CONVERSION OF RED WING AND WILMARTH COAL FIRED STEAM GENERATORS TO RDF FUEL

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ABSTRACT

The conversion of Northern States Power Company's (NSP) Red Wing and Wilmarth steam generators to fire refuse-derived fuel (RDF) is a unique project—a retrofit repowering from coal to RDF is a first-of-a-kind. The use of the existing plant with the necessary modifications to the boilers has allowed NSP to effectively incinerate the fuel as required by Washington and Ramsey Counties.

A preceding paper given at the 1986 Joint Power Generation Conference discussed the background, evaluations, and final designs of the conversion project [1]. This presentation summarizes that background and presents operating issues, actual vs expected performance, and evaluations of how early design decisions resulted in actual operation.

BACKGROUND

Two coal-fired power plants in Red Wing and Mankato, Minnesota, have been converted to burn 100% RDF. Four boilers, two each at Red Wing and Wilmarth steam plants, were selected for the conversion by the utility, Northern States Power Company. NSP's evaluation of future power generation needs indicated an opportunity to supplement conventional fuels, extend the life of older plants, and alleviate a waste disposal problem. The utility had capacity within its system (relative to more modern NSP plants) that was used for peaking service only.

The two plants were 35 years old and had two steam generators each, rated at 125,000 lb/hr while firing coal on a stoker. They operated at pressures and temperatures similar to those of new units that were being sold to burn waste fuels. Burn trials conducted at both plants demonstrated the ability to burn RDF.

Solid waste disposal is a particular problem in the Minnesota counties of Ramsey and Washington, which includes the city of St. Paul. A state mandate issued in 1980 declared that all waste must be delivered to a resource recovery facility by 1990. Existing landfills were full or nearly full. Carving out new ones is costly because of environmental restrictions and controls. Also, hauling distances increase as landfills are being located well away from metropolitan areas.

It was clear to NSP that an energy and material recovery program involving municipal wastes was needed. Thus, they began to consider proposals for processing municipal solid wastes (MSW).

The RDF Solution

In mass burning, refuse in its as-received, unprepared state undergoes selective removal of bulky items such as refrigerators, mattresses, etc., with the remainder being fed into a furnace from which other noncombustibles are discharged for disposal following combustion of the total feed mass. The RDF method further refines the as-received refuse by shredding, magnetically separating the iron, and by employing multiple stages of screening and air classification. The various separated streams are reclaimed to yield recyclable products and a fuel. The fuel can then be burned in a conventional stoker-fired boiler dedicated to RDF combustion.

NSP contracted with the two counties to provide solid waste processing service for 20 years. During the planning, design, and construction of the processing facility, the 35-year-old boiler plants were redesigned and modified. The utility also contracted with three boiler vendors to perform engineering studies covering the conversions from coal to RDF. Ultimately, Babcock & Wilcox was selected to redesign the plants and provide the material to permit conversion of these four boilers from coal firing to RDF. The objective of the repowering was to burn 15 tons/hr of RDF for each boiler.

This paper discusses the plant design decisions, specifics of the steam generator design modifications, construction and operating problems/solutions, and presents the expected versus initial performance attained.

FUEL PROCESSING SYSTEMS

RDF Facility

The Ramsey/Washington County Resource Recovery Facility, which is owned and operated by Northern States Power, is an RDF processing plant located in Newport, Minnesota. Newport is approximately five miles southeast of the St. Paul metropolitan area. This location was selected primarily because it is centrally situated to the MSW supply and convenient to both the Red Wing and Wilmarth steam plants.

The Resource Recovery Facility is a "state-of-the-art" plant wherein 1000 TPD of MSW are received and processed into approximately 700 tons of fuel which is shipped to one or both of the power plants.

MSW is received at the processing plant in the raw form from both the counties and private residents. The MSW is dumped from the county trucks onto a tipping floor, from where it is fed by front-end loaders onto a series of infeed apron conveyors. Grapple cranes are used to remove large nonprocessible, noncombustible materials (i.e., refrigerators, waterheaters and other large ferrous materials). The apron conveyors feed the MSW into a flail mill, which shreds the material and discharges it to a belt feed conveyor where a magnetic separator removes nearly all of the ferrous material. Then the feed conveyor moves the material to a series of disc screens, a secondary shredder, and air classifiers where most of the remaining noncombustibles are removed and the material is properly sized. The nonferrous, noncombustible materials (also called heavies) are conveyed from the air classifiers to a Residue Loadout Trailer for disposal at an off-site landfill. The ferrous materials are conveyed to a load-out trailer for off-site recycling. The remaining product is RDF, which is conveyed on a belt conveyor to the RDF loading area.

