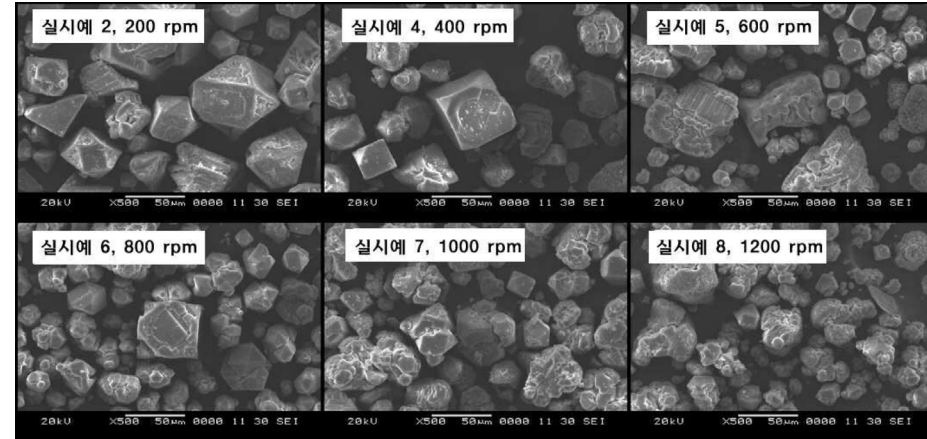
Result: Continuous mass production, safety (HF), compact scale reactor



