Blast Furnace Gas-Fired Boiler for Ereğli Iron & Steel Works (Erdemir), Turkey

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Introduction

Ereğli Demir ve Çelik Fabriklari T. A. Ş. (Ereğli Iron and Steel Works Inc.), known as "Erdemir" is a modern integrated iron and steel works on the Black Sea coast of Turkey, producing flat steel plate. Facilities include two blast furnaces, coke ovens, and hot & cold rolling mills, with a full supporting infrastructure. Four oil- and gas-fired steam boilers provide steam for electric power generation, and to drive steam turbine driven fans for Blast Furnace process air. Two of these boilers (Babcock & Wilcox Type FH) were first put into operation in 1965, and still reliably produce 100 tons/hour of steam at a pressure of 45 kg/cm^2 and a temperature of 445C.

In 1989 Erdemir initiated a Capacity Increase and Modernization Project to increase the steel production capability from two million to three million tons annually. This project also incorporates technology to improve the product quality. Its goals include a reduction in energy expenses to improve Erdemir's competitiveness. The project's scheduled completion is in late 1995.

The by-product gases of the blast furnaces, coke ovens, and basic oxygen furnaces represent a considerable share of the consumed energy in an integrated iron and steel works. Efficient use of these fuels is an important factor in improving the overall efficiency of the operation.

Erdemir has been using these by-product fuels in the Power House in the two Babcock & Wilcox boilers since their installation, and in two additional Foster Wheeler boilers since 1978. The steam produced by these boilers satisfies the plant needs for electricity, for combustion air for the blast furnaces, and for process steam. These boilers are fueled by 35 to 50% blast furnace gas. As a result of recent increases in steel production the blast furnace gas production has also increased beyond what is required for fueling these boilers. Consequently the excess gas has been blown off to the atmosphere since 1988. This represents an important energy loss. For this reason, in order to utilize this gas in an efficient manner, various energy investment projects involving electricity production and process steam supply have been studied.

Initially a project for a Gas Turbine Cogeneration Plant was developed. It was hoped to use the blast furnace gas to fuel the gas turbine, producing electrical energy and process steam. Since no satisfactory offer was received for this plant, the project was cancelled. Subsequently, it was decided to install a new boiler to produce 160 tons/hour of steam, fired principally by the surplus blast furnace gas.

Following international competitive bidding, the order for the new boiler was awarded in 1992 to Babcock & Wilcox of Cambridge, Ontario, Canada in conjunction with their Turkish joint-venture company, Babcock & Wilcox Gama, of Ankara. The boiler was put into commercial operation in 1994 and has demonstrated efficient, reliable performance.

Technical Description

Ereğli Iron and Steel Works (Erdemir) contracted with Babcock & Wilcox for a PFT style boiler capable of burning the fuels blast furnace gas (BFG), converter gas (OG), coke oven gas (COG), natural gas, and No. 6 oil. The 160 tph (352,800 lb/hr) capacity boiler, the fifth boiler in the plant, produces steam at 45 kg/cm^2 (640 psig) and 445C (833F) to a common header. The boiler design did not vary from Babcock & Wilcox's standard PFT design, except that the superheater was custom-designed as always, and the burners required special consideration to meet Erdemir's requirements for burning the wide range of fuels.

The PFT is an Integral-Furnace Industrial Boiler; a bottom-supported, flat floor unit with sizing flexibility and capability of meeting EPA regulations. Four furnace depths and ten unit widths are available. The PFT is designed to utilize shop-assembled components to the maximum extent possible, although an appreciable amount of field erection work is still required. Capacities range from 350,000 to 800,000 lb/hr steam flow. Pendant or drainable superheaters are designed for up to 960F with control on oil to 60% load, and natural gas to 40% load. The "dropped" furnace provides a tall furnace independent of boiler bank height. The tall and deep furnace permits more effective NO_x control. Typically the unit is pressurized providing zero leakage, and the elimination of the induced draft fan saves power, fan, and auxiliaries installation and maintenance costs.

Erdemir's Boiler No. 5 is a PFT-32-24-36, meaning its drum centers are 32 feet apart vertically, the nominal distance between furnace sidewall centerlines is 24 feet, and it has a 36 foot nominal furnace depth (Figure 1). The superheater is drainable, and a spray attemperator to control steam temperature is located between the third and fourth stages of the superheater. The unit is not pressurized, having an induced draft fan, per Erdemir's specifications. BFG should preferably be fired in a balanced-draft unit, although a pressurized furnace is acceptable when the gas is clean (less that 0.05 grains per cubic foot). The six burners on the furnace frontwall are arranged three high by two wide, with the combustion air fed from the integral duct running underneath the furnace.