The RDF is transported to the Red Wing and Wilmarth Steam Plants by a fleet of 20-ton, enclosed, RDF transfer trailers.

RDF Transport and Delivery

The RDF transfer trailers are specially designed for loading, transport, short-term storage and unloading of RDF. Each trailer can hold approximately 75 cu yd of RDF. The trailers are loaded from the back. A ram-type compactor pushes the fuel into the trailers, compacting the fuel enough to ensure that the truck is completely filled to capacity, yet is not packed so tightly as to hinder unloading or handling at the plant sites. The fronts of the trailers are equipped with deflectors that prevent overcompacting of the trailers when loading, and the trailers are equipped with hydraulic rams.

A total of 50 RDF and ash disposal trucks arrive daily at the Red Wing Station. The RDF is delivered to a building which contains a live-bottom receiving pit. This receiving building is large enough to accommodate up to 20 RDF trailers at the same time. Unloading from individual trailers is automatic and is monitored, as necessary, by surveillance cameras or by receiving area operators. The receiving area presently accommodates 10 trucks. Filled trailers are stored at the Newport Facility with Red Wing deliveries established to meet actual firing rates.

Fuel Feed System

Upon arrival at the facility the RDF trailers are unloaded, according to fuel demand, directly into the receiving pit. The bottom of the steel-lined receiving pit is a walking floor similar to those in the RDF transport trailers. These walking floors are operated when necessary to supply fuel onto the truck-unloading apron conveyor. A scalping roll over the apron conveyor effectively breaks apart the clumps of RDF into their original size distribution.

The apron conveyor discharges onto the RDF transfer conveyor, which is located in the former coal gallery at the Red Wing Plant. The existing coal transfer conveyor was removed and replaced by a new, 54-in. belt conveyor. The transfer conveyor is approximately 324 ft (horizontal length) long and conveys the RDF from the receiving area into the boiler room, in the area of what was once the existing coal bunkers. The coal bunkers were removed to make room for the new fuel feed bins and distribution conveyor. The head end of the transfer conveyor is now equipped with a self-cleaning magnet. The prime separation is done at the RDF processing facility. The purpose of the magnet is to remove as much residual ferrous material as possible. Ferrous materials and aluminum can plug or restrict fuel feed equipment and/or plug undergrate air ports if they melt due to the intense heat on the grate.

The transfer conveyor discharges onto the distribution flight conveyor (see Fig. 1 for a schematic diagram of the fuel feed system) which is common to both units. This conveyor feeds the fuel as necessary to the fuel feed bins. Slide gates in the bottom of the conveyor control the feed of fuel to each fuel metering bin.

Fuel is fed to each boiler by two (per unit) fuel metering bins. Each bin has a capacity of 2½ tons and each has a live bottom consisting of six variable speed screw feeders. The rate of fuel feed into the boilers is controlled by the speed of these screw feeders, which, in turn, is controlled by the new combustion control system. The metering bin screw feeders discharge into a pant-leg type section of chutework, where each leg discharges into an air swept spout-type fuel feeder. The four air swept spouts (per boiler) distribute the fuel in the furnace and are located on the stoker front, just above the grates. Each feed chute is equipped with a balance draft damper to provide a boiler seal and prevent back drafts and fires in the fuel feed system in the event of swings in the furnace pressure.

