American Institute of Chemical Engineers

STUDENT CONTEST PROBLEM

1969

345 East 47 Street • New York, New York 10017

CONTEST PROBLEM

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AMERICAN INSTITUTE OF CHEMICAL ENGINEERS STUDENT CHAPTERS

Open Only to Undergraduates or Those
Without a Degree in Chemical Engineering

DEADLINE FOR MAILING

Solution must be postmarked not later than midnight, June 15, 1969

RULES OF THE CONTEST

Solutions will be graded on (a) substantial correctness of results and soundness of conclusions, (b) ingenuity and logic employed, (c) accuracy of computations, and (d) form of presentation. Accuracy of computations is intended to mean primarily freedom from mistakes; extreme precision is not necessary.

It is to be assumed that the statement of the problem contains all the pertinent data except for those readily available in handbooks and similar reference works. The use of textbooks, handbooks, journal articles, and lecture notes is permitted. In cases where there is disagreement in the data reported in the literature, the values given in the statement of the problem have been chosen as being most nearly applicable.

The problem is not to be discussed with any person whatever until June 15, 1969. This is particularly important in cases where neighboring institutions may not begin the problem until after its completion by another chapter. Submission of a solution for the competition implies adherence to the foregoing condition.

A period of not more than 30 consecutive days is allowed for completion of the solution. This period may be selected at the discretion of the individual counselor, but in order to be eligible for an award a solution must be postmarked not later than midnight, June 15, 1969.

The finished report should be submitted to the chapter counselor within the thirty-day period. There should not be any variation in form or content between the solution submitted to the chapter counselor and that sent to the AIChE office. The report should be neat and legible, but no part need be typewritten.

The solution should be accompanied by a letter of transmittal giving only the contestant's name, school address, home address, and student chapter, lightly attached to the report. This letter will be retained for identification by the Secretary of the Institute. The solution itself must bear no reference to the student's name or institution by which it might be identified. In this connection, graph paper bearing the name of the institution should be avoided.

Each counselor should select the best solution or solutions, not to exceed two, from his chapter and send these by registered mail to

Mr. F. J. Van Antwerpen, Secretary
American Institute of Chemical Engineers
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STATEMENT OF PROBLEM

A company on the West Coast is steam-stripping vegetable oils, such as coconut oil, to remove small quantities of free fatty acid. Because the present plant has batch equipment which is antiquated and badly in need of repair, the company has decided to

1. Expand capacity by 100 per cent.
2. Modernize the process.
3. Recover the stripped fatty acid in an economically useful form.

You have been assigned to design a new system. Your report should include the following items:

1. A detailed flow sheet for your proposed system.
2. The design of the stripper, including calculations.
3. A fatty-acid recovery-system design, including calculations.
4. Recommended operating conditions and the basis for your recommendations.
5. A comparison of the operating costs of the proposed system with those of the current system in $/unit of stripped oil.

It will be necessary to consider more than one processing system in order to determine the best solution to the problem.

BACKGROUND

Vegetable oils, such as coconut oil, consist of mixtures of triglyceride molecules (glycerine totally esterified with various fatty acids). When extracted from the source raw material, they commonly contain small quantities (1 to 10 per cent) of unesterified monocarboxylic acids, called "free fatty acids," dissolved in the oil. These fatty acids are usually even-numbered linear carboxylic acids of 8 to 24 carbon atoms per molecule. They may be saturated or may have one or more double bonds per molecule. The presence of these free fatty acid molecules in the oil hinders certain applications of the oil because of adverse flavors, odors, a tendency to smoke, and other factors. The fatty acids have economical applications in such products as toilet soap, cosmetics, pharmaceuticals, and others too numerous to mention, but the acids must be available in a relatively pure form.

Removal of these free fatty acids is in some instances done by a steam-stripping operation under a vacuum at elevated temperatures. The operation is done under a vacuum to prevent oxidation of the oil due to exposure to air at elevated temperatures and to increase the driving force for the stripping operation.

The fatty acids are usually recovered by some form of condenser in the vacuum vapor line or else they come out in the condenser water from the ejector system commonly used for creating the vacuum. The latter method results in a very impure fatty acid material which has little commercial value.

PRESENT SITUATION

Company X has a plant on the West Coast that currently processes 100,000 lb./day of coconut oil. The stripped oil is either further processed into edible products or sold as edible oil on the market. The fatty acid stripped out is not recovered and ends in the ejector condenser water supply, where it becomes an air or water pollution hazard.

The present plant contains one batch stripping still which is over 40 years old and in poor condition.

The company desires to

1. Increase plant capacity to 200,000 lb/day.
2. Recover the stripped fatty acid if justified. (A market for it has recently opened nearby.)
3. Modernize the plant system.

CURRENT SYSTEM

The batch still consists of an 8-ft. – diameter vessel 30 ft. high. An internal coil is used for heating with steam or cooling with water. An internal sparge ring at the bottom of the vessel introduces stripping steam. A three-stage ejector connected to the vessel provides vacuum. It has been determined that repairs to the current still will cost $100,000. Modernizing costs as yet have not been estimated.

The following cycle typifies the batch operation:

1. Charge still with coconut oil at room temperature	30 min.
2. Heat to stripping temperature	1 hr.
3. Strip with sparging steam	1 to 4 hr.
4. Cool to room temperature	2 1/2 hr.
5. Discharge still	30 min.

