INCREASE Performance, Inc.
"Fired Process Solutions"
3158 S. 108th E. Ave. #280
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Prolonging Heater Run Time Equals Huge Return:

Improved Combustion Improves Heat Flux Distribution

Author: David Schmitt, President

Increase Performance was incorporated in 1996, in Tulsa Oklahoma, with a primary focus of providing evaluations of existing fired heaters, furnaces and boilers to provide assistance in furnace tuning, to assure proper combustion results, revamps and expansions. We serve the petroleum refining, chemical, power, ammonia, hydrogen, as well as other related industries. We have complete in house design capabilities, allowing us to provide all services required from initial design concept models to installations and start-up. Along with our service experience we are the designers of a turn-key furnace monitoring system called ***FurnaceMANAGER*** that will continuously monitor the interior of your fired equipment 24 hours a day, seven days a week.

Prior to the startup of IPI, I was one of the early pioneers that developed the Low NOx burner technology currently used in the industry today. We continue to be directly involved in improving these designs as well as leading the industry in an effort to provide the best available design, techniques, and products to our market.

In early 2006, our client, a refinery in Mid-west USA, asked that we review a coker heater that was experiencing tube failures causing unscheduled shutdowns twice a year, in addition to the scheduled shutdowns approximately every 6 months for decoking (pigging). The heater is a horizontal tube, cabin type with the radiant section in coking service and the convection section in another service. The heater is equipped with a cast iron design, two fan balanced, air preheat system. The burners are side fired, plenum mounted along two walls of the furnace. Tube failures and shutdowns occurred with air preheat or natural draft operation.

Our evaluation of the heater revealed the major problem with the heater was poor combustion, lazy flames and an imbalance in combustion air distribution, resulting in insufficient air fuel mixing in the combustion zone, and a very poor flame shape. Complete combustion with the appropriate flame is necessary to release the maximum amount of energy and to provide an even and well distributed flux in the radiant tube absorption plane.

Proper combustion depends on the burner design providing the optimum air and fuel mixture at the correct location which will assure there is just enough oxygen to bond with every carbon and hydrogen atom in the fuel. This ratio is normally referred to as the stoichiometric ratio. Of course, this cannot be realistically achieved in a typical furnace, so we design the combustion process to allow for an excess of air to be available in the combustion zone to assure complete combustion. Maintaining this excess air at a minimum is critical to an efficient furnace operation. As important as complete combustion is, it is equally important to assure that the heat energy is released in a defined zone such that the black body tubes receive an even heat wave, such that hot spots on tubes are avoided.

In the photo here, the poor combustion is evident, but it is more difficult to "see" the poor flux distribution. This picture was taken shortly after repairs to the radiant section had been made. You can see the temporary vertical supports placed in the radiant section in an attempt to prevent the tubes from bowing out of position along the walls. What we determined is that due to the outdated burner design along with the burners being mounted in a common plenum box alongside the heater, there was no realistic way to assure an equal amount of combustion air to each burner. The photo below shows the design of the internally lined burner plenum. Note that the fresh air door was open due to the air preheat system not being in operation at the time of photo.

In our attempt to model the fired heater and air preheat system, there were difficulties determining the actual design of the heater due to numerous modifications and revamps being made through the years, along with changes in the process. For this reason, we included in our recommendations that new data sheets and a new set of General Arrangement drawings be created to fully describe the heater as modified.

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New thermal design rating calculations were done for the revamped heater including those for current operation, future operation with various fuels, both with and without air preheat system. Radiant section results for one of these calculations are reprinted below:

Radiant Section :

