ENERGY CONSERVATION IN COAL CONVERSION

High Pressure Steam Generation From Heat Recovery Boilers

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ABSTRACT

This report develops a methodology for calculating and evaluating the increased work potential possible from high pressure steam generation in waste heat boilers. This methodology is applied to the Ralph M. Parsons commercial concept of the Oil/Gas Complex. Implementation of the proposed scheme would result in an export power increase of 7.7 MW which is a 4% increase of the 210 MW generated by the Oil/Gas Complex at a cost of $2110/KW.

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Introduction

This report develops a methodology for calculating and evaluating the increased work potential possible from high pressure steam generation in waste heat boilers. The methodology is applied to the Ralph M. Parsons commercial concept of the Oil/Gas Complex[1].

Operating steam generators at higher pressures than steam users allows for work to be extracted by depressurization. Topping turbines can be used to bring the pressure down from the generation pressure level to the user pressure level. However, higher boiler operating pressures and additional turbines require a higher capital investment.

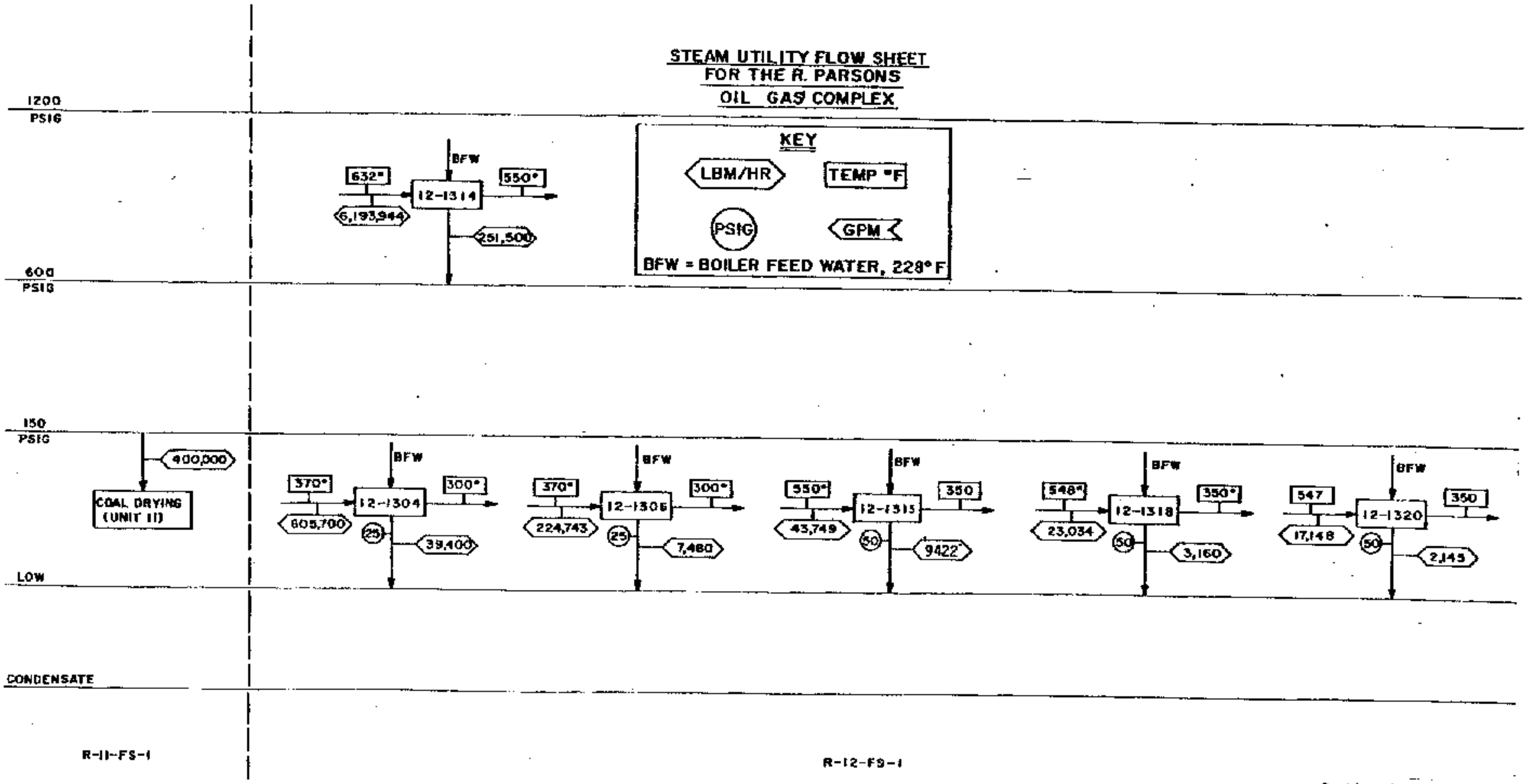
Method of Approach

Use of a steam balance format simplifies the approach (Fig. 1). Headers were drawn to represent all steam generation and user pressure levels and condensate. Steam generators were drawn above the corresponding headers, while users are drawn below these headers. Generators and users are labeled with their corresponding equipment numbers and steam mass flow rates. Heat exchanger gas mass flow rates are shown, as well as the gas inlet and exit temperatures.

Heat exchangers are then evaluated on an individual basis to determine if steam at the next highest incremental pressure can be generated. The results calculated (Appendix A) are shown in Table 1.

Two approaches are used to determine if higher pressure steam can be generated. The first approach is to hold the heat transfer constant, and evaluate the effect on the steam mass flow rate and the

STEAM UTILITY FLOW SHEET
FOR THE R. PARSONS
OIL GAS COMPLEX



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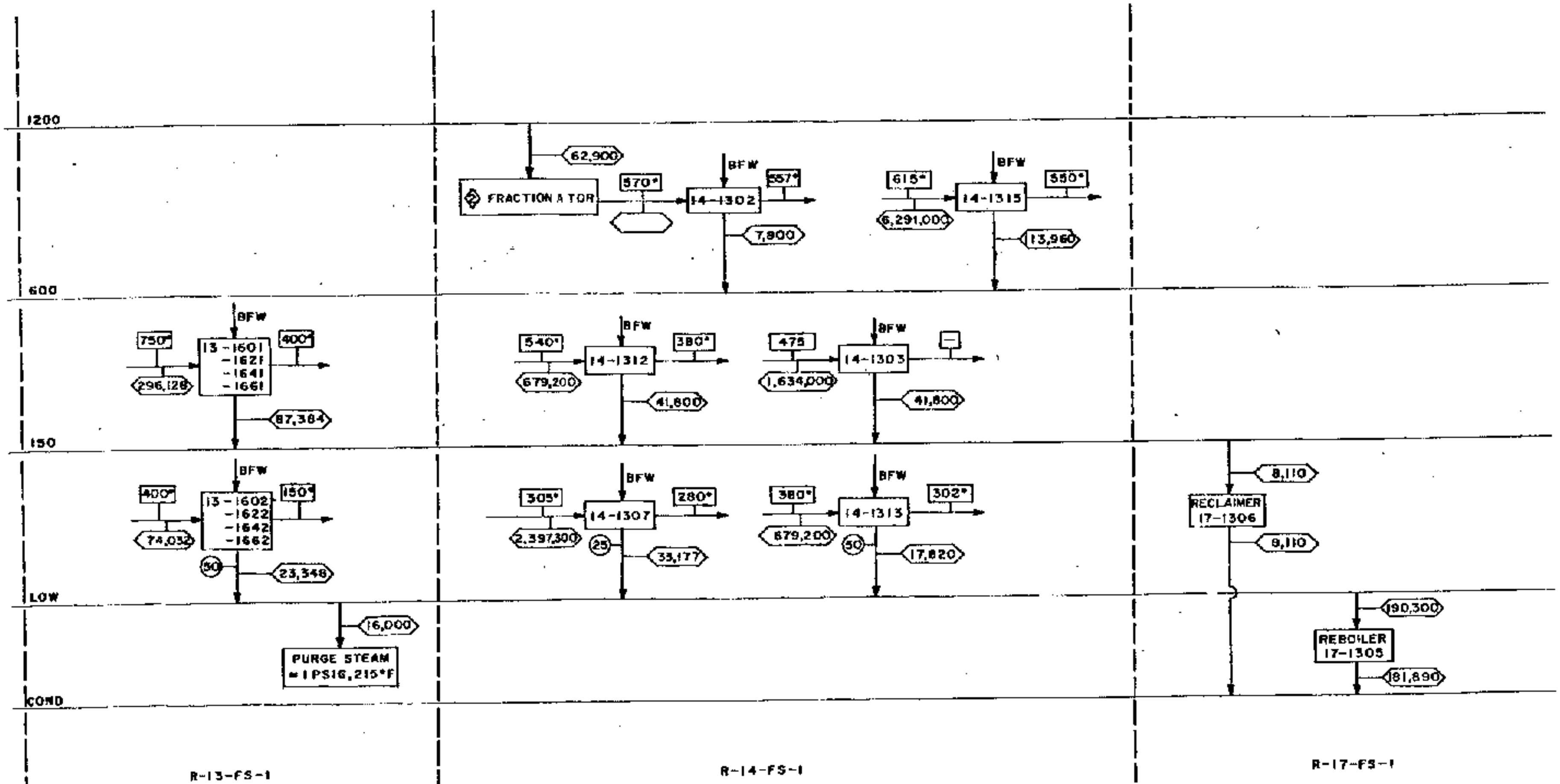