Erdemir's fuel usage requirements (Table 1) determined the burner design. Blast furnace gas and converter gas are mixed upstream of the boiler. Their mixture forms the main fuel, providing 95% of the total heat input to the boiler. The volume of converter gas to be mixed with the blast furnace gas varies from 0 to 50%.

Erdemir's specifications required that the coke oven gas be used as the pilot fuel and the supplementary fuel, but also that the burner system be designed such that an amount of COG up to 10,000 Nm^3/hr (373,224 scfh) could be diverted to the boiler for burning.

The specifications also required that in the case of non-availability of COG, natural gas be used as the pilot fuel and also be fired to produce 60% of the boiler MCR steam rating. Similarly, the boiler has the capability of producing 60% MCR on No. 6 oil. Due to the size of the burners, the air velocities would be too low for stable operation should all six (6) burners be used for natural gas alone or No. 6 Oil alone. For 60% MCR on either of these two fuels, four (4) burners are used.

The six B&W Tri-Fuel Burners (Figure 2) were specially designed to accommodate Erdemir's fuel usage requirements. The Tri-Fuel Burner is a circular burner with a scroll for imparting a swirl to the BFG/OG mixture as it enters the burner and proceeds along the outer "nozzle."

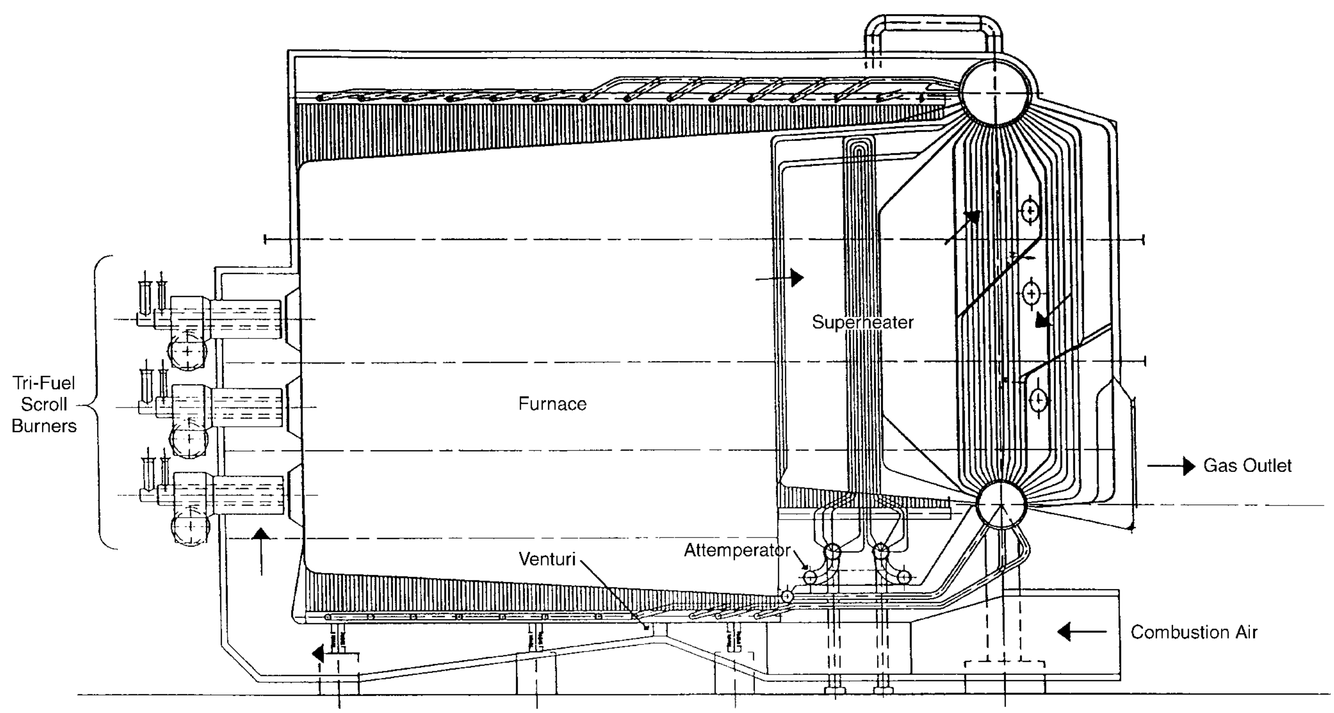
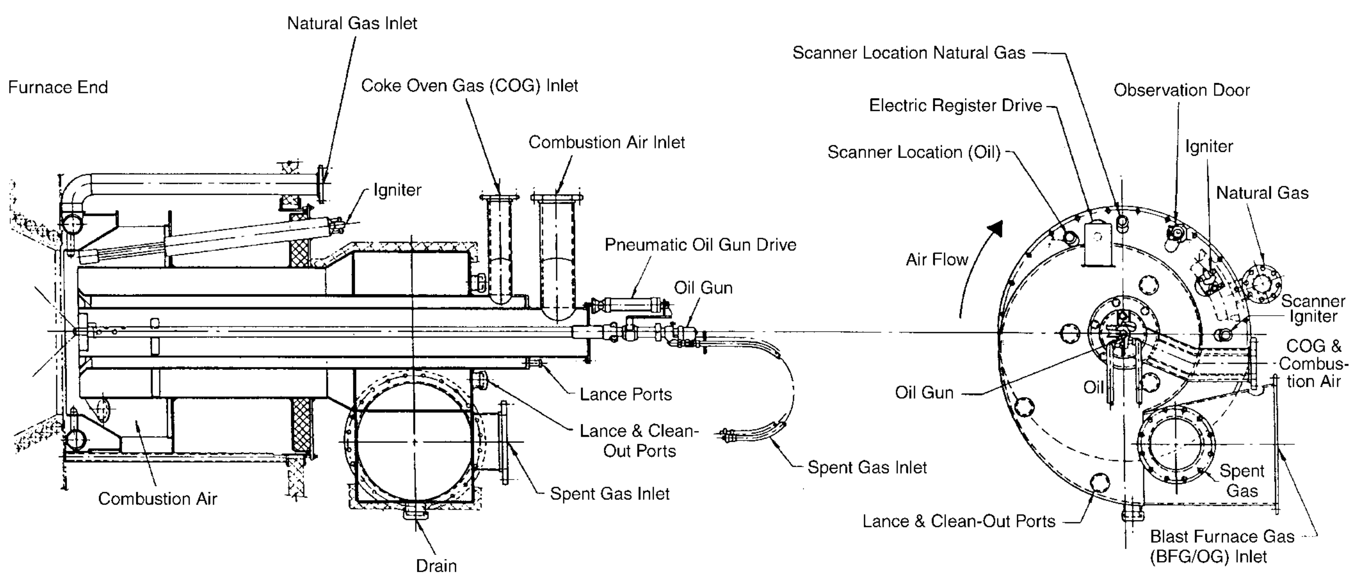


