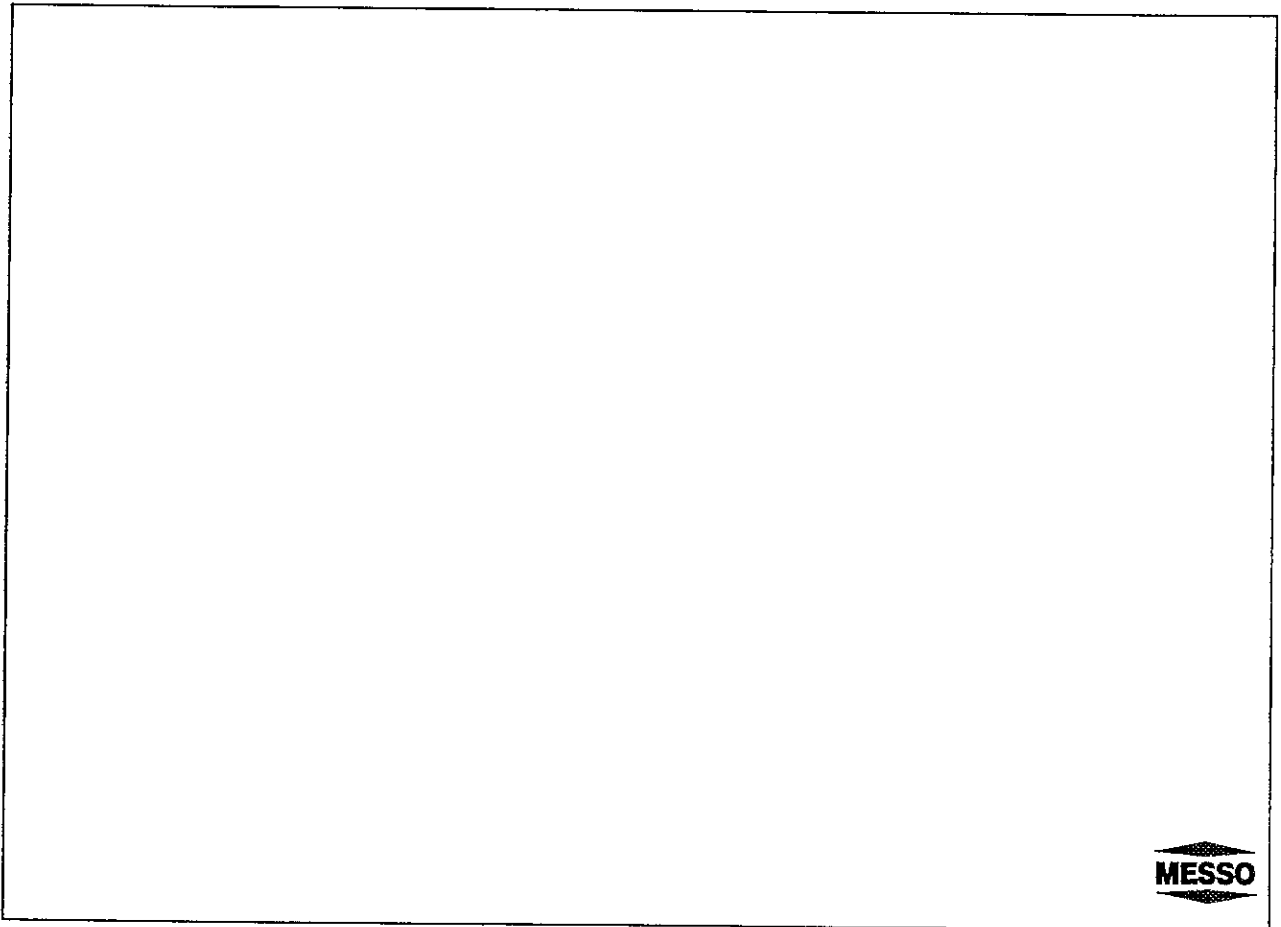


Fermentation Processes for the Production of Citric Acid

Joseph Shierholt



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In this article the author looks at the technology and economy of two different fermentation processes for the production of citric acid.

Up to the present, the technical manufacture of citric acid is effected to a high extent by fermentation of sugar-containing material, particularly with micro-organisms of the species *Aspergillus niger*.

