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## ECONOMIC EVALUATION OF HERB EXTRACTION USING SUPERCRITICAL FLUID

*Due to the climate diversity in different parts of Iran, a variety of plants grow across the country, many of them having pharmaceutical applications. At present, only a few companies are producing herbal essence, all of them are technically based on conventional methods of extraction such as steam distillation and others. Because of the current serious concern with respect to the environmental conservation law the use of green technology seems imperative. The supercritical fluid extraction is considered as a practical and procedural method which has become under serious consideration in recent years. For this, an economical analysis is made of herb extractions using a supercritical fluid. The results of such a survey can clarify the new methods to be of great concern. The aim of this paper is to present the feasibility studies of supercritical fluid extraction units used for producing a different plant extract and especially that of rosemary.*

*Key words: supercritical fluid; herb; extraction; rosemary; essence.*

Supercritical Fluid Extraction (SFE) is one of the methods that can selectively extract specific components. This method has several privileges such as the simplicity of the solvent recovery from the extracted material, the minimization of losses of materials, high purity of the product, as well as the retention of volatile constituents [1]. On the other hand, and due to high investment requirements comparing to conventional or traditional methods such as solvent extraction and steam distillation of the products like rosewater, the method is paid less attention. However, one of the disadvantages of this method is the difficulty in maintaining a continuous process that is an alternative method to the batch systems in which a considerable decrease in the product amount is achieved. Regarding the fact that the cost of the synthetic products is low, SFE can not compete with these products. The selective advantage of the extraction method is the flourishing one. Such advantage can easily be achieved depending on the operating conditions. Therefore, this method cannot be feasible when only one compound is extractable in which

case the conventional method is more likely to be used. Low operating cost is another advantage of the supercritical extraction.

Because of the plant variation, and also the availability of inexpensive raw material and low labor cost in Iran and the global demand for high quality products, this method has been given a great concern for producing essences. However, the economical aspect of SFE has also been paid a serious concern in the literature, but they are either focused on specific regions, (*e.g.* Latin America, etc.) [2], or deal with the extraction based on the use of liquefied gases [3,4]. Pereira and Meireles [5] have made a survey on the issue by which they proved that the manufacturing costs of the extracts produced by SFE were lower than those produced by conventional methods.

Designing an industrial unit of SFE cannot be simply supported by laboratory data and so it is highly recommended that mass transfer parameters for large scale units are carefully taken into account. While the scale-up processes may face problems such as fluid channeling, a pressure drop, agglomeration of material; the laboratory data for economical analysis could suffice with minimum error.

### EQUIPMENT

In order to achieve a reasonable analysis, a laboratory SFE unit was set-up for running up a semi-

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-batch process. It typically consisted of an extractor, a series of stills for separating the extracted materials from the solvent; a condenser for re-liquefaction of CO<sub>2</sub>, a reservoir for CO<sub>2</sub> storage, a heater to maintain the operating temperature and a pump to supply the required high pressure of the system. A schematic diagram of the set-up is shown in Fig. 1. As the pressure drop between the extractor and the separator is increased, the more energy is required. So the extraction cost of the specific compounds for which the operating pressure of the extractor approaches that of the separator, is lower. Due to the non-polarity of CO<sub>2</sub>, the solubility of some functional groups is low. Therefore, for a better extraction one can add an auxiliary solvent such as ethanol [6]. It is important to consider that the method used in this paper could be further improved by adopting a better selection of the extraction time.

Generally, the manufacturing cost of a typical unit is 70-85% of the total investment cost, which is related to the high-pressure vessels, pumps and safety as well as instrumentation parts. So the more diffi-

cult is the operating conditions such as pressure and temperature; the higher investments are required. For this reason, a pressure correction factor can be defined as below [7]:

$$PCF = 0.490 + 0.00128\rho_{\text{nom}} \quad (1)$$

Most of the studies done by the researchers are carried out at temperature range of 10-120 °C and pressure range of 50-690 bar [7,8]. While the ratio of height to diameter of the extractor vessel in a laboratory scale is between 2 to 29; in an industrial case it is taken to be between 5 to 7 [1]. In the current work, this ratio is considered as 2.

