The Hong Kong University of Science and Technology
The Department of Chemical and Biological Engineering

"Towards the Continuous Manufacture of Personalized Lipsticks"

Authors:	ALVINA, Maria Joscelind	CBME
	CHENG Wing Tung	CEEV
	CHEN, Man Yan	CBME
	HADI, Kristhalia	CEEV

Abstract

The batch production method in conventional lipstick manufacturing is no longer effective to fulfill the demand for cheap and fast individualized lipsticks. A more automated and nonstop approach has to be applied. In this project, continuous manufacturing is introduced as a practical solution to make personalized lipstick readily and economically available to the market.

In lipstick manufacture, the ultimate goal is to achieve a homogeneous mixture. Lipstick raw ingredients are viscous liquid at 80 degrees Celsius and they are tricky to be uniformly mixed. To fulfill lipstick mixing requirements, static mixer is chosen to be the continuous mixing technology to replace the traditional batch mixing. Static mixer is a motionless mixer and it is desirable due to its less energy and maintenance traits.

In this project, the mixing performance of different geometries of static mixers is analyzed to see which one is the most suitable for lipstick production. The simulation results of the static mixers' mixing performances from COMSOL Multiphysics CFD model show promising results with uniformities at the outlet above 99% in all geometries we simulated. The 2 static mixer geometries with the highest uniformities are then 3D-printed, connected to inlet flows, tested experimentally to scrutinize the mixing performance further.

1. Introduction

Cosmetics are often used as a tool to express one-unique-self. That being said, beauty customization is seen as the future of cosmetics. The interest in personalized products is continually growing, especially among Millennials and Gen Z. A study found that 72% of 13- to 34-year-olds acknowledge that products made specifically for them are better than mass-produced ones [1]. As lipsticks are among the most widely used cosmetics with 800 million of them sold each year [2], their personalization is anticipated in the beauty industry.

Currently, personalized lipsticks with custom-made shades, finishes, or tubes are available on the market. However, they are expensive and take a long time to make – the cheapest costs more than 30 USD and takes a week to produce [3]. The underlying reason lies in their manufacturing process that still adopts the industry standard of mass-produced lipsticks (shown in Figure 1), which utilizes the batch production method. As the name suggests, products are made in specific batches within a time frame [4]. Since in each production stage, processing of subsequent batches can only occur after the current ones are completed, there are pauses between stages. Moreover, labor is required to move each batch from one stage to another. Hence, this time-consuming and labor-intensive production is unsuitable for the mass-production of uniquely made personalized lipsticks.

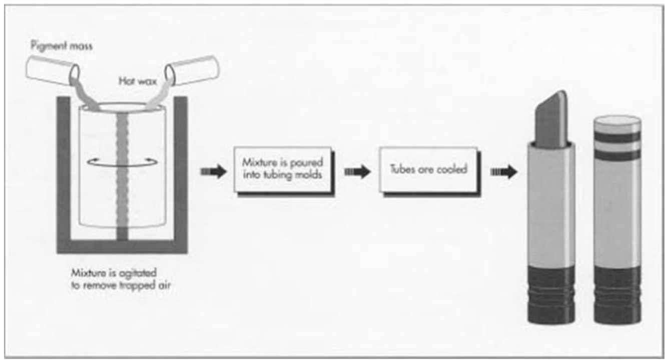


Figure 1: Simplified diagram of lipstick batch production [5]

The need to make personalized lipsticks readily and economically available to large markets persists and very few studies have been conducted to solve them. Continuous production can be adopted as one of the feasible solutions to satisfy this need. In contrast to batch production, continuous production consists of nonstop and uninterrupted processes to obtain the final product [4]. Thus, since the continuous operation does not require labor and feeds the materials continuously, it reduces production cost and time.

2. Objectives

This project aims to:

- 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.

3. Lipstick Formulation

Lipsticks are composed of pigments dispersed into a mixture of oils, waxes, and other solvents. Since lipsticks are cosmetic products, the range of pigments and other raw materials used is strictly limited by regulatory authorities, such as the EU and FDA [6].

The most used oils include castor oil, mineral oil, or petrolatum; waxes include beeswax, carnauba, candelilla, and ozokerite (ceresin) [6]. Depending on the formulation, other ingredients, such as emollients, pigment dispersants, preservatives, and fragrances may also be used. Some products also incorporate additional properties such as UV protection or pearlescent finish [6].

The lipstick formulation employed in our design is listed in Table 1, together with the functions and the physical properties of the ingredients. Based on this formulation, a homemade lipstick was made and is shown in Figure 2.

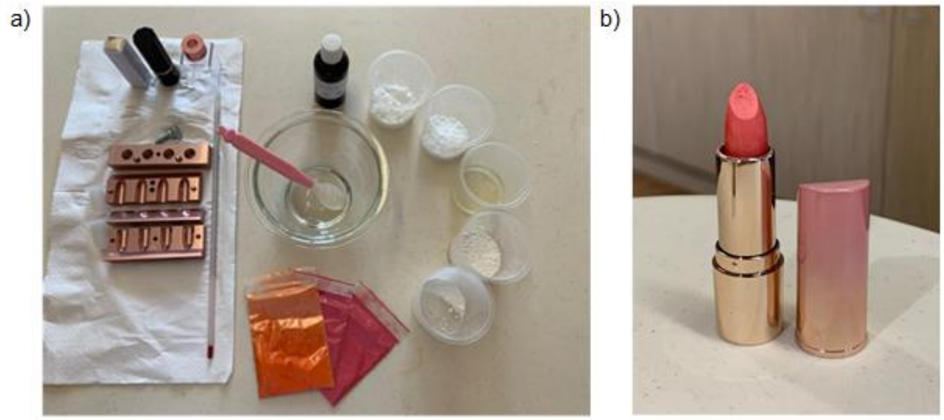


Figure 2: a) Lipstick ingredients and equipment used for homemade lipsticks, b) The result of the homemade lipstick