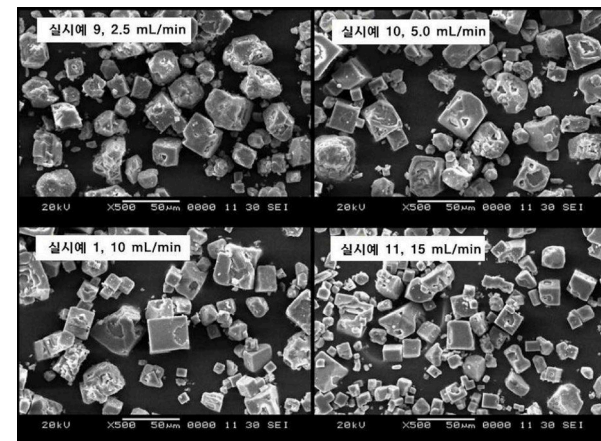
<Luminescence center wavelength>



<Particle size control>



a) Agitation speed



b) Feeding rate

Dissolution

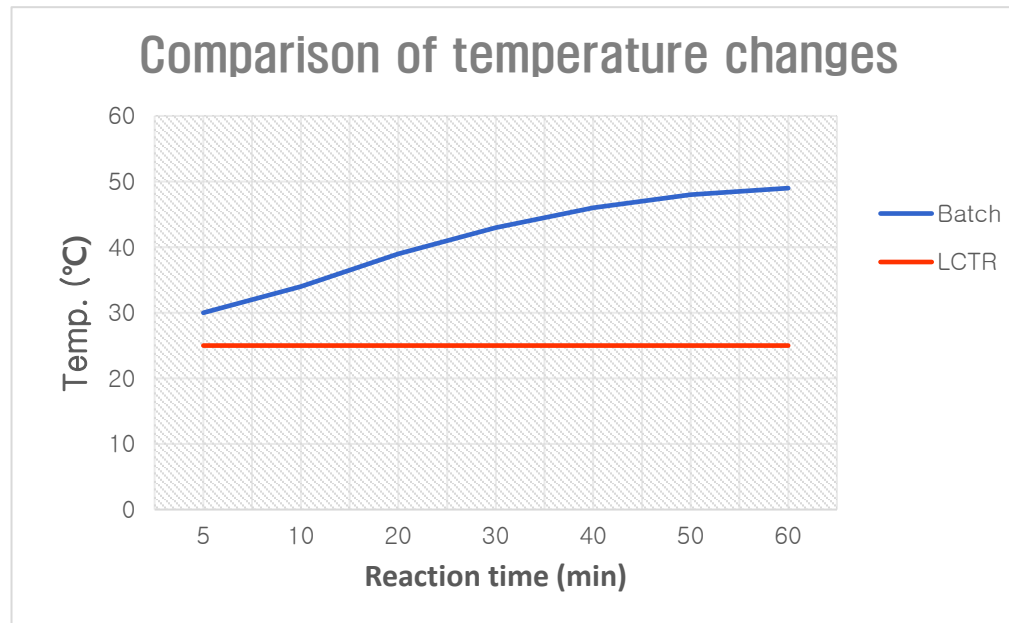
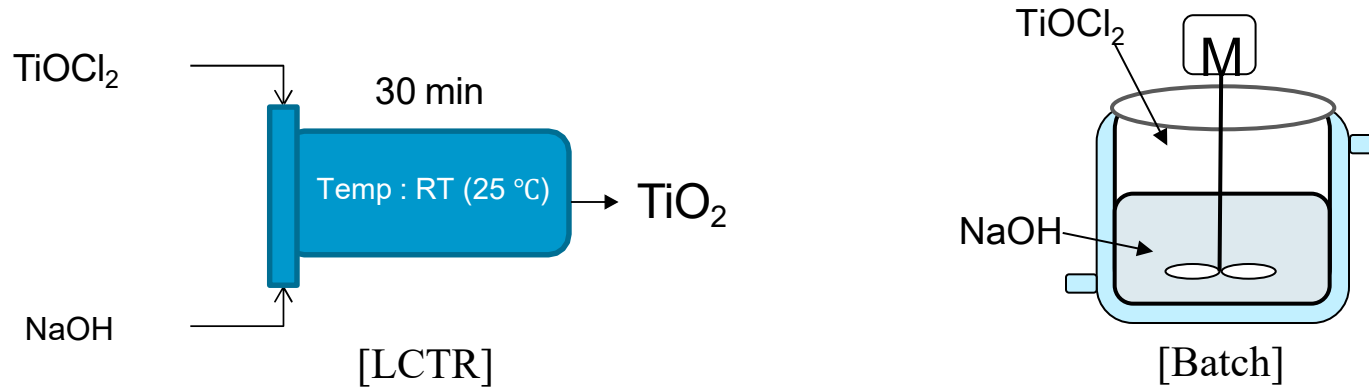
Target : Reduction of dissolving time, Insoluble powder dissolved



Division	Batch	LCTR
Production process	Non-continuous	Continuous
Dissolution time (h)	24	6

Exothermic reaction

Target : Temperature control, safe operating





Thank you !!

Inorganic compound (Reaction crystallization)

1. Potassium carbonate (K_2CO_3)



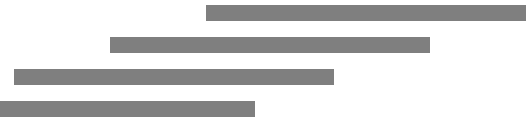
	Conventional	Laminar Reactor
Production Process	Evaporation	Drowning-out method
Recovery Rate (%)	60	80
Reaction Time (h)	3	0.5
Form	5 H ₂ O	1.5 H₂O

2. Lithium carbonate (Li_2CO_3)



	Conventional	Laminar Reactor
Production Process	Evaporation	Crystallization
Purity (%)	99.5	99.5
Particle Size (μm)	100	200 and over
Reaction Time (h)	3	0.5

Re-crystallization for high-purity



1. Flame retardant: Remove chlorine

	Conventional	Laminar Reactor
Production Process	Evaporation	Drowning-out
Recovery Rate (%)	80	90 and over
Purity (%)	100	100
Concentration of chlorine ion(ppm)	1000	400 and less

2. NaI : Remove chlorine



	Conventional	Laminar Reactor
Production Process	Evaporation	Drowning-out
Particle Distribution	Non-uniform distribution	Uniform distribution
Impurity (ppm)	2000	0
Recovery Rate (%)	95	99

Re-crystallization for high-purity



3. Toner materials : Reduce heavy metals

	Conventional	Laminar Reactor
Production Process	Evaporation	Drowning-out
Recovery Rate (%)	60	90
Purity (%)	98.03	98.5
Heavy metal ion (ppm)	150	80 and less

