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A simulation model capable of performing the calculations involved in defining a crude preheat train

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A SIMULATION MODEL CAPABLE OF PERFORMING THE CALCULATIONS INVOLVED IN DEFINING A CRUDE PREHEAT TRAIN

by

ROBERT G. PARKER

A Thesis
Presented in Partial Fulfillment of the
Requirements for the Degree
of
Master of Science in Chemical Engineering
at
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ABSTRACT

A simulation model has been developed for a system of exchangers to preheat the feed to a crude distillation unit. In conjunction, a Fortran program for the performance of the model calculations by digital computer was written. Two types of preheat system were simulated, a single train system and a split (or parallel) train system. A number of features were included in the program for flexibility and versatility. A particular effort was made to have the model represent as economical a preheat system as possible.

The model program was used to obtain computer-calculated results for both single-train and split-train preheat systems. Computer runs were made to show the effect of using different temperature approach values. The computer output data as printed for several sample problems is presented. Results have been analyzed with regard both to type of preheat system and to temperature approach value.

APPROVAL OF THESIS

A SIMULATION MODEL CAPABLE OF PERFORMING THE CALCULATIONS INVOLVED IN DEFINING A CRUDE PREHEAT TRAIN

BY

ROBERT G. PARKER

FOR

DEPARTMENT OF CHEMICAL ENGINEERING

NEWARK COLLEGE OF ENGINEERING

BY

FACULTY COMMITTEE

APPROVED:____________________________

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CHAPTER I

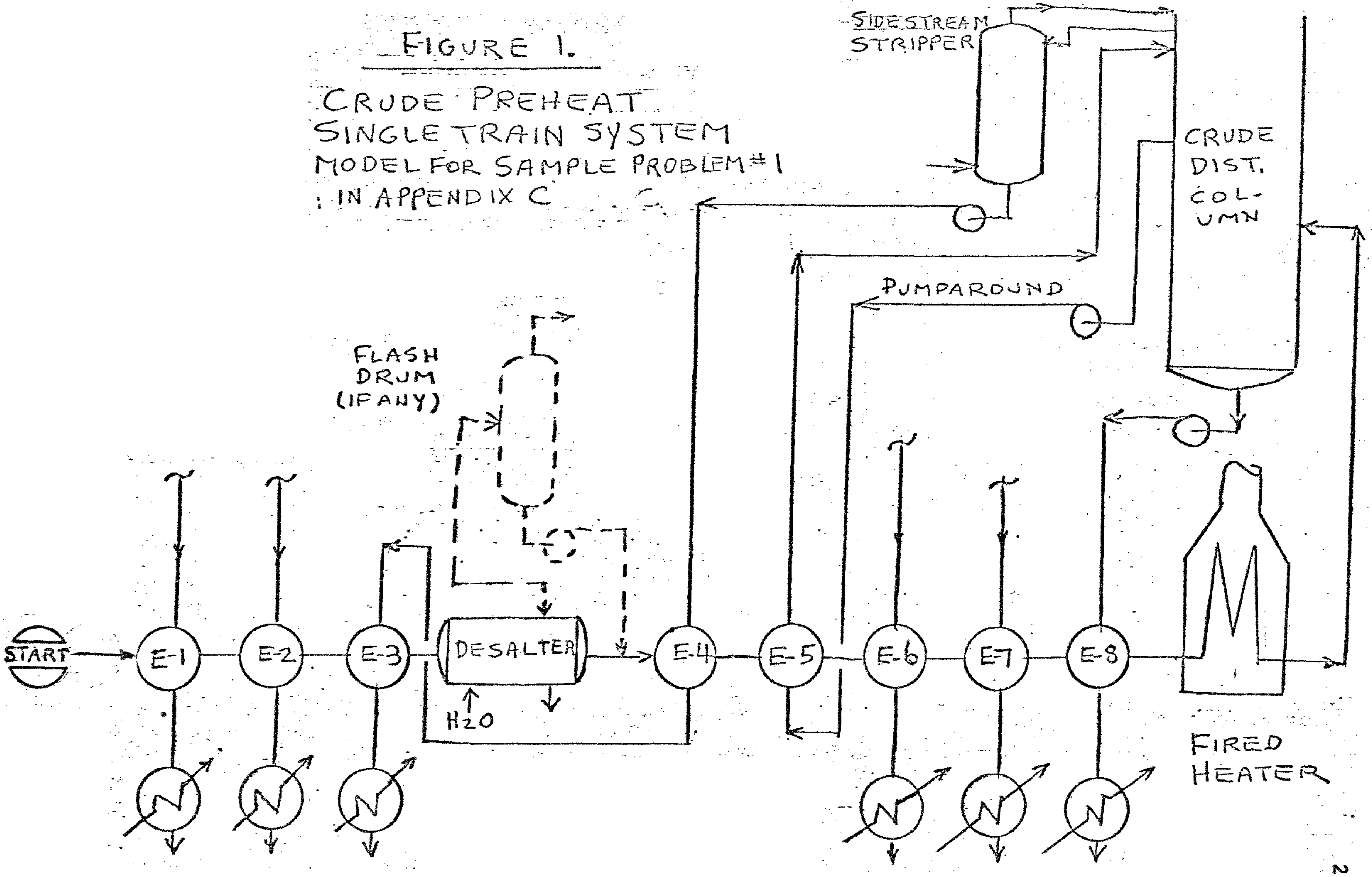
INTRODUCTION

The purpose of this thesis project was the development of a simulation model to perform the calculations required for preheating the feed to a crude oil distillation unit. Economic considerations as well as heat transfer principles are involved in the preheat problem itself, and in the model that has been developed. The model program is entitled "Preheat."

The problem of feed preheat is encountered whenever a new crude distillation unit is designed for the petroleum industry. The feed to a crude unit must be heated sufficiently to effect the required amount of vaporization at the inlet of a distillation tower operating at essentially atmospheric pressure, and a system of equipment to accomplish this must be selected. Such a system is shown in Figure 1. The principal components of the system are heat exchangers, coolers, and a fired heater or furnace. Liquid sidestreams are withdrawn from the atmospheric distillation tower at elevated temperatures and must be cooled before leaving unit limits. These streams may be routed through heat exchangers to preheat the feed by indirect heat transfer, before flowing through coolers (air or water) to be brought to required battery limits temperatures. That portion of the required heat not supplied by the heat exchangers must be supplied by the fired heater, using gas and/or oil as fuel. The problem is to determine how many heat exchangers to employ, how much heat

FIGURE 1.

CRUDE PREHEAT
SINGLE TRAIN SYSTEM
MODEL FOR SAMPLE PROBLEM #1
IN APPENDIX C



should be provided by each, and consequently how much must be supplied in the fired heater. A great deal of engineering effort is involved in establishing a suitable system of equipment. The necessary calculations include many, many heat balances, and numerous studies involving the various economic factors that are applicable. Since the amount of heat involved is usually large, fuel costs and equipment investment costs will be correspondingly high. Careful and detailed studies are required in order to minimize these costs. A great deal of time can be consumed if the above calculations are carried out "by hand", i.e. with pencil, slide rule and/or desk calculator. Use of a computer to perform the calculations is indicated and desirable. Not only can engineering time be saved, but the resulting design should more nearly approach the optimum from an economic standpoint. The model developed here is intended primarily as a time saving tool and has been kept as simple as feasible. However, its use should result in economical designs since it provides the capability of comparing results obtained when significant parameters are varied.

A number of articles have been published dealing with the economics of heat exchangers, both with regard to relatively simple systems involving but one exchanger and cooler, and with more complex systems involving banks of exchangers and their associated coolers. The articles stress the importance of employing optimum cold-end temperature approaches for the exchangers. This concept of optimum cold-end approach has been used in the development of the simulation model.

Figure I shows a vessel marked "desalter"as being included in the preheat system. The purpose of the desalter is the removal from the crude of salt which would otherwise be deposited in the tubes of the high temperature heat exchangers and the furnace. The desalter is usually electrical, an imposed voltage promoting coalescence of brine droplets which are formed on pre-mixing a small amount of water with the crude. The desalting temperature is usually 260-270°F. and this temperature requirement must be met in order to establish a satisfactory preheat system.

A preflash drum is also shown in Figure 1, represented with dotted lines to indicate its inclusion is less common than that of a desalter. The flash that occurs is defined by the input data to the model program.

CHAPTER 2

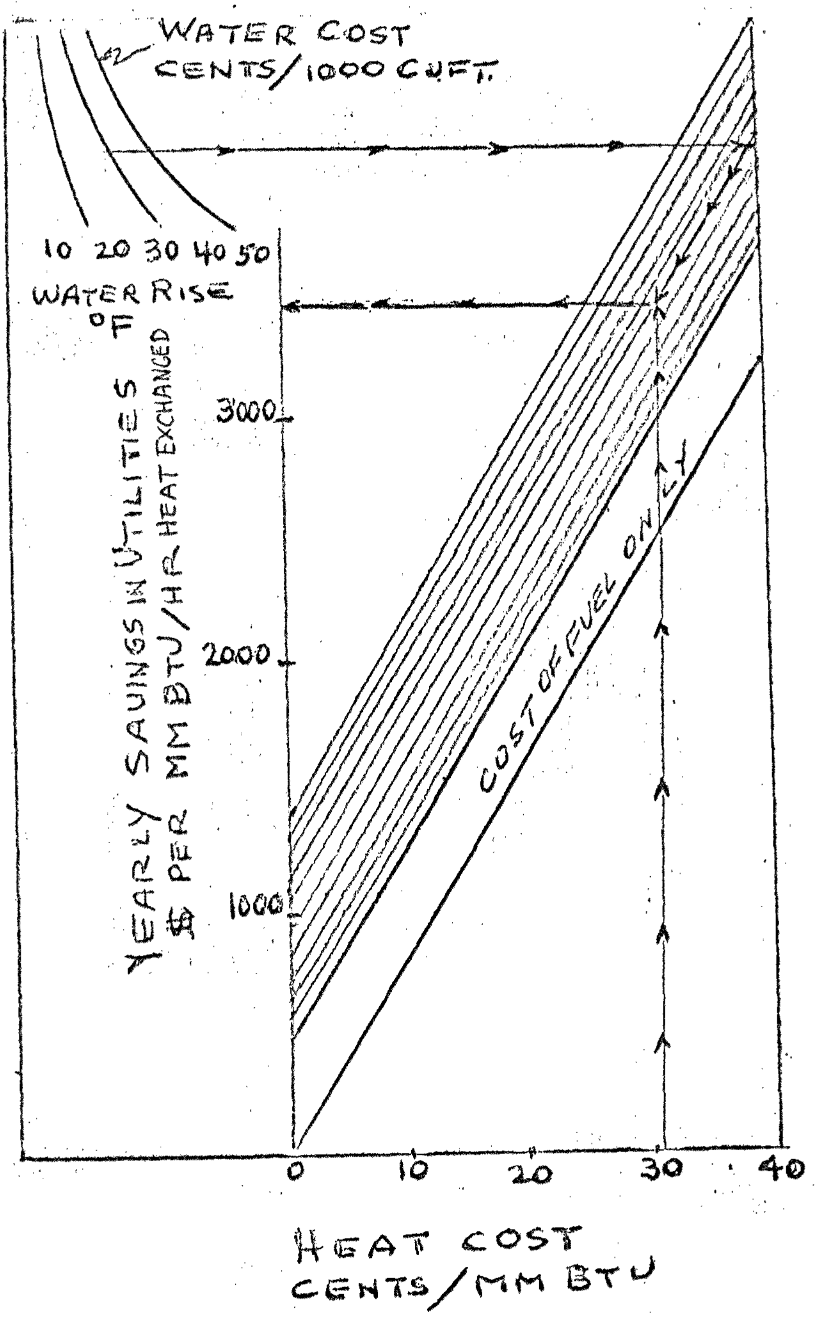
ECONOMIC CONSIDERATIONS AND COSTS

The heat exchangers included in the preheat train of a crude distillation unit serve the dual purpose of removing heat from streams that must be cooled and of supplying the crude with the heat required for fractional distillation. The streams to be cooled are product streams and pump around streams. Pump around streams, which are sometimes called circulating reflux streams, are used to remove heat from the distillation column at temperature levels suitable for heating crude. A great deal of heat must be supplied to the crude to comply with the conditions required at the "flash zone" of the distillation column. Much of this heat must be supplied in a fired heater by burning fuel. Generally substantial savings of money can be effected by using exchangers to recover as much heat as possible from the product and pump around streams, thus reducing the amount of fired heat required. This not only reduces the amount of fired heat, but also the extent of cooling with water and/or air. Besides the savings in fuel and water costs which result, the investment cost of the furnace and cooling equipment are both reduced.

As previously indicated, reductions in utility costs effected by heat exchange are regarded as "savings". Figure 2 gives yearly savings in utility costs per million BTU/hr. of heat exchanged. Both fuel costs and cooling water costs are included in these savings. Figure 2 is based on a similar chart

FIGURE 2

COST OF UTILITIES



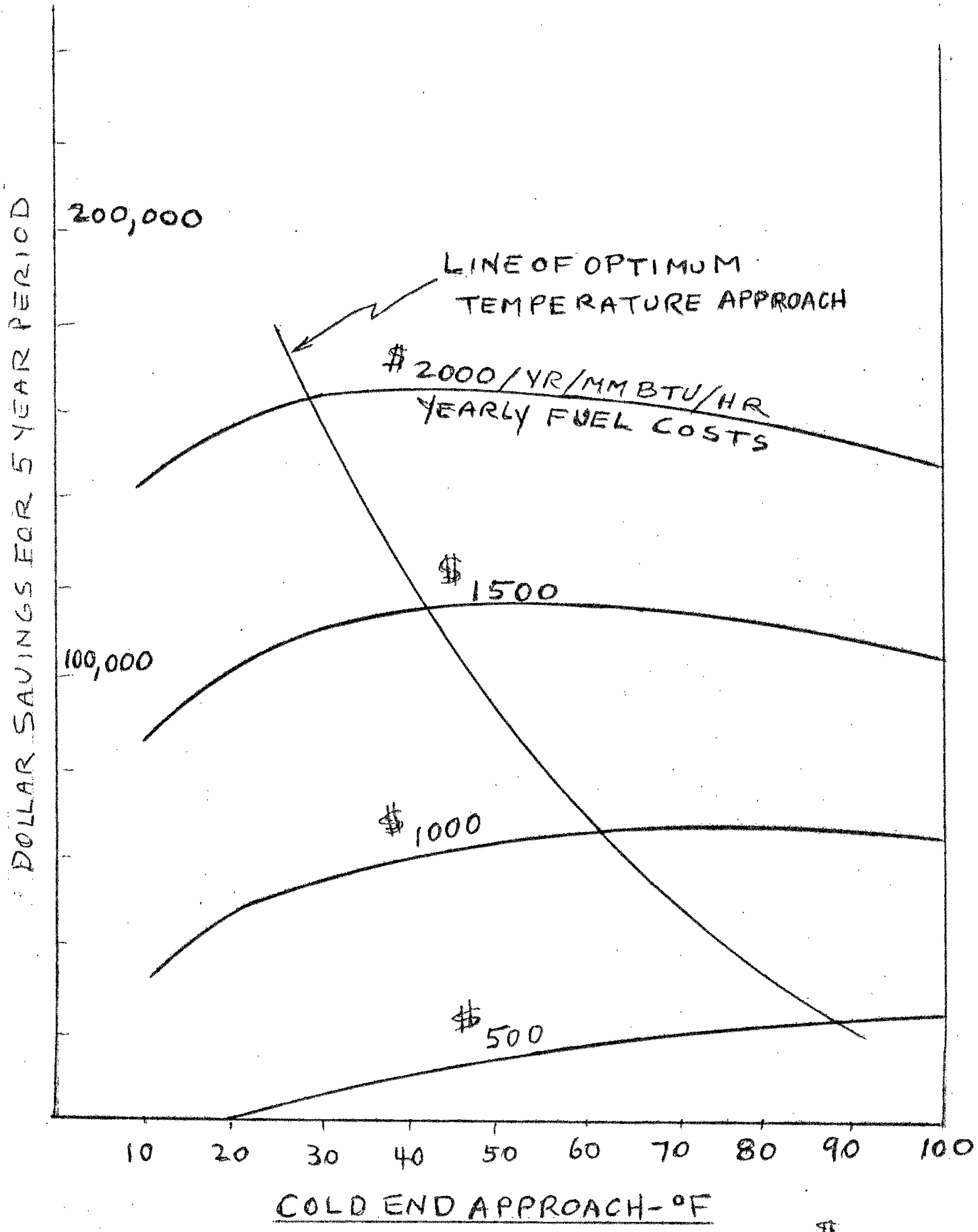
NOTE: COST/MM BTU HEAT SAVED = $\frac{\text{FUEL COST/MM BTU}}{\text{FURNACE EFFICIENCY, \%}} \times 100$

presented in an article by Whistler (3). To attain these savings, equipment costs must be incurred. Equipment costs include capital charges, or investment costs, which must cover not only the purchase price of the exchangers themselves, but the cost of associated piping, foundations, insulation, etc., as well as installation costs. Equipment maintenance expenses are also involved. These include cleaning costs as well as the cost of replacement parts, such as new exchanger tubes. After yearly gross savings and the investment costs have been calculated, the yearly net savings can be calculated by subtracting a fixed percentage of the investment cost, e.g., 20%, from the yearly gross savings. These are "before tax" savings. The "payout time" can be calculated by dividing equipment cost by savings. A payout time of from 2 to 3 years on a "before tax" basis is usually considered satisfactory. Thereafter, the net savings that result for the rest of the life of the equipment may be considered as "profit". Another way of evaluating the desirability of the exchanger installation in question is to divide the yearly savings by the investment cost, giving yearly return on investment as "per cent return" . A return of 30% or better before taxes is usually considered satisfactory.

