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RAW DATA-ON THE EFFECT OF ATOMIZATION VARIABLES ON HEAT TRANSFER FROM OIL FLAMES

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Canadian Combustion Research Laboratory

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by

G.N. Banks*, R. Prokopuk** and R. Fouhse***

ABSTRACT

This report compiles the raw data obtained in Phase I of the FERA project, which was commissioned to investigate what effect the lowering of steam consumption has on the operation of a steam-atomized oil burner. Since this information was required as soon as possible by the Combustion Sub-Committee of the Ferrous Energy Research Association, no attempt has been made to interpret the results and the data compiled in the ninteen tables was not typewritten in the original report submitted to the Sub-Committee.

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INTRODUCTION

This project was commissioned by the Canadian Sub-Committee of the Ferrous Energy Research Association (FERA). The work was performed at the Energy Research Laboratories during June and July, 1979, under CANMET Project No. 332106-03 (Job No. 024358), using the Canadian Combustion Research Laboratory (CCRL) tunnel furnace. For the purpose of this investigation, the CCRL tunnel furnace was equipped with an industrial full-emulsion atomizer burner, provided by FERA, and the furnace wall was lined with 2 in. refractory brick, leaving a 15 in. unlined sector along the length of the wall.

The objective of this investigation was to demonstrate the effect of lowering the steam consumption in steam-atomized oil burners from the current industrial use of about 1 kg of steam per kg of oil to about 0.5 kg of steam or lower per kg of oil. This reduction in steam consumption must not produce unacceptable changes in heat transfer distribution or increases in atmospheric pollutant emissions. If this can be accomplished it would represent a saving of about one million dollars to a plant presently consuming about 200×10^6 gallons of oil per year at the current steam to oil weight ratio of 1/1.

EXPERIMENTAL PROCEDURE

The variables investigated during this phase of the FERA project were:

1. Varying the steam/oil weight ratio by maintaining a constant oil flame rate at a constant temperature and varying the steam flow rate at a constant temperature input. Investigation of this variable, while operating the burner according to the manufacturer's specification, produced an unstable flame with an oscillating flame front. These results were labelled "unanchored" flame. A stable flame, regarded as being of industrial quality, was then maintained in the system through the introduction of an oxy-acetylene pilot-flame and the investigation of the steam/oil weight ratio variable was repeated. This modification of burner operation, which introduced less than 1% of the total thermal input, was maintained throughout the investigation of the other variables.

2. Varying the oil feed input temperature at a constant oil flow rate and steam/oil weight ratio input levels of 0.30 and 0.20.

3. Varying the input temperature of the superheated steam at a constant oil feed rate and temperature with steam/oil weight ratio input levels of 0.30 and 0.20

4. Varying the size of the burner tip nozzle, while maintaining the other variables constant at steam/oil weight ratio input level of 0.30.

5. Varying the size of the steam inlet orifice, while maintaining the other variables constant at a steam/oil weight ratio input level of 0.30.

The data accumulated for the above variables involved a total of 24 test flames (plus 6 unanchored flames and an additional anchored flame). Each test flame was operated for approximately two hours duration. This data is listed under input variables, output variables and heat transfer, for each of the basic variables investigated, in Tables 2-19.

Table 1 - Analyses of No. 6 fuel oil (average of 6 samples)

	Min	Max	Average
Specific gravity (60/60°F)	0.997	1.000	1.000
API at 60°F	10.00	10.43	10.08
Carbon (%)	86.30	86.50	86.40
Hydrogen (%)	10.19	10.41	10.31
Sulphur (%)	2.52	2.81	2.67
Nitrogen (%)	0.42	0.51	0.46
H_2O (%)	<0.01	<0.01	<0.01
Ash (%)	0.046	0.050	0.049
Flash point (°F)	225	240	231
Viscosity at 122°F (cSt)	419.6	485.5	450.8
Pour point (°F)	40	45	41
Heat of combustion (Btu/lb) (corrected for Sulphur)	17,980	18,205	18,135

Table 2 - Varying steam/oil ratio (unanchored flame)