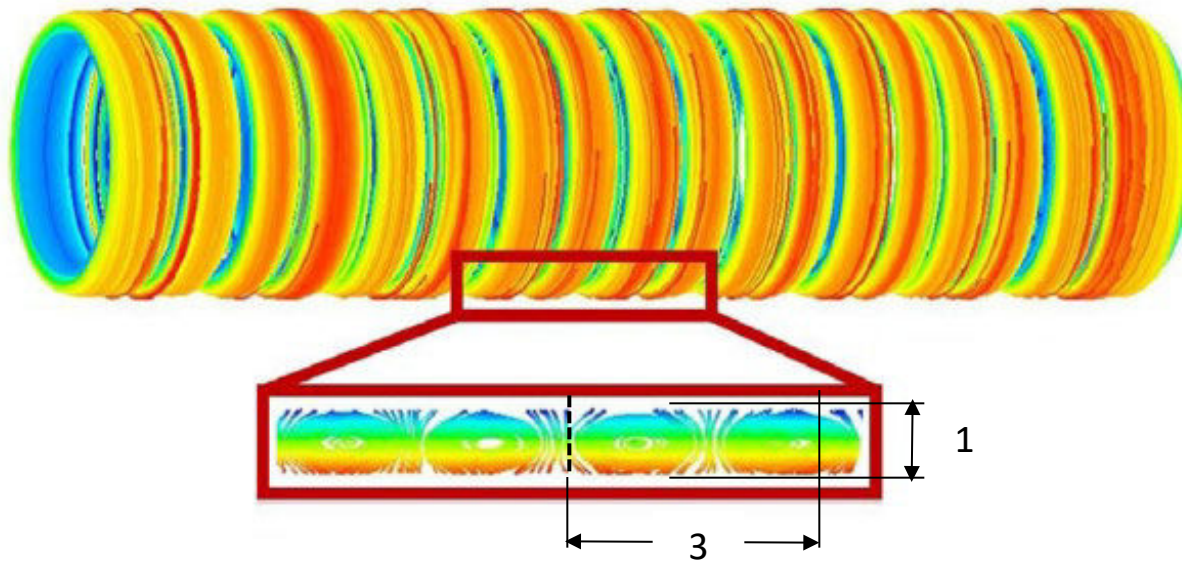
4. Barium nitrate : Reduce heavy metals



	Conventional	Laminar Reactor
Production Process	PFR	Cooling process
Recovery Rate (%)	80	85
Reaction Time (h)	4	1
Concentration of heavy metal (ppm)	10	2.5 and less