In determining how much heat from a hot stream should be exchanged with the crude stream entering an exchanger, a number of outlet temperature values can be assumed for the hot stream and the per cent return calculated for each case. The temperature difference between the hot stream leaving an exchanger and the cold stream (crude) entering it is called the "cold end" temperature approach. Savings can be plotted against cold end approach

FIGURE 3

UTILITY SAVINGS VS. TEMPERATURE APPROACH



BASED ON INSTALLED SURFACE COST OF $6.00/FT^2
HEAT TRANSFER COEFFICIENT = 75 BTU/HR/FT^2/°F
AV. DUTY = 20,000,000 BTU/HR
HOT FLUID @ 450°F, COLD FLUID @ 100°F
MAINTENANCE = $1.20/SQ.FT/YR

to give curves showing maximum savings at an optimum approach. Whistler (3) presents several such sets of curves, Figure 3 illustrating a typical set. Fuel costs, incremental exchanger costs, and the exchanger heat transfer coefficient all affect the value of the optimum temperature approach. High annual fuel costs result in "closer" approaches if incremental exchanger costs and the heat transfer coefficient stay the same. Higher exchanger costs and/or a lower heat transfer coefficient result in a larger optimum temperature approach value for cases where the fuel cost remains the same.

Typical yearly fuel cost values in $/year/MMBTU/Hr range from about 2000 to 4000. Gulf Coast fuel costs are usually relatively low since natural gas is often available at low cost. East Coast fuel costs are generally at the higher end of the range. A typical value for the cost of water is $.02/1000 gallons which includes the cost of required equipment, including cooling tower and piping, as well as the cost of the power for pumping. Installed cost of exchanger surface, $/sq. ft., will usually vary from as low as $6 to as high as $20. Heat transfer coefficients may vary from 30 - 75 BTU/hr/sq.ft./°F for the exchangers in a crude train.

Average values of $10/sq.ft. for exchanger surface and 50 BTU/hr/sq.ft./°F for the heat transfer coefficient can usually be used quite satisfactorily in determining the optimum temperature approach for all the exchangers in a crude preheat train. This is true because the hotter exchangers, which tend to have the higher heat transfer coefficients, and also tend to cost more because they require more expensive materials. Higher fouling factors at hotter temperatures also tend to keep the heat transfer coefficient values from varying excessively. The "return" versus approach curves are relatively flat at approach values above the optimum, as is shown by Figure 3. Below the optimum approach the decline in yearly savings is quite abrupt, so it is better to use approaches slightly above, rather than below, the optimum. Inspection of the above curves seems to indicate that the optimum approach will usually fall between 35 and 75.

Happel (1) suggests "as a rule of thumb" starting with a value of 30°F when making calculations to determine an optimum exchange approach. While this may be all right as a starting point, it appears from Whistler's work that such a close approach would only be justified when fuel is quite expensive (about $.45/MMBTU/Hr heat absorbed or when exchanger surface is unusually cheap, in the order of $6/sq.ft. installed).

In summary it appears from Whistler's article that an approach value of 40°F could safely be used if the cost of fuel is fairly high relative to the cost of exchanger surface, while a value of 50°F could be used when the cost of fuel is, again relatively, somewhat low. However, a more precise method of determining optimum approach is detailed in Chapter 3. Whether or not its use is justified will be determined by experience.

CHAPTER 3

OPTIMUM TEMPERATURE APPROACH

Establishing the most economical preheat system for a crude unit is a matter of establishing the order in which the available streams should exchange their heat with the crude and of determining to what extent the streams (other than fixed-duty streams) should be cooled by the crude before undergoing further cooling in air or water coolers.

Considering a system with only one heating stream, the inlet temperatures of the hot and cold streams will be constants, with the outlet temperatures as variables (of course fixing either outlet temperature fixes the other). There will be an optimum outlet temperature for the hot stream which will result in the most profitable exchanger-cooler system from the standpoint of utility savings realized. This problem is dealt with in considerable detail by Happel (1) in his text book. He shows calculations for a number of base cases and presents results in tabular form. The most significant case is for "East Coast" utilities and for 1-2 multipass exchangers. Results for this case are given in Table I. Optimum approach temperature is the dependent variable with R and D (see nomenclature) as the independent variables. The temperature approach values given are "hot end" approaches. This is somewhat inconvenient since approach is generally considered to refer to "cold end" approach. This is the "approach" used by Whistler and by Happel himself in another chapter in his book

TABLE I

* OPTIMUM APPROACH (HOT END) = $t_1 - T_2$, °F

EAST COST UTILITIES 1-2 MULTI PASS EXCHANGER

$R = \frac{wc}{WC}$ = APPROXIMATE RATIO OF HOT FLUID TO CRUDE

$D = t_1 - T_1$	R								
D	.1	.25	.50	.75	1.0	2.0	4.0	6.0	10.0
50	46	40	33	28	24	17	12	10	8
100	91	79	64	53	45	28	18	13	11
200	182	158	126	104	86	52	30	22	17
300	272	235	188	153	127	75	42	30	21
400	363	313	250	203	169	98	56	40	28

TABLE II

* OPTIMUM APPROACH (COLD END) = $t_2 - T_1$, °F

EAST COAST UTILITIES 1-2 MULTI PASS EXCHANGER

$R = \frac{wc}{WC}$ = APPROXIMATE RATIO OF HOT FLUID TO CRUDE

$D = t_1 - T_1$	R								
D	.1	.25	.50	.75	1.0	2.0	4.0	6.0	10.0
50	10	10	16	21	24	34	41	43	46
100	10	16	28	37	45	64	80	86	91
200	20	32	52	72	86	126	58	170	182
300	20	40	76	104	127	187	235	255	272
400	30	52	100	137	169	249	314	340	363

* "COLD" APPROACH = $\frac{RD - D + \text{"HOT" APPROACH}}{R}$

(See Nomenclature for Definition of Symbols) entitled, "Practical Rules of Thumb". There it says that as a first trial a 30°F difference between incoming hot stream and leaving cold stream may be employed. Table II has been prepared and included here for convenience. The results in Table II are the same as in Table I except that "cold end" approaches have been substituted for "hot end" approaches.

Where there is a bank or train of exchangers, the problem of optimization is more complicated because the possible savings for each exchanger are affected by the exchangers which "follow it" in the train to further heat the crude. This problem is dealt with by Ten Broeck (2) who gives detailed calculations for the optimum outlet temperatures for each exchanger in a "bank" of three. A sample problem is solved in Appendix C to illustrate Ten Broeck's method. Reference to this problem indicates that only the exchangers which follow affect the savings for a particular exchanger. Both Ten Broeck and Happel use nomographs developed by Ten Broeck in calculating optimum temperatures. Refer to Figures 9 and 10 in Appendix C for nomographs to be used for multi-pass (1-2) exchangers and multi-pass (2-4) exchangers respectively.

In view of the above, one way to employ the model program for accurate results is to use Ten Broeck's method of obtaining optimum outlet temperatures for each exchanger in a train, using known utility and equipment costs. The calculated "cold-end" approach for each exchanger should then be entered with the other input data, and will be used in the heat transfer calculations. This appears to be the best way to approach true optimization without unduly complicating the mathematical model.

The simulation program itself could have been written to include an optimization procedure, but, in view of the large number of variables involved, and the complexity of their relationships, much simplification and approximation would have been necessary. The results obtained from such an over-simplified procedure could hardly have been considered optimum from a theoretical standpoint.

If the Ten Broeck method of determining optimum temperatures is found to be too laborious, a "trial and error" method of attack can be employed. Several cases would be investigated, each with a separate set of estimated approach temperatures. Then, since the model gives values for the amount and cost of both exchanger and cooler surfaces, the case giving the best results in terms of per cent return on incremental investment would be selected as the design case.

This trial and error approach should prove reasonably practical since, as shown in Figure 3, relatively little variation in savings occurs over a rather wide range of temperature approach values, as long as the approach value employed is above, rather than below, the "exact" optimum. Chapter 6, "Conclusions", gives results of a sample problem where three sets of approach values were used, with the same approach used throughout each set for each variable-duty exchanger in the preheat train.

CHAPTER 4

FIXED DUTY STREAMS

A great deal of the material in Chapter 3 referred primarily to variable-duty streams, such as the product streams from a distillation tower, which must be cooled to relatively low temperatures before leaving the distillation unit area. Heat not transferred to crude by an exchanger must be removed in an air or water cooler. The temperature of the hot stream leaving the exchanger depends on the optimum approach which in turn depends on utility and equipment costs. Besides these variable-duty streams, fixed-duty streams also supply heat to crude. Pumparound streams (or circulating reflux streams) are important examples of this type. Both the amount of heat to be removed and the temperatures of the pumparound stream entering and leaving the heat exchanger are supplied as input data to the program. Sometimes, instead of the entire pumparound duty being transferred to crude, a trim cooler is incorporated in the pumparound circuit. The amount of trim cooling is a process rather than an economic consideration however,and the amount of pumparound heat to crude is still predetermined, even though it may not be 100% of the heat removed by circulating reflux.

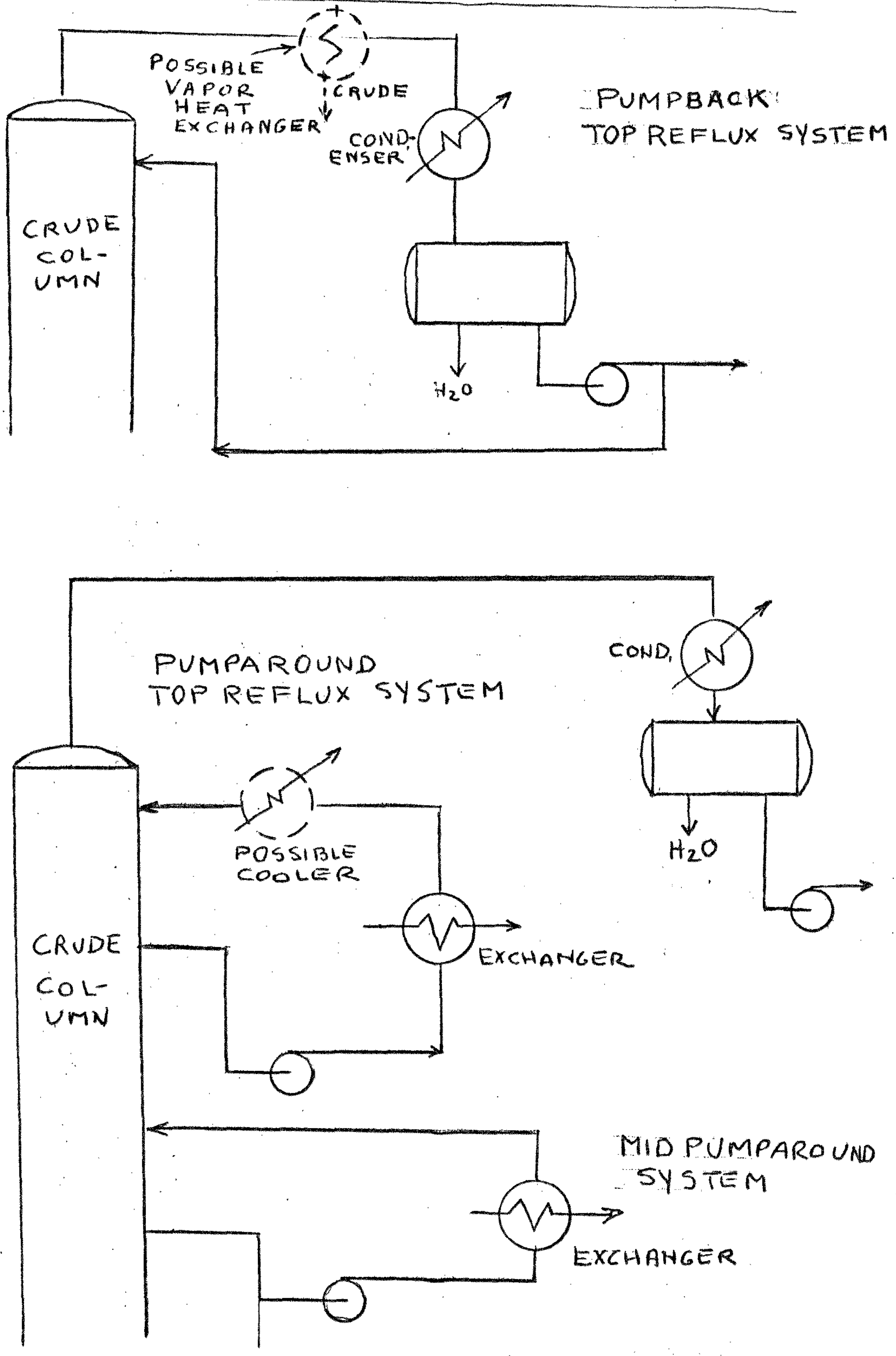
As to the nature of pumparound streams, they are used to remove heat from a crude distillation column. A certain amount of the heat entering the column with the partially vaporized feed must be removed at the top of the tower to satisfy fractionation requirements. This heat may be removed by pumping back condensed overhead as reflux, or by circulating an externally cooled pumparound stream over several of the tower trays to generate internal reflux. Figure 4 shows these two systems. Usually one or more additional pumparound systems are located farther down the column for the balance of the heat removal.

The use of pumparound systems has two advantages. First, heat is made available at sufficiently high temperature levels to be advantageous for economically preheating crude. Second, the diameter of the tower need not be as large, if mid-pumparound heat removal is employed instead of letting all the heat flow up the tower to be removed by top reflux.

A pumparound system usually is comprised of several heat transfer trays located immediately below a sidestream product drawoff tray, a pump for circulating liquid, and associated exchangersand/or coolers. While the primary function of these trays is the generation of internal reflux by direct heat transfer, they also afford a limited amount of fractionation. When a crude tower is being designed, the lower pumparound duties are established on the basis of removing as much heat as possible at as high a temperature level as possible, while still allowing enough heat to pass up the tower to result in adequate fractionation between the product streams above. The amount of pumparound and the drawoff and return temperatures are selected to correspond to an integral number of pumparound trays within the column, usually two, three or four. As to temperatures, the pumparound stream should usually be withdrawn at a temperature approximately 30°F below the

FIGURE 4

PUMPBACK AND PUMPAROUND REFLUX SYSTEMS



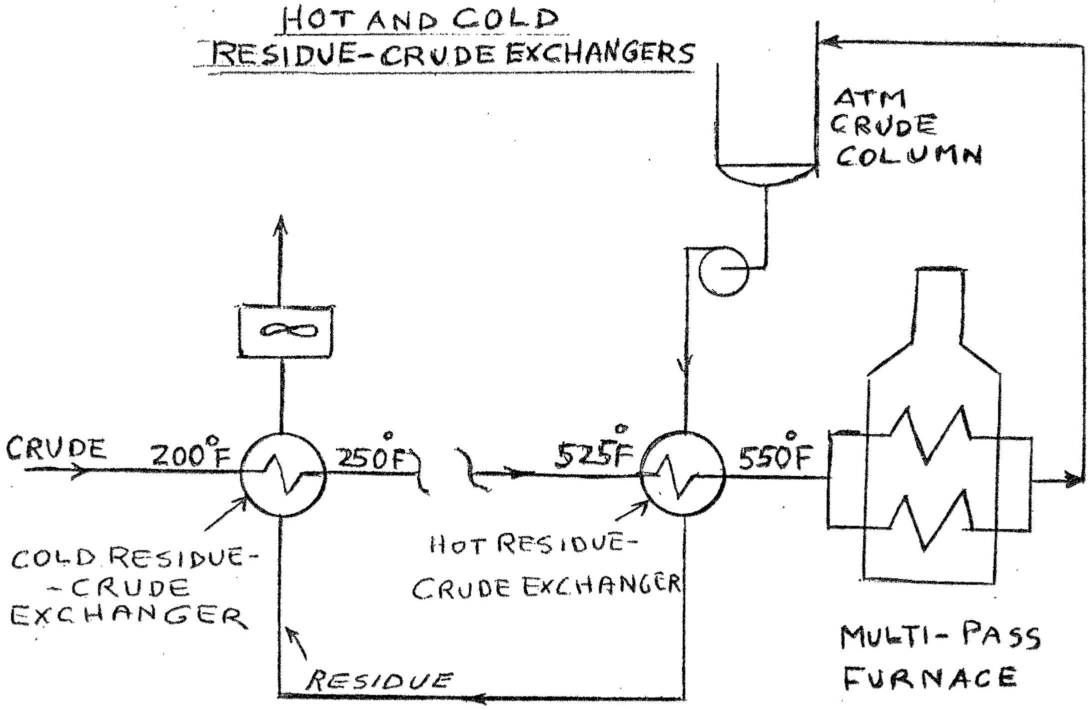
temperature of the ascending vapor at the withdrawal point. The return temperature should be such as to give a good mean temperature difference for transferring heat to crude while at the same time satisfying the internal heat removal requirements. The system selected should result in minimum cost for heat transfer trays, external heat transfer surface and pump, with capitalized pumping costs included.

If a top pumparound system is employed, it may well turn out to be the first preheat stream and to flow through the first exchanger in the train because of its relatively low temperature level. When a top pumparound system is not employed, the overhead condensing duty of the tower may be large. In such a case it may prove economical to employ a vapor heat exchanger to recover part of this heat by preheating crude. When using the model program, the duty for a vapor heat exchanger should be pre-established by the user. This is because the program relationships apply only to liquids, not to condensing vapors.

Another type of stream that may sometimes require special treatment is a "residue" or tower bottoms stream. The temperature of such a stream leaving a tower is invariably high and if the quantity is fairly large, the amount of associated heat available for preheating the crude may be large. Because of the high temperature, such a stream will usually flow through the last exchanger in a preheat train. Frequently, the residual stream leaving this last exchanger will still contain too much high temperature level heat to be "thrown" to water. In using "preheat" in such a situation, the procedure would be to calculate a duty for the last exchanger based on a reasonably good estimate of the final preheat temperature to be achieved. This hot stream should then be treated as a pumparound or fixed duty stream when supplying the necessary input data to "Preheat". The residue at the exit temperature from the "hot residue exchanger" should be entered as a separate variable duty stream. This stream will then transfer heat to the crude at a point in the train corresponding to the "Pseudo T" value calculated by the program. The program will also carry out all the necessary calculations including the calculation of cooler surface, etc. Figure 5 shows a train with "hot" and "cold" residue exchangers. The figure also shows the crude from the "hot" residue exchanger flowing to a multi-pass heater. Most heaters, except small ones, are multi-pass. Because of this, the crude should not be heated above its bubble point at the heater inlet pressure, since instrumentation problems make it impractical to split a two-phase stream.