Table 1: Lipstick ingredients, their functions and physical properties

Composition	Ingredient (state at 25°C)	Functions	Absolute Viscosity at 80°C (cP)	Melting Point (°C)
0.55	Castor Oil (liquid)	• Gives skin-softening, glossiness, easy-application properties [7] • Acts as a solvent for soluble dyes and as a dispersing agent for any insoluble pigments [7]	36	-10 to -18
0.15	Beeswax (solid)	• is important for the structure and shape of the lipstick [7] • acts as an emulsifying agent to help other ingredients bind together [7]	5	62 to 64
0.145	Stearic acid (solid)	• as saturated fatty acid, it is used along with castor oil to prepare softeners in textile sizing [8] • gives the skin a soft and smooth appearance [9]	7.79	69.3
0.09	Titanium Dioxide (solid)	• has a dying compound: a white compound in isolation [7] • added to red dyes in varying amounts to produce a range of pink colored lipsticks [7]	N/A	1855
0.03	Zince Oxide (solid)	• gives calming effects on rosacea, inflammation, acne and melasma [10]. • helps skin reparation [10] • has sun-shielding effect[10]	N/A	1974

4.1 Viscosity of the Mixture

Beeswax, castor oil, and stearic acid make up around 80% of the lipstick mixture. Thus, the absolute viscosities of these three ingredients (listed in Table 2) are utilized to estimate the kinematic viscosity of the lipstick mixture by utilizing the Refutas equation [11].

Table 2: Absolute and kinematic viscosities and densities of beeswax, castor oil, and stearic acid

Ingredient	Absolute Viscosity at 80°C (cP)	Absolute Viscosity at 80°C (N-s/m^2)	Density (kg/m^3)	Kinematic viscosity (m^2/s)
Beeswax	5	5000	961	5.202913632
Castor Oil	36	36000	927.7	38.80564838
Stearic Acid	7.79	7790	450	17.31111111

To apply the Refutas equation to calculate the mixture viscosity, we need to convert the absolute viscosities of these 3 ingredients into kinematic viscosities by dividing their absolute viscosities with their densities. The results of this calculation are also recorded in Table 2.

Then, a Viscosity Blending Number (VBN) of each component i is calculated by Eq. (1) to calculate the VBN of the liquid mixture by Eq. (2). Then by Eq. (3), we can obtain the kinematic viscosity of the mixture. The results from the calculation are recorded in Table 3.

$$VBN_i = 14.534 \times \ln(\ln(v_i + 0.8)) + 10.975 \qquad \text{Eq. (1)}$$

$$VBN_{mixture} = \sum_{i=0}^{N} x_i \times VBN_i \qquad \text{Eq. (2)}$$

$$v_{mixture} = \exp\left(\exp\left(\frac{VBN_{mixture} - 10.975}{14.534}\right)\right) - 0.8 \qquad \text{Eq. (3)}$$

where VBN_i is the viscosity blending number of component *i*, v_i is the kinematic viscosity of component *i*, x_i is the mass fraction of component *i*, $VBN_{mixture}$ and $v_{mixture}$ are the viscosity blending number the kinematic viscosity of the mixture, respectively.

Table 3: Kinematic viscosity and VBN of the raw materials

Ingredient	Kinematic viscosity (m^2/s)	VBNi	x VBNi
Beeswax	5.202913632	19.45513844	2.918270766
Castor Oil	38.80564838	29.90747232	16.44910978
Stearic Acid	17.31111111	26.4320828	3.832652005
$VBN_{mixture}$	23.20003255		
$v_{mixture}$ (m^2/s)	9.365440586		

The estimated kinematic viscosity of the mixture to be $9.37\ m^2/s$.

4. **Process Overview**

The process diagram is shown in Figure 3. For the color mixing, the RYB (red-yellow-blue) model is applied since it is one of the best color models to predict the color of the mixture. Thus, the three pigment-suspension (pigments suspended in castor oil) vessels (processes 1-3) contain red, yellow, and blue pigments, respectively. The Dispersion Vessel (process 4) contains a dispersion of beeswax, stearic acid, zinc oxide, and titanium dioxide. Both mixtures (F5 and F6) are mixed inside a continuous mixer to obtain a homogenous mixture (process 7). The entire process before molding in process 9, is targeted to be operated at 80°C to prevent any solidification. Then, the mixture cools down and is ready for molding.

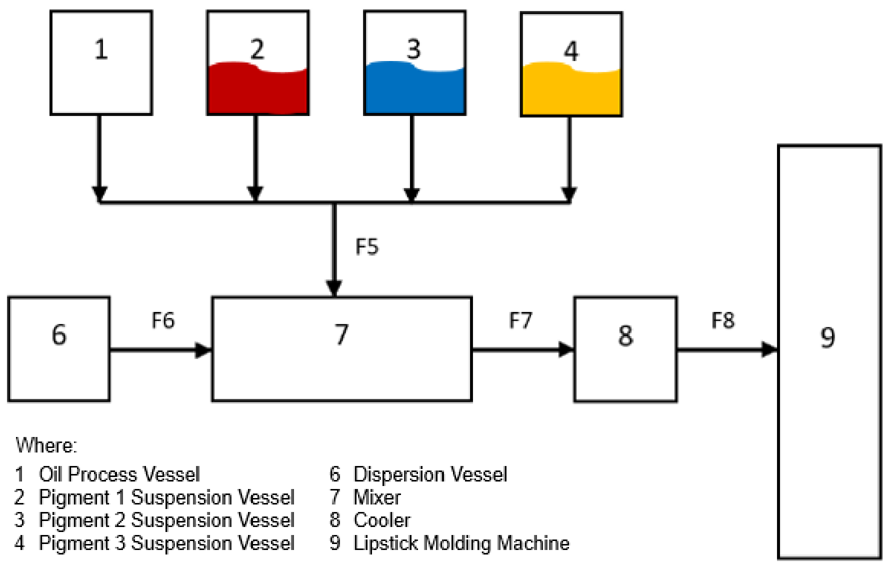


Figure 3: Simplified process diagram of the overall process excluding the control systems (e.g. valve control, temperature control) and heat exchangers

Our target production is 7500 tubes of lipsticks per hour. Assuming the mass of one lipstick is 4 grams, then the target mass flow is 30,000 grams per hour.