Figure 1 Side view of the Erdemir PFT boiler.

Table 1
Erdemir Tri-Fuel Circular Type Burners — Fuel Firing Conditions

Imperial Units	BFG	COG		OG	Natural Gas		No. 6 Oil
		Normal (5% Input)	Maximum		60% MCR	To Ignitors	60% MCR
Total Heat Input to Burners (Btu/hr)	483,570,000	26,430,000	178,028,000	336,330,000	309,280,000	48,357,000	284,680,000
Total Flow to Burners (scfh)	5,128,570	55,410	373,224	1,594,000	289,047	45,193	15,594 lb/hr
Number of Burners	6	6	6	6	4	6 Ignitors	4
Heat Input per Burner (Btu/hr)	80,595,000	4,405,000	29,671,310	56,055,000	77,320,000	8,059,500	71,170,000
Flow per Burner (scfh)	854,762	9,235	62,204	265,660	72,262	7,532	3,900 lb/hr
Fuel Heating Value (Btu/scf)	94.3	477	477	211	1070	1070	18,255 Btu/lb
Required Fuel Pressure at Burner	4 in. wg.	0.25 psig	1 psig	1.6 in. wg.	5.2 psig	*	120 psig
Fuel Temperature (°F)	68	68	68	68	68	68	68
Secondary Air Flow per Burner (lb/hr)	65,432				66,880		68,273
Secondary Air Temperature per Burner (°F)	400				290		300
Secondary Air Pressure Required (in. wg.)	2.85				2.6		2.7
Spent Gas Flow for Cooling BFG Nozzle & Scroll (lb/hr/burner)	Not Required	Not Required	Not Required in Combination with BFG	Not Required in Combination with BFG		13,387 at 302F	
Atomizing Steam Pressure at Burner (psig)	Not Required	Not Required	Not Required	Not Required	Not Required	Not Required	140
Atomizing Steam Flow per Burner (lb/hr)	Not Required	Not Required	Not Required	Not Required	Not Required	Not Required	390