Scalability

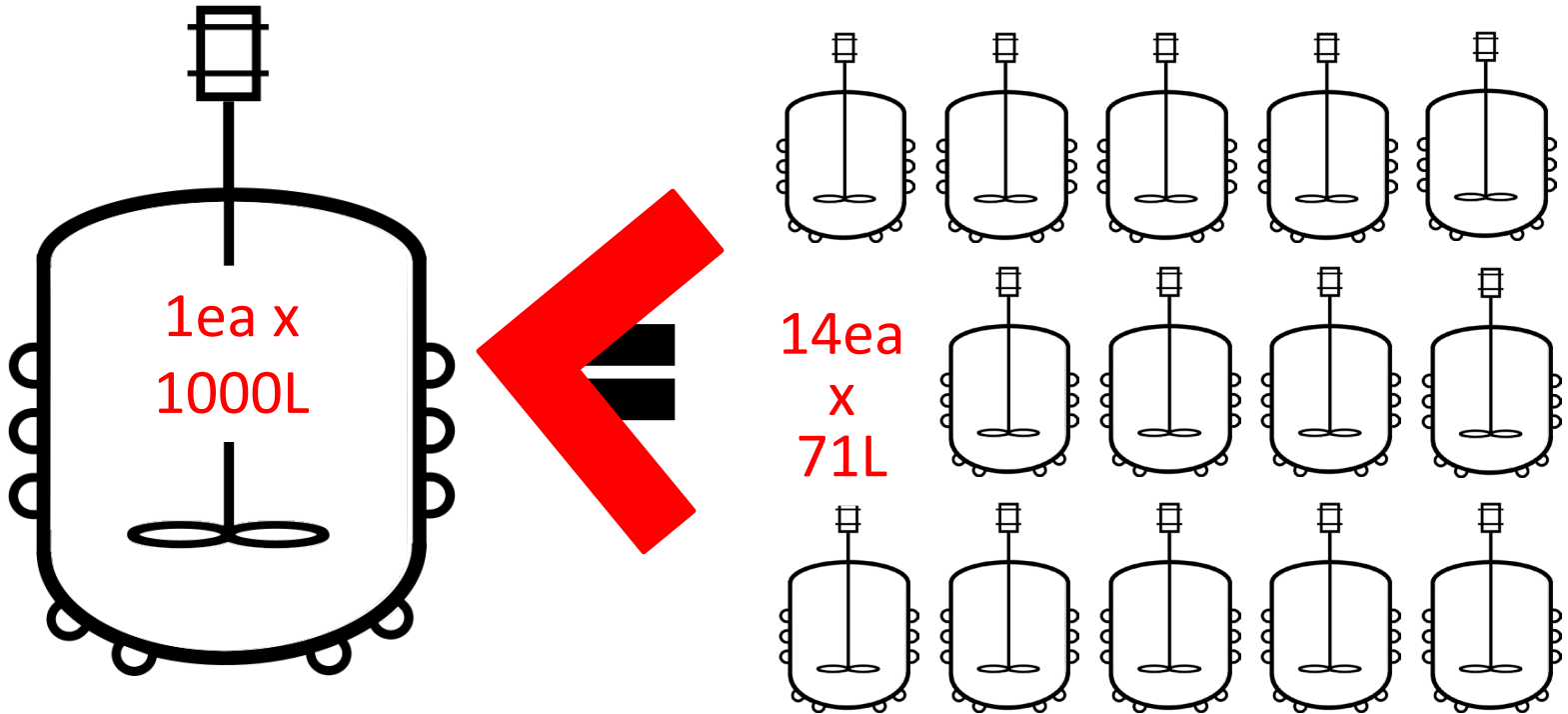
Reason for easy scale-up



1 Taylor Vortex = 1 Reactor

Scalability

Reason for easy scale-up



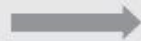
Scalability

Scalable? Scalable!

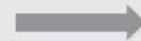
1L → 50L → 1000L scale-up



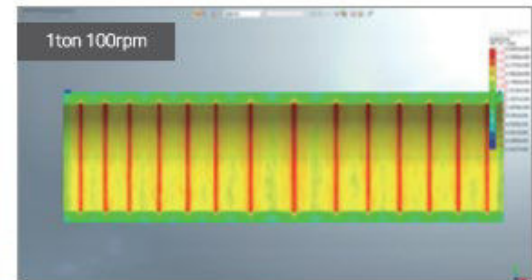
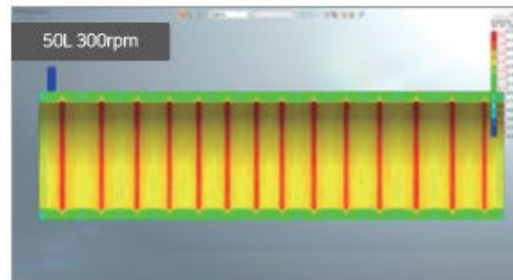
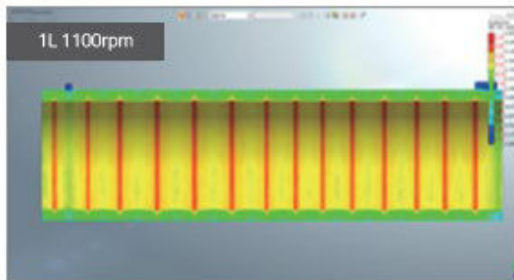
1L



