Manufacturing Process Scale-up in the Personal Care Industry: Problems and Solutions

SITARAM DIXIT
Corporate Manager – Fragrances
S.H. Kelkar & Company P. Ltd.
E-mail: sitaram_dixit@shkelkar.com

We all know that developing any new personal or household care product, involves laboratory work. During this early period of product development – whether new or even an improvement on the existing one – all development activities initially revolve around the product development laboratories equipped with basic standard equipment. Small-scale product trials using 500 to 1000 grams quantity is the norm in almost all product development laboratories, to establish the required essential properties in a newly developed product.

Small scale laboratory trials

A product development formulator uses laboratory samples for confirming principal product claims, aesthetic appeal, packaging possibilities, effect of fragrances, colour, etc., in addition to aiding derive a provisional method for large-scale commercial manufacture. The product development laboratory also helps in understanding the order of addition of various ingredients in the manufacturing process, the required temperature conditions for ingredient solubility, its stability, its compatibility and the optimum processing time. However, the important point to note here is that we should design all laboratory processes in a manner that it is neither overdone nor under processed, as either case will only lead to product instability and failure.

A small-scale laboratory helps the formulator build the final product formulation gradually and precisely, as required. In short, we cannot avoid the use of small-scale laboratory work, if we have to achieve success in establishing the basic product attributes, optimise manufacturing techniques and procedures in any new product development activity. Parallel to the above activity, a formulator also uses laboratory samples to undertake tests, to ascertain product performance, product stability, effectiveness of the product preservation system, customer and consumer likeability, in addition to product safety during manufacture and use.

Product development procedure is dynamic; typically involving continuous modifications and changes in the product formulation, so that the final product created fulfils the basic requirement envisaged at the beginning of the development process. Small-scale laboratory samples also enable formulation personnel to obtain product data related to quality assurance, various analytical control procedures necessary in manufacturing the product, which compares favourably with the set standard limits. Even though one establishes the provisional manufacturing process procedures in a pilot plant laboratory, the transfer from a laboratory scale to a full-fledged commercial scale, will invariably involve further fine-tuning pilot or larger plant trials, to sufficiently ensure that the product manufactured in the commercial plant is near identical to the one made in the laboratory.

Plant scale trials

Transition from a small-scale laboratory preparation, to a full manufacturing scale is plagued with a variety of problems. Many times these problems are neither easily rationalised nor resolved satisfactorily. In case of personal care products, problems can also arise in very simple processes that may only require dissolving a solid in a liquid medium or involve mixing together two or more similar liquids. In case of new products, change in raw material quality often cause unexpected scale-up problems. In complex formulations, as in the case of cosmetic creams and lotions, the problems commonly encountered may include solubilisation difficulties of an otherwise soluble ingredient, or changes in viscosity of the component system. Once laboratory development trials are completed, the next step is to carry out pilot plant trials.

Normally, we carry out pilot plant trials using around 50 kg / litre quantities or below, unlike full commercial scale plant trials, which is not below one tonne quantity. Pilot plant trials help the formulation development chemists to verify the laboratory tested formulation and the proposed manufacturing route. Carrying out pilot plant trials is an economically convenient method to confirm suitability of the formulation and the manufacturing technique, before proceeding to large-scale plant trial, as pilot plant equipments are normally near-identical to commercial plant equipments. The influence of scale-up factor depends largely on the nature of the product, the complexity of the formulation, the type of processing equipment used etc. If pilot plant trials are successful, then we can expect the subsequent full plant trial to be a success, even though there is no guarantee that scale-up problems may still not occur. Enumerated below are some typical cases.

Addition of ingredients

In any small-scale laboratory preparation, we add minor ingredients like actives, preservatives, colorants, fragrances in very small fractions of grams due to factors of scale. Since the batch preparation in a laboratory is small, we normally add all minor ingredients over and above the regular batch size, unlike in a larger plant batch wherein the total batch quantity makes up to one hundred in percentage terms. Moreover, when we manufacture the same formulation on a larger scale, we will add these ingredients at higher quantities due to factors of scale-up. This often requires adjustments of specified quantities, in comparison to the original formulation followed in the laboratory. It is important that when we effect changes in specified ingredients in any formulation, it should be in the range of at least ±0.5%, if we have to produce a readily and easily discernable change in the product. Adjustments at lower levels of 0.2% and below are not advisable, as minor change levels often produce very little perceivable change for taking decisions. Once positive effects of these active ingredient changes are firmly established, only then can we confirm the desired level and finalise the product formulation.

Mixing

When mixing liquids we find that laboratory size equipments are normally more efficient, when compared to a full size plant mixer, even though laboratory machinery requires extended trials to obtain the desired product homogeneity. The type of mixer used for making products is also very important, as the outcome of the product depends on it. Similarly, selecting the correct agitator type is also equally important for satisfactory results. Simple anchor type, paddle type or propeller type agitators are usually adequate for mixing miscible liquids or for dissolving solid ingredients in a liquid medium. If we have to prepare creams and lotions, or have to disperse an insoluble solid in a liquid medium, then we will have to make use of powerful high-speed, high-shear mixing units. It is important that the agitator used should have a speed controller system, to avoid unwanted product aeration caused by vortex formation during mixing.

