Towards the Continuous Manufacture of Personalized Lipsticks

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Introduction

While personalized lipsticks are available in the market, the industry standard of a batch manufacturing process, long production time, and high costs make personalized lipsticks out of reach of the majority of the market.

Batch production process is a repeatable process to produce a fixed number of products by executing one or more steps in their designed order. The time-consuming and labor-intensive production is unsuitable for the mass-production of personalized lipsticks.

Compared to batch production process, continuous production processes are processes where the product moves continuously without breaks through multiple steps of each process. It is the perfect fit to drive the increase in mass personalization for the large market, creating unique and user need centric lipsticks at a low cost, efficiently.

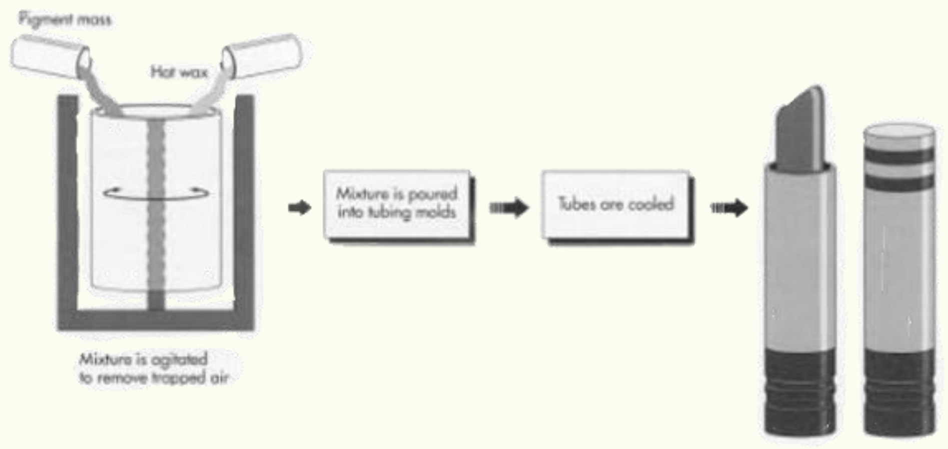


Fig.1: Simplified diagram of lipstick batch production

Objectives

- Produce personalized lipsticks at higher rates with lower costs
- Design a faster and more automated manufacturing process of personalized lipsticks by utilizing the approach of continuous production
- Select a suitable continuous mixing technology, analyze and modify its mixing performance to be later integrated into the whole manufacturing process

Market Analysis

Lipsticks and Customized Cosmetics Market

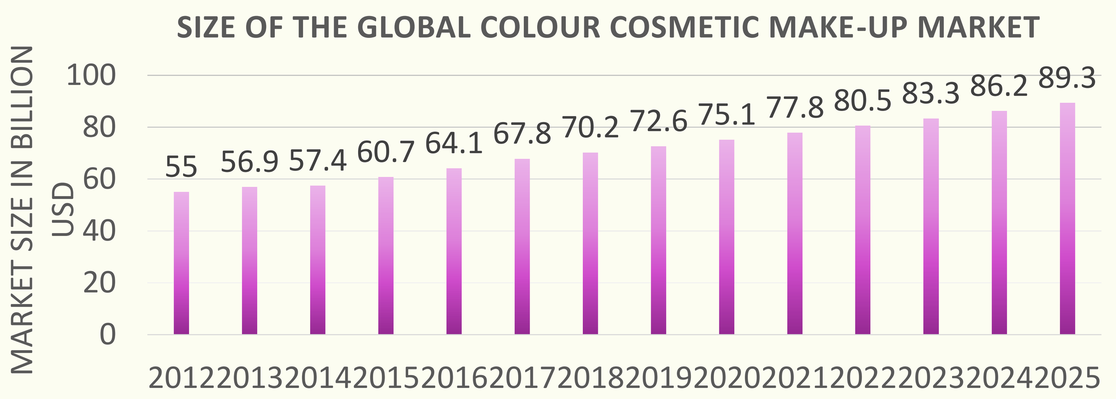


Fig. 2: Market size of the global colour cosmetic [1]