FIGURE 5

HOT AND COLD RESIDUE-CRUDE EXCHANGERS



(TEMPERATURES SHOWN
ARE TYPICAL ONLY)

CHAPTER 5

MODEL PROGRAM DESCRIPTION

The model program, entitled "Preheat", simulates a system of heat exchangers preheating the feed to a crude distillation unit. Two types of system are simulated. The first of these, designated "single train", is represented physically in Figure 1 of Chapter 1. Figure 6 gives a "heat picture", or thermal representation, of such a single train system.

The second type of system simulated is the split, or parallel, train. This is represented by the heat picture in Figure 7. The split occurs after the crude flows from the desalter. The crude is divided into two equal parallel streams, each of which is then heated by an individual set of heating streams. The program selects the heating streams for each set in such a way that the two parallel streams receive approximately equal amounts of heat. The parallel trains are called the "A Train" and the "B Train" respectively. The heat loads for the "A" and "B" trains are represented in Figure 7.

The crude stream is not usually split upstream of the desalter, primarily because much of the heat absorbed up to that point is generally supplied by a low temperature, high heat capacity stream, for example an atmospheric top pumparound stream or an atmospheric tower overhead vapor stream. Such a stream can exchange heat efficiently with the whole crude stream.

The heat pictures show how each variable-duty heat stream

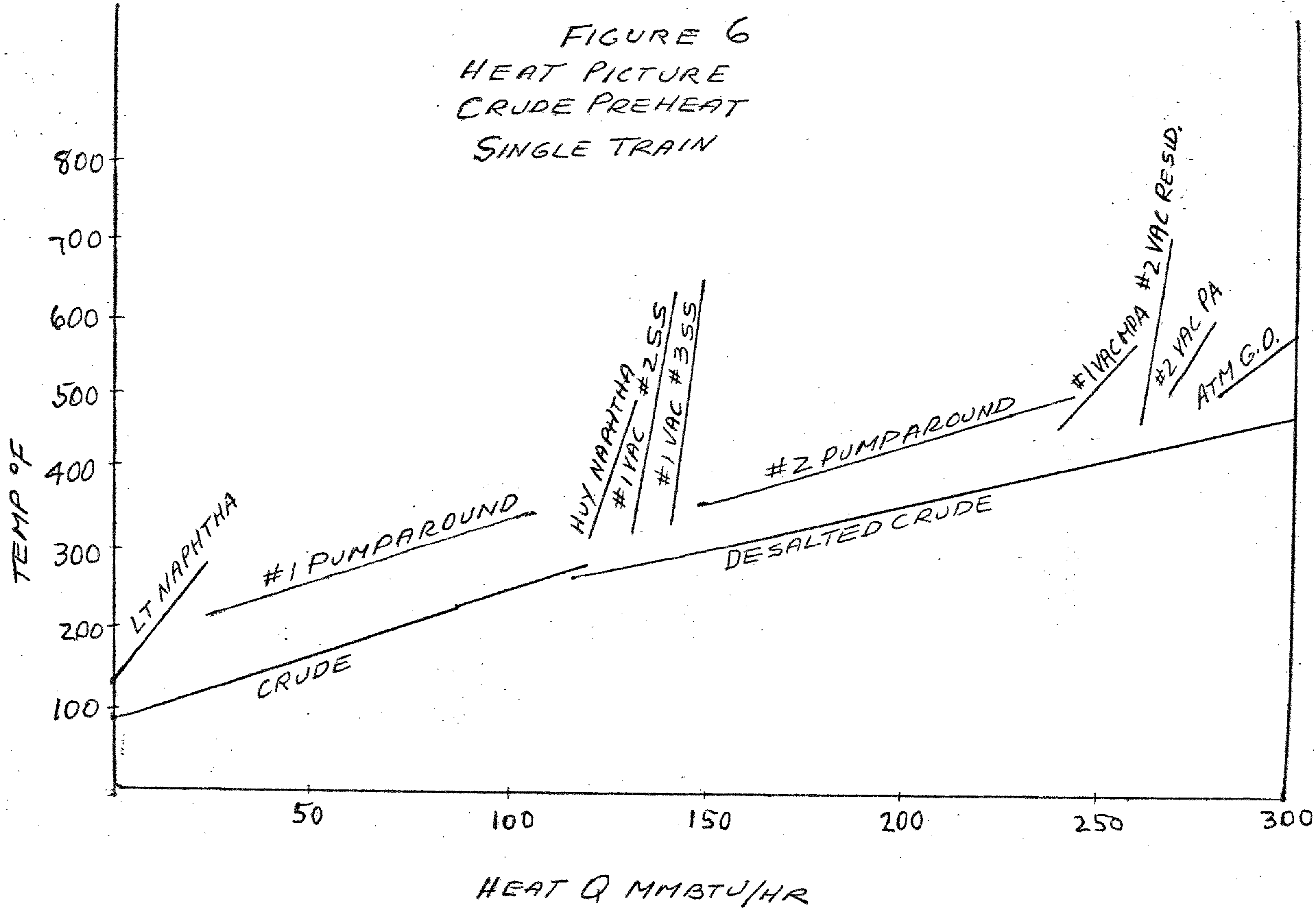
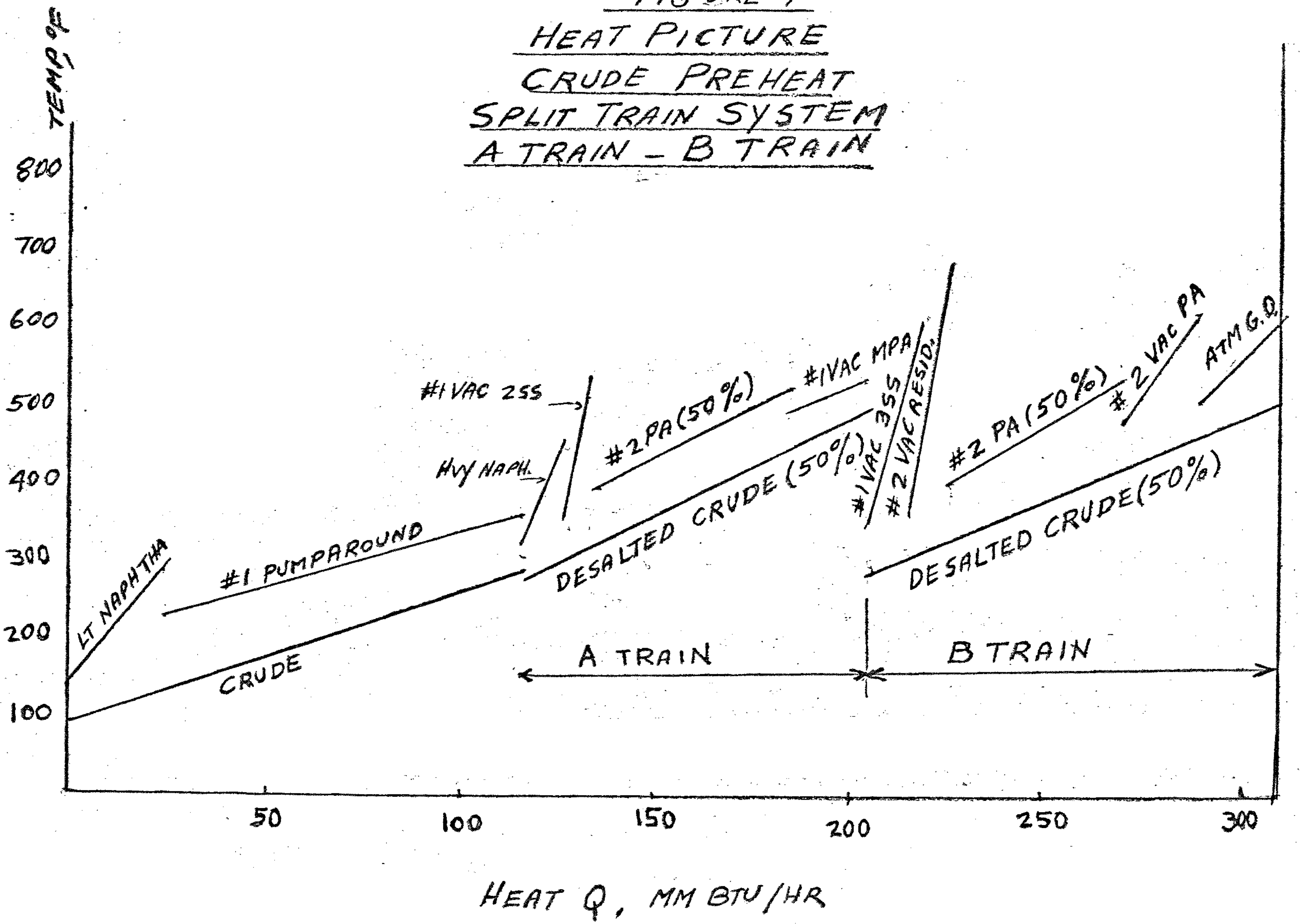


FIGURE 6
HEAT PICTURE
CRUDE PREHEAT
SINGLE TRAIN

FIGURE 7

HEAT PICTURE
CRUDE PREHEAT
SPLIT TRAIN SYSTEM
A TRAIN - B TRAIN



exchanges heat with the crude until the specified temperature approach is reached. The pictures also show that more heat can be transferred from the heating streams to the crude as the heat-temperature lines representing the heating streams tend to parallel the heat-temperature line (or curve) of the crude. This is not only true for individual exchangers, but applies to the relative arrangement of exchangers in a train as well.

The model program may be considered to represent heat exchanger trains mathematically in much the same way that heat pictures, such as Figures 6 and 7, represent them graphically. The order in which the individual exchanger calculations are to be performed is determined by the program. This corresponds to determining the order in which the exchangers should be arranged physically. Then the calculations corresponding to the transfer of heat are carried out, with the temperature rise of the crude being determined in each exchanger. In the case of the variable-duty heating streams, the duty corresponding to the specified temperature approach (to crude) must be calculated, This is not required for fixed-duty heating streams.

Detailed information relative to preheat is given in Appendices A, B and C. Appendix A describes the program's features, defines its variables and gives detailed instructions for its use. Appendix B contains the statement list for the program and gives results for three sample problems. Appendix C covers the selection of economic temperature approach values by Ten Broeck's method.

CHAPTER 6

CONCLUSIONS

Some conclusions based on results obtained using "Preheat" are discussed in this chapter. More definite conclusions as to practical selection of economic temperature approach values and the type of preheat system to be employed, whether single or split train, can better be made after further use of the program.

As to evaluation of an optimum temperature approach, computer runs were made for a sample problem, corresponding to a single train system, using the same temperature approach value for each "variable duty" exchanger in each run. The data for this sample problem were essentially the same as for sample problems #1 and #2 in Appendix B. Three runs were made with the approach (or temperature difference) having values of 30, 40 and 50°F. Comparative heat duties as well as fuel and equipment costs are shown in Table 3. The "total equivalent incremental equipment cost" listed in the table equals the incremental equipment costs plus the incremental utility costs for a "payout" period of three years (before taxes). Incremental costs for the three cases were plotted versus temperature approach. The curve plotted in Figure 8 indicates that a 40° approach gives the lowest cost for the case investigated. The results in this example are not particularly sensitive to the value of the approach used for for the variable duty exchangers, due to the large amount of "fixed duty" heat associated with the pumparound streams in the

TABLE 3

APPROACH ECONOMICS FOR SINGLE TRAIN EXCHANGER SYSTEM. OPTIMUM APPROACH IF SAME VALUE USED FOR ALL VARIABLE DUTY EXCHANGERS

	APPROACH °F		
	30	40	50
Exch. Duty MMBTU/Hr	77.29	76.12	74.95
Incremental Exchanger Duty MMBTU/Hr	2.34	1.17	0.0
Incremental Heater Duty MMBTU/Hr	0.0	1.17	2.34
Incremental Fuel Cost for 3 years - $	0.0	12,700	25,400
Surface Cost - $	334,000	314,800	249,600
Incremental Heat Cost, $ @ $3.00/1000 BTU/Hr Capacity	0.0	4,700	9,400
Total Equipment Cost, $	334,000	319,500	309,000
Incremental Equipment Cost, $	25,000	23,200	25,400
Total Equivalent Incremental Equipment Cost, $ (including 3 yrs Fuel Cost)	25,000	23,200	25,400

NOTES:

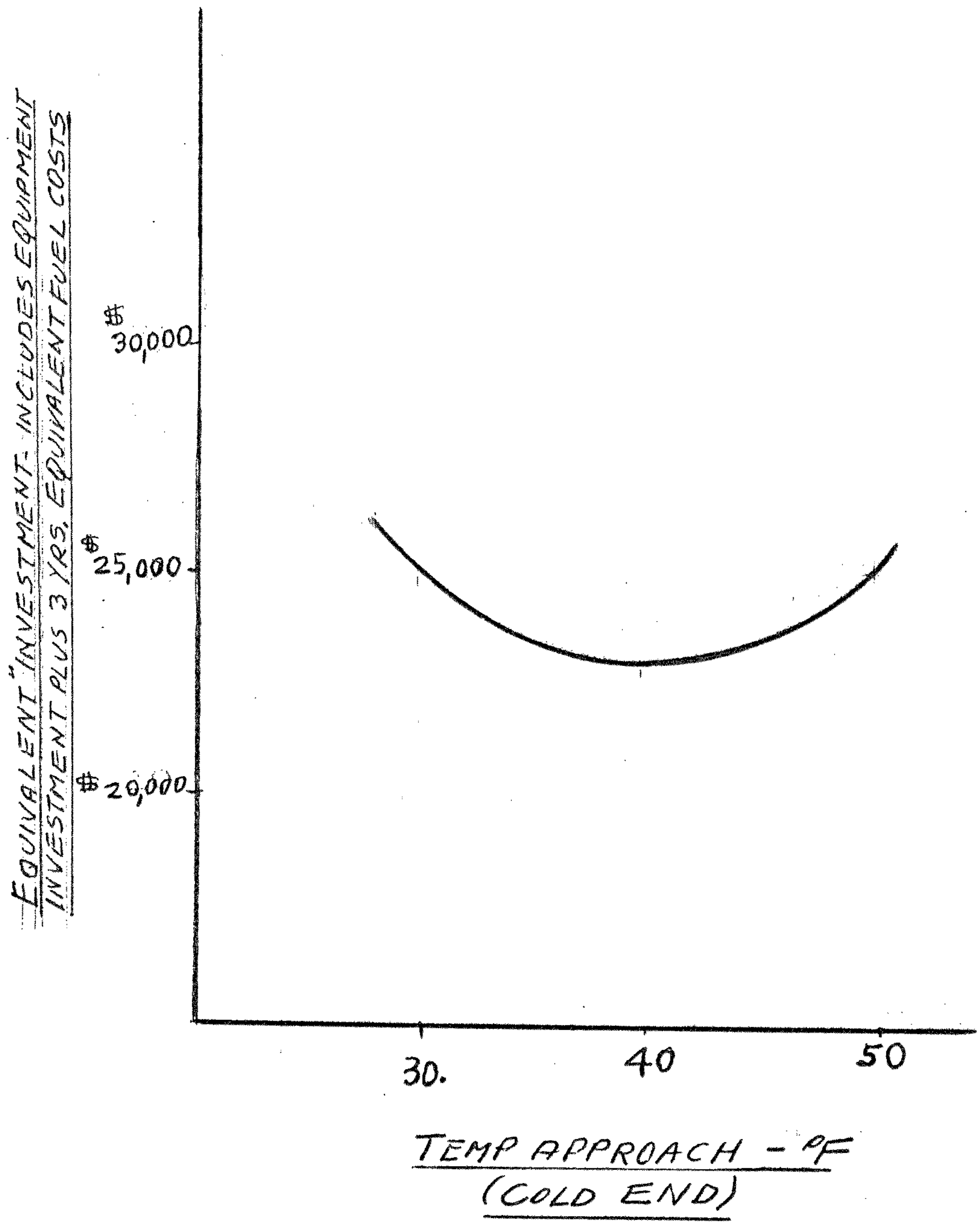
1) See Figure 8 for plot of results.

2) Basis - 3 yrs. of fuel savings (before taxes)

$$3 \text{ yrs Equiv. Fuel Cost} = \frac{1.17 \text{ MM}}{.75 \text{ Effy}} \times 0.33 \text{ \$/MM} \times 3 \text{ yrs.} \times (8750 \times .93) \text{ Hrs/Yr.} = \$12,700$$

FIGURE 8

EQUIVALENT INVESTMENT
VS. TEMPERATURE APPROACH



preheat train. This will be true of many preheat trains.

To further investigate the subject of temperature approach, two more computer runs were made for a single train exchanger system. The results appear as the output for sample problems #1 and #2 in Appendix B. The arrangement of the exchangers in the train differed slightly from that on which the calculations of Table 3 were based. One run was made using a 40°F temperature approach for each variable duty exchanger (sample problem #1 in Appendix B.) For the other computer run the temperature approaches used for the variable duty exchangers were 60°F, 50°F, 30°F and 20°F, with the lower values being used for the hotter exchangers (sample problem #2 in Appendix B). Comparative heat duties as well as fuel and equipment costs are shown in Table 4.

It will be noted that the incremental cost for the "varied approach" case is less than for the "40°F approach" case. However, the difference of approximately $2,000 is so small as to be almost insignificant, representing only about 0.6% of the total actual equipment cost.