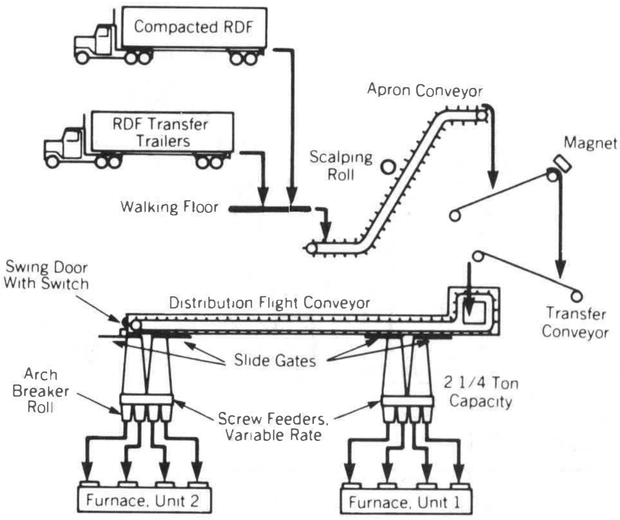

FIG. 1 RDF RECEIVING AND CONVEYING DIAGRAM

Ash Handling System

Bottom ash, fly ash, and boiler ash are conveyed by a series of mechanical flight conveyors (Fig. 2). The bottom ash conveying system consists of a 3-ft submerged drag chain conveyor. The flooded upper trough quenches the ash as it falls off the grate and also provides an effective boiler seal. The ash is pulled from the submerged trough by the flights and dewatered on the 50-ft inclined (40 deg. from horizontal) section of conveyor. The conveyor operates at 8 ft/min to minimize wear and maximize dewatering of the ash by increasing the time the ash is on the dewatering section. Dewatering of the ash to approximately 25% moisture content is important to minimize the potential for freezing in the trucks. All conveyor wear parts are of abrasion-resistant material (400 Brinnel).

Boiler ash, including air heater economizer, superheater hopper and siftings ash, is carried to the bottom ash conveyor by enclosed dry mechanical conveyors.

STEAM GENERATOR DESIGN MODIFICATIONS

Background

RDF has been burned in various ways since the late 1960s, both alone and in combination with other fuels. The Red Wing and Wilmarth repowering projects have benefitted from the earlier experiences, which provided the design approach used for the repowering. Most combustion problems (slagging, fouling, erosion/corrosion) have been remedied by improvements in process facilities and increased conservatism in the steam generator design. The project is unique in that it is the first to utilize existing steam generators [2].

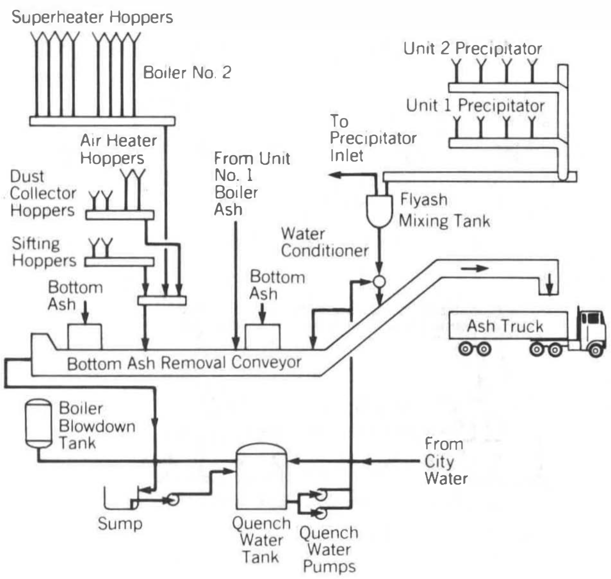

FIG. 2 ASH RECEIVING AND CONVEYING SYSTEM

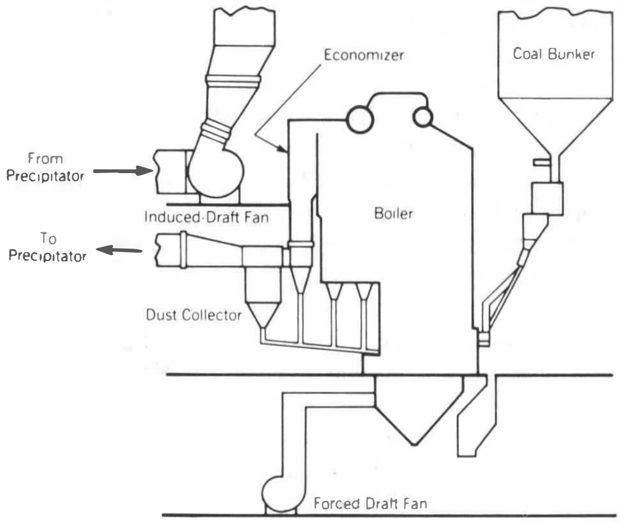

FIG. 3 PRECONVERSION BOILER OUTLINE

Boiler Modifications

The existing boilers are balanced draft with variable speed I.D. fans. New electrostatic precipitators were installed in the early 1980s. The existing furnaces are of tube and tile construction. Neither plant was equipped with steam temperature control. The existing Wilmarth boilers were equipped with bare tube economizers. The existing Red Wing boilers had extended surface economizers. None of the boilers were equipped with air heaters. Figure 3 shows the preconversion boiler outline that is typical of both plant sites.

