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FINE WALL (22 BWG) 90-10 AND 70-30 COPPER-NICKEL CONDENSER TUBE USE AT THE HENNEPIN ENERGY RESOURCE COMPANY POWER PLANT

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ABSTRACT

Hennepin Energy Resource Co. (HERC) has been operating its six year old 38MW Minneapolis, MN waste to energy power plant since October, 1989 with twenty-two gage wall (22 BWG - 0.028" wall) 90-10 and 70-30 copper-nickel condenser tubes. Twenty gage wall (20 BWG - 0.035" wall) 90-10 and 70-30 copper-nickel tubes have been used successfully in both sea water and fresh water power plant condensers since the early 1970's as both new construction and replacement tubes. However, this is the first, known to the authors, use of 22 BWG wall 90-10 and 70-30 copper-nickel condenser tubes in a power utility condenser although there certainly are locations where this material combination and wall thickness would make a good choice. This paper describes the plant with emphasis on the condenser and its tubes, the condensate side and water side interfaces, tube performance, and the copper-nickel alloy features.

INTRODUCTION

Each man, woman, and child in the United States generates about 4 pounds of garbage daily, the great majority of which is disposed of in landfills. But landfill capacity is diminishing in some areas of the country and the nation now faces a challenge: how to safeguard the environment while maximizing the potential uses of solid waste.

Hennepin County, a national leader in solid waste management, established an integrated solid waste management system in which non-recycled waste is safely combusted and its energy value retrieved at a state-of-the-art waste-to-energy facility; recyclables are collected, sold, and processed into usable goods; common household contents, such as cleaning solvents, batteries, and motor oil, are collected separately for safe disposal; and combustion ash and non-combustible waste are deposited in a properly lined landfill.

Hennepin County's waste-to-electric-energy facility anchors this fully integrated solid waste management system, processing about one-third of the County's waste. Located on the edge of downtown Minneapolis, the facility is owned and operated by the Hennepin Energy Resource Company, L.P., a subsidiary of Ogden Projects, the country's largest waste-to-energy company. The facility returns more than two-thirds of energy sales revenues to the Hennepin County Department of Environmental Management.

Although a few instances exist where 20 BWG wall 90-10 copper-nickel condenser tubes have been installed prior to 1970, the concept was initiated in 1972 [1,2] and continued to develop during the decade of the 1970's and into the 1980's until now it is a well established and proven material application. It has been extensively used in both new construction and retubing applications with seawater, brackish water, fresh water, and cooling tower water cooling.

Lighter wall copper alloy tubes are commonly used in air conditioning applications. It is common, for instance, to supply 0.032" (21 BWG) and even 0.030" wall 90-10 copper-nickel tubes for heat pump applications and 0.022" (24 BWG) wall 95-5 copper-nickel tubes for lithium bromide chiller applications. The Hennepin Energy Resource Co. facility is the first electric power generating plant condenser application for 22 BWG wall 90-10 and 70-30 copper-nickel condenser tubes known to the authors.

THE HENNEPIN POWER PLANT

The Hennepin resource recovery facility, Figure 1, began commercial operation in October, 1989 and converts up to 1212 tons/day and 365,000 tons/year of solid waste to salable energy. While the facility is capable of producing 38 megawatts of electricity, it runs on the power it produces with resource recovery operations consuming about four megawatts. The remainder is sold to the local utility and used to power area homes and businesses, thus offsetting the burning of non-renewable fuels, as well as reducing related emissions. As of December 31, 1995, the plant has generated 1,529,597,000 kwh of electricity, saving the equivalent of approximately 1,100,000 tons of coal or 2,600,000 barrels of fuel oil and disposed of 2,197,066 tons of waste, conserving approximately 4,200,000 cu yds of landfill.

The facility utilizes the mass burn combustion technology mentioned in Reference 3 to reduce the volume of delivered waste by 90%, see Figure 2. Waste is combusted at furnace temperatures exceeding 1800 °F and reduced to an inert ash residue. Before leaving the facility, combustion air is directed through technologically advanced air pollution control equipment including dry gas scrubbers and fabric filter baghouses. In addition, the facility uses anhydrous ammonia injection into the furnace to reduce NO_x emissions and powdered activated carbon injection at the inlet to the scrubbers to reduce mercury emissions. Facility emissions and waste water discharges are strictly regulated by state and federal agencies, as are handling and disposal of combustion ash.

THE CONDENSER

The Hennepin Energy condenser is of the cylindrical profile, see Table I. Water flows in a two pass configuration: in at the bottom of one end, through the lower bank of tubes to the return end, returning by the upper bank of tubes to the discharge end. Water flow is 27,160 gpm which represents a nominal velocity of 7 fps through the tubes. Steam flow is approximately 300,000 lbs/hour with a normal turbine back pressure of 2.5 inches of mercury. There are (9) nine support plates with a nominal 26" spacing over the 22 foot long tubes.

In addition to its normal operation, the condenser is expected to be capable of receiving instantaneous full turbine inlet steam flow in the event of a turbine trip, and full steam flow from both steam generators during periods of turbine/generator maintenance. The HERC facility has no separate by-pass or dump condenser but relies on a full flow steam conditioning valve to reduce pressure and temperature to approximately 50 psig saturation conditions prior to admission to the main condenser. The main condenser is designed with distribution headers and surface area to accommodate these conditions. Full load turbine trips put added stress on the condenser, its tubes, and the tube-to-tubesheet joints. Turbine inspections are accommodated by isolating the turbine outlet from the condenser by means of a specially designed guillotine isolation damper [4], which allows turbine cover and rotor removal while operating at capacity with reasonable condenser pressures and temperatures.