Input variables

Flame No.		4B	3	2	1	4A	5
Date		28/6/79	27/6/79	27/6/79	26/6/79	28/6/79	29/6/79
Oil							
Flow	(kg/h)	37.9	37.8	37.9	37.6	37.7	38.2
Temperature	(°C)	84	83	83	82	83	82
Pressure	(psig)	23	23	29	34	47	55
Steam (saturated)							
Flow	(lb/h)	6.0	9.7	17.0	24.5	34.0	42.0
Temperature	(°C)	167	165	166	166	167	165
Pressure	(psig)	94	90	91	90	93	89
Flow (acfh at F.G. Temp)		430	750	1275	1830	2660	3125
Ratio (steam/oil)	(kg/kg)	0.07	0.12	0.20	0.30	0.41	0.50
Steam (superheated)							
Temperature	(°C)	182	178	182	182	182	183
Pressure	(psig)	4.5	6.0	21	36	55	69
Degrees of superheat	(°C)	73	68	55	37	32	27
Combustion Air							
Temperature	(°C)	175	180	180	175	175	180
Line pressure	(in. of H_2O)	19.2	18.8	19.1	19.5	19.9	18.5
Flow							
acfh (at comb. temp)		26,640	26,550	27,120	26,400	26,040	27,140
acfh (at F.G. temp)		56,590	59,650	61,700	60,400	60,000	61,280
Burner hardware							
Oil orifice no.		10	10	10	10	10	10
Steam orifice no.		10	10	10	10	10	10
Burner tip no.		10	10	10	10	10	10

Table 3 - Varying steam/oil ratio (unanchored flame)

Output variables

Flame No.	4B	3	2	1	4A	5
Date	28/6/79	27/6/79	27/6/79	26/6/79	28/6/79	29/6/79
Mixing chamber						
Temperature (°C)	100	102	113	123	133	139
Pressure (psig)	1	3	11	17	29	39
Internal flame temperature						
1 metre location (°C)	750	1210	1485	1539	1548	1580
2 metre location (°C)	1090	1224	1367	1346	1429	1360
Total incident radiation						
1 metre loc. ($Btu/ft^2/h$)	25,520	27,000	27,440	25,780	22,735	19,600
Total heat flux						
2 metre loc. (Btu/ft /h)	48,340	50,950	60,130	57,270	51,390	43,500
Flue gas						
Temperature (°C)	720	745	755	750	755	750
Flow (acfh at F.G. temp)	51,630	63,080	65,280	65,910	51,630	60,600
Soot (% of carbon input)	1.21	0.20	0.41	0.23	0.26	0.37
SO_2 (ppm)	1330	1290	1250	1125	1320	1295
SO_3 (ppm)	27	33	36	43	31	36
NO (ppm)	130	170	235	290	320	400
CO_2 (%)	13.0	12.8	13.0	12.6	12.0	12.7
H_2O (%)	8.0	8.5	11.0	7.0	11.0	12.0
O_2 (%)	2.2	2.0	2.0	1.8	2.0	2.0
Visuals on flame appearance						
Stability	←		Unstable			→
Flame length (metres)	2	2	2-2.5	2	>2.4	1.5-2.0
Flame dia. (metres)	0.25	0.4-0.5	0.5-0.6	0.25-0.3	>0.5	0.25-0.3
Comments	←		Oil carry-over from all flames			→

Table 4 - Varying steam/oil ratio (unanchored flame)

Heat transfer

Flame No.		4B	3	2	1	4A	5
Date		28/6/79	27/6/79	27/6/79	26/6/79	28/6/79	29/6/79
Heat to cooling plates (Btu/h)							
Plate area = 5 ft^2	1	6,575	9,625	8,385	9,625	8,670	9,245
	2	11,530	15,625	16,105	13,341	16,200	17,245
	3	10,240	16,960	17,725	17,438	17,055	17,820
	4	13,150	20,105	20,295	21,955	20,010	20,585
Circuit A	5	14,865	21,155	21,345	26,586	20,965	21,630
Plates 1 to 10	6	18,390	25,155	24,965	26,300	23,345	24,300
	7	24,585	31,730	29,825	31,350	27,730	29,655
	8	22,775	29,920	28,300	30,300	26,205	28,300
	9	26,965	33,925	31,825	30,015	29,540	30,495
	10	27,160	34,210	33,445	33,350	30,780	29,920
Total		176,240	238,410	232,215	240,260	220,500	229,195
	11	23,095	28,235	28,635	28,770	26,300	27,165
	12	22,895	27,165	28,370	28,170	26,965	27,435
	13	25,430	26,965	27,570	28,235	27,370	27,900
	14	21,425	22,360	23,430	26,435	23,030	23,895
Circuit B	15	24,900	25,230	26,965	26,235	26,700	27,300
Plates 11 to 20	16	22,960	22,295	23,495	23,095	23,765	23,895
	17	24,030	23,365	23,830	21,130	24,165	24,700
	18	19,890	18,625	19,025	18,690	18,890	19,760
	19	23,160	20,425	20,560	18,825	21,360	21,360
	20	19,890	16,420	16,285	16,355	17,690	17,555
Total		227,675	231,085	238,165	235,940	236,235	240,965
	21	18,125	16,305	16,345	16,870	17,030	17,110
	22	16,790	13,835	14,200	14,320	15,170	15,090
Circuit C	23	18,285	16,100	16,180	16,140	16,910	17,515
Plates 21 to 27	24	15,375	12,905	13,755	13,310	13,835	13,835
	25	15,415	12,705	13,105	13,310	14,765	14,605
	26	14,485	12,155	12,260	11,610	13,430	12,945
	27	13,955	11,815	12,135	11,855	12,580	12,745
Total		112,430	95,820	97,980	97,415	103,720	103,845
Total heat to plates (Btu/h)		516,345	565,315	568,360	573,615	560,455	574,005
Total area (ft^2)		135	135	135	135	135	135
Average - (Btu/ft^2/h)		3,825	4,188	4,210	4,249	4,152	4,252