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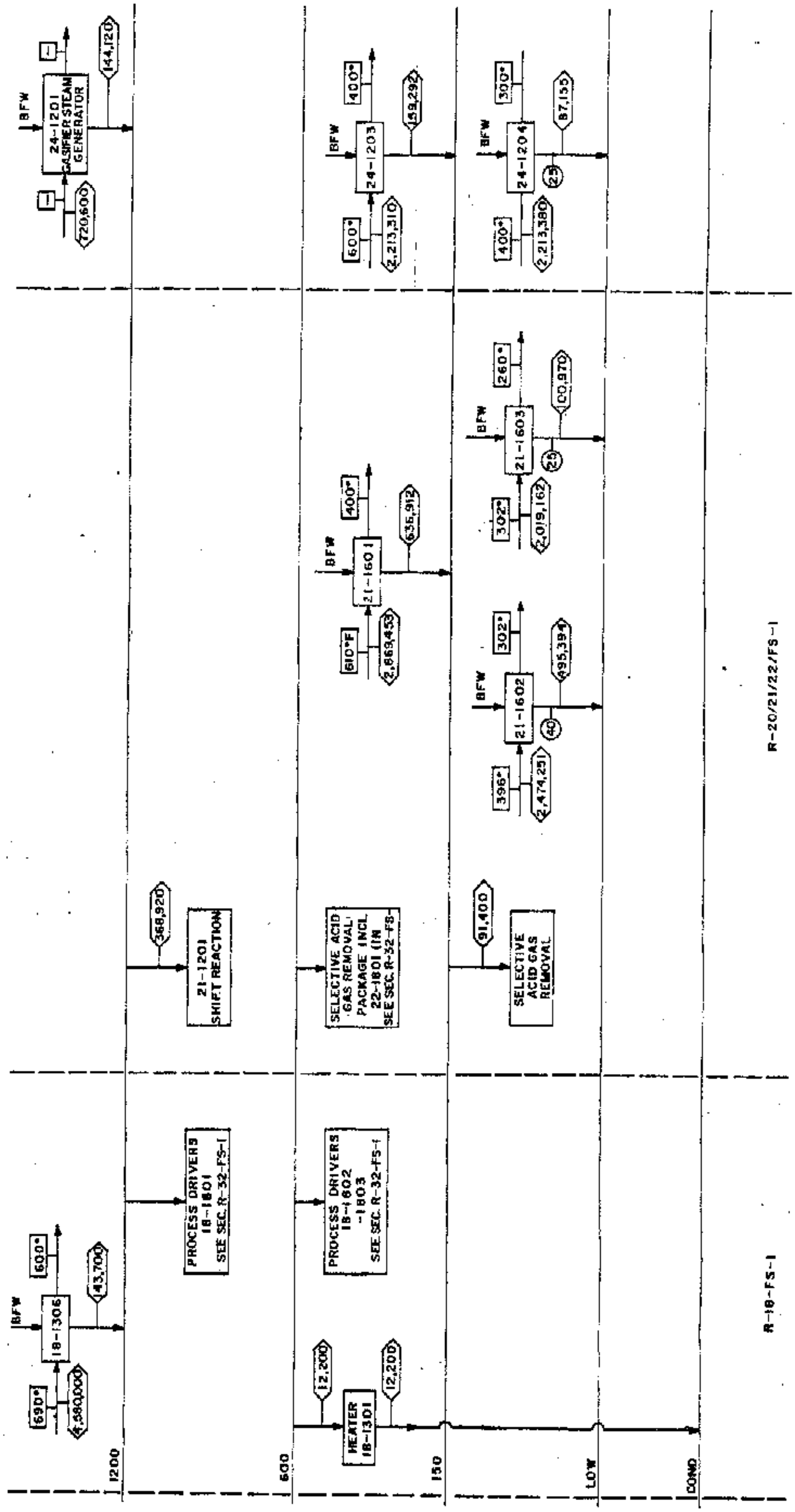

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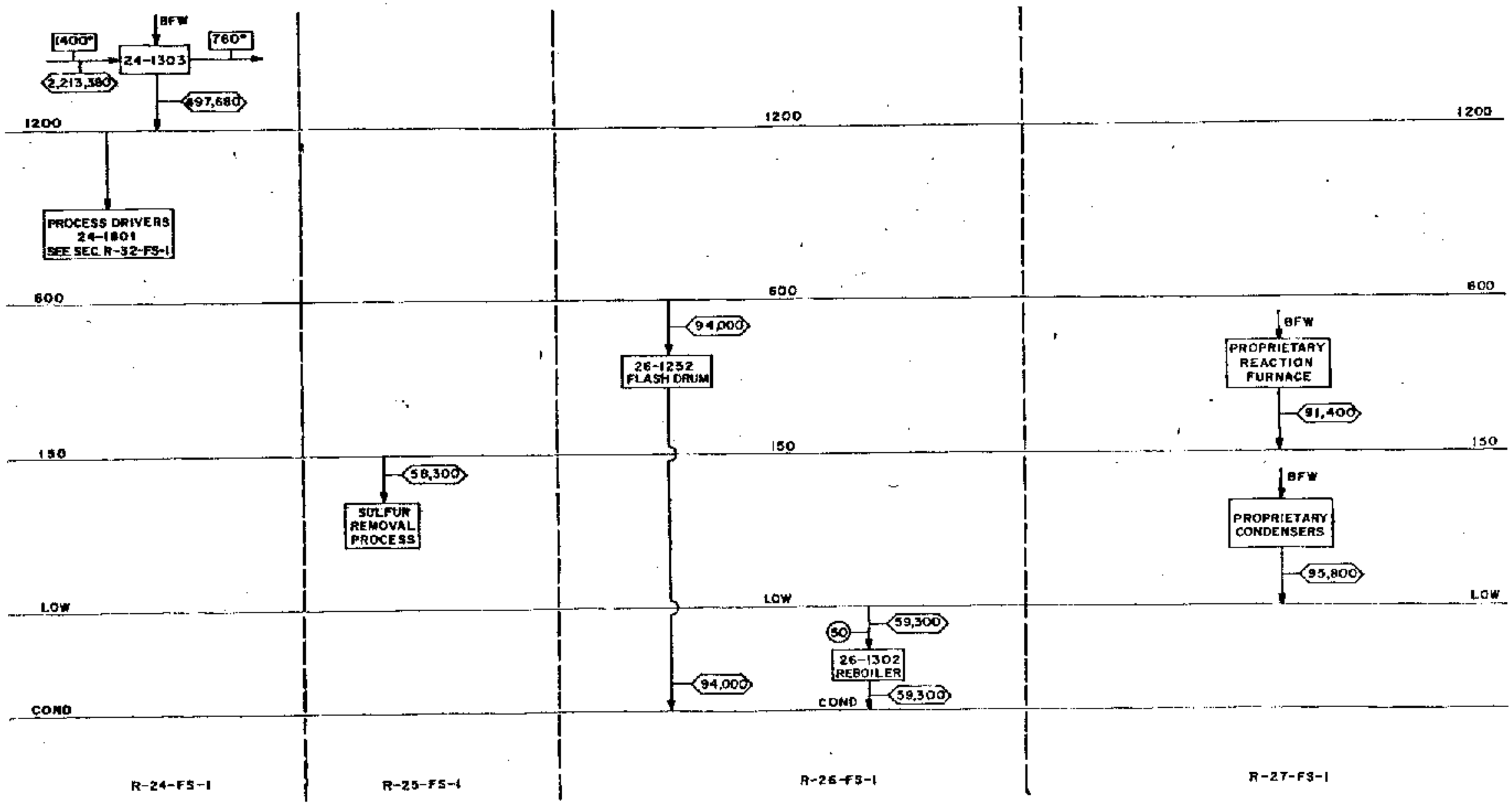

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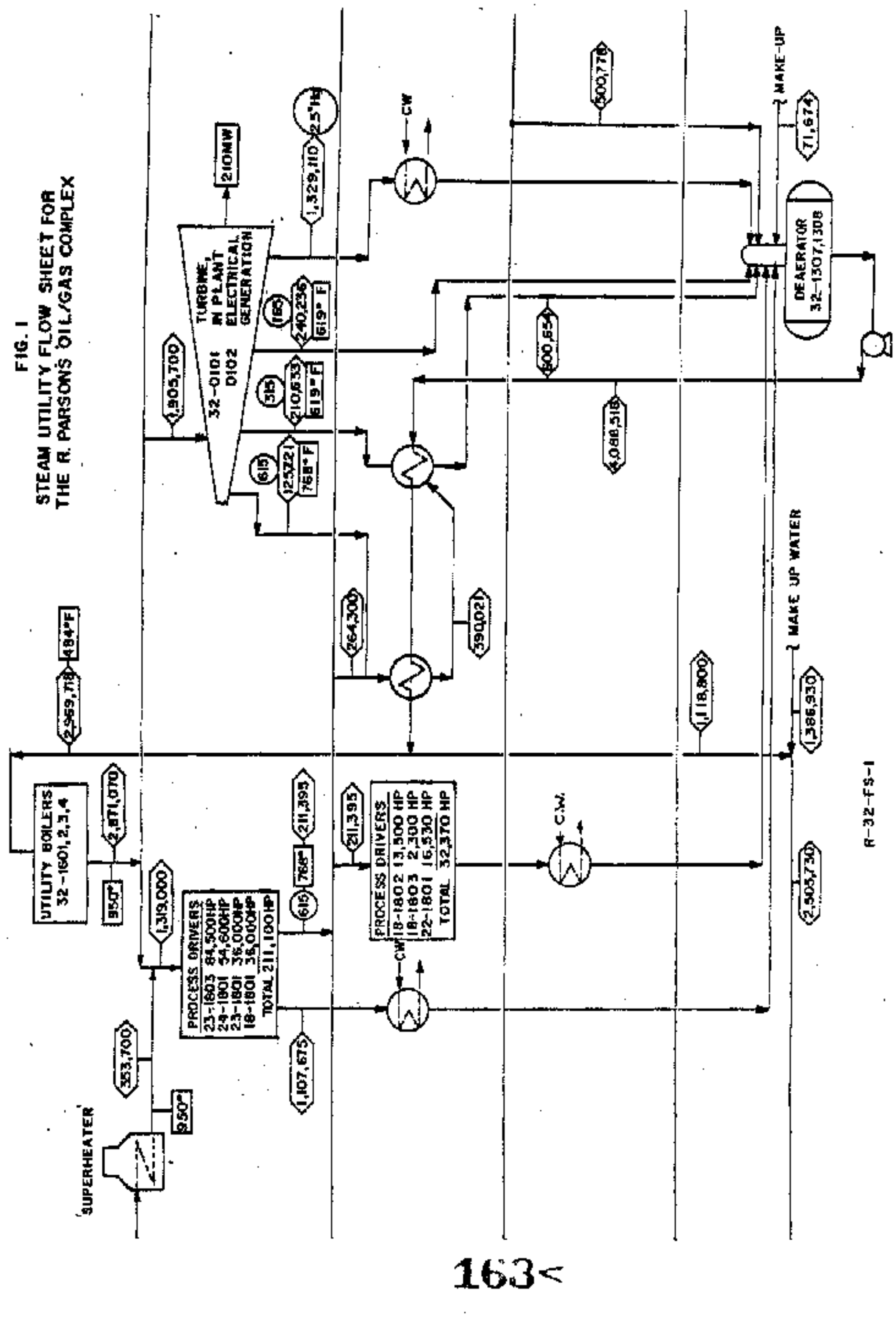