The density of lipstick according to [12] is 0.9895 g/cm^3. From the density, the volumetric flow rate can be calculated to be 8421.76 mm^3/s, by

$$Volumetric\ flow\ rate = \frac{30{,}000\ g/h}{0.9895\ g/cm^3} \times \frac{1\ h}{3600\ s} \times \frac{1000\ mm^3}{1\ cm^3} = 8421.76\ mm^3/s$$

The volumetric flowrate would be used to calculate the velocity as the input parameter for the simulation.

Based on the target production and mass fraction, the flowrates in each process described in the diagram are determined and shown in Table 4.

Table 4: Mass balance and flowrates of the streams

		F5	F6	F7	F8
Based on Formulation	Beeswax	0.000	0.150	0.150	0.150
	Stearic acid	0.000	0.145	0.145	0.145
	Castor oil	0.550	0.000	0.550	0.550
	Pigments	0.035	0.000	0.035	0.035
	Titanium dioxide	0.000	0.090	0.090	0.090
	Zinc oxide	0.000	0.030	0.030	0.030
	Total	0.585	0.415	1.000	1.000
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	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	(g)	2.34	1.66	4.00	4.00
Mass Flow	Beeswax	0.0	4,500.0	4,500.0	4,500.0
	Stearic acid	0.0	4,350.0	4,350.0	4,350.0
	Castor oil	16,500.0	0.0	16,500.0	16,500.0
	Pigments	1,050.0	0.0	1,050.0	1,050.0
	Titanium dioxide	0.0	2,700.0	2,700.0	2,700.0
	Zinc oxide	0.0	900.0	900.0	900.0
Total Mass Flow	**(g/h)**	**17,550.0**	**12,450.0**	**30,000.0**	**30,000.0**

5. Technology Review

In general, lipstick manufacture consists of 4 separate processes of melting, mixing, pouring, and packaging [13], with mixing as the key process.

The property differences in lipstick formulation cause them to be tricky to be uniformly mixed.

Conventionally, the mixing process in lipstick production is done by troublesome batch mixing. Unlike in batch mixing, where each batch is introduced at different times; in continuous mixing, the materials and the products are continuously fed and produced as can be seen in Figure 4. In addition to lower cost and better mixing performance, this method eliminates batch-related problems of long production time, inconsistent quality, and additional stages. Figure 4: Batch mixing (a) versus continuous mixing (b) [14].

There are various continuous mixing technologies available for various applications. Static mixer, micromixer, and extruder are the most suitable technologies for lipstick manufacturing, where viscous materials are handled. Among these continuous mixers, static mixer was chosen to be further analyzed, modified and integrated with other processes to design a revolutionary continuous production of personalized lipstick.

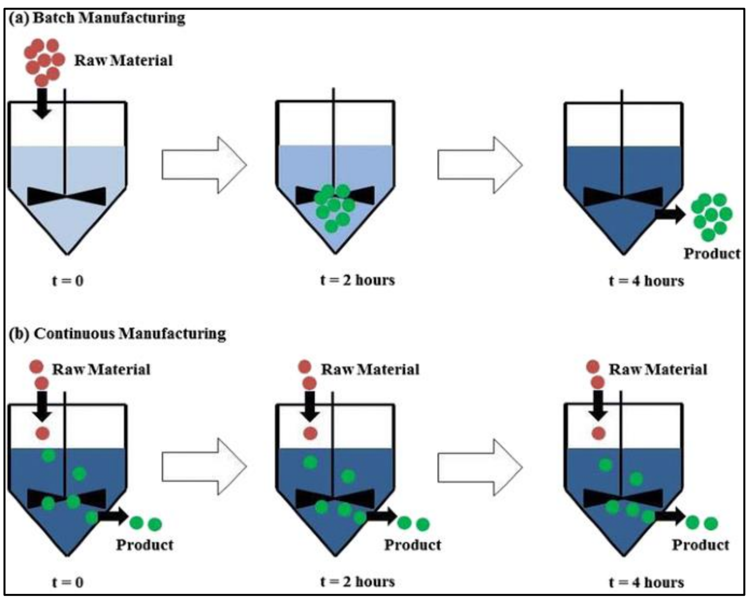


Figure 4: Batch mixing (a) versus continuous mixing (b) [14]

5.1 Static Mixer

Static mixer, also known as a motionless mixer as it does not involve any moving component, is a continuous engineered fluid mixer commonly used for liquids. Due to its motionless trait, it requires less energy and less maintenance [15]. Static mixers vary in types, sizes, geometries, and parameters with diameters ranging from 4 millimeters up to 6 meters [15]. The most common geometry of static mixers consists of a series of identical static inserts, known as mixing elements, arranged in a cylindrical tube or pipe. The number of the elements and the ratio of length to the diameter of a single element can be adjusted according to the application [15]. The selection of static mixers suitable for lipstick production must be carefully done since only some of them have the ability to handle high viscosity liquid. Each type of static mixer is adjusted to the flow regime. Thus, to determine the type of static mixer to be used, the flow regime in lipstick formulation mixing needs to be identified. Laminar flow is described by smooth regular paths of the fluid while turbulent flow is described by irregular paths of the fluid. From the energetic point of view, laminar mixing is more efficient than turbulent flow [16]. Additionally, laminar flow usually happens at higher viscosities and lower velocities. Since the lipstick formulation is viscous, a laminar mixing is expected. The Sulzer SMX mixer and Kenics mixer are types of static mixer that provide excellent mixing of viscous mixtures, even of fluids with greatly differing viscosities [16]. Their compact design is another advantage that can reduce cost [16].