The condenser tubes are:

Main Body:
6342 x 3/4" dia. x 22 BWG (0.028") avg. wall x 22' 2-1/2" long.
Alloy: UNS C70600 90-10 copper-nickel.
Temper: As-welded, Light Cold Worked.
Specification: ASTM-B-543 "Welded Copper and Copper-Alloy Heat Exchanger Tube".

Air Removal Section:
238 x 3/4" dia. x 22 BWG (0.028") avg. wall x 22' 2-1/2" long.
Alloy: UNS C71500 70-30 copper-nickel.
Specification: ASTM-B-111 "Copper and Copper-Alloy Seamless Condenser Tubes and Ferrule Stock".

Tube-to-tubesheet joints were designed to Heat Exchange Institute (HEI) Standards [5] and support plate spacing, a vibration consideration when using reduced wall tubes, was calculated using HEI principles [5,6]. There were no special methods used during rolling-in of the tubes to the tubesheets and there has been no vibration damage to the condenser during its six years of service.

WATER SIDE

The water side flow arrangement is shown in Figure 3. Two 350 hp pumps provide the 27,160 gpm flow at approximately 30 psig positive pressure at the condenser. A forced draft cooling tower is used with blowdown to the storm sewer and make-up from the Minneapolis city water supply. The tower is of a wet-dry design, with heat exchangers for cold weather vapor plume abatement. Since the blowdown is required to be sent to the storm sewer, its water treatment program is appropriately designed for discharge to the Mississippi River system. The pH of the cooling water is controlled by addition of blended organic phosphonates and synthetic anionic polymeric dispersants. Five to seven cycles of concentration is targeted and normal pH range between 8.5 and 8.8 is achieved without addition of sulfuric acid. A hetero-cyclic azole is also added to protect copper and copper-alloy metals. Blended anionic and nonionic polymeric dispersants are also added to effectively disperse calcium phosphate and iron which is normally found in cooling water systems. Isothiazolone biocide is batch-fed as required with appropriate holding times for microbiological control. Chlorine added by Minneapolis for drinking water treatment is scavenged prior to discharge to the storm sewer system.

CONDENSATE SIDE

The condensate, feedwater, and steam system is shown in Figure 4. There are one each low and intermediate pressure feedwater heaters and one deaerating heater and storage tank which discharges to the inlet of the boiler feedpumps. Boiler water make-up comes from two 70 gpm demineralizers which accept Minneapolis city water input. There is one condensate polisher which accepts a 10% condensate side-stream flow.

Oxygen scavenging is accomplished by the use of a blend of di-ethyl-hydroxyl amine (DEHA) fed into the condensate system downstream of the hotwell. This injection point was selected in order to protect the feedwater heaters and piping. A volatile neutralizing amine product is added to the feedwater system downstream of the feedwater pumps. Condensate/feedwater pH is maintained between 8.2 and 9.2. The steam generators are protected by a blend of polyphosphate and sodium hydroxide with a polymeric sludge dispersant injected into the steam drum with the feedwater. Since make-up levels rarely reach 2%, boiler OH^- alkalinity can be maintained between 5 and 10 ppm.

FEATURES OF THE COPPER-NICKEL ALLOYS

There are several copper alloy materials that are identified as copper-nickel alloys, see Table II. However, the most commonly used copper-nickel condenser tube materials are 90-10 (UNS C70600) and 70-30 (UNS C71500) copper-nickel. For condenser applications, tubes of these materials are commonly supplied in 18 BWG (0.049"), 19 BWG (0.042"), or 20 BWG (0.035") wall thicknesses[7]. As replacement tubes (retubings), it is common for 19 BWG or 20 BWG wall 90-10 copper-nickel to be selected as the replacement material for 18 BWG wall admiralty tubes whose useful life has been met.

A unique feature of 90-10 and 70-30 copper-nickel is their wide range of application areas. They may be used in (clean) waters of high total dissolved solids (TDS), such as seawater (30,000ppm TDS, 19,000ppm chlorides), to fresh water (<1000ppm TDS) from a wide range of sources, in addition to cooling tower applications. On the condensate side, the copper-nickel alloys may be used in the main heat transfer section of the condenser, the air removal section, and the peripheral sections due to their high resistance to ammonia containing compounds and steam impingement, Table III.

COPPER-NICKEL CONDENSATE SIDE

The copper-nickel alloys, UNS C70600 90-10 copper-nickel and UNS C71500 70-30 copper-nickel are far superior to the other commonly used copper and brass alloys in resistance to ammonia on the condenser condensate side. Tests conducted[8] in 1000 ppm (aerated) ammonia (pH = 10.9) show that 90-10 copper-nickel is approximately 25 times better than admiralty and 70-30 copper-nickel is approximately 125 times better than admiralty in this environment, as shown in Figure 5. The copper-nickel alloys stand apart from the traditional copper alloys like admiralty brass, aluminum brass, or arsenical copper in ammonia resistance. In addition, the copper-nickel alloys are essentially immune to stress corrosion cracking (SCC) in an ammonia environment[9,10], as shown in Table IV.

