NEW DIRECTIONS IN ENERGY TECHNOLOGY

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The sharing of information is essential to the continued growth of the energy profession. AEE is proud to have played a major role in sponsoring this important conference.

Albert Thumann, P.E., C.E.M.
Executive Director
Association of Energy Engineers

Chapter 39

ELECTRIC BOILERS

M.A. Getz

INTRODUCTION

Pass electric current through a resistant wire and you get heat. That is how an electric range boils water. That is also how an immersion element boiler produces steam or hot water. Pass a current through water and the resistance of the liquid itself will convert the electric energy directly into hot water or steam. This is what happens in an electrode boiler.

Immersion element boilers were first manufactured by Coates in the early 1920's. Electrode boilers were develped before World War II and have been built occasionally since then for special applications. Now with energy suddenly a precious commodity these sophisticated devices are being considered, and they are going into commercial and industrial buildings in sizes that would have seemed gigantic just a few years ago.

In order to properly evaluate possible use of an electrode boiler, first let's seek applications. It is important to recognize the changes that have recently taken place in the relative status of various forms of fuel within the larger energy picture, and also to speculate on what further changes are likely to occur in the future. Electricity is an onsite fuel, has always had several attractive features - it is safe, clean, and efficient. Unfortunately, it is also expensive, particularly when compared with pentiful natural gas or cheap fuel oil. Coal and other solid fuels were only considered for the very largest applications because of the enormous capital cost of modern equipment and the polution problem associated with burning solid fuels.

Today in many areas of the country, industry is discovering that natural gas is readily available, however the price per Therm is increasing. If the price of natural gas is eventually deregulated (an increasingly likely possiblity especially for industry) it may also no longer be cheap. All over the country fuel oil prices have risen drastically, availability has sometimes been a problem, and reliability of supplies is open to question. Increasingly more stringent polution control requirements, plant locations, and fuel handling problems, rising capital costs, and tight fuel supplies all tend to restrict the burning of coal or other solid fuels to only the largest industrial installations, or to utility generating plants, and particularly to sites remote from large polution centers. In those situations where it is more available than natural gas, more economical than fuel oil, and cleaner and easier to use than coal, electricity has become an increasingly realistic alternate fuel.

For the future electricity enjoys one of the very important advantages over fossil fuels. There are many possible sources of electricity, including tidal, solar, geothermal, wind, and thermal nuclear in addition to hydro, nuclear, and fossil fuel. A great deal of time, effort and money is being devoted to the development of both new technologies and new resources. It is significant that electricity is a form of energy, a way of transmitting energy and making it available for use, it is not a source. Fossil fuels, on the other hand, are more probably a source. While much effort is being expended to find a reserve, very little can be expended to find new resources or create fuel. It is not a renewable resource. When supplies are exhausted, alternatives will have to take their place.

ECONOMICS

Quite naturally since electricity is the fuel of an electrode boiler, the electric utility becomes the key to the feasibility of any electrode boiler installation. If the utility is short of generating capacity, availability of energy may be a problem. Capital, shortages, and siting problems result in tight electricity supplies in some areas. If the utility generates extensively with oil, the cost of electricity may also be too high. The efficiencies of the generating process may get more attractive to burn oil on site rather than be first converted to electricity for transmission and consumption. Electrode boilers may merit the most serious consideration in those areas where the electric utilities have adequate or even excess generating capacity (both present and planned), and where generation is based extensively on the use of hydro, coal or nuclear power plants.

If the utility is in a favorable position, the relative cost and availability of alternate energy forms should be studied. Here several unique characteristics of electricity must be considered. The economics of electrical generation dictate that the utility try to maximize the use of the facilities (load factor). Unfortunately, electricity as such cannot be stored. If generated and not used, it is gone forever. As a result, applications which avoid peaks or which fill in the valleys in a utility seasonal or daily load pattern are particularly attractive. Most utilities attach a cost to additions, to peaks, to main charges, and many provide incentive to fill valleys in the form of lower off-peak rates. Rate incentives are often available for improvement in overall planned factors. These special considerations can significantly alter the effective energy cost of any electrode boiler installation.

