Facultad de Ingeniería Mecánica y Eléctrica
de la U. N. L.

ASOCIACION MEXICANA DE INGENIEROS MECANICOS Y ELECTRICISTAS, A. C.

SEMINARIO DE ING. MECANICA

Ponencia:

TRENDS IN STEAM GENERATOR DESIGNS FOR ELECTRIC UTILITY AND INDUSTRIAL APPLICATIONS

Presentada por:
W. W. SCHROEDTER
R. J. ROCCATAGLIATA

Monterrey, N. L.
Agosto de 1967.

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TRENDS IN STEAM GENERATOR DESIGNS FOR ELECTRIC UTILITY AND INDUSTRIAL APPLICATIONS

The tremendous growth of electric power during the last two decades, has created a demand for steam generators of increasingly larger inputs at increasingly higher pressures. It has been the successful manipulation and control of the two distinct processes of heat liberation from fuel and heat recovery for steam generation in large unit sizes which, in conjunction with larger turbines, other plant equipment and distribution systems, have made possible the remarkable feat of modern, low cost generation of electric power.

Among the contributions to the development of low cost steam generation probably none has been more universally observable than the drum-type boiler. This is the oldest and yet also the newest type of steam generator. Of particular note is the contribution made by this company of the Controlled Circulation design for high subcritical pressures.

Controlled Circulation

The reliability, availability, and safe operation of Controlled Circulation boilers have justified their selection in power plants throughout the world as demonstrated by the records. During the past 10 years C-E has sold 311 utility boilers with a total capacity of 56,370 Mw. Of these, 114 were of the Controlled Circulation design with a total capacity of 34,105 Mw. which represents 60 percent on a Mw basis.

At this pint it may well be worthwhile to consider some basic relation ships in the steam generation process at subcritical pressure. The common characteristic of all such boilers is the presence of three basic heat recovery surfaces - the economizer, the evaporator and the superheater. For all of these sections we may define circulation as the movement of water or steam, or a mixture of both, through heated tubes. Circulation must be adequate to absorb heat from the tube metal at a rate to keep the tube temperature at or below its design temperature. Circulation should also keep the tube within other physical and chemical limitations required by the inside and outside environment. In contrast to the circulation in economizers and superheaters, the circulation in evaporators, which in modern high pressure units are utilized as furnace wall systems, may have the type of circulation involving only the flow entering and leaving, known as the once-through flow, and also that wich involves recirculation at a flow greater than the throughput of the steam generator.

The natural circulation and the Controlled Circulation units are included in the last group and share the feature of a steam drum as a characteristic of subcritical recirculating units.

For pressures up to the 2000 psig level, furnace wall systems with natural circulation boilers are generally accepted as the best technical and economical answer to the various requirements for steam generation.

Natural circulation boilers employ the effect of the saturated density differential between water and mixtures of water and steam to promote circulation.

Controlled Circulation is a recirculating system at subcritical pressures in wich the driving force of the thermal head is supplemented by an external mechanical force produced by constant-speed circulating pumps within the down comer piping. A comparison of natural and Controlled Circulation for a furnace wall system is shown schematically in Fig. 1.

It can be seen that the most obvious difference between Controlled and natural circulation is in the introduction of a circulating pump between the downcomer systemand the steam generating surface and the introduction of orifices. The circulation through economizer, superheater and reheater is the same for both types.

The basic elements of a furnace wall system in a Controlled Circulation boiler are shown in Fig. 2. The system employs a drum which receives a mixture of steam and water from the steam generating tubes and feedwater from the economizer. Steam drum internals separate the steam from the excess boiler water. The saturated steam containing a minimum of impurities discharges from the top of the steam drum to the superheater portion of the unit. The separated excess water mixes with the feedwater in the steam drum and is returned to the furnace wall by the circulating pump.

All furnace wall tubes are arranged in parallel and in a single upward pass. They are fed from waterwall inlet headers at the lower end terminate in waterwall outlet headers at the upper end. From there the steam-water mixture is relieved to the steam drum.

With a design circulating ratio of 4 to 1, the system provides an average 3 lbs of recirculated fluid for every pound of fluid entering and leaving the boiler. This flow is distributed and stabilized by a system of orifices in the lower water-wall headers at the circuit inlet.

Because the recirculating system is integral with the steam generator and independent of other plant equipment, the protection it affords to the furnace-wall system is present in full force not only during normal operation over load range, but also for startup, extremely low loads, and shutdown. The furnace-wall system, therefore, does not require a bypass system and is immune from failures due to controls and interlocks associated with such systems. The recirculating system is independent of pressure above a minimum as determined by load and will maintain circulation for low- and high-pressure operation during steady-state as well as transient conditions.

Basic Design Principles

Protection of tubes against failure through overheating is achieved, then, by these principles:

1) Recirculation of water at the ratio of 4 to 1, designs into the system a large margin of safety for all system circuits under any operating condition.

