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WEDNESDAY MORNING SESSION
June 17, 1964

The meeting reconvened at 9:30 A.M., Second Vice-President Carl W. Signor presiding.

Vice-President Signor: Gentlemen, the meeting will please come to order. Two committees will report at this session—Steam Station and Distribution. The Chairman of the Steam Station Committee, Thomas Bishop, will now present his program.

REPORT OF THE STEAM STATION COMMITTEE

THOMAS C. BISHOP, Chairman

Chief Engineer, Cities Heating Company, Limited
London, Ontario, Canada

Chairman Bishop: The first paper, written by Messrs. B. H. Smith and E. W. Kiss, will be presented by Mr. Kiss.

SELECTION OF BOILER EQUIPMENT IN CENTRAL HEATING AND COOLING PLANTS

B. H. SMITH and E. W. KISS, Industrial Equipment Engineers,
Combustion Engineering, Inc., Windsor, Conn.

(In this paper the authors describe the Hartford Gas Company's heating and cooling plant which forms a nucleus for the city of Hartford urban redevelopment program. This description is supplemented with a discussion of basic design parameters for steam and hot-water boiler selection in central heating and cooling plants.)

Central heating plants have been in use for years in some large cities, but their application was frequently difficult to justify, especially for systems that would operate only six months each year. With increased demand for air conditioning, however, a central plant to provide both heating and cooling does have considerable justification. The boilers supplying the hot water or steam for such central systems are significant equipment items in the initial capital investment and the overall plant operating efficiency.

A recent such installation was an important part of the urban redevelopment program carried out by the City of Hartford, Connecticut. The Hartford story is typical of what can be accomplished in the area of central heating and cooling systems; the potential is tremendous across the country for similar urban redevelopment projects.

The Hartford Story

Early in 1950, influential civic groups in Hartford began to study major urban redevelopment to improve the utility and appearance of its downtown section. By 1958, plans were completed for Hartford's urban renewal program, which would form the customer-nucleus of the first utility-operated district-steam and chilled-water plant (Fig. 1).

As plans for Hartford's Constitution Plaza unfolded prior to 1960, the Hartford Gas Company worked with the original developers on the basis that this utility would operate, *but not own,* a district chilled-water and steam plant adjacent to the site. However, when Constitution Plaza, Inc., was formed by Travelers to develop the program, the utility was asked to own as well as operate the plant. With this new responsibility for financing and locating the plant, Hartford Gas looked about for ways to enlarge this central-plant concept to serve additional customers.

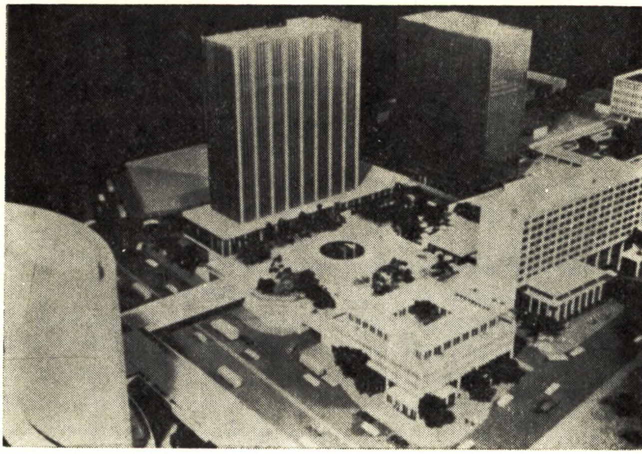

Fig. 1—Model of Constitution Plaza—Hartford's downtown urban redevelopment project.

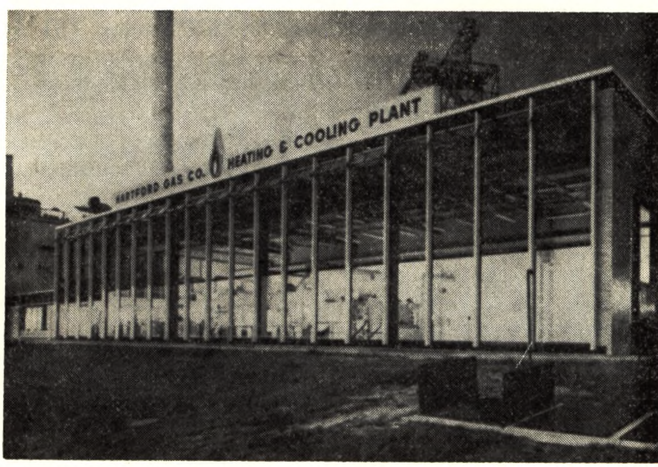

Fig. 2—The Hartford Steam Company's central heating and cooling plant.

