Ch.E. 453 Project Problem Due Monday 11 / 16 / 05 project C-3 + memo

Optimization Problem C-3

Memo

To: Dr. David Drown

From:

Date: 11/10/98

Re: Optiunm Reflux Ratio

The total annual cost of our distillation column is a function of the reflux ratio. A recent analysis of the column operating cost was performed to determine the optimum reflux ratio that minimizes cost. This analysis was performed using a golden section search optimization spreadsheet to within .0003 % of the original parameters. Other objectives included determining the sensitivity of the cost around the optimum, determining the response to be unimodal or multi-modal and deciding if the optimum is a local or overall optimum.

The results indicate that the optimum reflux ratio is 10.58 with a total cost of 58,056 dollars. This result is very reasonable response and is slightly below the expected valve of 12, which is 1.2 times the minimum reflux ratio. The cost is very insensitive between a reflux ratio of 10.5 and 10.7 giving 50 dollars above the optimum cost in both directions. The cost takes of rapidly with a reflux ratio below 10.4 and above 10.7 and thus is very sensitive when not in the optimum range of 10.5 to 10.7. The optimum reflux ratio is the overall optimum giving and overall minimum total cost. The response is uni-modal within the range of reflux ratios expected between 10 and 400. These constraints where found by setting the limit of stages to infinity and solving for the reflux ratio and the setting the number of stages to the minimum and solving for the reflux ratio.

Given the constraints and sensitivity of the reflux ratio and cost response the optimum reflux ratio is between 10.5 and 10.7. While the exact optimum is at 10.58, it will be sufficient to operate between 10.5 and 10.7 because of the lack of sensitivity of the response. It is also unreasonable to expect the column to run at an exact reflux ratio of 10.58 all the time so the range of 10.5 to 10.7 is sufficient.

Sincerely,

OPTIMIZATION PROBLEM No. 2

REFLUX RATIO CONSTRAINED BY MINIMUM THEORETICAL

$R_m = 10.0$ HOWEVER $S \rightarrow \infty$ AT MINIMUM

$\therefore R > 10.0$ USE 10.1

UPPER BOUND = MINIMUM No. THEORETICAL STAGES

$S_m = 100$ HOWEVER $R \rightarrow \infty$

$\therefore$ ASSUME WHOLE STAGES NEEDED, USE $S = 101$

$$R = \frac{390}{(101-100)} + 10 = 400$$

THEREFORE R BOUNDED BY APPROXIMATE PHYSICAL PROBLEM

$$10.1 \leq R \leq 400$$

KNOWN ROUGH APPROXIMATION: PETERS & TIMMERHAUS pp 388

OPTIMUM USUALLY FALLS BETWEEN 1.1 AND 1.3 TIMES MINIMUM

$\therefore$ EXPECTED RESULT BETWEEN $11.0 < R < 13.0$

SEE ATTACHED PRINTOUT FOR MINIMIZING TOTAL COST

$$Cost = 48\,R^{0.3}\,S^{0.6} + 2800\,R^{0.6} + 3900\,R$$

$$S = \frac{390}{(R-10)} + 100$$

OPTIMUM $R = 10.5853\,4$ Cost = \$58,056.2487

A. RESULT IS REASONABLE AND SLIGHTLY BELOW EXPECTED RANGE

B. BETWEEN 10.5 AND 10.7 COSTS ARE INSENSITIVE ±\$50 TO VARIATIONS IN REFLUX RATIO

BELOW $R < 10.4$ COSTS ESCALATE RAPIDLY

D. OVERALL OPTIMUM, UNIMODAL RESPONSE FOR REALISTIC REFLUX RATIOS BETWEEN 10 AND 400

Problem C-3 **ECONOMIC OPTIMUM REFLUX RATIO** D. C. Drown

=48 * (G2 ^ 0.3)*(((390/(G2-10))+100)^0.6) + 2800 * (G2 ^ 0.6) + 3900 * G2

Equation to Optimize in terms of G2	58056.26563
Independent Variable	10.584263
Upper Limit	14
Lower Limit	10.1
Accuracy Limit	1
Max # of Iterations	50

[redacted]