Despite the advantages over traditional batch mixer, the usage of continuous mixer is still limited. Thus far, none of the continuous mixing technologies has been used in lipstick manufacture. However, there is no doubt that these technologies can be adopted for a better lipstick mixing process as each has its own unique asset that makes it rewarding.

6. Computational Methods

Computational analysis in COMSOL Multiphysics was done to better understand the mixing performance of SMX and Kenics mixers with different geometries and the number of mixing elements. To simulate the fluid flow, a CFD (Computational Fluid Dynamics) module with laminar and single-phase flow physics was utilized.

As mentioned before, the inlet volumetric flowrate to the mixer is fixed at 8421.76 mm3/s.

By considering the Reynolds number (Re) of the mixer (calculated by Eq. (4)), an inner diameter of 4 mm was chosen to maintain a laminar flow regime (Re < 2000) and have a good mixing at the same time (Re > 100). The Reynolds number was found to be 286.

$$Re = \frac{\rho v D}{\mu} \qquad \text{Eq. (4)}$$

Then, the volumetric flowrate (8421.76 mm3/s) and the diameter (4 mm) were used to calculate the mean inlet velocity (flowrate divided by the cross-sectional area) which was the parameters needed to be inputted in COMSOL (Table 6).

The parameter diffusion coefficient was also introduced in COMSOL to be 10-9 s-1 as it is the usual diffusion coefficient of waxy components in oil [17].

Table 5: Parameters for simulation

Parameter	Value	Unit
Diameter (fixed)	4	mm
Input surface 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

The fluid properties data, density, and dynamic viscosity were also defined. Since according to the diagram in Figure 3, F5 and F6 are the inlets of the mixer, fluid properties (calculated from available data of individual ingredients) of each stream were inputted for the simulation (Table 7).

Table 6: Absolute viscosity and density of F5 and F6

Stream	Absolute Viscosity at 80C (cP)	Density (kg/m^3)
F5	36	927.7
F6	4.28	596.52

Mixture F5 is mostly composed of castor oil, so we assumed its fluid property to be the same as castor oil. The dynamic viscosity of castor oil at 80^{o}C is 36 mPas and the density is 927.7 kg/m^3.

Mixture F6 is composed of beeswax, stearic acid, and titanium dioxide. Thus, using the Refutas equation as discussed in the previous section, we calculated the VBN from the viscosity of each component, the VBN of the mixture and the kinematic viscosity of the mixture.

The kinematic viscosity of the mixture was obtained to be 3.41 mm^2/s. This value was converted into dynamic viscosity since it is the required value in COMSOL simulation. To do so, the density (ρ) of the mixture needs to be calculated by Eq. (5).

$$\rho_{mixture} = \sum_{1}^{i} mass\ fraction\ component\ i\ \times \rho_{component\ i} \qquad \text{Eq.(5)}$$

The density was obtained to be 0.597 g/cm3. Dividing the kinematic viscosity by the density of the mixture, we obtained the dynamic viscosity to be 2.036 mPas.

Titanium oxide remains in solid form at 80°C so it does not have the absolute viscosity value and its contribution was ignored in the previous calculations. However, since it has a significant mass fraction of 0.22, we took into account its effect as the suspension by using the viscosity of suspension model developed by Einstein (Eq. (6)) [18]

$$\mu_{eff} = \mu_o(1 + [\eta]\phi) \qquad \text{Eq. (6)}$$

μ_{eff} is the effective viscosity of the suspension, μ_o is the dynamic viscosity of the base fluid which has been calculated in the previous step. $[\eta]$ is the intrinsic viscosity of the suspension and according to [19] the intrinsic viscosity of titanium dioxide is 3.55. ϕ is the solid volume concentration, which was obtained to be 0.31 for mixture F6.

Plucking all the values into Eq. (6), we got the effective dynamic viscosity of F6 to be 4.28 mPas.

The calculated densities and dynamic viscosities of both mixture F5 and F6 are defined in the materials.

To generate the concentration profiles, we used the laminar flow and transport of diluted species studies. The inlet and outlet of the mixer are specified on the laminar flow and transport of diluted species studies. Then the simulation was run for each geometry and the concentration profile was generated.

7. Static Mixer Geometry

The geometry design of a static mixer influences its mixing performance. For the simulation, different geometries of SMX and Kenics static mixers are imported and tested. In this section, detailed explanations of the geometries are provided.

7.1 SMX Static Mixer Geometry

SMX static mixers have multilayer mixing elements. As can be seen in Figure 7, the standard Sulzer Chemtech's SMX mixer comprises four mixing elements [20]. In each element, there are eight crossing bars over the width with a total of three sets of parallel crossbars [20]. Every second element is rotated by 90 degrees with respect to the previous ones [20].

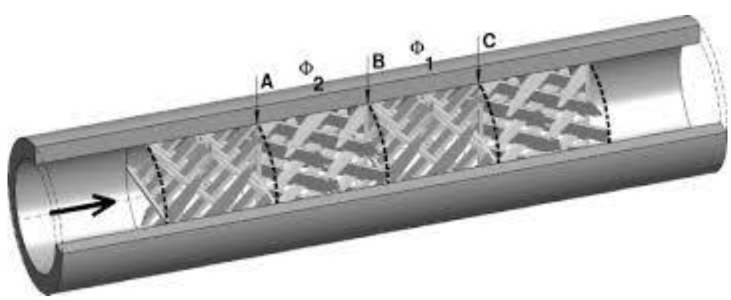


Figure 5: Standard Sulzer Chemtech's SMX static mixer [20]

Understandably, three design parameters determine the final fate of the mixing:

1. Number of crossbars over the width channel (Nx)
2. Number of crossbars per element (Np)
3. Angle between crossbars (θ)