SOLVING ENERGY PROBLEMS

The reasons for actually purchasing an electrode boiler are as many and as varied as the users themselves. In most cases, the choice involves some combination of energy cost and availability. For many, natural gas is restricted or unavailable, and oil costs are too high. In some cases on interruptible gas, electrode boilers are used as standby to gas/oil boilers to supply space and process heating loads on an interruptible base. In other cases where the amount of gas is restricted, an electrode boiler may be used to supply steam or hot water requirements while the gas is reserved or used where alternative fuels are less suitable, such as heat treating. In many areas natural gas is not available for new facilities or even expansions of existing ones. Electrode boilers have been base loaded as a sole source or are backed up with oil standby. In some other areas gas is short, but oil is more reasonably priced. Electrode boilers may be used to satisfy desires for an alternate fuel. Today it often makes as much sense to have a standby fuel capability as it does to have standby equipment.

Often there are seasonal relationships between gas and electricity that make a combination of gas/oil and electrode boilers attractive. Many utilities have a summer peak and consequently have excess capacity in winter months. Conversely, most gas shortages occur during the winter. In this situation the use of an electrode boiler to satisfy winter space or process heating loads will not only improve the utility's load factor but also relieve pressure on gas supplies. During the summer the relationship is reversed. Since natural gas storage is often difficult and expensive, this seasonal relationship is especially important.

Electrode boilers can also be used to take advantage of daily peaks in a utility system whenever attractive off-peak rates or significant demand penalties exist. With an appropriate demand control, an electrode boiler can easily be set up to cut back or shut off during peak electrical consumption. Where there is a nighttime demand for space or processed heat the electrode boiler can operate on lower off-peak rates while a gas/oil burner supplies daytime requirements or the electrode boiler may be base loaded while an oil fired unit is used for peaking requirements. With this arrangement more attractive electricity is used to supply the bulk of the plant requirements, and oil is used to supply peaks and hold electrical demand charges down. In some situations, electricity may be consumed at low off-peak rates and stored, usually in the form of hot water in accumulators for use for some or all of the peak hours of the day. This approach is being used very effectively in several district heating projects in Canada. An even more attractive application of load leveling concept is possible at those plants which are able to purchase their electric requirements as block power. In this case a customer pays a fixed amount for his power requirements providing they do not exceed a maximum demand. Whenever the plant electrical load drops off below this maximum there is free energy available. An electrode boiler controlled by a master demand controller can be used to convert this free or excess electricity into heat or use by the plant while other fuel fired boilers are cut back, and fuel is saved for later use. The result in uniform power consumption results in maximum utilization of the power distribution equipment and enables the company to benefit from all the energy it is paying for. Several large pulp and paper mills are using this concept successfully with electrode boilers as large as 30,000 KW with capacities in excess of 100,000 lbs. steam per hour.

Electrode boilers are especially well suited to take advantage of the way electricity is sold, a must in many areas if electricity is to be competitive. The units always start at zero load. The load increases gradually so that no sudden peaks are created, yet the load can be varied rapidly to respond to changes in the system's demand for heat or electricity. Start up or shut down are also rapid so that a boiler operating on demand control can take advantage of dips in the plant's demand without the danger of establishing new peaks. Output and/or consumption is infinitely variable enabling the boiler to closely follow the plant load or electric demand pattern. The opportunity for both local and remote control adds additional flexibility to the operation of an electrode boiler. With a unity power factor both power factor penalties and the need for compensary capacitors may also be reduced or eliminated.

At times polution also becomes an important criterion. Many oil burning and most coal or solid burning installations are faced with emission control problems. The cost of equipment to enable facilities to meet ever more stringent air qaulity standards can be substantial. Maintaining and operating this equipment effectively can also add to this problem. This is especially true when older less efficient equipment must be upgraded or replaced in order to conform to new standards. Electrode boilers on the other hand avoid these onsite problems. With electricity as the fuel, there are no emissions or other products of combustion and no need for unsightly stacks, or noisy air handling equipment. Polution control was of prime consideration for one forest product company who uses electrode boilers to help grow trees in two large seedling nurseries. This ability to meet strict onsite air quality standards and avoid additional capital expenditures may help to overcome operating costs' disadvantages in some situations.

INSTALLATION

A major factor in any equipment decision is capital investment. The high cost of capital, measured either by interest rate, or rate of return, often adds significantly to the effective operating cost of a boiler installations. The installed cost of a new electrode boiler will usually be less than 10% of the cost of a new coal-fired facility and can be as little as 25% of a new oil-fired facility. A large part of these differences can be found in the support facilities required by fuel-fired boilers. Certain items, such as, deaerators, blowdown systems, and water treatment equipment are as appropriate to electrode boilers as they are to coal and oil-fired boilers. Electrode boilers also require a significant investment in electrical switchgear. They do, however, eliminate the need for special boiler rooms and fire walls, fuel handling and storage equipment, air handling equipment, preheaters or economizers, stacks and emission control equipment, ash handling and disposal facilities, combustion safety systems, noise abatement equipment, and of course, the space and installation costs associated with this equipment. The use of a high voltage electrode boiler will also eliminate the cost of step-down transformers and reduce the cost of power supply feeders. The electrode boiler itself, will generally cost more than a good fire-tube boiler; but, less than the better water-tube boilers, depending on size, and may require as little as 25% of the floor space. Actual installed cost comparisons will vary, depending on the amount of existing equipment which can be utilized versus the new equipment required.