50L



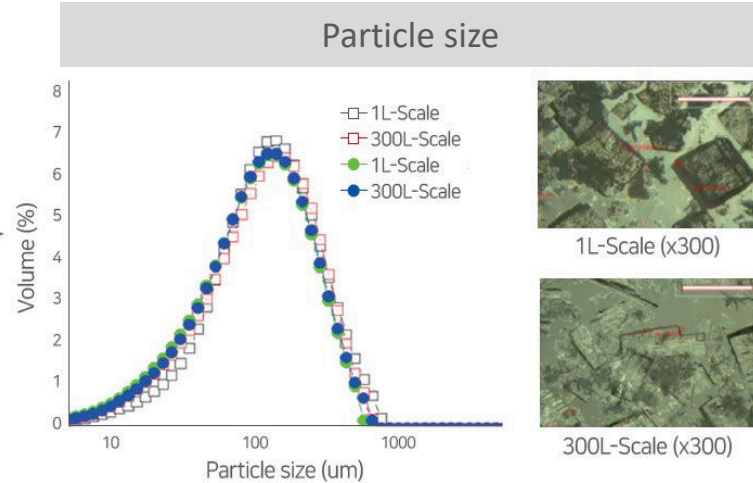
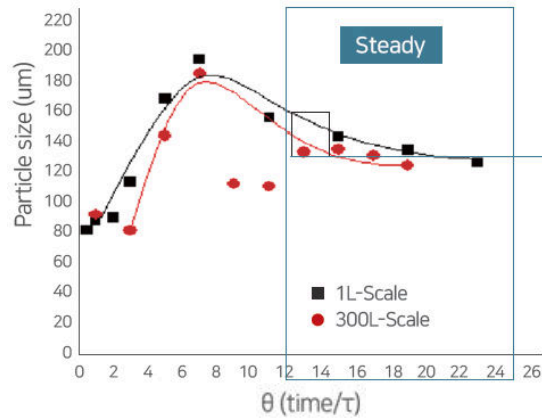
1,000L



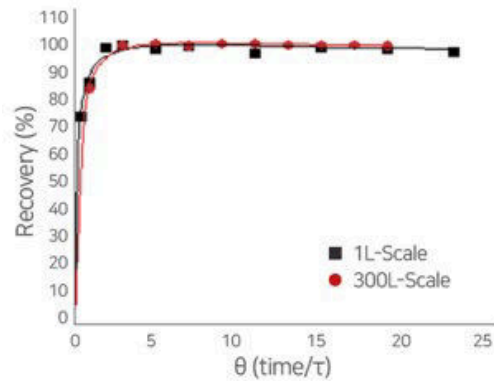
Volume (L)	Linear velocity (m/s)	Agitation speed (rpm)	The number of Taylor flow
1	4.29	1100	14
50	4.35	300	14
1000	4.58	100	14

Scalability

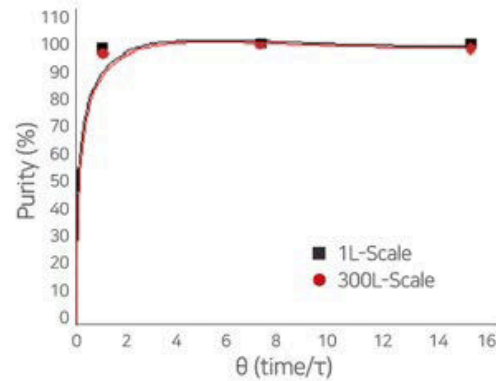
Scalable? Scalable! 1L to 300L scale-up



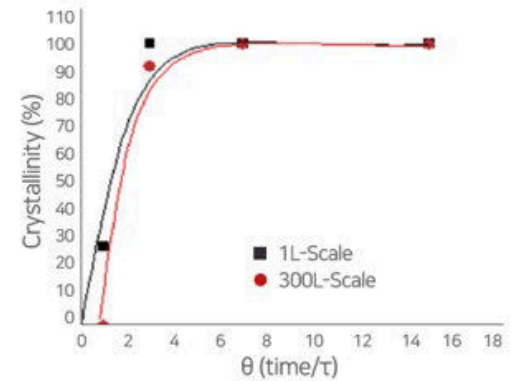
Recovery rate



Purity



Crystallinity



Scalable? Scalable!