- The global make-up market is estimated to increase to about 90 billion U.S. dollars by 2025
- The market size of the global lipstick industry was estimated to be at $8.2 billion in 2018 and is expected to increase to $12.5 billion by 2026 [2]
- One in five consumers who are interested in personalized cosmetics is willing to pay an extra of 20% [3]

Serviceable Available Market (SAM)

Our targeted SAM is females from age 15 to 65. According to the Census and Statistics Department, in mid-2020 the female population aged 15-65 in Hong Kong is 2.924 million.

Survey Results

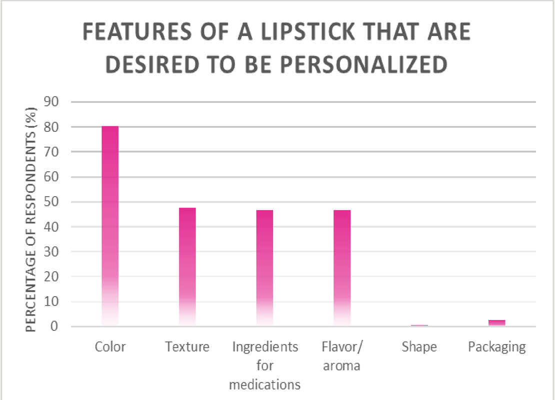


Fig. 3: Desired personalized features

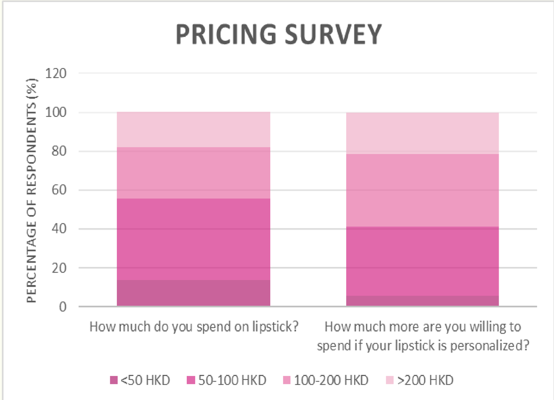


Fig. 4: Pricing survey results

- The respondents were 97.2% females and 2.8% males with age ranging from 21 to 50 years old, mostly living in Hong Kong
- 76.7% of the respondents were interested to purchase personalized lipsticks
- 80.4% of respondents want the color of lipsticks to be personalized (Fig. 4)
- 37.5% of people are willing to spend an additional of 100-200 HKD to get their lipsticks personalized compared to mass produced lipstick (Fig. 5)

Lipstick Formulation

Lipsticks are made out of pigments, oils, waxes, and other ingredients, such as emollients, pigment dispersants, preservatives, and fragrances.
The lipstick formulation utilized in this project is listed in Table 1.

Table 1: Lipstick formulation and the ingredients' physical properties

Composition	Ingredient	Melting Point (°C)	Absolute Viscosity μ (cP) at 80°C
15%	Beeswax	62 to 64	5
55%	Castor Oil	-10 to -18	36
3.50%	Pigments	N/A	N/A
14.5%	Stearic Acid	69.3	7.79
9%	Titanium Dioxide	1855	N/A
3%	Zinc Oxide	1974	N/A

Lipstick formulation is important to design our process:

- Melting points of most of the raw materials are around 70°C → the process will run at 80°C to maintain them in liquid state
- Lipstick mixture is a viscous liquid (compared to water: μ at 80 °C = 0.355 cP and μ at 25°C = 0.890 cP).→ the inlets of the process are viscous liquid at 80°C

Fig. 5: The lipstick raw materials and a lipstick made based on the formulation

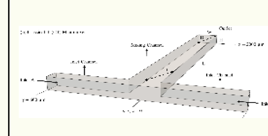
Fluid properties the lipstick mixture made out of the formulation:

- Density = 0.9895 g/cm^3
- Absolute Viscosity = 9.272 cP

Continuous Mixing Technology

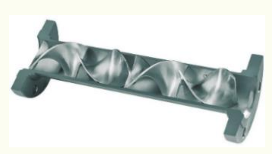
Mixing is the key process of lipstick manufacture. Thus, selecting the best continuous mixing technology to replace the conventional batch mixer is crucial. Three most suitable technologies for lipstick mixing are compared (Table 2).

