A KEY STRATEGY TO SUPPORT THE EVOLUTION OF PERSONALIZED SKIN CARE

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ABSTRACT

Consumers of today are demanding greater efficacy and sensory satisfaction in their personal care products. Two key aspects in meeting the consumer's needs are delivering the expected efficacy, while at the same time providing the sensory qualities that support continued use of the products. Some skin care needs could be generally based on ethnicity. Ethnic skin studies have demonstrated that the appearance of wrinkles and sagging occurs later in life for Asians than for Caucasians and that skin hydration is better in non-Caucasian ethnic groups (1). However, the ethnicity cannot account for the differences in the environment or lifestyle, suggesting the need for additional customization. A recent Genome-Wide Association Study (GWAS) in Caucasian women identified gene polymorphisms correlated with photoaging of the skin (2). Another polymorphism study of Caucasians demonstrated the contribution of different polymorphisms in skin properties, such as antioxidant capacity, skin elasticity and hydration (3). These studies support the importance of personalized skin care products and regimens that improve the health and appearance of an individual's skin. The challenge is in provide the personalized products desired.

In order to create skin care products within the constraints of ingredient stability and compatibility, safety and cost that meets users' expectations, an exclusive delivery system was developed with unique formulation compartments and a novel mini laminar flow mixing and dispensing system that allows metered dosing of a finished topical product. Multiple designs of turbulent flow and laminar flow mixers were evaluated. Turbulent mixers designed to propel fluid through a small orifice, a grille, around right-angle bends and straight pipes at low to extremely high velocities were tested. Numerous laminar mixer designs based on the recombination of strata via different configurations were also tested. Analyses were performed in COMSOL Multiphysics, using the laminar CFD and transport of diluted species physics models in two stages. The laminar flow profile was computed and a diluted species concentration was applied to half of the inlet channel, a small diffusion coefficient was applied to the fluid, and the diffusion of the species was simulated through the fluid. Multiple formulations tested with multiple mixer designs demonstrated that the best performance was achieved with a conventional laminar mixer composed of 2 to as many as 10 mixing elements.

The final consumer product composed of multiple sub-components that are mixed and delivered upon demand is tailored according to instructions given by a customer-driven application program designed to interpret a customer's skin care needs and personal sensory preferences.

This presentation describes the development of a multi-component delivery system directed by a novel application program that addresses the key aspects of delivering expected efficacy and customer-desired sensory attributes.

INTRODUCTION

Skin care products are mixtures of different ingredients. Some ingredients would deliver efficacy, another would improve sensory satisfaction and others are required for stable formulation. In order to have a well-blended emulsion of oil-soluble ingredients and water-soluble ingredients, cosmetic formulations require surfactants in the final homogeneous product. Otherwise, the emulsion would separate into different phases. Separated emulsions will result in unsatisfactory user experience.

Ingredient stability and compatibility are important features of final product safety and usage. There are also ingredients that would never mix, or shouldn't be mixed. For example, salad dressing contains both oil and vinegar, which do not mix; they are incompatible with each other. Another example is the use of lyophilized powder for stability. When a compound is freeze-dried (lyophilized) and stays frozen, the shelf-life of the compound can be extended, until moisture (water) is introduced. Lyophilization is a way to preserve a perishable ingredient. These non-compatible or non-stable ingredients are separated into different chambers for late-minute mixing.

When it is necessary to separate ingredients into two or more chambers, different packaging containers are available, such as a dual chamber pump dispenser. Some pumping mechanism can incorporate the mixing apparatus. When multiple chambers are required, it is harder to find a compatible packaging with mixing apparatus due to constraints, such as pressure applied, accurate dispensing, viscosity and drip. A simple fix would be manual mixing by users, however manual mixing can lead to non-compliant application due to inconvenience. Mixing for aesthetic reasons cannot be overlooked. Uniformly mixed formulation is more visually pleasing compared to non-consistent formulation, unless streaking, non-homogenous formulation was intentionally prepared, such as toothpastes with different color strips. In addition, multiple-chambers will help customize the final product allowing different preferences to be selected. This innovative multicomponent delivery system is also designed with compliance in mind. A simple reminder helps people with medication compliance (4). This multicomponent delivery system is a simple to use, hands-free delivery system, which will reduce cluttering.

With no available compatible three-chamber container, this new multi-component delivery system with innovative mixing apparatus was developed. With three-chamber mixing channel, ingredients are separated into different sub-components, uniformly mixed and single-use doses are delivered as needed. With this demand-driven delivery system will make the usage of final product to be more convenient, which will lead to improved product efficacy and user satisfaction.

