

WOOD COFIRING EXPERIENCE IN CYCLONE BOILERS

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Key Words: wood waste, cyclone boilers, cofiring

ABSTRACT

Wood waste has been cofired with coal in cyclone boilers at the Allen Fossil Plant of TVA, the King Station of Northern States Power Co., and other generating stations. This practice is sufficiently interesting that TVA plans long term testing of cofiring wood at Allen. This practice can be separate from, or combined with, cofiring tire-derived fuel (TDF) in cyclone boilers. Cofiring has been practiced with the wood waste being fed to the boilers simultaneously with the coal, and with the wood waste being introduced into the secondary air system of cyclone boilers, for separate feeding. The practice of cofiring wood waste with coal in cyclone boilers has been shown to reduce emissions of SO₂ and NO_x, while also reducing the cost of fuel in selected locations. Foster Wheeler Environmental Corporation has evaluated this practice both with engineering design studies and with field testing for the Electric Power Research Institute and the Tennessee Valley Authority. This paper summarizes testing and experience in several locations, focusing upon the following issues: 1) the impact of cofiring on boiler performance and consequent airborne emissions, 2) the alternative designs to accomplish cofiring, and 3) the economics of cofiring under various conditions.

INTRODUCTION

Cofiring of biofuels with coal provides utilities with the opportunity to accomplish the following objectives: 1) reduce fuel costs by utilizing residuals from the forest products industry; 2) reduce formation of SO₂ by using a fuel which contains virtually no sulfur; 2) reduce formation of NO_x by using the biofuels that are low in nitrogen and that burn at lower temperatures than most coals (e.g. wood wastes; some agricultural materials can be high in nitrogen and therefore do not satisfy this objective); 3) reduce the formation of CO₂ from fossil fuels, thereby addressing issues associated with the global climate challenge; and 4) support economic development in the utility's service area, thereby enhancing baseload customer growth and plant utilization. All of these objectives are mandated by law and regulation, results of voluntary utility actions (e.g. fossil CO₂ reductions), or are conventional utility practice for managing costs and loads.

From a materials handling and fuel preparation perspective, the biofuels are fundamentally different from coal. They can not be ground by traditional pulverizing methods, but must be shredded or chopped. Biofuels are fibrous. Consequently, fuel preparation methods can be fundamentally different. Biofuels respond to hammermills and derivative systems, but not to ball mills, bowl mills, and other coal pulverizing technologies. The additional material handling property of consequence is bulk density. Coal is typically on the order of 40 - 50 lb/ft³ while wet wood is on the order of 18 - 20 lb/ft³, dry wood is about 10 - 12 lb/ft³ and most agricultural wastes are on the order of 8 - 12 lb/ft³ as well. These bulk densities require careful management practices such that the fuel storage system is not compromised when cofiring is considered.

Chemically, biofuels, particularly wood waste, are fundamentally different from coal as is shown in Table 1. As mentioned previously, biofuels are low in sulfur content. Further the wood wastes are typically very low in nitrogen content, although some agricultural wastes including rice hulls and alfalfa stems may have nitrogen contents that are at moderate to high levels (e.g. 0.5 - 2.0%, dry basis). These fuels are somewhat oxygenated, typically moist, and have modest heat contents. Of more consequence, these fuels can have low to moderate ash percentages (e.g. 3 - 6%). The ash, however, is fundamentally different from coal with high concentrations of alkali metals: potassium, calcium, and sodium.

Base/acid ratios are in the range of 2.0 - 6.0, with some B/A values exceeding 10.

The behavior of biofuel/coal blends in combustion systems can be readily predicted from weighted arithmetic averaging of the properties of the individual fuels, with particular attention to proximate and ultimate analysis, higher heating value, and formation of combustion products. The one exception is ash fusion temperature, where blending shifts the base/acid ratio towards 1.0, and consequently impacts ash fusion temperatures according to the following equations:

$$AFT_i = 1268.7W^2 - 980W + 2336 \quad [1]$$

$$AFT_h = 1025.9W^2 - 494W + 2069 \quad [2]$$

Where AFT_i is the initial deformation temperature, W is the weight percentage of wood (dry basis) in the blend, and AFT_h is the hemispherical temperature (reducing environment).

The high concentration of alkali metals in the ash further complicates the analysis based upon the potential for slagging and fouling. The potassium oxide is of particular concern due to the low temperatures at which it vaporizes, leading to the potential for condensation in backpasses of the boiler.

The consequence of these characteristics is that biofuel cofiring, particularly wood cofiring, is more readily achieved with cyclone boilers than with pulverized coal (PC) boilers; this ease of accomplishment is particularly apparent at moderate cofiring percentages which are on the order of 10 - 15% by heat input or 20 - 30% by mass.