Until the middle of this century, surface fermentation was almost exclusively applied. From then, fermentation in deep tanks, the so-called submerged process has also been employed. Clear criteria allowing a technical and economical evaluation to outsiders have been fairly unknown up to the present.

Whether surface fermentation or submerged fermentation is used, the required expenditures for either differ greatly with respect to buildings, equipment, pre-treatment of raw materials for fermentation, culture growth as well as required energy consumption.

This study attempts to present the economical advantages and disadvantages of both processes, as well as comparing technical details.

The following values were taken as far as possible from industrial plants.

For the costs resulting from fermentation, plant capacities of 72 t/d = 3 t/h and 12 t/d = 500 kg/h of citric acid were taken as the basis.

A fermentation yield of 70 kg of citric acid per 100 kg of sugar content of the raw material was calculated for both processes. To get comparable conditions, values were taken from fermentations using beet molasses as raw material in both cases.

The surface fermentation was presupposed to require a medium fermentation time of 9 days including formation of *mycelium*, cleaning, charge and discharge of the fermentation chambers. The submerged fermentation process is based on a medium time of 7 days, the cultivation of pellets requires an additional 2 days, including cleaning, charge and discharge.

Trays for the charge and discharge of the fermenters are automatic in both cases. However, to remove the *mycelium* from the trays of the surface fermentation and to clean the chambers, additional personnel are required and the fermentation chambers have to be entered.

With the submerged process, the volume of the fermentation tank is 300 m³ for the bigger plant and 150 m³ for the smaller plant. Due to the formation of emulsion and foam, they are charged to about 40% of their volume with fermentation solution.

At submerged fermentation, the viscosity in the fermentation media rises up to values of 450-750 c-poise. At surface fermentation, there is no evident change in viscosity. It is presumed that under optimal conditions in the fermentors of the submerged fermenta-

tion, a total pressure of 2,2 bar abs. has to be overcome. Therefore, due to increasing viscosity of the fermentation suspension, the consumption of electrical energy is relatively high.

With surface fermentation, the required quantity of air is fed out of central aeration systems according to the actual demand for cooling. Air is conveyed into the fermentation chambers with only a slight overpressure. Therefore, the fans require little energy even at high air capacities.

In the surface fermentation process, fermentation is carried out in large trays, arranged in several layers one above the other and side by side. Fermentation takes place on the surface of the solution in the *mycelium* layer, thus the thickness of the fermentation liquor has to be kept low.

This requires a large floor space for the fermentation station and therefore, higher investment costs in buildings (Table 1, subject 1). A mechanical system guarantees uncomplicated charge and discharge of the fermentation trays and their inoculation with the microorganism from outside as well (Table 1, subject 5). To remove the *mycelium* and for cleaning purposes, the fermentation chambers have to be entered. A homogeneous aeration of all chambers is very important. By using jet effects, this can be carried out with great effectiveness.

The submerged process requires large fermentation tanks with agitation and aeration systems as well as cooling systems to remove reaction heat.

Fermentation takes place in small pellets with a size of 0,5 to 1 mm, each formed by 500-600 spores, whose good consistence and distribution in the fermentation solution has to be ensured. In submerged fermentation, the raw material pretreatment has to be controlled more severely than in surface fermentation. The need of floor space and personnel for the submerged process, however, is lower than for the surface fermentation.

Aeration and circulation of the fermentation suspension require electrical energy. To overcome the hydrostatic pressure and the viscosity of the fermentation suspension increasing during fermentation, the energy

consumption is relatively high and the equipment for this purpose is more complicated and subject to relatively rapid wearing. On the other hand, more than 90% of the equipment in surface fermentation (trays and their frames) are simple and don't wear. So the equipment costs in submerged fermentation are higher than in surface fermentation (Table 2, subject 1).

The expenses on raw material are shown in Table 3. Here there are not many differences between the two processes. Only the pre-treatment costs are higher in the submerged fermentation (Table 3).

Table 4 shows the cost of the electrical energy consumption for both processes. The high consumption of electrical energy used for aeration, stirring and defoaming in the submerged fermentation is noticeable.