As to the economics of a split train system (following the desalter) versus a single train system, it has been thought that the split train system is more economical where large capacity crude units are involved. However, the results of sample problem #3 in Appendix B, as summarized in Table 5, show a yearly return of but 7% on the incremental investment required for the split train system. Use of a split train system is certainly not justified for the case on which this sample problem was based. The crude

TABLE 4

APPROACH ECONOMICS FOR SINGLE TRAIN EXCHANGER SYSTEM

COMMON APPROACH VALUE VS. VARIED APPROACH VALUES FOR VARIABLE-DUTY EXCHANGERS

	Single Value 40°F	Varied Values 60-20°F
Exch. Duty, MM BTU/Hr	73.2	73.5
Incr. Exch. Duty, MM BTU/Hr	0	0.3
Incr. Heater Duty, MM BTU/Hr	2.9	2.6
Incr. Fuel Cost for 3 yrs, $	31,300	28,100
Surface Cost, $	11,600	10,400
Incremental Heat Cost, $, @ $3.0/1000 BTU/Hr Capacity	248,930	251,220
Total Equipment Cost, $	260,530	261,620
Incremental Equip. Cost, $	0	1,090
Total "Equivalent" Incremental Equip. Cost (Includes 3 yrs Fuel Cost)	31,300	29,190

NOTES: 1) Basis: - 3 yrs Fuel Savings (Before Taxes)

$$3 \text{ yr. Equiv. Fuel Cost} = \frac{1.17}{0.75 \text{ Effy}} \times 0.33 \text{ \$/MM} \times 3 \text{ yrs} \times (8750 \times .93) \text{ Hrs/Yr} = \$12,700$$

unit in this case was a large one and the low return on investment raises considerable doubt as to whether many cases will arise in which a split train system would be justified.

TABLE 5

ECONOMIC COMPARISON OF SINGLE TRAIN VS. SPLIT TRAIN PREHEAT EXCHANGER SYSTEMS

	Single Train System	Split Train System
Exch. Duty MMBTU/Hr	305.11	307.0
Incr. Htr. Duty, MMBTU/Hr	1.89	0.0
Exch. Cost, $	931,400	1,035,500
Cool Cost, $	224,200	224,200
Total Surf Cost, $	1,155,600	1,259,700

Yearly Savings @ HT Value of $0.33/MM BTU/Hr.

Heat to Oil:

1.89 MM BTU/Hr. x $0.44/MM Ht. Fired x 8250 Hrs/Yr. = $6,800/yr.

% Annual Return on Incremental Equip. Investment:

$1,259,700 - $1,155,600 = $98,100

$6800/$98,100 = 7.0%

APPENDIX A

1. Program Features
2. Program Variables
3. Program Instructions

APPENDIX A

1. Program Features

Some of the principal features of the program are enumerated and explained below.

a. Array of Heat Streams

Input and output data for the program are conveniently stored and handled in the form of an array. The various heat streams correspond to the columns of the array and there are fourteen of them. The various characteristics of each stream, or the calculated values for that stream, correspond to the rows of the array. There are eighteen of these rows. Thus, the subscripted variable HTSTR (I, J) represents any input or output value related to any of the preheat streams, where I can have any value from 1 to 18 and J any value from 1 to 14. For example, HTSTR (4, 4) would designate the °API of preheat stream #4.

The array is first printed to show input data: The streams have been rearranged at this point in ascending order of their "Pseudo T's". Other array positions not containing input data show "0.0" at this point. After the preheat calculations have been carried out and the significant results have been stored in their proper positions, the array is again printed, this time showing not only the input data but all the pertinent output data as well. Of course provision had to be made for the fact that in some cases there will be more output streams than input streams. This happens, for example, when one of the heating streams must be split into hot and cold streams to bring the crude to the required desalting temperature. The lower temperature stream heats the crude to its desalting temperature, while the higher temperature stream exchanges heat with the crude leaving the desalter.

b. Rearrangement of Heat Streams

Heat streams need not be arranged in any particular order when being submitted as input. The program will rearrange the heat streams in the proper order in accordance with their "heat transfer potential" called "Pseudo T" and defined by formula in the list of Program Variables. This formula is somewhat empirical but appears to give satisfactory results. However, a variable has been included in the program which permits the formula to be "adjusted". For further flexibility, provision has been made so that heat streams can be submitted in any desired order and not be rearranged, i.e. the preheat calculations will be carried out with the heating streams supplying heat to the crude in predetermined sequence. This feature might be desirable if, for example, the amount of heat available from one stream, say the crude residue, were large, and it was decided to "split" the duty between two exchangers, the high temperature exchanger presumably being the last in the train, and the low temperature exchanger located at any desired point in the train but at a lower crude temperature level.

c. Suitability to Crude Unit Preheat

While the program could quite easily be adapted to other types of preheat systems, it is specifically intended for a crude distillation unit. Crude units almost always include an electrolytic desalter as discussed in Chapter I. The desalting process should take place at a rather specific temperature, related to the nature of the crude but usually approximating 260°F. The program takes this problem into account and proportions the heat exchanger duties so that the required desalting temperature is obtained between exchangers. The program also assures that the duties of the exchangers immediately upstream and downstream of the desalter are of suitable magnitude, that is not too small to be practical. A crude temperature rise requirement of at least 10°F provides for this. Furthermore, the program provides for the fact that a temperature drop occurs when the crude flows through the desalter. The temperature to the next exchanger is 5-10°F lower than that from the preceding exchanger. Quite often a flash drum is included in a preheat train, sometimes in addition to, and sometimes instead of, a desalter. The quantity and temperature of the crude will usually change when flowing through a flash drum and the program is also sufficiently versatile to take this into account.

d. Types of Preheat Streams

There are two principal types of preheat streams. Sidestreams withdrawn from the tower exchange heat with the crude in the order of their heat transfer potential, and down to a temperature corresponding to an "economic" cold end approach. This temperature approach is a function of fuel cost, exchanger cost, etc. and is to some extent related to the heat transfer characteristics of the other streams from which heat may be transferred. Usually, however, this optimum approach is fairly constant over a considerable range in the value of the above factors. A value of 40°F is frequently satisfactory in cases where fuel and exchanger costs are "normal". Streams of this first type may be designated "variable duty" streams.

Streams of the second type may be designated "fixed duty" streams. Tower pumparound streams are the principal examples of this type of stream. For such streams, outlet exchanger temperatures and heat duties are supplied to the program as input data, rather than calculated as with product streams. If, as is sometimes the case, a vapor heat exchanger is used to preheat crude, it should be treated as a pumparound stream, and a "1" should be placed in the proper position to designate it as such.

e. Parallel Trains

When dealing with small or medium sized crude units, all the exchangers providing heat to the crude are usually arranged in series for the sake of simplicity and to avoid inclusion of exchangers that might be somewhat too small to be economical. When dealing with large units however, say 100,000 BPSD (barrels per stream day) or more, it has been found advantageous to split the crude into two parallel streams immediately downstream of the desalter. This arrangement makes it possible to preheat the crude to higher temperatures than would otherwise be possible. The program makes provision for this. The program user can specify that the calculations be performed and results printed for a single train system only; or he can specify the run be made for a parallel train system. In the latter case, not only will the single train calculations be performed and printed, but the program will continue on through the calculations for a system with parallel trains of exchangers downstream of the desalter (trains "A" and "B"). The results for both systems will be printed and comparison can be made of the final preheat temperatures, amounts of exchanger and cooler surface, and the relative costs of such surface.

f. Temperature Approach

An individual value for "cold end" temperature approach must be entered for each variable duty heating stream. The need for achieving an optimum preheat system made it seem advisable to make provision for using "varied" approach values.

g. Subroutine "SPHT"

A subroutine entitled "SPHT", is incorporated in the program. Every time a heat exchanger duty, cooler duty, or change in temperature is calculated, a specific heat value must be employed that is correct for the particular temperature range involved. The subroutine calculates the specific heat value as a function of temperature and the °API of the fluid undergoing the temperature change. There are three cases for which the subroutine must determine a specific heat value. The simplest is when two temperatures are known and can be given as arguments, along with the °API of the liquid. The second is when the heat duty and the hotter temperature, along with the °API, are the arguments. The third is when the duty and colder temperature (again with the °API) are the arguments. For the latter two cases, the subroutine performs a trial and error type of calculation, in which the second trial gives a sufficiently accurate specific heat value. In the first case, with both temperatures known, the specific heat can be calculated directly.

APPENDIX A

2. Program Variables

The variables used in "Preheat" are defined as follows:

HTSTR (I, J) - This array is used for storing input and output data associated with the various streams available for preheating crude. "J" represents a particular preheat stream while "I" represents either an input value or a calculated value for that stream. "J" can be any number from 1 to N, where N is the value read into the computer representing the number of heat streams. "I" is any of 18 values associated with each stream, either as input or calculated. The various "I" variables are as follows:

HTSTR (1, J)) Stream Name, alpha meric
) 3 words totalling 10
HTSTR (2, J)) characters used for
) each name
HTSTR (3, J))

HTSTR (4, J) - Specific gravity as °API

HTSTR (5, J) - quantity of heat stream, lbs/hr.

HTSTR (6, J) - inlet (hot) stream temp., °F.

HTSTR (7, J) - temp. of stream from "system", °F.

HTSTR (8, J) - either "0" or "I". If a "I" is entered then the stream is a pumparound stream with a fixed amount of heat to be transferred. If a "0" is entered, then the stream is not a pumparound and the amount of heat to be exchanged must be calculated, primarily as a function of the "cold end" temperature approach to the crude entering the heat exchanger.

HTSTR (9, J) - Exchanger Duty - BTU/hr.

HTSTR (10, J) - Temperature of heating stream from exchanger, °F.

HTSTR (11, J) - Temperature of crude leaving exchanger "J", °F.

HTSTR (12, J) - Cooler duty, BTU/hr.

HTSTR (13, J) - Pseudo T, °F.

- Pseudo T is the name given to an empirical function that is regarded as indicative of the heat transfer potential of a heating stream. The program causes the streams to be rearranged, in ascending order, in accordance with the calculated Pseudo T values, before the preheat calculation proceeds. The Fortran formula employed is:

HTSTR (13, J) = HTSTR (6, J) - (FACT*CRLB/HTSTR (5, J) or

$$\text{Pseudo } T = t_1 - \left(\text{FACT} \times \frac{W}{w}\right)$$

The value recommended for the factor employed (FACT) is 10.0. If experience should indicate it to be desirable, a different factor can be introduced as input data to alter the order in which the streams exchange heat with the crude.

HTSTR (14, J) - Exchanger heat transfer surface, sq.ft.

HTSTR (15, J) - cooler heat transfer surface, sq.ft.

HTSTR (16, J) - Exchanger Cost, $

HTSTR (17, J) - Cooler Cost $

HTSTR (18, J) - "Approach" - The "cold end" temperature approach to be used for the heating stream. No value is entered for a pumparound stream.

N - number of heating streams.

MODE - either "1" or "2" must be read into MODE. If "1", calculations are made on a single train arrangement only. If "2", the calculations are first made for a single train and then for a parallel train arrangement so the results can be compared.

IFFL - either "1" or "0" must be entered under IFFL. If "1", the presence of a flash drum in the train is indicated and the quantity of flashed crude leaving the flash drum and its temperature and specific gravity must be included as input data. If "0", there is to be no flash drum and consequently no flashed crude data is provided as input.

NOAR - either "1" or "0" must be read into "NOAR". If "NOAR" is 0 (considered the more usual case) the streams will be rearranged in order of ascending "Pseudo T" values. If "NOAR" is "1", the heat streams will not be arranged in ascending order in accordance with their "Pseudo T" values, but remain in the predetermined order in which their data is read into the array "HTSTR".

CRAPI - specific gravity of crude, °API.

CRLB - quantity of crude, lbs/hr.

CRTIN - temperature of crude to unit, °F.

TW1 - temperature of cooling water to users, °F.

TW2 - temperature of cooling water from coolers, °F.

FCRAPI - specific gravity of flashed crude, °F.

FCRLB - quantity of flashed crude, lbs/hr.

FCRTIN - temperature of crude from flash drum, °F.

DESALT - temperature of crude to desalter, °F.

TTOL - temperature tolerance, or allowable deviation from prespecified value of desalting temperature, °F.

FUCOST - cost of fuel, \$/MM BTU/hr.

ACOST - average cost of exchanger (and cooler) surface, \$/sq.ft.

UAV - average heat transfer coefficient for exchangers, and coolers.

PAYRS - number of years allowed for "paying off" an investment, years.

DROP - drop in crude temperature from desalter inlet to outlet, °F.

ECAP - economic "cold end" temperature approach between heating stream leaving and exchanger and crude entering the exchanger, °F.

CP - specific heat, BTU/lb/°F.

DELT - temperature difference, °F.

NB - number of exchangers before desalter.

NAFT - the number of the first exchanger after the desalter. NAFT will equal NB + 1.

MAFT - number of exchangers following desalter in single train.

NEWN - number of heating stream after split at desalter and/or after division a large heating stream into 2 parallel streams with parallel trains.

FACT - factor to be employed in formula for calculating "Pseudo T".

XMTD - log mean temperature difference for exchanger or cooler, °F.

DELTH - hot end temperature difference for exchanger or cooler, °F.

DELTC - cold end temperature difference for exchanger or cooler, °F.

SPLIT - "split" is to contain "1" if a stream is split to provide heat downstream as well as upstream of desalter. "0" in split means no such "split" occurs.

SUM 9 - sum of exchanger duties, BTU/hr.

SUM 14 - sum of exchanger surfaces, sq. ft.

SUM 15 - sum of cooler surfaces, sq. ft.

SUM 16 - sum of exchanger costs, $

SUM 17 - sum of cooler costs, $

A(I,J) - A train array (1st parallel train).

B(I,J) - B train array (2nd parallel train).

SUMA - sum of heat duties of A train exchangers.

SUMB - sum of heat duties of B train exchangers.

DIF - DIF = SUMA - SUMB.

RISE - increase in temperature of crude in exchangers.

NAT - number of exchangers in A train.

NBT - number of exchangers in B train.

HAFCR - quantity of crude lbs/hr. thru each of Trains A & B.

SALT - temperature from desalter (DESALT - DROP).

Subroutine Variables

T1 - high temperature

T2 - lower temperature

Q - duty, BTU/hr.

XLB - stream quantity, lbs/hr.

COUNT - number of iterations (0 to 1).

API - Specific gravity, °API.

APPENDIX A

3. Program Instructions

Data cards must be prepared and placed in back of the program deck in the usual manner. As discussed under "Features", the input data associated with the heating streams and all the results considered significant for output are stored in the array named HTSTR (I, J) where variable "J" represents the streams providing heat to the crude and variable "I" represents values associated with the stream. "I" may represent a property such as °API or the quantity in lbs/hr.; or it may represent a calculated result such as the temperature of crude from the exchanger or the duty of the exchanger corresponding to the heat stream. The other input data to be provided is specified in the description of the individual cards which follows:

Data Card 1 - "Integers"

All the variable values for this card must be entered as integers, right justified.

Columns	Variable Name
1 - 2	N, number of heating streams entered here.
3 - 4	MODE - enter "1" for a single stream exchanger system and "2" if both a single stream arrangement and a parallel stream arrangement are desired.
5 - 6	IFFL - enter "1" if a flash drum is to be included at some point in the heat exchanger train and "0" if no such drum is included.

Columns	Variable Name
	NOAR - enter "1" if the heating streams are to remain in the order in which they are entered on the input data card and "0" if (as would be usual) the program is to rearrange the streams in ascending order of their "Pseudo T's".

Data Card 2 - Crude Data

All the variable values punched on this card as to decimals (floating point).

Columns	Variable Name
1 - 10	CRAPI - specific gravity of crude, °API.
11 - 20	CRLB - quantity of crude, lbs/hr.
21 - 30	CRTIN - inlet crude temperature, °F.
31 - 40	TW1 - inlet water temperature, °F.
41 - 50	TW2 - exit water temperature, °F.
51 - 60	FCRAPI - specific gravity of flashed crude (if flash drum included), °API.
61 - 70	FCRLB - quantity of flashed crude, lbs/hr.
71 - 80	FCRTIN- temperature of flashed crude, °F.

Data Card 3 - Miscellaneous Data

Enter these variable values as decimals.

Column	Variable Name
1 - 10	DESALT - desalting temperature, °F.
11 - 20	TTOL - allowable deviation from desalting temperature (+ or -), °F.

Columns	Variable Name
21 - 30	FUCOST - cost of fuel, $/MM BTU.
31 - 40	DROP - temperature drop of crude in flowing through desalter, °F.
41 - 50	UAV - average heat transfer coefficient for exchangers and coolers, BTU/hr/°F./ft.sq.
51 - 60	PAYRS - number of years for investment "payback"
61 - 70	ACOST - Cost of exchanger and cooler surf, $/ft. sq.
71 - 80	ECAP - economic exchanger "cold end" temperature approach, °F (may or may not be entered).

Data Card 4 - Factor

Enter this variable as a decimal number in columns 1-10 of this card.

The usual value is 10.0.FACT is used by the program in the calculation of "Pseudo T" values for each heating stream.

Data Cards 5 and 6 - Stream Names - HTSTR (1-3, J)

Stream names are to be entered alphamerically in columns 1-10, 11-20, etc.

Two cards must be included even though the second may be blank.

Data Cards 7 thru 2N + 6 - Input Data for Heating Streams

(N above equals the number of heating streams).

Enter this data as decimals. Two cards must be included for each stream even if the second is a blank.

1st Card

Columns	Variable Name
1 - 10	HTSTR (4, J) - specific gravity of heating stream, °API.
11 - 20	HTSTR (5, J) - quantity of heating stream, lbs/hr.
21 - 30	HTSTR (6, J) - inlet temperature of heating stream, °F.
31 - 40	HTSTR (7, J) - temperature of heating stream leaving cooler, °F. (enter "0" if stream is a pumparound stream).
41 - 50	HTSTR (8, J) - enter "1" if stream is a pumparound stream (with "fixed" duty). Enter a "0" otherwise.
51 - 60	HTSTR (9, J) - enter duty, BTU/Hr, if stream is a pumparound stream. Otherwise leave blank.
61 - 70	HTSTR (10, J) - Enter temperature of stream leaving exchanger in case of a pumparound (fixed duty) stream. Otherwise leave blank.
71 - 80	To be left blank.