Additionally, electrode boilers are often adaptable to existing boiler rooms with minimal modifications to previously installed equipment being required. This becomes an especially attractive feature when the electrode boiler is being installed to provide standby or peak load capacity. A relatively simple valving arrangement can integrate steam from the electrode boiler when needed, with steam being generated by fuel-fired boilers.

OPERATION AND MAINTENANCE

Maintenance and safety are issues which usually merit considerable review. The simplicity of the electrode concept reduces the number and complexity of operating control and safety devices. Hazards associated with combustion are eliminated as is maintenance to remove combustion residue. Since heat is generated directly in the water itself, no part of the boiler is at a temperature higher than the steam or water. This lack of elevated temperatures reduces the tendency for scale to form and eliminates the problem of thermal shock. While scaling is to be avoided, and its presence will increase maintenance, there will be no loss in boiler efficiency or danger to personnel or equipment. The use of the boiler water to conduct electricity, and generate heat, also means that electrode boilers are fail-safe on low water. Without water, the circuit is open, no current can flow and no heat can be generated. There are no tubes to foul or burn out. The absence of these common boiler problems means not only less frequent and less costly repairs, but, safer operation as well. When maintenance is required an electrode boiler both cools down and restarts faster for reduced downtime. With fewer moving parts and less instrumentation, reliability is increased and requirements for spare parts and maintenance personnel are lowered substantially.

REDUCED PERSONNEL REQUIREMENTS

The absence of combustion often reduces the need for operating personnel as well. Electrode boilers are designed for unattended operation. There is no need for routine cleaning operations for such components as oil guns or strainers. Most controls are automatic and few require manual reset. Without danger from low water conditions, frequent inspection in unnecessary. Automatic controls are available for power supply, pressure or temperature, water level, conductivity, electrical demand, component failure and start-up or shut-down sequence. In many instances, these parameters are monitored or controlled from remote locations. Usually, one inspection visit per shift is sufficient to observe boiler operation and check parameters. Periodic checks of the water treatment system are also mandatory.

PROPER WATER TREATMENT IS REQUIRED

The importance of proper water treatment for an electrode boiler cannot be emphasized too strongly. As with all boilers of any size, feedwater should be thoroughly softened, sludge should be conditioned, ph should be controlled, and oxygen should be removed or scavenged. Unlike fuel-fired boilers, however, boiler water conductivity must be monitored and controlled. The electrode principle requires that the boiler water be capable of conducting electricity. The higher the conductivity, the greater the amount of current a given cross-sectional area of water can carry a constant voltage. Thus, boiler water conductivity determines, to a certain extent, the amount of heat that a particular electrode boiler can produce. If too low, capacity will be restricted and chemicals must be added to enable greater output. As conductivity rises, more current will be carried by less water. If conductivity gets too high, current concentrations (amp density) may reach levels where erosion of components, such as electrode, may occur. Or, conductivity may reach a point where the associated total dissolved solids (T.D.S.) is sufficient to cause foaming in the boiler. Foaming may also be caused by use of improper chemicals or amounts. Foaming will provide electrical paths across the spaces between the electrodes and ground (shorts) and will result in current surges which may take the boiler off the line on either ground fault or overcurrent. Consequently, the effect of all water treatment chemicals on both conductivity and foaming water must be carefully considered.

The most common means of controlling high conductivity in an electrode steam boiler is with a continuous surface blowdown. The amount of surface blowdown required is a function of the conductivity of the raw feedwater and the amount of raw feedwater required. In general, the more condensate that is returned, the less surface blowdown is required. Automatic conductivity controls are frequently used to initiate surface blowdown on high alarm and chemical feed or low alarm. With either sufficient condensate, or, rather pure feedwater, conductivity may also be controlled by periodic bottom blowdown.

Where electrode hot water boilers are used in closed systems, the use of de-mineralized, or de-ionized water will be required to lower system conductivity. This relationship between the amount of condensate and the conductivity of raw feedwater should be reviewed carefully. In extreme cases, blowdown requirements may be high enough to significantly reduce efficiency, and create disposal problems. Under such circumstances, part, or all of, the raw feedwater may have to be deionized.