Numerical simulation of ammonium perchlorate particles based on a population balance equation model in Taylor-Couette flow

Sung-Ho Yoon^{a,b,1}, Jang Gyun Lim^{a,c,1}, Jongpal Hong^d, Sang-Keun Han^e, Moon Ki Kim^{b,c}, Jae-Boong Choi^{b,*,2}, Tae-Rin Lee^{b,*,2}

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ARTICLE INFO

Article history:
Received 31 January 2020
Received in revised form 26 April 2020
Accepted 23 May 2020
Available online xxx

Keywords:
Ammonium perchlorate
Population balance equation
Taylor-Couette flow
Particle growth simulation

ABSTRACT

Taylor-Couette flow, multiple vortex rings, is developed by rotating a co-axial rod in a cylindrical reactor. It is helpful in applying stable shear forces to suspended particles in the fluid domain. Recently, by using the Taylor-Couette flow, various experiments were performed to prepare micro-size particles at the laboratory level. However, unlike the simple concept of particle preparation by the Taylor-Couette flow, it is challenging to predict particle growth in Taylor-Couette reactor. In this paper, a population balance equation model is used to predict the particle growth in Taylor-Couette reactor. In the fluid flow, by using a population balance equation model, physical and empirical parameters of all, physical and empirical parameters are predicted by using experimental data in a Taylor-Couette reactor. The simulation method are fully discussed. The simulation method of ammonium perchlorate particles was reliable in predicting their sizes along time. In addition, without changing the model parameters, the simulation results matched well with the experiments in the scale-up reactor. Based on the simulation results, it is expected that the suggested method can be utilized to estimate particle size distributions in various boundary and operating conditions.
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Introduction

Ammonium perchlorate is an agent used in various propellants [1]. For the best performance as an oxidizer, it is crucial to control the size and shape of ammonium perchlorate particles in chemical reactors. Related to particle growth, Taylor-Couette flow, continuously generating vortex rings, has been considered in the preparation of nano- and micro-sized materials, e.g. graphene layers [2–5], lithium nickel cobalt manganese oxides [6,7], multi-walled carbon nanotubes [8], etc. Consequently, the Taylor-Couette

flow based reactors can be utilized in the preparation of ammonium perchlorate particles with micro-sized diameters as well. However, only by experiment, it is challenging to optimize operating conditions during the processes of aggregation and breakage in the micro-mixing environment.

In this reason, it is needed to use computational methods for predicting particle growth in fluid flow. There are several previous studies for estimating particle size in the Taylor-Couette flow by using computational methods. Wang et al. [9] investigated the shear rate effect on the aggregation and breakage of latex particles in laminar Taylor-Couette flow. Marchisio et al. [10] simulated turbulent precipitation in a reactor based on the Taylor-Couette flow. Rudman [11] studied fluid flow and particle dispersion in the wavy regime of the Taylor-Couette flow. The previous studies were focused on simulating the fluid flow patterns in the given reactors. Also, the particle growth was predicted by determining physical and

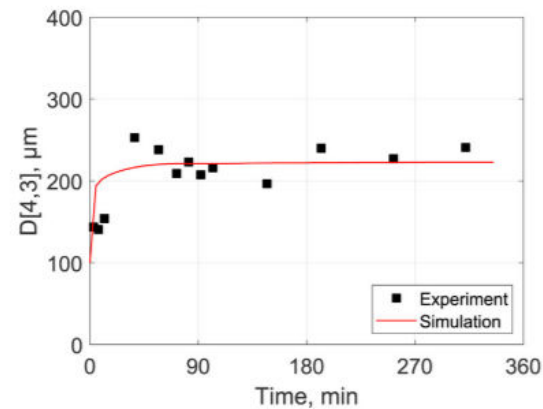


Fig. 13. Particle growth simulation results for 1 L Taylor-Couette reactor.

“The simulation method predicted the experimental data of 10 L reactor as well”

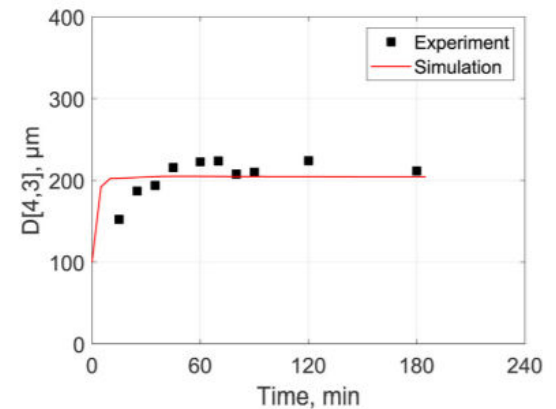


Fig. 14. Particle growth simulation results for 10 L Taylor-Couette reactor.