OBJECTIVE

The project's primary objective is to develop a multi-component delivery system with innovative mixing apparatus, in order to meet the consumer's needs of better efficacy and user experience.

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RESULTS AND DISCUSSION

A novel mixing/dispensing system allows metered dosing of the finished topical product.
The system is tightly constrained by a number of requirements: ingredient stability, ingredient compatibility, safety, cost (which limits the available technologies), and user experience. The user experience requirement can be further broken down into additional limitations on the system. For example, it must not use too much power (for battery life reasons), it must be compact (to fit into any home), it must not take too long to operate, it must not generate too much noise/vibration, and the system must not involve any complex setup/loading/priming operations.

Mixing the ingredients or formula is a non-trivial challenge:

1. Some of the components have very high viscosity (up to 88,000 cP).
2. The different components may have extremely different viscosity. Some are as low as 6,000 cP, or 15 times less viscous than the highest-viscosity.
3. The quantities delivered are small, typically just 150 µl of each of the ingredients.
4. The flow rates are relatively low.
5. 'Dead volume' in the mixer (i.e. ingredient that remains at the end of dispense) must be minimal, for reasons of accurate dispensing and user experience (they should not have to clean the system out).

Cost, space, durability and noise constraints limited us to a 'static' mixer, without moving parts.
Dynamic mixing, e.g. with an impellor, is energy-intensive, particularly with high-viscosity fluids. Also, it would require actuators (e.g. motors) and gearing, which would lead to significant increases in both system size and system cost. With high-velocity parts, there are also concerns about product life span and reliability. Therefore, we will depend on a 'convective' mixer, where only the ingredients themselves move.

Static mixing technologies can be categorised as

1. Turbulent – the simplest type. These depend on the generation of eddies to mix fluids, and can do so by any of
   a) Propelling the fluid through a small orifice
   b) Propelling the fluid through a grille
   c) Propelling the fluid round right-angle bends in pipes at high velocity
   d) Propelling the fluid through straight pipes at extremely high velocity
2. Laminar mixers. These work by subdividing the flow, and recombining the strata in a different configuration, akin to shuffling a deck of cards. These are typically more complex in geometry, requiring an extra component, but are effective at velocities that are too low to generate turbulence.

Based on these categories and types, an appropriate type was determined by looking at the Reynolds number of the flow (ratio of viscous to inertial forces). Even for the lowest-viscosity ingredient, Re = 0.037, which is extremely low. Turbulent designs a) and b) require Reynolds numbers in excess of 1: c) requires higher numbers still, and d) requires Reynolds numbers in excess of 2000. Therefore, we focussed on laminar designs only. Numerous laminar mixer designs based on the recombination of strata via different configurations were evaluated and tested.

Analyses were performed in COMSOL Multiphysics®, using the laminar CFD and transport of diluted species physics models.
Simulations of mixing were carried out to guide the design, before prototype testing began.

A full 2-phase mixing simulation is extremely computationally intensive, and requires a large benchmarking effort. A much more efficient approach was to carry out a simplified analysis that enables a comparative evaluation of different designs, against each other and against a benchmark off-the-shelf technology of known, but inadequate, performance. This analysis was performed in two stages:

1. The flow profile was computed, using a single-phase laminar-flow FEA model for the highest-viscosity formula. The use of the highest-viscosity element minimises turbulent-mixing phenomena, and is therefore a reasonable approximation of the worst-case scenario. As there is only a single phase, no turbulence parameters and we assume that all behaviour is isothermal (thermodynamic effects on mixing are not expected to be significant). There are only 4 dependent variables (a 3D velocity vector and a pressure scalar), and this model is very quick to run.
2. Taking the flow profile computed in step 1, a diluted species concentration was applied to half of the inlet channel, a small diffusion coefficient was applied to the fluid, and the diffusion of the species was simulated through the flow. This analysis only has a single scalar dependent variable (concentration), and is therefore extremely quick to run.

The diffusion coefficient is chosen to give similar results for the benchmark mixer. However, as we were looking purely at comparative performance, the exact value is not significant.

