Encapsulation via Microfluidics: An Economic Feasibility Study

Rodrigo-Gomez, R.; Gasull-Morales, A.; Fernandez-Prieto, S.; Smets, J.*
Procter and Gamble, Brussels Innovation Centre, Strombeek-Bever, Belgium

INTRODUCTION AND OBJECTIVES

Microfluidics devices enable a high control of the flow of the fluids by enclosing them in micro-channels. These devices have been applied to microencapsulation because of three main reasons:

1) Monodisperse Capsule Size
2) Control of Capsule Wall Thickness
3) Capsule Payload Uniformity

The right combination of these parameters can make the release of the capsule very well targeted in terms of trigger mechanism and level needed for delivering the active. Thus, the capsules obtained by using microfluidics would be very attractive for a huge range of applications.

In addition to the technical properties of a product, an important criterion for a successful industrial development is the affordability. Although the microfluidics field has been growing since its beginning, there is a lack of cost analysis of this technology, therefore, this work is aimed at developing a feasibility analysis for the production of microcapsules by using a microfluidics device.

MATERIALS AND METHODS

In this work, a feasibility study of the production of microcapsules using microfluidics was carried out. The block diagram of the process is shown in Fig. 1, where a microfluidics nozzle was implemented into a spray drier.

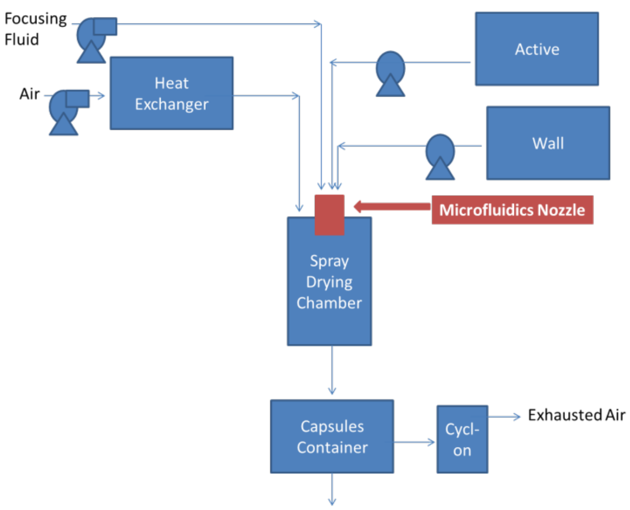

Figure 1. Block diagram of the microcapsule Manufacturing Process

The final cost of a given product is the addition of every cost involved in its manufacturing process, as shown in Eq. 1:

$$\mathbf{Cost}_{\mathrm{Capsule}} = \sum_{i=1}^{n} \mathbf{Cost}_{i} \qquad (1)$$

where $\mathrm{Cost}_{\mathrm{Capsule}}$ is the cost of the manufacturing and delivering the capsules and Cost_i are those cost involved in the whole process, such as materials, utilities, operating labor, maintenance, environmental control expenses, plant overheads, depreciation, shipment, etc. Due to the novelty of the technologies, the cost structure was simplified and the model was rearranged and given by Eq. 2:

$$\mathbf{Cost}_{\mathrm{Capsule}} = \mathbf{Cost}_{\mathrm{Mat.}} + \mathbf{Cost}_{\mathrm{Operating}} + \mathbf{Cost}_{\mathrm{Dep.}} \qquad (2)$$

where:

- $\mathrm{Cost}_{\mathrm{Mat.}}$ refers to the cost of all the materials involved in the process of manufacturing the capsules and was calculated according to the mass balance of the encapsulation process analyzed.
- $\mathrm{Cost}_{\mathrm{Operating}}$ mainly involves the cost of operating labor (direct and indirect workers) and utilities. The calculation for estimating the operating labor was performed by using predictive models as a function of the production rate of capsules (Vian-Ortuño, 1991; Wessel, 1952). In case of the cost of utilities, the calculation was made taking into account the energy balance.
- $\mathrm{Cost}_{\mathrm{Dep.}}$ refers to the intent of recovering the cost of the plant investment over a period of time, therefore, this term is basically the yearly amount of money dedicated to pay back for the initial investment for building the facility to manufacture the capsules. Then, this cost would include the estimation of the capital investment, based on the scaling factor method (Vatavuk, 2003).

The prices of the materials and utilities as well as the cost of equipments and labor were obtained through an internet survey.