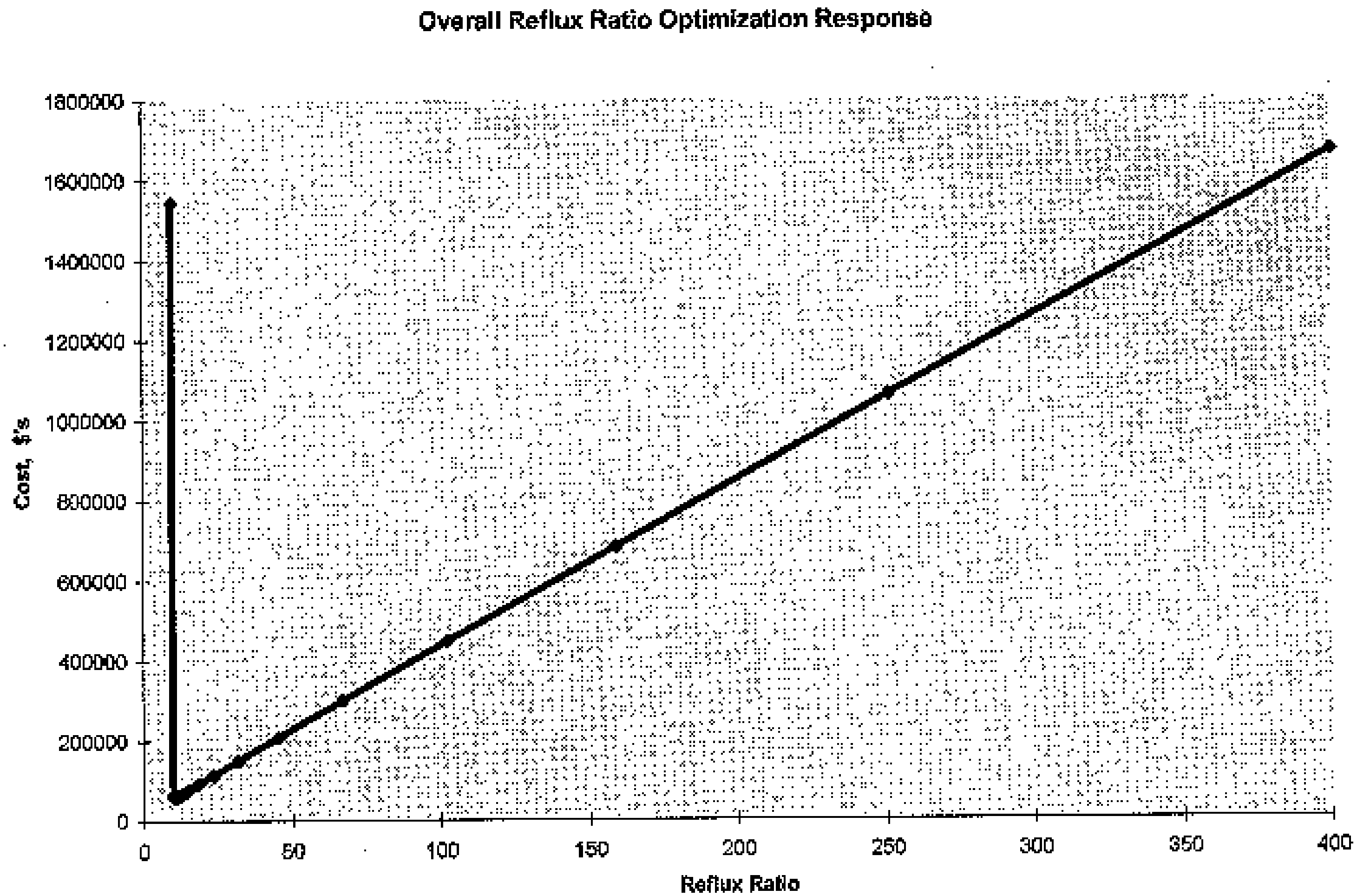
Parameter
○ Maximize
◉ Minimize

[illegible]

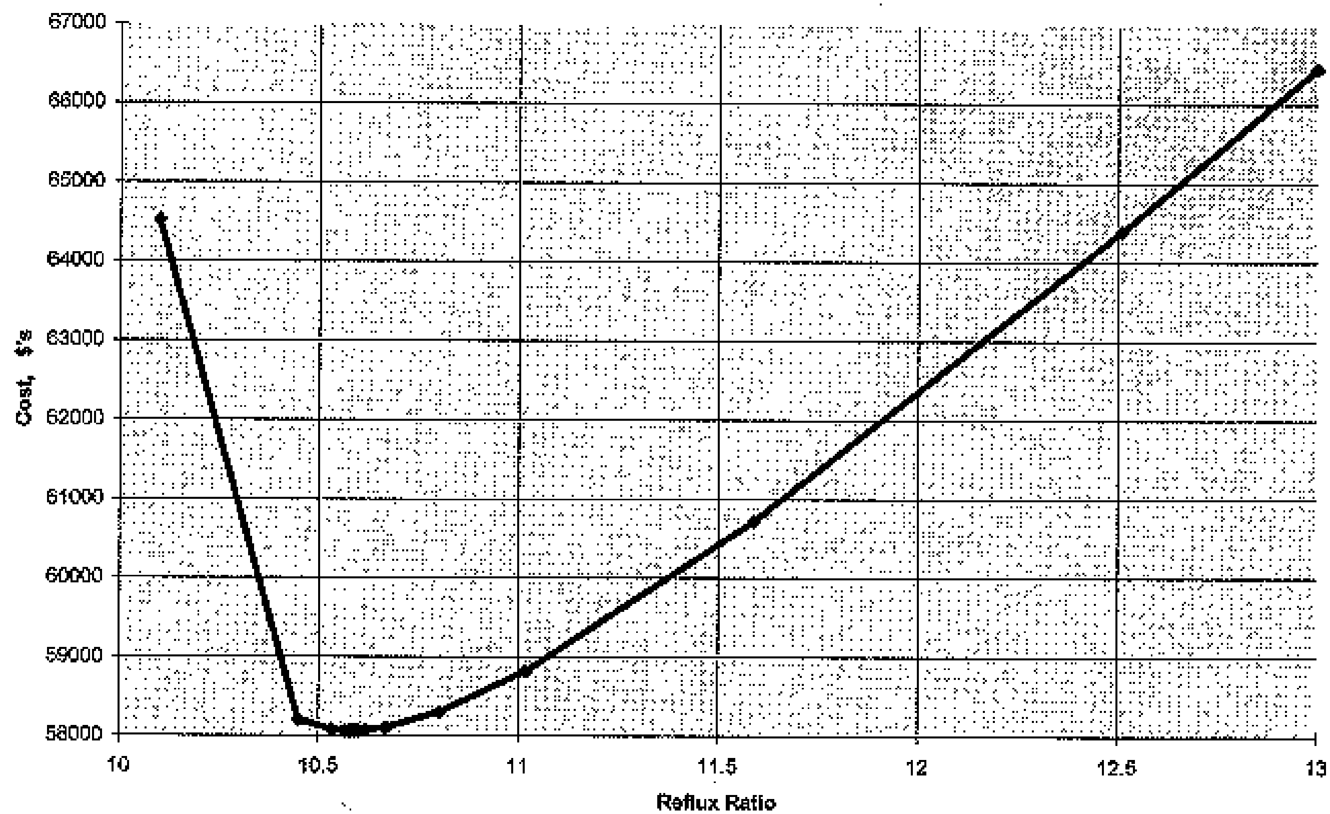
Output:

