Material Balances
Design Project

Production of a Drying Oil

Drying oils are additives to products like paint and varnish to aid the drying process when these products are coated on a surface.

The purpose of this project is to do a preliminary analysis to determine the feasibility of constructing a chemical plant to manufacture 50,000 tonne/y drying oil.

A suggested process flow diagram is attached. You should use this as a starting point. Your primary task is to recommend operating conditions for the reactor and a reactor choice that maximizes the gross profit (defined later). However, any change that you can justify that does not violate the laws of nature is allowed. Your assignment is to develop a "best" case, where "best" is dependent upon economic considerations.

Chemical Reaction

The raw material is acetylated castor oil, which we will model as palmitic acid ($C_{15}H_{31}COOH$). The primary reaction is one in which the acetylated castor oil is thermally cracked to the drying oil (which we will model as tetradecene, $C_{14}H_{28}$) and acetic acid (CH_3COOH). There is an undesired reaction in which the drying oil dimerizes to form a gum, which we will model as $C_{28}H_{56}$.

The chemical reactions are as follows:

$$C_{16}H_{32}O_2(l) \rightarrow CH_3COOH(g) + C_{14}H_{28}(l) \tag{1}$$

$$2C_{14}H_{28}(l) \rightarrow C_{28}H_{56}(s) \tag{2}$$

Process Description

The process is illustrated in Figure 1. The acetylated castor oil (ACO) feed is mixed with recycled ACO and is fed to the reactor. In the reactor, reactions in Eqs. (1) and (2) occur. Immediately following the reactor, there is a filter that removes any solid gum formed in the reactor. Following the filter, there are two distillation columns that purify the ACO for recycle, the drying oil (DO) for sale, and the acetic acid (AA) for sale as a by-product.