Meeting the objective of burning 15 tons/hr set the required furnace size, and operating experience dictated the addition of selective corrosion protection. Lower furnace operating in an alternating reducing oxidizing atmosphere required overlay and the superheater was designed utilizing alloy materials in certain areas. The existing furnace had to be enlarged to meet the desired objective throughput, while at the same time insuring adequate tube wall life. Experience indicated that a furnace exit gas temperature (FEGT) of 1600°F is a practical maximum, given the economic trade-offs of alloy versus conventional gas-side tube materials for this corrosive environment. The up to 800 ppms of chlorides in the flue gas stream preclude the use of traditional stainless materials as the optimal tubing material choice. Ash materials in the RDF demonstrate slagging and fouling characteristics, not unlike coal, which must be removed to permit heat transfer to take place. It is not desirable to clean superheater and screen tubes to bare metal due to the accelerating effect this would have on corrosion.

The cyclic removal of protective oxide coatings has not retarded corrosion. The designer's experience indicates that, at present, the best FEGT to balance the superheater corrosion-slagging-fouling/burnout concern is attained by limiting the furnace gas outlet temperature to 1600°F at maximum continuous rating (MCR) on RDF.

It is desirable to reduce release rates for RDF below these rates for coal because RDF is a more difficult fuel to burn and generates corrosive gases. Longer residence times will aid combustion and reduce FEGT and associated furnace slagging. Additional furnace height could be gained by extending the furnace downward into the basement, removing the traditional stoker coal-bottom ash hopper and replacing it with a low-head submerged chain conveyor. Design evaluations indicated that the 15 tons/hr could be combusted and the FEGT of 1600°F not exceeded (Fig. 4).

Other Furnace Modifications

The 14-ft furnace extension was fabricated from membrane panels and overlaid with 50 mils of high nickel alloy in selective areas to inhibit corrosion. The connection to the existing tube and tile "upper" furnace was accomplished, using a full periphery ring