In Table 5 the expenses on personnel are shown. Here there are not many differences in the processes. The *mycelium* separation station and the cleaning of the fermentation rooms require more personnel in the surface process and in this case the expenses on personnel are higher, especially in countries with high wages. Contrary to this, the higher expenditure for preparing inoculum must be stated for the submerging process. In principle it is possible that further automation may occur for both processes and thereby the expenses on personnel may be further reduced. It should, however, be stated that due to the more complicated control of fermentation, automation is more expensive in the submerged process.

Table 6 shows total expenses. Taking annual depreciation into account, the annual costs of production shown on Table 7 are calculated. Interest, profits, etc., are not taken into consideration.

Only the expenses on fermentation have been considered. The costs for recovery of citric acid are not calculated. Furthermore, costs of storage and pumping of molasses and process water have not been taken into consideration, since they do not depend on the different fermentation processes and are nearly equal in both cases. The costs for sterilisation of the molasses solutions are not shown either, since it is supposed that they are equal in both cases.

a) Surface fermentation		72 t/d	(12 t/d)	b) Submerged fermentation		72 t/d	(12 t/d)
1. Fermentation chambers		30,0	(5,0)	1. Fermentation buildings		10,8	(2,2)
2. Pre-treatment station		1,2	(0,3)	2. Pre-treatment station with ion exchange		2,0	(0,6)
3. Biological rooms and laboratory		1,6	(0,4)	3. Biological rooms and laboratory		3,2	(0,6)
4. Space requirements for fans, sterile filters and air shafts		9,4	(1,6)	4. Space requirements for compressors and sterile filters and air ducting		9,6	(1,6)
5. Rooms for charge and discharge		12,0	(2,0)	Total		25,6	(5,0)
6. Sterile and control corridors		2,8	(0,6)				
Total		57,0	(9,9)				

*Dr. J. Schierholt, Standard-Messo Duisburg, Gesellschaft für Chemietechnik, Postfach, 4100 Duisburg 1, W. Germany.

Conclusions

- The building investment costs connected with the surface fermentation process are 2.5 times higher than those connected with the submerged fermentation process.
- Contrary to this, the expenses on equipment are considerably higher at submerged fermentation, and more than 60% of those expenses consist of complicated components which are subject to relatively high wear. On the other hand, more than 90% uncomplicated and almost non-wearing items (fermentation trays, tray frames) are used at surface fermentation.
- The total investment costs for the submerged process are about 25% lower for higher capacities and 15% lower for smaller capacities than for surface fermentation.
- The more favourable total investment costs for the submerged process are in contrast to considerably higher production costs for any capacity. Especially evident is the high consumption of electrical energy which is about 10 times as much as that required at surface fermentation.
- In the present stage of development, the expenses on personnel are higher for the surface process, especially in highly-developed industrial countries with extremely high wages. Nevertheless, a noticeable advantage at surface fermentation can be ascertained in industrial plants. For smaller plants as well in countries with low-wage level this advantage increases.
- In countries where cooling water temperatures exceed 20°C, additional expenses for cooling the fermentors are incurred by installation of cooling aggregates for the submerged process.
- Contrary to surface fermentation, the submerged fermentation is very sensitive to short interruptions or breakdowns in aeration and to infections, which results not only in losses of yield, but also in a total breakdown of the respective batch.
- At surface fermentation, the resulting citric acid solution is much more concentrated than at submerged fermentation, effected by higher evaporation rates during fermentation. Expenses and losses at the subsequent preparation of pure citric acid are adequately lower.

Finally, it should be mentioned that for a few years other kinds of microorganisms, *Candida oleophila* in particular, have been used for the technical production of citric acid. They do not substantially change the technical expenditure, especially the high requirements of electrical energy in submerged fermentation, however, seem to be less sensitive in the fermentation process. On the other hand, they often form undesired by-products, e.g. isocitric acid, and supply fermentation solutions with lower concentrates of citric acid (e.g. 5-6% in case of *Candida oleophila*).

As a result of the investigations on which this paper is based, the surface fermentation is supposed to be superior to the submerged fermentation. Essential criteria for industrial management are for example the ground requirements as well as the number and costs of assistants to be employed.