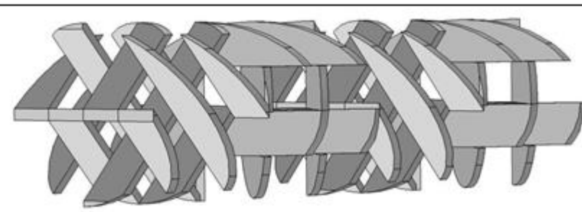
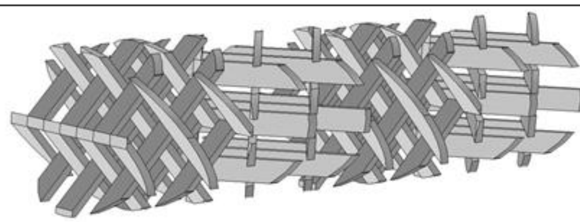
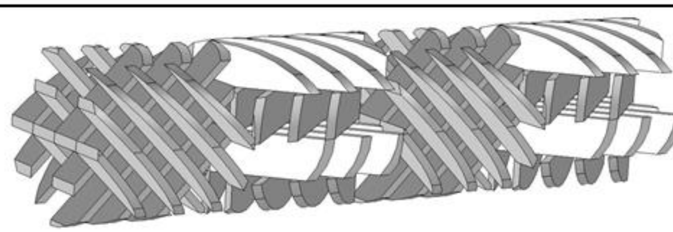
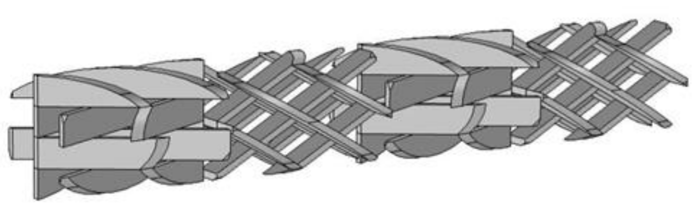
The performance of SMX mixers has been experimentally or computationally studied by many works of literature. Mickaily-Hubber et al. found that 90 degrees are the most optimum crossing angle (θ) for mixing [21]. To characterize Newtonian and non-Newtonian fluid mixing, Hrymak and his coworkers [22] numerically and experimentally examined the effect of the number of crossbars over width (Nx) and found that a design with 10 crossbars provides the best mixing.

For our COMSOL Multiphysics simulation, 4 geometries of SMX mixing elements based on the three design parameters are compared to determine which mixing elements give the best performance. Moreover, to see which of the three design parameters highly affect the mixing performance, an element of SMX mixer with design parameters: Nx = 4, Np = 3, θ = 90° (subsequently referred to as SMX mixing element A) was set as a reference and three more element geometries are made with respect to it as follows:

- SMX mixing element B: Nx = 7, Np = 3, θ = 90° (increased Nx from element A)
- SMX mixing element C: Nx = 4, Np = 5, θ = 90° (increased Np from element A)
- SMX mixing element D: Nx = 4, Np = 3, θ = 120° (increased θ from element A)

We compared the performance of these mixing elements with different geometries by simulating four 4-mixing-element SMX mixers since the standard SMX mixer consists of 4 mixing elements (Table 7). The inner diameter of the mixers is 4 mm. The length of each mixing element is 4 mm with a thickness of 0.5 mm.

Table 7: SMX mixer geometries

	Mixing element	Inside the SMX Mixer with 4 Elements
A		
B		
C		
D		

Simulation results (will be discussed in detail in the subsequent header) showed similar results between these 4 mixers with different elements. Since element A showed a slightly better result, another mixing simulation of SMX mixer with 6 mixing elements A (Figure 6) was performed to see whether the number of elements will affect the result.

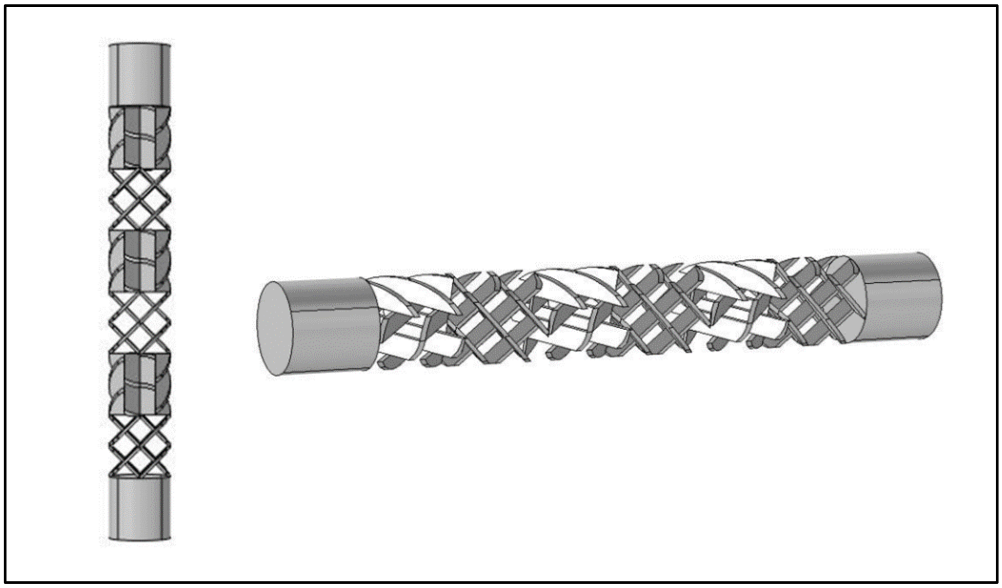


Figure 6: Top view and side view of the inside of the SMX mixer with 6 mixing elements A

7.2 Kenics Geometry

Kenics static mixer (shown in Figure 7) is made up of multiple helical-shaped mixing elements that alternate right and left hand at 180-degree to direct the flow of material radially toward the pipe walls and back to the center. The elements are positioned such that the leading edge of one element and the trailing edge of the next element are perpendicular to each other. According to [23], uniform mixing was achieved using Kenics static mixer for fluid at laminar flow. Kenics static mixer provides excellent radial mixing through the combination of shearing at the elements' junctions, flow splitting, and folding within elements.