2nd Card

1 - 60	To be left blank.
61 - 70	HTSTR (18, J) - leave blank if the stream is a pumparound (fixed duty) stream. Otherwise enter the "cold end" temperature approach for the exchanger.

Column	Variable Name
71 - 80	To be left blank.

Data Cards 2N + 7 thru 34

Include enough blank cards to bring the total number of data cards to 34. This will introduce "0.0's" into the array in the positions where no stream values would otherwise be introduced, which is desirable when the array is written out.

Sample Input

The data input form which follows is included as an example only. The data shown corresponds generally to the input data for sample problems #1 and #2 included in Appendix B.

Output

Input data printed on the first output page for convenience includes data on the crude stream and on the flashed crude stream, if flashing occurs. Other data used on heat balances and economic calculations, such as desalting temperature, cooling water temperatures, fuel cost, etc., are also printed.

On the second page is printed the heating stream array showing all the input data provided relative to these streams. The streams appear as rearranged in order of ascending "Pseudo T" values rather than in the order in which they were "read in" (unless NOAR = 1, in which case no rearrangement occurs).

The heating stream array for a single train arrangement is always printed on the third output sheet. The order of the streams will be the same as on the preceding sheet, but it will be observed that calculated values for each stream, such as exchanger duty, cooler duty, etc., now appear in place of the previously printed

"0" values. The calculated temperature of the crude leaving each exchanger in the train is also printed.

It should be noted that the streams are identified as pumparound streams if a "1" appears in row "PA?". Calculated values of "Pseudo T" are also printed.

In the event the programmed calculations result in the splitting of one of the heating streams into a cold stream and hot stream, to achieve the required desalted temperature, the two streams are printed in sequence. The temperature of the crude from the "cold" stream represents the temperature to the desalter (DESALT). The "hot" stream will heat the crude further in the stream immediately following the desalter (or following a flash drum should one be included in the system). Below the single train heat stream array are printed totals for the combined exchanger duties, exchanger surfaces, cooler surface, etc., for the entire single train arrangement.

If operating MODE '1" was specified in the input data, then only the single train calculations are made and this third sheet will be the last sheet of output data.

Fourth and fifth output sheets are printed if the program proceeds according to MODE "2". In this case, after the single train crude preheat calculations have been completed and printed, the program continues on to perform calculations for a "split" train. The crude stream leaving the desalter is split in half. If the duty of any of the heating streams is found to be large (i.e. sufficiently large to heat the crude as much as 60°F), that stream also is split in half to give two heating streams. The resulting heating streams are arranged in order of their "Pseudo T" values in the heat stream array. Next, the heat streams are arranged in two "parallel" arrays called "A" and "B". Array "A" will thus be comprised of alternate streams from the HTSTR array, starting with the first heat stream after the desalter and continuing on through the array, using the 3rd, 5th, etc. streams after the desalter. Array "B" will similarly be comprised of the 2nd, 4th, etc. streams after the desalter. After the calculations to preheat the two (half quantity) crude streams have been performed, using the heating streams in array, "A" and "B" respectively, the amount of heat transferred is summed up for each of the trains, and the sum compared. If the totals differ by more than the amount of the last exchanger duty of the array with the higher duty summation, then that stream is transferred to the other array to make the two summations nearly equal.

On the fourth output sheet, the heat streams preceding the desalter are printed out, for convenience, with all their input and calculated values appearing. On the fifth output sheet are printed the newly formed "A" train and "B" train arrays. In addition, values for the total exchanger duty, total exchanger and cooler surfaces, and total exchanger and cooler costs which have been calculated by the program, are also printed out for ease of comparison with the corresponding values for the previously calculated single train arrangement.

FOSTER WHEELER CORPORATION

DATA INPUT FORM

	1–5	6–10	11–20	21–30	31–40	41–50	51–60	61–70	71–75	76–80
1	7. 1	1 0								1
2	41.2		347760.	60.	90.	110.	40.	340000.	255.	2
3	260.		10.		10.	50.	3.0	10.0		3
4	10.									4
5	VAP. HT. EX.		KERO-CR	UPPER PA	LGO-CR	LOWER PA	HGO-CR	RESID-CR		5
6										6
7	57.2		289300.	245.0	0.0	1.0	24600000.	200.		7
8										8
9	42.6		95150.	440.0	100.0	0.0				9
10								50.0		10
11	42.6		280000.	407.0	0.0	1.0	17500000.	307.		11
12										12
13	32.2		44420.	463.0	150.0	0.0				13
14								40.0		14
15	32.2		187000.	463.0	0.0	1.0	6000000.	413.		15
16										16
17	32.1		34860.	529.0	150.0	0.0				17
18								35.0		18
19	22.4		68230.	612.0	200.0	0.0				19
20								30.0		20
21										7+2N
22										BLANKS REQ'D
23										
24										
25										34

DATA DESCRIPTION DATA FOR SAMPLE PROB #1 (MODE 1-SMALL CR. UNIT)

PREPARED BY R. PARKER

DATE 1/11/71 PAGE 1 OF 1

FORM 284-31

APPENDIX B

1. Program Statement List for "Preheat". All the statements comprising the main program and for Subroutine "SPHT" are listed. Comment cards are included to aid in following and using the programs.
2. Explanation of Output for Sample Problems.
3. Output for Sample Problem #1. Single train system with 40°F approach for variable duty exchangers.
4. Output for Sample Problem #2. Single train system with varied temperature approach values for variable duty Exchangers.
5. Output for Sample Problem #3. Single train and split train systems with 40°F approach for variable duty exchangers.

PROGRAM LISTING FOR "PREHEAT"

```
FORTRAN IV G LEVEL  18                MAIN              DATE = 71011          12/20/24              PAGE 0001

      DIMENSION HTSTR(19,14)
      DIMENSION A(19,7)
      DIMENSION B(19,7)
      READ(1,1) N,MODE,IFFL,NOAR
    1 FORMAT(4I2)
      READ(1,5)CRAPI,CRLB,CRTIN,TW1,TW2,FCRAPI,FCRLB,FCRTIN
    5 FORMAT(8F10.0)
      READ(1,5)DESALT,TTOL,FUCOST,ACOST,UAV,PAYRS,DROP,ECAP
      READ(1,5)FACT
      READ(1,2)((HTSTR(I,J),I=1,3),J=1,14)
    2 FORMAT(8(2A4,A2)/6(2A4,A2))
      READ(1,4)((HTSTR(I,J),I=4,19),J=1,14)
    4 FORMAT(8F10.0/8F10.0)
      WRITE(3,105)
  105 FORMAT('1'//55X,'OUTPUT SHEET 1'//55X,'MISC. INPUT DATA'/)
      WRITE(3,106)CRAPI,CRLB,CRTIN
  106 FORMAT(3X,'CRUDE DATA',5X,'API=',F4.1,5X,'LBS/HR=',F10.0,5X,
     1'IN TEMP=',F4.0/)
      WRITE(3,107)FCRAPI,FCRLB,FCRTIN
  107 FORMAT(3X,'FL.CRUDE DATA',5X,'API=',F4.1,5X,'LBS/HR=',F10.0,
     15X,'IN TEMP=',F4.0/)
      WRITE(3,104)DESALT,TTOL,ACOST,UAV,DROP
  104 FORMAT(3X,'TEMP TO DESALTER=',F4.0,5X,'TEMP TOL=',F4.1,5X,
     1'SURF COST=',F4.1,5X,'UAV=',F4.1,5X,'DESALTER TEMP DROP=',F4.1/)
C WRITE OUTPUT SHEET 1 SHOWING MISCELLANEOUS INPUT DATA
      WRITE(3,131) N,MODE,IFFL,NOAR,TW1,TW2,FACT
  131 FORMAT(3X,'N=',I2,5X,'MODE=',I2,5X,'IFFL=',I2,5X,'NOAR=',I2,5X,
     1'TW1=',F4.0,5X,'TW2=',F4.0,5X,'FACT=',F4.1/)
C CALC PSEUDO T FOR EACH STRM
      DO 6 J=1,N
    6 HTSTR(13,J)=HTSTR(6,J)-(FACT*CRLB/HTSTR(5,J))
      DIMENSION TEMP(19)
      IF(NOAR)113,112,113
C ARRANGE STMS IN ORDER OF ASCENDING PSEUDO T'S
  112 M=N-1
      DO 8 J=1,M
      L=J+1
      DO 8 K=L,N
      IF(HTSTR(13,J)-HTSTR(13,K))8,8,7
    7 DO 9 I=1,19
      TEMP(I)=HTSTR(I,J)
      HTSTR(I,J)=HTSTR(I,K)
    9 HTSTR(I,K)=TEMP(I)
    8 CONTINUE
C WRITE REARRANGED HTSTR ARRAY WITH INPUT DATA AS OUTPUT SHEET 2
  113 K=MIN0(7,N)
      WRITE(3,108)
  108 FORMAT('1'//55X,'OUTPUT SHEET 2'//)
```

```
            WRITE(3,40)
            WRITE(3,43)((HTSTR(I,J),I=1,3),J=1,K)
            WRITE(3,41)((HTSTR(I,J),J=1,K),I=4,18)
            IF(N-7)110,110,111
        111 WRITE(3,45)
            WRITE(3,43)((HTSTR(I,J),I=1,3),J=8,N)
            WRITE(3,41)((HTSTR(I,J),J=8,14),I=4,18)
         40 FORMAT(55X,'SINGLE TRAIN'//30X,'1',10X,'2',10X,'3',10X,'4',
           110X,'5',10X,'6',10X,'7'/)
         43 FORMAT(3X,'NAME',19X,7(3A4))
         45 FORMAT(55X,'SINGLE TRAIN CONTD'//27X,'8',10X,'9',10X,'10',
           110X,'11',10X,'12',10X,'13',10X,'14'/)
      C EXCHS BEFORE DESALT
      C CHECK WHETHER THE CRUDE TEMP FROM EACH SUCCESSIVE EXCHANGER EQUALS THE DESALT-
      C ING TEMP (WITHIN THE ALLOWABLE TOLERANCE)
        110 IF(HTSTR(8,1))10,10,11
         10 HTSTR(10,1)=CRTIN+HTSTR(18,1)
            CALL SPHT(HTSTR(4,1),HTSTR(6,1),HTSTR(10,1),0.,0.,CP)
            HTSTR(9,1)=HTSTR(5,1)*CP*(HTSTR(6,1)-HTSTR(10,1))
         11 CALL SPHT(CRAPI,0.,CRTIN,HTSTR(9,1),CRLB,CP)
            DELT=HTSTR(9,1)/(CP*CRLB)
            HTSTR(11,1)=CRTIN+DELT
            J=2
         12 K=J-1
            IF(HTSTR(8,J))13,13,14
         13 HTSTR(10,J)=HTSTR(11,K)+HTSTR(18,J)
            CALL SPHT(HTSTR(4,J),HTSTR(6,J),HTSTR(10,J),0.,0.,CP)
            HTSTR(9,J)=HTSTR(5,J)*CP*(HTSTR(6,J)-HTSTR(10,J))
         14 CALL SPHT(CRAPI,0.,HTSTR(11,K),HTSTR(9,J),CRLB,CP)
            DELT=HTSTR(9,J)/(CP*CRLB)
            HTSTR(11,J)=HTSTR(11,K)+DELT
            IF(HTSTR(11,J)-DESALT)15,17,17
         15 IF(HTSTR(11,J)+10.-DESALT)16,18,18
         16 J=J+1
            GO TO 12
         17 IF(HTSTR(11,J)-10.-DESALT)18,18,19
         19 NB=J
            NAFT=J+1
            NEWN=N+1
            HTSTR(11,J)=DESALT
            CALL SPHT(CRAPI,HTSTR(11,K),DESALT,0.,0.,CP)
      C IF WHEN THE CRUDE TEMP FROM THE ORIGINAL EXCHS. EXCEEDS DESALT,IT DOES SO BY
      C MORE THAN THE ALLOWABLE TOLERANCE,THEN THE HEATING STRM WHICH PRODUCES THE
      C HIGH TEMP IS SPLIT INTO TWO HEATING STREAMS.
            DUTY1=(DESALT-HTSTR(11,K))*CRLB*CP
            DUTY2=HTSTR(9,J)-DUTY1
            HTSTR(9,J)=DUTY1
            CALL SPHT(HTSTR(4,J),0.,HTSTR(10,J),HTSTR(9,J),HTSTR(5,J),CP)
```

```
 0081              DELT=HTSTR(9,J)/(CP*HTSTR(5,J))
 0082              STORE=HTSTR(6,J)
 0083              HTSTR(6,J)=HTSTR(10,J)+DELT
             C INCREASE J OF STREAMS AFTER DESALTER BY ONE TO MAKE ROOM IN ARRAY FOR THE
             C ADDITIONAL HEATING STREAM RESULTING FROM THE SPLIT.
 0084              NAFT=N-NB
 0085              DO 20 M=1,NAFT
 0086              J=N+1-M
 0087              L=J+1
 0088              DO 20 I=1,19
 0089           20 HTSTR(I,L)=HTSTR(I,J)
             C MAKE STRM AFTER DESALTER CORRESPOND TO HOT PORTION OF SPLIT STRM
 0090              J=NB
 0091              L=NB+1
 0092              DO 21 I=1,5
 0093           21 HTSTR(I,L)=HTSTR(I,J)
 0094              HTSTR(6,L)=STORE
 0095              HTSTR(7,L)=0.
 0096              HTSTR(8,L)=HTSTR(8,J)
 0097              HTSTR(9,L)=DUTY2
 0098              HTSTR(10,L)=HTSTR(6,J)
 0099              DO 22 I=12,17
 0100           22 HTSTR(I,L)=0.0
 0101              SPLIT=1.
 0102              GO TO 23
 0103           18 DESALT=HTSTR(11,J)
 0104              NB=J
 0105              NAFT=J+1
 0106              NEWN=N
 0107              SPLIT=0.
 0108              GO TO 23
             C ADJUST CRUDE TEMP FOR DROP THAT OCCURS IN THE DESALTER.
 0109           23 SALT=DESALT-DROP
             C IF THE CRUDE IS NOT FLASHED,THEN THE CRUDE PROPERTIES DOWNSTREAM OF THE
             C DESALTER ARE MADE THE SAME AS UPSTREAM.
 0110              IF(IFFL) 24,24,25
 0111           24 FCRLB=CRLB
 0112              FCRTIN=SALT
 0113              FCRAPI=CRAPI
             C PERFORM PREHEAT CALCS FOR EXCHS. AFTER DESALTER.
 0114           25 IF(SPLIT)26,26,27
 0115           26 J=NAFT
 0116              HTSTR(10,J)=FCRTIN+HTSTR(18,J)
 0117              CALL SPHT(HTSTR(4,J),HTSTR(6,J),HTSTR(10,J),0.,0.,CP)
 0118              HTSTR(9,J)=HTSTR(5,J)*CP*(HTSTR(6,J)-HTSTR(10,J))
 0119           27 CALL SPHT(FCRAPI,0.,FCRTIN,HTSTR(9,NAFT),FCRLB,CP)
 0120              DELT=HTSTR(9,NAFT)/(CP*FCRLB)
 0121              HTSTR(11,NAFT)=FCRTIN+DELT
```

```
      L=NAFT+1
      DO 30 J=L,NEWN
      K=J-1
      IF(HTSTR(8,J))28,28,29
   28 HTSTR(10,J)=HTSTR(11,K)+HTSTR(18,J)
      CALL SPHT(HTSTR(4,J),HTSTR(6,J),HTSTR(10,J),0.,0.,CP)
      HTSTR(9,J)=CP*HTSTR(5,J)*(HTSTR(6,J)-HTSTR(10,J))
   29 CALL SPHT(FCRAPI,0.,HTSTR(11,K),HTSTR(9,J),HTSTR(5,J),CP)
      DELT=HTSTR(9,J)/(CP*FCRLB)
   30 HTSTR(11,J)=HTSTR(11,K)+DELT
C CALCULATE COOLER DUTIES.
      DO 33 J=1,NEWN
      IF(HTSTR(8,J))31,31,33
   31 CALL SPHT(HTSTR(4,J),HTSTR(10,J),HTSTR(7,J),0.,0.,CP)
      HTSTR(12,J)=CP*HTSTR(5,J)*(HTSTR(10,J)-HTSTR(7,J))
      DELTH=HTSTR(10,J)-TW2
      DELTC=HTSTR( 7,J)-TW1
      XMTD=(DELTH-DELTC)*.9/ALOG(DELTH/DELTC)
      HTSTR(15,J)=HTSTR(12,J)/(XMTD*50.)
      HTSTR(17,J)=HTSTR(15,J)*ACOST
   33 CONTINUE
C CALCULATE COOLER SURFACES & COSTS.
      DO 35 J=2,NEWN
      K=J-1
C CALC. HT EXCH SURFS & COSTS
   32 DELTH=HTSTR(6,J)-HTSTR(11,J)
      DELTC=HTSTR(10,J)-HTSTR(11,K)
      XMTD=(DELTH-DELTC)*.9/ALOG(DELTH/DELTC)
      HTSTR(14,J)=HTSTR(9,J)/(XMTD*50.)
   35 HTSTR(16,J)=HTSTR(14,J)*ACOST
      DELTH=HTSTR(6,1)-HTSTR(11,1)
      DELTC=HTSTR(10,1)-CRTIN
      XMTD=(DELTH-DELTC) *.9/ALOG(DELTH/DELTC)
      HTSTR(14,1)=HTSTR(9,1)/(XMTD*50.)
      HTSTR(16,1)=HTSTR(14,1)*ACOST
C GET TOTAL PREHT DUTY,EXCH SURF & COST&COOLER SURFACE & COST FOR SINGLE TRAIN
C EXCHANGER SYSTEM.
      SUM9=0.0
      SUM14=0.0
      SUM16=0.0
      SUM15=0.0
      SUM17=0.0
      DO 36 J=1,NEWN
      SUM9=SUM9+HTSTR(9,J)
      SUM14=SUM14+HTSTR(14,J)
      SUM16=SUM16+HTSTR(16,J)
      SUM15=SUM15+HTSTR(15,J)
   36 SUM17=SUM17+HTSTR(17,J)
```

```
                C WRITE HTSTR ARRAY FOR SINGLE TRAIN SYSTEM ON OUTPUT SHEET NO.3 THE ARRAY NOW
                C INCLUDES ALL THE CALCULATED VALUES AS WELL AS THE INPUT VALUES.
 0165                 WRITE(3,141)
 0166             141 FORMAT('1'//55X,'OUTPUT SHEET 3'//)
 0167                 WRITE(3,40)
 0168                 K=MIN0(7,N)
 0169                 WRITE(3,43)((HTSTR(I,J),I=1,3),J=1,K)
 0170                 WRITE(3,41)((HTSTR(I,J),J=1,K),I=4,18)
 0171              41 FORMAT(3X,'API',15X,7F12.1/3X,'LBS/HR',12X,7F12.0/3X,'TIN,F',13X,
                     17F12.0/3X,'TOUT,F',12X,7F12.0/3X,'PA7',15X,7F12.0/3X,'EX.DUTY,BTU/
                     2HR',4X,7F12.0/3X,'EXOUT TEMP,F',6X,7F12.0/3X,'TEMP CRUDE OUT,F',
                     3                        2X,7F12.0/3X,'COOL.DUTY,BTU/HR',2X,7F12.0/
                     43X,'PSEUDOT',11X,7F12.0/3X,'EX.SURF,SQFT',6X,7F12.0/3X,
                     5'COOL.SURF,SQFT',4X,7F12.0/3X,'EXCOST$',11X,7F12.0/3X,
                     6'COOL.COST,$',7X,7F12.0/3X,'APPROACH,F',8X,7F12.0//)
 0172                 IF(NEWN-7)44,44,42
 0173              42 WRITE(3,45)
 0174                 WRITE(3,43)((HTSTR(I,J),I=1,3),J=8,NEWN)
 0175                 WRITE(3,41)((HTSTR(I,J),J=8,14),I=4,18)
                C WRITE THE SUM OF THE DUTIES,SURFACES&COSTS ON OUTPUT SHEET NO.3 FOR SINGLE
                C TRAIN SYSTEM.
 0176              44 WRITE(3,46)SUM9,SUM14,SUM16,SUM15,SUM17
 0177              46 FORMAT(3X,'TOTAL DUTY=',F11.0,'BTU/HR'/3X,'TOTAL EXCH SURF=',F8.0,
                     1'FTSQ'/3X,'TOTAL EXCH COST=$',F 7.0/3X,'TOTAL COOLER  SURF=',F7.0,
                     2'FTSQ'/3X,'TOTAL COOLER COST=$',F 7.0)
 0178                 DIMENSION TEMP1(19,14)
 0179                 GO TO (300,200),MODE
                C START OF TWO TRAIN SEGMENT
                C CHECK ON MAGNITUDE OF HEATING STRMS. SPLIT ANY HEATING STREAM IN HALF WHICH
                C RAISES THE TEMP OF THE CRUDE MORE THAN 60 F. ADD THE NEW STRMS TO THE  HTSTR
                C ARRAY IN THE CORRECT POSITION.
 0180             200 DO47 J=NAFT,NEWN
 0181                 RISE=HTSTR(9,J)/(FCRLB*.6)
 0182                 IF(RISE-60.)47,48,48
 0183              48 K=J+1
 0184                 DO 49 L=K,NEWN
 0185                 DO 49 I=1,19
 0186              49 TEMP1(I,L)=HTSTR(I,L)
 0187                 HTSTR(5,J)=HTSTR(5,J)/2.
 0188                 HTSTR(9,J)=HTSTR(9,J)/2.
 0189                 DO 150 I=1,19
 0190             150 HTSTR(I,K)=HTSTR(I,J)
 0191                 DO 54 L=K,NEWN
 0192                 DO 54 I=1,19
 0193                 M=L+1
 0194              54 HTSTR(I,M)=TEMP1(I,L)
 0195                 NEWN=NEWN+1
 0196                 J=J+1
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  0197          47 CONTINUE
  0198             WRITE(3,101) NEWN
  0199         101 FORMAT('1',3X,'NEWN=',I4)
             C SET UP A TRAIN AND B TRAIN
  0200             NAT=0
  0201             K=1
  0202             DO 50 J=NAFT,NEWN,2
  0203             DO 203 I=1,19
  0204         203 A(I,K)=HTSTR(I,J)
  0205             NAT=NAT+1
  0206          50 K=K+1
  0207             NAFT=NAFT+1
  0208             NBT=0
  0209             K=1
  0210             DO 51 J=NAFT,NEWN,2
  0211             DO 204 I=1,19
  0212         204 B(I,K)=HTSTR(I,J)
  0213             NBT=NBT+1
  0214          51 K=K+1
             C OBTAIN SUM OF ATRAIN & BTRAIN DUTIES & COMPARE THEM.
  0215             SUMA=0.0
  0216             DO 55  J=1,NAT
  0217          55 SUMA=SUMA+A(9,J)
  0218             SUMB=0.0
  0219             DO 56 J=1,NBT
  0220          56 SUMB=SUMB+B(9,J)
  0221             DIF=SUMA-SUMB
             C SHIFT THE LAST EXCH FROM THE ATRAIN TO THE BTRAIN OR VICE VERSA TO EQUALIZE
             C AS AN ATTEMPT TO EQUALIZE  THE OUTLET TEMPERATURES FROM THE TWO TRAINS.
  0222             IF(DIF)58,64,57
  0223          57 IF(DIF-A(9,NAT)) 64,64,60
  0224          60 J=NBT+1
  0225             DO 59 I=1,19
  0226             B(I,J)=A(I,NAT)
  0227          59 A(I,NAT)=0.0
  0228             NAT=NAT-1
  0229             NBT=NBT+1
  0230             GO TO 64
  0231          58 IF(B(9,NBT)+DIF)61,64,64
  0232          61 J=NAT+1
  0233             DO 62 I=1,19
  0234             A(I,J)=B(I,NBT)
  0235          62 B(I,NBT)=0.0
  0236             NAT=NAT+1
  0237             NBT=NBT-1
             C MAKE PREHEAT CALCS FOR ATRAIN.
  0238          64 SALT=DESALT-DROP
  0239             HAFCR=FCRLB/2.
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```
      IF(A(8,1))53,52,53
   52 A(10,1)=SALT+A(18,1)
      A(11,1)=A(10,1)
      CALL SPHT(A(4,1),A(6,1),A(10,1),0.,0.,CP)
      A(9,1)=A(5,1)*CP*(A(6,1)-A(10,1))
   53 CALL SPHT(FCRAPI,0.,SALT,A(9,1),HAFCR,CP)
      DELT=A(9,1)/(CP*FCRLB/2.)
      A(11,1)=SALT+DELT
      DO 69 J=2,NAT
      K=J-1
      IF(A(8,J))67,67,68
   67 A(10,J)=A(11,K)+A(18,J)
      CALL SPHT(A(4,J),A(6,J),A(10,J),0.,0.,CP)
      A(9,J)=A(5,J)*CP*(A(6,J)-A(10,J))
   68 CALL SPHT(FCRAPI,0.,A(11,K), A(9,J),HAFCR,CP)
      DELT=A(9,J)/(CP*FCRLB/2.)
   69 A(11,J)=A(11,K)+DELT
C MAKE PREHEAT CALCS FOR BTRAIN.
      IF(B(8,1)) 103,102,103
  102 B(10,1)=A(10,1)
      CALL SPHT(B(4,1),B(6,1),B(10,1),0.,0.,CP)
      B(9,1)=B(5,1)*CP*(B(6,1)-B(10,1))
  103 CALL SPHT(FCRAPI,0.,SALT,B(9,1),HAFCR,CP)
      DELT=B(9,1)/(CP*FCRLB/2.)
      B(11,1)=SALT+DELT
      DO 72 J=2,NBT
      K=J-1
      IF(B(8,J)) 70,70,71
   70 B(10,J)= B(11,K)+B(18,J)
      CALL SPHT(B(4,J),B(6,J),B(10,J),0.,0.,CP)
      B(9,J)=B(5,J)*CP*(B(6,J)-B(10,J))
   71 CALL SPHT(FCRAPI,0.,B(11,K),B(9,J),HAFCR,CP)
      DELT=B(9,J)/(CP*FCRLB/2.)
   72 B(11,J)=B(11,K)+DELT
C MAKE COOLER CALCS FOR ATRAIN.
      DO 73 J=1,NAT
      IF(A(8,J))74,73,73
   74 CALL SPHT(A(4,J),A(10,J),A(7,J),0.,0.,CP)
      A(12,J)=CP*A(5,J)*(A(10,J)-A(7,J))
      DELTH=  A(10,J)-TW2
      DELTC= A(7,J)-TW1
      XMTD=(DELTH-DELTC)*.9/ALOG(DELTH/DELTC)
      A(15,J)=A(12,J)/(XMTD*50.)
      A(17,J)=A(15,J)*10.
   73 CONTINUE
C MAKE COOLER CALCS FOR BTRAIN.
      DO 75 J=1,NBT
      IF(B(8,J))76,75,75
```