Table 5 - Varying steam/oil ratio (anchored flame)

Input variables

Flame No.	4B	3	2 (base)	1 (base)	4A	5
Date	6/7/79	5/7/79	6/7/79	10/7/79	10/7/79	5/7/79
Oil						
Flow (kg/h)	37.7	38.2	37.6	37.6	37.3	37.6
Temperature (°C)	82	82	85	82	82	83
Pressure (psig)	24	25	29	37	46	55
Steam (saturated)						
Flow (lb/h)	5.2	10.0	17.0	25.0	33.0	42.0
Temperature (°C)	167	165	167	166	166	167
Pressure (psig)	93	90	92	90	91	91
Flow (acfh at F.G. temp)	375	735	1240	1830	2410	3130
Ratio (steam/oil) (kg/kg)	0.06	0.12	0.21	0.30	0.40	0.51
Steam (superheated)						
Temperature (°C)	185	183	184	182	182	182
Pressure (psig)	3	8	22	35	53	69
Degrees of superheat (°C)	84	70	56	43	33	25
Combustion air						
Temperature (°C)	166	168	163	163	160	167
Line pressure (in. of H_2O)	20.5	20.2	20.5	19.2	19.7	20.2
Flow						
acfh (at comb. temp)	25,280	25,385	25,750	26,510	25,950	25,845
acfh (at F.G. temp)	57,150	58,030	58,790	60,975	61,420	60,035
Burner hardware						
Oil orifice no.	10	10	10	10	10	10
Steam orifice no.	10	10	10	10	10	10
Burner tip no.	10	10	10	10	10	10

Table 6 - Varying steam/oil ratio (anchored flame)

Output variables

Flame No.	4B	3 (base)	2 (base)	1	4A	5
Date	6/7/79	5/7/79	6/7/79	10/7/79	10/7/79	5/7/79
Mixing chamber						
Temperature (°C)	100	103	114	123	133	140
Pressure (psig)	1	7	12	18	29	39
Internal flame temperature						
1 metre location (°C)	790	1230	1319	1342	1375	1344
2 metre location (°C)	979	1170	1169	1169	1188	1201
Total incident radiation						
1 metre loc. ($Btu/ft^2/h$)	15,245	24,040	24,040	24,400	21,600	22,035
Total heat flux						
2 metre loc. ($Btu/ft^2/h$)	49,210	50,780	47,905	49,210	48,430	48,340
Flue gas						
Temperature (°C)	720	735	725	730	730	750
Flow (acfh at F.G. temp)	52,000	59,615	57,260	57,190	57,090	62,575
Soot (% of carbon input)	3.25	0.22	0.24	0.22	0.18	0.32
SO_2 (ppm)	980	1310	1375	1370	1440	1390
SO_3 (ppm)	25	33	30	25	11	29
NO (ppm)	100	-	240	260	310	400
CO_2 (%)	10.4	13.9	12.8	13.6	13.9	14.0
H_2O (%)	7.5	7.5	8.0	8.5	12.0	11.0
O_2 (%)	4.3	2.0	2.0	2.0	2.0	1.8
Visuals on flame appearance						
Stability	Unstable	← Stable →				
Flame length (metres)	>3	2.4	2.4	2.1	2.3	2.3
Flame dia. (metres)	>0.5	0.2-0.5	0.2-0.4	0.2	0.2	0.2
Comments	Black smoke from stack	Some black smoke from stack	← Smokey flame tips →		← Clean hard flame →	

Table 7 - Varying steam/oil ratio (anchored flame)