Abbreviations: PBE, population balance equation; QMOM, quadrature method of moments; PSD, particle size distribution.
¹ Corresponding authors.
E-mail addresses: bocong13@skku.edu (J.-B. Choi), taerinkoo@skku.ac.kr (T.-R. Lee).
² These authors are equally contributed on this work.

Scalability

Scalable? Scalable!



Process Development and Scale-Up of Advanced Active Battery Materials



Scalability Evaluation
from 1L → 10L → 40L

Ozge Kahvecioglu Feridun (PI)

Argonne National Laboratory
Project ID: BAT167

June 11, 2019

This presentation does not contain



1L TVR – 10 g/hr
(1cm reaction zone)



10L TVR – 100 g/hr
(2cm reaction zone)



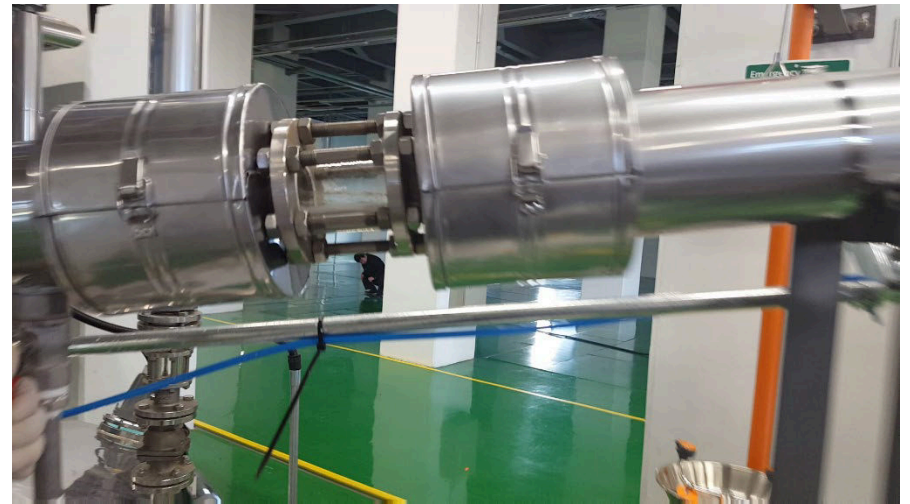
40L TVR – 400 g/hr
(2.5cm reaction zone)

Specifications

1. Working Volume : 1000 L
2. Working Temp : 40~60 °C
3. Reaction time : Min 1 h
4. Agitation speed : Max 300 rpm
5. pH : 10.8~12.8
6. Materials : SUS316L