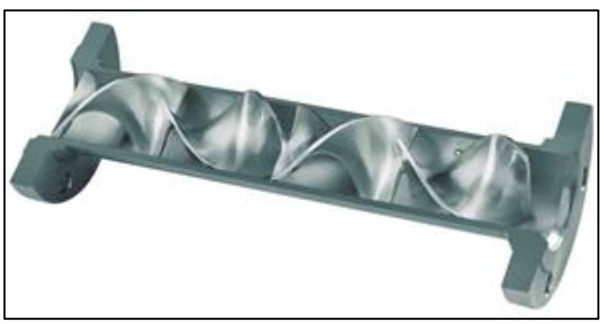
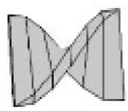
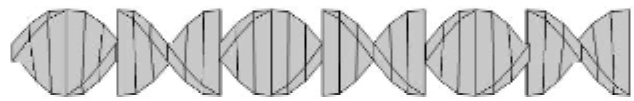


Figure 7: Kenics static mixer

For our COMSOL Multiphysics simulation, as the helical static mixer is already available in the COMSOL library, our design is a modification of the available model.

The geometry of the Kenics mixer we are using is shown below in Table 9 and it has 6 elements. The inner diameter of the mixer is 4 mm. The length of the 120º-twisted blade equals 6 mm while its thickness is 1 mm.

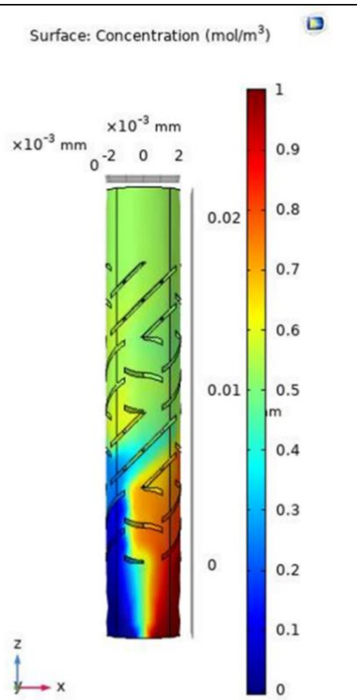
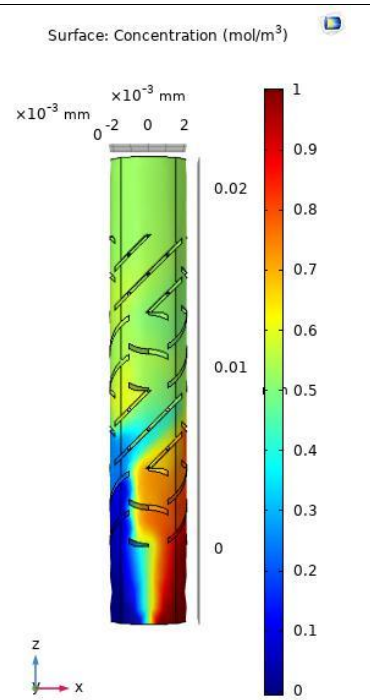
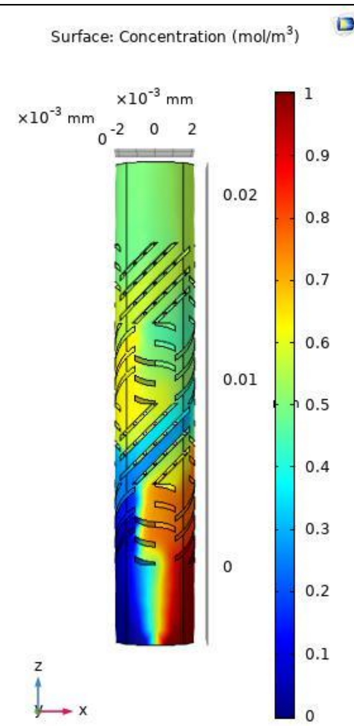
Table 8: Mixing elements of Kenics mixer

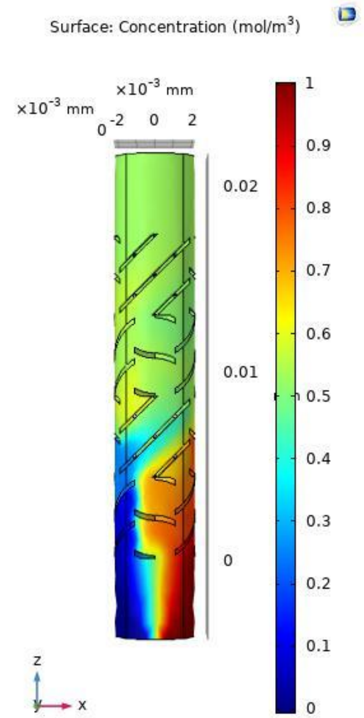
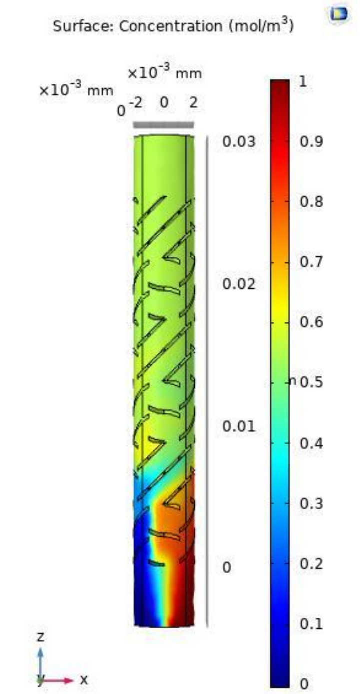
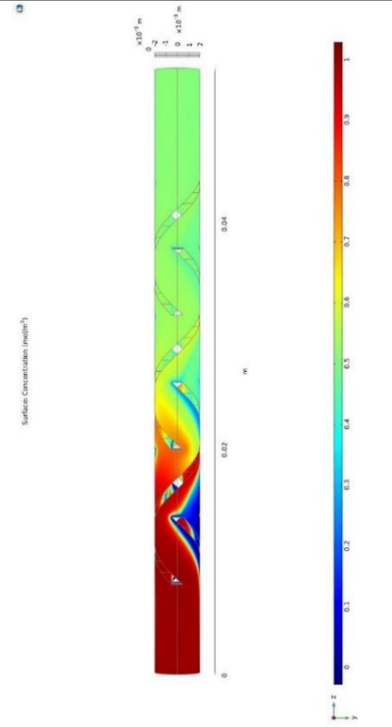
Mixing element	Inside the Kenics mixer with 6 Elements
	