BACKGROUND

Within the past few years, several utilities have initiated cofiring experiments or practices. Northern States Power (NSP) has initiated cofiring at its cyclone-based King Station, and consumes wood waste from the Andersen Windows manufacturing plant on a regular basis. This practice has gone on for the past several years, and NSP has been very successful. Cofiring occurs in 3 of the 12 cyclone barrels at the plant, and firing levels of 15% wood (heat input basis) have been achieved. The wood, which is dry and pulverized, is introduced through the secondary air system. Wood fuel storage and preparation is separated from coal storage and preparation. The Big Stone Plant of Otter Tail Power also has cofired wood waste in the form of railroad ties. This plant, also a cyclone boiler, was designed for lignite. It has provisions for fuel drying. It also has a very large primary furnace in order to ensure burnout of char particles.

TVA and EPRI initiated cofiring investigations in 1992. The investigations included both PC boilers and cyclone boilers, with the latter focusing upon cofiring at the Allen Fossil Plant (ALF) in Memphis, TN. The concept developed had broader application than the design used at the King Station of NSP: in this concept, wood waste is mixed with coal in the fuel yard and simultaneously transported to the fuel bunkers and then to the cyclone burners. TVA also contemplated using green wood (40 - 50% moisture) as opposed to the dry wood (8 - 12% moisture) being fired at the King Station of NSP (See Fig 1).

EPRI/TVA INVESTIGATIONS

The EPRI/TVA investigations, through Foster Wheeler Environmental Corporation (then Ebasco Environmental Corporation) were initiated by development of conceptual process designs and associated calculations. These were followed by mechanical systems designs, cost estimates, evaluations of environmental impacts, and economic assessments.

The studies generally demonstrated that cofiring at 10% by heat input, or 20% by mass, would have the following impacts: 1) not affect the ability of the plant to achieve capacity based upon fan capacities and related factors, 2) reduce boiler efficiency by about 1.5%, depending upon the specific condition of the wood, 3) reduce the SO_2 emissions as a function of fuel substitution, and 4) reduce NO_x emissions disproportionately based upon fuel effects

(reduced nitrogen content in the fuel) and temperature effects in the cyclone barrel.

The initial designs, calculations, and evaluations led to the conclusion that cofiring would be economically feasible at the ALF location. The economics were favorable as a consequence of the following factors: 1) a low capital cost (\$130 - \$200/kW supported by wood waste), a fuel price differential of \$0.40/10⁶ Btu between wood and Western Kentucky bituminous coal delivered to the site, 3) modest incremental operating and maintenance costs utilizing one additional person and capitalizing upon existing maintenance infrastructure at the plant, and 4) modest credits for SO₂ removal (\$136/ton SO₂ based upon recent market prices). No credits were taken for NO_x or fossil CO, although they are the source of significant economic analysis.

The initial investigations led to a week of parametric testing at the facility. The testing involved evaluations of the ability to achieve capacity at ALF when cofiring wood with coal, boiler efficiency when firing wood and coal at various levels, and reductions in airborne emissions. The testing program involved cofiring at percentages ranging from 1.6 to 20%, mass basis. The wood was obtained from local sources, and the coal was a Western Kentucky coal (see Table 1).

The testing confirmed the results from the calculations: capacities were largely not impacted by cofiring, boiler efficiencies were reduced by less than 2% when cofiring even at significant wood percentages, SO₂ emissions declined in proportion to the Btu substitution of wood for coal, and NO_x emissions declined in response to fuel substitution and temperature effects.

Additional testing performed under this program involved storage and flow characteristics of wood/coal blends; and this work was performed largely by Reaction Engineering International in support of the Foster Wheeler Environmental program. This testing demonstrated that wood waste improved the flow of fuel through the bunkers, and virtually eliminated dusting on the coal belts. Additional testing performed by Foster Wheeler Environmental also documented that the wood did not compromise storage from the perspective of inducing spontaneous combustion.

The parametric tests and supporting investigations were initial indications of the potential for wood cofiring. They have resulted in the decision to pursue additional tests during the first half of 1995, pursuant to commercializing cofiring using the system shown in Fig. 1. These tests will be conducted firing wood with Utah bituminous coal, and with combinations of coal, wood, and tire-derived fuel (TDF).

CONCLUSIONS

The cofiring program conducted at the Allen Fossil Plant of TVA is advancing to extended testing, more detailed materials handling engineering, and additional economic analyses. This program integrates the EPRI/TVA approach to cofiring into the range of options being pursued by other utilities. Such utilities are testing cofiring wood waste at low percentages in PC boilers, transporting <5% wood (mass basis) through the pulverizers with the coal. Such testing is also considering cofiring wood in PC boilers at higher percentages, using separate biofuel preparation. These systems fire the biofuels through dedicated burners into the boiler. Utilities pursuing such options include TVA as well as Georgia Power, Savannah Electric, New York State Electric and Gas, and others. The cofiring program at the Allen Facility has not yet completely proven the commercial viability of cofiring in cyclone boilers using the design configuration shown in Fig. 1; however the program is sufficiently advanced that such commercial demonstration is anticipated as a consequence of the next sequence of tests plus some planned long term test activities.