The mixing method and type of agitation is as important as the type and quantity of emulsifying agent used for manufacturing any emulsified product. Most commercial emulsifying units used in manufacturing are fitted with two separate types of agitators. The first one is a high-speed, high-shear unit, fitted near the bottom of the manufacturing vessel, producing an emulsion of uniform droplet size, operating for a shorter duration while the two immiscible phases are mixed. The second agitator is a slow speed, anchor type stirrer that comes into operation during the cooling stage of the emulsified product.

Temperature control

Controlling temperature in a production plant is much easier and effective than in a laboratory, even though we encounter larger volumes in plants, requiring extended heating and cooling. This is because larger capacity vessels have better controlled agitator speed fittings, fixed baffles, internal wall scrapers etc., that help eliminate the risk of unwanted localised over-heating, which we cannot avoid in a small scale laboratory standard equipment without these specialised fittings.

Large-scale operations require handling larger amounts of raw materials. Adding individual materials, to complete the formulation, requires longer transfer time, unlike in case of a small-scale preparation. If we add the raw materials in the mixer very quickly, without proper and adequate agitation, it may adversely affect the clarity of the product, giving viscosity variation due to unwanted localised concentrations of the ingredients mixed.

Aeration

The speed and degree of agitation is very important, especially when mixing liquids. If the speed of mixing is too great, or the position of the agitator is improper, we get a liquid vortex, which causes viscosity problems in the product, in addition to accumulating air on the surface or incorporating too much air inside. Air once incorporated is normally difficult to remove, and will require good vacuum facilities. Sometimes certain surfactants selected may allow unnecessary incorporation of air and cause foaming problems during manufacture. Foaming problems can be minimised by use of suitable anti-foaming agents, although it is better to prevent foaming by taking precautionary measures during product manufacture.

Water quality

Most cosmetic and toiletries contain 50-80% water, and it is a normal practice to use only distilled or deionised water to manufacture it. Distilled and deionised water has no dissolved salts and is soft in nature. The presence of soluble inorganic metal salts of iron, copper, nickel and other transition metals in the process water can often lead to change in fragrance profile, colour deterioration, unwanted colour reaction, phase separation and instability. In certain cases, it is helpful to add chelates or sequestering agents (synergists) in a combination, to stabilise the cosmetic product and to retain the pleasant appearance (e.g., colour, odour, prevent cloudiness etc.), supplement the effectiveness of the preservative system, and ensure stability and efficacy of incorporated active ingredients (e.g., fragrances).

Synergists are complex metallic ions, primarily copper, iron and nickel, that act as catalyst in lipid oxidation. EDTA salts (ethylenediaminetetraacetic acid as di & tetra sodium salt), citric acid, tartaric acid, phosphoric acid, EHDP (ethane hydroxyl-1,1-diphosphonic acid), magnesium silicate, are most commonly used sequestrants. Water softener, if used, can be a source of serious microbiological contamination and regular testing and disinfection procedures are essential. It is advisable to filter all process water to remove debris and other particulates.

Emulsified products

The above simple suggestions discussed are applicable to aqueous, water-based formulations like shampoos, conditioners, bath and shower products etc. Cosmetic creams, lotions and other emulsified cosmetics, however, will require complex manufacturing processes, as a variety of scale-up factors plague them. The type of equipment, the rate of heating and cooling, order of ingredient addition, type of agitator used in emulsification, process time etc., all have a major bearing on scale-up operations. In the preparation of creams and lotions, the type of equipment used in manufacturing is just as important as the formulation or its constituents. In many cases, a formulation satisfactorily processed, using one type of equipment, may be difficult to produce or may fail to perform similarly, with a different type of processing equipment.

High-speed homogeniser may be necessary in some cases to initiate formation of a stable emulsion, and sometimes the same high-speed homogeniser may prove detrimental and produce an unstable emulsion. We have to establish all these manufacturing related features in the laboratory stage itself; and reconfirm it again in a pilot plant trial, before carrying out trials in a commercial plant. Emulsions are all unstable and we cannot easily dispute this fact. Successful emulsions are one's that are stable throughout their normal usable life span. It is possible to achieve this only by use of a reliable formulation, tested repeatedly in a manufacturing set up consisting of standard process equipment. Emulsions can be either oil-in-water (O/W), or water-in-oil (W/O) type. Emulsions also exist in complex forms like water-in-oil-in-water (W/O/W). We can achieve emulsion stability only by the formation of small droplets of one phase and dispersing it uniformly in the other continuous phase. The equipment and the mixing method followed to create an emulsified product are as critical as the quality, type and quantity of emulsifier. If we have to obtain a stable emulsion on a full-scale plant, very similar to the one obtained in a laboratory trial, it will require equipment able to relatively reproduce the same degree of shear and turbulence. This is no doubt a difficult task, owing to the increased material quantities involved in scale up, but is it impossible to overcome?