8. Simulation results

The concentration profiles generated by the simulation of each geometry are shown below.

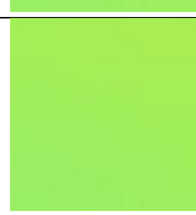
Table 9: Concentration profiles of the static mixers

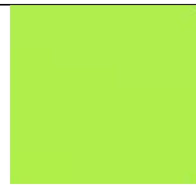
<table>
<tr><th>SMX Mixer with 4 mixing elements A</th><th>SMX Mixer with 4 mixing elements B</th><th>SMX Mixer with 4 mixing elements C</th></tr>
<tr><td>
</td><td>
</td><td>
</td></tr>
</table>

SMX Mixer with 4 mixing elements D	SMX Mixer with 6 mixing elements A	Kenics Mixer with 6 mixing elements
		

The blue and red colors represent mixture F5 and F6 in each of the mixers. From Table 9, it can be seen that all mixers achieved uniform mixing, shown by the gradual change from the two separated colors at the input to the green color at the end of the mixer. To get an objective measurement and judge which mixer performs better, we recorded the uniformity value of the color in the mixer outlet. The surface image of each mixer output was taken, and the uniformity of the color distribution was calculated using MATLAB. The results are shown in Table 10.

Table 10: Nonuniformity and uniformity results from the outlet of the mixers

Static Mixer	Surface photo	Nonuniformity	Uniformity
SMX mixer with 4 mixing elements A		0.40%	99.60%
SMX mixer with 4 mixing elements B		0.41%	99.59%

SMX mixer with 4 mixing elements C		1.57%	98.43%
SMX mixer with 4 mixing elements D		0.40%	99.60%
SMX mixer with 6 mixing elements A		0.23%	99.77%
Kenics mixer with 6 mixing elements		0.36%	99.64%

Generally, all the mixers except the SMX mixer with mixing elements C gave uniformity results of almost 100%. From table 11, SMX mixer A with 6 elements and Kenics mixer elements have the two highest uniformity. Therefore, these two designs are chosen to be 3D printed and analyzed experimentally.

9. Prototyping Through 3D-Printing

The approximate results we got from the simulations are promising so we decided to understand the process better by doing experiments using 3D-printed SMX mixer with mixing element design A and Kenics mixer.

For the early trial, we have printed SMX mixer with 6 mixing elements A with geometry according to the simulation (shown in Figures 8 and 9).

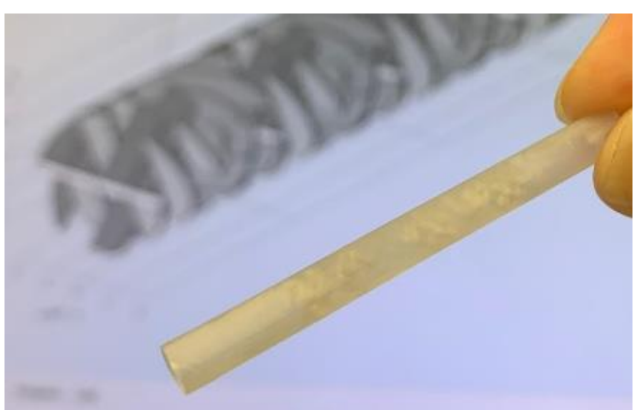


Figure 8: 3D-printed SMX mixer with 6 mixing elements A

Figure 9: 3D-printed SMX mixer with 6 mixing elements A

Inlet flows with specified flowrates and fluid properties will be inputted to analyze the mixing performance. Moreover, a water jacket will be 3D-printed around the static mixer to maintain the mixing process at 80°C.

10. Conclusion and Future Plan

Increasing consumer demand and limited supply for personalized lipsticks are enlarging the gap in the market. A faster, automated continuous manufacturing process is needed to make personalized lipstick economically available to the majority of the market. In this project, we have conducted simulations to estimate the mixing performance of the mixers. In the coming weeks, we are planning to do experiments on the 3D-printed prototype based on the exploration of possible technologies for the manufacturing process in the reality. We believe once the inflection point can be achieved, personalized lipsticks will be ready for the mass market, creating unique and user-need-centric lipsticks at a low cost, efficiently.

References

[1] YPulse Inc. - Youth research and insights, “How Customization is Taking Over The Beauty Industry,” Startpage. [Online]. Available: https://www.ypulse.com/article/2019/02/13/howcustomization-is-taking-over-the-beauty-industry/. [Accessed: 12-Nov-2020].

[2] J.-Y. B. et V. Gallon, “Lipsticks: a safe bet,” Premium Beauty News, 25-Feb-2009. [Online]. Available: https://www.premiumbeautynews.com/lipsticks-a-safe-bet,675. [Accessed: 12-Nov2020].

[3] “Custom Lipstick,” Finding Ferdinand. [Online]. Available: https://www.findingferdinand.com/collections/customize/products/create-a-custom-lipstickcolor. [Accessed: 12-Nov-2020].