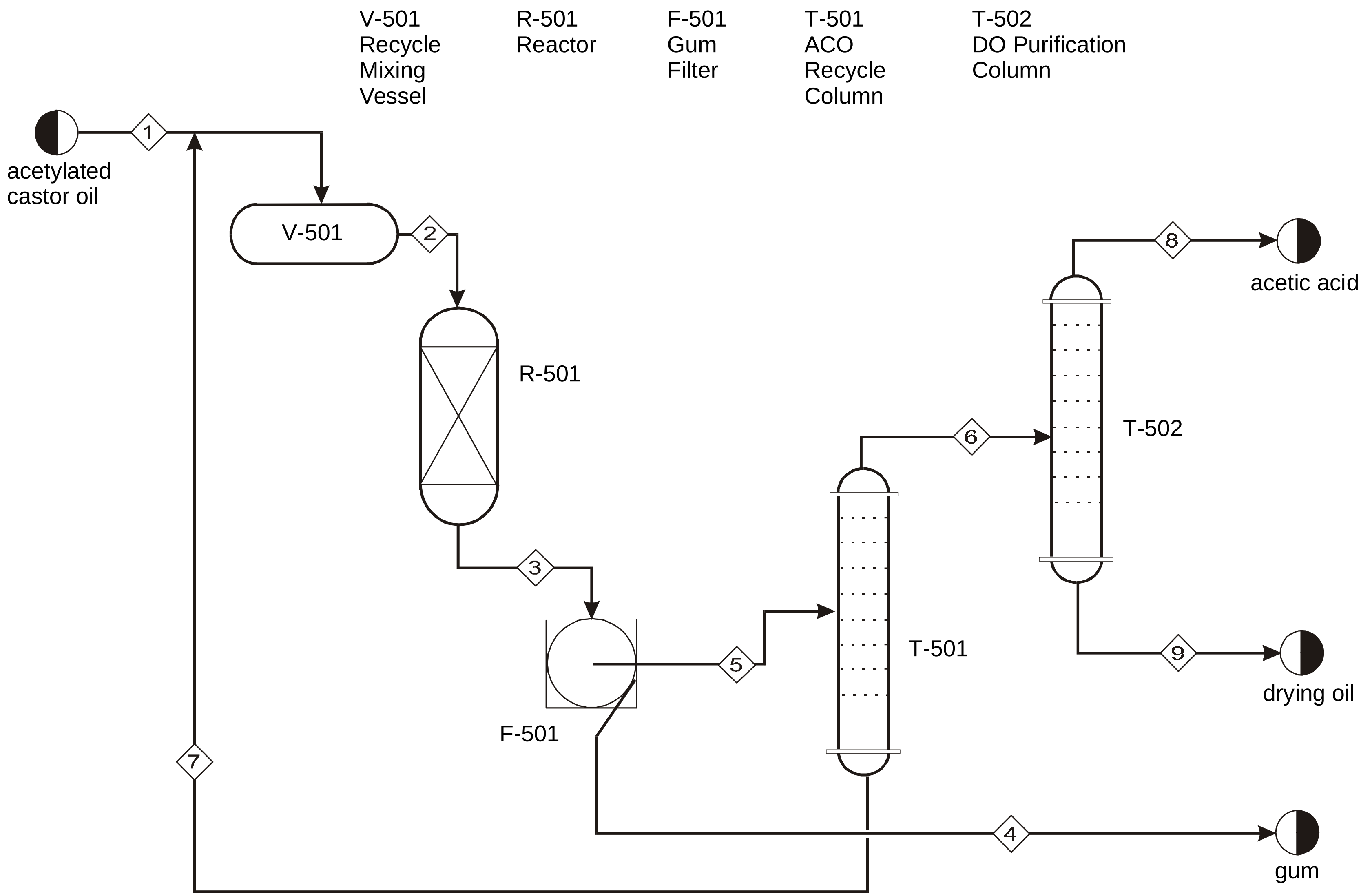

Figure 1: Preliminary Process Flowsheet for Drying Oil Production

Process Details

Feed Stream and Effluent Streams

Stream 1: ACO – \$0.59/kg

Stream 4: Gum waste – no value

Stream 8: Acetic acid by-product – \$0.99/kg

Stream 9: DO – \$1.19/kg

Equipment

Vessel (V-501): location where feed and recycle streams mix

Reactor (R-501): where the reactions in Eqs. (1) and (2) occur

Filter (F-501): all gum is removed in Stream 4, all AA, ACO, and DO go to Stream 5

Distillation Column (T-501): all AA in Stream 5 goes to Stream 6, all ACO in Stream 5 goes to Stream 7, 99.5% of DO in Stream 5 goes to Stream 6

Distillation Column (T-502): 99.5% of AA in Stream 6 goes to Stream 8, 99.5% of DO in Stream 6 goes to Stream 9

Economic Analysis

When evaluating alternative cases, the following relationship should be used:

gross profit estimate = value of products – cost of feed – cost of recycle – cost of separations (3)

The value of products and cost of feed were given earlier in the Process Details section. There is a cost for recycle, since equipment and utilities (not shown on the current flowsheet) cost more if there is more recycle. The cost of recycle may be estimated by

$$\text{cost of recycle} \, (\$/\text{kg ACO leaving reactor}) = 3\times10^{-2}(\dot{m}_{ACO}/\dot{m}_{DO})^2 \qquad (4)$$

where $\dot{m}_{ACO}/\dot{m}_{DO}$ is the ratio of the mass flowrate of ACO/mass flowrate of DO in Stream 3.

There is also a cost associated with removing the gum, which can be ignored (and F-501 removed) if the gum level is below 1 ppm (mass basis) in Stream 3. This cost is function is

$$\text{cost of gum removal (\$/kg DO leaving reactor)} = 10^{-3}[(\text{ppm gum in Stream 3}) - 1] \qquad (5)$$

If the cost of gum removal in Eq. (5) is less than zero, the cost is zero.

Reactor Information

The reaction conditions are limited to temperatures between 310°C and 400°C. Table 1 gives conversion and selectivity information for the reactor for two different size reactors. You should recommend whether to use the smaller or larger reactor. The lower the space time, the smaller the reactor.

Table 1: Reactor Conversions and Selectivities

T **(°C)**	***X*** **conversion to AA space time 10 min**	**selectivity moles DO/moles gum space time 10 min**	***X*** **conversion to AA space time 4 min**	**selectivity moles DO/moles gum space time 4 min**
310	0.130	6.43×10^{7}	0.069	6.41×10^{8}
320	0.184	4.97×10^{6}	0.107	6.44×10^{7}
330	0.245	9.18×10^{5}	0.161	4.28×10^{6}
340	0.314	2.38×10^{5}	0.214	7.58×10^{5}
350	0.375	7.08×10^{4}	0.283	1.74×10^{5}
360	0.444	2.29×10^{4}	0.345	4.92×10^{4}
370	0.513	8.55×10^{3}	0.413	1.61×10^{4}
380	0.559	3.38×10^{3}	0.475	3.78×10^{3}
390	0.597	1.43×10^{3}	0.528	2.22×10^{3}
400	0.635	5.58×10^{2}	0.574	9.17×10^{2}

Other Information

You should assume that a year equals 8000 hours. This is about 330 days, which allows for periodic shut down and maintenance.

Deliverables

Each group must deliver a word-processed report. It should be clear and concise. The format is explained in a separate document. When presenting results for different cases, graphs are superior to tables. The body of the report should be short, emphasizing only the results and briefly summarizing computational strategies. The report appendix should contain details of calculations that are easy to follow. Calculations that cannot be followed easily will lose credit.

The project is due November 6, 2002, at the beginning of class. There will be oral presentations of project results on that day.

Anyone not participating in this project will automatically receive an F for ChE 201, regardless of other grades earned in this class.

Groups

You will work on this project in groups of 3 or 4. More details of group formation and peer evaluation will be discussed in class.

Revisions

As with any open-ended problem; i.e., a problem with no single correct answer, the problem statement above is deliberately vague. The possibility exists that as you work on this problem, your questions will require revisions and/or clarifications. You should be aware that these revisions/clarifications may be forthcoming.