FIG. I
STEAM UTILITY FLOW SHEET FOR
THE R. PARSONS OIL/GAS COMPLEX

Item #	existing P_s PSIG	existing $\dot{m}_s$ lb/hr	existing ΔT_p °F	existing U_B Btu/hr.ft²°F	existing A_{tot} ft²	existing mat'l SH/T	existing cost $/ft²	increased pressure, q_t = const. P_s PSIG	q_t = const. $\dot{m}_s$ lb/hr	q_t = const. ΔT_p °F	q_t = const. A_{tot} ft²	q_t = const. mat'l SH/T	q_t = const. cost $/ft²	increased pressure, ΔT_p = 50° P_s PSIG	ΔT_p = 50° $\dot{m}_s$ lb/hr	ΔT_p = 50° Te °F	ΔT_p = 50° A_{tot} ft²	ΔT_p = 50° mat'l SH/T	ΔT_p = 50° cost $/ft²	remarks
12-1304	25	39,340	35.6	131	5,300	-----	-----	50	38,956	7	----	-----	-----	50	13,150	----	-----	-----	-----	ΔT_p to low; $\dot{m}_s$ to low
12-1306	25	7,464	35.6	114	1,130	-----	-----	50	7,394	7	----	-----	-----	50	2,493	----	-----	-----	-----	ΔT_p to low; $\dot{m}_s$ to low
12-1314	600	252,900	82	56.5	42,680	CS/SS	78	900	255,000	42.6	64,050	CS/SS	105	900	218,700	561	51,970	CS/SS	105	ΔT_p acceptable; $\dot{m}_s$ acceptable
								1200	258,500	12.2	----	-----	-----	1200	66,200	-----	-----	-----	-----	ΔT_p to low; $\dot{m}_s$ to low
12-1315	50	9,422	65	153	456	CS/SS	17.6	150	6,513	11.1	----	-----	-----	150	5,041	394	510	CS/SS	35.9	ΔT_p to low; $\dot{m}_s$ acceptable
								600	-----	-----	----	-----	-----	600	442	-----	-----	-----	-----	not possible; $\dot{m}_s$ to low
12-1318	50	3,140	67	139	230	CS/CS	17.6	150	3,086	12	----	-----	-----	150	2,250	396	290	CS/CS	35.9	ΔT_p to low; $\dot{m}_s$ acceptable
12-1320	50	2,141	66	97	200	CS/CS	17.6	150	2,105	10.7	-----	-----	-----	150	1,613	395	132	CS/CS	35.9	ΔT_p to low; $\dot{m}_s$ acceptable
13-1601/21/41/61	150	21,900	83	20.6	5,400	CS/CS	35.9	600	21,726	7	-----	-----	-----	600	18,045	416	6,550	CS/CS	-----	ΔT_p to low; $\dot{m}_s$ acceptable
								900	-----	-----	-----	-----	-----	900	15,465	502	5,944	CS/CS	115	ΔT_p to low; $\dot{m}_s$ acceptable
13-1602/22/42/62	50	5,837	17	30	3,997	----	-----	150	-----	-----	-----	-----	-----	150	-----	-----	-----	-----	-----	not possible; not possible
14-1302	600	7,890	71	82.6	1,330	----	----	900	7,849	26.6	-----	-----	-----	900	-----	-----	-----	-----	-----	ΔT_p to low; not possible
14-1315	600	111,630	78	20.3	43,860	CS/CS	36	900	112,520	36.7	74,835	CS/CS	48	900	77,980	570	90,455	CS/CS	48	ΔT_p acceptable; $\dot{m}_s$ acceptable
								1200	114,000	8	-----	-----	-----	1200	-----	-----	-----	-----	-----	ΔT_p to low; not possible
14-1313	50	19,450	27	30	12,650	----	-----	150	-----	-----	-----	-----	-----	150	-----	-----	-----	-----	-----	not possible; not possible
14-1307	25	33,177	16	-----	19,940	----	-----	50	-----	-----	-----	-----	-----	50	-----	-----	-----	-----	-----	not possible; not possible
18-1306	1200	143,650	66	479	11,700	A285C/CS	60	1500	147,543	42	15,430	A285C/CS	-----	1500	125,904	613	12,360	A285C/CS	82	ΔT_p acceptable; $\dot{m}_s$ acceptable
								1800	150,482	22	-----	-----	-----	1800	54,370	-----	-----	-----	-----	ΔT_p to low; $\dot{m}_s$ to low
21-1601	150	636,912	63	565	34,488	----	-----	600	-----	----	-----	-----	-----	600	292,460	-----	-----	-----	-----	not possible; $\dot{m}_s$ to low
21-1602	25	495,394	38.7	134	54,220	----	-----	150	-----	----	-----	-----	-----	150	-----	-----	-----	-----	-----	not possible; not possible
21-1603	10	100,970	20.6	-----	23,574	----	-----	50	-----	----	-----	-----	-----	50	-----	-----	-----	-----	-----	not possible; not possible
24-1201	1200	144,120	-----	-----	-----	----	-----	-----	-----	----	-----	-----	-----	-----	-----	-----	-----	-----	-----	lack of information
24-1303	1200	497,680	400	13.6	55,000	SA285C/SS	480	1500	504,624	364	55,560	-----	-----	1500	947,116	-----	-----	-----	-----	ΔT_p acceptable; not possible
								2000	622,340	419	49,170	SA285C/SS	630	2000	1,079,680	-----	-----	-----	-----	ΔT_p acceptable; not possible
24-1305	150	159,292	63	-----	38,500	-----	-----	600	-----	----	-----	-----	-----	600	65,860	-----	-----	-----	-----	not possible; $\dot{m}_s$ to low
24-1306	25	87,155	36	18.3	61,360	-----	-----	50	84,435	9	-----	-----	-----	50	47,325	----				ΔT_p to low; $\dot{m}_s$ to low

P_s = steam generation pressure

$\dot{m}_s$ = steam flow

ΔT_p = pinch point temperature difference

U_B = over-all heat transfer coefficient of boiler section

A_{tot} = total area of heat exchanger

mat'l = heat exchanger materials = SH/T = Shell/Tubes

Te = exit temperature of heating stream

CS = carbon steel

SS = stainless steel

TABLE I

"pinch point" temperature differential - the minimum temperature difference between the exchanger heating stream and the saturation temperature of the steam being generated. The heat exchanger area is then calculated.

In the second approach, the "pinch point" is set at 50°F, a common design point, and the effect on the steam mass flow rate, the heating stream exit temperature, and the exchanger area are found.

While considering increasing the operating pressure of the heat exchangers, two requirements were set. First, the new mass flow rate of the steam must be within - 30% of the former steam mass flow rate. Second, the "pinch point" temperature differential must be a minimum of 36°. Also, the highest incremental steam pressure possible (up to 2000 PSIG) was of course chosen. When it was possible to replace an exchanger with either scheme, the total heat transfer held constant or the "pinch point" held at 50°, it was decided to keep the heat transfer constant wherever possible. This avoids any possible complications from the heating stream outlet temperature rising excessively.

The replaced exchangers are shown in Table 2. (The exchanger costs were found as shown in Appendix B.) The total installed cost of the existing exchanger is found by multiplying the heat exchanger area by the cost per unit area. The total installed cost of the replacement exchanger is found the same way. The difference between these two costs is the "Δ installed cost". The total increased capital investment in heat exchangers, then, is found to be $12,555,020.

Table 2

Exchanger Costs

Item #	low pressure			high pressure			Δ Installed Cost
	Area (ft^2)	Cost ($\$/ft^2$)	Cost ($)	Area (ft^2)	Cost ($\$/ft^2$)	Cost ($)	
12 -1314	42,680	78	3,300,000	64,050	105	6,725,000	3,425,000
12-1315	456	17.6	8,000	510	35.9	18,300	10,300
12-1318	230	17.6	4,000	290	35.9	10,400	6,400
12-1320	200	17.6	3,520	132	35.9	4,740	1,220
13-1601/21/ 41/61	5400(x4)	35.9	775,000	5,944(x4)	115	2,734,000	1,959,000
14-1315	43,860	36	1,579,000	74,835	48	3,592,000	2,013,000
18-1306	11,700	60	702,000	15,430	82	1,265,000	563,000
24-1303	55,000	480	26,400,000	49,170	630	30,977,000	4,577,000

Δ Installed cost total = $12,555,000

Table 3 shows the "accounting" of the new steam balance. The column headed "lbs/hr needed" indicates the shortage of steam at the indicated pressure due to generating the steam at a higher level. The column headed "lbs/hr generated" designates the steam now generated at a higher level.

Figure 2 demonstrates how power can be generated by utilizing the higher pressure steam. The steam is expanded through a turbine and extracted at the levels required to rebalance the system. The turbine in Figure 2, however, would be prohibitive in terms of cost due to the complexity of controls in such an induction-extraction arrangement.

Figure 3 shows how the arrangement of Figure 2 can be implemented by utilizing six separate turbines. The costs for these turbines are given in Table 4. The costs for the corresponding generators is also shown. The power output of the generator was found as shown in Appendix C. Thus, the total generator output of 7760 kw cost $3,815,600 for turbine and generation equipment, and $12,555,000 represents the increase in total installed cost of the waste heat boilers (Table 2). Thus, the proposal to generate steam at a higher pressure results in a 7760 kw power increase at a cost of $16,370,000 or $2110/kw.

