COST ESTIMATION FOR CO_2 SUPERCRITICAL EXTRACTION SYSTEMS AND MANUFACTURING COST FOR HABANERO PEPPER

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Abstract. An equation to estimate cost of industrial size supercritical extraction systems is provided and used to estimate the cost of manufacturing (COM) for habanero pepper oleoresin on extraction cells from 5 to 400 liters. The correlation is based on quoted cost for five sizes of supercritical extraction plants, and takes into account inflation with the use of chemical engineering plant cost index. COM for habanero pepper is based on experimentation on a 0.1 liter cell.

Keywords: prediction of cost, supercritical extraction, cost of manufacturing, habanero pepper oleoresin

1. Introduction

Habanero pepper (Capsicum chinense Jacq) is popular specie at the Yucatan peninsula in Mexico. Like Tequila, it is protected by a denomination of origin and is valued by its sensorial attributes of color, pungency and aroma. Actually at Yucatan it is sold as fresh fruit, hot sauces, pastes and dry powder. It is desired to extend the chain of habanero pepper products and one possibility is the production of oleoresin or habanero pepper oil that contains capsaicinoids and carotenes.

Capsaicinoids are used worldwide as natural flavor and colorant in the food industry, as animal repellent, for the production of security sprays, as well as raw material for pharmaceutical industries. According to the Scoville scale, habanero is one of the most hot peppers but still with a good aroma and flavor. By appropriate dilution it can accompany almost any meal.

When capsaicinoids are used for human consumption the extraction process should not employ organic solvents like hexane, but could be done by using supercritical carbon dioxide.

It have been reported the supercritical extraction of capsaicinoids using carbon dioxide on several type of peppers: black pepper [1], paprika [2], Jalapeño [3], chili (var. Byedige) [4]. For habanero pepper we found a Korean patent [5] and a conceptual design for a plant that use CO_2 to produce capsaicinoids [6]. A recent work [7] report capsaicinoids extraction during osmotic dehydration of habanero chili pepper in brine.

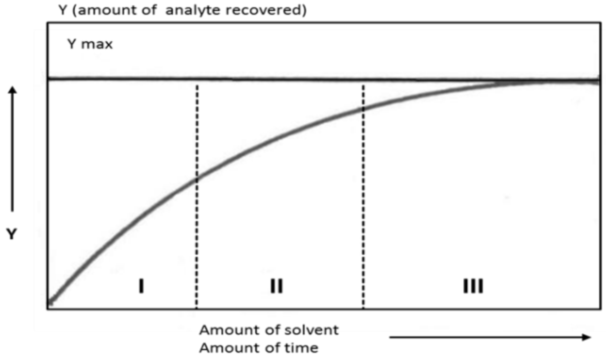

Figure 1. Extraction yield versus time and mass of carbon dioxide

Figure 1 shows the theoretical extraction profile of an analyte from a solid matrix using a dynamic system. The profile can be divided into three distinct regions: The initial extraction of material occurs rapidly and is dependent upon the solubility of the bulk analyte in the supercritical fluid (region I). Region II is an intermediate region where the extraction process occurs at a slower rate of extraction due to diffusion-controlled kinetics. Region III represent the portion of the extraction where the process is truly diffusion limited.

For manufacturing cost estimation [8, 9] only the first linear region, known as the constant extraction region is used. This corresponds to the extraction of the more accessible solute, and hence the mass transport is dominated by the convection in the solvent film surrounding the particles.

Development of commercial supercritical extraction systems requires economical evaluation of process at different levels. At the initial stages or order of magnitude estimates the cost of equipment and cost of fabrication could be approximate but need to take into account capacity and inflation. These estimates need to be more accurate when we advance in the project and approach definitive or detailed estimates.

Equation 1 may be used to estimate equipment cost as function of inflation and capacity by knowing the cost of equipment at other capacity purchased in other time and cost index like Chemical Engineering Plant Cost Index (CEPCI)

$$C_2 = C_1\left(\frac{I_2}{I_1}\right)\left(\frac{V_2}{V_1}\right)^n \qquad (1)$$

C_2 is the cost (USD) of desired equipment with capacity V_2 (liters) at actual time
C_1 is the cost (USD) of known capacity V_1 (liters) at reference time
I_2 Cost index at desired or actual time
I_1 Cost index at base time when cost is known
n Cost exponent (often around 0.6)

The present work use quoted and reported data to elaborate a prediction for the cost of supercritical CO_2 extraction equipment. Then use it together with the format proposed by Rosa and Meireles [8] and Meireles [9] to estimate the manufacture cost of habanero pepper with supercritical CO_2. Comparing manufacturing cost with commercial cost may provide a sense of the viability of the process.