ACKNOWLEDGEMENTS

This is to acknowledge support for the program from the Electric Power Research Institute and the Tennessee Valley Authority.

Table 1. Typical Fuel Compositions for Eastern Bituminous Coal, Wood, and Alfalfa Stems

	Bituminous Coal	Wood Fuel	Alfalfa Stems
Proximate Analysis (wt %, dry basis)			
Volatile Matter	37.22	84.58	76.03
Fixed Carbon	52.97	14.26	17.45
Ash/Inerts	9.81	1.16	6.52
Ultimate Analysis (wt %, dry basis)			
Carbon	74.77	49.23	45.35
Hydrogen	5.08	5.93	5.75
Oxygen	6.32	43.27	40.24
Nitrogen	1.44	0.38	2.04
Sulfur	2.31	0.02	0.10
Chlorine	0.27	0.01	0.15
Ash/Inerts	9.81	1.16	6.52
Heating Value (Btu/lb)			
As-Received	11,748	5,431	7,108
Dry Basis	13,040	8,338	7,940
Moisture/Ash Free	14,457	8,437	8,494
Typical Moisture Content			
Weight Percent	10	40	10
Ash Analysis (wt %)			
SiO ₂	44.16	23.70	1.44
Al ₂ O ₃	22.89	4.10	0.60
TiO ₂	1.00	0.36	0.05
Fe ₂ O ₃	22.86	1.65	0.25
CaO	2.16	39.95	12.90
MgO	0.47	4.84	4.24
Na ₂ O	0.25	2.25	0.61
K ₂ O	1.97	9.81	40.53
P ₂ O ₅	0.50	2.06	7.67
SO ₃ ⁻	1.93	1.86	1.60
Undetermined	1.81	9.43	17.44
Ash Fusibility			
Base/Acid Ratio	0.41	2.08	28.01
T ₂₅₀ Temperature (°F)	2,397	2,440	---
Ash Fusion Temperatures (°F)			
Oxidizing Atmosphere			
Initial	2,406	2,546	> 2,700
Softening	2,545	2,563	> 2,700
Hemispherical	2,552	2,566	> 2,700
Fluid	2,565	2,577	> 2,700
Reducing Atmosphere			
Initial	2,082	2,274	> 2,700
Softening	2,273	2,577	> 2,700
Hemispherical	2,325	2,583	> 2,700
Fluid	2,429	2,594	> 2,700

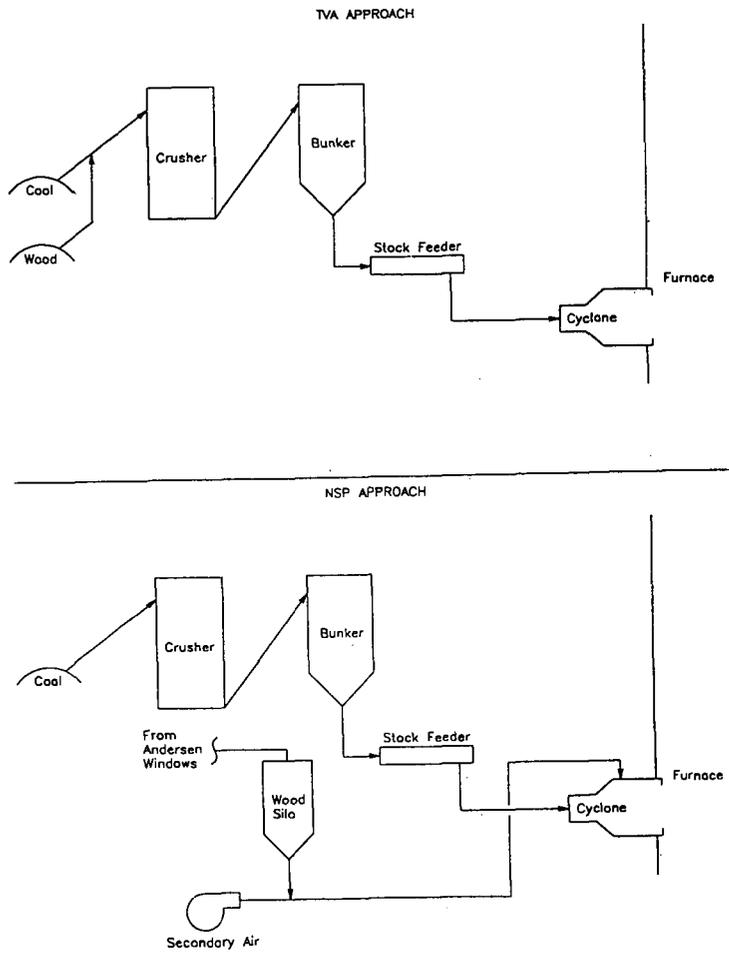


Fig. 1. Alternative Approaches to Cyclone Cofiring