This impact of blowdown on electrode boiler efficiency is important. In an electrode boiler, 100% of the electrical energy consumed by the boiler is converted to heat in the water. There are no stack losses and no energy is expended handling fuel or air. Even the horsepower used to run internal circulatin pumps goes into the pumped water as heat. Only two sources of heat loss remain; radiant loss to the boiler room and blowdown losses. A well insulated electrode boiler may have a radiant loss of less than 5%. Operating efficiency runs from 99.5% at full load to 95% at only 10% of full load; far higher than the best fuel-fired boilers, particularly at the lower loads. These efficiencies will then be reduced further by actual blowdown losses. The interaction of this efficiency characteristic with system load patterns will yield the actual operating energy cost. Electrode boilers are available in both hot water and steam versions. Water temperatures may range from 70°F to over 400°F while steam pressures are available from 12 psi to over 600 psi. High voltage electrode steam boilers are available for operation at distribution voltages from 4.16 to 25 KV in capacities from 1,000 KW (3,000 lbs. per hour) to 50,000 KW, or over 150,000 lbs. per hour.

High voltage electrode hot water boilers are available for operation at distribution voltages from 4.16 to 16 KV in capacities from 2,000 KW, or 6.8 million Btu's to 20,000 KW or over 68 million Btu's.

The savings realized in the operation and maintenance of an electrode boiler in comparison to a fuel-fired boiler, are frequently great enough to offset the higher cost of electricity.

HEATING APPLICATIONS

While electrode boiler have unique and sometimes "different" characteristics, they are flexible enough to have found a place in an ever widening range of applications. The list includes food processing, pulp and paper, forest products, chemical, manufacturing, shipbuilding, automotive, warehousing, commercial buildings, hospitals and schools, power generation, district heating, sewage treatment, plating, mining, and many more.

The following installations are typical examples of the application of high voltage electrode boilers to satisfy diverse space heating requirements:

Lane Community College, Eugene, Oregon

Two electric boilers furnish hot water to heat the 14 buildings of the Lane Community College in Eugene, Oregon. Rated 3,000 KW at 4,160 volts each, the boilers operate on the principle of the familiar electric vaporizer. That is, they generate hot water as long as electrodes remain immersed in water, which acts as the electrolyte. Shields are raised or lowered by motorized gears to obtain greater or less exposure of electrodes to the water as the heating demands fluctuate. The heated water is then pumped through a closed-loop piping system to heating units located throughout the buildings.

Because the system is totally closed, dissipation of water due to evaporation is prevented, and makeup requirements are negligible. Moreover, the closed loops exclude external contaminants, and electrodes can remain immersed indefinitely without becoming corroded. Motorized load controllers in each boiler can regulate unit outputs between 25% and 120% of rated capacities, and the two boilers can operate singly, together, or alternately as required.

Boiler efficiency is 98% when output is 25% of rated capacity, climbing to 99.2% when loadings reach 75%. This indicates excellent power/heat conversion economy. Yet, economy is enhanced even further through savings obtained by the elimination of stack and fuel problems, conserving space and reducing maintenance of equipment.

Because the closed-loop distribution system holds considerable residual heat, it is possible to build up water temperatures prior to planned shutdown periods and then capitalize on stored residual heat while boilers are deactivated for reasonably brief periods to allow for inspection, maintenance or repair. This feature also makes it feasible to restrict the college's electrical demand during short periods when demands in other parts of the power utility's service territory are high. By granting this option to the utility, the college obtained an attractive power rate reduction.

Such periods of power curtailment have been infrequent, occuring (when they do) generally during a 90-minute period or between 5:00 and 6:30 in the evening. In all cases, these periods have been anticipated by the utility sufficiently far in advance to advise the college of possibility; therefore, ample time has been provided to build up stored heat in the system. Actual boiler shutdown are then initiated directly from the power company's midtown remote-control center, and no further load-balancing is required at the college.

Hamilton Place Project, Hamilton, Ontario

The heating system for this 8-building city-center complex consists of two 5,500 KW electrode type high temperature hot water boilers. The boilers are supplied with 13.8 KV by Hamilton Hydroelectric System.

There are four 45,000 gallon hot water storage tanks and two heat exchangers to hold the distribution system water at 200°F. Water is stored in the insulated tanks at 385°F, boilers recharge these tanks during nighttime hours based on off-peak power rates. This off-peak electricity heats office buildings and a theatre for ten hours during winter days.