2. Materials and methods

Table 1 shows the data used to develop the correlation to predict the cost of CO_2 supercritical extraction equipment. A typical extraction system have two extraction cells and two separation vessels, one for high pressure and one for low pressure.

Table 1. Data for equipment cost

Volume (Lt)	Cost (US$)	Reference
5.0	75,000.	Cited by Meireles, 2009
12.0	271,000.	Quoted on 2008
50.0	400,000.	Cited by Meireles, 2009
200.0	1,253,000.	Quoted on 2008
400.0	2,000,000.	Cited by Rosa and Meireles 2005, and Meireles, 2009

For the development of equipment cost correlation we used quotation (July, 2008) for 12 and 200 liter cells and three costs of the extraction units cited in [8, 9] corresponding to 5, 50, and 400 Lt.

It is observed that the same cost were used in 2005 by Rosa and Meireles [8] and then at 2009 by Meireles [9] neglecting inflation of four years.

Equation 2 shows the recommended expression [8, 9] for the estimation of manufacturing cost (COM) as function of capital investment or equipment cost (F_{CI}), operational labor cost (C_{OL}), utilities cost (C_{UT}), waste treatment cost (C_{WT}), and cost of raw material (C_{RM}).

$$COM = 0.304\,F_{CI} + 2.73\,C_{OL} + 1.23\cdot(C_{UT} + C_{WT} + C_{RM}) \qquad (2)$$

3. Results and discussion

3.1 Correlation for cost of SFE equipment

Data of Table 1 was correlated using Excel Spreadsheet with polynomial and potential approximation. Equation 3 shows the correlated expression to calculate the cost of the equipment with the volume value in liters and cost in U. S. Dollars at year 2009 with a CEPCI value of 521.9

$$Cost\,(U.S.Dollars)=\left(\frac{I_2}{I_{2009}}\right)\cdot\left[31901\times Volumen\,(liter)^{0.6909}\right] \qquad (3)$$

Figure 2 shows the correlated values. By example in 2011 CEPCI was 585.7 giving a ratio of 585.7/521.9= 1.122 meaning that in those two years inflation increases the values of equipment about 12 %. The estimation of a 100 liters system would provide: 768,430 USD in 2009 and 862,367USD in 2011.

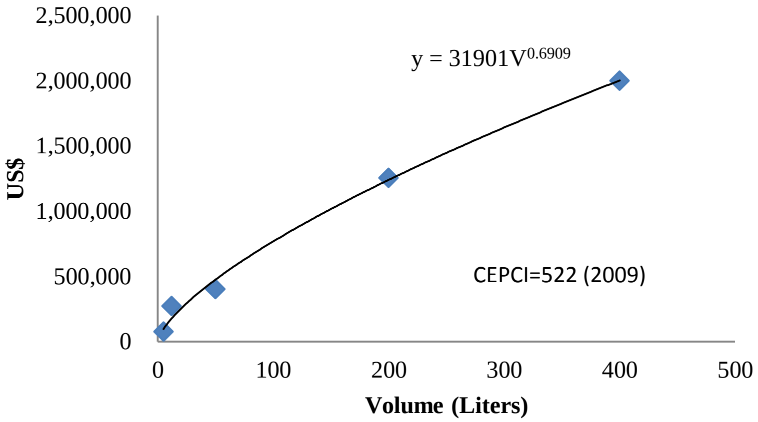

Figure 2. Correlated cost for SFE equipment

3.2 Correlation for cost of manufacturing

First we used the paper of Rosa and Meireles [8] for clove buds in a system with two cells of 400 Lt (0.4 m^3). One cell is in operation and the other is discharging, cleaning or preparing next feed. The pressure at the cell is 100 bars and the temperature is 15°C in the paper [8] and 35°C in the book. The second temperature fixes more clearly supercritical conditions.

The heuristic is that industrial cell would have the same performance as that of the laboratorial scale unit. This will happen for bed density and mass flow rate of CO_2. In the paper [8] the bed density seems to be (208 kg/0.4 m^3=520 kg/m^3) but in the book [9] they use a density of 750 kg/m^3.