Constitution Plaza itself represented a cooling load of 2500 tons and heating requirements of 38,000 lb per hr of steam. The existing home office complex of the Travelers Insurance Companies added a load of 3240 tons of cooling and 56,900 lb of steam to the central heating plant. The Phoenix Mutual Life Insurance Company decided to build a new home office adjacent to Constitution Plaza. This addition brought the total air conditioned service to approximately 6660 tons of cooling and 108,000 lb per hr of steam. Due to the stimulus of the Constitution Plaza redevelopment project, certain existing buildings, and new buildings under construction or in the planning stage, decided also to become customers of the new central plant.

At this stage the Hartford Gas Company decided to locate the central plant on its own property about one half mile from Constitution Plaza. Three factors were responsible for this decision: (1) The company had personnel, facilities and supervision at this location and would not have to purchase additional property. (2) Nearby on the Connecticut River there was an existing water-intake screening

FIG. 3—Four lines laid in street trenches distribute and return steam and chilled water.

facility that had been abandoned when highways were relocated. River water could be used to condense refrigerant and eliminate cooling towers. (3) Access to this facility would be easy (Fig. 2).

Many factors influenced whether the central-heating plant should be steam or high-temperature water:

1. To justify the distribution system cost, there must be a concentration of load. This is especially important with piping-system costs running about $200 to $250 per lineal ft.
2. Location of existing buildings and proposed construction should be studied. This might result in longer pipe lines justified by the prospect of picking up additional customers.
3. Pipeline routes should be selected to avoid rock substrata or streets heavily undercut by utilities (Fig. 3).
4. Remote location of the central plant on low-cost land might help pay for pipelines and afford the possibility for obtaining additional customers.

The ultimate decision to use steam was based on: (1) A TV studio that wanted to use the central facilities plant was expected to be in operation prior to completion of the new central-heating plant. (2) The Travelers Insurance Companies had a 700-ton refrigeration plant and modern steam-generating facilities which it wished to abandon. These were, therefore, leased to Hartford Gas and piping run underground to serve the TV studio. For this reason the entire system was designed for steam.

Having picked steam, distribution economics required steam at about 125 psig. Having this pressure available, steam-turbine-driven centrifugal units were selected because of their low water rate. Absorption machines were ruled out because their capacity limitation of 1000 tons would mean a large number of units in the expected final plant size.

The central facility was initially designed for a cooling capacity of 10,500 tons and 225,000 lb per hr steam capacity, with provision for another 75,000-lb per hr boiler in the future. The central-plant structure is 100 by 140 ft with a 22-ft ceiling.

The plant presently consists of three Combustion Engineering 75,000 lb per hr package boilers operating at 250 psig (Fig. 4). The additional 75,000-lb per hr boiler (Fig. 5) has already been purchased because of increased demand. It will be in operation in 1964. The boilers are equipped to fire natural gas as the primary fuel with No. 6 oil as standby.

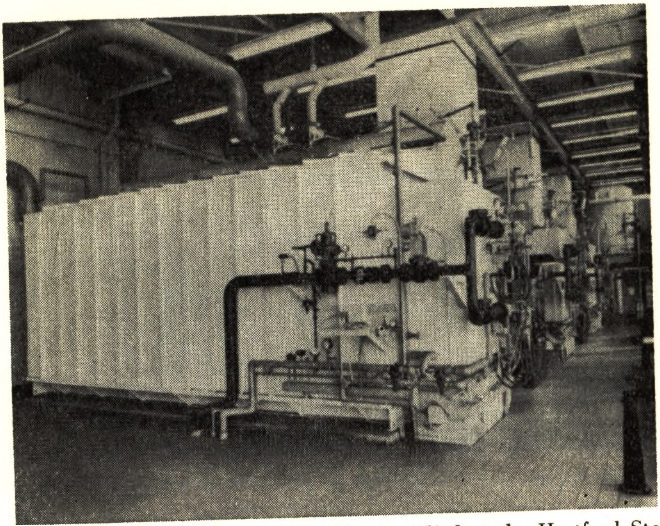

FIG. 4—Three 75,000 lb per hr C-E package boilers installed at the Hartford Steam Company's central heating and cooling plant.