2) Low steam quality present over the full length of all tubes which are sized for a mass flow adequate for all flux rates, assures nucleate boiling conditions with the bulk fluid temperature at saturation level in every tube at any elevation.

3) A system of orifices establishes and maintains these safety features by (a) Distributing the total flow through all tubes in relation to the heat pickup of individual circuits or groups of circuits, with the possibility of easy readjustment if required and, (b) Stabilizing the flow under transient flux conditions by the nature of inlet orifices with as much pressure drop as is present in the heated circuit.

With these principles, the design is able to control the metal temperature in a tube panel, as it is influenced by the heat flux, and the inside film coefficient.

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The temperature distribution for a welded tube panel with heat flux on the furnace side is shown in Fig. 3, isotherms are plotted on a typical tube configuration for a constant flux with different inside film coefficients. With increased inside resistance to the flow of heat, the temperature level in the crown region increases, and more heat flows towards the backside of the panel. The distribution also shows that the thermal loading of the tube by the heat flow from the fin always remains below that experienced by the crown of the tube.

Because the recirculating system establishes a minimum inlet velocity for all tubes under any operating conditions, it protects the tubes against the danger of overheating even at comparatively low flux rates when the film coefficent depends on subcooled water flow without boiling.

While there is heat transfer by film conductance of subcooled water at comparatively low flux near the tube inlets in the lower portion of the furnace, the bulk of the heat absorbed in the furnace is transmitted from the tube to the fluid by nucleate boiling.

The stable and high film coefficient which is produced by nucleate boiling, is established by a steam-water mixture of sufficiently low quality - a mean of 25 percent at the evaporator outlet - and a mass flow wholly adequate for even the highest anticipated furnace flux rates. A large number of the tube metal measurements on Controlled Circulation units and extensive laboratory tests with furnace tubes modeled in a full size loop confirm the predictions based on present knowledge about the thermodynamics of boiling heat transfer. Because of the metal temperature control exerted by assurance of proper cooling, the thermal loading under any furnace condition is well within the elastic range of the material end completely without influence on fatigue in case of cycling.

Drum Internals

The drum internals are devices used to separate water from steam and to direct the flow of water and steam in a manner so as to obtain an optimum distribution of drum metal temperature in boiler operation.

The drum internals for a Controlled Circulation unit are shown in Fig. 4 with characteristic arrangement of primary and secondary separators as well as the final dryers. Feedwater is introduced below the water level and in this manner mixes with the recirculated, saturated water to produce the subcooled flow to the circulating pumps.

One distinct advantage of the Controlled Circulation design is the internal shrouding in the drum. This water-tight shrouding directs the return flow of steam and water from the furnace around the inside surface of the drum, providing for uniform heating or cooling of the drum and drum heads.

Because of the importance of orifices to the protection of the furnace-wall system, care is taken to prevent their plugging by foreign material. The orifices which are made of austenitic steel are located in the inlet headers and protected by screen plates extending along the entire length of the header. The 3/16-in. openings in these screens are smaller than the smallest orifice dia used in Controlled Circulation units. The range of the orifice sizes and water velocities through the orifices (in the order of 20 to 30 ft per second) also prevents smaller particles from clogging the orifice proper.

Experience with the very large number of Controlled Circulation units in operation under the widest range of power plant operating conditions has shown that chemical buildup in orifices does not occur if proper feedwater treatment is followed.

In addition, the differential head across the pump which is measured and monitored acts as a reliable and clearly recognizable signal concerning the absence or presence of any deposition in the orifice or heating surface. If deposition does occur, this differential will gradually increase and indicate the need for a remedial action long before the tube circuits themselves fail.

<u>Circulating Pumps</u>

Because circulating pumps are the key element in the furnace-wall system and are essential to tube protection under all operating conditions, a multiple pump arrangement with shutoff valving for each pump is provided. This in itself insures that availability is not impaired by possible failure of any individual pump.

The number of pumps selected for any system may vary between two and four. Because experience with Controlled Circulation units has established the reliability of modern circulating pumps, spare pumps are not normally provided. Each installed pump can be isolated by a motor-operated suction valve and a discharge stop-check valve. In case of failure, a pump may be isolated for a sufficient length of time to effect repairs without impairing the full-load capacity of the unit. It is recommended that for overall safety of the furnace-wall system, orifices (in the order of 20 to 30 ft per second) also prevents smaller particles from clogging the orifice proper.

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Furnace-wall-system protection by the circulating pump is further insured by various interlocks and other protective devices. The details of these depend on the particular type of pump installed. A device common to all Controlled Circulation units is a firing interlock which will not permit heat input without having the minimum number of pumps in operation. This is evidenced by the measured pressure differential between the pump suction header and the wall inlet header. This also provides a signal on loss of any pump.