Tube OD, in	= 4.000	Tube ID, in	= 3.444
No. Of Tubes	= 100	Tube Length, ft	= 40.083
Tube Spacing, in	= 8.000	Tube Eff Lgth, ft	= 38.000
Tube Width, ft	= 20.229	Tube Supports	= Ends
Inside Height, ft	= 32.479	Inside Width, ft	= 21.229
Inside Length, ft	= 38.000	Area Wall Tubes, ft^2	= 3,979.351
Tube Material	= A-213 T9		
Average Wall Tube Flux, Btu/hr-ft^2	= 10,555		
Average Front 180° Tube Flux, Btu/hr-ft^2	= 14,356		
Maximum Tube Flux, Btu/hr-ft^2	= 17,988		
Tube Therm Cond, Btu/hr-ft-°F	= 15.434		
Inside Foul Res, hr-ft^2-°F/Btu	= 0.0010		
Average Fluid Film Temp, °F	= 856		
Maximum Fluid Film Temp, °F	= 996		
Average Fluid Film Coef, Btu/hr-ft^2-°F	= 186		
Maximum Fluid Film Coef, Btu/hr-ft^2-°F	= 232		
Avg.Front 180° Tube Wall Temp, °F	= 896		
Maximum Tube Wall Temp, °F	= 1,038		
In Tube DP, psi	= 131.729		
Ar, Insul Area, ft^2	= 4,777.695	Aw, Insul Area, ft^2	= 2,414.106
Acp, CP Area, ft^2	= 2,676.771	áAcp, CP Area, ft^2	= 2,363.589
á, Rel Effect., ft^2	= 0.883	Aw/áAcp Ratio	= 1.021
Gas Part Press, atm	= 0.261	Mean Beam Lgth, ft	= 19.551
Gas Emissivity	= 0.571	PP*Bl, atm-ft	= 5.106
Gas Temp Out, °F	= 1,594.444	Exchange Factor	= 0.677
Tot Rad Heat, Btu/hr	= 39,971,690	Total Conv Ht, Btu/hr	= 4,171,259
Tot Ht Trans, Btu/hr	= 44,142,950	Tot Rad Tran, Btu/hr	= 42,001,030
Shld Rad Ht, Btu/hr	= 2,141,924	Heat In Air, Btu/hr	= 5,455,212
Heat In Fuel, Btu/hr	= 0	Heat Loss, Btu/hr	= 662,144
Tot Heat Rls, Btu/hr	= 68,144,860	Heat Out, Btu/hr	= 28,794,970

Temp Air Entering Air Heater, °F	= 80.000
Temp Air Leaving Air Heater, °F	= 419.000
Temp Gas Entering Air Heater, °F	= 614.865
Temp Gas Leaving Air Heater, °F	= 322.058
Total Air Heater Duty, Btu/hr	= 5,155,869
System Efficiency With Air Heater, %	= 92.277