COPPER-NICKEL WATER SIDE

The copper-nickel alloys were originally developed as seawater condenser tube materials and found wide use in both land based and shipboard condensers. They are frequently used in both once through and recirculating cooling water systems where the water has a broad range of total dissolved solids (TDS). To be successful, the copper-nickel condenser tube material must be resistant to selective attack such as pitting and erosion in addition to being resistant to biofouling for good heat transfer characteristics.

90-10 copper-nickel has been reported to have been installed in two units of a fresh water cooled power plant in the United States over 40 years ago. Test tubes of 90-10 copper-nickel were installed in a power plant on the Ohio River in 1949. With the long passage of time, it is difficult to confirm the performance of these tubes. However, in 1981, both sites were reported to be performing well. A more timely installation with which the authors are familiar is the use of 20 BWG wall 90-10 copper-nickel throughout the condensers of two 1300MW supercritical generating units at the Tennessee Valley Authority Cumberland Station which started operation in 1973. It is our understanding that these tubes have been performing well over their 22 year life, to date.

COPPER-NICKEL MECHANICAL PROPERTIES

The mechanical properties of the condenser tube material are very important factors in the condenser design and condenser tube installation. A condenser tube must resist tube vibration in service while being capable of making a satisfactory rolled tube-to-tubesheet joint. 90-10 copper-nickel has a modulus of elasticity of 18×10^6 psi while 70-30 copper-nickel has a modulus of elasticity of 22×10^6 psi. These are both higher than the other copper alloys commonly used in power plant condensers, such as admiralty brass, and provide the required stiffness for service and ductility for installation.

Figure 6 shows a relationship between tube support plate spacing, tube wall thickness, and steam velocity for 90-10 copper-nickel tubes[11]. It is especially important when retubing an 18 BWG admiralty brass tubed condenser, for instance, with 20 BWG or 22 BWG wall copper-nickel tubes to be certain that a vibration problem is not created. As an approximate guide, if the existing 18 BWG wall admiralty brass condenser tubes do not have a vibration problem, it is unlikely that replacement 20 BWG wall 90-10 copper-nickel condenser tubes will have a vibration problem. Further, vibration problems are typically localized, i.e.: between one or two support plates, and are also typically isolated to the outer few rows of tubes in a tube bundle. If vibration problems are considered possible, the tube bundle may be selectively "staked" to prevent damage.

The tube-to-tube-sheet joint is commonly made with a torque controlled roller expander. Most of these tools have three rollers while some have four or five, the latter for rolling of the more difficult to roll materials. There were no unusual steps taken to roll the 22 BWG wall 90-10 and 70-30 copper-nickel tubes into the tubesheets of the Hennepin Energy Resource condenser. We understand that it is common practice to roll 24 BWG wall (0.022") copper alloy tubes with three roller expanders fitted with a thin wall thrust collar.

COPPER-NICKEL HEAT TRANSFER

One of the principle reasons that the copper alloys have a prominent position for heat exchanger applications, including power utility condensers, is their generally high thermal conductivity, shown in Table V. The Heat Exchange Institute (HEI), after extensive tests and calculations, has recently re-ranked the various condenser tube materials in their ability to transfer heat[5], a portion of which is shown in Table VI. Note that clean, 18 BWG wall admiralty brass is rated as 1.00 and all other materials and wall thicknesses are rated as better (above 1.00) or poorer (below 1.00) in heat transfer performance. 22 BWG wall 90-10 copper-nickel has an HEI rating of 0.98, essentially the same as 18 BWG wall admiralty brass.

In addition to this high heat transfer rating, the copper-nickel alloys, especially 90-10 copper-nickel, have high resistance to biofouling in most waters and, therefore, are able to command high design heat transfer coefficients.

CONDENSER AND TUBE PERFORMANCE

There is no on-line cleaning system at the HERC power plant; cooling water is regularly monitored for fouling and treatment program effectiveness. Condensate is regularly monitored for in-leakage of cooling water as well as other criteria. Corrosion coupons are used and semi-annual water box inspections are scheduled to remove plastic and other debris from the tube sheets. Two eddy current inspections of random tubes have occurred with no defects discovered with the exception of one questionable reading at a support plate. That tube was mechanically plugged as a precaution. There have been no tube cleanings, no tube replacements, and no condenser tube leaks in the history of operation of the facility. Hennepin Energy considers the 90-10 and 70-30 copper-nickel tube performance to be excellent and trouble free.

The design heat transfer has also been excellent. Hennepin has been able to maintain their desired design backpressure of 2.5 inches of mercury under a wide range of operating temperatures. There has been no sign of biofouling or scaling of the tubes.

CONCLUSION

The Hennepin Energy Resource Co. has been successful in turning common waste collected in the Minneapolis area into electrical energy for the region having generated over 1,529,597,000 kwh of electricity, disposed of 2,197,066 tons of waste, conserving 4,200,000 cu yds of landfill space. In addition, HERC has reclaimed approximately 66,000 tons of ferrous steel after the combustion process. This steel is sold to local scrap metal dealers for reprocessing into new steel products, with the revenues returned to Hennepin County.