*1.4 psig at ignitor without plug cock; 8.5 psig at ignitor with plug cock



Side Sectional Elevation

Front Elevation

Figure 2 Erdemir BFG Tri-Fuel burner.

The COG is fed along an inner pipe to seven concentric nozzles. At the burner's center is the oil gun. Between the oil gun and the COG pipe is a secondary air pipe used to provide combustion air to the oil should oil ever be fired simultaneously with BFG/OG. A swirler located at the furnace end imparts a spin sending the air to the required combustion zone. Natural gas is fed to gas spuds located around the periphery of the burner. The natural gas ignitor is angled to ignite the fuel from any of the entrances. All burners fire the same fuels as the windbox is not compartmentalized. The fuels which may be fired simultaneously in the same burner are:

- BFG/OG, COG and natural gas
- COG and oil
- Natural gas and oil
- Natural gas and COG
- Oil and BFG/OG

Whenever BFG/OG is not being fired, spent gas enters the BFG/OG nozzle to provide cooling. The spent gas is flue gas taken from the air heater outlet, and because it is relatively hot, requires the scroll to be insulated.

The range of operation of a unit on BFG firing with all burners in service is approximately two to one and the minimum load is usually limited by poor ignition resulting from low furnace temperatures. For this reason, and the fact that BFG is an interruptible fuel, Babcock & Wilcox recommends continuous lighters with an input of ten percent (10%) of the full load BFG burner input. Although the Erdemir ignitors are designed for 10%, Erdemir chooses to run the burners with only 5% sustaining fuel, so that the full 95% heat input from the BFG/OG available can be utilized.

The combustion air zone forms an annulus between the BFG/OG nozzle and the refractory on the bent tube throat. Because the BFG is not heated, the combustion air is 400F at full load. Twelve air scoops are located around the burner diameter to provide additional direction for the combustion air.

The range of COG inputs presented a problem at the design stage. Erdemir wanted as little as five percent of the burner heat input to be provided by COG as the sustaining fuel for the BFG/OG. Five percent represents 4.4 x 10^6 Btu/hr from each burner. The other requirement to burn up to 10,000 Nm^3/hr (373,224 scfh) meant that the heat input from each COG burner would be 30 x 10^6 Btu/hr. This turndown could be accomplished with COG through the ignitors for the sustaining fuel, and with seven nozzles at the end of the COG pipe for the largest heat input required from the six burners. The turndown on COG from each burner is 2:1, and by turning down the burners and then shutting them down one by one until left with ignitors only, the full range of COG heat inputs would be available. Due to the low COG pressure of 1 psig at the ignitors, the plug cock at the entrance to each ignitor needed to be removed. This meant that the COG piping to each ignitor would need exact balancing to avoid starving any of the ignitors. In the end, Erdemir preferred to use the COG nozzles for the sustaining input. The seven nozzles needed inserts to reduce their open area for the much lower COG volume required for sustaining the BFG/OG firing. This rendered the nozzles useless for immediate accommodation of the higher COG quantity.

Controls

Combustion and Boiler Controls

The following major control loops are included, together with the monitoring of various auxiliary parameters of boiler operation, by means of a Bailey INFI-90 Distributed Control System.

- Plant Master
- Boiler Master
- BFG Flow
- COG Flow
- Supplementary Fuel Flow
- Total Combustion Air Flow
- O_2 Trim
- Furnace Draft
- Three-element Drum Level & Feedwater Flow
- Final Superheater Outlet Temperature
- Continuous Blowdown Flow
- Auxiliary Loops for Fuel Preparation Systems

Burner Management System

The Burner Management System is designed in accordance with the NFPA 85C standard. Multi function processors are arranged in redundant pair configuration for both the boiler common trip and the burner operation system logics in the INFI 90 DCS.

Hardwired safety trip relays for fuel header cutoff are also provided, in addition to the microprocessor based system features, in order to provide maximum system safety. The hardwired trip relays are also connected to an emergency trip button system, which allows unit trip independent from the DCS system.