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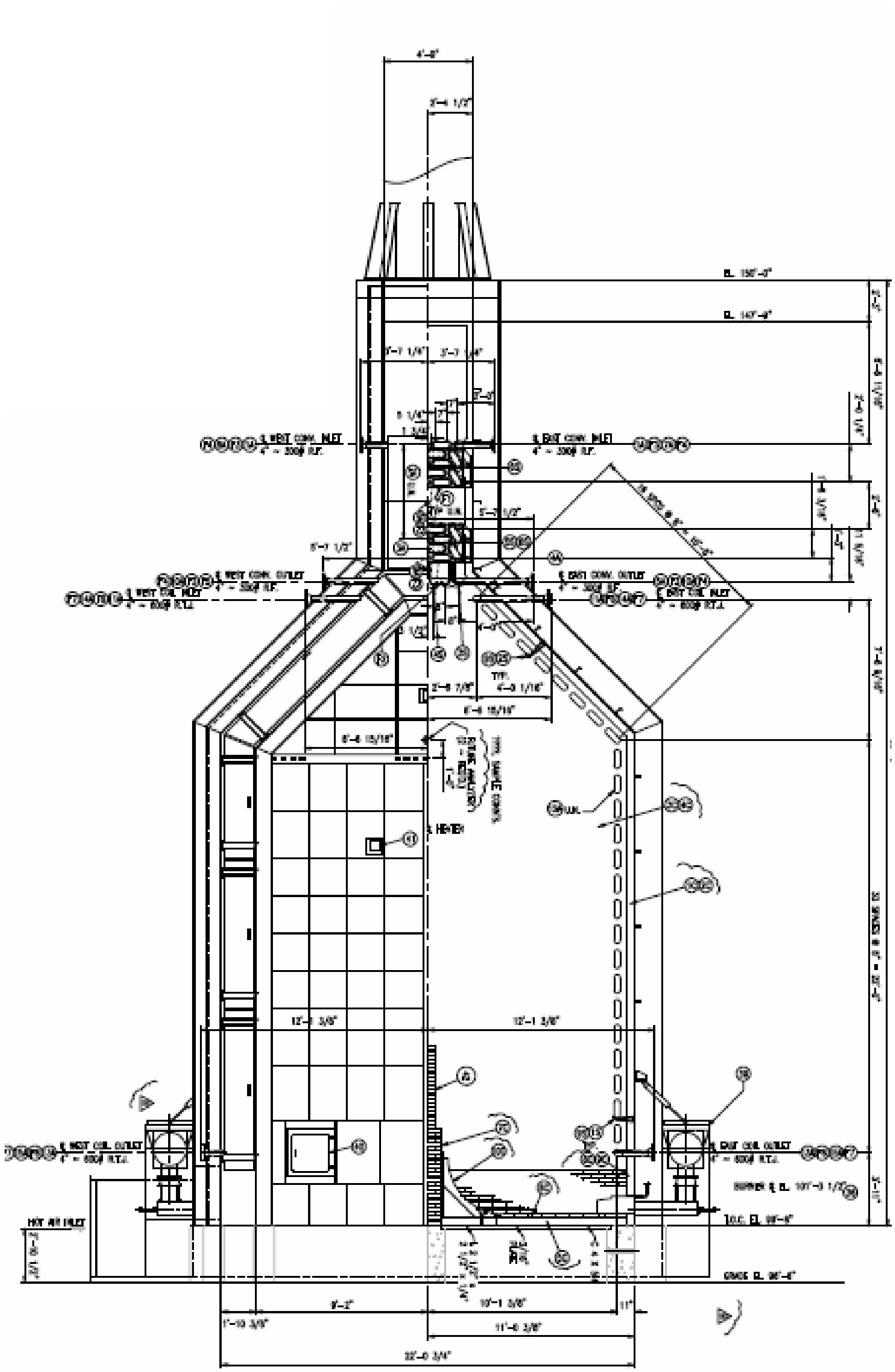
Below is a cross section of heater as revised.