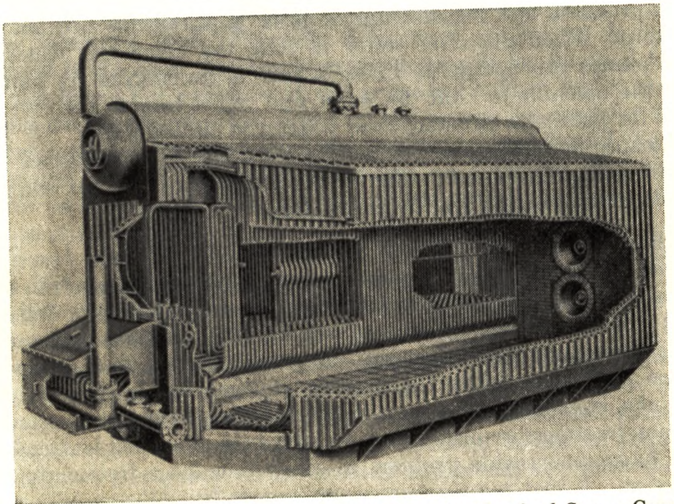

FIG. 5—A C-E package boiler similar to those installed at the Hartford Steam Company's central heating and cooling plant.

Chilling equipment (Fig. 6) consists of: two 1500-ton compressor units, one 3000-ton compressor unit, and one 4500-ton compressor unit.

Chilled water pumps supply 1.6 gal per minute per ton. At Hartford this is approximately 18,000 gpm at peak load supplied by four turbine-driven pumps, with a fifth pump on standby.

Six motor-driven condenser pumps handle approximately 3 gpm per ton through a 36-in. pipeline. At Hartford this is about 31,500 gpm at peak load from a screen and pump house in the Connecticut River. River water temperatures vary from 33 F in winter to 82 F in summer.

Original plans called for operation of a 500-ton steam-powered absorption refrigeration machine to provide the small amount of chilled water required in winter. However, this machine has been eliminated from the system because 10 to

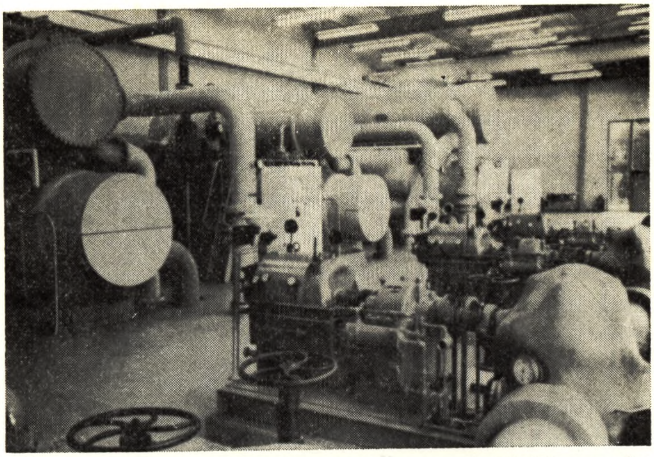

FIG. 6—Chilled-water pumps and refrigeration machines provide 10,500 tons of refrigeration to Hartford's downtown area.

15 per cent of the centrifugal refrigeration capacity is available even without operating the compressors, and because the off-peak requirements are not expected to exceed 500 tons. When the river water is cold, the condenser water pump and chilled-water pumps are operated. Enough heat is transferred by natural convection through the machine to chill the water and reject heat to the river. Power is required only for pumps to circulate river water and chilled water.

Against the specific background of the Hartford story, let us review some of the general considerations that bear on the selection of steam- and hot-water generating equipment for central-heating and cooling plants.

HIGH TEMPERATURE WATER VS. STEAM

The decision to use high-temperature water or steam for central heating and cooling plants depends on the size, arrangement, and type of load. Where pumping costs are not excessive (such as in a system serving multiple one- and two-story buildings) high-temperature water has some advantages over steam—simplified piping systems which can follow the contour of the ground; elimination of traps, condensate tanks, condensate pumps, and the associated reduction in maintenance; simplified water treatment required only to take care of system leakage; and elimination of the oxygen-corrosion problem in condensate lines frequently experienced in a steam system. A high-temperature water system has substantially greater heat-storage capacity than a steam system. As a result, fluctuating loads in the system tend to be damped out so that they do not directly or immediately affect boiler loads. The boilers, therefore, operate at a more constant rate. This improves their operating efficiency and the efficiency of the heating system as well.

Steam can have definite advantages in multi-story buildings where ideal conditions exist for gravity return of condensate. It may also be required as a result of the type of refrigeration equipment selected or as necessary for integration with an existing steam system as at Hartford.

The final selection of the system to be used depends on many other factors that can be evaluated properly only by the purchaser or his consultant.

LOAD FACTOR AND EFFECT ON DESIGN

Load conditions should be considered carefully when selecting boilers and fuel-burning equipment. The system must have capacity to meet a maximum demand which for most installations occurs only a few times a year and then, only for short periods of time. But our experience shows that even where several boilers are installed they operate considerably below their maximum rating most of the time—operation at 25 per cent of load is not uncommon. Therefore, the boiler should be designed for maximum efficiency and operating stability at average contemplated loads with the capability to supply maximum load requirement. To meet this design criteria, the selection of firing equipment and its associated auxiliaries becomes very important. Tolerances used to set design points for power or process boilers operating continuously at 75 to 100 per cent of design cannot be used for boilers operating frequently at 25 to 50 per cent of design rating. Over-sized firing equipment can result in reduced boiler turndown and poor operating characteristics at low loads.