The steam utility flow sheet revised to show the implementation of the higher pressure waste heat boilers and additonal turbines is shown in Figure 4.

Table 3

Steam Balance

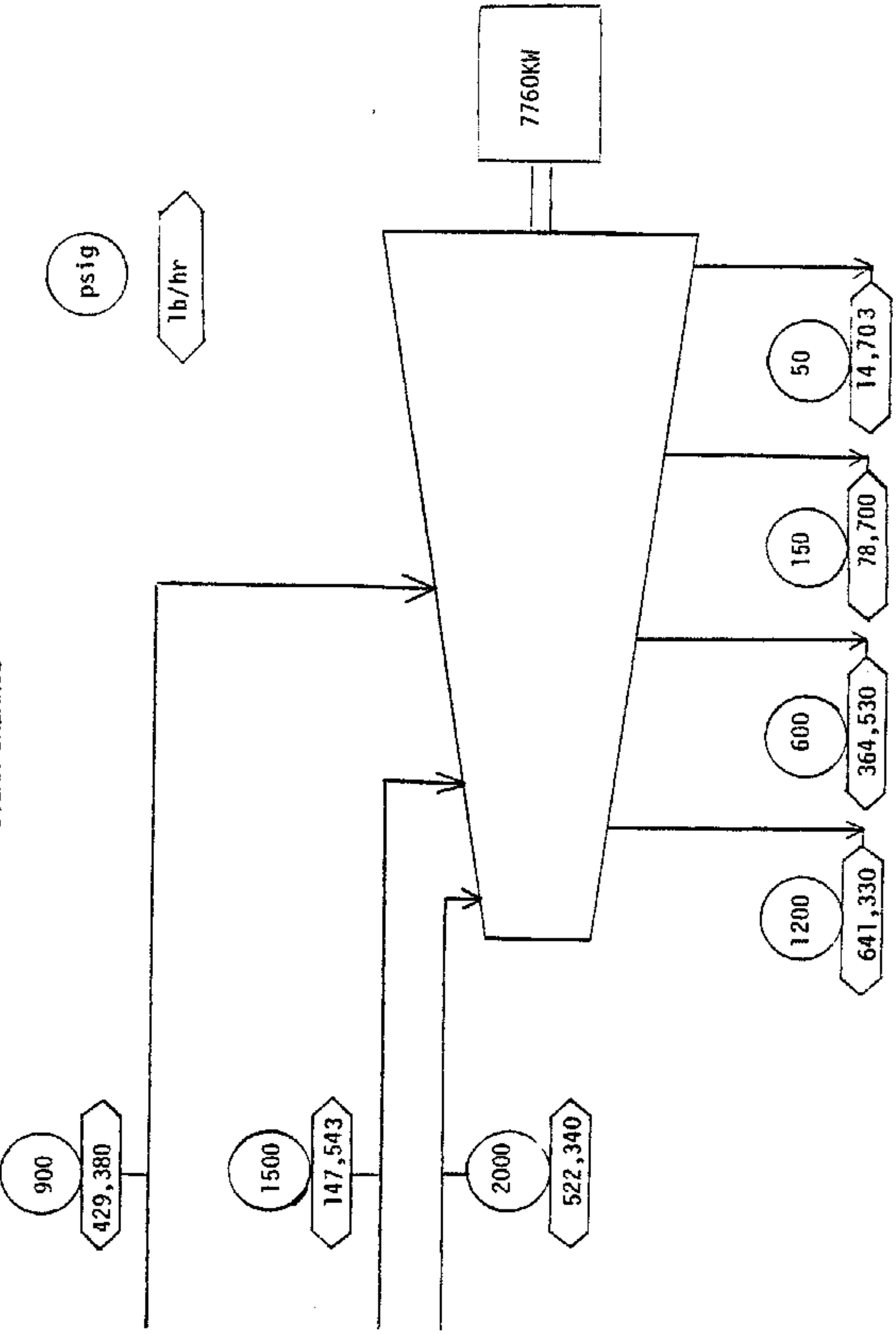
Unit #	PSIG	lbs/$_{hr}$ needed	PSIG	lbs/$_{hr}$ generated
12-1314	600	252,900	900	255,000
12-1315	50	9,422	150	5,041
12-1318	50	3,140	150	2,250
12-1320	50	2,141	150	1,613
13-1601/21/41/61	150	21,900(x4)	900	15,465(x4)
14-1315	600	111,630	900	112,520
18-1306	1200	143,650	1500	147,543
24-1303	1200	497,680	2000	522,340

A turbine operating under the following conditions would satify the above requirements:

PSIG	$\dot{m}_{in}$	m_{out}
2000	522,340	
1500	147,543	
1200		641,330
900	429,380	
600		364,530
150		78,700
50		14,703

Figure 2

STEAM BALANCE



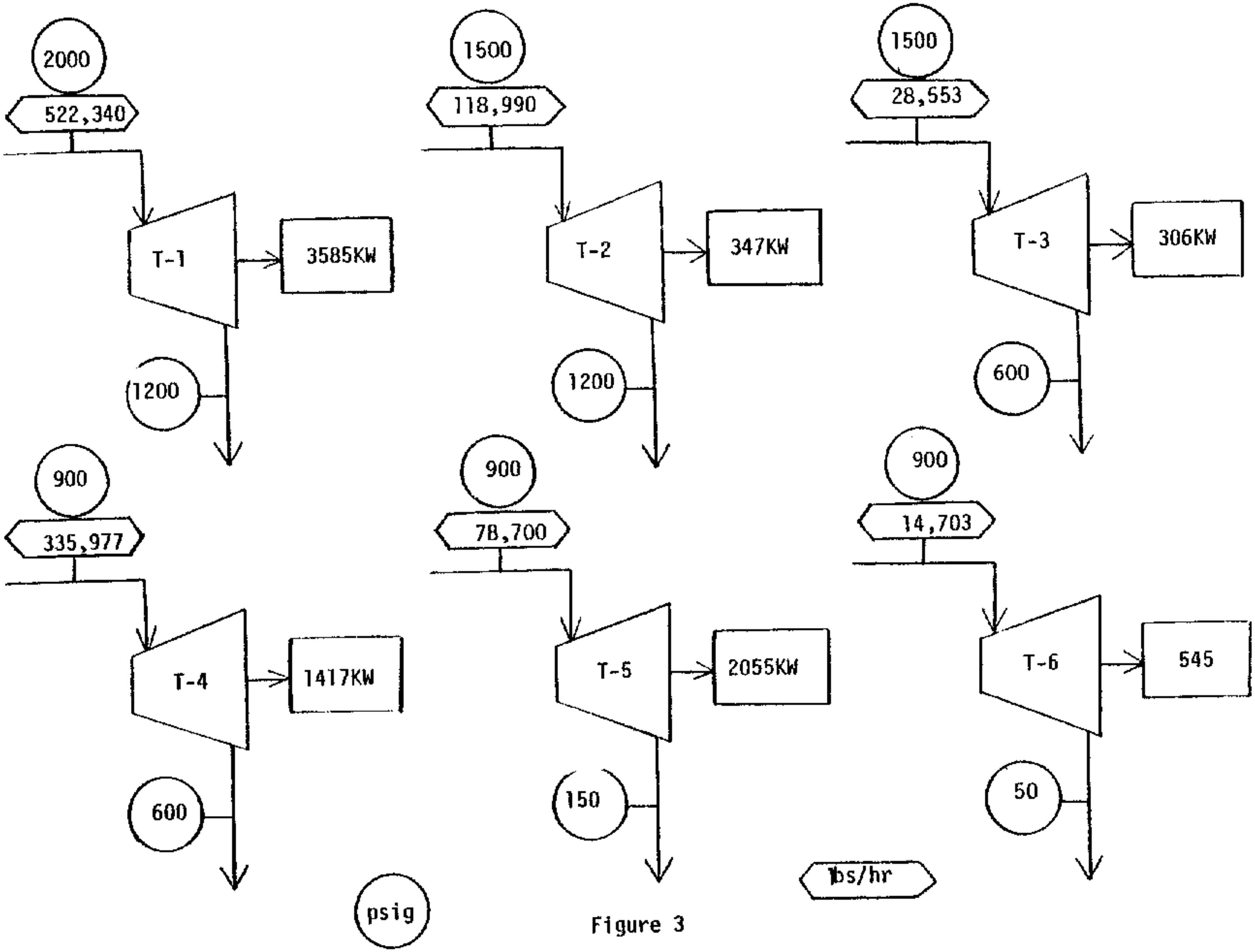


Figure 3

GENERATION SCHEME

Table 4

Turbine and Generator Costs

	HP/KW	Turbines* Installed Cost	Generators** Installed Cost
1)	4805/3585	$1,200,000	430,200
2)	465/347	525,000	41,640
3)	410/306	250,000	36,720
4)	1900/1417	425,000	170,000
5)	2755/2055	250,000	246,000
6)	730/545	175,000	65,400
Total	11,065/8255	2,825,000	990,600