Table 2: Possible continuous mixing technology

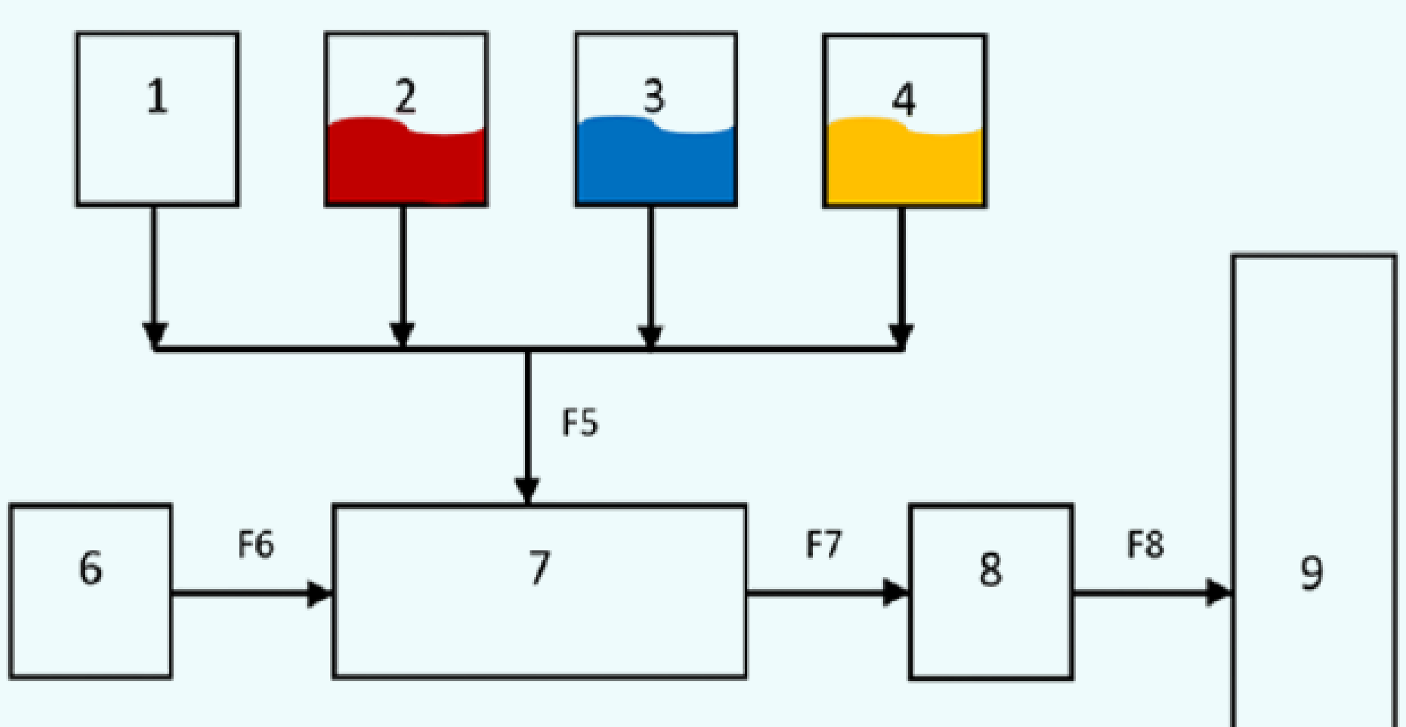
Mixer	Description	Advantages
Static Mixer [4] 	Motionless engineered fluid mixer with a common geometry of a series of mixing elements, arranged in a cylindrical tube or pipe.	• Requires less energy and less maintenance • Versatile due to its various geometries
Micromixer [5] 	A device in micrometer dimensions, made out of mechanical micro parts, used to mix fluid.	• Enables control over parameters and conditions that are technically impossible in large-scale • Allows turbulent flow mixing
Extruder [6] 	A mixer comprises of a single or twin rotating screws tightly fitted inside a stationary barrel with a die at the end.	• Manages to perform compounding: mixing through distributive and dispersive mixings