FIRING EQUIPMENT

It is essential that the fuel-burning equipment be selected to give good combustion with minimum manual adjustment at low ratings. For package oil- and gas-fired units, the burner (or burners), forced-draft fan, combustion controls, and flame-safeguard device, are invariably furnished as an integrated package which, depending on physical size and arrangement, may be shipped attached to the boiler or in one or more separate components. Field-erected units cannot have the same degree of compactness since components are larger.

To obtain good combustion, burning-equipment and forced-draft-fan sizing must consider the minimum load. Excessive tolerances on burner firing rate should not be specified in the hope that more performance will be obtained for the money. But this is not true. For example, if the proposed burner has a turn-down ratio of 4 to 1, and the specification requires that the burner be sized for 25 per cent in excess of that required for rated load, the resultant turndown of the boiler would be approximately 3 to 1. Excessive tolerances on F-D fans also would have an adverse effect on air control at the low end of the operating range, and will reduce the stable turn-down ratio.

Normal liquid and gas fuels are No. 6 oil and natural gas respectively. Oil burners are of the gun type, usually incorporating steam atomization. When atomizing steam is not available, for example in a high-temperature water system, wide-range mechanical atomization is used. Gas burners are of the gun or ring type. To take advantage of seasonal fuel-cost variations, most burners are designed to burn either oil or gas, but not in combination. Ready conversion from one fuel to another can be accomplished by relatively simple changes. Although burners are available to burn these two fuels simultaneously, insurance requirements and the complication and expense of the control equipment involved should be carefully evaluated against the actual need for such an arrangement.

Selection of stoker-firing equipment is more critical than for oil- or gas-fired units due to the minimum firing rate required for smokeless operation. Also, as the minimum firing rate is approached, very high excess air is required for smokeless operation. This reduces boiler efficiency. To obtain acceptable operating characteristics at minimum load, a high stoker release rate should be used for the maximum continuous rating of the boiler.

Continuous ash-discharge spreader stokers or traveling-grate stokers are generally used for heating boilers of reasonable size. The traveling grate stoker, being a mass burning stoker, can efficiently burn only free burning coals. Ash and cinder carryover into the convection surface is less than with a spreader stoker and therefore does not present erosion and stack emission problems.

With spreader stoker firing, due to suspension burning, there is carryover of unburned carbon particles into the boiler and some degree of fly-ash reinjection must be considered to improve the boiler efficiency. Reinjection from a boiler hopper or from a decantation dust collector is the practical limit of reinjection. Total reinjection should not be considered, as it increases the dust load into the unit to the point where boiler-tube erosion can take place. There is also another serious problem associated with total reinjection. As the re-circulated particles of ash get smaller and cannot be collected by the dust collector, they are emitted to the atmosphere. With the trend in local communities for cleaner stack emission, total reinjection of fly ash on spreader stokers can result in local ordinance violation.

An over-fire air system must be integrated into the furnace design to create over-grate turbulence and assure complete combustion of fuel before leaving the furnace.

Oil- and Gas-Fired Boilers

Partial or complete shop assembly of oil- and gas-fired boilers has increased markedly in recent years. The most significant advantage is lower installed cost compared to a field-erected unit. This differential results from the development of standard designs with maximum use of standardized fabrication procedures and minimum field installation costs. Since capacities up to 100,000 lb per hr can be obtained from these units, the tendency is to install multiple packages rather than field-erected units in central-heating and cooling plants.

Shipping clearances determine the allowable height and width dimensions of a complete shop-assembled unit (and to some degree a partially shop-assembled unit). One of the problems of the design is, therefore, to use the available height and width to the best advantage.

Extensive use of water-cooled surface in the furnace is typical of modern, water-tube boilers. This heat-absorbing surface that "sees" the flame determines temperature of the combustion gases leaving the furnace. Liberal use of water cooling not only reduces the furnace temperature, but also reduces or completely eliminates furnace refractory with its attendant maintenance. The amount of furnace volume, or heat release rate per cu ft of furnace volume, bears no direct relationship to the furnace exit temperature; the amount of water-cooled furnace surface, or the heat-release rate per sq ft of effective radiant absorbing surface, is the valid criterion for determining furnace conditions. For shop-assembled boilers, due to size and furnace configuration, the ratio of radiant surface to furnace volume (which is greater than for the larger field-erected unit) permits considerably higher furnace liberation rates per cu ft of furnace volume.