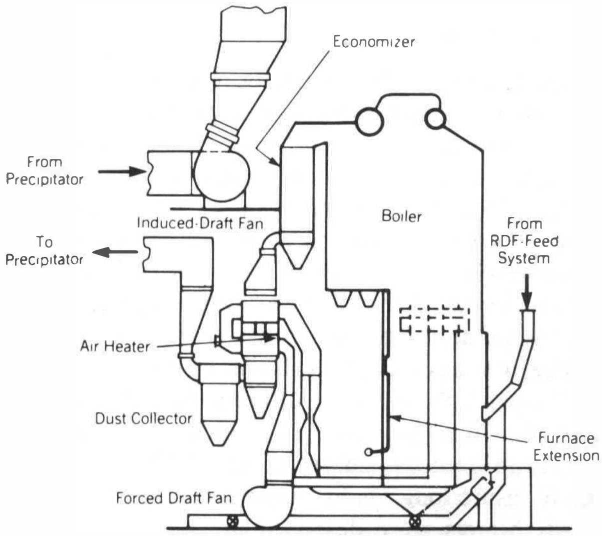

FIG. 4 POST CONVERSION BOILER OUTLINE

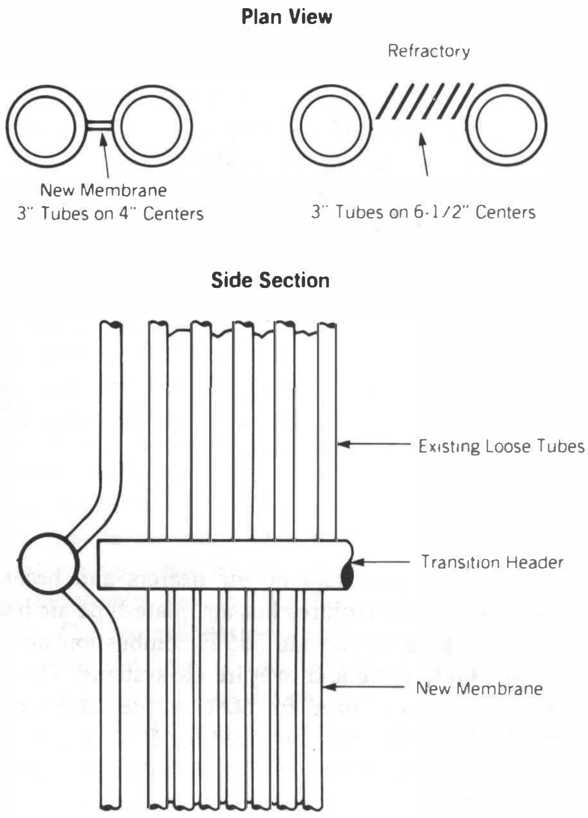

FIG. 5 TRANSITION NEW FURNACE TO OLD

header, located outside of the heated area. The header permitted the former mismatch of tube spacings (old 6½ in. to new 4 in.) to be matched. The water supply to the furnace extension is from the four new lower four-wall headers (Fig. 5). The extension is supported by spring hangers from existing support steel.

The boiler outlet screen was redesigned to increase the side spacing (now 18 in. total), and thereby improve cleanability and increase the shielding of the superheaters from direct radiant heat transfer. The increased shielding was attained by rerouting two rows of generating tubes, turning them into new screen tubes.

Combustion System

The air, firing, and fuel feed systems all had to be modified to process the new fuel. The RDF design heating value of 5750 Btu/lb would vary due to the changes in moisture and constituents as a function of the time of the year.

Natural gas firing capability was maintained to provide heat for start-up and for load carrying as a standby in the event RDF was not available. There were no plans to co-fire these fuels.

Stoker

The furnace enlargement forced the lowering of the former coal traveling grate stokers by 14 ft. That relocation permitted opening the ash discharge height to 18 in. to insure free ash discharge. That increase in turn required a new flat arch (to provide radiation shielding), new stoker front extension, and a new upper front support for the fuel feeders. Existing grate bars were retained and, as they failed, were to be replaced with ductile iron. New rear tuyeres were installed, the rear coking section was removed, and new lower front seal, and new grate wear strips were installed to handle the new fuel.

Fuel Feed

The distribution of the RDF on the grate is critical for proper combustion efficiency and to minimize the potential for lower furnace corrosion. The fuel feed was integrated with the air system to insure complete mixing, combustion, and to minimize corrosion due to reducing conditions. A multilevel, multiported heated, high static overfire air system (OFA) was installed to insure that the best possible mixing would be available so that all the advantages of the increased fuel preparation costs could be realized. The OFA system is intended to aid in keeping the RDF particle in suspension—enhacing dehydration—and by creating turbulence which increases its residence time.

Four stoker air swept spouts per unit were installed across the front face. Spouts measuring 18-in. × 30-in. had been used previously, and are the size applied to this project. The air swept spouts must distribute the fuel with some of the fines going into suspension, all the heavies on the grate, and the intermediates mixed. Grate speed has been increased from 8 ft/min to a 20-ft/hr maximum rate. Feed to the spouts is by two live bottom bins per boiler.

Air System

The existing unit had no air heaters and because RDF combustion requires hot air, plate-type air heaters were added to provide 355°F combustion air for both the undergrate and overfire air systems. The undergrate system is sized for 50% of the total air required. The OFA system is sized for 50% of the total air required. The objective of the combustion system, air plus fuel feed, is to maximize suspension burning of the fines while maintaining the combustion on the bed. The highly turbulent OFA system has been successfully demonstrated on RDF projects. The three rows of OFA nozzles plus the use of the air in the feed spouts has evolved over the years as an excellent mixing system. The OFA system required a fan to provide high static pressure to obtain the design nozzle velocities to insure penetration. The existing forced draft fan(s) had to be replaced with a higher static-pressure (now 5-in. H_2O) fan to develop additional static to overcome pressure drops associated with the new air heater and the thicker ash bed on the grate. A new OFA fan using hot FD fan discharge air was supplied to provide the required overfire air.

Superheaters

The existing superheaters have been replaced with a new counterflow single-pass design, with increased clear side spacing. The coolest steam is in the hottest gas path and will act to lower tube metal temperatures. The original design had 850°F final steam temperatures; the redesign provides 700°F final steam temperature, which reduces metal temperatures, reducing both the fouling and corrosion potential. Spray attemperation is used to provide a final steam temperature control range, and alloy steel is utilized where tube metal calculations dictate.