Heat Transfer

Flame No.		4B	3	2 (base)	1 (base)	4A	5
Date		6/7/79	5/7/79	6/7/79	10/7/79	10/7/79	5/7/79
Heat to cooling plates (BTU/H) Plate area = 5 ft^2	1	6,765	11,055	13,055	11,815	11,530	10,480
	2	13,720	19,440	21,250	18,770	17,245	17,630
	3	17,150	21,510	23,155	-	-	18,965
Circuit A	4	17,150	24,490	26,395	22,775	21,440	21,920
Plates 1 to 10	5	19,354	25,635	27,350	25,345	23,630	22,105
	6	24,775	27,445	28,585	26,205	24,775	23,725
	7	25,060	30,400	30,300	29,065	28,780	27,635
	8	25,350	29,350	30,015	27,730	26,870	26,490
	9	25,350	28,110	29,920	29,345	27,635	28,395
	10	24,395	27,255	28,780	28,110	27,060	28,970
Total		199,069	244,690	258,805	219,160	208,965	226,315
	11	21,895	23,565	25,230	25,230	24,700	26,030
	12	21,225	22,695	24,230	24,365	24,365	26,365
	13	24,165	24,700	25,630	25,365	25,565	26,965
	14	18,690	19,825	20,555	21,225	21,160	23,095
Circuit B	15	-	-	-	-	-	24,700
Plates 11 to 20	16	20,625	20,760	21,695	21,625	22,495	24,700
	17	21,360	21,960	21,295	22,095	23,030	24,630
	18	19,690	18,025	18,155	17,555	19,225	19,825
	19	18,755	19,490	18,255	18,755	19,425	22,030
	20	17,355	16,020	15,420	15,755	16,755	18,425
Total		173,760	187,040	190,435	191,970	196,720	236,765
	21	17,800	16,990	15,695	15,775	15,070	18,245
	22	15,050	14,565	13,270	14,035	14,440	16,425
Circuit C	23	18,165	15,940	15,090	15,775	12,295	18,125
Plates 21 to 27	24	14,970	14,000	12,540	12,590	13,715	14,400
	25	14,845	13,755	12,300	13,470	13,750	15,170
	26	13,755	12,745	11,730	12,420	12,420	14,080
	27	13,190	11,730	11,285	11,530	11,850	13,310
Total		107,775	99,725	91,910	95,595	95,540	109,755
Total heat to plates (Btu/h)		480,604	531,455	541,150	506,725	501,225	572,835
Total area (ft^2)		130	130	130	125	125	135
Average - (Btu/ft^2/h)		3,697	4,088	4,163	4,054	4,010	4,243

Table 8 - Varying oil feed temperature

Input variables

Flame no.		6	7	8	9	10
Date		11/7/79	11/7/79	11/7/79	12/7/79	12/7/79
Oil						
Flow	(kg/h)	37.7	37.4	37.2	37.8	37.8
Temperature	(°C)	78	94	105	77	104
Pressure	(psig)	39	35	34	32	36
Steam (saturated)						
Flow	(lb/h)	25	25	25	17	17
Temperature	(°C)	166	165	165	168	163
Pressure	(psig)	91	89	88	97	96
Flow (acfh at F.G. temp)		1835	1830	1830	1245	1230
Ratio (steam/oil)	(kg/kg)	0.30	0.30	0.31	0.20	0.20
Steam (superheated)						
Temperature	(°C)	182	183	184	183	180
Pressure	(psig)	37	37	37	22	22
Degrees of superheat	(°C)	42	44	45	55	52
Combustion air						
Temperature	(°C)	163	164	164	178	177
Line pressure (in. of H_2O)		19.7	19.5	19.2	19.3	19.0
Flow						
acfh (at comb. temp)		26,230	26,260	26,720	25,705	26,640
acfh (at F.G. temp)		60,645	60,260	61,320	57,330	58,800
Burner hardware						
Oil orifice no.		10	10	10	10	10
Steam orifice no.		10	10	10	10	10
Burner tip no.		10	10	10	10	10

Table 9 - Varying oil feed temperature

Output variables

Flame no.		6	7	8	9	10
Date		11/7/79	11/7/79	11/7/79	12/7/79	12/7/79
Mixing chamber						
Temperature	(°C)	124	125	126	112	115
Pressure	(psig)	19	19	19	10	11
Internal flame temperature						
1 metre location	(°C)	1370	1370	1380	1325	1330
2 metre location	(°C)	1200	1216	1205	1197	1185
Total incident radiation						
1 metre loc.	($Btu/ft^2/h$)	25,260	21,600	24,215	28,395	22,820
Total heat flux						
2 metre loc.	($Btu/ft^2/h$)	48,340	47,555	45,030	49,560	51,130
Flue gas						
Temperature	(°C)	735	730	730	730	730
Flow	(acfh at F.G. temp)	59,885	59,575	59,735	54,675	59,490
Soot	(% of carbon input)	0.28	0.31	0.31	0.17	0.22
SO_2	(ppm)	1390	1370	1300	1380	1385
SO_3	(ppm)	10	20	20	20	20
NO	(ppm)	190	190	220	160	200
CO_2	(%)	13.6	14.0	13.6	13.4	13.5
H_2O	(%)	10.0	9.0	9.0	9.0	9.0
O_2	(%)	2.0	2.0	2.1	2.1	2.0
Visuals on flame appearance						
Stability		← Stable →				
Flame length	(metres)	2.1	1.8	1.8	>3.0	>3.0
Flame dia.	(metres)	0.3	0.3	0.3	0.5	0.5
Comments		← Some sparklers & oil droplets impinging on fce walls →			← Smokey flame large sparklers →	