For the mass flow rate of CO_2 through the cell it seems that they use a mass flow rate residence time $\tau(s)$=kg of solids in cell/mass flow rate of CO_2 (kg/s). In the paper [8] it seems that the values are: $\tau(s)$=208(kg)/0.02506 (kg/s) =8300 s and then the mass flow rate of CO_2 in kg/hr for the industrial size equal 90.2 kg/hr.

With the flow rate of CO_2 and using the simulator Aspen Plus, we calculate the energy required to expand the outlet of the extraction cell assuming a flash operating at 40 bar then reducing pressure from 100 to 40 bar, then a condenser is used to transform the vapor outlet into liquid, then a pump is used to re-compress the CO_2 back to 100 bar, and finally a heater to get the original temperature of 35°C.

We read from Figure 1 of the paper [8] the yield (kg of oleoresin extracted/kg of clove buds in cell) for each time and calculate the mass extracted per cycle for each time used. Dividing the number of hours worked in a year (2920) between the hours of the extraction we got the number of cycles per year and then multiplying it times the kg produced for cycle we got the mass (kg) produced in one year. Then we calculate the amount of raw material used.

Capital investment or equipment cost (F_{CI}) was calculated multiplying the cost of the equipment US$2,000,000 by the annual depreciation (0.1) obtaining US$200,000 for F_{CI}; Operational labor cost (C_{OL})

was calculated multiplying the number of operators estimated (2) times the number of hours in one operational year (7920) times the number of U. S. Dollars per hour paid (3.00); Utilities cost (C_{UT}) were calculated using the Kcal/hr estimated with Aspen Plus times the following values suggested by the SuperPro Design Simulator: US\$0.0133/Mcal for saturated steam, US\$0.0837/Mcal for cold water, and US\$0.0703/Mcal for electric power. Other possible sources is Table 6.3 from Turton´s et al. book [10]; Waste treatment cost (C_{WT}) was neglected taking in consideration that most of spent seeds still have nutrients that are of interest of other people and are used as animal feed; Finally the cost of raw material (C_{RM}) was calculated taking in consideration the cost of raw material (US\$505/ton) and the cost of pre-processing (US\$30). Also a loss of 2% CO_2 was considered in the raw material cost considering a cost of US\$0.10/kg of CO_2

The same described procedure was applied to the other sizes. Figure 3 shows what we got for Figure 6.6.2 of Meireles book [9].

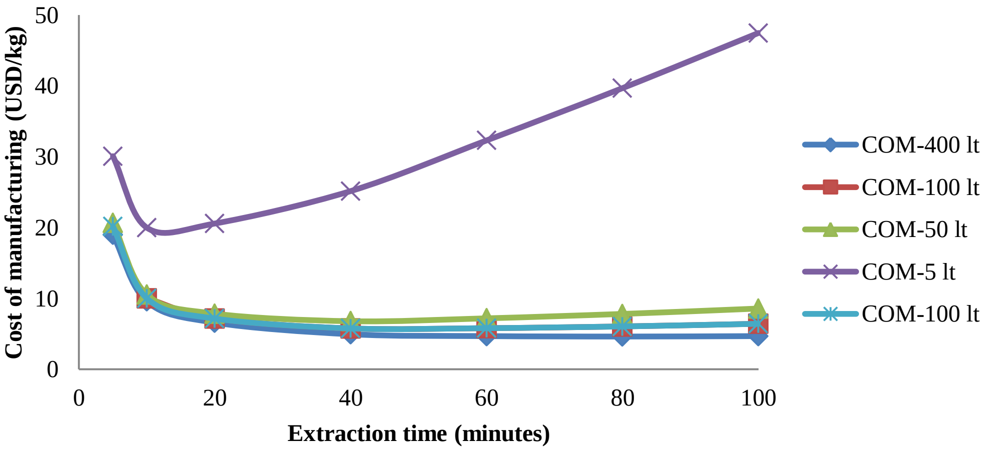

Figure 3. Cost of manufacturing for Clove buds

Then we applied the same procedure to the habanero pepper data. Using experimental results of Guillermo [11] and kinetic data obtained in this study shown in Figure 4 as the experimental CO_2 extraction curve for habanero pepper. In the thesis of Guillermo the yield defined as grams of oleoresin extracted divided by the grams of dried powder of habanero pepper charged into the extraction cell and reported is a little more than twice the reported in Figure 4. We believe that Guillermo used a variety of habanero pepper with better yield. Then our study uses the conservative lower yield.