Total turbine and generator installed costs = $3,815,600

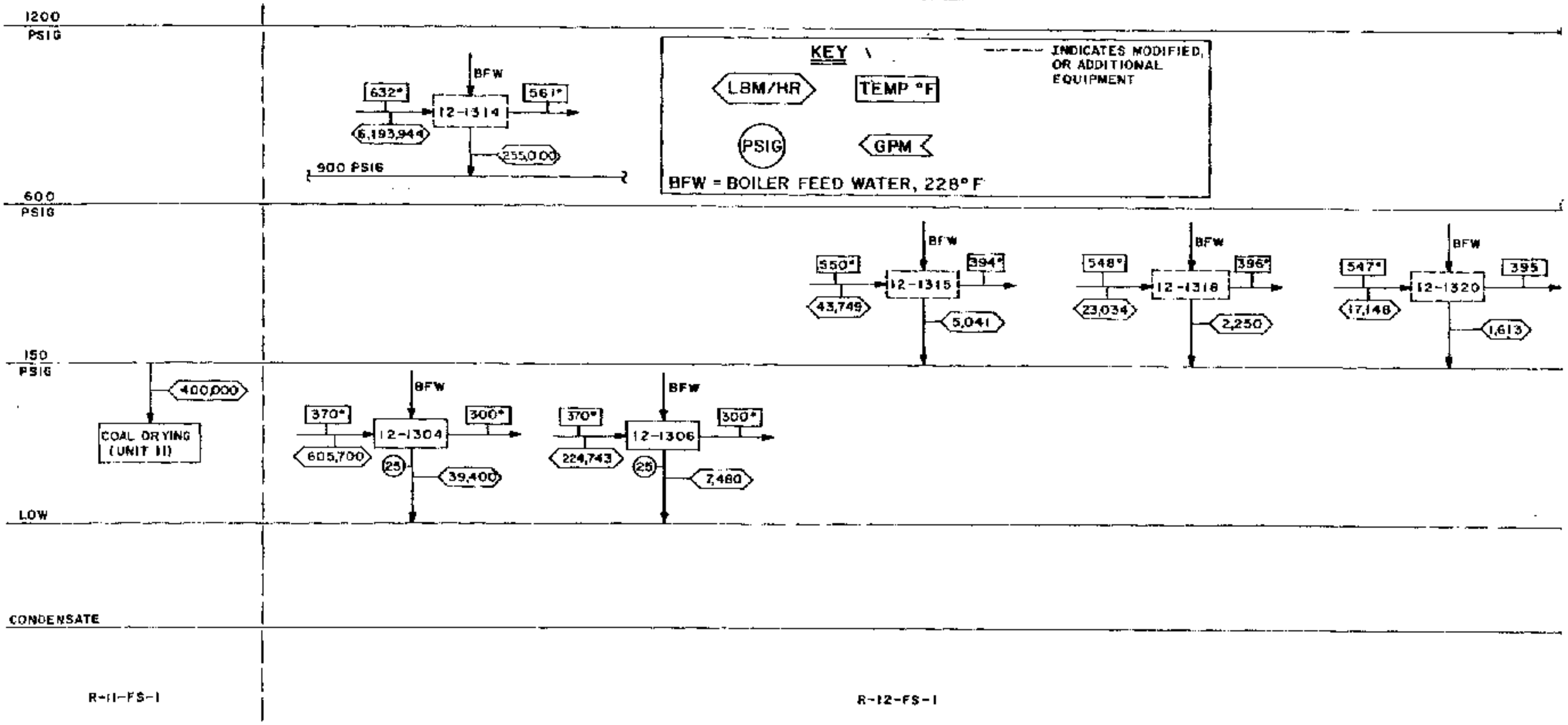
Total power output = 8255 KW x 94%[8] = 7760 KW

*Appendix C

**Based on an $80/KW quote ± 10% for generators in the range shown, plus 40 - 50% for gear reduction equipment. (Reference 8.)

FIG. 4

REVISED STEAM UTILITY FLOW SHEET
FOR THE R. PARSONS OIL GAS COMPLEX



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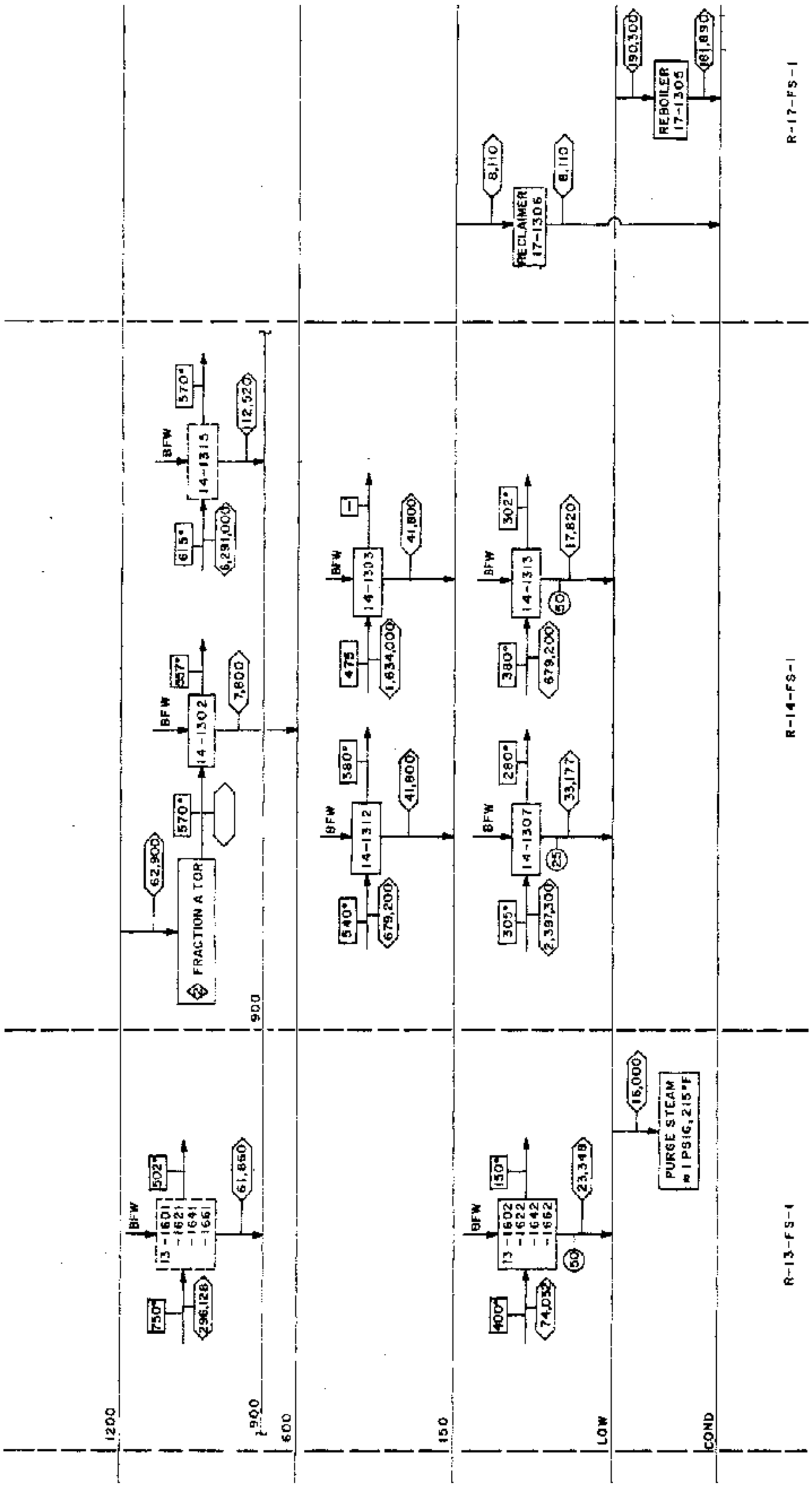

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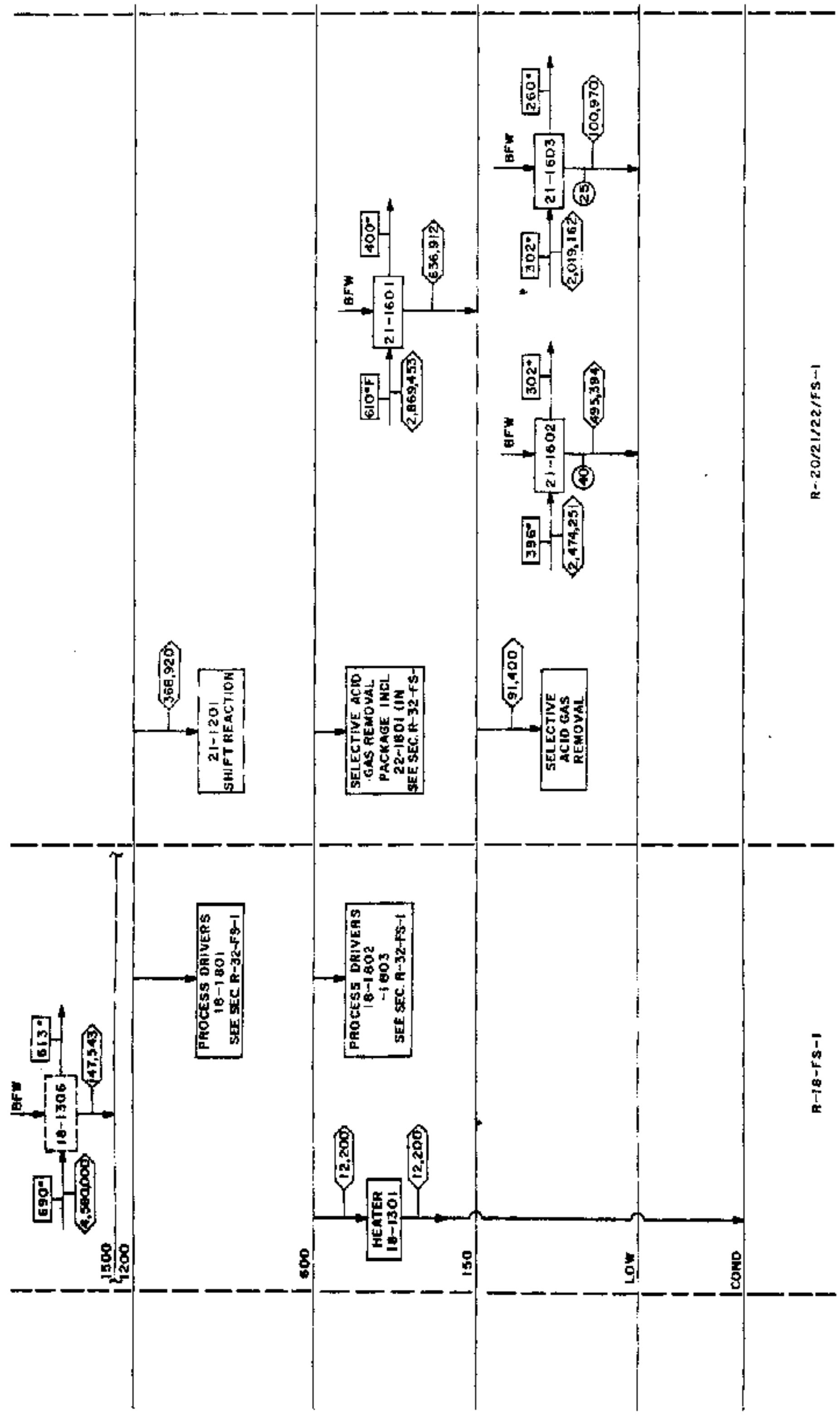