Table 10 - Varying oil feed temperature

Heat transfer

Flame no.		6	7	8	9	10
Date		11/7/79	11/7/79	11/7/79	12/7/79	12/7/79
Heat to cooling plates (Btu/h) Plate area = 5 ft^2	1	12,960	11,150	11,530	12,390	11,910
	2	18,485	18,295	18,865	21,060	20,200
	3	-	-	-	22,205	23,060
Circuit A	4	22,680	22,870	23,060	24,585	25,440
Plates 1 to 10	5	25,540	24,775	25,155	27,920	28,780
	6	26,110	25,540	25,635	28,395	29,445
	7	28,780	30,015	27,920	-	31,445
	8	27,350	27,255	27,445	28,780	30,015
	9	28,780	29,160	28,490	30,495	30,590
	10	28,680	28,395	28,015	28,205	28,585
Total		219,365	217,455	216,115	224,035	259,470
	11	26,500	26,165	26,300	25,350	26,100
	12	26,365	25,965	25,830	25,500	25,900
	13	27,235	27,370	27,035	26,765	17,835
	14	21,960	21,825	21,695	21,625	21,625
Circuit B	15	-	-	-	-	-
Plates 11 to 20	16	23,430	23,430	23,030	22,230	22,830
	17	23,095	23,160	23,230	22,630	22,960
	18	20,425	19,225	18,755	17,955	18,490
	19	19,360	19,155	19,960	18,755	18,425
	20	16,755	16,285	16,555	15,550	15,220
Total		205,125	202,580	202,390	196,360	189,385
	21	17,030	16,545	16,545	16,060	15,695
	22	14,685	14,200	14,200	14,080	14,040
Circuit C	23	16,140	16,020	15,900	13,270	15,370
Plates 21 to 27	24	12,905	12,945	13,270	12,380	12,420
	25	12,865	12,500	12,175	12,420	12,620
	26	12,215	11,855	11,770	11,125	11,410
	27	11,570	11,770	12,015	11,125	11,245
Total		97,410	95,835	95,875	90,460	92,800
Total heat to plates (Btu/h)		521,900	515,870	514,380	510,855	541,655
Total area (ft^2)		125	125	125	125	130
Average - (Btu/ft^2/h)		4,175	4,127	4,115	4,087	4,167

Table 11 - Varying steam temperature

Input variables

Flame No.	11	12	13	14	15	16
Date	12/7/79	13/7/79	13/7/79	16/7/79	16/7/79	16/7/79
Oil						
Flow (kg/h)	37.5	37.3	37.6	37.6	37.6	38.0
Temperature (°C)	83	82	82	82	82	82
Pressure (psig)	38	39	39	29	30	31
Steam (saturated)						
Flow (lb/h)	25	25	25	17	17	17
Temperature (°C)	166	166	165	165	166	167
Pressure (psig)	91	91	87	88	91	89
Flow (acfh at F.G. temp)	1810	1810	1810	1210	1230	1205
Ratio (steam/oil) (kg/kg)	0.30	0.30	0.30	0.21	0.21	0.20
Steam (superheated)						
Temperature (°C)	205	234	261	205	232	261
Pressure (psig)	38	40	40	29	30	31
Degrees of superheat (°C)	65	92	119	73	103	130
Combustion air						
Temperature (°C)	175	175	176	172	173	172
Line pressure (in. of H_2O)	19.2	19.3	19.0	20.0	19.0	19.0
Flow						
acfh (at comb. temp)	25,620	28,245	26,855	25,045	26,975	26,970
acfh (at F.G. temp)	56,860	59,625	59,352	55,785	60,140	58,915
Burner hardware						
Oil orifice no.	10	10	10	10	10	10
Steam orifice no.	10	10	10	10	10	10
Burner tip no.	10	10	10	10	10	10