SOUTH ELEVATION

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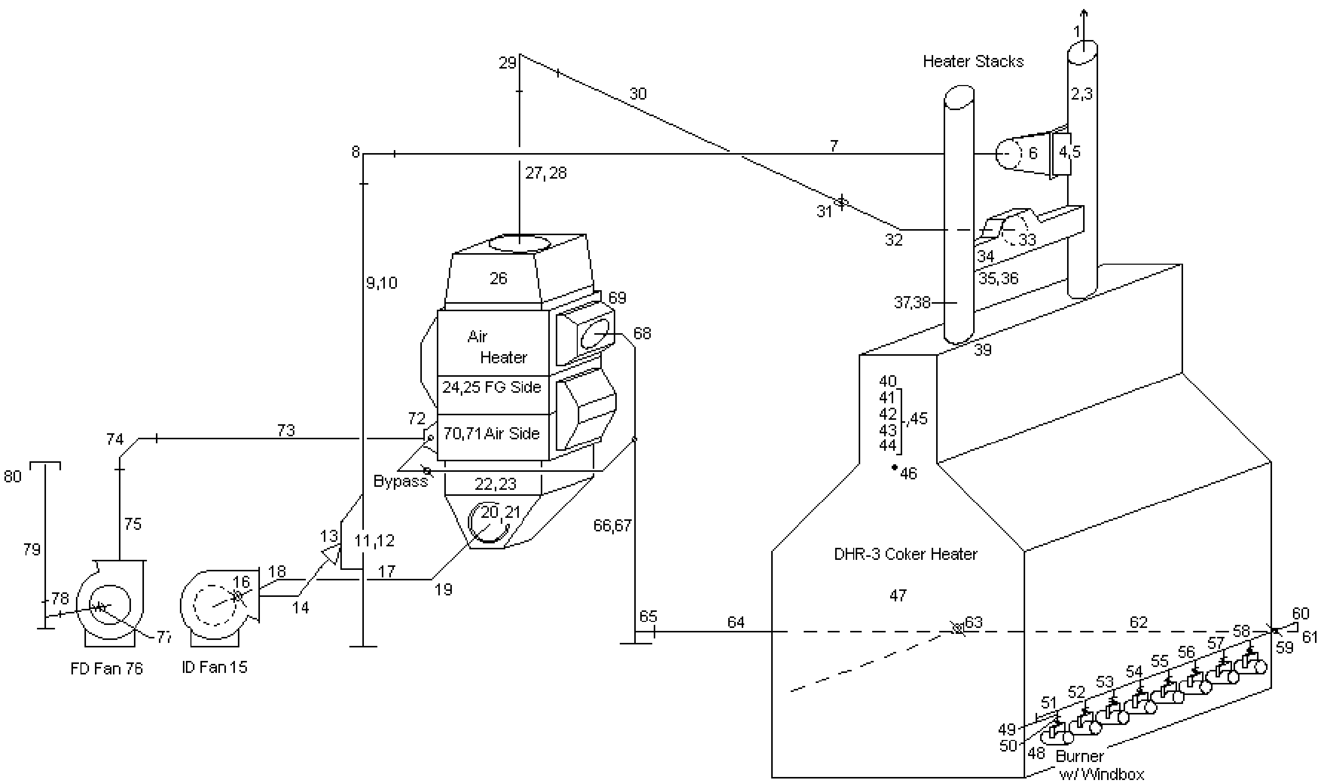
Additionally, the air preheat system was modeled to determine correct design for revised distribution ducting.



Air Preheat System Schematic

A Flow analysis was ran on all of the various design scenarios both with and without the air preheat system in operation. Point inlet summary is shown below for one of these runs:

Summary Of Point Inlet Conditions

Point No.	Size (W/H or Dia)	Area ft⁄	Velocity ft/sec	DeltaP inH20	Static inH20	Dynamic inH20	Total inH20
1	4.548	16.245	21.856	0.0721	0.0000	0.0721	0.0721
2	4.548	16.245	21.855	0.0180	0.0180	0.0721	0.0902
3	4.548	16.245	21.855	-0.2741	-0.2561	0.0721	-0.1840
4	3.396	9.058	39.219	0.0480	-0.3681	0.2321	-0.1360
5	1.958/4.625	9.056	39.352	0.3336	-0.0354	0.2329	0.1976
6	3.458	9.392	37.935	0.1083	0.0893	0.2165	0.3058
7	3.458	9.392	37.933	0.0216	0.1109	0.2165	0.3274
8	3.458	9.392	37.923	0.1082	0.2192	0.2165	0.4356
9	3.458	9.392	37.916	0.0689	0.2881	0.2164	0.5045