The Maximum Feasible Region is X =	10.5814	To	10.586
Function Values Y =	58056.27	To	58056.3168
The best value obtained was X =		10.5831	
with function value Y =		$58,056.26	
Fraction of original region remaining =	0.0012		
Function Accuracy =	0.0506		
Required Accuracy =	1		
Calculation Steps =	16		

Chart400


Overall Reflux Ratio Optimization Response
1800000
1600000
1400000
1200000
1000000
800000
600000
400000
200000
0
Cost, $'s
0
50
100
150
200
250
300
350
400
Reflux Ratio

Optimum Reflux Ratio



Memo

Date: November 11,1998
To: Plant Manager, Dr. David Drown, Ph. D.
From:
Subject: **Reflux Ratio for Minimum Total Annual Cost**

This memorandum presents the reflux ratio that results in the least total annual cost, as requested by the plant manager, Dr. Drown. It outlines recommendations regarding the optimum reflux ratio.

Summary

The optimum economic reflux ratio is 10.5829 with a total annual cost of $58056.25. Data for the optimum reflux ratio are as follows (search summary data are appended):

Table 1: Economic Optimum Reflux Ratio Data

Reflux Ratio	*Number of Stages*	*Column Investment*	*Condenser and Reboiler Investment*	*Utilities and Operating Costs*	*Total Annual Cost*
10.5829	769.07	$ 5250.51	$ 11532.43	$ 41273.31	$ 58056.25 ✓

The number of plates used in the column should be 769, since a fractional number is not realistic. The total annual cost is relatively insensitive to changes in reflux ratio for reflux ratios between of 10.5 and 10.7: there is approximately a $50 increase in total annual cost over this range (see Figure 1). Since total annual cost increases more rapidly below the optimum reflux ratio than above it, it would be better to err and operate at a reflux ratio higher than the optimum than to err and operate at a reflux ratio lower than the optimum. The optimum reflux is the only minimum for the entire range of realistic reflux ratios (see Figure 2). The optimum was found to within 0.01% of the original search region, reflux ratios from 10.1 to 15. ← GOOD POINT

Discussion

Modality

The total annual cost response is unimodal over the range of realistic reflux ratios: the optimum reflux ratio is the only minimum.

Reasonability

The results seem reasonable within the range of the realistic reflux ratios, minimum reflux (10) to total reflux. Since the optimum reflux ratio usually is between 1.1 and 1.3 times the minimum reflux ratio, the search was not performed over the entire feasible region. A range of reflux ratios from 10.1 to 15 was used instead. The optimum reflux ratio was slightly lower than the expected range of values. Minimum and total reflux were not tested since the number of plates and reflux ratio are infinite at those points, respectively.

Sensitivity

Near the optimum reflux ratio, the total annual cost increases only slightly: for reflux ratios from 10.5 to 10.7, the total annual cost increases by about $50 over the optimum. However, below a reflux ratio of 10.5, the total annual cost increases rapidly. Above a reflux ratio of 10.7, the total annual cost does not increase as rapidly. It would be better err and operate at a reflux ratio higher than the optimum than to err and operate at a reflux ratio lower than the optimum. ✓

Recommendations

The number of plates used in the column should be 769, since a fractional number of plates is not possible. Since total annual cost increases more rapidly below the optimum reflux ratio than above it, it would be better err and operate at a reflux ratio higher than the optimum than to err and operate at a reflux ratio lower than the optimum.

Enclosures

All graphs and calculations are appended.