Boiler Island Common Controls

The 0.4 kV motor starting and operation monitoring, including those for sootblowers, auxiliary plant, and motorized operators, are included in this section. The monitoring of those boiler island parameters requested in the specifications, such as medium voltage motor slot and bearing temperatures, vibration, and motor current, is also included.

Operator Interface Facilities

Two different types of operator interface are provided to monitor and control the above systems.

- The first type is the CRT-Keyboard based operator station. One OIS20 operator console and one Process Control View console are provided. The latter is also designed to be used as an Engineering Work Station.
- The second type of interface, located on Auxiliary Side Panels, includes classical status and alarm indicators, selector switches, and control buttons. One Auxiliary Side Panel is located close to the burners, and features back-up operator interface to the Burner Management System. A similar Auxiliary Side Panel provides a local interface facility for the Sootblowers.

Flame Detection System

Flame detection and monitoring are provided by a Bailey FLAMON system. One Main Flame detector and one Pilot Flame detector are provided for each of the six burners. The Pilot Flame detector also acts as a secondary redundant detector for Main Flame detection, once the burner is in operation.

Performance Testing

Following completion of construction and erection, performance tests were conducted in accordance with the contractual requirements. Data collection was performed by operator console logging facilities. A 30 second sample time over a one hour period was used in the data collection, reporting average, minimum, and maximum values over the one hour period. A sample of the results is shown in Table 2.

Blast furnace gas volumetric analysis and heating value (HHV) were provided by Erdemir's laboratories. A typical BFG analysis is:

H_2	4.0% by volume
N_2	54.2%
CO	23.0%
CO_2	18.0%
CH_4	0.8%

Higher Heating Value 866 Kcal/Nm^3

Flue gas ORSAT analysis was also provided by Erdemir's laboratories.

The contract required that boiler efficiency be guaranteed at full load, with 95% of heat input from the BFG and the remainder from COG. Tests were conducted, and analysis performed, in accordance with the requirements of ASME Power Test Code 4.1 for steam generating units.

A sample of the efficiency calculations, at 40% excess air, is provided at Table 3. This shows that the unit exceed its contractual requirement of a minimum of 85% efficiency.

Following these tests the unit was officially accepted by Erdemir. Since that time the boiler has operated with an availability exceeding 98%.

Conclusion

Based on an estimate of the natural gas saved by the burning of the previously wasted blast furnace gas, Erdemir considers that they recovered their capital cost of the installation in less than a year of operation.

These savings will continue for the life of the unit, which, if the evidence of the adjacent B&W FH boilers is any indication, will be well into the next century.

Table 2
Erdemir BFG Fired Boiler — Performance Test Operational Data

Parameter	Unit	Instant	Average	Minimum	Maximum
Steam Flow Rate	Tons/Hour	162	160	146	166
Feedwater Flow Rate	Tons/Hour	153	150	137	153
Economizer Inlet Water Temperature	°C	112	113	112	113
Economizer Outlet Water Temperature	°C	184	186	184	188
Attemperator Inlet Steam Temperature	°C	435	436	431	439
Attemperator Outlet Steam Temperature	°C	347	348	344	352
Superheater Outlet Steam Temperature	°C	440	440	436	443
Steam Drum Pressure	kg/cm^2	49	49	48	50
Superheater Outlet Steam Pressure	kg/cm^2	44	44	44	45
Forced Draft Fan Outlet Air Pressure	MBar	13	15	12	16
Regenerative Air Heater Outlet Air Pressure	MBar	7	9	5	11
Windbox Air Pressure	MBar	4	6	1	9
Furnace Draft	mm WC	-27	-11	-55	14
Forced Draft Fan Outlet Air Temperature	°C	21	20	20	21
Regenerative Air Heater Inlet Air Temperature	°C	23	22	22	23
Regenerative Air Heater Outlet Air Temperature	°C	243	243	239	245
Boiler Exit Gas Temperature	°C	387	385	379	387
Economizer Outlet Gas Temperature	°C	261	262	259	263
Regenerative Air Heater Outlet Gas Temperature	°C	161	161	157	163
Forced Draft Fan Motor Current	Amps	74	74	74	75
Forced Draft Fan Damper Position	%	41	41	40	41
Induced Draft Fan Motor Current	Amps	351	353	345	359
Induced Draft Fan Damper Position	%	36	36	33	38
Feedwater Pump Motor Current	Amps	124	122	118	124
Blast Furnace Gas Burner Pressure	MBar	14	18	9	23
Coke Oven Gas Burner Pressure	MBar	73	73	59	98
Blast Furnace Gas Flow Rate	SM^3/Hour	167,481	176,760	155,800	192,196
Coke Oven Gas Flow Rate	SM^3/Hour	2,525	2,494	2,190	3,069
Combustion Air Flow Rate	kg/Hour	179,244	175,819	170,240	185,280
Blast Furnace Gas Temperature	°C	22	22	21	23
Coke Oven Gas Temperature	°C	29	30	28	31
Stack Gas Oxygen Content	%	4	5	3	8
Steam Coil Air Heater Valve Position	%	2	2	2	2
Blowoff Valve Position	%	1	1	1	1
Attemperator Spray Valve Position	%	7	6	5	7