Welded Walls

The welded wall design, Fig. 5, has proven practical in fabricating panels in large quantities, with commercially available tubing. The panels have proven their long-term reliability, under practically all possible operating conditions. Experience and development have permitted design, support, and erection techniques to grow simultaneously with the rapidly increasing size and pressure requirements.

With increased use of pressurized firing and because of design simplification as well as easier erection procedures, the past decade has seen a continuous increase in the use of welded furnace walls until today it has become a standard C-E component for all utility contracts (Fig. 6).

Typical 370 Mw Controlled Circulation Unit

Figure 7 shows a 370 Mw Controlled Circulation pulverized-coal-fired steam generator purchased in the early 1960's. It is designed for 2.5 million lbs/hr of steam at 2500 psig and 1005 F with reheat of 1005 F. The furnace is 55 ft wide, with a division wall at the center and a complete tangential firing circle in each half. The superheater has a horizontal section, intermediate platen and finishing pendant sections while the reheater is composed of a horizontal and a finishing pendant section. The furnace-wall system is fabricated utilizing fusion welded panel construction consisting of 1 3/4-in. dia tubes on 2 1/8-in. centers. The furnace is a gas tight enclosure including the roof where welded seals are provided for entrance of superheater and reheater elements.

Industrial Boilers

In the industrial boiler field, a variety of drum tupe boilers are being manufactured in the United States. The increasingly popular shop assambled or package tupe have now reached steam capacities of over 200,000 lbs/hr. They are being used where previously only conventional field erected boilers were available. Mass production methods and other economics of factory assembly have brought costs and erection time of such boilers down well below that of comparable capacity field erected tupes.

Our experience with the shop-assembled boilers brought about our modular concept of partial shop assembly and standardization of component parts for the larger field erected industrial boilers.

Modular Design Concept

A modular design is one in which a product is built with a combination of various building blocks or modules. Each module must perform its intended function within a defined degree of flexibility and must be capable of being fitted to adjacent modules to form an integrated final product. The main purpose of applying this design concept is, of course, to produce a better product at lower cost. With a properly conceived and executed program, better quality and lower cost are compatible.

For this modular design concepto, welded-wall construction was ideally suited because it allowed the fabrication of large tube panels in the shop. Backed up by the necessary buckstays, the welded wall, because of its continuity, provides structural strength for support of the boiler and also a tight gas enclosure for pressurized firing of fuel. It eliminates the need for, and attendant problems with, a pressure casing. Welding the modular inlet and outlet headers to the sidewall tube panels in the shop minimized the field welding to a limited number of large dia feeder and relief tubes, completing this portion of the circulation system. Fins on edge tubes of the individual shop-assembled panels are welded together in the field to complete an integral pressure-tight envelope around not only the furnace, but the boiler section as well. This gas-tight envelope, made up of tubes and fins, operates at a saturation temperature corresponding to the operating pressure of the boiler. This temperature is well above the dewpoint of the corrosive gases in the products of combustion. Insulation on the welded walls is isolated from this corrosive atmosphere on the hot side and covered by a preformed metal casing on the cold side.

VU-60

This modular concept was applied in developing the VU-60 in the early 1960's (Fig. 8). This is a bottom-supported, field-erected, natural-circulation, various building blocks or modules. Each module must perform its intended function within a defined degree of flexibility and must be capable of being fitted to adjacent modules to form an integrated final product. The main purpose of applying this design concept is, of course, to produce a better product at lower cost. With a properly conceived and executed program, better quality and lower cost are compatible.

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It is worth mentioning at thispoint the names of various contracts our subsidiary company CE-rrey S.A. of Monterrey has in various stages of construction. These units are among the largest industrial boilers totally fabricated in Mexico.

The VU-50, the predecessor of the VU-60, is a field erected boiler. Units of this type have been fabricated for various industrial fims in Mexico by CE-rrey S.A. Recent typical installations are a 34 ton/hr capacity unit operating at 42 Kg/cm^2 and 400°C for Celanese Mexicana; a 63 ton/hr boiler at the same operating conditions installed at Industrias del Alcali. CE-rrey has also fabricated for CIA. Fundidora de Fierro y Acero de Monterrey, S.A. two VU-50 with 60 ton/hr at 43 Kg/cm^2 and 445° C steam outlet conditions.

Recent contracts include two modified VU-60, 180 ton/hr, 42 Kg/cm^2 and 400°C for Pemex, C.D. Madero, Tamaulipas.

The latest contract has been awarded to CE-rrey by Westinghouse in connection to the expansion of the CIA Fundidora de Fierro y Acero de Monterrey, S.A. This contract calls for a blast furnace gas and natural gas fired modified VU-60 with a capacity of 110 ton/hr at 64 Kg/cm^2 and 490°C steam outlet conditions.