Table 2 Investment Costs, Equipment (Mill. DM)					
a) Surface fermentation			b) Submerged fermentation		
	72 t/d	(12 t/d)		72 t/d	(12 t/d)
1. Fermentation trays	13,5	(2,25)	1. Fermentors with ventilation	28,0	(5,2)
2. Tray frames	8,55	(1,5)	2. Pre-fermentors with ventilation	5,57	(0,9)
3. Pre-treatment station	0,9	(0,2)	3. Pre-treatment station	3,2	(0,7)
4. Culture growing and laboratory	0,62	(0,35)	4. Culture growing and laboratory	1,5	(0,8)
5. Central ventilation equipments	3,05	(0,5)			
Total	26,62	(5,0)	Total	38,27	(7,6)

Table 3 Production Costs, Raw Materials (Mill. DM/a)					
a) Surface fermentation			b) Submerged fermentation		
	72 t/d	(12 t/d)		72 t/d	(12 t/d)
1. Molasses	9,4	(1,5)	1. Molasses	9,4	(1,5)
2. Additional chemicals	1,26	(0,22)	2. Additional chemicals and regenerants	3,0	(0,5)
3. Nutrient medium for microorganisms	0,1	(0,017)	3. Nutrient medium for microorganisms	0,3	(0,05)
Total	10,76	(1,737)	Total	12,7	(2,05)

Table 4 Production Costs, Electrical Energy (Mill. DM/a)					
a) Surface fermentation			b) Submerged fermentation		
	72 t/d	(12 t/d)		72 t/d	(12 t/d)
1. Central ventilation equipments for fermentation chambers	0,9	(0,1)	1. Ventilation and agitating of the principal fermentors	7,9	(1,3)
2. Other power consumption	«0,1	(«0,1)	2. Ventilation and agitating of pre-fermentors	0,8	(0,1)
			3. Foam removers	1,6	(0,2)
			4. Separators	0,1	(0,01)
			5. Cooling water pumps	«0,1	(«0,01)
			6. Other power consumption	«0,1	(«0,01)
Total	0,9	(0,1)	Total	10,4	(1,6)

Table 5 Expenses on Personnel (Mill. DM/a)					
a) Surface fermentation			b) Submerged fermentation		
	72 t/d	(12 t/d)		72 t/d	(12 t/d)
1. Pre-treatment station	1,39	(0,35)	1. Pre-treatment station	2,08	(0,69)
2. Fermentation station	1,04	(0,35)	2. Fermentation station	1,04	(0,35)
3. Mycelium separation station and cleaning of fermentation rooms	7,0	(1,38)	3. Mycelium separation station	0,26	(0,26)
4. Culture growing laboratory and chief for fermentation station	3,44	(0,82)	4. Culture growing, laboratory and chief for fermentation station	4,52	(1,68)
Total	12,87	(2,9)	Total	7,9	(2,98)

Table 6 Total Expenses (Mill. DM)					
a) Surface fermentation			b) Submerged fermentation		
	72 t/d	(12 t/d)		72 t/d	(12 t/d)
1. Investment costs, buildings	57,0	(10,0)	1. Investment costs, buildings	25,6	(5,0)
2. Investment costs, equipment	26,62	(5,0)	2. Investment costs, equipment	38,27	(7,6)
3. Production costs/a	24,53	(4,78)	3. Production costs/a	30,99	(6,53)

Table 7 Annual Costs					
a) Surface fermentation			b) Submerged fermentation		
	72 t/d	(12 t/d)		72 t/d	(12 t/d)
1. Investment Costs (Mill. DM)					
1.1 buildings	57,0	(9,9)	1.1 buildings	25,6	(5,0)
1.2 equipment	26,62	(5,0)	1.2 equipment	38,27	(7,6)
total	83,62	(14,9)	total	63,87	(12,6)
2. Production Costs (mill. DM/a)					
2.1 raw materials	10,76	(1,74)	2.1 raw materials	12,70	(2,05)
2.2 electrical energy	0,90	(0,1)	2.2 electrical energy	10,40	(1,60)
2.3 personnel	12,87	(2,9)	2.3 personnel	7,90	(2,98)
total	24,53	(4,74)	total	31,00	(6,63)
3. Total annual costs (mill. DM/a)					
3.1 depreciation on equipment	1,78	(0,33)	3.1 depreciation on equipment	2,55	(0,51)
3.2 depreciation on buildings	1,90	(0,33)	3.2 depreciation on buildings	0,85	(0,17)
3.3 production costs	24,53	(4,74)	3.3 production costs	31,00	(6,63)
total	28,21	(5,40)	total	34,40	(7,31)