RESULTS AND DISCUSSION

The feasibility study was started by assuming some base conditions. Afterwards, a study of sensibility was made in order to understand the impact of the different production costs on the capsule cost. The values of the variables are summarised in Table1 and Fig. 1 displays the result obtained in each scenario.

Table 1. Different scenarios simulated

	Scenarios				
Variable	1	2	3	4	5
Production rate (unit/year)	$6*10^3$	$6*10^2$	$6*10^3$	$6*10^3$	$6*10^3$
$\left(\frac{\text{Active}}{\text{Wall}}\right)_{\text{Capsule}}$	60/40	60/40	80/20	60/40	60/40
$\left(\frac{\text{Active}}{\text{Wall}}\right)_{\text{Cost}}$	5	5	5	8	5
Nozzle Cost	C.[1]	C.	C.	C.	0.1C.

[1]C. refers to current price.

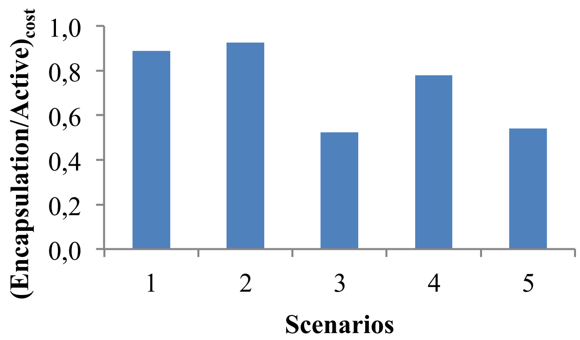

Figure 2. Results of the scenarios summarised in Table 1.

According to these results, the encapsulated active cost is up to 95% higher than before the encapsulation. Also, it can be observed that the most impacting variables are the cost of the nozzles and the capsule payload. The cost of the nozzle directly impacts on the investment needed to build the plant, which is transferred into the capsule cost as depreciation cost. Then, a reduction of the cost of the microfluidics technology used for the encapsulation implies a reduction in the capsules production cost of the capsule. The impact of the capsule payload on their final cost can be explained in three different terms. Firstly, an increase in the payload of the capsule entails a reduction of the wall material used, and in this way, a reduction in the material cost used to form a specific capsule. Secondly, the increase of capsule payload means a reduction of the production cost, since a lower usage of the utilities is translated into a lower operating cost. The third term at which the payload of the capsule has impact on is the depreciation, since an increase would imply a reduction of the number of nozzles used assuming that the total production rate of the nozzle is kept constant regardless of the individual production rate of the wall and the active.

The reduction of the production rate of active encapsulated seems not to have a big impact in the encapsulation cost. The decrease of the variable costs is not high enough to bring down the capsule final costs. It is obvious that the material has an impact on the capsule cost and this effect will be highly system dependant.

A sixth scenario was developed as summarised in Table 2. This scenario is the result of the combination of the values of the variables at the level of the lowest capsule cost obtained. The result is also summarised in Table 2. In light of the sixth scenario, the optimization of the capsule properties and the selection of cheap wall chemistry can bring a huge cost impact on the capsule cost by using microfluidics.

Table 2. Results for the Best Case Scenario

	Scenario	(Encaps./Active) Ratio Cost
Variable	6	
Production rate (unit/year)	$6*10^3$	0.25
$\left(\frac{\text{Active}}{\text{Wall}}\right)_{\text{Capsule}}$	80/20	
$\left(\frac{\text{Active}}{\text{Wall}}\right)_{\text{Cost}}$	8	
Nozzle Cost	0.1C.	

CONCLUSIONS

A feasibility analysis of a scaled plant of microencapsulation by using microfluidics devices was carried out. According to the results, the increase of the cost of the encapsulated active may range from 125% to 195% related to raw active. The most impacting variables seem to be the capsule payload and the investment to build the facility.

REFERENCES

- Vatavuk, W. (2003) *Cost engineering* in Chopey, N. P. (Ed.) Handbook of Chemical Engineering Calculations, McGraw-Hill, 3rd Ed., New York (USA), Section 18.
- Vian-Ortuño, A. (1991) *El Pronóstico económico en industria química*, EUDEMA, 4th Ed (in Spanish), (Madrid, Spain) pp114.
- Wessel, H. E. (1952) *New Graph Correlates Operating Labor for Chemical Process*. Chemical Engineering, 59 (July), 209-210.

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