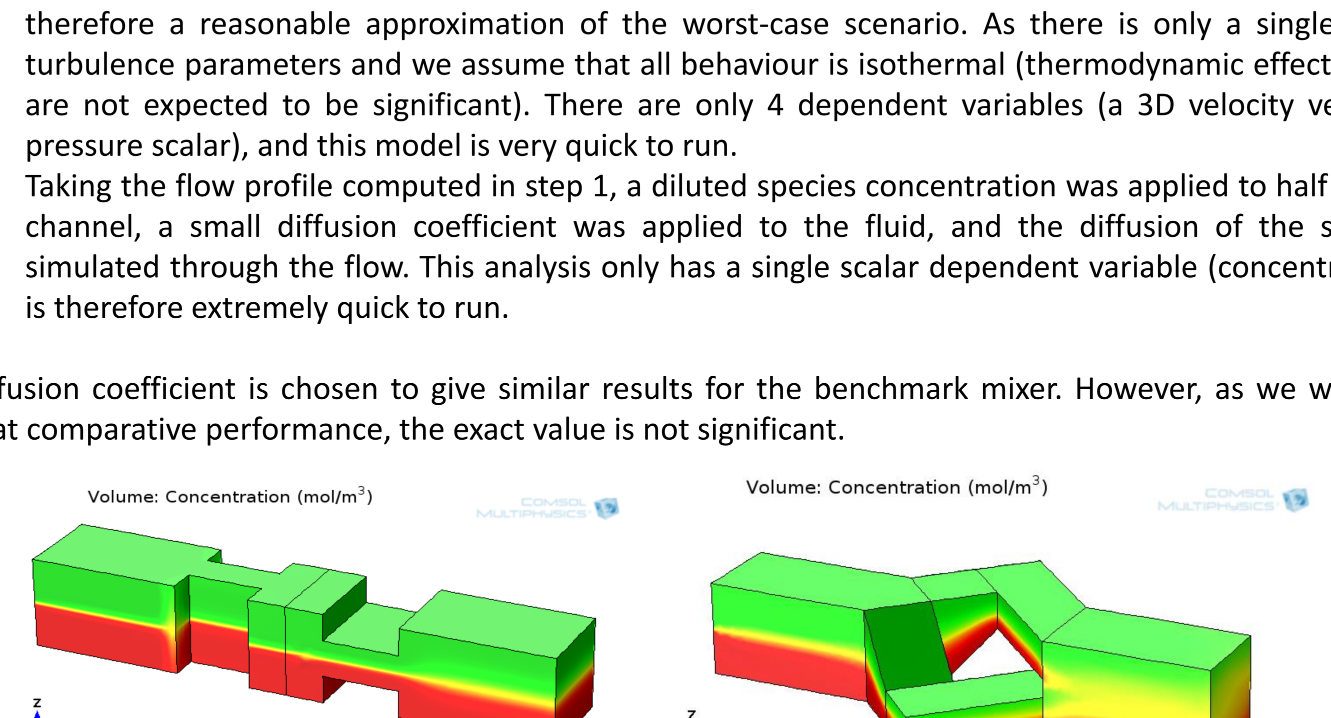

Figure 1. COMSOL Multiphysics Modeling. An example of a 2-stage turbulent mixer is shown on the left, and an example of a simple single-stage laminar mixer is shown on the right.

Figure 1 shows simulation results. Flow is left-to-right and the initial species are red and green. Once mixed, mixed regions show as yellow. Mixing is minimal on the turbulent mixer, but the simple laminar mixer is showing improved mixing with more yellow. For the turbulent mixer, there is negligible mixing. For the laminar design, there is significant mixing. If further identical stages were added in series, the laminar design would quickly achieve a more effective mix.

For each of the various geometries investigated, we simulated a single mixing element. The intent was that the elements would be multiplied in series for improved mixing, but fewer elements means a more compact device and lower dead volume. Division and recombination of the flow, with no rotation at all, provided the best results.

As shown in Figure 2, the analysis showed that effective mixing was not possible without an extra part, to ensure that the divided laminar flows were recombined 90° away from the division.

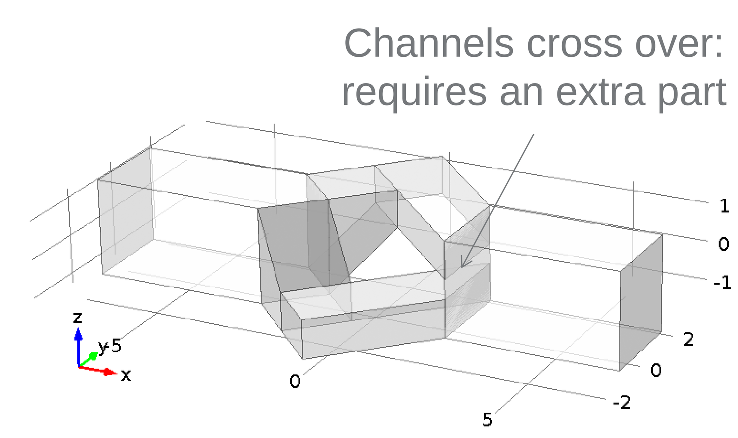

Figure 2. Evaluation of Geometry.