The VU-60 has evolved from previous VU designs built over a 40-year period. Good features from previous designs, proven by years of successful operation, have been retained. To further increase the reliability of this unit, service reports were analyzed to establish the natural of all previous problems, however minor, and, as necessary, design modifications were made. In addition, the latest technology and manufacturing techniques were used whenever applicable.

Based on accepted performance parameters, the range of physical dimensions of the steam generator was established. It was desirable to provide maximum flexibility to meet varying operating conditions and possible on-site space limitations. The major variables of width, depth, and height as well as steamdrum dia were set up to be varied independently of each other and were exactly defined. For example, the furnace width is varied in 16-in. increments and furnace depth in 12-in. increments. There are several incremental drum-center distances, boiler-tube sizes, and a considerable variation in design pressures. Considering the width, depth, height, drum diameters, boiler tube sizes, and design pressure variables, there are over 10,000 usable combinations.

<u>Flexibility</u>

To illustrate the application of the modular concept to achieve wide flexibility, consider a section of the VU-60 as shown in Fig. 9. These furnace sidewall modular panels consist of tubes, whose terminal ends are welded into pipe headers.

The top illustration shows three basic modules; A, B, and C; each having a particular width. When welded together in the field, they make up the sidewall of a unit having a furnace depth of 19 ft. The lower illustration uses the same basic modules to form the sidewall of a unit having a furnace depth of 31 ft., but in this case utilizing a greater number of B modules. This example was not selected as an over simplification, but rather to illustrate the repetitious use of these modules as they are actually used in this boiler design. The VU-60 is currently available in 22 different furnace depths in which modules such as A, B and C are used in varying quantities. In actual practice, modules A and B are each available in several widths and each module A, B, and C may also be furnished in three different height dimensions.

As mentioned before, each module consists of tubes and pipe headers which are shop assembled into finned paneled walls. There are 6 basic tubes and 5 basic headers which may be used in varying quantitites to make 24 different variations of assembled modules similar to A, B, and C. When used in combination, modules A, B, and C will permit 66 variations in furnace height and depth.

Figure 10 illustrates two VU-60 units of different furnace width and furnace depth. As mentioned before, with the modular approach, steam generators of varying size may be constructed using standard components. In the illustration, modules identified with a subscript are identical to those without the subscript except for a linear dimension.

The largest single cost reduction realized is in erection. Erection time is considerably reduced by the use of the large modular welded panels. Insulation is attached to, and supported by, the welded-wall envelope by impaling pins welded to the fins. Application of the preformed metal lagging is simple. The structural strength of the welded-wall envelope permits a simple four-point support and attendant savings in foundation costs. Because of the physical size of the boiler bank, the tubes are individually expanded into the drums.

With standard modules, it is far simpler and requires considerably less time to process the necessary fabrication information. This is essential since many units are sold for short delivery. With the necessary engineering information covering all possible assemblies and parts available in the shop, engineering processing can frequently be reduced to indentifying rather than completely describing these items.

To pre-engineer all modules represents a considerable initial investment in engineering costs. When distributed over a large number of boilers, however, the cost against each becomes nominal and obviously substantially less than the cost to completely engineer each unit on an individual contract basis.