The cell has a volume of 0.1 Lt ($0.0001m^3$) and we usually charge 30 gr of powder of dried habanero pepper. The density of the bed was experimental determined and gives 602.5 kg/m^3. For the laboratory cell most of the runs used 1.8 gr/min=0.000030 kg/s CO_2 that gives τ=0.030 kg/0.000030=1000 s. Then the density allows the calculation of the mass in each commercial size cell, and the mass flow rate of CO_2 may be calculated with: Kg CO_2=kg of habanero pepper /1000 s. The procedure was applied for the supercritical extraction cells of 5, 50, 100, and 400 liters.

The global results are shown in Figure 5. It is observed that the COM is almost the same for cells of 50, 100 and 400 liters and increased only for the 5 liters cell.

Trying to see how each factor contributes to the overall cost of manufacturing, we present Table 2 and Table 3 with the clove buds and habanero pepper data respectively. In these tables the contribution of each factor is multiplied for his coefficient in Equation 2. This was done in order to get the total of the contributions equal to 100. Last column of both tables present the direct contribution of the supercritical extraction equipment. It is observed that it ranges from 1-18 % for clove buds and from 5-20 % for habanero pepper.

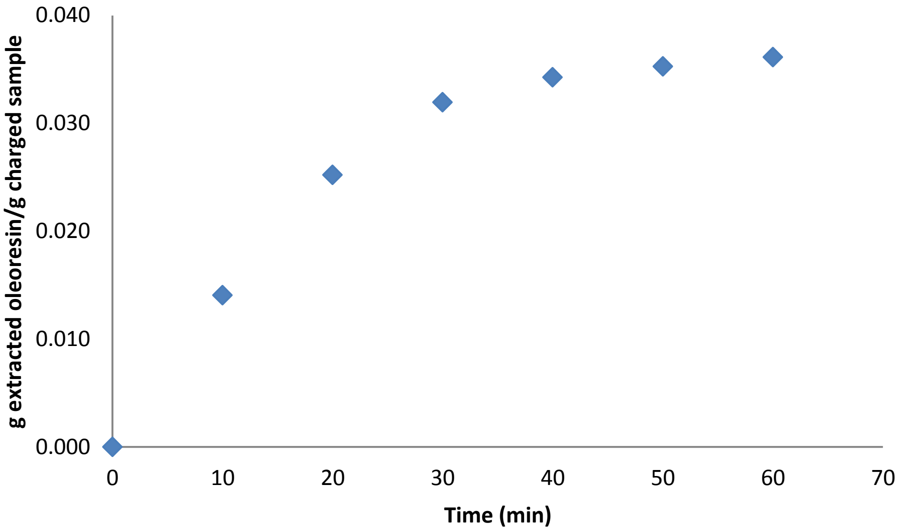

Figure 4. Experimental CO_2 extraction curve for habanero pepper at P=500 bar y T=40 ^{o}C

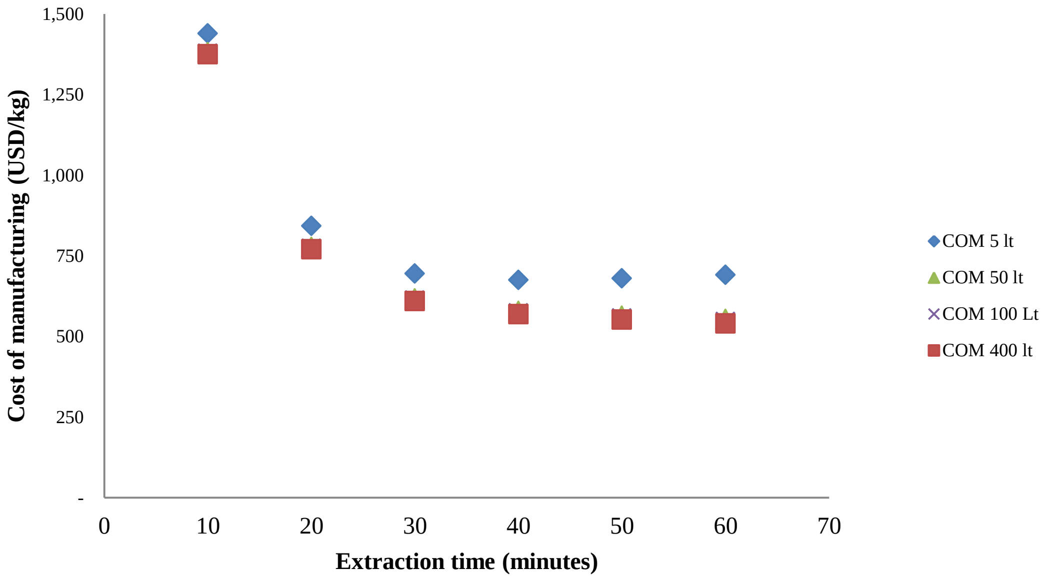

Figure 5. Cost of manufacturing for habanero pepper

It is observed that the cost of raw material takes the biggest part: 92 % average for clove and 99 for habanero pepper; The second contribution is for the cost of labor with average of 5 for clove and 0.2 for habanero pepper; The third contribution is for equipment cost that uses 2.54 % for clove buds and 0.1 for habanero pepper, the lowest contribution is for energy cost.