It has been shown that the cost of plant increases with capacity according to the following equation [9]:

$$FCI_2 = FCI_1(RM_2/RM_1)^{0.6} \quad (2)$$

A more accurate method for estimating the cost is introduced by Perrut [10] who has formulated the corresponding parameters as in the Eq. (3):

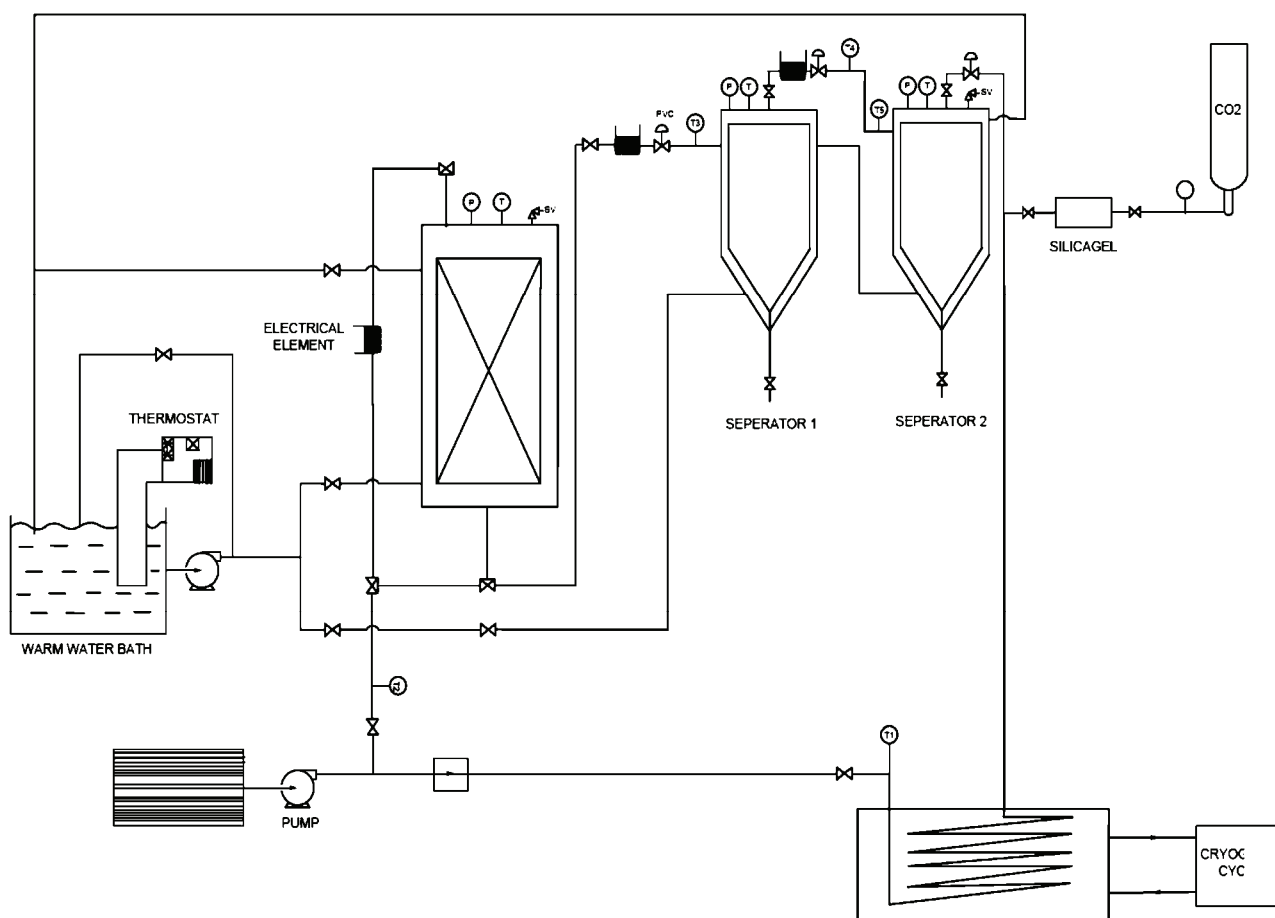


Figure 1. SFE Pilot Plant Scheme.

$$FCI_2 = FCI_1 \left( \frac{V_{E2} f_{CO_2 2}}{V_{E2} f_{CO_2 1}} \right)^{0.24} \quad (3)$$

This formula applies for a wide range of size and application.

## COSTS

In general, the overall costs of a plant such as those in a SFE unit could be direct and/or indirect. Direct expenses include fixed and operating costs, the former of which mainly cover a design and equipment purchase, while the operating costs consist of raw material, labors, CO<sub>2</sub> supply, as well as the utility. The indirect expenses include issues like tax, insurance, depreciation sales, marketing etc. Subtracting these costs from sales income leads to gross-profit.