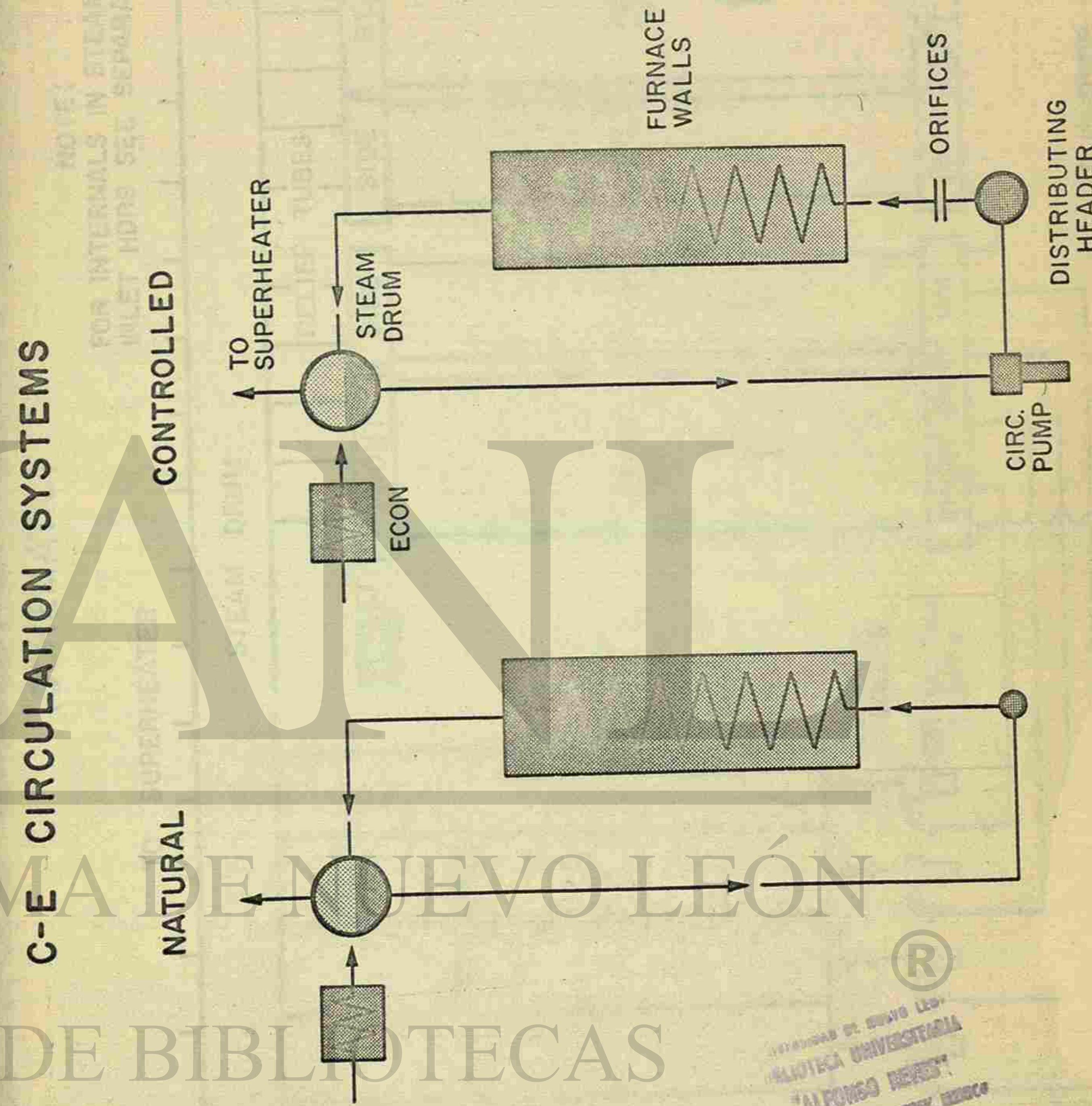

C-E CIRCULATION SYSTEMS
NATURAL
CONTROLLED
TO SUPERHEATER
STEAM DRUM
ECON
FURNACE WALLS
ORIFICES
DISTRIBUTING HEADER
CIRC. PUMP

Fig. 1

CONTROLLED CIRCULATION FURNACE WALL SYSTEM
(SCHEMATIC)