As was mentioned in [8] the difference between selling price of clove bud oil and COM are US$40.00/kg - US$7.00/kg= 37 US$/kg provide o good perspective for economical development.

For habanero pepper oleoresin extrapolating from an 85,000 US$/kg selling price for oleoresine with 60 % of capsaicinoids we get 7,000 USD/kg for oleoresin of 5 % capsaicinoids that is higher than the 600 US$/kg estimated COM then providing other good economical perspective. According with [12] the selling price of habanero pepper oleoresin increase to 325,000 USD/kg for 97 % of capsaicinoids in the oleoresin.

Table 2. Cost of manufacture for Clove buds in supercritical extraction (400Lt)

Extraction time (minutes)	% 0.304*FCI	% 2.73*COL	% 1.23*CUT	% 1.23*CRM	COM (USD)	kg produced/year	Specific COM (USD)	% FCI
5	0.32	0.68	0.04	98.96	18,960,670	997,920	19.00	1.05
10	0.63	1.35	0.08	97.94	9,581,535	997,920	9.60	2.09
20	1.24	2.65	0.15	95.95	4,890,955	741,312	6.60	4.09
40	2.39	5.10	0.29	92.23	2,545,665	513,216	4.96	7.86
60	3.45	7.35	0.41	88.78	1,763,901	375,408	4.70	11.34
80	4.43	9.45	0.53	85.59	1,373,019	295,812	4.64	14.57
100	5.34	11.39	0.64	82.62	1,138,490	242,352	4.70	17.57

Table 3. Cost of manufacture for Habanero Pepper in supercritical extraction (400Lt)

Extraction time (minutes)	% 0.304*FCI	% 2.73*COL	% 1.23*CUT	% 1.23*CRM	COM (USD)	kg produced/year	Specific COM (USD)	% FCI
5	0.01	0.03	0.01	99.95	443,901,091	158,431	2801.85	0.05
10	0.03	0.06	0.02	99.90	222,082,274	161,478	1375.31	0.09
20	0.05	0.12	0.04	99.79	111,166,104	144,299	770.39	0.18
30	0.08	0.17	0.06	99.69	74,194,047	121,776	609.26	0.27
40	0.11	0.23	0.08	99.58	55,708,019	97,917	568.93	0.36
50	0.14	0.29	0.10	99.48	44,616,402	80,853	551.82	0.45
60	0.16	0.35	0.11	99.37	37,221,990	68,905	540.19	0.54

If we could get a habanero pepper with the yield of capsaicinoids obtained by Guillermo [11] that got twice the yield obtained in this study, the manufacturing cost for habanero pepper would reduce to half the calculated COM.

In this study it was supposed that between two cycles no time is needed. We believe that a better estimation for cost of manufacturing should take into account an additional time for discharge and clean the column.

4. Conclusions

Oleoresin may be extracted from habanero pepper powder using supercritical CO_2 providing capsaicinoids and carotenoids free of organic solvents that may be used in food preparation.

Supercritical extraction of habanero pepper oleoresin may increase the number of commercial products derived from this fruit at the Yucatan peninsula in Mexico.

The difference between cost of manufacturing (600 USD/kg) and probably selling price (7000 USD/kg) presents a good perspective for industrial application.

Estimating the cost of supercritical extraction systems may improve the development of the field and the application of this technology may help to get products that provide a better living for society. The proposed Equation 3 for the prediction of industrial supercritical CO_2 extraction systems is based on five industrial systems from 5 to 400 liters in capacity and has into consideration depreciation with time.

For habanero pepper about 81 % of the cost of manufacturing goes for the cost of raw material that is powder of dried habanero pepper, for clove buds this value is 75 %. The supercritical extraction system with CO_2 separation and recompression are between 0.05-0.54 % of the COM for habanero pepper and between 1.05 and 18 % for clove buds.

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