The boiler exit-gas temperature is a function of the arrangement of furnace and boiler surface. Comparing relative performance or contemplated maintenance of boilers on the amount of boiler surface alone is a fallacy that should be avoided. Such yardsticks negate the advantages of well-integrated boiler designs. Regardless of the amount of surface installed, the return on the investment will be determined by the unit thermal efficiency, as indicated by the excess air required to burn the fuel, and the stack temperature.

In arranging the convection surface, consideration should be given to maintaining a minimum cold-end temperature above the dew point of gases from high sulfur fuels. For steam boilers, this is not a problem except at very low operating pressures since the surface at the boiler exit (which is most critical) contains a water-steam mixture at saturation temperature.

For high-temperature hot-water boilers, the water temperature through the unit varies and, therefore, the flow arrangement can dictate the cold-end condition. Fig. 7 shows a parallel-flow arrangement with the water entering the lower header and leaving the outlet header at the gas outlet of the boiler. In this manner, the higher water temperature is in the area requiring the maximum protection to prevent corrosion.

Since these units are operating at part load most of the time, evaluation of unit efficiency should not be made at full-load rating. The characteristic of the efficiency

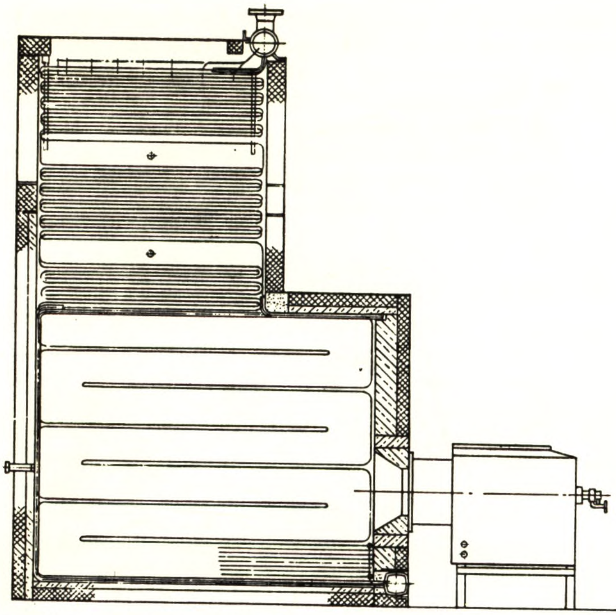

FIG. 7—A parallel-flow, oil- or gas-fired, shop assembled, high-temperature-water boiler.

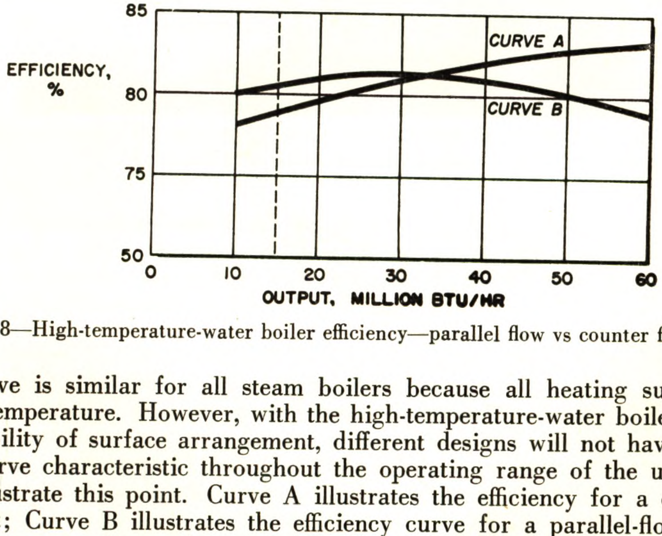

FIG. 8—High-temperature-water boiler efficiency—parallel flow vs counter flow.

vs load curve is similar for all steam boilers because all heating surface is at saturation temperature. However, with the high-temperature-water boilers, because of the flexibility of surface arrangement, different designs will not have the same efficiency-curve characteristic throughout the operating range of the unit. Fig. 8 can best illustrate this point. Curve A illustrates the efficiency for a counterflow arrangement; Curve B illustrates the efficiency curve for a parallel-flow arrangement. As you can well see, the parallel-flow arrangement has a lower efficiency at full load, while at half load, it is better than the counter-flow arrangement. With a unit normally operating at half load, a comparison of various designs based on full-load efficiency will not be a meaningful evaluation.