Over six (6) years of trouble free performance at the Hennepin Energy power plant indicates that 22 BWG wall copper-nickel condenser tubes are not only technically viable for use in electric power generating plants but that they have been properly designed into this application. The fine wall (22 BWG = 0.028") offers additional cost savings over 20 BWG wall (0.035") 90-10 copper-nickel, a common new construction condenser tube material selection and replacement material for 18 BWG (0.049") wall admiralty brass condenser tubes. The copper-nickel alloys provide the favorable heat transfer and biofouling resistance advantages of the copper alloys while offering improved water side pitting and erosion resistance in a wide range of cooling waters. In addition, the copper-nickel alloys possess the resistance to stress corrosion cracking (SCC) and ammonia containing compounds often needed for good condenser condensate side performance. In addition to main condenser tubes, reduced wall copper-nickel tubes may also be considered for use in power plant auxillary heat exchanger applications such as in auxillary condensers, cooling water coolers, recirculating water coolers, bearing water coolers, inter and after coolers, demineralizers, etc. The performance of 22 BWG wall copper-nickel condenser tubes at the Hennepin Energy Resource Company power plant may not be indicative of all installations. Each installation should be technically evaluated. Further, it is always wise, when replacing existing 18 BWG wall tubes with reduced wall tubes, to assure that no vibration or other mechanical problems will be created.

ACKNOWLEDGEMENTS

The authors thank Jorge Comacho, at Ecolaire Corporation, for providing information on the condenser and the isolation damper and Tim Hunter, of ChemTreat, Inc., for providing the boiler system and cooling system schematics and information.

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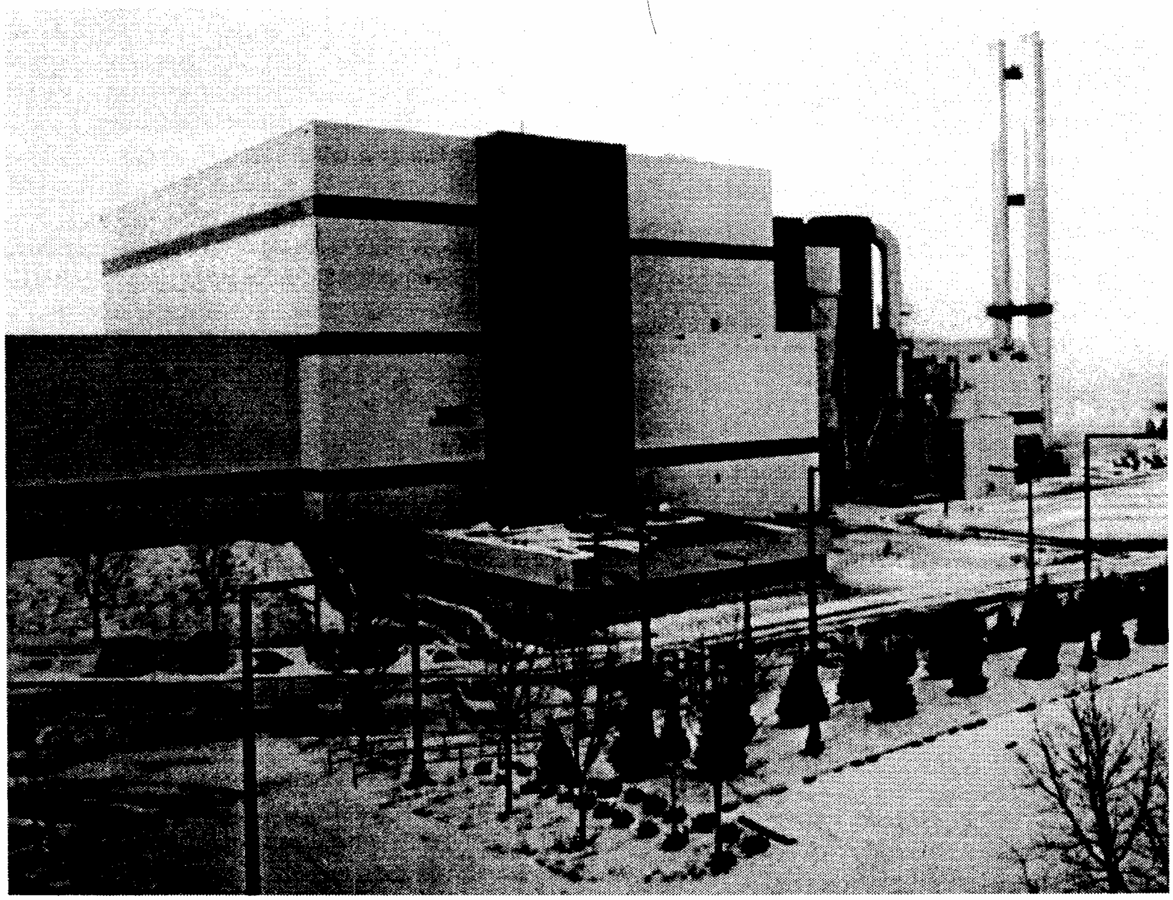
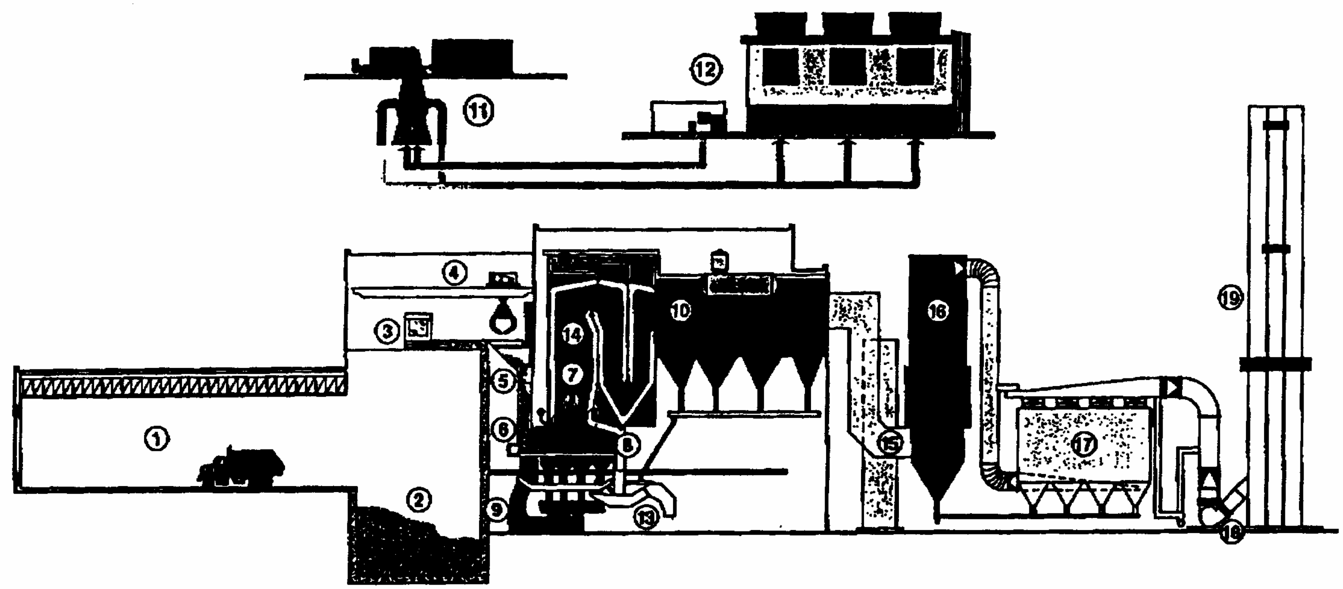