### Direct costs

The direct costs in a SFE unit cover 30–70% of total production expenses [2]. This cost rises directly with the price of raw material, labor and the utility, while decreases with the extraction time. So:

$$DC = CRM + CL + CU \quad (4)$$

Raw material costs include: herb price, preparation expenses and transportation, as well as the amount of CO<sub>2</sub> lost. In some cases a pretreatment of raw material is required before the extractor process. For example, if the water content of the feed is above 15%, it will cause the extraction yield to diminish. Therefore, it is necessary to dry out the feed before the extraction process, which is run at a medium room temperature with ambient flowing air. Depending on the type of material (*i.e.*, root, fruit, leaf and granule); there are other preparation processes such as; cutting, cleaning, milling and classifying. Since the extraction units are usually built in the vicinity of the farms, the transportation cost is normally neglected.

Loaded material in each batch depends on the density, as well as on the particle size distribution of the raw material. One has to bear in mind that with the higher water content, the higher density is to be expected. In a SFE process, if the product remains in a solid phase (such as those in the case of the extraction of tea, coffee etc.), the apparent shape of the raw material must be maintained constant. But when the product is in a liquid phase, changing the shape is not going to have much effect on the product, as the feed material can, up to some extent, be compressed which is due to achieve a better production rate.

Moreover, the cost of the raw material can be found as:

$$RMC = V_E \rho_B \frac{W}{t_B} P_R + W_h W_d f_{CO_2} I_{CO_2} P_{CO_2} \quad (5)$$

In an industrial system, when the extraction vessels are unloaded and the sample extract is retrieved, CO<sub>2</sub> loss occurs with the amount of 0.5 kg/kg extract [11]. Considering the safety precaution for a more efficient system, this can be decreased up to an amount of about 2% per cycle [12]. Since the mass transfer rate depends on *Re* and *Sc* numbers, the higher the solvent rate, the lower is the time to achieve a fixed efficiency, while the cost of CO<sub>2</sub> loss, utility and pumping CO<sub>2</sub> will increase.

However, the increasing of the extractor height, while maintaining CO<sub>2</sub> flow rate constant, will cause the extraction rate to decrease. That is due to the decrease of the driving force at the end of the container and the solvent may then become saturated. SFE is a process where the solvent/solute form a much diluted solution and saturation is never achieved. What happens is that the easily accessible solute on the particles surface decreases as the extraction progresses. Hence, the rate of the extraction decreases. Therefore, no mass transfer will take place. If superficial velocity were a key factor for deciding the flow rate, the yield would decrease considerably. In order to ensure a desired performance in an industrial unit based on a laboratory or pilot unit data, the Eq. (6) for CO<sub>2</sub> flow rate is suggested [13]:

$$\left( \frac{f_{CO_2}}{V_E \rho_B} \right)_2 = \left( \frac{f_{CO_2}}{V_E \rho_B} \right)_1 \frac{H_{B1}}{H_{B2}} \quad (6)$$

Most industrial SFE units are equipped with automatic control devices. Therefore, not many man powers are required for loading and unloading the extractors. So the labor costs can simply be calculated by Eq. (7):

$$LC = N_w W P_w \quad (7)$$

The required utility for a typical SFE unit includes electricity, steam, and cooling water. Electricity is used for running a pump, a condenser, and a possible warming up of the process water up to a desired temperature. The utility cost can also be determined by the following equation, [10]:

$$UC = (POP_E + m_s P_s + m_c P_c) W \quad (8)$$

### Indirect costs

The annual production rate is not dependent on indirect costs, the list of which is shown in Table 1, while there are other general costs that are required to be considered and are not directly related to the

operating or fixed costs. These are also the sales, marketing, research and development as well as administrative costs for which an approximate amount of 5% of the total investment is considered [9].

Table 1. Approximate amount of indirect cost [9]

Insurance	1 % FCI
Depreciation	10 % FCI
Maintenance	2 % FCI
Property tax	1 % FCI

### Profit analysis

In most cases, the achieved income of the herb extraction is through the sales of the “final product” and in other cases the residue as a by-product is sold out. In order to determine the net profit, the total cost must be deduced from the total income. The net profit is calculated as:

$$TI = ES + BPP_{BP} \quad (9)$$

$$E = V_E \rho_B \frac{W}{t_B} Y_E \quad (10)$$

Since the extraction yield-time profile shows an increasing trend, the net profit of the SFE process for the fixed extraction time  $t_B$ , reaches its maximum value. An optimum value of  $t_B$  can be determined by differentiating the yield function *versus* time. At the beginning of the process, the extraction rate normally changes linearly with time, while at higher yields the trend decays. So, for economical consumption of raw material and hence decreasing the solid waste, it is suggested to proceed with the extraction process until the rate becomes constant. But for the case when the raw material is expensive, the optimum extraction time might exceed the constant rate. To increase the efficiency, two extraction vessels are used. That is simply because when one is in operation, the other one is loading the content.