Partial operation of this system began in 1976 and full capability was placed in operation in 1979.

Seattle Steam Corporation, Seattle, Washington

Seattle Steam Corporation is a privately owned central steam utility, serving customers in downtown Seattle from a one-million-pound-per-hour-steam plant. Until 1976, all of the steam required by this system was produced by burning fossil fuels, primarily natural gas.

In the summer of 1976, Seattle Steam installed a 30,000 KW Coates electrode high voltage steam boiler, capable of producing in excess of 100,000 lbs. of steam per hour, at 180 psig. This boiler operates at 13.8 KV, supplied directly from a utility substation, located close-by. With careful planning, Seattle Steam was able to install the boiler and integrate into their system for less than $3.00 per pound, including boiler, instrumentations, and electrical switchgear, compared to $8.00 per pound or more for fuel-fired boilers.

Since September of 1976, the boiler has operated as a base load at 30 MW; producing 100,000 lbs. of steam per hour, 24 hours per day, seven days per week. The boiler operated in conjuction with one or more of the company's fuel-fired units and produces 180 psi steam at greater than 99.5% steam quality, while operating at better than 99.7 efficiency. By base-loading the electric boiler, the electric demand charge is spread over the maximum number of kilowatt hours and results in the lowest possible effective electric energy cost. So low, in fact, that the cost per million Btu's using interruptible natural gas is nearly twice that of the electric boiler.

One of the keys to this very successful installation was careful planning. The other was proper water treatment. Since this system returns no condensate, 100% raw water must be treated properly to ensure minimum maintenance and maximum efficiency in the operation of the fuel-fired boilers as well as the electrode boiler. In addition to the usual concern with the hardness, ph, oxygen, and the like, Seattle Steam must also contend with high alkalinity and silica in all of the boilers. They must also control the conductivity in the electrode boiler by means of a continuous surface blowdown. With careful design of the water treatment program and attention to its implementation, Seattle Steam has found that the electrode boiler was unattended with only minimal inspection and maintenance.

Actually, the boiler runs so reliably and so quietly, that without an ammeter, KW meter, or flow meter, a visitor would hardly notice that the boiler was operating.

ELECTRIC SUPERHEATERS

Coates electric steam superheaters are available for use with steam boilers as an auxiliary piece of equipment. Superheaters are custom made and built to meet specific design requirements of each application.

Steam is supplied to the superheater inlet at the steam header supply pressure and at saturated condition. The steam is fed simultaneously from the supply manifold through heater sections and is collected at the discharge manifold. The superheater discharge temperature is sensed at the discharge manifold outlet and the superheater power input is regulated to maintain constant superheater discharge temperature. Over-temperature limit controls are provided on each of the heater sections to prevent damage to the heating elements. Power input to the superheater is time-proportioned by the SCR power controller to provide the precise KW input needed to accomplish the desired superheat. Variations in steam flow will be sensed as temperature changes at the superheater outlet and the power input will be corrected accordingly.

The electric superheater is designed to provide superheated steam at the pressure and temperatures and flow rates required and includes the pressure vessel, thermal insulation and lagging, heating elements, heating element terminal boxes, power input controls, temperature regulating and limit controls, safety valve, and supplemental protection panel.

The superheater will be fabricated, hydrostatically tested, and stamped in accordance with the ASME Boiler and Pressure Vessel Code, Section I, and shall be National Board inspected and registered.

Electric heating elements are alloy sheathed, resistance type and designed for the maximum superheater operating temperature.

An indicating temperature controller is provided to control the discharge temperature of the superheater by regulating the power input to the heating elements. Superheater outlet temperature controlled within plus/minus $10^{o}F$ of the instrument setpoint.

Electric power to the superheater is regulated by an SCR-type power controller in accordance with the demands of the temperature control. Controller can be either air or water cooled.

The power controller, the temperature control, and the high-limit temperature controls are housed in a single, floor-standing control panel. All pushbuttons, selector switches, potentiometers, relays, and pilot lights necessary to operate the superheater are included in this panel.

All operating controls are mounted on the panel door. A bolted contact disconnect switch with shunt trip is provided in the panel to disconnect the superheater from power if either of the high-limit temperature control's setpoint is exceeded and to provide a manual safety disconnect. A barrier is provided between the switch and the SCR compartment. A Kirk key interlock is provided on the disconnect switch, the control panel doors and the supplemental protection panel doors to prevent unauthorized entry into the electrical panels.