STOKER-FIRED BOILERS

Since a solid fuel is relatively slow burning compared to a liquid or gaseous fuel, the furnace of a stoker-fired boiler must be arranged for sufficient grate area with adequate distance for flame travel to the convection generating surface. To prevent slagging in the convection section, ample water cooling is provided in the

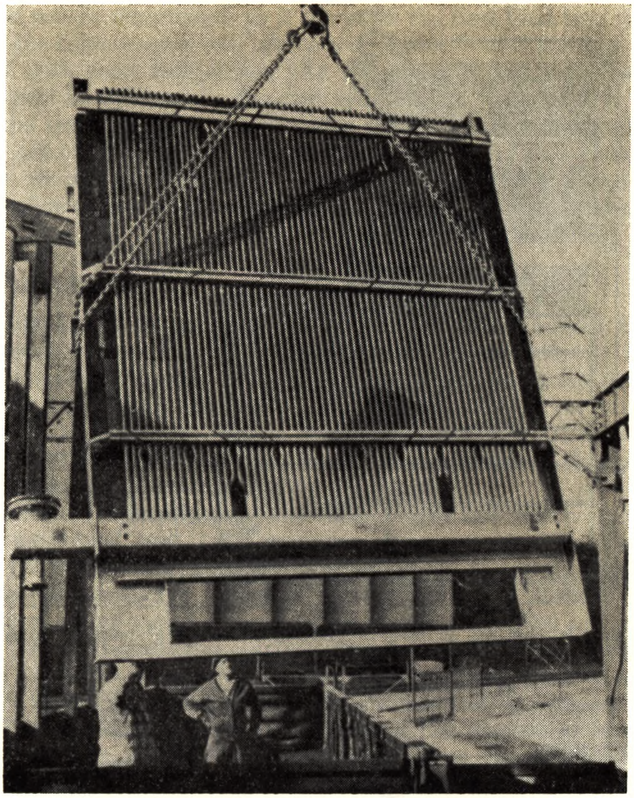

FIG. 9—Inlet header and furnace rear-wall assembly for a field-erected high-temperature-water boiler.

furnace to reduce the gas temperature below the softening temperature of the ash. Because of these considerations, the furnace, and therefore the complete boiler, is substantially larger for a given output than a design for oil and gas firing only. Depending on the size, the units can be shipped in subassemblies or components for minimum field erection.

Fig. 9 shows a boiler inlet header and furnace rear-wall subassembly being erected. Fig. 10 shows the convection bank including casing being shipped.

Typical stoker-fired steam boilers are shown in Figs. 11 and 12. A stoker-fired, high-temperature-water boiler is shown in Fig. 13.

Comments previously made under "*Oil and Gas-Fired Boilers*" also pertain to the design of stoker-fired units regarding maintenance of cold-end temperatures to minimize corrosion with high sulfur fuels and the load at which efficiencies should be evaluated.

CONTROLS

Since the loads on boilers supplying steam or high-temperature water for central-heating and cooling plants are relatively steady, there is no need for complex controls. The mere addition of complexity to a control system does not guarantee additional efficiency or operating economy. A simpler system is easily understood and maintained by the operators and will result in more consistent performance.

A number of varying factors tend to complicate the selection of combustion-control equipment and safety devices that will suit exactly the requirements of all

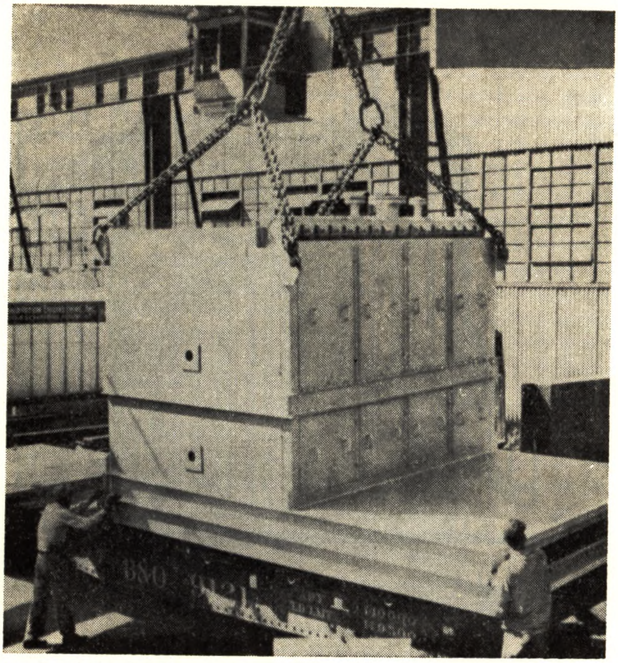

FIG. 10—Convection bank (including casing) for a large boiler being shipped as a sub-assembly.

potential users. Yet, the practice of custom engineering each individual control system entails the loss of all of the advantages of using standard equipment. To insure the retention of these benefits, control systems are offered as standard, performance-proven combinations of various components. Thus, the selection process requires only an engineering evaluation of system requirements and selection of the standard control combination which best meets the system requirements.