Figure 1. Hennepin Energy Resource Co. refuse burning and electric generating station.



The Hennepin Energy Resource Co., recovery facility is housed to enhance operating effiency, cleanliness and odor control. Trucks enter the **Tipping Hall (1)** and unload directly into the **Refuse Pit (2)**. From the **Crane Pulpit (3)**, an operator controls a twelve ton Bridge Crane (4) with an eight cubic yard grapple to mix the waste in the pit and feed it to the **Feed Hopper (5)**. From the hopper, waste is pushed by a **Ram Feeder (6)** into the **Combustion Chamber (7)** and onto the **Double-Motion Overthrust Grate (8)** where it is combusted at temperatures exceeding 1,800°F. The **Primary Combustion Fan (9)** supplies air beneath the grate. The secondary combustion fan supplies air above the grate to facilitate the combustion process and ensure complete combustion of all volatiles while still in the combustion chamber.

The **Boiler (10)** is designed to recover heat from the combustion of refuse. Steam generated by the boiler can be used directly or fed into the **Turbine Generator (11)** to produce electricity (35 MW - enough electricity to supply about 30,000 homes). The exhausted steam is cooled by water from a **Wet/Dry Cooling Tower (12)** designed to not produce a visible plume in winter conditions.

Bottom ash remaining on the grates after combustion is removed from the combustion chamber by an **Ash Discharger (13)** and then by a conveyor where separation of oversize material and ferrous metals takes place. Oversize and ferrous materials are sent to a scrap metal dealer for recycling.

Ammonia is injected into the **Furnace (14)** to control NO_x in the flue gas. Flue gas exiting the boiler is treated with **Activated Carbon (15)** to absorb mercury in the flue gas. The flue gas then passes through a **Dry Scrubber (16)** where it is treated with a lime based spray to remove gases. Next a **Fabric Filter Baghouse (17)** and **Induced Fan (18)** work like a vacuum cleaner to trap any remaining ash and particulates. Fly ash collected in the air quality control equipment collects in hoppers and is conveyed to and treated in a conditioner and added to the bottom ash as it is conveyed to the ash storage building.

The gas discharged from the air quality control equipment is exhausted through the **Flue (19)** where the continuous emissions monitoring system (CEMS) monitors, logs and reports conditions and quality of the flue gases.

Figure 2. How Hennepin County's waste-to-energy facility works.