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10	3.458	9.392	37.916	-0.2704	0.0177	0.2164	0.2341
11	3.130	7.694	46.492	0.0163	-0.0735	0.3239	0.2504
12	1.615/5.365	8.664	41.252	0.1766	0.1718	0.2552	0.4270
13	2.281/3.063	6.987	51.179	0.0209	0.0552	0.3927	0.4479
14	2.281/3.063	6.987	51.104	0.2907	0.3465	0.3921	0.7386
ID Fan	2.843/2.843	8.083	44.206	-6.6677	-6.2223	0.2932	-5.9291
16	3.208	8.083	44.365	0.1471	-6.0762	0.2942	-5.7820
17	2.927	6.729	53.289	0.0225	-6.1840	0.4245	-5.7595
18	2.927	6.729	53.217	0.2756	-5.9079	0.4240	-5.4839
19	2.927	6.729	53.181	0.2754	-5.6322	0.4237	-5.2085
20	5.341	22.405	15.982	0.1208	-5.1260	0.0382	-5.0877
21	2.927	6.729	53.129	0.5502	-4.9608	0.4233	-4.5375
22	2.417/9.271	22.408	15.945	0.0007	-4.5750	0.0381	-4.5368
23	2.417/9.271	22.408	15.945	0.0163	-4.5587	0.0381	-4.5206
PreHtr	2.417/9.271	22.408	19.039	2.3062	-2.2599	0.0455	-2.2144
25	2.417/9.271	22.408	19.039	0.1549	-2.1050	0.0455	-2.0595
26	2.003/2.003	4.012	122.501	1.0491	-2.6472	1.6367	-1.0104
27	4.011	12.636	38.898	0.0157	-1.1598	0.1650	-0.9948
28	4.011	12.636	38.898	0.1509	-1.0089	0.1650	-0.8439
29	4.011	12.636	38.876	0.0824	-0.9263	0.1649	-0.7614
30	4.011	12.636	39.095	0.0280	-0.8993	0.1659	-0.7334
31	4.011	12.636	39.087	0.0829	-0.8163	0.1658	-0.6505
32	4.011	12.636	39.066	0.1077	-0.7085	0.1657	-0.5428
33	1.833/3.583	6.568	37.570	0.2227	-0.4734	0.1533	-0.3201
34	1.833/3.583	6.568	37.782	0.0081	-0.4662	0.1542	-0.3120
35	4.031/4.031	16.249	15.271	0.0383	-0.2990	0.0252	-0.2738
36	1.833/3.583	6.568	37.757	0.2266	-0.2013	0.1541	-0.0472
37	4.548	16.245	15.264	0.0010	-0.0714	0.0252	-0.0462
38	4.548	16.245	15.264	-0.0642	-0.1356	0.0252	-0.1104
39	9.609	72.518	3.420	0.0086	-0.1031	0.0013	-0.1019
40	3.792/38.250	145.044	3.420	-0.0467	-0.1499	0.0013	-0.1486
41	3.792/38.250	145.044	3.892	0.0875	-0.0625	0.0014	-0.0611
42	3.792/38.250	145.044	4.821	0.0442	-0.0187	0.0018	-0.0169
43	3.792/38.250	145.044	5.937	0.0261	0.0070	0.0022	0.0092
44	3.792/38.250	145.044	6.267	0.0110	0.0179	0.0023	0.0202
45	3.792/38.250	145.044	6.267	-0.0679	-0.0500	0.0023	-0.0477
Arch	3.792/38.250	145.044	6.267	-0.0500	-0.0500	0.0023	-0.0477
47	21.095/38.000	801.610	6.267	-0.3324	-0.3824	0.0023	-0.3801
Burner	0.666/2.000	1.332	17.954	1.0000	0.5771	0.0429	0.6199
49	0.666/2.000	1.332	17.910	0.0020	0.5791	0.0427	0.6219
50	0.666/2.000	1.332	17.909	0.0214	0.6005	0.0427	0.6433
51	1.063/2.000	2.126	11.220	0.0145	0.6410	0.0168	0.6578
52	2.000/1.063	2.126	22.440	0.0071	0.5978	0.0671	0.6649
53	2.000/1.594	3.188	22.446	0.0040	0.6018	0.0672	0.6690
54	2.000/2.125	4.250	22.450	0.0032	0.6050	0.0672	0.6721
55	2.000/2.656	5.312	22.452	0.0028	0.6078	0.0672	0.6749