Among the factors which influence ultimate control selection are local codes and ordinances, insurance regulations, initial and operating costs, the nature of the boiler load, the type of fuel or fuels to be burned, and the degree of training and availability of operating and maintenance personnel.

Limit controls on gas- and oil-fired units insure safe operating conditions. When a limit is exceeded, the control automatically shuts the burners down, but experience shows that an excessive number of limit controls can cause nuisance shutdowns. Since explosion hazards are directly related to the number of burner reignitions, it is therefore important to reduce the number of these limit-control devices to significant malfunctions such as low water, inadequate fuel supply conditions, or loss of air supply. The proper use of alarms, such as a low-water alarm, can forewarn the operators so that corrective action can be taken before an automatic shutdown becomes mandatory.

For fully automatic operation of oil- and gas-fired package boilers, the steps necessary to start up and shut down the boiler are programmed automatically by flame safeguard controls with an electric timer and necessary relays. However, an operator must restart the burner after a flame failure or extended power failure. With semi-automatic operation, the boiler will be shut down automatically (and sound an alarm), but an operator must perform some of the steps in starting up the boiler.

When plant load requirements are such that operation below the burner turn-

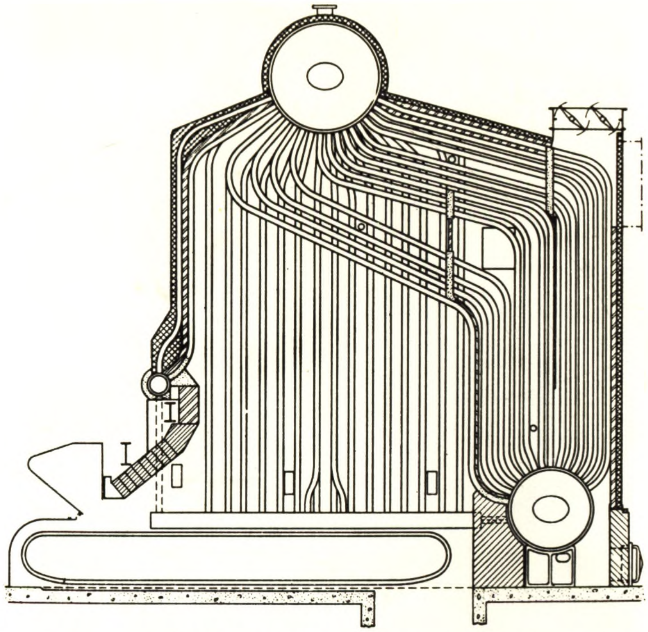

FIG. 11—Field-erected, natural-circulation steam generator arranged for a chain-grate stoker.

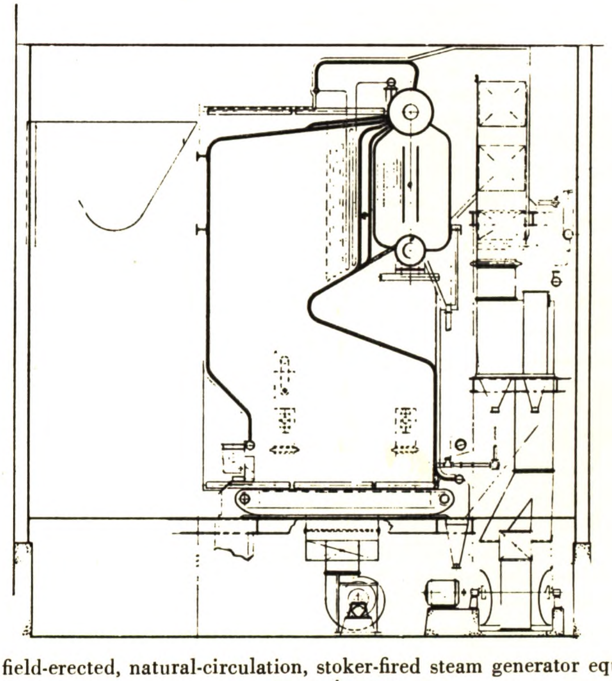

FIG. 12—Large, field-erected, natural-circulation, stoker-fired steam generator equipped with heat recovery equipment.