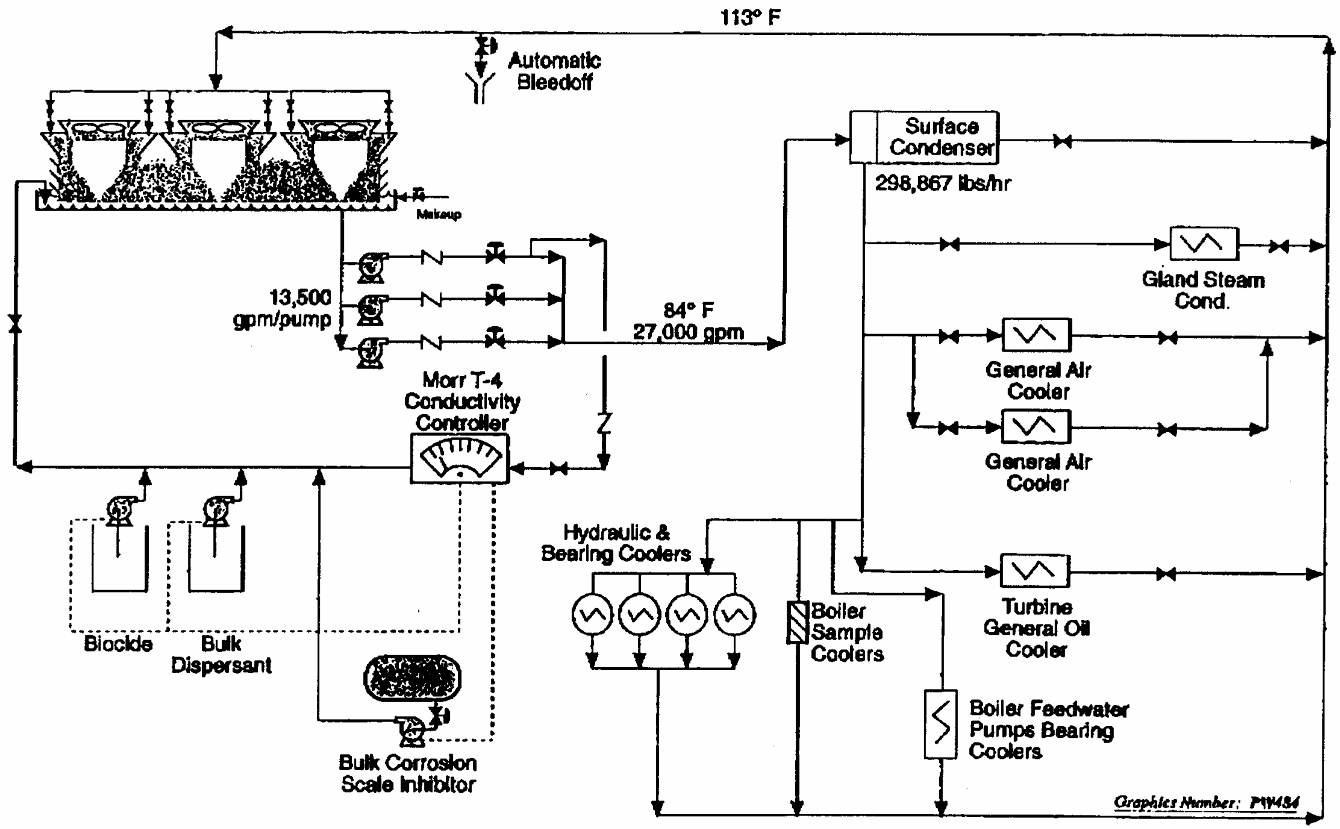


Figure 3. Hennepin Energy Resource Facility Cooling Water System. (Courtesy ChemTreat, Inc.)