Generating Bank

Internal tile baffles originally installed to promote cross-flow generating-bank heat transfer were removed. The generating bank is now a single-pass, once-through, design that reduces erosion and plugging potentials. The resulting reduction in heat transfer has been made up by adding three rows of generating bank tubes which utilize the drum holes created by the relocated screen. The additional generating surface decreases gas temperatures entering the economizer.

The existing economizers—one, an extended surface (Wilmarth); the other, bare tube with high gas velocities (Red Wing)—were replaced with bare tube types spaced to limit gas-side velocities at MCR to 30 ft/sec to insure long life by minimizing erosion.

Air heaters were described in the section on air system and are of the plate-type design. Regenerative air heaters had been used with RDF previously but were located in a clean gas stream after the electrostatic precipitators. Plugging of the hot, inlet side, due to oversize particulate carryover, was of high enough potential to eliminate a regenerative application. Tube and shell design would have been acceptable, but the plate type offered simplicity and equivalent performance. Gas temperature has been reduced to 450°F, which matches the existing electrostatic precipitator operating gas temperature. Gas side erosion is of concern, and erosion shields are being used on the leading edge of each air heater plate to minimize this possibility. Existing variable speed I.D. fans and electrostatic precipitators have been reutilized.

CONSTRUCTION

Demolition of the boiler's bottom section and removal of asbestos were the first steps in construction. The stoker support steel was to be reused and had been match-marked for ease in reassembly. The match-marking, however, was not entirely accurate and time was lost during the reassembly.

The sequence for erection had Unit 2 reconstructed first which forced all new pieces to be routed past Unit 1. Access was limited and space extremely constrained when components arrived. Certain interferences also became apparent; for example, cable trays, drain lines, blowdown piping, natural gas line, sootblowers for adjacent units, and both fuel and ash handling equipment all required interface connection, which demanded redesign time and additional costs. One specific example is the apron conveyor portion of the scalping conveyor, which is a device that takes RDF off a walking floor and transports it to the transfer conveyor. It could not be field assembled without torch-cutting the pieces apart, partially assembling the sections and re-welding the equipment. Though the procedure of assembling the apron conveyor appeared to be a four-day job, unsuccessful attempts consumed four man-weeks.

START-UP

Construction problems delayed start-up by approximately 3 months. Boiler hydrostatic testing was complicated by the combination of old, existing tubing and the new tubing. The boiler was brought to hydrostatic test pressure (1.5 × operating pressure). On boiler No. 2, only a few handholes and small valves were found to be leaking. However, on boiler No. 1, during a pre-hydro test, an old tube in the generating bank failed. Cause was attributed to localized tube erosion due to sootblowers. Chemical cleaning and steam blows were successfully completed in one week for each unit.

All existing plant systems were checked out prior to first fire of RDF. The turbine lube oil was found to be excessively dirty at both plants. At Red Wing the cause was attributed to the location of the reserve oil tank beneath the operating floor which allowed floor sweepings to enter the oil tank. A filtration system was installed and the oil cleaned to within guidelines. At Wilmarth, filtration failed to clean the oil. Further investigation revealed that the old oil piping was scaled internally, and had to be totally replaced.

The Overfire Air System

The overfire air system, as designed, supplied both the windswept spouts and the overfire nozzles. The windswept spouts required separate flow control to permit optimum distribution, and so the necessary dampers and damper drive will be retrofitted to permit this to occur.

The screw feeders are encountering a larger RDF particle size than that for which they were designed. Initial RDF supply, running at 10-in. minus, was oversized as the feeders were designed for a 6-in. maximum. At higher loads, the screw would stop feeding and "plugging" occurred. RDF sizing is being adjusted at the preparation plant, and this problem is expected to be resolved when the feed size meets specification.

Operation

The operation of the RDF handling system with the walking floor and metering bins was a new experience for NSP. Consequently, checking out this system prior to the first RDF fire was prudent. A trailer of RDF was unloaded onto the walking floor, conveyed to the scalping conveyor, onto the transfer conveyor and into the plant. The fuel was fed into the metering bins and diverted from the pant legs (before the air swept spouts) onto a temporary conveyor which went outside to an open top trailer. In spite of some internal pessimism, this jury-rigged check-out system worked and permitted system checks to proceed without the need of actually firing the RDF.