Static mixer is chosen among other mixers due to its advantages and desirable traits. Two types of static mixer, SMX and Kenics (Table 3), that are suitable for high-viscosity, laminar mixing are further analyzed.

Table 3: Types of static mixer considered

SMX Static Mixer [4]		The multilayer design is used for mixing highly viscous fluids.
Kenics Static Mixer [4]		Comprises of helical elements that alternate right and left hand at 180-degree.

Process Overview



1 Oil Process Vessel
2 Pigment 1 Suspension Vessel
3 Pigment 2 Suspension Vessel
4 Pigment 3 Suspension Vessel
6 Dispersion Vessel
7 Mixer
8 Cooler
9 Lipstick Molding Machine

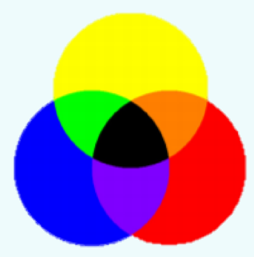
Fig. 6: Proposed Process Flow Diagram
*Control systems (i.e. valve control) and heat exchangers have not been included

Description

- The three pigment-suspension (pigments suspended in castor oil) vessels (processes 2-4) contain red, yellow, and blue pigments, respectively.
- The dispersion vessel (process 6) contains a dispersion of beeswax, stearic acid, zinc oxide, and titanium dioxide
- The raw ingredients from streams F5 and F6 are mixed in a continuous mixer 7 to obtain a homogenous mixture
- The entire process before molding in process 9 is maintained at 80°C to prevent any solidification

Color Mixing: RYB Model

One of the best color model, wide variaties of color produced, can well-predict the color outcome



Target

Target Production:	7,500	tubes/h
Mass of 1 lipstick:	4	g
Mass flowrate:	30,000	g/h
Lipstick density:	0.9895	g/ cm³
Volumetric flowrate:	8421.76	mm³/s

Based on this target production and mass fraction from the formulation, the flowrate of each process diagram are determined by mass balance in Table 4.
The volumetric flowrate calculated from the mass flowrate is an important parameter to determine the mixing performance.

Table 4: Flowrate of the streams

		F5	F6	F7	F8
Mass fraction	Beeswax	0.000	0.361	0.150	0.150
	Stearic acid	0.000	0.349	0.145	0.145
	Castor oil	0.940	0.000	0.550	0.550
	Pigments	0.060	0.000	0.035	0.035
	Titanium dioxide	0.000	0.217	0.090	0.090
	Zinc oxide	0.000	0.072	0.030	0.030
Mass per mixing (g)	Beeswax	0.00	0.60	0.60	0.60
	Stearic acid	0.00	0.58	0.58	0.58
	Castor oil	2.20	0.00	2.20	2.20
	Pigments	0.14	0.00	0.14	0.14
	Titanium dioxide	0.00	0.36	0.36	0.36
	Zinc oxide	0.00	0.12	0.12	0.12
Total mass per mixing (g)		2.34	1.66	4.00	4.00
Total mass flow (g/hr)		17,550.0	12,450.0	30,000.0	30,000.0