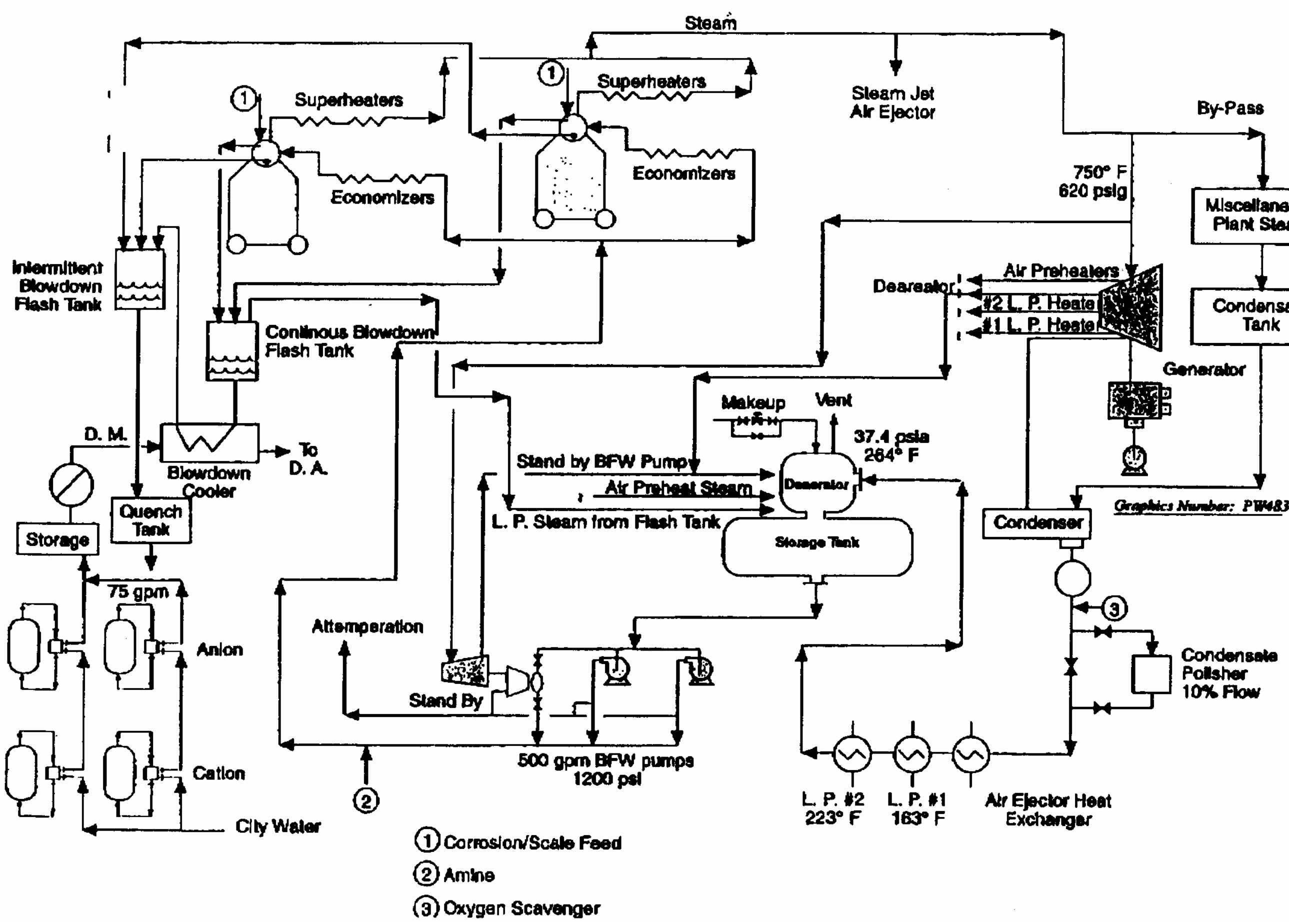


Figure 4. Hennepin Energy Resource Facility Boiler System. (Courtesy ChemTreat, Inc.)

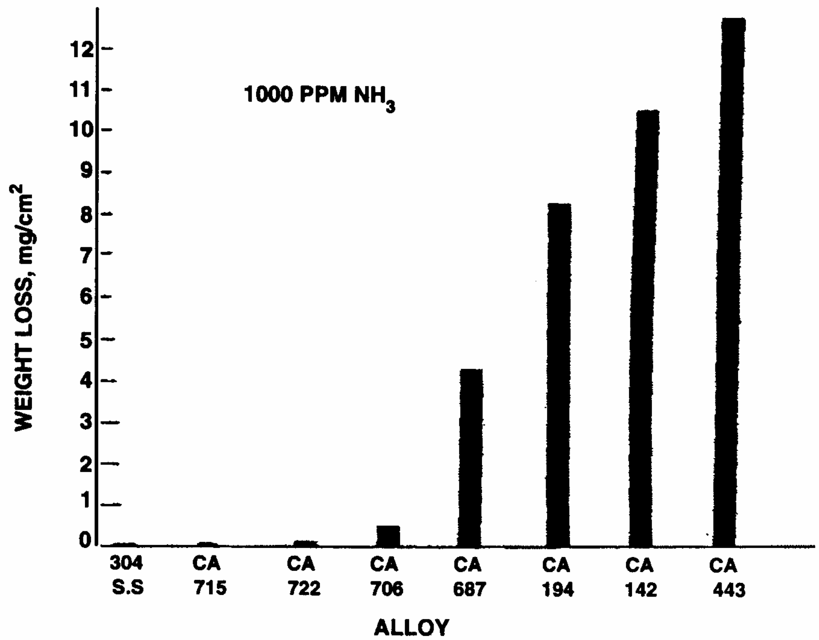


Figure 5. Weight losses of various alloys after testing for 10 days in 1000 ppm NH_3 contaminated condensate at 38°C (100°F).

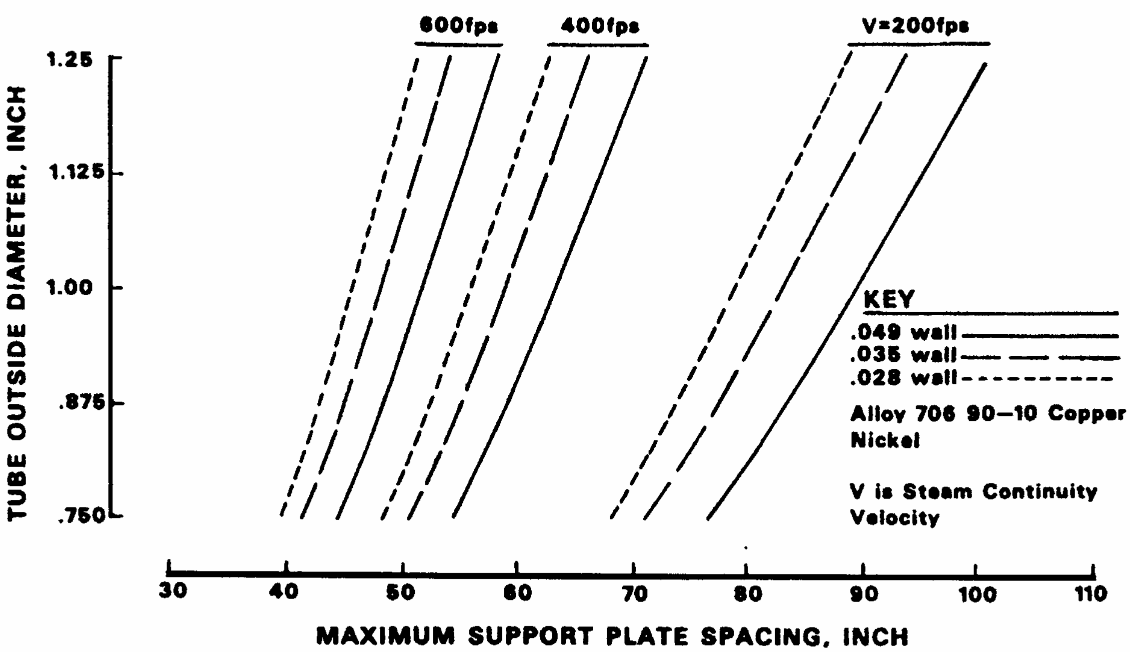


Figure 6. Effect of diameter, wall thickness, and steam velocity on support plate spacing.

