

# Low-Energy Emulsification: Beyond Energy Conservation

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Today's recurring blackouts and power shortage in California are a painful reminder that energy conservation is still important even in a wealthy nation like America. Two years after the world-wide oil crisis of 1974, I first presented the concept of Low-Energy Emulsification (LEE) at the Society of Cosmetic Chemists (SCC) meeting in New York. Since then, LEE has helped cosmetic manufacturers around the world process a wide range of emulsified skin- and hair-care products and color cosmetics, including facial creams, moisturizing lotions, hair conditioners and fluid makeups. LEE can also be used to process many non-emulsion products like shampoos and hair gels with considerable energy saving.

There is little question that LEE can be used to save considerable energy in processing many cosmetic products. Significant reductions in processing energy consumption (30 to 60%) have been demonstrated in a wide variety of cosmetic emulsions. However, in lecturing on LEE, I have noted that even those who are familiar with it have some misconceptions about the method. Three important misconceptions are:

- LEE is only for energy conservation.
- Emulsion quality is inevitably compromised by using LEE.
- The LEE procedure either works or does not work for a given formulation.

Actually, none of the above statements is true.

- In addition to saving energy, LEE can improve cooling efficiency, can markedly shorten the processing time required for batch operation, and can often increase productivity of the manufacturing facility by 100% or more.
- When correctly implemented, LEE can produce an emulsion having quality superior to that of the same emulsion made by conventional method.
- LEE is not a fixed procedure; it is a principle that allows much flexibility in application. By understanding the principle and by making efforts to find the optimal processing conditions, LEE can be used to process many emulsions as well as non-emulsions using diverse processing equipment.

This paper reviews the latest developments in LEE technology, and corrects some of the common misconceptions regarding the applications of LEE.

## Principle of Low-Energy Emulsification

I have presented six papers<sup>1-6</sup> related to different aspects of LEE at various conferences of the SCC and International Federation of the Societies of Cosmetic Chemists (IFSCC). These papers explained details of the many experiments conducted.

My coworkers and I determined the extent of potential energy savings, the impact of emulsification temperature, and effects of changing process variables such as the volume of the unheated phase. We studied factors affecting emulsion quality, and we explored a special technique for processing high-internal phase emulsions. We also studied the applications and limitations of the method.

**Energy conserved:** In the first paper,<sup>1</sup> I pointed out that significant energy conservation is possible by using LEE processing for cosmetic emulsions. This conservation occurs because the amount of energy expended in a typical commercial operation is several orders of magnitude greater than the theoretical minimum amount of work required to form fine emulsion droplets, as a look at the process clearly shows.

Whether the emulsion is made by a batch or a continuous process, thermal energy is applied first, to heat the ingredients, and then mechanical energy is applied to mix and homogenize the emulsion. Ad-

### Key words

*emulsions, manufacturing, quality, processing time, formulation*

### Abstract

*The quality of emulsions manufactured with low-energy emulsification can be equal or even superior to the same emulsions made by a conventional hot process if conditions are optimized.*

ditional mechanical energy is used to cool the batch, with the heat actually removed by cooling water or a refrigerated medium. The heat thus removed is usually discarded into the environment.

In direct contrast to the traditional commercial processing method, the LEE method calls for heating only pre-selected portions of the ingredients (the  $\beta$  phase). The remaining phase (called the  $\alpha$  phase) is withheld at room temperature; when  $\alpha$  is blended into the batch at a specified stage, it accelerates the cooling process. By applying thermal energy only where needed and when needed, much energy can be conserved. Because mixing is almost always needed to heat and to cool the batch in a kettle, a reduction in thermal energy input also means a reduced need for mechanical energy. Furthermore, since it takes time to supply and discard thermal energy, the reduction of thermal energy input from using LEE can also substantially shorten the processing time.

**Manufacturing a cosmetic emulsion:** Most cosmetic emulsions may be commercially produced by batch, continuous or semi-continuous processes; LEE can be adapted to all three methods.<sup>7</sup> Batch processing is most common in our industry, so it will be used here to illustrate the manufacture of a typical o/w emulsion.