To produce a stable emulsion, we follow two typical steps: The first one is to produce a primary emulsion, by relative slow mixing of the emulsifier, oil and water phases, to produce a coarse emulsion with relatively poor dispersion. The homogenisation stage, using high shear mixer follows next, to produce a finely and uniformly dispersed droplet phase, throughout the entire continuous phase. The mixing vessel contains within both the homogenous unit and a variable speed agitator. It is important to make a similar arrangement in the pilot plant equipment, so that we can take care of scale-up issues suitably, in small-scale level itself, before proceeding to commercial scales.

We can achieve good droplet dispersion, even without using high speed, high dispersion motor by using the phase inversion technique. In any emulsification procedure, we normally add the dispersed phase to the continuous phase, with sufficient agitation and obtain a suitable emulsion. In an O/W emulsion, we normally add the oil phase to the continuous water phase and in a W/O emulsion it is vice-versa. In case of phase inversion technique, the situation exactly reverses: we add the continuous phase to the dispersed phase with continuous stirring, to obtain an unstable reversed emulsion that, on continued stirring, inverts itself to the desired correct phase, producing a very stable emulsion.

Many cosmetic emulsions have pseudo-plastic behaviour, i.e., when subjected to high shear mixing, it results in a significant loss of viscosity, although reduction of viscosity is not permanent, as it usually reverts to its original viscosity values after some time. Excess agitation of certain emulsions may change its viscosity permanently, even at lower temperatures. We may have to reprocess these emulsions, at the original emulsification temperature, to get our desired value, before finally cooling to it ambient conditions.

Personal care and laundry care bars

Soaps, syndet and combo bars are all produced on commercially available small-scale equipment. In the initial product development stage, we can use a small-scale toilet soap-making machine, for also manufacturing syndet and combo bars samples. The laboratory equipment is very similar to a commercial one, consisting of a sigma mixer, a triple roll mill, refiner, an extruder (with or without vacuum), cutter and a stamping machine. Samples made by using laboratory machine are suitable for assessing the effect of additives, colour, fragrance and even translucency, in case of a translucent soap. Laboratory-made samples smells better, with the fragrance smelling stronger, when compared to plant samples. Remember, laboratory samples do not have to undergo high temperature working. Moreover, small-scale equipments used in a development laboratory, usually do not sport vacuum facilities and so they have minimum loss of fragrance, unlike in a production plant, where you cannot avoid fragrance losses. However, we cannot use laboratory samples for assessing wear rate, cracking, degree of mushiness, aesthetic finish, hardness etc. We know that working in a pilot plant with kilogram amounts, is entirely different from working in an actual production site with several tons of material. Still, we can use pilot plant samples for assessing general hand wash trial, to test effect of soap additives, lathering and foaming properties and fragrance stability, as we can achieve these attributes, almost equivalent to the commercial samples.

Volume calculations

One issue that we always come across in this industry, while scaling up operations is the problem with capacities. Supposing we want to fill up 7,000 bottles with a liquid product, we will find that we have run out of stocks by only filling 6703 bottles, 297 bottles short. After a running round, trying to decipher the reasons, our investigation will reveal that our 100 ml capacity bottles, actually holds 104.62 ml. This seems a simple calculation error, but surprisingly happens in the industry quite regularly. I am sure that every company encounters this problem at some point of time. Preventing this problem from occurring is not difficult, but many a times, we either bypass these details due to paucity of time and urgency in completing the job of filling up the bottles or sometimes because someone supposed to work this out and make decisions is not even aware of it. It is important that everyone involved in the manufacture and packing of any liquid product, knows the basis of determining actual capacity of a product container, even if their current job may not directly require them knowing about it. In any case, nobody loses anything to anybody, if everybody knows something more about somebody!

Regulatory packaging law requires marketers to mention the net contents in the bottle label and packing. Liquids sell in volumes and the unit of measure most commonly used in cosmetic personal care product in India are millilitres and litres. The cited example above will make us realise how important it is for a production planner to know the actual net contents of the packaging, so as not to end up short on product packs. This minor error can become major, when we plan a larger production run, wherein the differences observed will become elephantine. Similarly, in case of relatively expensive products, these errors will be diabolical, especially in a high urgency situation, which is the bane of modern times. Product development procedures will encounter scale-up problems that we can neither predict nor prevent. However, the preliminary small-scale plant trials can seriously prove to be a good guide, helping to anticipate problems, enabling us to take the necessary steps to control the parametric preventive checks and balance our speedy quest to succeed.

ADDITIONAL READING

1. Product Development – A Perspective, Sitaram Dixit; *Chemical Weekly;* Jul. 9, 2002.
2. Consumer Product Research and Development – A stepping stone to success, Sitaram Dixit; *Chemical Weekly;* Oct 20, 2009.