Simulation Design

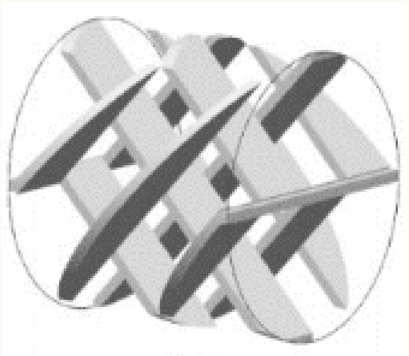
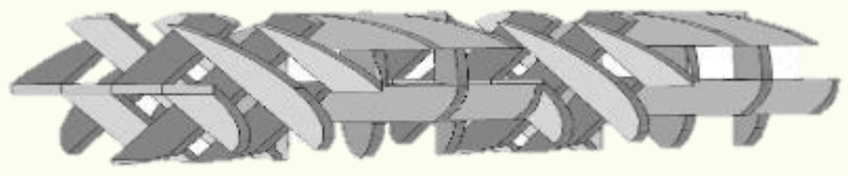
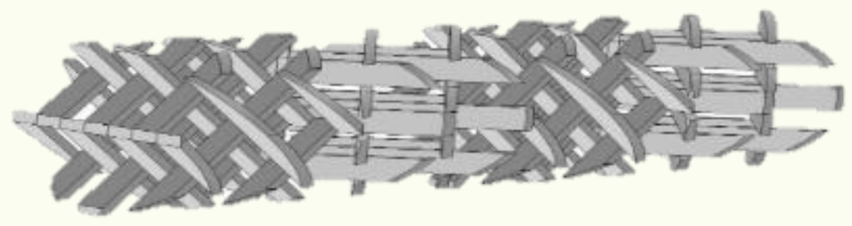
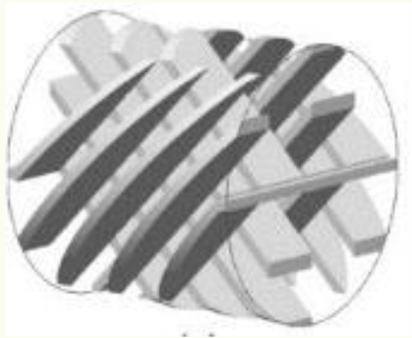
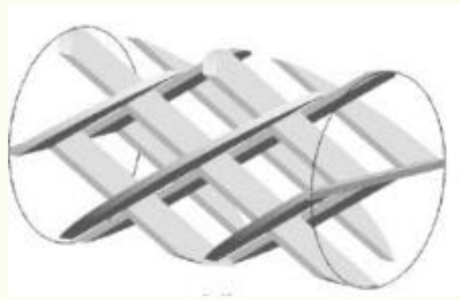
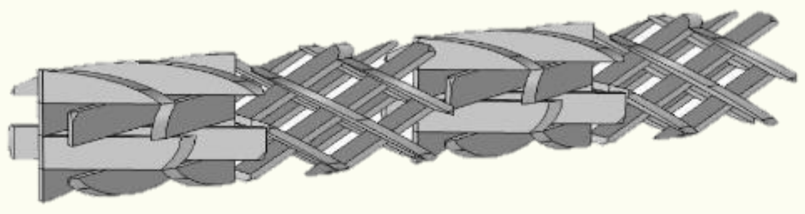
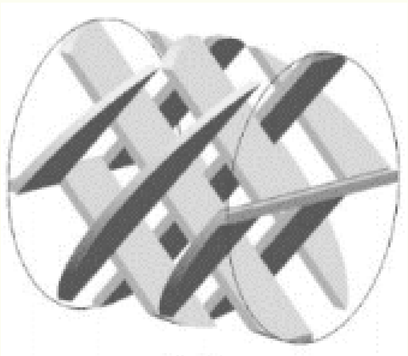
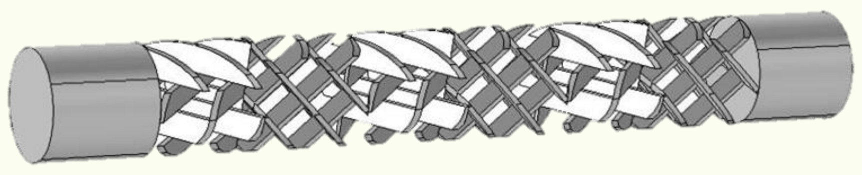
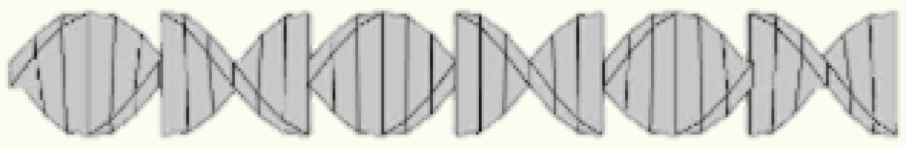
To simulate the fluid flow, CFD (Computational Fluid Dynamics) module in COMSOL Multiphysics with laminar and single-phase flow physics was utilized.