56	2.000/3.188	6.376	22.446	0.0026	0.6104	0.0671	0.6775
57	2.000/3.719	7.438	22.448	0.0024	0.6128	0.0672	0.6800
58	1.958/4.208	8.239	23.159	0.0642	0.6726	0.0715	0.7441
59	2.000/4.250	8.500	22.546	0.0337	0.7104	0.0675	0.7778
60	2.000/4.250	8.500	22.541	0.0974	0.8078	0.0674	0.8752
61	2.000/4.250	8.500	22.535	0.0974	0.9052	0.0674	0.9726
62	2.000/4.583	9.166	20.897	0.0110	0.9257	0.0580	0.9837
63	1.000/4.583	4.583	83.533	0.2503	0.3069	0.9271	1.2340
64	2.000/4.583	9.166	41.766	0.0056	1.0078	0.2318	1.2395
65	2.000/4.583	9.166	41.732	0.3324	1.3404	0.2316	1.5719
66	3.302	8.563	44.867	0.0320	1.3375	0.2665	1.6039
67	3.302	8.563	44.867	0.1029	1.4403	0.2665	1.7068
68	2.926/2.926	8.561	44.822	0.3994	1.8399	0.2663	2.1062
69	3.563/11.549	41.149	9.326	0.0071	2.1018	0.0115	2.1133
PreHtr	3.563/11.549	41.149	7.507	3.7906	5.8947	0.0093	5.9039
71	3.563/11.549	41.149	7.507	-0.0892	5.8054	0.0093	5.8147
72	2.322/1.729	4.015	57.596	0.4770	5.5620	0.7297	6.2917
73	2.322/1.729	4.015	57.595	0.0131	5.5752	0.7297	6.3048
74	2.322/1.729	4.015	57.443	1.0791	6.6562	0.7277	7.3840
75	2.322/1.729	4.015	57.438	0.0464	6.7027	0.7277	7.4304
FD Fan	2.067/2.067	4.272	54.647	-7.8319	-1.0521	0.6506	-0.4016
77	2.333	4.275	53.901	0.3207	-0.7222	0.6413	-0.0809
78	2.708	5.760	39.995	0.2181	-0.2160	0.3532	0.1371
79	2.708/2.708	7.333	31.404	0.0066	-0.0741	0.2178	0.1437
80	2.708/2.708	7.333	31.398	0.0740	0.0000	0.0000	0.0000

The new combustion air distribution ducts, designed and manufactured by IPI are shown in the photo

here. As before, the ducting is fitted with fresh air doors to allow operation without the air preheat system when necessary. Below the duct are the newly designed and manufactured Low-NOx burners by IPI. These burners are a windbox design with individual damper on each burner air inlet. This burner and combustion air distribution system allows the burner excess air to be carefully controlled, independently for each burner. The ducting is externally lined with expansion joints to allow for thermal expansion, and a rain shield was added over the fresh air doors.

Another photo of the radiant section interior now shows a well defined burner flame providing an even flux to the wall tubes located above the side wall burners. The specially designed interior center firing wall assists in holding the flame throughout the combustion process. The wall tubes are now laying straight in the tube supports, without the necessity of the vertical supports to restrain them. Most importantly is the fact that no tubes have needed to be replaced in this unit since these modifications were completed.

To best describe the success of this project, we will let the following excerpt from an email from the client's own personnel tell the story:
"Prior to the revamp, we would have about two unscheduled heater shutdowns per year to re-tube the heater. During these unscheduled shutdowns, we would lose about 3.5 days of production each time to shutdown and replace tubes. Using an average upgrade value of $5.00 per barrel for a barrel of coker charge, an average downtime of 7 days per year and a charge rate of 14,000 barrels per day, the cost for lost production due to unscheduled downtime calculates to be $490,000 per year. To that amount, add the tube materials replacement cost of approximately $60,000 per year along with the miscellaneous labor costs of $12,000 per year, you then end up with a total cost of $562,000 per year. These are realistic numbers when considering the cost savings due to elimination of production downtime.

Since the revamp, we have not had a single tube replacement

= $1,686,000 payback

In conclusion, at the time of this presentation, it has now been three years since the completion of this revamp project. We believe this to be a *classic example* of the relationship between good combustion, proper excess air adjustment and properly designed burners, resulting in even flux distribution within the radiant section.