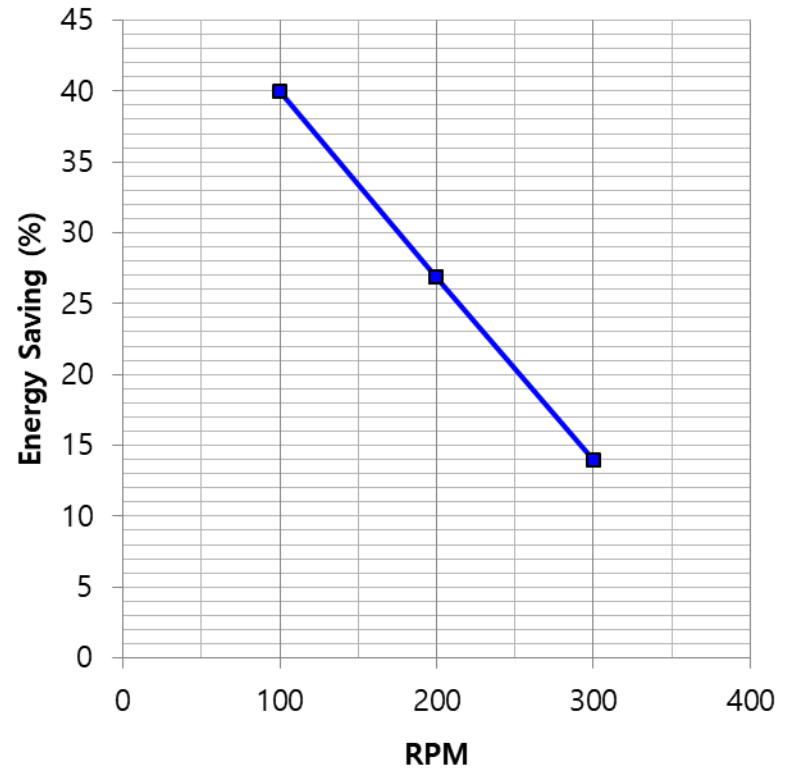
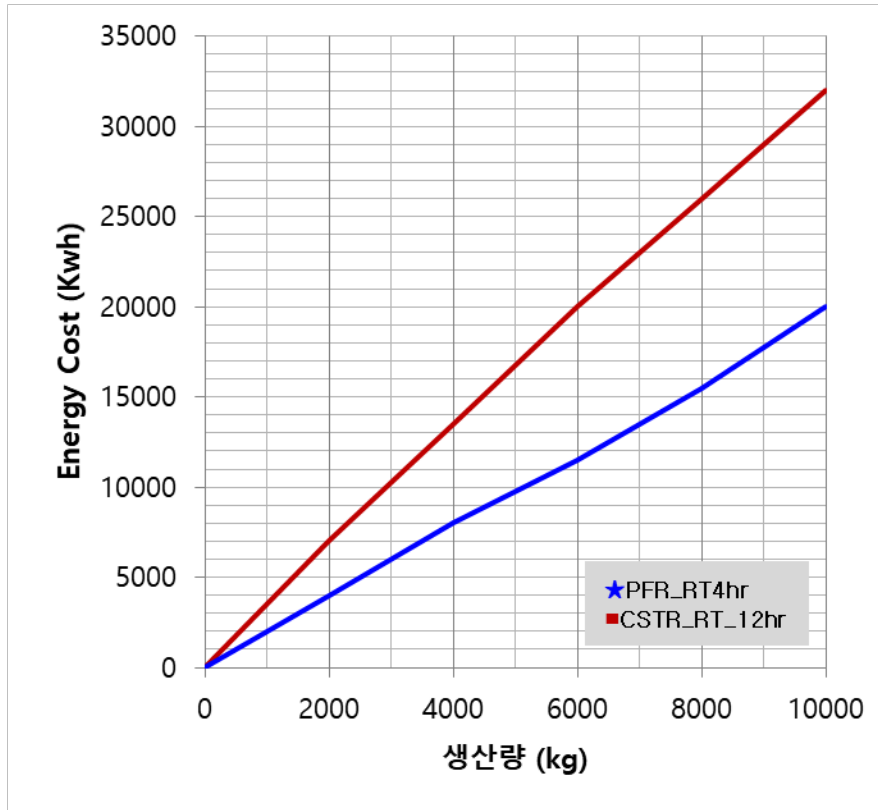
Economics



Economics

Standard : 250 tone/yr NMC prodction

Division		LCTR (kW)	CSTR (kW)
Pump	Metal Pumping	1.15	0.39
	NaOH Pumping	0.76	0.25
	NH4OH Pumping	0.15	0.05
Heat Exchanger	Heating line	0.55	0.17
	Reactor	1.69	0.85
	Metal	2.81	1.41
	NaOH	0	0
	NH4OH	2.81	1.41
Agitating & etc	Reactor	6.66	5.25
	Metal	3.69	2.41
	NaOH	3.69	2.41
	Ammonia	1.47	1.08
	Receiver tank	5.50	1.41
Reaction time (h)		4	12
Energy Cost (kWh)		121.56	205.08



**Energy savings 40%
compared to CSTR**

<Economics Review>

Division	Contents	Unit (USD)
Capital cost	Reactor & Utility	1,946
Operating cost / year	Materials	2,546
	Utility / Electricity / Labor	513
Revenue	Precursor price : 15\$ (Assumption) NMC 250 ton/year	4,124
Depreciation	5 years	389
Profit	Tax 20% included	655
ROI		26.95%

- Initial investment costs can be redeemed **within 2 years**