### Rosemary

In this section, the economical analysis of the supercritical fluid extraction of rosemary is taken into consideration. Rosemary is widely grown in Iran. The optimum operating condition for rosemary extraction is 300 bar and 40 °C [14]. As the temperature is low enough, using the steam for warming up the extractor is not necessary. The price of this herb in a wet basis is around \$400/ton in Iran. Figure 2 is an indication of the process yield in terms of one kg of the extract per 100 kg of rosemary plant [14]. The yield trend attained in this research is comparable to that of others in the literature [1,2]. The results showed the independency

of the yield to time at higher rates. This has also been approved by other researchers [11].

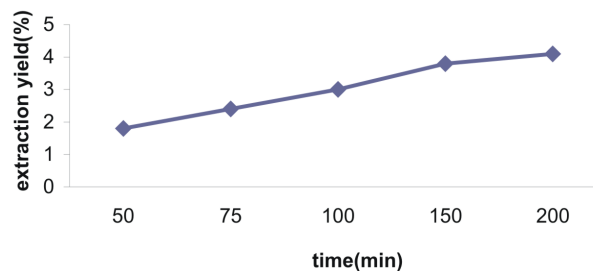


Figure 2. Rosemary extraction yield at 40 °C and 300 bar versus time.

Based on the above methods, and considering the work done by Del Valle [7], the corrected price of a simple supercritical plant - together with possible changes in capacity, the flow rate and pressure - would end up to \$1,400,000. Regarding other expenses such as land, buildings, working capital and other relevant expenses, the total Fixed Capital Investment, FCI, for such a unit is estimated to be about \$1,800,000. The sale price for the extracted essence in a bulk form is about \$200/kg. The analyzed data are summarized in Table 2.

Table 2. Assumed data used in this analysis

FCI	\$1,800,000
Cost of raw material	\$400/ton
Selling price	\$200/kg
Extractor volume	200 dm <sup>3</sup>
Cost of CO <sub>2</sub>	\$0.3/kg
CO <sub>2</sub> loss	0.04 total flow for CO <sub>2</sub> loss
Labor cost	\$2/h
Number of workers per shift	2
Electricity	\$0.02/MJ
Working hours	16 h/day
Working day	300 day/year
Fixed cost	14% FCI
General expense	5% FCI
Income tax	30% total income
Batch time	50 min
Bed density	350 kg/m <sup>3</sup>
Product yield	1.8 kg <sub>Product</sub> /100 kg <sub>Feed</sub>

## RESULTS AND DISCUSSION

The residue of the process often has not had a considerable value, though it may be used for agricultural purposes. But the extract, on the other hand is the main source of income of a SFE factory. However, the amount of raw material can be obtained, using the equation below:

$$RM = V_E \rho_B \frac{W}{t_B} = 403200 \text{ kg/year} \quad (11)$$

In order to determine the annual rate of CO<sub>2</sub> loss, pumping power and condenser duty it is necessary to calculate the CO<sub>2</sub> flow rate. Carvalho Jr. *et al.* [14] suggested a relation for calculating the flow rate of the two SFE units with an equal *L/D* ratio:

$$\left( \frac{f_{CO_2,1}}{f_{CO_2,2}} \right) = \left( \frac{RM_2}{RM_1} \right)^2 \frac{H_{B1}}{H_{B2}} \left( \frac{d_{B1}}{d_{B2}} \right)^3 \quad (12)$$

Since the optimum height to diameter ratio *L/D* for rosemary extraction is 2.8 [14], the best size extractor vessel is a cylinder with 125 cm height and 45 cm diameter. Therefore the CO<sub>2</sub> flow rate for 200 L extractor unit is found to be 51 kg/h; the cost of CO<sub>2</sub> loss and the cost of raw material can be determined as below:

$$CLC = W f_{CO_2} / c_{CO_2} P_c = 16 \times 300 \times 51 \times 0.04 \times 0.3 = 2,938 \text{ \$/yr} \quad (13)$$

$$RMC = R P_R + CLC = (403.2 \times 400) + 2,938 = \$164,217/\text{yr} \quad (14)$$

With respect to manpower and a better operating performance, two labors are required for every work shift. Hence:

$$\$LC = N_w W P_w = 2 \times 16 \times 300 \times 2 = \$19,200/\text{yr}$$

As mentioned earlier, it is not necessary to use steam for rosemary essence, therefore the production process plant requires only electricity. The power required for the unit is the sum of the power of CO<sub>2</sub> pump, a compressor used for a condenser, a water heater and other miscellaneous items such as lightning and others. Table 3 shows the approximate amount of the electricity consumption for all required utilities.