Figure 1A illustrates conventional hot processing, in which both the internal and

external phase ingredients are heated to about 85°C and the two phases are combined to form an emulsion. If the amounts of heat supplied to internal and external phase ingredients are designated as  $h$  and  $H$  respectively, the heat that must be removed to reach room temperature is approximately equal to  $h+H$ , neglecting a small amount of heat loss and heat of mixing.

For most cosmetic emulsions, the size of the external phase is generally much greater than that of the internal phase. Many o/w moisturizers and hand lotions contain 85-92% water in the external phase of the emulsion. In Figure 1B, the external phase of the same emulsion is divided into the  $\alpha$  and  $\beta$  phases, but only the  $\beta$  phase is heated to make the emulsion concentrate in the first stage of the LEE processing. The second stage involves dilution of the concentrate by addition of the cold  $\alpha$  phase at a specified point in the manufacturing process. If  $\alpha$  and  $\beta$  represent weight fractions of the alpha and beta phases, the amount of heat that must be removed is now  $h + \beta H$ . Clearly, by making the ratio of  $\alpha/\beta$  as large as possible, a large amount of energy can be conserved.

### Improving Productivity through LEE

**Larger batch sizes:** As a consultant specializing in emulsion technology, I have visited many cosmetic factories in the US, Asia and Europe during the past 30 years. The basic manufacturing processes for cosmetic products have not changed very much, but the scale and complexity of the operations have grown markedly during the past 20 years.

As the market for cosmetic emulsions has grown, many manufacturers have increased batch size by installing larger tanks. Processing kettles holding 5000 gallons or more are commonly seen in many US factories today. Increased competition is also pressuring many manufacturers to reduce processing costs.

By increasing the batch size of a cream from 1000 to 3000 gallons, for example, a manufacturer may hope not only to triple its production capacity, but also reduce its compounding cost per kilogram of product by two-thirds. The assumption is that

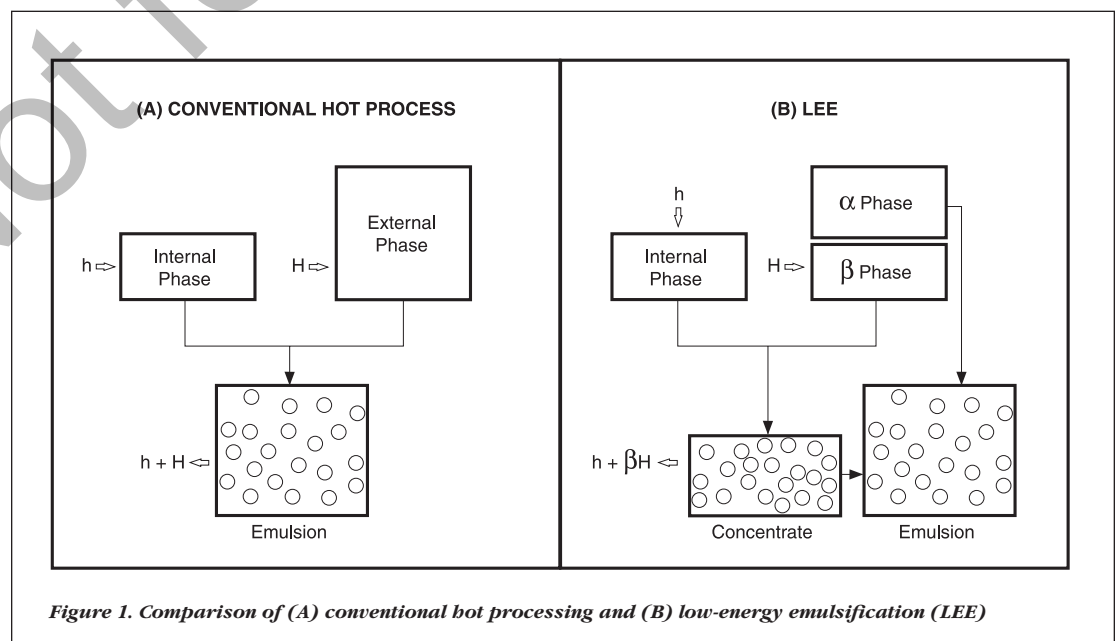


Figure 1. Comparison of (A) conventional hot processing and (B) low-energy emulsification (LEE)