TABLE I. HENNEPIN CONDENSER DESCRIPTION

Manufacturer - Ecolaire, Easton, PA USA
Drawing Number - E-57T-EC28-501X1
Serial Number - 874232
Cylindrical profile
Water Passes - two (2)
Design water velocity - 7 fps
Water flow - 27,160 gpm
Steam flow - 298,870 lbs/hr
Normal backpressure - 2.5 inches of mercury

Tubes
Main Body:
6342 x 3/4" dia. x 22 BWG (0.028") avg. wall x 22' 2-1/2" long
Alloy: UNS C70600 90-10 copper-nickel
Temper: As-welded, Light Cold Worked
Specification: ASTM-B-543 "Welded Copper and Copper-Alloy Heat Exchanger Tube"

Air Removal Section:
238 x 3/4" dia. x 22 BWG (0.028") avg. wall x 22' 2-1/2" long
Alloy: UNS C71500 70-30 copper-nickel
Specification: ASTM-B-111 "Copper and Copper-Alloy Seamless Condenser Tubes and Ferrule Stock"

Tube sheets
Material - 90-10 Copper-Nickel (ASTM-B-171/706)
Thickness - 1.25"

Support plates
Material - Carbon Steel (ASTM-A-516/70)
Quantity - 9
Thickness - 0.500"
Spacing - Midspan - 26-1/8"
Endspan - 26-1/2"

Tube-to-tubesheet joint - Rolled

Special equipment - Mosser turbine isolation damper

TABLE II. SOME COPPER ALLOY TUBE MATERIALS

MATERIAL	NAME	COPPER PLUS ALLOYING ELEMENTS
Alloy UNS C44300	Arsenical Admiralty	Zinc, tin, arsenic
Alloy UNS C60800	Aluminum Bronze	Aluminum, arsenic
Alloy UNS C68700	Aluminum Brass	Zinc, aluminum, arsenic
Alloy UNS C70400	95-05 Copper-Nickel	5% Nickel, Iron, Manganese
Alloy UNS C70600	90-10 Copper-Nickel	10% Nickel, Iron, Manganese
Alloy UNS C71000	80-20 Copper-Nickel	20% Nickel, Iron, Manganese
Alloy UNS C71500	70-30 Copper-Nickel	30% Nickel, Iron, Manganese
Alloy UNS C72200	85-15 Copper-Nickel	15% Nickel, Iron, Chromium

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TABLE III. COPPER-NICKEL ALLOY CONDENSER TUBE MATERIALS

NAME	TYPICAL WATER*	APPLICATION IN CONDENSER		
		MAIN	PERIPHERY	ARS**
90-10 Copper-Nickel	Sea/Brackish/Fresh	X	X	X
70-30 Copper-Nickel	Sea/Brackish/Fresh	X	X	X
85-15 Copper-Nickel	Sea/Brackish/Fresh	X	X	X

* Brackish includes cooling tower water
** Air removal section

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TABLE IV. STRESS CORROSION PERFORMANCE OF SOME COPPER ALLOYS IN AMMONIACAL ENVIRONMENT

C14200 Phosphorous deoxidized copper, arsenical	Essentially immune
C19400 Phosphorous deoxidized copper, iron	Essentially immune
C71500 70-30 copper-nickel	Essentially immune
C70600 90-10 copper-nickel, iron solutionized	Essentially immune
C70600 90-10 copper-nickel, iron precipitated	Moderately susceptible
C60800 5% aluminum bronze	Moderately susceptible
C68700 Aluminum brass, arsenical	Moderately susceptible
C44300 Admiralty brass, arsenical	Highly susceptible
C44400 Admiralty brass, antimonial	Highly susceptible
C44500 Admiralty brass, phosphorized	Highly susceptible

TABLE V. THERMAL CONDUCTIVITY OF SOME MATERIALS USED AS CONDENSER TUBE ALLOYS

ALLOY	CONDUCTIVITY (Btu/hr-ft-°F)
Arsenical Admiralty	64
90-10 copper-nickel	26
85-15 copper-nickel	20
70-30 copper-nickel	17
Titanium	12.5
TY304 stainless steel	8.6

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TABLE VI. HEAT EXCHANGE INSTITUTE (HEI) STANDARDS FOR STEAM SURFACE CONDENSERS (Ninth Edition, Table 3)

	TUBE WALL THICKNESS (BWG)		
MATERIAL	22	20	18
Admiralty brass	1.02	1.01	1.00
Arsenical copper	1.03	1.03	1.02
Copper-Iron 194	1.04	1.03	1.03
Aluminum brass	1.02	1.01	0.99
Aluminum bronze	1.01	1.00	0.98
90-10 copper-nickel	0.98	0.96	0.93
70-30 copper-nickel	0.95	0.92	0.88
TY304 stainless steel	0.86	0.82	0.75
Titanium	0.91	0.88	0.82