For the present still, process conditions are as follows:

1. Charge size	25,000 lb.
2. Stripping temperature	400°F.
3. Vacuum	10 mm. Hg—absolute at ejector suction
4. Stripping steam	1 to 2% by weight of oil per hour depending on stripping load
Load	2% steam for 1 1/2 hr. to strip an oil containing 5% fatty acid
5. Free fatty acid in unstripped oil	1 to 10% (avg. 5%)
6. Heat transfer coefficients	U overall heating @ 280°F. = 100 B.t.u./(hr.) (sq. ft.) U overall cooling @ 280°F. = 40 B.t.u./(hr.) (sq. ft.)
7. Personnel	One man/shift

PROPOSED SYSTEM

The proposed system should be the most economical one from the standpoint of processing cost. The needed capacity expansion resulting from the creation of new markets makes the problem of capital investment less critical; however, there is little room for overdesign or unnecessary frills. The payout on the investment will affect operating costs directly.

The company has considered continuous systems in the past but has had no experience with them. Although continuous systems are recognized as being possibly more economical, no calculations have as yet been made. A consideration of several potential systems is necessary to determine the most economical one in regard to processing and capital costs.

DESIGN DATA AVAILABLE

1. Fatty acids

The approximate composition of the stripped fatty acids is as follows:

C:12 (lauric acid), 50%
C:14 (myristic acid), 45%
C:16 (palmitic acid), 5%

The vapor pressure of these acids versus temperature is as follows:

Vapor pressure, mm. Hg	Temperature, °C. Acid C:12	Acid C:14	Acid C:16
1	130.2	149.2	167.4
2	141.8	161.1	179.0
16	181.8	202.4	221.5
64	214.6	236.3	257.1
256	256.6	281.5	303.6
760	298.9	326.2	351.5

The chemical reactivity of these acids must be considered in the design of a recovery system. Excessive copper and iron contamination will destroy the economic value.

2. Vegetable oil

The vapor pressure of the triglyceride oil may be considered negligible over the normal range of steam-stripping temperatures. An upper temperature limit of 500° F. should be assumed, however, as a thermal breakdown of the oil becomes a factor at 530° F. Fatty acids are stable at this temperature.

The use of steam as a stripping agent, combined with the temperatures used normally, results in an equilibrium fatty acid content of about 0.02% due to hydrolysis and/or thermal decomposition of the oil. At this point fatty acid is being formed at the same rate as it is stripped out. The figure of 0.02% by weight may therefore be assumed to be the lowest attainable limit for removal.

Air solubility in coconut oil is 6% by volume of air-free oil at room temperature and 1 atm. pressure.

3. Utilities

a. Steam, 750 lb./sq. in. gauge saturated	$1.50/1,000 lb.
b. Cooling water, 80°F.	$0.30/100 cu. ft. $0.10/100 cu. ft. (sewer charge for clean water) $0.05/lb. of fatty material to sewer biological oxygen demand surcharge
c. Condenser water, 90° F. min. temp. available	
d. Electricity	$10/1,000 kw.-hr.

4. Ejector system

Assume air leakage into any system, a minimum of 1 lb./hr.

5. Prices

Unstripped coconut oil	$20/100 lb.
Stripped coconut oil	$24/100 lb.
Fatty acid—premium grade (98% min. fatty acid, Lovibond color, max. 15/1.5, yellow/red)	$15/100 lb.
nonpremium grade	$4/100 lb.

6. Heat capacity data, liquid

Coconut oil	25°C., 0.51; 200°C., 0.61 cal./(g.)(°C.)
Fatty acid (C:14)	25°C., 0.52 cal./(g.)(°C.)

7. Heat of vaporization of fatty acids, C:14 90 cal./g. @ 120 mm. Hg

8. Miscellaneous data

Solubility of Fatty Acids in Water, g. Acid/100 g. Water

Acid	Temperature 0° C.	30° C.	60° C.
C:12 lauric	0.0037	0.0063	0.0087
C:14 myristic	0.0013	0.0024	0.0034
C:16 palmitic	0.00046	0.00083	0.0012

Viscosity data

a. Coconut oil

Specific gravity (20°/4° C.) 0.9226

Viscosity	100° F.,	29.79 centistokes
	212° F.,	6.06 centistokes

b. Fatty acids

Lauric acid	50° C.,	7.3 centipoises
	75° C.,	3.84 centipoises
Myristic acid	75° C.,	5.06 centipoises
Palmitic acid	75° C.,	7.1 centipoises

Density data

Lauric acid	75° C.,	0.8516 g./cc.
	80° C.,	0.8477 g./cc.
Palmitic acid	80° C.,	0.8414 g./cc.

9. Condenser design

McAdams's "Heat Transmission" contains data and references to the design of tubular-type and direct-liquid-contact-type of condensers for condensables in the presence of noncondensables. It will be necessary to avoid condensation of the stripping steam while the fatty acids are condensing; otherwise, nonpumpable emulsions result.

10. Present operating costs (average 12 months)

$/100 lb. finished oil	
Wages	$0.120
Repairs and expenses	0.040
Utilities	0.150
Depreciation	0.002
Others	0.010
Total	$0.322

GENERAL REFERENCES

1. "Bailey's Industrial Oil and Fat Products," D. Swern, ed., 3 ed., Interscience, New York (1964).
2. K. S. Markley, "Fatty Acids," Interscience, New York (1947).