the time required for processing a 3000-gallon batch does not differ significantly from that required for a 1000-gallon batch. This reasoning may be perfectly sound for scaling-up production of a low-viscosity product such as a toning lotion, which requires no heating during manufacturing. However, if the product is a viscous cream or a heavy suspension, this assumption may be faulty. The time required to weigh raw materials for a larger batch is probably not much greater than that required for the smaller batch, but heating and cooling a 3000-gallon batch in a jacketed kettle can take much longer than a 1000-gallon batch in a geometrically similar kettle.

**LEE improves cooling efficiency:**

Temperature curves for two different size batches (Figure 2) show the significant difference in processing time when the batch size is increased by three-fold. Sup-

pose that an identical o/w cream is to be processed in these two kettles, and that both batches start at room temperature (25°C) in the compounding kettle containing all water-phase ingredients and ends at 35° when completed.

The curve ABCEI represents the temperature history in the smaller kettle. It takes about 1 h to weigh and place all raw materials in the compounding kettle. Heat is applied at point B and the temperature of the aqueous phase in the kettle reaches 85°C after 1.5 h (C). The oil phase is kept at 85°C in another kettle, and is then added to start emulsification. After 1 h, cooling water is introduced into the jacket (E). From this point, it takes about 3.5 h to cool the batch to 35°C, completing the process. The operation takes 7 h to reach the final temperature.

The temperature curve of the larger 3000-gallon batch is represented by ABDFGJ. As shown here, it takes only an extra half hour to heat the larger aqueous phase to 85°C, but an extra 5 h is required to cool the batch from 85°C to 35°C. The reason for this is the difference in heat-transfer efficiency. Before emulsification, the aqueous phase in the kettle has very low viscosity. Mixing is efficient and the temperature of the steam in the jacket is much greater than that of water at room temperature. After emulsification, the viscosity increases and the efficiency of cooling drops. As the waxes and higher alcohols in the formula begin to solidify at around 55°C, the emulsion gains yet more viscosity and yield value, further reducing the efficiency of mixing and heat-transfer. In addition, the temperature difference between the batch and cooling fluid in the kettle jacket decreases as the batch temperature drops, further contributing to poor cooling efficiency.

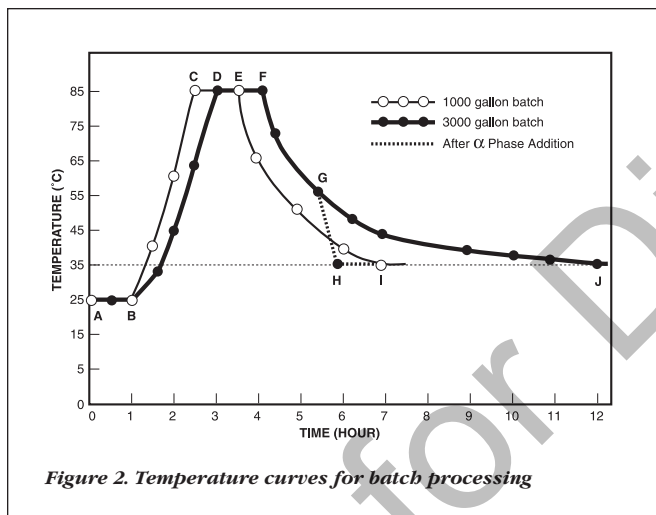
The advantage of LEE in promoting cooling efficiency is evident from the broken line on the cooling curve, starting at G, where the cold  $\alpha$  phase is introduced directly into the batch. From there it takes only a short time to blend the  $\alpha$  phase and the batch reaches the final temperature of 35°C in about 30 min.

By applying the principle of LEE in this example, it takes only 6 h, instead of 12 h, to process the 3000-gallon batch. Actually, the processing time would be even shorter if we had taken into consideration the shortened heating time due to the reduced mass of the  $\beta$  phase. In this example, it actually takes less time to process a larger 3000-gallon batch with LEE than to process a smaller 1000-gallon batch of the same cream using a conventional process.