Table 3. Energy consumption of different auxiliary equipments

CO <sub>2</sub> pump	1 hp
Compressor	5 hp
Heater	2 hp
Miscellaneous	2 hp

Based on Eq. (4):

$$DC = RMC + LC + UC = \$186,000/\text{yr}$$

and referring to Table 2:

$$FC = 0.14 FCI = \$252,000/\text{yr}$$

$$GC = 0.05 FCI = \$90,000/\text{yr}$$

Hence, the total cost is found to be:

$$TC = DC + FC + GC = \$528,000/\text{yr} \quad (15)$$

where *TC* is total cost. For calculating the process benefit, the first step is to calculate the total production in a year. So the extracted material is determined by:

$$E = RMY_E = 403,200 \times 0.018 = 7258 \text{ kg/yr} \quad (16)$$

Also the total income - neglecting any by-product - can be found as:

$$TI = ES = 7258 \times 200 = \$1,451,600/\text{yr}$$

Hence, the gross profit is determined as below:

$$GP = TI - TC = \$923,600/\text{yr} \quad (17)$$

Turton *et al.* [12] has shown a simple method for calculating the production cost in a SFE unit:

$$TC = 0.304 FCI + 2.73 LC + 1.23 RMCUC \quad (18)$$

based on which the total annual cost would be \$805,000. This will result in an amount of \$453,000 benefit *per year*.

## CONCLUSION

Considering the wide scope availability of different plant species in Iran, the inexpensive labor, the government support policy for supplying low interest loans on such plants, the extraction processes of herbs are found to be a suitable option in the region. Based on these reasons, the application of an Industrial SFE unit can be potentially implemented. Establishing such units in northern or central part of the country is more feasible because of the high profitability and low pay-out period.

Further research work on the topic can be directed towards the optimization by an improved experimental design and conditions.

## Nomenclature

<i>BP</i>	By-product mass (kg/yr)
<i>CL</i>	Cost of labor (\$/yr)
<i>CLC</i>	Cost of lost CO <sub>2</sub> (\$/yr)
<i>CRM</i>	Cost of raw material (\$/yr)
<i>CU</i>	Cost of utility (\$/yr)
<i>d<sub>B</sub></i>	Bed diameter (m)
<i>DC</i>	Direct cost (\$/yr)
<i>E</i>	Extracted material (kg/yr)
<i>FC</i>	Fixed costs
<i>FCI</i>	Fixed capital investment
<i>f<sub>CO2</sub></i>	CO <sub>2</sub> flow rate (kg/h)
<i>GC</i>	General Costs
<i>GP</i>	Gross profit (\$/yr)
<i>H<sub>B</sub></i>	Bed height (m)
<i>LC</i>	Cost of labor (\$/yr)

$I_{CO_2}$	CO <sub>2</sub> loss (%)
$m_c$	Cooling water flow rate (kg/h)
$m_s$	Steam flow rate (kg/h)
$N_W$	Number of workers per shift
$P$	Pressure (bar)
$P_{BP}$	By-product price (\$/kg)
$P_c$	Cooling water price (\$/kg)
$P_{CO_2}$	Cost of CO <sub>2</sub> (\$/kg)
$P_E$	Electricity price (\$/MW h)
$PCF$	Pressure correction factor
$p_{nom}$	Nominal pressure (psi)
$PO$	Total power required (MW)
$P_R$	Raw material cost (\$/kg)
$P_s$	Steam price (\$/kg)
$P_W$	Labor's cost (\$/man-hour)
$Re$	Reynolds number
$R$	Rate of raw material (kg/yr)
$RM$	Raw material (kg/yr)
$RMC$	Cost of raw material (\$/yr)
$S$	Product selling price (\$/kg)
$Sc$	Schmidt number
$t_B$	Batch time (h)
$TC$	Total cost (\$/yr)
$TI$	Total income (\$/yr)
$UC$	Cost of utility (\$/yr)
$V_E$	Extractor volume (m <sup>3</sup> )
$W$	Annual working hours (h/yr)
$W_d$	Annual working day (d/yr)
$W_h$	Daily working hours (h/d)
$Y_E$	Extraction yield (kg <sub>Product</sub> /kg <sub>Feed</sub> )

*Greek Symbol* $\rho_B$  Bed density (kg/m<sup>3</sup>)

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