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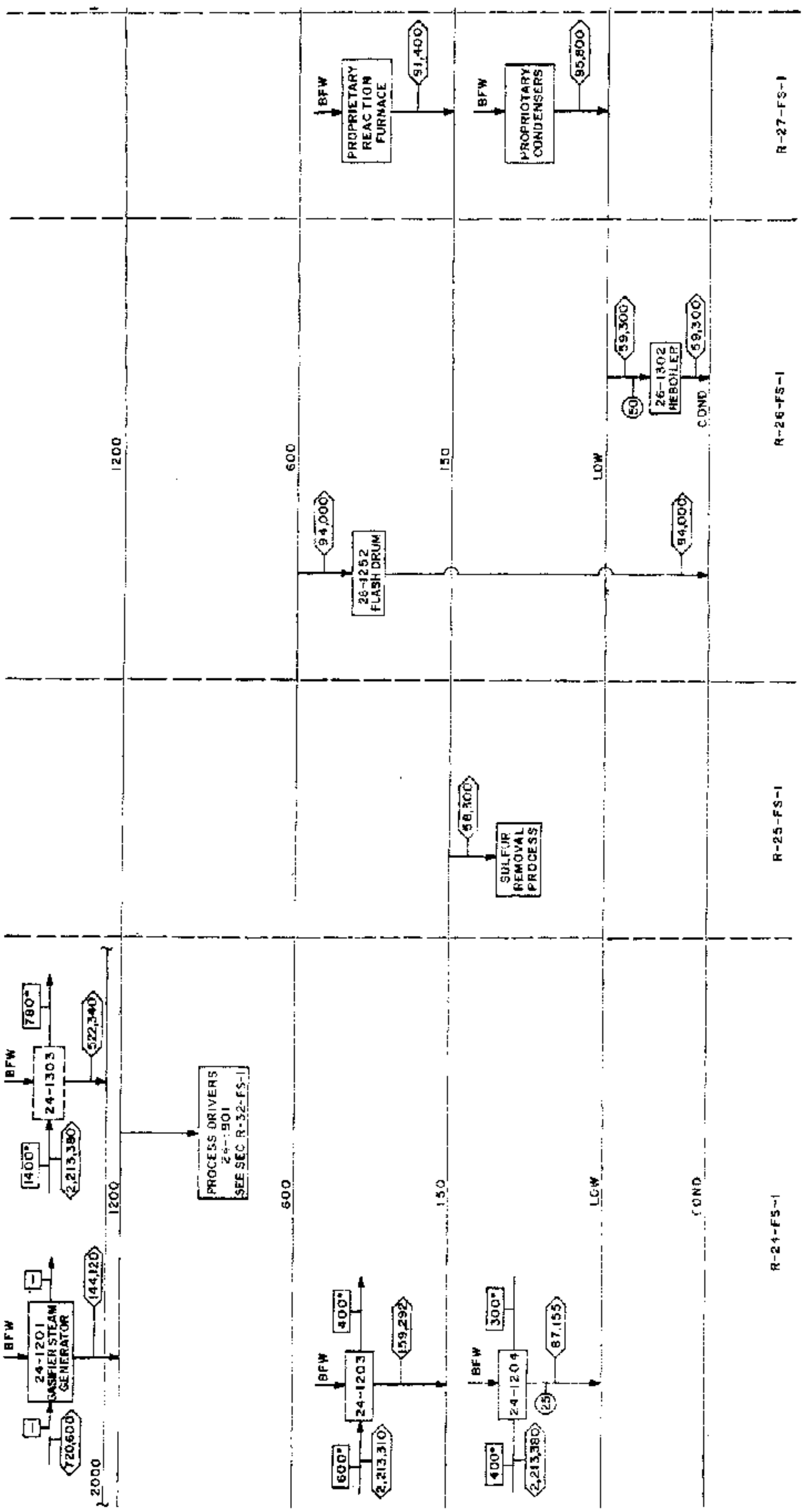

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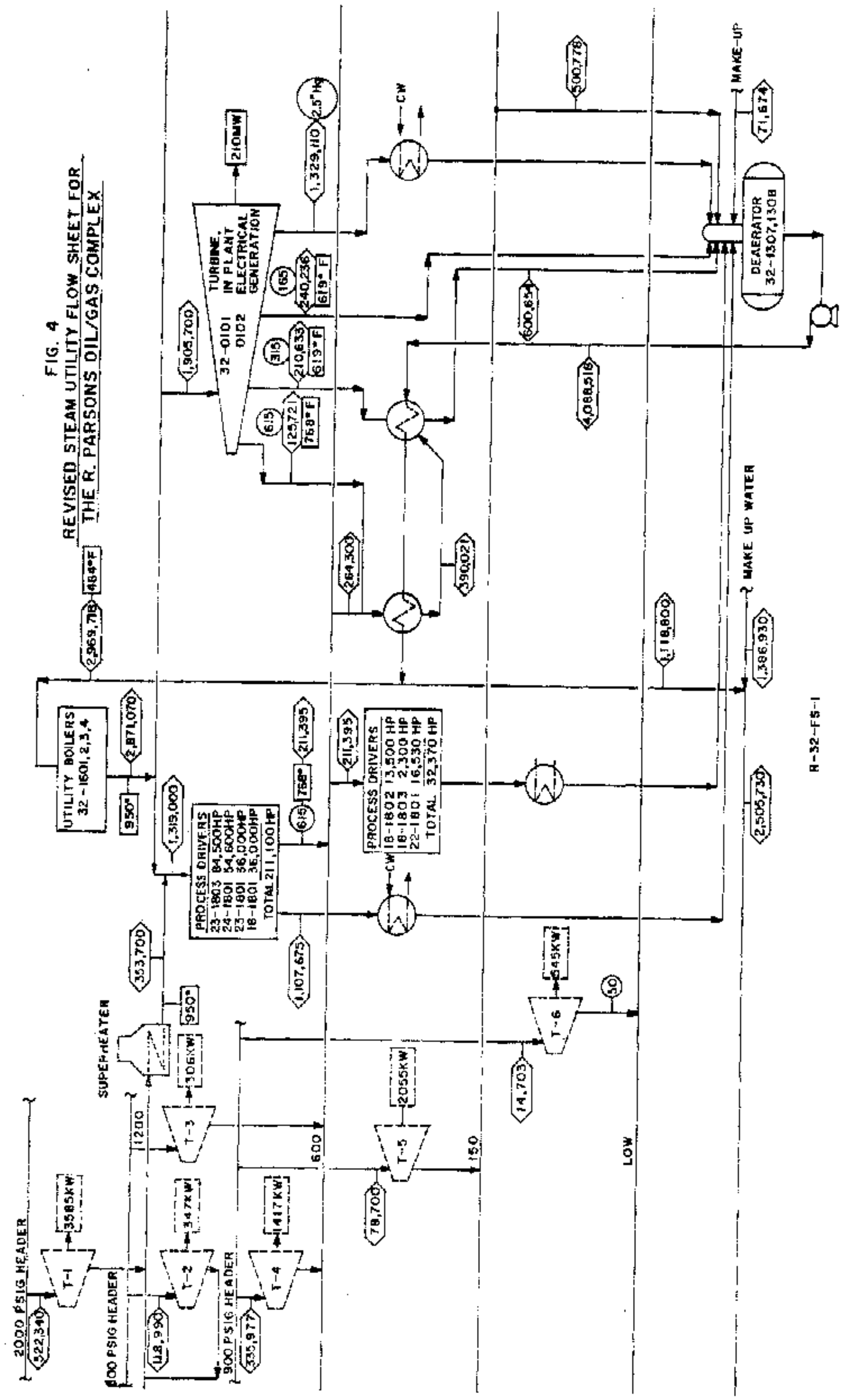

FIG. 4
REVISED STEAM UTILITY FLOW SHEET FOR THE R. PARSONS OIL/GAS COMPLEX

R-32-FS-1

CONCLUSION

Implementation of the scheme shown in Figure II results in a 7760 KW power generation increase, at a total cost of $16,370,000.

References

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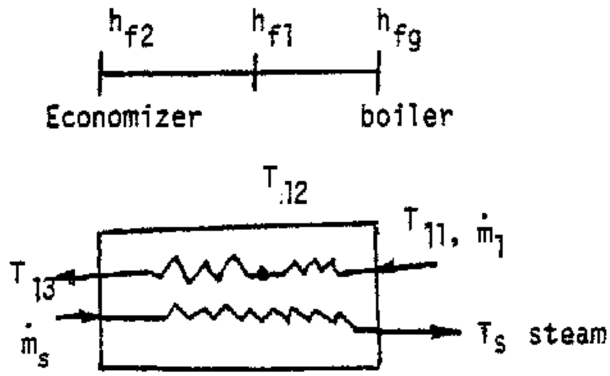
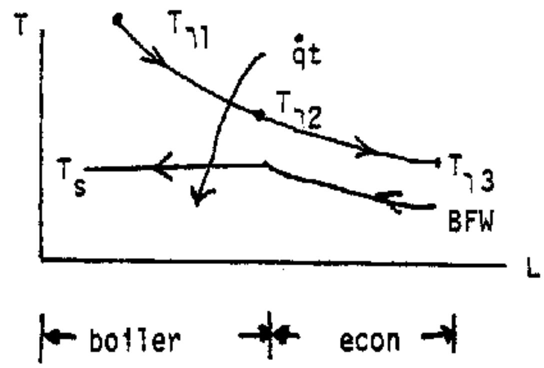
APPENDIX A

SAMPLE CALCULATION





12-1314 From the flow diagram (R-12-FS-1):

$T_{11} = 632°F$ $\dot{q}_t = 254.892$ MM Btu/hr

$T_{13} = 550°F$ $\dot{m}_1 = 6,193,944$ lb/hr

$P_s = 600$ PSIG

From the equipment specifications (Section 13):

$$A_{total} = 42,680 \text{ ft}^2$$

The following is an analysis of the existing exchanger.