Table 5: Parameters for simulation

Inlet cross-section area	12.57	mm^2
Flowrate (fixed)	8421.76	mm^3/s
Mean inlet velocity	670.18	mm/s
Diffusion coefficient	1.00E-09	m^2/s

Static Mixer Geometry

Table 6: Mixing element of static mixer and the geometry inside the static mixer

	Mixing element	Inside the Static Mixer
A		 N = 4, Nx = 4, Np = 3, θ = 90°
B		 N = 4, Nx = 7, Np = 3, θ = 90°
C		 N = 4, Nx = 4, Np = 5, θ = 90°
D		 N = 4, Nx = 4, Np = 3, θ = 120°
E		 N = 6, Nx = 4, Np = 3, θ = 90°
F		 N = 6, d = 4mm, l = 1mm, φ = 120°

Mixers A-F are SMX Mixers; Mixer F is a Kenics Mixer
N = Number of mixing elements Nx = Number of crossbars over the width channel; Np = Number of crossbars per element; θ = Angle between crossbars; d = inner diameter of mixer; l = blade thickness; φ = blade twisted angle

3D-Printed Prototype & Future Plan

To understand the process better, experiments using 3D-printed prototypes will be done.
For an early trial, since static mixer design E gives the highest uniformity at the outlet, cross-section area, it is printed with geometry in accordance with the simulation (Fig. 8 & Fig. 9). The design of the mixer will be adjusted to be more suitable if needed according to the experiment results. Static mixer design F will also be printed
Inlet flows with specified flowrate and fluid properties will be inputted and the mixing performance will be analyzed. Moreover, a water jacket will be 3D printed around the static mixer to maintain the mixing process at 80°C.