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  0285            76 CALL SPHT(B(4,J),B(10,J),B(7,J),0.,0.,CP)
  0286               B(12,J)=CP*B(5,J)*(B(10,J)-B(7,J))
  0287               DELTH=B(10,J)-TW2
  0288               DELTC=B(7,J)-TW1
  0289               XMTD=(DELTH-DELTC)*.9/ALOG(DELTH/DELTC)
  0290               B(15,J)=B(12,J)/(XMTD*50.)
  0291               B(17,J)=B(15,J)*10.
  0292            75 CONTINUE
             C A&BTRAIN COOLERS DONE,EXCHS FOLLOW.
             C CALCS FOR FIRST ATRAIN EXCH.
  0293               DELTH=A(6,1)-A(11,1)
  0294               DELTC=A(10,1)-SALT
  0295               XMTD=(DELTH-DELTC)*.9/ALOG(DELTH/DELTC)
  0296               A(14,1)=A(9,1)/(XMTD*50.)
  0297               A(16,1)=A(14,1)*10.
             C CALCS FOR FIRST BTRAIN EXCH.
  0298               DELTH=B(6,1)-B(11,1)
  0299               DELTC=B(10,1)-SALT
  0300               XMTD=(DELTH-DELTC)*.9/ALOG(DELTH/DELTC)
  0301               B(14,1)=B(9,1)/(XMTD*50.)
  0302               B(16,1)=B(14,1)*10.
             C CALCS FOR REST OF ATRAIN EXCHS.
  0303               DO 77 J=2,NAT
  0304               K=J-1
  0305               DELTH=A(6,J)-A(11,J)
  0306               DELTC=A(10,J)-A(11,K)
  0307               XMTD=(DELTH-DELTC)*.9/ALOG(DELTH/DELTC)
  0308               A(14,J)=A(9,J)/(XMTD*50.)
  0309            77 A(16,J)=A(14,J)*10.
             C CALCS FOR REST OF BTRAIN EXCHS.
  0310               DO 78 J=2,NBT
  0311               K=J-1
  0312               DELTH=B(6,J)-B(11,J)
  0313               DELTC=B(10,J)-B(11,K)
  0314               XMTD=(DELTH-DELTC)*.9/ALOG(DELTH/DELTC)
  0315               B(14,J)=B(9,J)/(XMTD*50.)
  0316            78 B(16,J)=B(14,J)*10.
             C SUMMATION OF DUTIES,ETC. FOR EXCHS BEFORE DESALTER.
  0317               SSUM9=0.0
  0318               SSUM14=0.0
  0319               SSUM16=0.0
  0320               SSUM15=0.0
  0321               SSUM17=0.0
  0322               DO 79 J=1,NB
  0323               SSUM9=SSUM9+HTSTR(9,J)
  0324               SSUM14=SSUM14+HTSTR(14,J)
  0325               SSUM16=SSUM16+HTSTR(16,J)
  0326               SSUM15=SSUM15+HTSTR(15,J)
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 0327          79 SSUM17=SSUM17+HTSTR(17,J)
            C SUMMATION OF DUTIES,ETC. FOR ATRAIN EXCHS.
 0328             ASUM9=0.0
 0329             ASUM14=0.0
 0330             ASUM16=0.0
 0331             ASUM15=0.0
 0332             ASUM17=0.0
 0333             DO 80 J=1,NAT
 0334             ASUM9=ASUM9+A(9,J)
 0335             ASUM14=ASUM14+A(14,J)
 0336             ASUM16=ASUM16+A(16,J)
 0337             ASUM15=ASUM15+A(15,J)
 0338          80 ASUM17=ASUM17+A(17,J)
            C SUMMATION OF DUTIES,ETC. FOR BTRAIN EXCHS.
 0339             BSUM9=0.0
 0340             BSUM14=0.0
 0341             BSUM16=0.0
 0342             BSUM15=0.0
 0343             BSUM17=0.0
 0344             DO 81 J=1,NBT
 0345             BSUM9=BSUM9+B(9,J)
 0346             BSUM14=BSUM14+B(14,J)
 0347             BSUM16=BSUM16+B(16,J)
 0348             BSUM15=BSUM15+B(15,J)
 0349          81 BSUM17=BSUM17+B(17,J)
            C SUMMATION(TOTAL)OF ALL DUTIES,ETC.
 0350             TSUM9=SSUM9+ASUM9+BSUM9
 0351             TSUM14=SSUM14+ASUM14+BSUM14
 0352             TSUM16=SSUM16+ASUM16+BSUM16
 0353             TSUM15=SSUM15+ASUM15+BSUM15
 0354             TSUM17=SSUM17+ASUM17+BSUM17
            C WRITE HTSTR ARRAY FOR EXCHS BEFORE DESALTER ON OUTPUT SHEET NO.4.
 0355             WRITE(3,85)
 0356             WRITE(3,43)((HTSTR(I,J),I=1,3),J=1,NB)
 0357             WRITE(3,86) (HTSTR(4,J),J=1,NB)
 0358             WRITE(3,87) (HTSTR(5,J),J=1,NB)
 0359             WRITE(3,88) (HTSTR(6,J),J=1,NB)
 0360             WRITE(3,89) (HTSTR(7,J),J=1,NB)
 0361             WRITE(3,90) (HTSTR(8,J),J=1,NB)
 0362             WRITE(3,91) (HTSTR(9,J),J=1,NB)
 0363             WRITE(3,92) (HTSTR(10,J),J=1,NB)
 0364             WRITE(3,93) (HTSTR(11,J),J=1,NB)
 0365             WRITE(3,94) (HTSTR(12,J),J=1,NB)
 0366             WRITE(3,95) (HTSTR(13,J),J=1,NB)
 0367             WRITE(3,96) (HTSTR(14,J),J=1,NB)
 0368             WRITE(3,97) (HTSTR(15,J),J=1,NB)
 0369             WRITE(3,98) (HTSTR(16,J),J=1,NB)
 0370             WRITE(3,99) (HTSTR(17,J),J=1,NB)
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      WRITE(3,100)(HTSTR(18,J),J=1,NB)
   85 FORMAT('1'//30X,'OUTPUT SHEET 4'//25X,'EXCHANGERS DEFORE DESALTER'
     1/)
   86 FORMAT(3X,'API',15X,4F12.1)
   87 FORMAT(3X,'LBS/HR',12X,4F12.0)
   88 FORMAT(3X,'TIN,F',13X,4F12.0)
   89 FORMAT(3X,'TOUT,F',12X,4F12.0)
   90 FORMAT(3X,'PA?',15X,4F12.0)
   91 FORMAT(3X, 'EX.DUTY,BTU/HR',3X,4F12.0)
   92 FORMAT(3X,'EXOUT TEMP,F',6X,4F12.0)
   93 FORMAT(3X,'TEMP CRUD OUT,F',2X,4F12.0)
   94 FORMAT(3X,'CCOL.DUTY,BTU/HR',2X,4F12.0)
   95 FORMAT(3X,'PSEUDOT',11X,4F12.0)
   96 FORMAT(3X,'EX.SURF,SQFT',6X,4F12.0)
   97 FORMAT(3X,'COOL.SURF,SQFT',4X,4F12.0)
   98 FORMAT(3X,'EXCOST,$',10X,4F12.0)
   99 FORMAT(3X,'COOL COST,$',7X,4F12.0)
C PUT 0.'S IN 'A'ARRAY POSITIONS NOT OCCUPIED BY HEATING STREAMS.
  100 FORMAT(3X,'APPROACH,F',7X,4F12.0)
      K=NAT+1
      CO 126 J=K,7
      CO 126 I=1,19
  126 A(I,J)=0.0
C PUT 0.'S IN 'B'ARRAY POSITIONS NOT OCCUPIED BY HEATING STREAMS.
      K=NBT+1
      DO 127 J=K,7
      CO 127 I=1,19
  127 B(I,J)=0.0
C WRITE 'A'ARRAY WITH PREHEAT VALUES AS CALCULATED ON OUTPUT SHEET NO.4.
      WRITE(3,120)
      WRITE(3,43)((A(I,J),I=1,3),J=1,NAT)
      WRITE(3,41)((A(I,J),J=1,7),I=4,18)
C WRITE 'B'ARRAY WITH PREHEAT VALUES AS CALCULATED ON OUTPUT SHEET NO.4.
      WRITE(3,121)
      WRITE(3,43)((B(I,J),I=1,3),J=1,NBT)
      WRITE(3,41)((B(I,J),J=1,7),I=4,18)
C WRITE SUMS OF CUTIES,ETC. FOR SPLIT TRAIN SYSTEM.
      WRITE(3,128) TSUM9
      WRITE(3,129) TSUM14
  129 FORMAT(10X,'TOT EX SURF,SQ FT=',F 10.0)
      WRITE(3,122) TSUM15
  122 FORMAT(10X,'TOT COCL SURF,SQ FT=',F 8.0)
      WRITE(3,123) TSUM16
  123 FORMAT(10X,'TOT EXCH COST,$=',F12.0)
      WRITE(3,124) TSUM17
  124 FORMAT(10X,'TOT COCL COST,$=',F12.0)
  120 FORMAT('1'//55X,'OUTPUT SHEET 5'//60X,'A TRAIN')
  128 FORMAT(10X,'TOT DUTY,BTU/HR=',F12.0)
```