From steam tables:

600 PSIG Steam: h_{fg} = 727.9 Btu/lbm

h_{f1} = 475.8

228°BFW: h_{f2} = 196.3

The mass flow of the steam is found:

$$\dot{m}_s = \frac{\dot{q}t}{h_{fg} + (h_{f1} - h_{f2})} = \frac{254.892 \times 10^6 \text{ Btu/hr}}{727.9 + 475.8 - 196.3 \text{ Btu/lbm}} = 2.53 \times 10^5 \text{lb/hr}$$

The heat transfer in the boiler section is:

$$\dot{q}_B = \dot{m}_s h_{fg} = (2.53 \times 10^5) \text{ lb/hr} \ (727.9) \text{ Btu/lb} = 1.84 \times 10^8 \text{ Btu/hr}$$

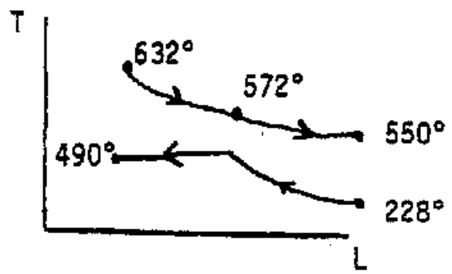
The heat transfer in the economizer is:

$$\dot{q}_E = \dot{m}_s (h_{f1} - h_{f2}) = (2.53 \times 10^5) \text{ lb/hr} \ (475.8 - 196.3) \text{ Btu/lb} = 7.08 \times 10^7 \text{ Btu/hr}$$

The average specific heat of the heating stream is:

$$C_p = \frac{\dot{q}t}{\dot{m}_1 \Delta T_1} = \frac{254.892 \times 10^6 \text{ Btu/hr}}{(6{,}193{,}944) \text{ lb/hr} \ (632 - 550)°\text{F}} = 0.5 \text{ Btu/lb °F}$$

The temperature-length profile is:



$LTD_B = 82°$, $GTD_B = 142°$ ⟹ $LMTD_B = 110°$

$LTD_E = 82°$, $GTD_E = 322°$ ⟹ $LMTD_E = 180°$

The overall heat-transfer coefficient of the economizer, U_E, was assumed to be $30 \dfrac{Btu}{hr \cdot ft^2 \cdot °F}$

The economizer area, then, is:

$$A_E = \frac{\dot{q}_E}{U_E \ LMTD_E} = \frac{7.08 \times 10^7 \ Btu/hr}{30 \dfrac{Btu}{hr \cdot ft^2 \cdot °F} 180°F} = 13{,}103 \ ft^2$$

The boiler area is:

$$A_B = A_{total} - A_E = (42{,}680 - 13{,}103) \ ft^2 = 29{,}577 \ ft^2$$

The overall heat-transfer coefficient of the boiler, U_B is:

$$U_B = \frac{\dot{q}_B}{A_B \ LMTD_B} = \frac{1.84 \times 10^8 \ Btu/hr}{29{,}577 \ ft^2 \ 110°F} = 56.5 \ \frac{Btu}{hr \cdot ft^2 \cdot °F}$$

This completes the analysis of the existing exchanger.

The possibility of generating 900 PSIG steam is examined, keeping $\hat{q}_t$ constant:

From the steam tables:

900 PSIG, 535°F Steam:	h_{fg}	= 665.6 Btu/lbm
	h_{f1}	= 529.8
228°F BFW:	h_{f2}	= 196.3

The mass flow of the steam is:

$$\dot{m}_s = \frac{\dot{q}t}{h_{fg} + (h_{f1} - h_{f2})} = \frac{254.892 \times 10^6 \text{ Btu/hr}}{665.6 + 529.8 - 196.3 \text{ Btu/lbm}} = 2.55 \times 10^5 \text{ lb/hr}$$

The heat transfer in the boiler is:

$$\dot{q}_B = \dot{m}_s h_{fg} = 2.55 \times 10^5 \text{ lb/hr} \quad 665.6 \text{ Btu/lb} = 1.68 \times 10^8 \text{ Btu/hr}$$

The heat transfer in the economizer is:

$$\dot{q}_E = \dot{m}_s(h_{f1} - h_{f2}) = 2.55 \times 10^5 \text{ lb/hr } (529.8 - 196.3) \text{ Btu/lb} = 8.51 \times 10^7 \text{ Btu/hr}$$

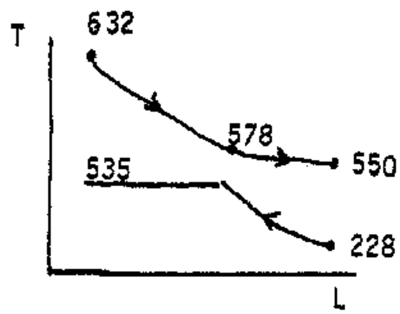
The intermediate heating stream temperature, T_{12}, is

$$T_{12} = T_{11} - \frac{\dot{q}_B}{\dot{m}_1 C_p} = 632°F - \frac{1.68 \times 10^8 \text{ Btu/hr}}{(6,193,944) \text{ lb/hr } (0.5) \text{ Btu/lb·°F}} = 578°F$$

The "pinch point" then, is:

$$\Delta T_p = T_{12} - T_{Steam} = 578° - 535° = 43°$$

The temperature length profile is:



$LTD_B = 43°$

$GTD_B = 97°$

$\Rightarrow LMTD_B = 67°$

$LTD_E = 43°$

$GTD_E = 322°$

$\Rightarrow LMTD_E = 145°$

The area of the boiler, assuming U_B is constant, is:

$$A_B = \frac{\dot{q}_B}{U_B \ LMTD_B} = \frac{1.68 \times 10^8 \ Btu/hr}{56.5 \ \frac{Btu}{hr \cdot ft^2 \cdot °F} \ 67°} = 44{,}485 \ ft^2$$

The area of the economizer is:

$$A_E = \frac{\dot{q}_E}{U_E \ LMTD_E} = \frac{8.513 \times 10^7 \ Btu/hr}{30 \ \frac{Btu}{hr \cdot ft^2 \cdot °F} \ 145°F} = 19{,}570 \ ft^2$$

The total area is:

$$A_t = A_B + A_E = 44{,}485 \ ft^2 + 19{,}570 \ ft^2 = 64{,}055 \ ft^2$$

The possibility of generating high pressure (900 PSIG) steam setting the "pinch point" at 50° is also analyzed:

Setting the "pinch point" also determines the intermediate heating stream temperature, $\ddot{T}_{12}$:

$$T_{12} = T_{Steam} + 50° = 535 + 50° = 585°F$$

The heat transfer of the boiler is found:

$$q_B = (T_{11} - T_{12}) \ \dot{m}_1 \ C_p = (632 - 585)°F \ (6.19 \times 10^6) \ \frac{lb}{hr} \ \frac{(0.5) \ Btu}{16°F} = 1.46 \times 10^8 \ \frac{Btu}{hr}$$

The mass flow of the steam is:

$$\dot{m}_s = \frac{\dot{q}_B}{h_{fg}} = \frac{1.46 \times 10^8 \text{ Btu/hr}}{665.6 \frac{\text{Btu}}{\text{lbm}}} = 2.19 \times 10^5 \text{ lb/hr}$$

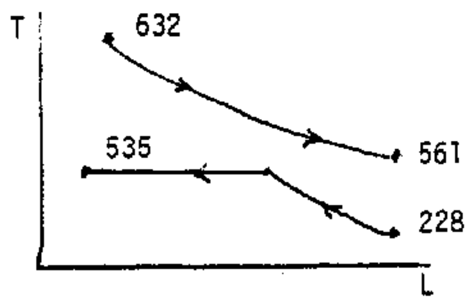
The heat transfer in the economizer is:

$$\dot{q}_E = \dot{m}_s (h_{f1} - h_{f2}) = 2.19 \times 10^5 \frac{\text{lb}}{\text{hr}} (529.8 - 196.3) \frac{\text{Btu}}{\text{lb}} = 7.3 \times 10^7 \frac{\text{Btu}}{\text{hr}}$$

The exit temperature of the heating stream, T_{13}, has changed since $\dot{q}_t$ has changed. It is:

$$T_{13} = T_{12} - \frac{\dot{q}_E}{\dot{m}_g C_p} = 585^\circ\text{F} - \frac{7.3 \times 10^7 \text{ Btu/hr}}{6{,}193{,}944 \frac{\text{lb}}{\text{hr}} 0.5 \frac{\text{Btu}}{\text{lb}\cdot{}^\circ\text{F}}} = 561.4^\circ\text{F}$$

The temperature-length profile is:



$LTD_B = 50^\circ$

$GTD_B = 97^\circ$

$\Rightarrow LMTD_B = 71^\circ$

$LTD_E = 50^\circ$

$GTD_E = 333^\circ$

$\Rightarrow LMTD_E = 155^\circ$

The boiler area is:

$$A_B = \frac{\dot{q}_B}{U_B \, LMTD_B} = \frac{1.455 \times 10^8 \text{ Btu/hr}}{56.5 \frac{\text{Btu}}{\text{hr} \cdot \text{ft}^2 \cdot {}^\circ\text{F}} 71^\circ\text{F}} = 36{,}270 \text{ ft}^2$$

The economizer area is:

$$A_E = \frac{\dot{q}_E}{U_E \, LMTD_E} = \frac{7.3 \times 10^7 \text{ Btu/hr}}{30 \dfrac{\text{Btu}}{\text{hr} \cdot \text{ft}^2 \cdot {}^\circ\text{F}} \quad 155^\circ\text{F}} = 15{,}700 \text{ ft}^2$$

The total area,then, is:

$$A_t = A_B = A_E = 36{,}270 \text{ ft}^2 + 15{,}700 \text{ ft}^2 = 51{,}970 \text{ ft}^2$$

APPENDIX B

The installed cost of the heat exchangers in $\$/ft^2$ was found from the curves on the following two pages, Figures 5 and 6.

The Ralph Parson's factored extimates were obtained from Reference 6. The quotations from John Zink were obtained from Reference 5, and were quoted as base costs. These base costs were converted to installed costs by multiplying by a factor of 2.5 for erection, piping, site-work, etc., as described in Reference 7.