The simulation-developed designs were verified with experiment, and compared against off-the-shelf solutions.
Disposable mixers operating on laminar principals are readily available as lab supplies, but these combined laminar division with an element of turbulent mixing. Testing showed that the off-the-shelf inserts were not as effective as our optimum design, even with twice as many mixing elements.

This design required a custom moulded insert, shown in Figure 3. This is half of the mixer subassembly, showing the insert in red. Flow is left-to-right across the mixer. Above the mixer are the three inlet channels, and below the mixer is a single outlet for the mixed formulation. The mixer element has 4 stages, although reasonable mixing was achieved with as few as 2, and up to 10 could be included before the pressure loss was too great.

Figure 4 shows the test system with genuine ingredients. This demonstrated significant improvement to the mixing from off-the-shelf solutions. Mixing capabilities were evaluated using diverse viscosity formulas with different emulsion types, which demonstrated effective mixing.

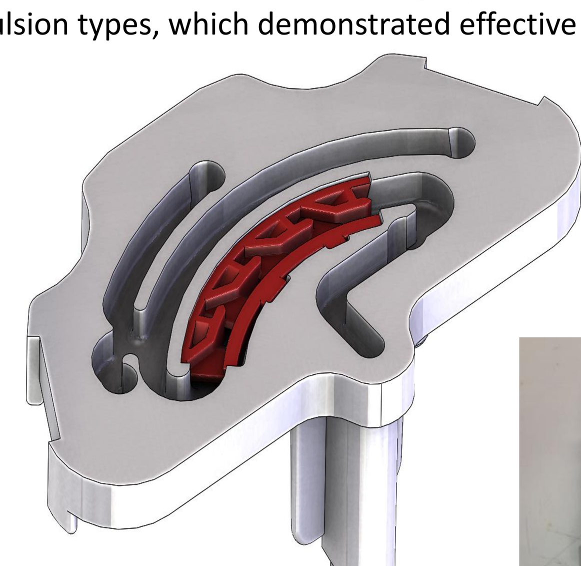

Figure 3. Laminar mixer design.

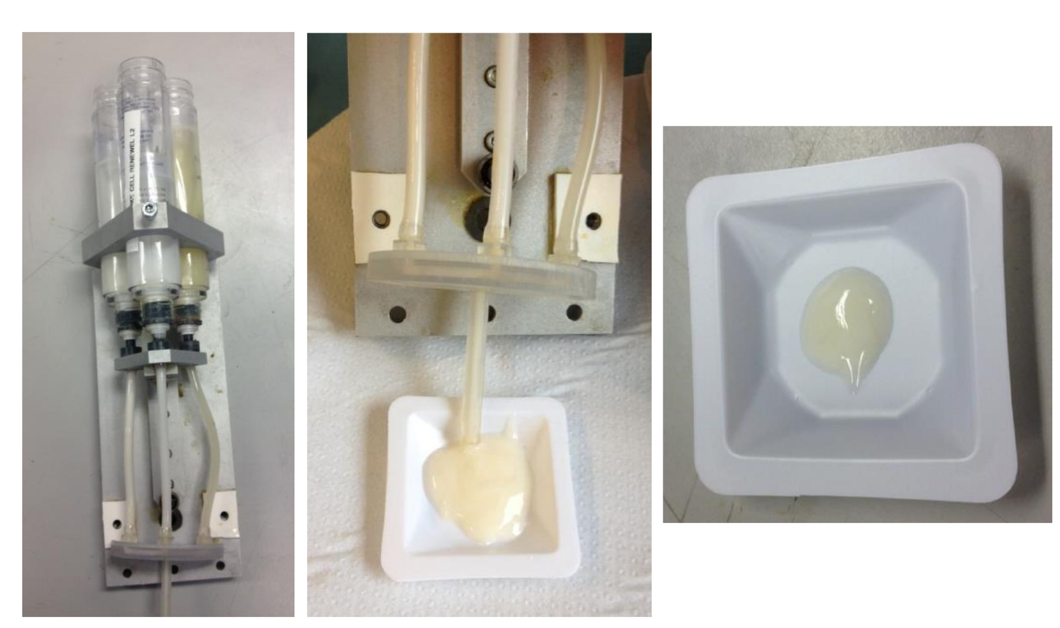

Figure 4. New laminar mixer component testing. A test rig for new laminar mixer components (left), a close–up of the mixing region (centre) and a dispensed cosmetic product mix of three different formula (right).

Figure 5. Image of the complete mixing/dispensing system without the dispense actuator

CONCLUSIONS

- This new mixing apparatus is mixing accurately and reproducibly without dripping.
- This meets the goal of a compact, effective low-cost technology for mixing diverse ingredients and formulas, which is a key component of an easy- and pleasing-to-use personalized skin care system.

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