Table 12 - Varying steam temperature

Output variables

Flame No.	11	12	13	14	15	16
Date	12/7/79	13/7/79	13/7/79	16/7/79	16/7/79	16/7/79
Mixing chamber						
Temperature (°C)	126	127	128	114	115	116
Pressure (psig)	19	20	20	10	11	11
Internal flame temperature						
1 metre location (°C)	1379	1354	1372	1312	1297	1302
2 metre location (°C)	1210	1203	1197	1175	1160	1168
Total incident radiation						
1 metre loc. ($Btu/ft^2/h$)	25,260	22,735	24,390	25,345	25,695	25,435
Total heat flux						
2 metre loc. ($Btu/ft^2/h$)	49,995	47,905	52,695	51,040	49,820	47,990
Flue gas						
Temperature (°C)	722	720	720	705	720	700
Flow (acfh at F.G. temp)	57,055	61,805	56,860	56,255	54,085	56,070
Soot (% of carbon input)	0.27	0.33	0.30	0.27	0.23	0.24
SO_2 (ppm)	1430	1360	1360	1490	1360	1300
SO_3 (ppm)	20	35	30	20	30	30
NO (ppm)	240	310	380	175	205	175
CO_2 (%)	13.4	14.0	14.0	14.2	14.1	14.3
H_2O (%)	11.0	9.0	10.0	10.0	9.0	10.0
O_2 (%)	2.0	2.0	1.9	2.0	2.0	1.9
Visuals on flame appearance						
Stability	← Stable →					
Flame length (metres)	3.0	2.5	2.5	2.5	2.5	2.5
Flame dia. (metres)	0.5	0.4	0.4	0.5	0.5	0.5
Comments	← Clean hard flame Small sparklers →			Larger sparklers Smokey Tips	Not as smokey Smaller ← sparklers →	
				Appears to be carbon ← Burning on fce bottom →		

Table 13 - Varying steam Temperature

Heat Transfer

Flame No.		11	12	13	14	15	16
Date		12/7/79	13/7/79	13/7/79	16/7/79	16/7/79	16/7/79
Heat to cooling plates (Btu/h)							
Plate area = 5 ft^2	1	10,960	11,815	10,770	12,195	13,340	20,290
	2	19,155	19,060	18,965	20,775	21,060	20,965
	3	21,535	21,345	20,585	22,395	22,490	22,585
Circuit A	4	23,440	23,345	22,680	24,680	25,345	25,250
Plates 1 to 10	5	26,150	26,585	23,820	26,775	25,730	27,160
	6	26,680	28,205	26,490	28,585	26,870	27,920
	7	29,065	29,350	28,680	31,155	31,165	30,780
	8	28,300	28,110	27,060	29,445	29,160	28,970
	9	30,780	29,540	26,965	30,780	29,445	30,015
	10	29,160	29,445	28,970	30,495	30,300	30,300
Total		245,225	246,800	234,985	257,280	255,375	256,235
	11	26,700	26,565	26,500	27,570	27,100	27,570
	12	27,100	26,365	25,965	26,300	26,765	26,965
	13	27,700	26,765	26,435	26,435	26,435	26,635
	14	22,430	22,630	22,095	21,825	21,495	22,095
Circuit B	15	-	-	-	-	-	-
Plates 11 to 20	16	23,365	22,295	22,495	21,560	21,360	22,560
	17	23,630	23,160	15,755	21,695	22,495	22,360
	18	19,290	18,825	19,490	18,020	18,555	17,755
	19	19,890	19,090	20,090	18,355	18,425	18,755
	20	15,755	16,220	16,420	15,285	15,685	15,955
Total		205,860	201,915	195,245	197,045	198,315	200,650
	21	16,790	15,940	16,060	13,160	15,495	15,415
	22	14,485	13,915	14,440	13,230	13,310	13,635
Circuit C	23	-	15,535	15,735	14,565	14,605	14,605
Plates 21 to 27	24	13,550	12,500	12,905	11,650	12,055	11,895
	25	12,945	12,215	13,105	11,370	11,935	11,770
	26	11,450	11,935	12,540	11,085	11,165	11,165
	27	11,165	11,125	10,720	10,315	10,435	10,230
Total		80,385	93,165	95,505	85,375	89,000	88,720
Total heat to plates (Btu/h)		531,470	541,880	525,735	539,700	542,690	545,605
Total area (ft^2)		125	130	130	130	130	130
Average - (Btu/ft^2/h)		4,252	4,168	4,044	4,152	4,175	4,197