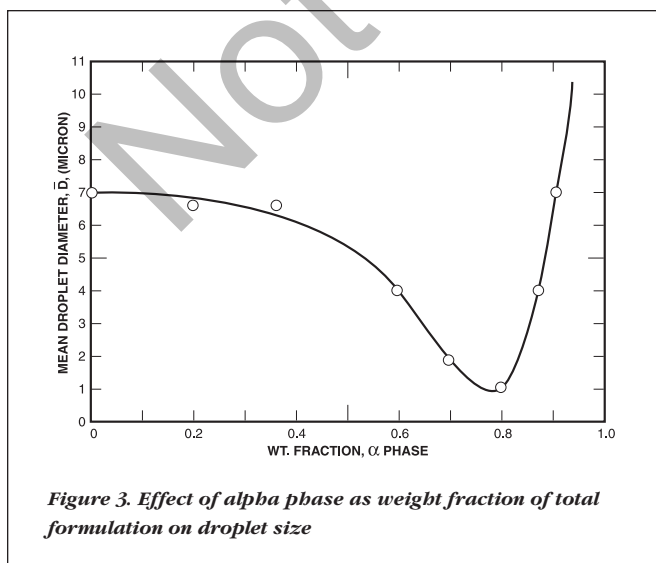
**Effects on Product Quality**

For most applications, an emulsion having finer average droplet size is more stable and regarded as better than ones with a larger droplet size. One of the most exciting discoveries in my LEE work was the accidental finding of a condition that allows finer emulsions to be formed with reduced energy input. It may be counter-intuitive, but this means that sometimes the quality of an emulsion can actually be improved by using less energy.

Figure 3 presents data from experiments designed to study the effect of the weight fraction of  $\alpha$  phase on the droplet size of the emulsion formed. In this system, emulsions formed



**Figure 2. Temperature curves for batch processing**



**Figure 3. Effect of alpha phase as weight fraction of total formulation on droplet size**

below  $\alpha$  value of 0.4 had virtually the same mean droplet size as the control emulsion made by a conventional hot method (i.e.,  $\alpha = 0$ ). Interestingly, the droplets became markedly smaller as the weight fraction of  $\alpha$  phase was increased, until the value reached 0.8. Since higher  $\alpha$  value means less energy input, this is an example of how using less energy can make better-quality emulsions.

One of the reasons why a very fine emulsion can be formed at the high  $\alpha$  value of 0.8 is the initial presence of a high concentration of surfactant in the emulsion concentrate. In this example, all of the surfactant is initially placed in the  $\beta$  phase and only 20% of the aqueous phase is used to make the concentrate.<sup>5</sup> Klein has reported a similar effect in his recent article on LEE.<sup>8</sup>

Many common cosmetic ingredients are heat-sensitive and can be degraded by high temperature. Sensitive materials include many fragrances, vitamins, preservatives and other active ingredients, such as dihydroxyacetone. These should

be added to the batch at a low temperature. By facilitating batch cooling, LEE can help prevent degradation and improve product quality.

## Conclusions

It is well known that the quality of an emulsion can be affected by many processing variables: emulsification temperature, mixing, cooling rate and even batch size. Adaptation of LEE inevitably involves introduction of many new variables in the manufacturing process. It is therefore not surprising that the quality of an emulsion made by LEE can be no different, worse or (sometimes) better than the same formulation made with a conventional hot process.

It is important to remember that LEE is not a single procedure that will either work or fail with a certain formulation. In addition to the process variables just mentioned, others (including the ratio of  $\alpha$  to  $\beta$  phase, the temperature at which  $\alpha$  phase is added and the rate of  $\alpha$  phase addition) can have pronounced effect on the properties of the emulsion manufactured with LEE. It is therefore very important to carefully carry out well-planned pilot-plant experiments, to determine the best procedure for each particular formulation and the available processing equipment.

The time spent on exploratory work will be well worth the reward, which is often much more than just energy conservation. LEE may well offer increased productivity, reduced processing cost and even reduced capital expenditure.

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