Table 3
Erdemir Blast Furnace Gas Fired Boiler — Efficiency Calculation

Pressures and Temperatures				
Steam Pressure in Boiler Drum	Bar g	49	psig	711
Steam Pressure at Superheater Outlet	Bar g	44	psig	638
Steam Temperature at Superheater Outlet	°C	440	°F	824
Water Temperature Entering Unit	°C	113	°F	235
Ambient Air Temperature at Boiler	°C	17	°F	63
Combustion Air Temperature (Reference Temperature)	°C	26	°F	79
Temperature of Fuel	°C	22	°F	72
Gas Temperature Leaving Unit	°C	160	°F	320
Unit Quantities				
Enthalpy of Output Steam	kJ/kg	3299.8	Btu/lb	1418.65
Enthalpy of Saturated Feed to Unit	kJ/kg	473.1	Btu/lb	203
Enthalpy of Vapor at 1 psia and Gas Leaving Temperature	kJ/kg	2802.3	Btu/lb	1204.8
Enthalpy of Liquid at Air Inlet Temperature	kJ/kg	108.9	Btu/lb	46.8
Enthalpy of Vapor at Air Inlet Temperature	kJ/kg	2550.6	Btu/lb	2096.6
Fuel Heating Value	kJ/kg	2865.6	Btu/lb	1232
Moisture in Fuel kg per kg As-Fired Fuel	kJ/kg	0.000	lb/lb	0.000
Moisture in Air, kg per kg of Dry Air	kJ/kg	0.013	lb/lb	0.013
Theoretical Air per kg As-Fired Fuel	kJ/kg	0.700	lb/lb	0.700
Carbon Burned per kg As-Fired Fuel	kJ/kg	0.1683	lb/lb	0.1683
Hydrogen Burned per kg As-Fired Fuel	kJ/kg	0.0038	lb/lb	0.0038
Dry Gas per kg As-Fired Fuel Burned	kJ/kg	2.1233	lb/lb	2.1233
Hourly Quantities				
Actual Water Evaporated	kg/hr	160,000	lb/hr	352,423
Fuel Quantity Required	kg/hr	183,659	lb/hr	404,536
Total Heat Input required	MW	146.19	MBtu/hr	498.39
Total Heat Output	MW	125.63	MBtu/hr	428.28
Flue Gas Analysis at Unit Outlet				
CO_2	% Volume	20.5		
O_2	% Volume	3.0		
CO	% Volume	0.2		
N_2 (by difference)	% Volume	76.3		
Excess Air	%	40		
Calculation of Heat Losses				
Heat Loss due to Dry Gas	kJ/kg	285.9	Btu/lb	122.914
Heat Loss due to Moisture in Fuel	kJ/kg	0.00	Btu/lb	0.00
Heat Loss due to H_2O from H_2 in Fuel	kJ/kg	91.07	Btu/lb	39.152
Heat Loss due to Moisture in Air	kJ/kg	3.21	Btu/lb	1.378
Heat Loss Efficiency				
Heat Loss due to Dry Gas	%	9.98		
Heat Loss due to Moisture in Fuel	%	0.00		
Heat Loss due to H_2O from H_2 in Fuel	%	3.18		
Heat Loss due to Moisture in Air	%	0.11		
Heat Loss due to Surface Radiation	%	0.30		
Unmeasured Losses	%	0.50		
Total Losses	%	14.07		
EFFICIENCY	%	**85.93**		
Total Error (Plus or Minus)	%	0.04		