A new era for an old plant (Red Wing) was begun with the first fire of RDF in May 1987. Operations and start-up engineers were stationed at critical points along the RDF feed route. All systems were operated in a manual mode initially, which necessitated many extra people on shift. One operator directed truck traffic, trained truck drivers to hook up hydraulic lines and monitored the walking floor and scalping conveyor. The operator assigned to monitor the stationary magnet at the head of the transfer conveyor quickly discovered a flaw in the design. The RDF specification stated that the RDF would include no more than 1% metal. One percent of 700 tons per day is a large quantity. The RDF system had to be shut down every 15 min to manually clean the magnet. A self-cleaning magnet has since been installed and Red Wing recycled ferrous material now fills a 20 cu yd dumpster in 1½ days.

Operators were also assigned to the distribution conveyor at the top of the metering bins. It was soon discovered that the bin level indicators were not reading accurately. Two causes were identified: *(a)* the distribution of RDF in the metering bin; and *(b)* the location of the electronics package in a high ambient temperature zone. The 90% angle of repose of the RDF was so steep that the initial placement of the bin level indicators could not read the actual bin level. The indicators and electronics have been moved, and an additional high level trip was added. A diverter plate was added to the bins to help direct the RDF flow to the opposite side of the bin, The feed to the bins was automated to keep the bins at 90% full.

Another area discovered to require frequent monitoring by operators was the ash bed on the grates. Maintaining a bed of 6–8 in. insulates the grates from the high temperatures. Plugging of the holes in the grates has been noticed, and after three months of operation, 15% of the holes were found to be plugged. These have been drilled out and do not appear to be replugging. When the holes were plugged, good undergrate air distribution became difficult to attain. The units are now on CO_2 continuous monitor/control and

TABLE 1

	Coal Design	Predicted RDF Design Perf.	Actual RDF Performance
Superheater Steam Outlet Temp.	825°F	700°F	720°F
Superheater Outlet Steam Flow	125,000 lb/hr	105,900 lb/hr	109,000 lb/hr
Superheater Outlet Steam Press.	625 psig	625 psig	604 psig
Economizer Inlet Feedwater Temp.	330°F	330°F	340°F
Economizer Outlet Temp.		359°F	378°F
Furnace Exit Gas Temp.	1820°F	1567°F	1480°F
Boiler Outlet Gas Temp.		729°F	660°F
Economizer Exit Gas Temp.	417°F	648°F	590°F
Air Heater Exit Gas Temp.	Not Applicable	450°F	420°F
Undergrate Air Temp.		353°F	315°F
Boiler Efficiency	80.15%	69%	70%
Effective Furnace Volume	8,250 cu.ft.	12,086 cu. ft.	
Furnace Liberation Rate	23,600 Btu/hr/ft^3	13,652 Btu/hr/ft^3	
Grate Heat Release	638,954 Btu/hr/ft^2	539,216 Btu/hr/ft^2	
Excess Air	30%	50%	65%
Economizer Gas Flow	229,000 lb/hr	234,400 lb/hr	
Combustion Air Flow	188,000 lb/hr	187,600 lb/hr^2	
MW			9.9
Overfire Air Static			23" H_2O
Undergrate Delta P			1.3" H_2O

Data is from the Red Wing Unit 2. Wilmarth data is comparable.
Overfire air/undergrate ratios of 51/49 typical

the undergrate air distribution is not troublesome. The 4 months of experience have resulted in smoother operation as well.

At loads (30–40% MCR) natural gas is utilized to aid in keeping the furnace hot. Operation at the lower loads has indicated that the OFA and undergrate air must be adjusted to avoid chilling the bed.

We are continuing to discover new ways to optimize boiler operation. Initially, 13 people/shift were required, at this writing 5 people/shift are sufficient with an intent to further improve efficiencies. This section has provided a candid review of the initial problems encountered and the solutions applied. The important fact is that RDF is being successfully converted to energy at design rates.

EXPECTED PERFORMANCE vs ACTUAL PERFORMANCE

Table 1 compares the performance of the original coal design with that of the predicted RDF design and with the actual preliminary RDF performance.

SUMMARY

The repowering of the Red Wing and Wilmarth power plants to fire refuse-derived fuel demonstrates how NSP was able to alleviate an increasing problem of solid waste disposal.

The conversion project is on time, within budget, and presently has all four steam generators on line firing refuse. The extensive modifications to the steam generators will permit NSP to use the RDF it processes from the Ramsey and Washington Counties' trash to generate power for years to come. The steam generator modifications have resulted in applying conservatively designed upgrades to insure the high reliability necessary for NSP to meet the contracted commitments of trash acceptance.

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