Fig. 8: 3D- printed mixer E

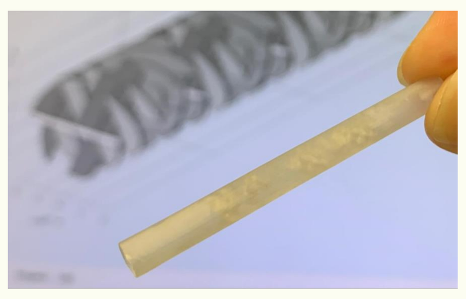


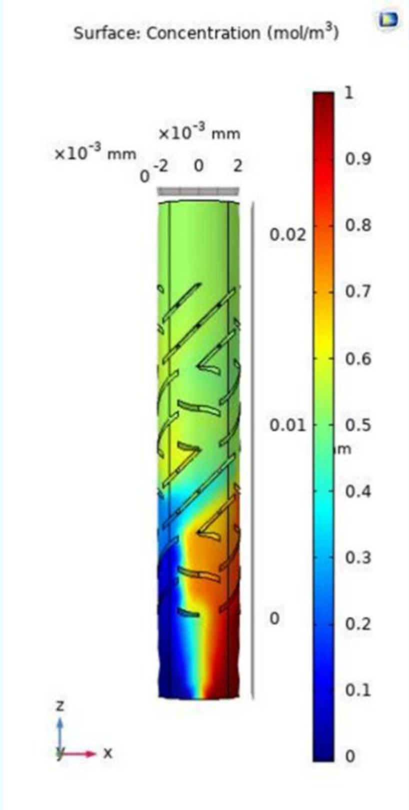
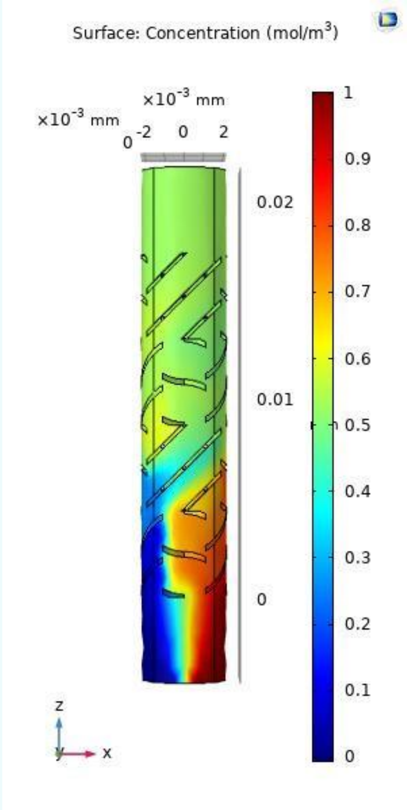
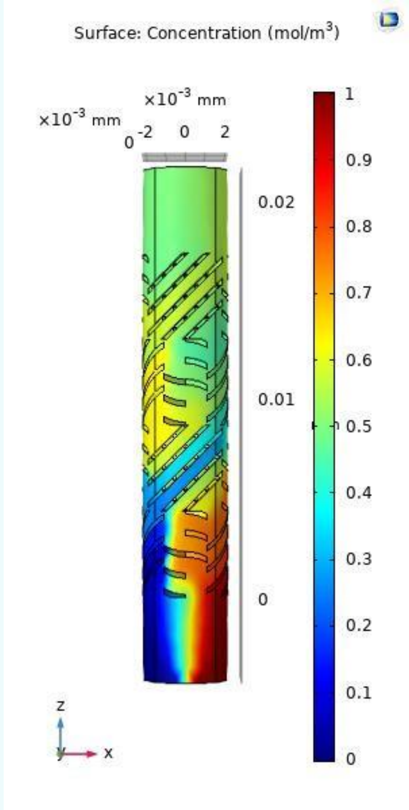
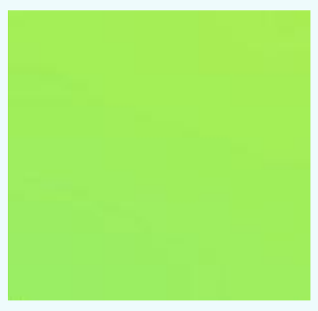
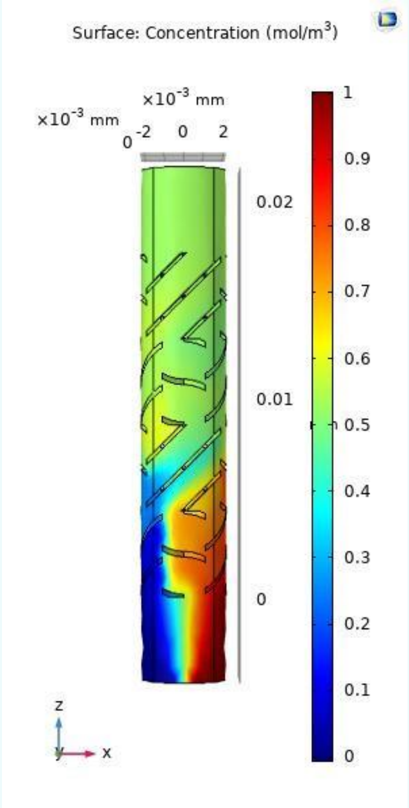
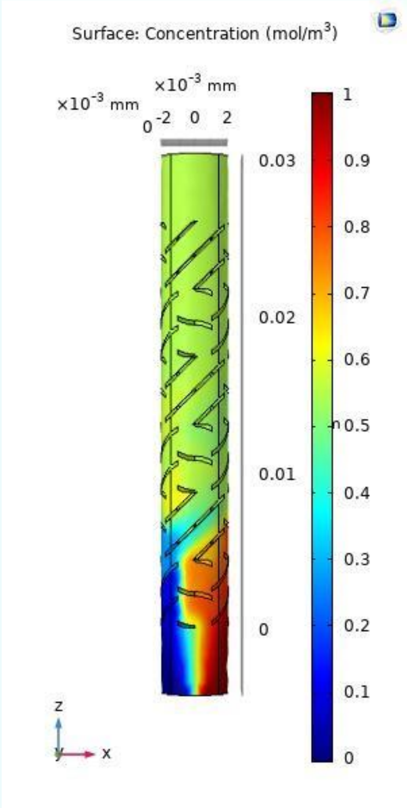
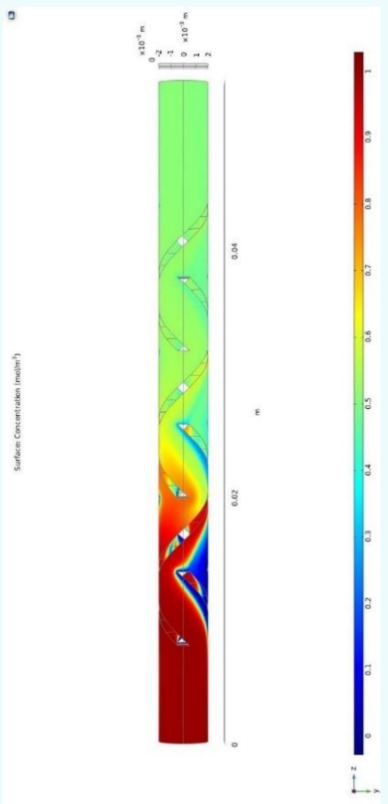
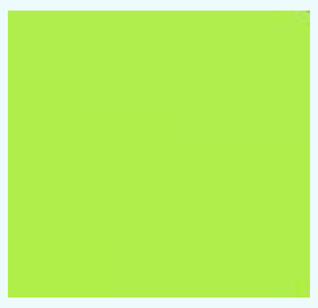
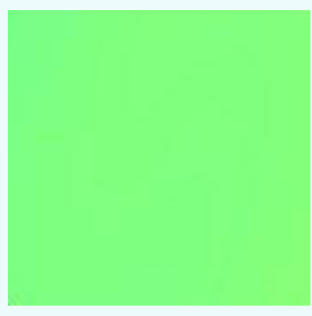
Fig. 9: 3D- printed mixer E