The quotations from John Zink, Inc., and Ralph Parsons on heat exchangers under 10,000 ft^2 allowed the extrapolation of the curve shown with a high level of confidence. The slope of this curve was assumed to remain the same for heat exchangers over 10,000 ft^2.

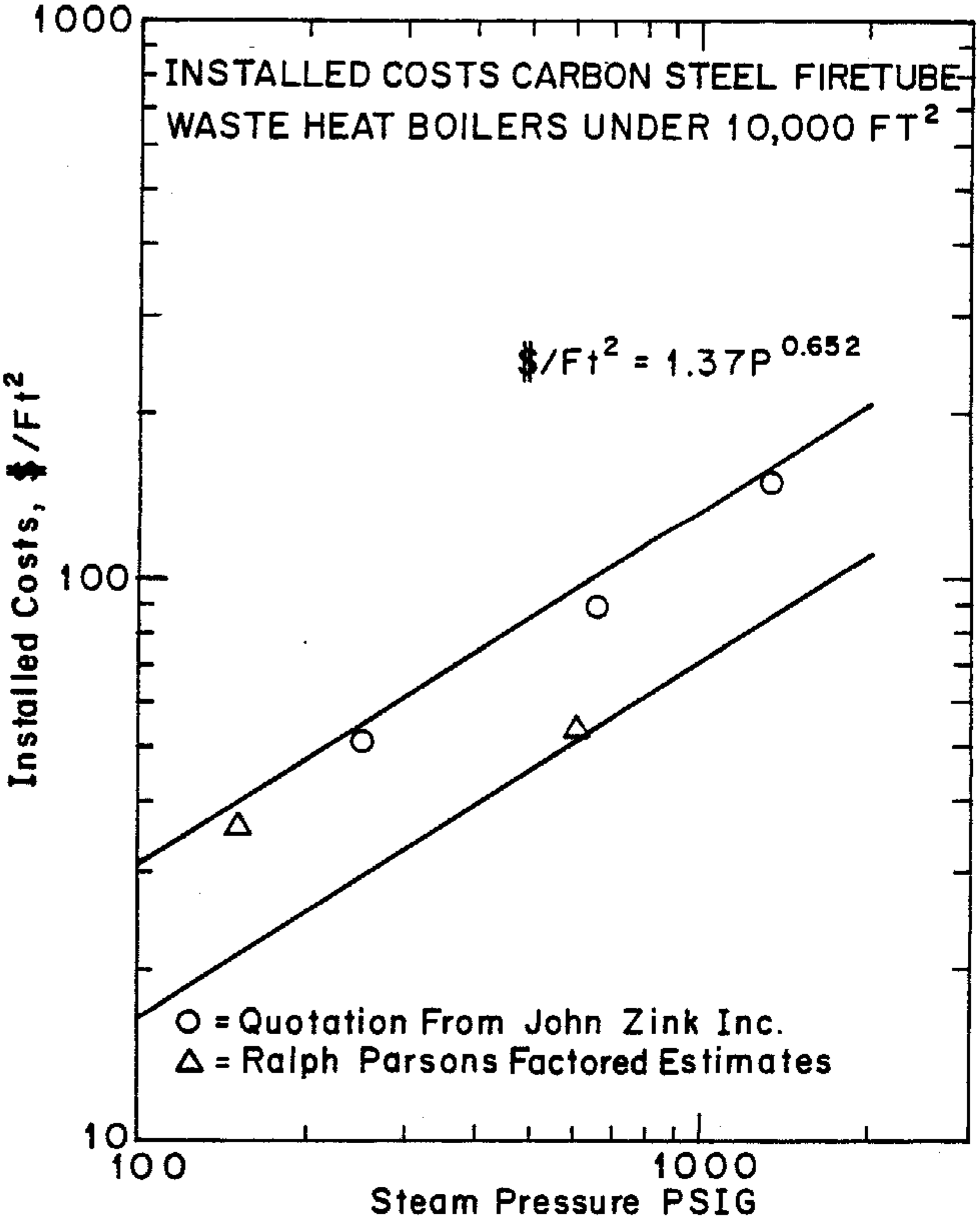

INSTALLED COSTS CARBON STEEL FIRETUBE WASTE HEAT BOILERS UNDER 10,000 FT²
$/Ft² = 1.37P^0.652
Installed Costs, $/Ft²
1000
100
10
100
1000
Steam Pressure PSIG
○ = Quotation From John Zink Inc.
△ = Ralph Parsons Factored Estimates

FIG. 5

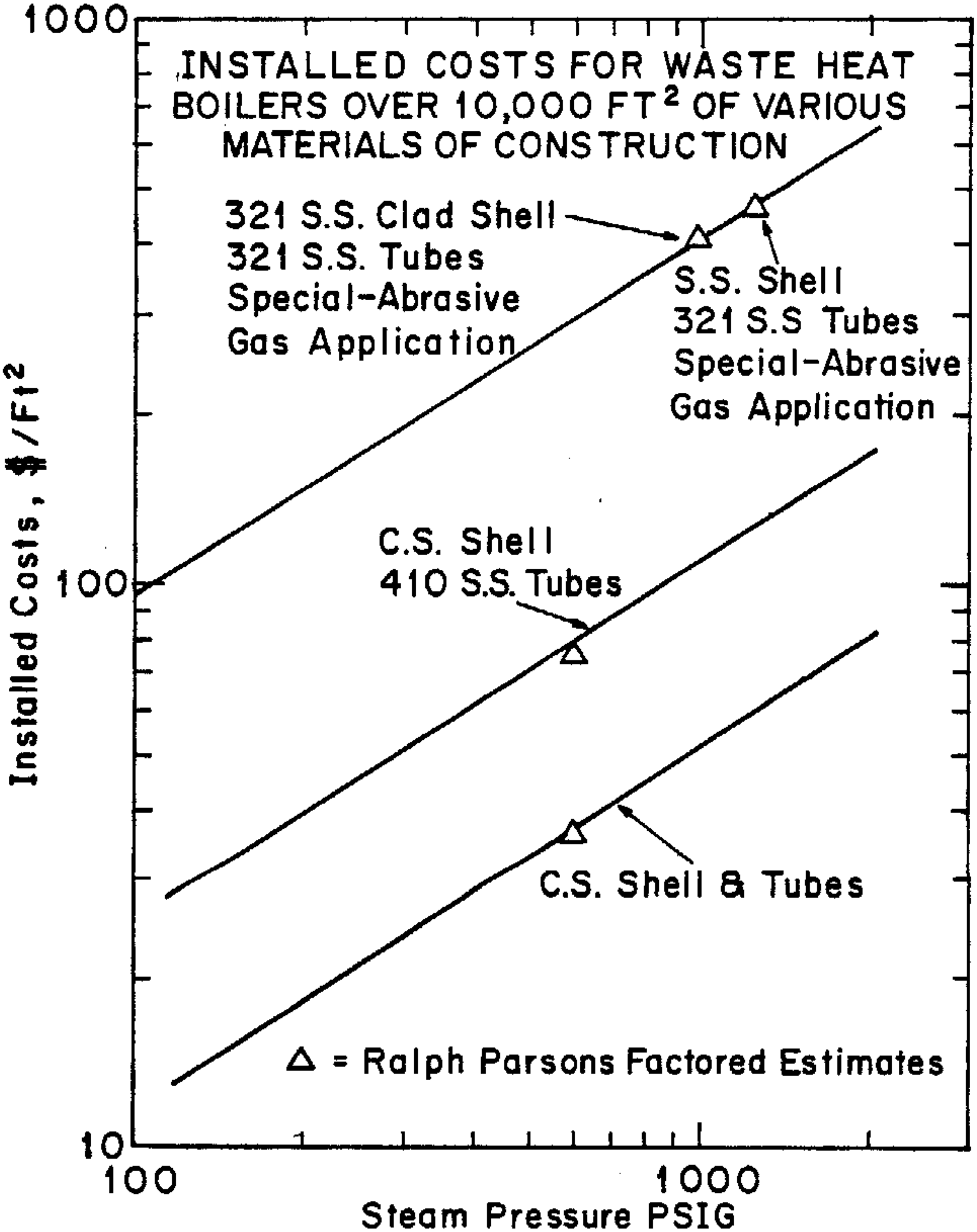

INSTALLED COSTS FOR WASTE HEAT BOILERS OVER 10,000 FT² OF VARIOUS MATERIALS OF CONSTRUCTION
321 S.S. Clad Shell
321 S.S. Tubes
Special-Abrasive
Gas Application
S.S. Shell
321 S.S Tubes
Special-Abrasive
Gas Application
C.S. Shell
410 S.S. Tubes
C.S. Shell & Tubes
△ = Ralph Parsons Factored Estimates
Installed Costs, $/Ft²
1000
100
10
100
1000
Steam Pressure PSIG

FIG. 6

APPENDIX C

The six turbines would operate under the following conditions:

Turbine	$\dot{m}$	P_{in}	P_{out}	h_1	$_1h_{25}$	N*	P	Installed cost*
	lb/hr	PSIG	PSIG	Btu/lbm	Btu/lbm	%	HP	$
1	522,340	2000	1200	1136	1100	65	4805	1,200,000
2	118,990	1500	1200	1169	1147	45	465	525,000
3	28,553	1500	600	1164	1096	50	410	250,000
4	335,977	900	600	1196	1164	45	1900	425,000
5	78,700	900	150	1196	1054	65	2755	250,000
6	14,703	900	50	1196	986	60	730	175,000

Total HP output of turbines = 11,065 HP

h_1 = enthalpy at P_{in}

$_1h_{25}$ = isentropic enthalpy at P_{out} with P_{in} reference

The output of turbine 1, for example was found to be:

$$P = \frac{\dot{m}\,(h_1 = {}_1h_{25})\eta}{2544\ \frac{Btu}{hp} - hr} = \frac{522{,}340\ (1136-1100)(.65)}{2544} = 4805\ HP$$

*The efficiencies (η) and costs were quoted by Westinghouse Canada, Ltd. (Ref. 2).