NOTE:
FOR INTERNALS IN STEAM DRUM AND INLET HDRS SEE SEPARATE ILLUSTRATIC

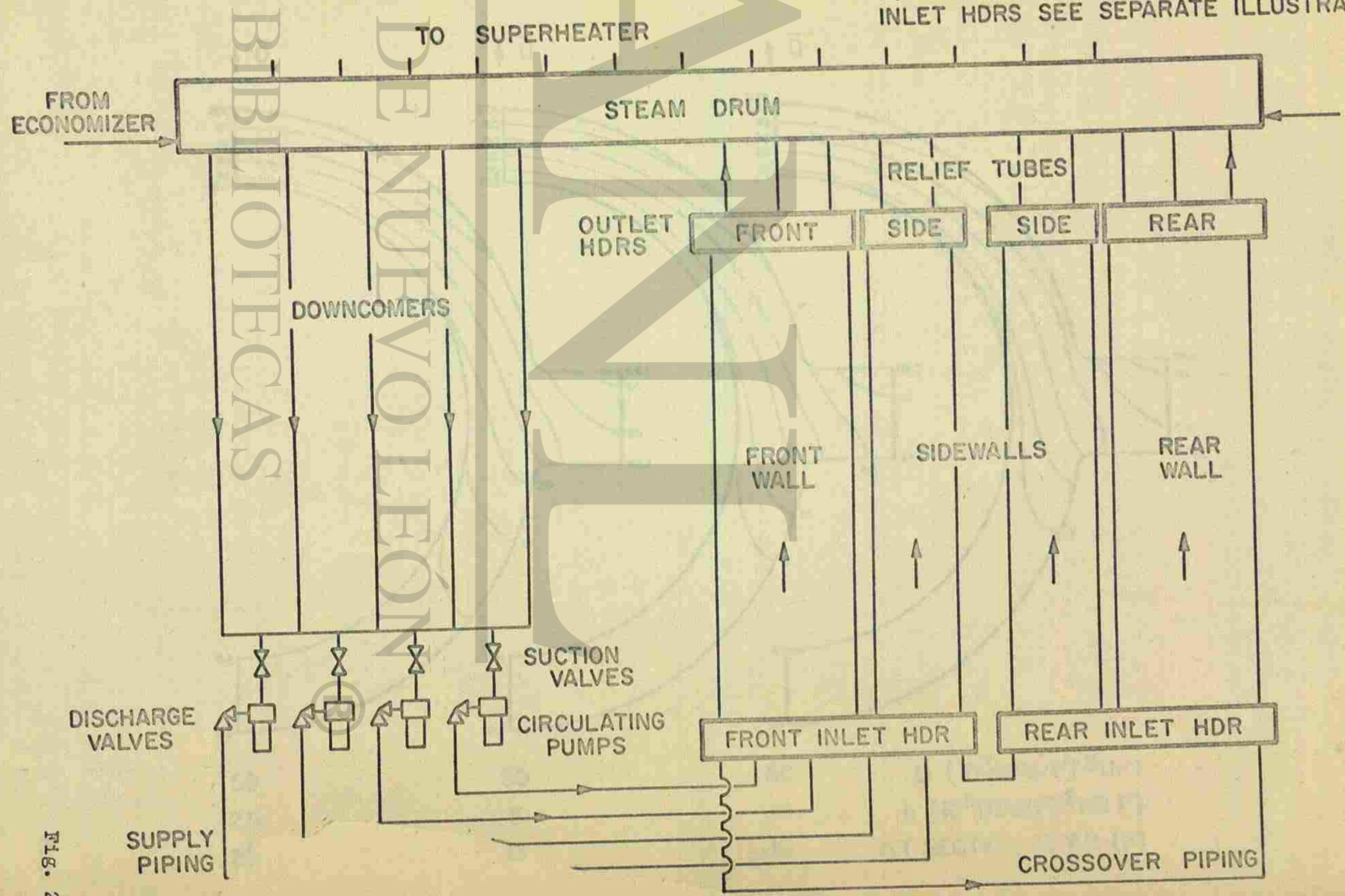
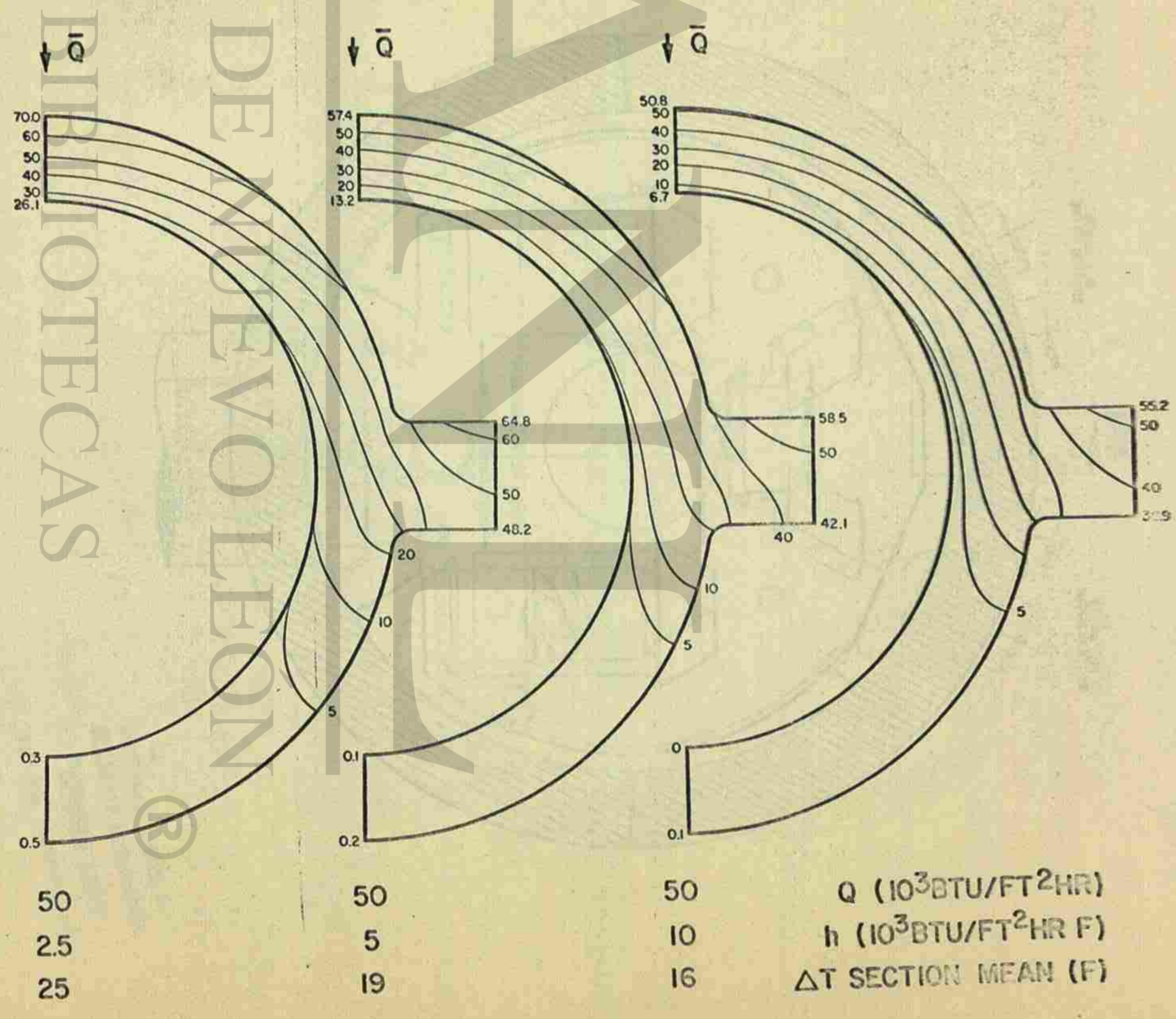