Conclusion

Increasing consumer demand and limited supply for personalized lipsticks are enlarging the gap in the market. In this project, simulations to estimate the mixing performance of static mixers have been conducted. By combining with experiments on the 3D-printed mixers, the results will be more realistic and trustworthy. We believe through this innovation, an inflection point can be achieved and personalized lipsticks will be ready for the mass market, creating unique and user-need-centric lipsticks at a low cost, efficiently.

Simulation Results

Table 7: Concentration profiles of the static mixers and the uniformity of the mixer outlet

A	B	C
		
Uniformity: 99.60% 	Uniformity: 99.59% 	Uniformity: 98.43% 
D	E	F
		
Uniformity: 99.60% 	Uniformity: 99.77% 	Uniformity: 99.64% 

Economic Analysis

To evaluate the profitability of the process with a target of 7500 tubes/h, an economic analysis is done.
The initial price target is set to be HK$200/tube. Annual operation hour is targeted to be 8000 hours and annual profit is roughly estimated.

Table 8: Estimation of the economic potential and annual profit in HKD

Raw material cost ($/h):	$5,473.61
Value of product ($/h):	$1,500,000.00
Economic Potential ($/h):	$1,494,526.39
Annual Operation Hour:	8000
Annual Economic Potential ($/yr):	**$11,956,211,110.05**

Equipment Cost ($):	$129,714.48
Annual Operating Cost ($/yr):	$25,942.90
Annual Profit ($/yr):	**$11,956,055,452.67**

Operating cost is assumed to cost 20% of the capital cost. As can be seen in Table 9, the annual profit is found to be more than HK$ 11T.

References

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