[4] S. McCarthy and S. McCarthy, “Converting to a ‘Batch-less’ World: Quality Implications of Continuous Manufacturing,” Pharmaceutical Processing World, 11-Oct-2019. [Online]. Available: https://www.pharmaceuticalprocessingworld.com/converting-to-a-batch-less-worldquality-implications-of-continuous-manufacturing/. [Accessed: 12-Nov-2020].

[5] “Lipstick,” How Products Are Made. [Online]. Available: http://madehow.com/Volume1/Lipstick.html. [Accessed: 12-Nov-2020].

[6] “How lipstick is made in factory?,” *Guangzhou Kenchi Automatic Equipment Co., Ltd.*, 07-Sep-2020. [Online]. Available: https://kenchieqp.com/how-lipstick-is-made-in-factory/. [Accessed: 04-Mar-2021].

[7] J. Mooresays: “Cosmetic Chemistry – The Compounds in Red Lipstick,” *Compound Interest*, 05-Apr-2017. [Online]. Available: https://www.compoundchem.com/2014/08/18/lipstick/. [Accessed: 04-Mar-2021].

[8] JamilaMUA and W. by JamilaMUA, “STEARIC ACID,” *Lipstick & Roses*, 30-Dec-2016. [Online]. Available: http://lipstick-roses.hipsfromhell.com/?glossary=stearic-acid. [Accessed: 04-Mar-2021].

[9] “Stearate Esters,” *Stearate Esters | Cosmetics Info*. [Online]. Available: https://cosmeticsinfo.org/ingredient/stearate-esters. [Accessed: 04-Mar-2021].

[10] G. Tolentino, “Lipstick Sunscreen Is Super Awesome - Here's Why,” *Charlottes Book*, 12-Sep-2016. [Online]. Available: https://www.charlottesbook.com/091216-suntegrity-lip-sunscreen-is-awesome-heres-why/. [Accessed: 04-Mar-2021].

[11] “Summary,” *Neutrium*. [Online]. Available: https://neutrium.net/fluid-flow/estimating-the-viscosity-of-mixtures/. [Accessed: 04-Mar-2021].
“Virtual University of Pakistan,” lipstick production process – Virtual University of Pakistan. [Online]. Available: https://vustudents.ning.com/m/blogpost?id=3783342%3ABlogPost%3A2251546. [Accessed: 12-Nov-2020].

[12] Micromeritrics, “Higher Accuracy Plus Faster Results When Measuring the Density of Commercial Items .” [Online]. Available: https://www.micromeritics.com/Repository/Files/ap66.pdf.

[13] S. Lee, T. F. O’connor, X. Yang, C. Cruz, S. Chatterjee, R. D. Madurawe, C. M. Moore, L. Yu, and J. Woodcock, “[PDF] Modernizing Pharmaceutical Manufacturing: from Batch to Continuous Production: Semantic Scholar,” undefined, 01-Jan-1970. [Online]. Available: https://www.semanticscholar.org/paper/Modernizing-Pharmaceutical-Manufacturing%3Afrom-to-Lee-O%E2%80%99connor/f5451d6b55351a4ef0b0e8b7e10af99fb6a72cd5. [Accessed: 13-Nov-2020].

[14] A. Ghanem, T. Lemenand, D. D. Valle, and H. Peerhossaini, “Static mixers: Mechanisms, applications, and characterization methods – A review,” Chemical Engineering Research and Design, 22-Jul-2013. [Online]. Available: https://www.sciencedirect.com/science/article/pii/S0263876213002906. [Accessed: 12-Nov2020].
[15] “Laminar vs Turbulent Flow: nuclear-power.net,” *Nuclear Power*, 25-Apr-2018. [Online]. Available: https://www.reactor-physics.com/engineering/fluid-dynamics/laminar-flow-vs-turbulent-flow/. [Accessed: 04-Mar-2021].
[16] “Static mixer SMX™ plus,” *Sulzer*. [Online]. Available: https://www.sulzer.com/en/shared/products/static-mixer-smx-plus. [Accessed: 04-Mar-2021].
[17] A. M. Sousa, H. A. Matos, and L. Guerreiro, “Wax deposition mechanisms and the effect of emulsions and carbon dioxide injection on wax deposition: Critical review,” *Petroleum*, 25-Sep-2019. [Online]. Available: https://www.sciencedirect.com/science/article/pii/S2405656118302013. [Accessed: 04-Mar-2021].
[18] B. M. Haines and A. L. Mazzucato, “A Proof of Einstein's Effective Viscosity for a Dilute Suspension of Spheres,” *SIAM Journal on Mathematical Analysis*, vol. 44, no. 3, pp. 2120–2145, 2012.
[19] H.-G. Yang, C.-Z. Li, H.-C. Gu, and T.-N. Fang, “Rheological Behavior of Titanium Dioxide Suspensions,” *Journal of Colloid and Interface Science*, 25-May-2002. [Online]. Available: https://www.sciencedirect.com/science/article/pii/S0021979700973739#:~:text=The%20value%20of%20intrinsic%20viscosity,aggregation%20property%20of%20the%20particles. [Accessed: 04-Mar-2021].
[20] M.K Singh et al. “Understanding and Optimizing the SMX Static Mixer.” *Macromolecular rapid communications* 30 4-5 (2009): 362-76 .
[21] E. S. Mickaily-Hubber, F. Bertrand, P. Tan-guy, T. Meyer, A. Renken, F. S. Rys, M. Wehrli, Chem. Eng. J. 1996, 63, 117. 14
[22] S. Liu, A. N. Hrymak, P. E. Wood, Chem.Eng. Sci. 2006, 61, 1753.
[23] Bakker, Andre & LaRoche, Richard & Marshall, Elizabeth. (1998). Laminar Flow in Static Mixer with Helical Elements.