```
  0413              121 FORMAT(60X,'B TRAIN'/)
  0414              300 RETURN
  0415                  END
```

```
FORTRAN IV G LEVEL  18               SPHT               DATE = 71011         12/20/24             PAGE 0001

              SUBROUTINE SPHT(API,T1,T2,Q,XLB,CP)
        C IF Q=0.0,CALC CP AT AV. OF T1&T2.
              IF(Q)6,5,6
            5 T=(T1+T2)/2.
              GO TO 9
        C IF Q DOES NOT EQUAL 0.0 CALC. APPROX DELT ANC AV. T VALUE,THEN CALC FIRST
        C TRIAL VALUE CF CP.
            6 COUNT=0.0
              CELT=Q/(.55*XLB)
            8 IF(T1)2,3,2
            2 T=T1-DELT/2.
              GO TC 9
            3 T=T2+DELT/2.
            9 CP=.341+.00275*API+.00038*T+.0000029*API*T
              GO TC 30
        C IF Q IS NOT 0.0 AND ALSO IF COUNT IS NOT 0.0,RECALCULATE CP.
           3C IF(Q)31,33,31
           31 IF(CUUNT)33,32,33
           32 COUNT=1.0
              DELT=Q/(CP*XLB)
              GO TO 8
           33 RETURN
              END
```

APPENDIX B

EXPLANATION OF OUTPUT FOR SAMPLE PROBLEMS

Program Output - Sample Problem 1

Three output sheets are included, which are essentially self-explanatory. They represent the results obtained from a computer run for a sample problem referred to as problem #1. This problem corresponds to the preheat system for a relatively small crude unit with a feed rate of approximately 30,000 BPSD. Only a "single train" run was made because the crude unit was so small. A 40°F temperature approach was used for all the variable duty exchangers.

Program Output - Sample Problem 2

Three output sheets are presented. This problem is identical with sample problem #1 except that varied temperature approaches were used for the variable duty exchangers. The approaches used ranged from 60°F down to 20°F with the higher values used for the low temperature exchangers.

Program Output - Sample Problem 3

Five output sheets are included. The first three are for a "single train system". The fourth and fifth apply to a split-train system. Since problem #3 corresponds to the preheat system of a rather large crude unit with a feed rate of almost 100,000 BPSD of crude, the run made was of the type giving results for both single and split train preheat systems. A temperature approach of 40°F was used for all variable duty exchangers.

```
                                OUTPUT SHEET 1

                                MISC. INPUT DATA

CRUDE DATA     API=41.2     LBS/HR=   347760.     IN TEMP= 60.

FL.CRUDE DATA     API=40.0     LBS/HR=   340000.     IN TEMP=255.

TEMP TO DESALTER=260.     TEMP TOL=10.0     SURF COST=10.0     UAV=50.0     DESALTER TEMP DROP=10.0

N= 7     MODE= 1     IFFL= 1     NOAR= 0     TW1= 90.     TW2=110.     FACT=10.0
```

"PREHEAT" OUTPUT
SAMPLE PROBLEM #1
40° APPROACH
SINGLE TRAIN

```
                                                    OUTPUT SHEET 2

                                                    SINGLE TRAIN

                           1           2           3           4           5           6           7

NAME                   VAP.HTEX.   LGO-CR      UPPER PA    KERO-CR     HGO-CR      LOWER PA    RESID-CR
API                       57.0        32.2        42.6        42.6        32.1        32.2        22.4
LBS/HR               289300.      44420.     280000.      95150.      34860.     187000.      68230.
TIN,F                   245.        463.        407.        440.        529.        463.        612.
TOUT,F                    0.        150.          0.        100.        150.          0.        200.
PA?                       1.          0.          1.          0.          0.          1.          0.
EX.DUTY,BTU/HR     24600000.          0.   17500000.          0.          0.    6000000.          0.
EXOUT TEMP,F            200.          0.        307.          0.          0.        413.          0.
TEMP CRUDE OUT,F          0.          0.          0.          0.          0.          0.          0.
COOL.DUTY,BTU/HR          0.          0.          0.          0.          0.          0.          0.
PSEUDCT                 233.        385.        395.        403.        429.        444.        561.
EX.SURF,SQFT              0.          0.          0.          0.          0.          0.          0.
COOL.SURF,SQFT            0.          0.          0.          0.          0.          0.          0.
EXCOST$                   0.          0.          0.          0.          0.          0.          0.
COOL.COST,$               0.          0.          0.          0.          0.          0.          0.
APPROACH,F                0.         40.          0.         40.         40.          0.         40.
```

```
                                   OUTPUT SHEET 3

                                   SINGLE TRAIN

                       1          2          3          4          5          6          7

   NAME             VAP.HTEX.   LGO-CR    UPPER PA   LPPER PA   KERO-CR    HGO-CR     LOWER PA
   API                 57.0       32.2       42.6       42.6       42.6       32.1       32.2
   LBS/HR            289300.     44420.    280000.    280000.     95150.     34860.    187000.
   TIN,F                245.       463.       347.       407.       440.       529.       463.
   TOUT,F                 0.       150.         0.         0.       100.       150.         0.
   PA?                    1.         0.         1.         1.         0.         0.         1.
   EX.DUTY,BTU/HR  24600000.   6313467.   7100907.  10399093.   6037069.   3657543.   6000000.
   EXOUT TEMP,F         200.       234.       307.       347.       345.       373.       413.
   TEMP CRUDE OUT,F     194.       225.       260.       305.       333.       349.       376.
   COOL.CUTY,BTU/HR       0.   1999824.         0.         0.  13617774.   4465351.         0.
   PSEUDCT              233.       385.       395.         0.       403.       429.       444.
   EX.SURF,SCFT        6184.      1265.      1874.      2459.      1971.       873.      1780.
   COOL.SURF,SQFT         0.       505.         0.         0.      4240.       722.         0.
   EXCOST$            61842.     12649.     18742.     24594.     19708.      8733.     17805.
   COOL.COST,$            0.      5049.         0.         0.     42395.      7223.         0.
   APPROACH,F             0.        40.         0.         0.        40.        40.         0.

                                   SINGLE TRAIN CONTD

                       8          9         10         11         12         13         14

   NAME             RESID-CR
   API                 22.4        0.0        0.0        0.0        0.0        0.0        0.0
   LBS/HR             68230.        0.         0.         0.         0.         0.         0.
   TIN,F                612.        0.         0.         0.         0.         0.         0.
   TOUT,F               200.        0.         0.         0.         0.         0.         0.
   PA?                    0.        0.         0.         0.         0.         0.         0.
   EX.DUTY,BTU/HR   9078231.        0.         0.         0.         0.         0.         0.
   EXOUT TEMP,F         416.        0.         0.         0.         0.         0.         0.
   TEMP CRUDE OUT,F     414.        0.         0.         0.         0.         0.         0.
   COOL.DUTY,BTU/HR 8426894.        0.         0.         0.         0.         0.         0.
   PSEUDCT              561.        0.         0.         0.         0.         0.         0.
   EX.SURF,SCFT        2042.        0.         0.         0.         0.         0.         0.
   COOL.SURF,SQFT       977.        0.         0.         0.         0.         0.         0.
   EXCOST$            20419.        0.         0.         0.         0.         0.         0.
   COOL.COST,$         9775.        0.         0.         0.         0.         0.         0.
   APPROACH,F            40.        0.         0.         0.         0.         0.         0.

   TOTAL DUTY=  73186256.BTU/HR
   TOTAL EXCH SURF=  18449.FTSQ
   TOTAL EXCH COST=$184491.
   TOTAL COOLER  SURF=  6444.FTSQ
   TOTAL COOLER COST=$ 64442.
```

```
                                        OUTPUT SHEET 1

                                        MISC. INPUT DATA

CRUDE DATA     API=41.2     LBS/HR=   347760.     IN TEMP= 60.

FL.CRUDE DATA     API=40.0     LBS/HR=   340000.     IN TEMP=255.

TEMP TO DESALTER=260.    TEMP TOL=10.0    SURF COST=10.0    UAV=50.0    DESALTER TEMP DROP=10.0

N= 7     MODE= 1    IFFL= 1     NOAR= 0     TW1= 90.     TW2=110.     FACT=10.0
```

"PREHEAT" OUTPUT
SAMPLE PROBLEM #2
SINGLE TRAIN
VARIED APPROACH

```
                                    OUTPUT SHEET 2

                                    SINGLE TRAIN

                         1         2          3          4          5          6          7

NAME               VAP.HTEX.   LGO-CR    UPPER PA    KERO-CR     HGO-CR   LOWER PA   RESID-CR
API                    57.0      32.2       42.6       42.6       32.1       32.2       22.4
LBS/HR              289300.    44420.    280000.     95150.     34860.    187000.     68230.
TIN,F                  245.      463.       407.       440.       529.       463.       612.
TOUT,F                   0.      150.         0.       100.       150.         0.       200.
PA?                      1.        0.         1.         0.         0.         1.         0.
EX.DUTY,BTU/HR    24600000.        0.  17500000.         0.         0.   6000000.         0.
EXOLT TEMP,F           200.        0.       307.         0.         0.       413.         0.
TEMP CRUDE OUT,F         0.        0.         0.         0.         0.         0.         0.
COOL.CUTY,BTU/HR         0.        0.         0.         0.         0.         0.         0.
PSELDCT                233.      385.       395.       403.       429.       444.       561.
EX.SURF,SCFT             0.        0.         0.         0.         0.         0.         0.
COOL.SURF,SQFT           0.        0.         0.         0.         0.         0.         0.
EXCOST$                  0.        0.         0.         0.         0.         0.         0.
COOL.COST,$              0.        0.         0.         0.         0.         0.         0.
APPROACH,F               0.       60.         0.        50.        30.         0.        20.
```

```
                                 OUTPUT SHEET 3

                                 SINGLE TRAIN

                          1          2          3          4          5          6          7

  NAME                VAP.HTEX.   LGO-CR     UPPER PA   UPPER PA   KERO-CR     HGO-CR    LOWER PA
  API                     57.0       32.2       42.6       42.6       42.6       32.1       32.2
  LBS/HR               289300.     44420.    280000.    280000.     95150.     34860.    187000.
  TIN,F                   245.       463.       350.       407.       440.       529.       463.
  TOUT,F                    0.       150.         0.         0.       100.       150.         0.
  PA?                       1.         0.         1.         1.         0.         0.         1.
  EX.DUTY,BTU/HR     24600000.   5811309.   7603075.   9896925.   5567236.   3973298.   6000000.
  EXOUT TEMP,F            200.       254.       307.       350.       353.       359.       413.
  TEMP CRUDE OUT,F        194.       223.       260.       303.       329.       346.       373.
  COOL.DUTY,BTU/HR          0.   2501983.         0.         0.  14087607.   4149597.         0.
  PSEUDOT                 233.       385.       395.         0.       403.       429.       444.
  EX.SURF,SCFT           6184.       994.      1946.      2278.      1615.      1043.      1711.
  COOL.SURF,SQFT            0.       580.         0.         0.      4285.       695.         0.
  EXCOST$               61842.      9943.     19460.     22778.     16145.     10435.     17107.
  COOL.COST,$               0.      5803.         0.         0.     42853.      6949.         0.
  APPROACH,F                0.        60.         0.         0.        50.        30.         0.

                                 SINGLE TRAIN CONTD

                          8          9         10         11         12         13         14

  NAME                RESID-CR
  API                     22.4        0.0        0.0        0.0        0.0        0.0        0.0
  LBS/HR                68230.         0.         0.         0.         0.         0.         0.
  TIN,F                   612.         0.         0.         0.         0.         0.         0.
  TOUT,F                  200.         0.         0.         0.         0.         0.         0.
  PA?                       0.         0.         0.         0.         0.         0.         0.
  EX.DUTY,BTU/HR     10053987.         0.         0.         0.         0.         0.         0.
  EXOUT TEMP,F            393.         0.         0.         0.         0.         0.         0.
  TEMP CRUDE OUT,F        415.         0.         0.         0.         0.         0.         0.
  COOL.DUTY,BTU/HR    7451137.         0.         0.         0.         0.         0.         0.
  PSEUDOT                 561.         0.         0.         0.         0.         0.         0.
  EX.SURF,SCFT           2886.         0.         0.         0.         0.         0.         0.
  COOL.SURF,SQFT          904.         0.         0.         0.         0.         0.         0.
  EXCOST$               28859.         0.         0.         0.         0.         0.         0.
  COOL.COST,$            9044.         0.         0.         0.         0.         0.         0.
  APPROACH,F               20.         0.         0.         0.         0.         0.         0.

  TOTAL DUTY=  73505792.BTU/HR
  TOTAL EXCH SURF=  18657.FTSQ
  TOTAL EXCH COST=$186569.
  TOTAL COOLER  SURF=. 6465.FTSQ
  TOTAL COOLER COST=$ 64650.
```

```
                                        OUTPUT SHEET 1

                                        MISC. INPUT DATA

 CRUDE DATA      API=45.7     LBS/HR=  1220000.      IN TEMP= 85.

 FL.CRUDE DATA      API= 0.0      LBS/HR=          0.      IN TEMP=  0.

 TEMP TO DESALTER=260.      TEMP TOL=10.0      SURF COST=10.0      UAV=50.0      DESALTER TEMP DROP=10.0

 N=10      MODE= 2      IFFL= 0      NOAR= 0      TW1= 85.      TW2=115.      FACT=10.0
```

"PREHEAT" OUTPUT
SAMPLE PROBLEM #3
SINGLE AND SPLIT TRAINS
40° APPROACH

```
                                        OUTPUT SHEET 2

                                         SINGLE TRAIN

                          1         2          3          4          5          6          7

   NAME               LT NAPH     PA1       HV NAPH    1VAC 3SS   1VAC 2SS   2VAC RES     PA2
   API                   52.0      52.0       44.2       21.4       24.8       11.8       44.2
   LBS/HR             279500.  1210000.    139000.     53000.     73800.     50000.   1050000.
   TIN,F                 290.      340.       425.       615.       565.       675.       475.
   TOUT,F                100.        0.       115.       150.       150.       275.         0.
   PA?                     0.        1.         0.         0.         0.         0.         1.
   EX.DUTY,BTU/HR          0.  92200000.        0.         0.         0.         0.  86300000.
   EXOUT TEMP,F            0.      215.         0.         0.         0.         0.       355.
   TEMP CRUDE OUT,F        0.        0.         0.         0.         0.         0.         0.
   COOL.DUTY,BTU/HR        0.        0.         0.         0.         0.         0.         0.
   PSEUDOT               246.      330.       337.       385.       400.       431.       463.
   EX.SURF,SCFT            0.        0.         0.         0.         0.         0.         0.
   COOL.SURF,SQFT          0.        0.         0.         0.         0.         0.         0.
   EXCCST$                 0.        0.         0.         0.         0.         0.         0.
   COOL.COST,$             0.        0.         0.         0.         0.         0.         0.
   APPROACH,F             40.        0.        40.        40.        40.        40.         0.


                                      SINGLE TRAIN CONTD

                          8          9          10         11         12         13         14

   NAME               1VAC MPA    2VAC PA    ATM GO
   API                   28.5       24.0       33.3        0.0        0.0        0.0        0.0
   LBS/HR             550000.    201000.    275000.         0.         0.         0.         0.
   TIN,F                 500.       600.       590.         0.         0.         0.         0.
   TOUT,F                  0.         0.       120.         0.         0.         0.         0.
   PA?                     1.         1.         0.         0.         0.         0.         0.
   EX.DUTY,BTU/HR   21000000.  12100000.         0.         0.         0.         0.         0.
   EXOUT TEMP,F          445.       509.         0.         0.         0.         0.         0.
   TEMP CRUDE OUT,F        0.         0.         0.         0.         0.         0.         0.
   COOL.DUTY,BTU/HR        0.         0.         0.         0.         0.         0.         0.
   PSEUDOT               478.       539.       546.         0.         0.         0.         0.
   EX.SURF,SCFT            0.         0.         0.         0.         0.         0.         0.
   COOL.SURF,SQFT          0.         0.         0.         0.         0.         0.         0.
   EXCOST$                 0.         0.         0.         0.         0.         0.         0.
   COOL.COST,$             0.         0.         0.         0.         0.         0.         0.
   APPROACH,F              0.        40.        40.         0.         0.         0.         0.
```

```
                              OUTPUT SHEET 3

                              SINGLE TRAIN

                                1            2            3            4            5            6            7

NAME                      LT NAPH          PA1      HV NAPH     1VAC 3SS     1VAC 2SS     2VAC RES          PA2
API                          52.0         52.0         44.2         21.4         24.8         11.8         44.2
LBS/HR                    279500.     1210000.      139000.       53000.       73800.       50000.     1050000.
TIN,F                        290.         340.         425.         615.         565.         675.         475.
TOUT,F                       100.           0.         115.         150.         150.         275.           0.
PA?                            0.           1.           0.           0.           0.           0.           1.
EX.DUTY,BTU/HR          27711984.    92200000.    12427567.    10627397.    11793509.    11033886.    86300000.
EXOUT TEMP,F                 125.         215.         289.         306.         318.         333.         355.
TEMP CRUDE OUT,F             128.         259.         266.         278.         293.         305.         412.
COOL.DUTY,BTU/HR         3853604.           0.    13941342.     4350593.     6708251.     1555106.           0.
PSEUDCT                      246.         330.         337.         385.         400.         431.         463.
EX.SURF,SCFT                7054.       24363.        3566.        1696.        2163.        1654.       34083.
COOL.SURF,SQFT              6944.           0.        3783.         828.        1229.         170.           0.
EXCCST$                    70544.      243634.       35656.       16958.       21631.       16540.      340832.
COOL.COST,$                69445.           0.       37826.        8279.       12290.        1698.           0.
APPROACH,F                    40.           0.          40.          40.          40.          40.           0.