Table 14 - Varying burner tip size

Input variables

Flame No.	17	18	19	22	23	24
Date	19/7/79	20/7/79	19/7/79	18/7/79	20/7/79	19/7/79
Oil						
Flow (kg/h)	37.6	38.0	36.9	37.5	38.2	37.7
Temperature (°C)	82	81	82	83	81	82
Pressure (psig)	37	29	63	29	25	47
Steam (saturated)						
Flow (lb/h)	25	25	25	17	17	17
Temperature (°C)	165	167	165	165	165	165
Pressure (psig)	89	93	89	91	94	90
Flow (acfh at F.G. temp)	1875	1875	1865	1250	1250	1260
Ratio (steam/oil) (kg/kg)	0.30	0.30	0.31	0.21	0.20	0.20
Steam (superheated)						
Temperature (°C)	183	182	183	183	182	182
Pressure (psig)	38	36	57	21	19	35
Degrees of superheat (°C)	43	43	32	55	52	40
Combustion air						
Temperature (°C)	175	172	177	173	174	175
Line pressure (in. of H_2O)	20.2	20.2	21.0	20.2	20.0	20.2
Flow						
acfh (at comb. temp)	25,575	26,455	24,630	25,515	26,035	26,065
acfh (at F.G. temp)	58,630	61,055	55,935	57,665	58,700	59,200
Burner hardware						
Oil orifice no.	10	10	10	10	10	10
Steam orifice no.	10	10	10	10	10	10
Burner tip no.	10	15	5	10	15	5

Table 15 - Varying burner tip size

Output variables

Flame No.	17 (base)	18	19	22 (base)	23	24
Date	19/7/79	20/7/79	19/7/79	18/7/79	20/7/79	19/7/79
Mixing chamber						
Temperature (°C)	125	115	144	114	106	131
Pressure (psig)	19	10	47	7	5	29
Internal flame temperature						
1 metre location (°C)	1349	1370	1337	1347	1329	1327
2 metre location (°C)	1218	1223	1183	1199	1204	1182
Total incident radiation						
1 metre loc. (Btu/ft^2/h)	21,775	23,300	21,425	21,775	24,215	23,255
Total heat flux						
2 metre loc. (Btu/ft^2/h)	46,860	47,730	50,865	49,035	51,300	47,645
Flue gas						
Temperature (°C)	755	755	750	735	735	745
Flow (acfh at F.G. temp)	65,095	59,705	62,245	59,510	61,895	62,200
Soot (% of carbon input)	0.33	0.31	0.22	0.25	0.29	0.22
SO_2 (ppm)	1350	1400	1375	1310	1330	1380
SO_3 (ppm)	25	25	25	30	30	30
NO (ppm)	260	240	195	200	190	200
CO_2 (%)	14.0	14.2	14.4	14.3	14.2	14.4
H_2O (%)	10.0	10.0	10.0	8.0	9.0	9.0
O_2 (%)	2.0	2.1	2.2	2.0	2.1	2.2
Visuals on flame appearance						
Stability	← Stable →			Unstable	← Stable →	
Flame length (metres)	2.1	2.5	2.5	2.5	3.0	2.5
Flame dia. (metres)	0.5	0.3	0.3	0.5	0.3	0.3
Comments	Reasonably hard flame			Dirtier flame		Smokey tips
	← Small sparklers →			← Larger sparklers →		Some sparklers pulsing
	Some Smokey tips →					
		← Pulsing →				
		Carbon burning on bottom				

Table 16 - Varying burner tip size

Heat Transfer

Flame No.		17 (base)	18	19	22 (base)	23	24
Date		19/7/79	20/7/79	19/7/79	18/7/79	20/7/79	19/7/79
Heat to cooling plates (Btu/h) Plate area = 5 ft^2	1	10,575	11,340	11,150	10,480	11,340	11,530
	2	18,675	19,155	18,965	20,010	20,870	21,150
	3	21,345	21,060	20,965	21,535	23,630	22,105
Circuit A	4	24,110	23,440	22,105	23,630	25,635	24,110
Plates 1 to 10	5	24,870	24,490	23,155	25,825	26,135	24,965
	6	25,825	25,730	25,440	27,730	28,205	26,395
	7	29,445	29,065	28,205	31,445	31,445	29,920
	8	28,015	27,635	26,870	29,345	30,300	28,475
	9	27,255	27,060	28,395	29,825	30,590	29,160
	10	28,970	29,255	28,680	30,400	30,875	30,400
Total		239,085	238,330	233,930	250,225	259,025	248,210
	11	25,700	25,700	26,635	27,770	27,435	27,235
	12	25,430	25,365	27,235	26,765	26,300	26,835
	13	26,235	26,030	27,700	27,035	26,835	27,500
	14	22,360	22,630	23,895	22,230	22,560	22,960
Circuit B	15	-	-	-	-	-	-
Plates 11 to 20	16	22,030	21,295	23,695	22,360	21,295	22,895
	17	22,960	22,895	24,430	22,430	22,560	23,230
	18	19,690	19,095	20,425	17,690	18,290	19,625
	19	20,090	19,360	20,360	18,955	19,155	19,490
	20	18,355	17,420	18,355	16,285	22,685	17,155
Total		202,850	199,790	212,730	201,520	207,125	206,925
	21	16,790	16,506	17,475	15,655	15,940	16,345
	22	15,090	15,090	15,415	14,240	13,715	14,400
Circuit C	23	16,545	15,900	16,950	15,090	15,050	15,940
Plates 21 to 27	24	13,675	13,470	13,835	12,420	12,340	13,190
	25	13,470	13,065	13,955	12,580	12,500	13,715
	26	12,660	12,540	12,705	11,125	11,690	12,260
	27	12,095	11,935	12,135	11,165	11,205	11,650
Total		100,325	98,560	102,470	92,275	92,440	97,540
Total heat to plates (Btu/h)		542,260	536,580	549,130	544,020	558,590	552,675
Total area (ft^2)		130	130	130	130	130	130
Average - ($Btu/ft^2/h$)		4,171	4,128	4,224	4,185	4,297	4,251