Fig. 2

TEMPERATURE DISTRIBUTION OF C-E FUSION WELDED FURNACE PANEL



50	50	50	Q (10^3BTU/FT^{2}HR)
2.5	5	10	h (10^3BTU/FT^{2}HR F)
25	19	16	ΔT SECTION MEAN (F)

Fig. 3

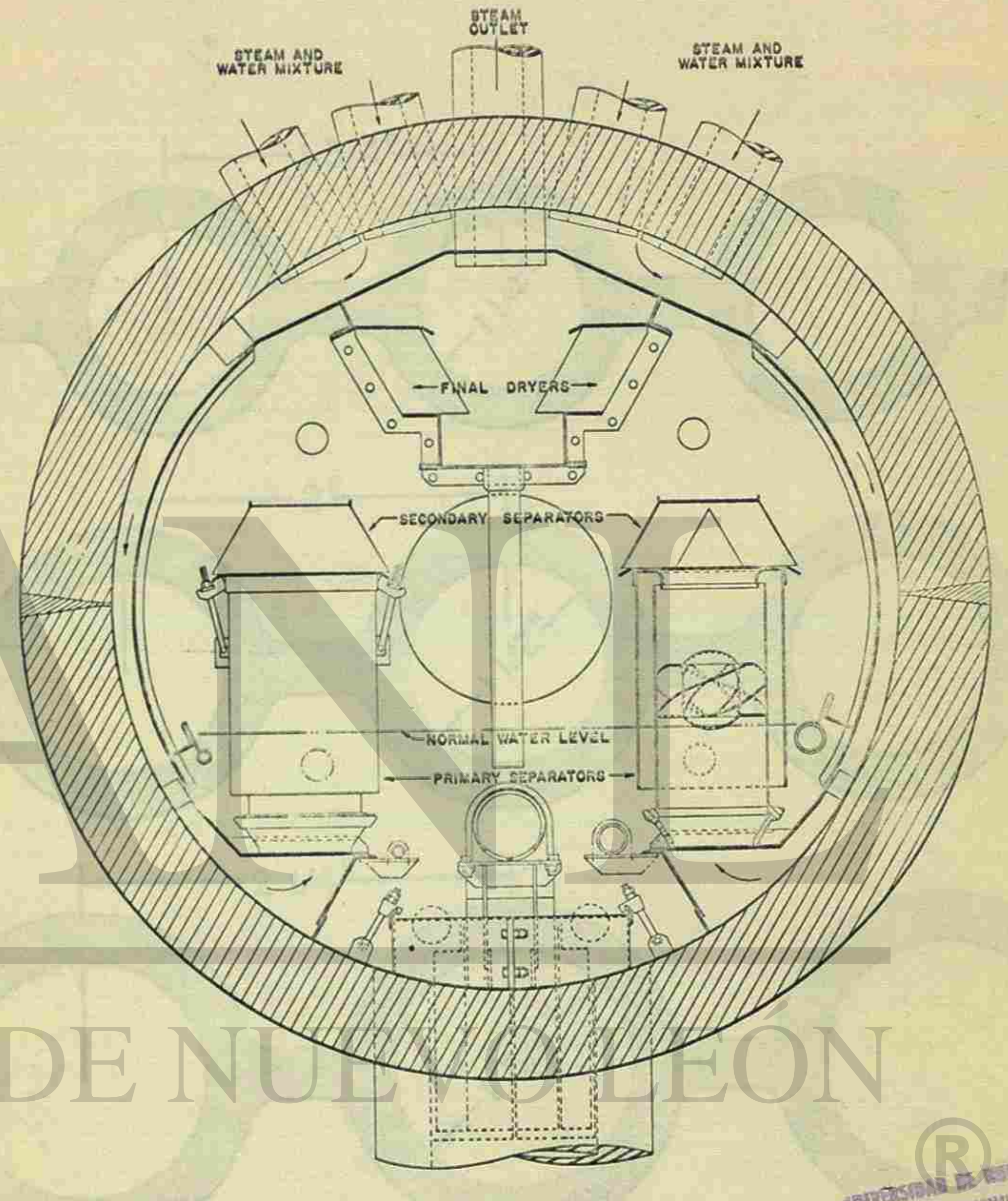

STEAM AND WATER MIXTURE