                              SINGLE TRAIN CONTD

                                8            9           10           11           12           13           14

NAME                     1VAC MPA      2VAC PA       ATM GO
API                          28.5         24.0         33.3          0.0          0.0          0.0          0.0
LBS/HR                    550000.      201000.      275000.           0.           0.           0.           0.
TIN,F                        500.         600.         590.           0.           0.           0.           0.
TOUT,F                         0.           0.         120.           0.           0.           0.           0.
PA?                            1.           1.           0.           0.           0.           0.           0.
EX.DUTY,BTU/HR          21000000.    12100000.    19922048.           0.           0.           0.           0.
EXOUT TEMP,F                 445.         509.         490.           0.           0.           0.           0.
TEMP CRUDE OUT,F             436.         450.         472.           0.           0.           0.           0.
COOL.DUTY,BTU/HR               0.           0.    61011008.           0.           0.           0.           0.
PSEUDCT                      478.         539.         546.           0.           0.           0.           0.
EX.SURF,SCFT                9910.        2512.        6138.           0.           0.           0.           0.
COOL.SURF,SQFT                 0.           0.        9462.           0.           0.           0.           0.
EXCCST$                    99101.       25121.       61378.           0.           0.           0.           0.
COOL.COST,$                    0.           0.       94621.           0.           0.           0.           0.
APPROACH,F                     0.          40.          40.           0.           0.           0.           0.

TOTAL DUTY= 305115904.BTU/HR
TOTAL EXCH SURF=  93139.FTSQ
TOTAL EXCH COST=$931394.
TOTAL COOLER  SURF= 22416.FTSQ
TOTAL COOLER COST=$224159.
```

```
                           OUTPUT SHEET 4

                      EXCHANGERS BEFORE DESALTER

NAME                    LT NAPH     PA1
API                        52.0        52.0
LBS/HR                  279500.    1210000.
TIN,F                      290.        340.
TOUT,F                     100.          0.
PA?                          0.          1.
EX.DUTY,BTU/HR       27711984.   92200000.
EXOUT TEMP,F               125.        215.
TEMP CRUD OUT,F           128.        259.
COOL.CUTY,BTU/HR       3853604.          0.
PSEUDCT                    246.        330.
EX.SURF,SCFT              7054.      24363.
COOL.SURF,SQFT            6944.          0.
EXCCST,$                 70544.     243634.
COOL COST,$              69445.          0.
APPROACH,F                 40.          0.
```

```
                                                            OUTPUT SHEET 5

                                                                 A TRAIN
NAME                           HV NAPH     1VAC 2SS     PA2          1VAC MPA
API                                44.2        24.8        44.2          28.5        0.0        0.0        0.0
LBS/HR                          139000.      73800.     525000.       550000.         0.         0.         0.
TIN,F                              425.        565.        475.          500.         0.         0.         0.
TOUT,F                             115.        150.          0.            0.         0.         0.         0.
PA?                                  0.          0.          1.            1.         0.         0.         0.
EX.DUTY,BTU/HR                12427567.   11629170.   43150000.     21000000.         0.         0.         0.
EXOUT TEMP,F                       289.        322.        355.          445.         0.         0.         0.
TEMP CRUDE OUT,F                   282.        312.        419.          467.         0.         0.         0.
COOL.DUTY,BTU/HR              13941342.    6708251.          0.            0.         0.         0.         0.
PSEUDOT                            337.        400.        463.          478.         0.         0.         0.
EX.SURF,SCFT                      3418.       2240.      19514.        15916.         0.         0.         0.
COOL.SURF,SQFT                    3783.       1229.          0.            0.         0.         0.         0.
EXCOST$                          34179.      22402.     195136.       159159.         0.         0.         0.
COOL.COST,$                      37826.      12290.          0.            0.         0.         0.         0.
APPROACH,F                          40.         40.          0.            0.         0.         0.         0.

                                                                 B TRAIN

NAME                           1VAC 3SS    2VAC RES     PA2          2VAC PA      ATM GO
API                                21.4        11.8        44.2          24.0        33.3        0.0        0.0
LBS/HR                           53000.      50000.     525000.       201000.     275000.         0.         0.
TIN,F                              615.        675.        475.          600.        590.         0.         0.
TOUT,F                             150.        275.          0.            0.        120.         0.         0.
PA?                                  0.          0.          1.            1.          0.         0.         0.
EX.DUTY,BTU/HR                11126515.   11415634.   43150000.     12100000.   21110112.         0.         0.
EXOUT TEMP,F                       289.        319.        355.          509.        483.         0.         0.
TEMP CRUDE OUT,F                   279.        308.        415.          443.        492.         0.         0.
COOL.CUTY,BTU/HR                4350593.    1555106.          0.            0.   61011008.         0.         0.
PSEUDOT                            385.        431.        463.          539.        546.         0.         0.
EX.SURF,SCFT                      1777.       1721.      18120.         2194.       7232.         0.         0.
COOL.SURF,SQFT                     828.        170.          0.            0.       9462.         0.         0.
EXCCST$                          17768.      17211.     181205.        21941.      72322.         0.         0.
COOL.COST,$                       8279.       1698.          0.            0.      94621.         0.         0.
APPROACH,F                          40.         40.          0.           40.         40.         0.         0.

          TOT DUTY,BTU/HR=  307020800.
          TOT EX SURF,SQ FT=   103550.
          TOT COOL SURF,SQ FT=  22416.
          TOT EXCH CCST,$=    1035498.
          TOT COCL CCST,$=     224159.
```

APPENDIX C

Example of Selection of Optimum Temperature Approach by Ten Broeck's Method

A sample calculation is given to illustrate Ten Broeck's method of determining the optimum cold end temperature approach for the exchangers in a preheat train. Figures 9 and 10, which give "P" values required in the application of this method, are included.

TABLE 6

USE OF TEN BROECK'S METHOD TO GET COLD-END TEMPERATURE APPROACH FOR AN EXCHANGER IN AN EXCHANGER TRAIN OR BANK. (NOTE 1)

$$R = \frac{T_2 - T_1}{t_1 - t_2} = \frac{wc}{WC} = \frac{34{,}860 \times .67}{347{,}760 \times .64} = \underline{0.105}$$

$$\frac{CH}{ZD} = \frac{.64H}{Z_1(529-332)} = \frac{.64 \times 8.1}{197\,Z_1} = \frac{.64 \times 8.1}{197 \times .22} = \underline{.12}$$

where $D = t_1 - T_1$

$$H_1 = \frac{114\,i\,E}{YU} = \frac{114 \times .33 \times 10}{.93 \times 50} = 8.1 \text{ (for exch)}$$

H_a : 8.1 also (for cooler)

$$Z_3 = C_3F_3 = .66 \times .55 = .36$$

$$Z_2 = C_2F_2 - Z_3R_3P_3 = .36 - (\overset{.062}{.36 \times .204 \times .85}) = .30$$

$$Z_1 = C_1F_1 - Z_2R_2P_2 - Z_3R_3P_3 = (\overset{.35}{.64 \times .55}) - (\overset{.07}{.30 \times .53 \times .44}) - .062 = 0.22$$

(NOTE 2.)

From Figure 9, with $R = .105$, and $\frac{CH}{ZD} = 0.12$, then $\underline{P = 0.82}$

$$\text{Then cold-end approach } t_2 - T_1 = D(1-P) = (\overset{197}{529-332})(.18) = 35.4°F$$

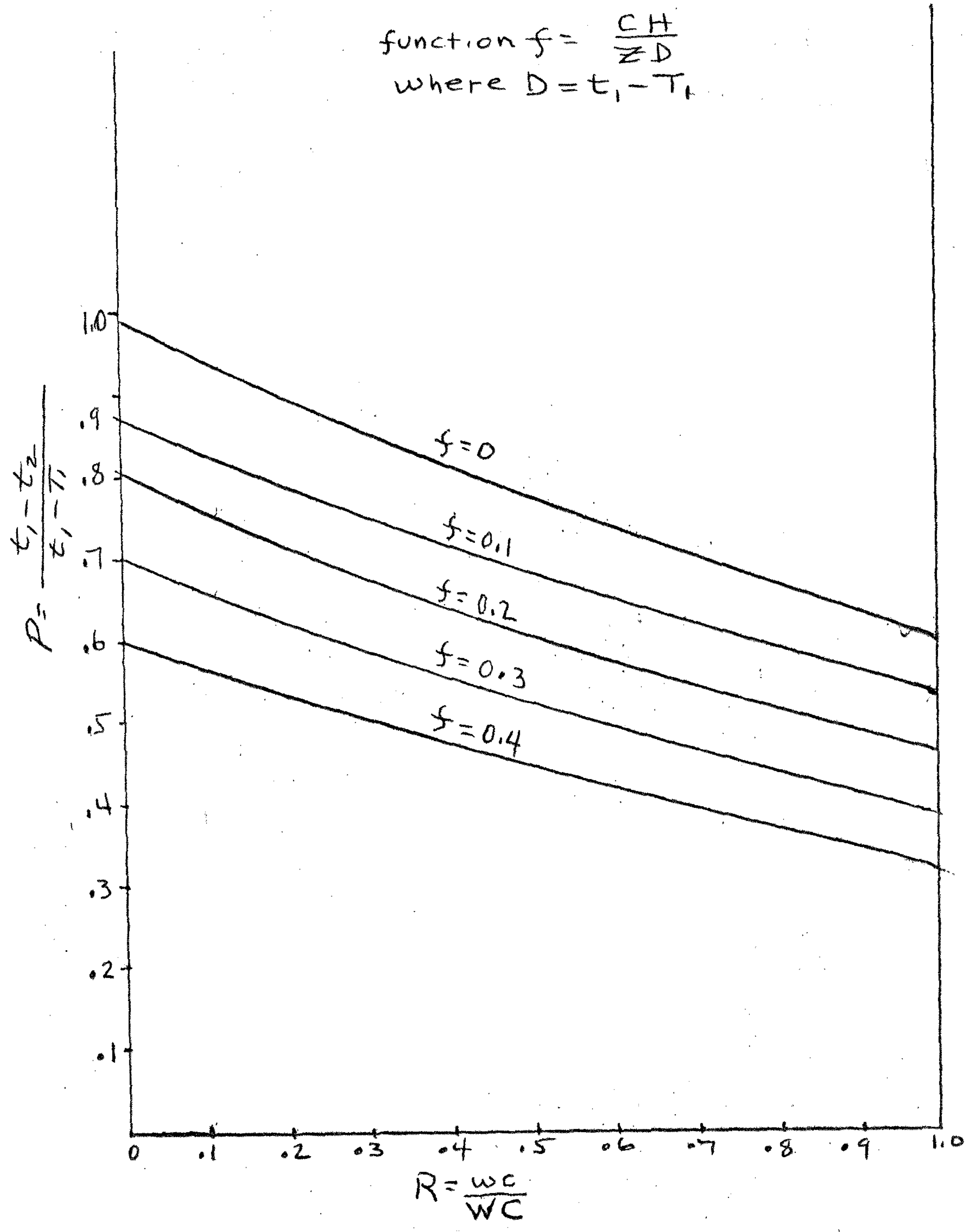
Then 35 °F IS APPROACH TO BE ENTERED AS HTSR(18, J)

NOTES:

1) Example calc. above for 5 TH EXCH. IN SAMPLE PROBLEM #1 IN APPENDIX C.
2) Z_1 APPLIES TO THE EXCH. FOR WHICH APPROACH IS being calculated and depends on Z's of all subsequent exchangers. In this case Z_3 corresponds to Z_7 and Z_2 to Z_6.

FIGURE 9

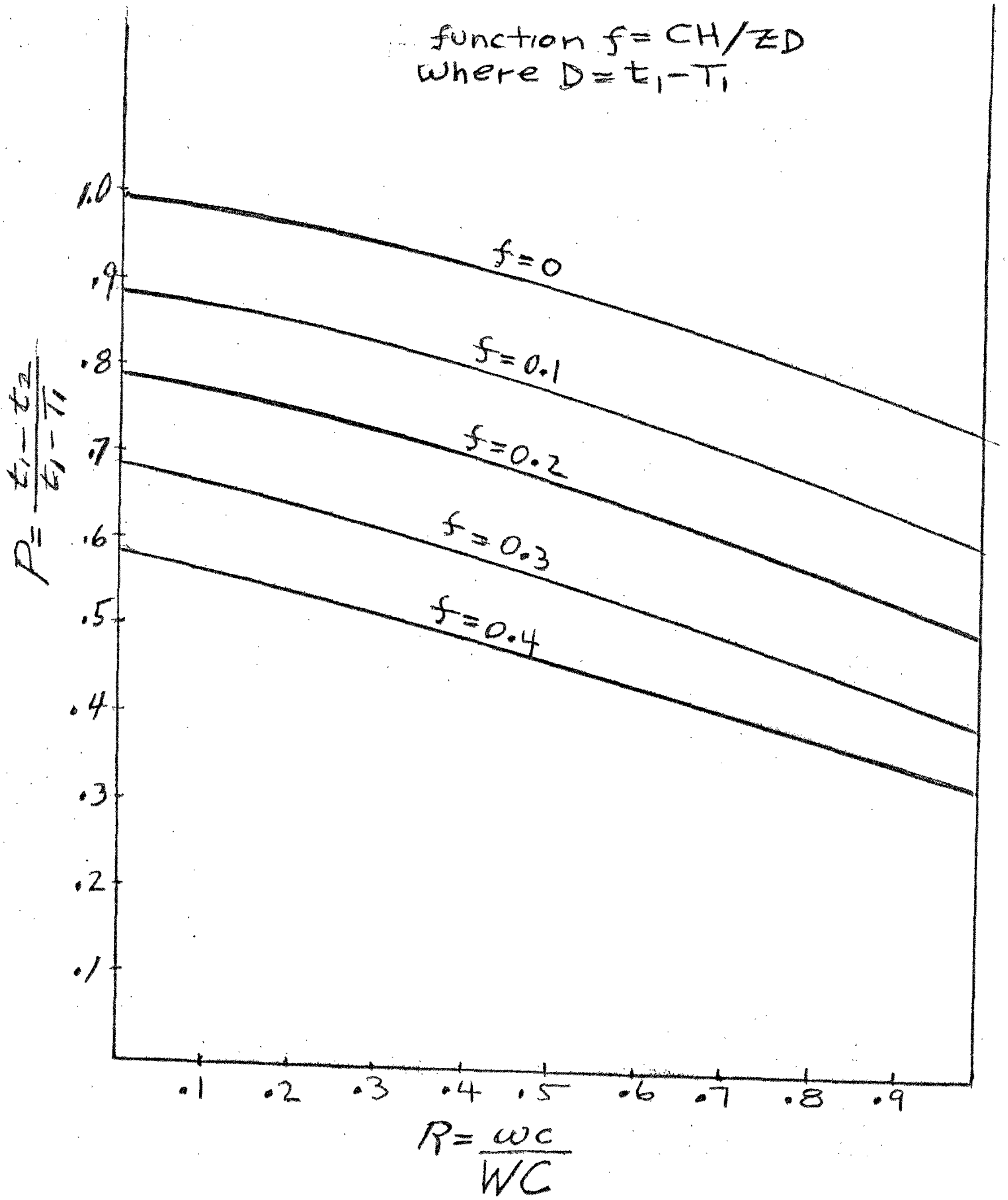
CHART TO OBTAIN VALUE OF P
(P = HEAT TRANSFER EFFICIENCY)
FOR
TYPE 1-2 MULTI-PASS EXCHANGERS



function $f = \frac{CH}{ZD}$
where $D = t_1 - T_1$

FIGURE 10

CHART TO OBTAIN VALUE OF P
(P = HEAT TRANSFER EFFICIENCY)
FOR
TYPE 2-4 MULTI-PASS EXCHANGERS



NOMENCLATURE

A = area of exchanger, ft. sq.

API = Specific gravity, °API $\quad$ $°\text{API} = \dfrac{141.5}{\text{Sp.gr.}} - 131.5$

C = specific heat of crude

c = specific heat of side stream

E = incremental exchanger cost, \$/ft.sq.

$D = t_1 - T_1$

$$F = H_f + H_{wat} + \frac{H_2}{t_2 - twa}$$

G = cost of water, \$/thousand gallons

H = 114 ie/YU

H_f = value of incremental heat, \$/million BTU

H_w = cost of water, \$/million BTU removed

i = rate of depreciation or amortization

$$P = \frac{t_1 - t_2}{t_1 - T_1}$$

Q = rate of heat transfer, BTU/hr.

$$R = \frac{T_2 - T_1}{t_1 - t_2} = \frac{wc}{WC}$$

S = savings, \$/yr.

T = temperature of crude stream, °F.

t = temperature of side stream, °F.

tw1 = inlet water temperature, °F.

tw2 = outlet water temperature, °F.

DeltH = $t_1 - T_2$, hot end approach, °F.

DeltC = $t_2 - T_1$, cold end approach, °F.

U = overall coefficient of heat transfer.

W = rate of crude stream, lbs/hr.

w = rate of sidestream, lbs/hr.

Y = fraction of year in operation.

Z = function related to position of exchanger in preheat train (See example in appendices)

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(3) Whistler, A. M. "Heat Exchangers as Money Makers" Petroleum Refiner - Vol. 27, No. 1, January, 1948.