Table 17 - Varying steam orifice size

Input variables

Flame No.		17	20	21
Date		19/7/79	18/7/79	18/7/79
Oil				
Flow	(kg/h)	37.6	37.5	37.5
Temperature	(°C)	82	84	82
Pressure	(psig)	37	37	38
Steam (saturated)				
Flow	(lb/h)	25	25	25
Temperature	(°C)	165	166	166
Pressure	(psig)	89	89	92
Flow	(acfh at F.G. temp)	1875	1873	1883
Ratio (steam/oil)	(kg/kg)	0.30	0.30	0.30
Steam (superheated)				
Temperature	(°C)	183	182	182
Pressure	(psig)	30	80	27
Degrees of superheat	(°C)	43	20	50
Combustion air				
Temperature	(°C)	183	182	182
Line pressure	(in. of H_2O)	20.2	21.2	22.0
Flow				
acfh (at comb. temp)		25,575	24,444	21,185
acfh (at F.G. temp)		58,630	56,700	49,255
Burner hardware				
Oil orifice no.		10	10	10
Steam orifice no.		10	5	15
Burner tip no.		10	10	10

Table 18 - Varying steam orifice size

Output variables

Flame No.	17 (base)	20	21
Date	19/7/79	18/7/79	18/7/79
Mixing chamber			
Temperature (°C)	126	123	125
Pressure (psig)	19	18	19
Internal flame temperature			
1 metre location (°C)	1349	1389	1379
2 metre location (°C)	1218	1224	1196
Total incident radiation			
1 metre loc. ($Btu/ft^2/h$)	21,775	24,390	23,865
Total heat flux			
2 metre loc. ($Btu/ft^2/h$)	46,860	47,905	53,565
Flue gas			
Temperature (°C)	755	755	760
Flow (acfh at F.G. temp)	65,095	60,160	55,150
Soot (% of carbon input)	0.33	0.37	0.22
SO_2 (ppm)	1350	1490	1360
SO_3 (ppm)	25	15	30
NO (ppm)	260	270	210
CO_2 (%)	14.0	14.2	13.6
H_2O (%)	10.0	9.0	9.0
O_2 (%)	2.0	1.0	2.4
Visuals on flame appearance			
Stability	Stable	← Unstable →	
Flame length (metres)	2.1	2.5	0.5
Flame dia. (metres)	0.5	0.5	0.5
Comments	Reasonably Hard Flame	Small sparklers Smokey tips	

Table 19 - Varying steam orifice size

Heat Transfer

Flame No.		17 (base)	20	21
Date		19/7/79	18/7/79	18/7/79
Heat to cooling plates (Btu/h) Plate area = 5 ft^2				
	1	10,575	9,715	10,385
	2	18,675	17,535	19,060
	3	21,345	19,915	21,155
Circuit A	4	24,110	22,585	23,345
Plates 1 to 10	5	24,870	23,630	24,490
	6	25,285	25,730	26,110
	7	29,445	28,300	28,575
	8	28,015	26,870	27,160
	9	27,255	27,730	27,635
	10	28,970	28,585	28,875
Total		239,085	230,595	236,790
	11	25,700	26,765	26,365
	12	25,430	25,965	26,165
	13	26,235	27,165	26,365
	14	22,360	22,430	22,030
Circuit B	15	-	-	-
Plates 11 to 20	16	22,030	22,895	23,230
	17	22,960	23,230	23,360
	18	19,690	19,560	19,090
	19	20,090	19,960	19,960
	20	18,355	17,355	17,890
Total		202,850	205,245	204,325
	21	16,790	17,475	17,155
	22	15,090	15,250	15,170
Circuit C	23	16,545	16,990	16,505
Plates 21 to 27	24	13,675	13,915	13,350
	25	13,470	12,945	14,120
	26	12,660	12,745	12,660
	27	12,095	12,540	12,055
Total		100,325	101,860	101,015
Total heat to plates (Btu/h)		542,260	537,700	542,130
Total area (ft^2)		130	130	130
Average - (Btu/ft^2/h)		4,171	4,136	4,170