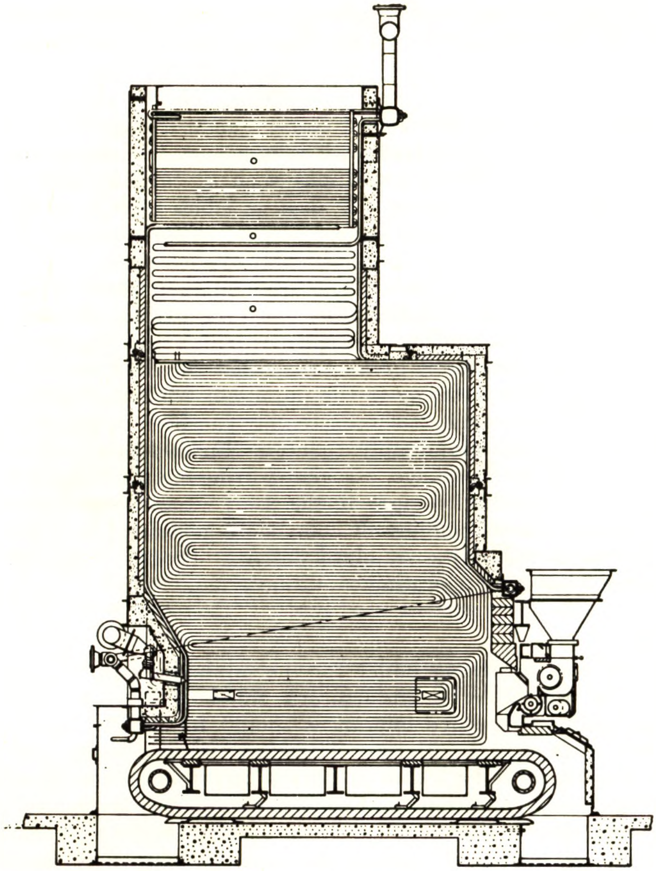

Fig. 13—Large, high-temperature-water, field-erected, stoker-fired boiler.

down range is infrequent, a semi-automatic arrangement should be encouraged. In addition to the lower initial cost, reduced hazards, and lower maintenance because of simpler equipment, a semi-automatic arrangement encourages familiarity by requiring the operator to perform some operations himself.

Oil-and gas-fired units larger than the package units, stoker-fired units, and units with superheaters, will normally use a semi-automatic control system.

Heat Recovery Equipment

Normally, heat-recovery equipment can be justified on boilers operating continuously near full rating. On low-pressure units, however, operating at low load factors, heat recovery is usually difficult to justify.

Factors that reduce the attractiveness of air heaters as heat-recovery equipment at low loads are:

1. Lower exit gas temperatures from the boiler reduce the efficiency gain in which the air heater can pick up.
2. Sulfur bearing fuels produce corrosion problems when adequate cold-end protection is not provided. Providing adequate cold-end protection reduces net efficiency gain since exit-gas temperature is held high to prevent corrosion.

Economizers are not suitable for sulfur-bearing fuels unless the feed-water temperature is higher than 250 F. This is not the usual situation in heating plants.

STANDARD DESIGNS

Standardization is the key to reduced costs; standard boilers are pre-engineered. In setting up a line of standard boilers, it is necessary initially to consider all possible variables involved. Design conditions such as capacity and operating pressures are then varied in increments. Physical variables such as terminal-connection locations may be varied to some limited extent; different types of burning and control equipment may be used to suit particular applications.

To make standard units suitable for a wide market, some degree of inherent flexibility is necessary, but this flexibility must be exactly defined to retain the advantages of the standardization concept. Although the engineering cost for a whole line of standard boilers is greater than that required for several individual boilers, this cost becomes a saving to the purchaser when distributed over a large number of units. Where complete shop assembly can be incorporated in a standard design, unit cost can be considerably reduced. Further cost reduction is accomplished by integrating, as a package, associated firing equipment and auxiliaries.

The advantage of standard designs to the user, whether completely shop assembled, field erected in sub-assemblies, or completely field erected, is lost if restrictive specifications require modifying standard designs. There is sufficient flexibility in standard designs to meet all operating conditions.

CONCLUSIONS

To obtain the best operating boiler for the minimum cost, complete advantage must be taken of the boiler manufacturer's standard designs. Load factors are extremely important. Excessive tolerances should be avoided on capacity, firing equipment, and associated auxiliaries. Therefore, when a boiler specification is to be prepared, it is far more logical to prepare a *performance* specification indicating precisely the operating conditions and what is expected of the boiler and accessory equipment rather than a *restricted specification* covering many details and minor items that will not necessarily assure the most suitable unit for the particular application.

ACKNOWLEDGMENTS

We are indebted to Mr. W. T. Jebb, President, Hartford Gas Company for much of the background information and for the illustrations showing the Hartford Urban Redevelopment Program; to the Carrier Corporation for many details of the cooling plant; and to Mr. Erik B. J. Roos of Seelye, Stevenson, Value & Knecht, Consulting Engineers, for background information regarding the choice between a steam and hot-water system.

Chairman Bishop: Thank you, Mr. Kiss. The next and final presentation of the Committee will be given by Mr. Russell Stem.