STEAM OUTLET
STEAM AND WATER MIXTURE
FINAL DRYERS
SECONDARY SEPARATORS
NORMAL WATER LEVEL
PRIMARY SEPARATORS

Fig. 4

TYPICAL TUBING ARRANGEMENT
CE CONTROLLED CIRCULATION FURNACE PANEL

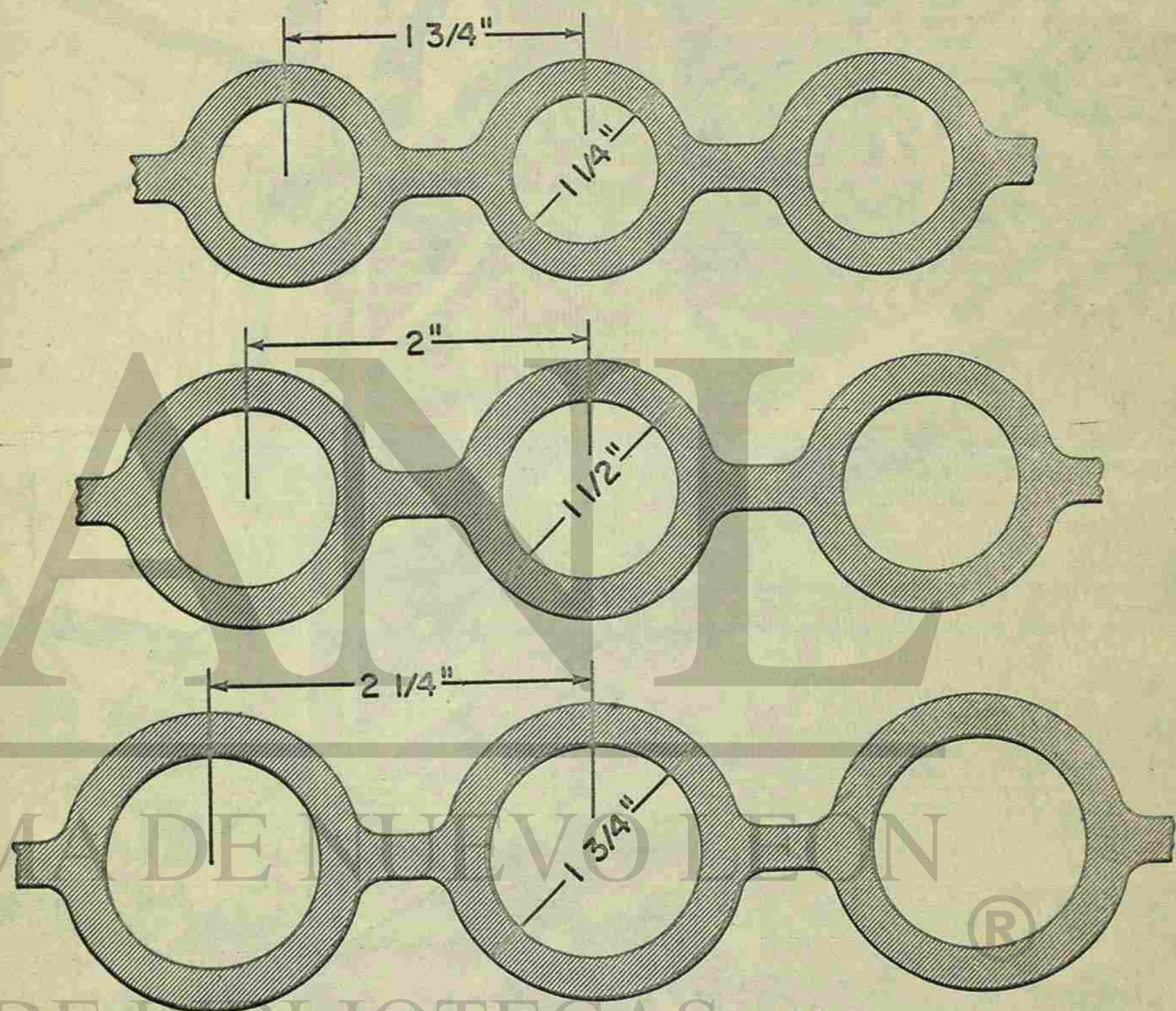
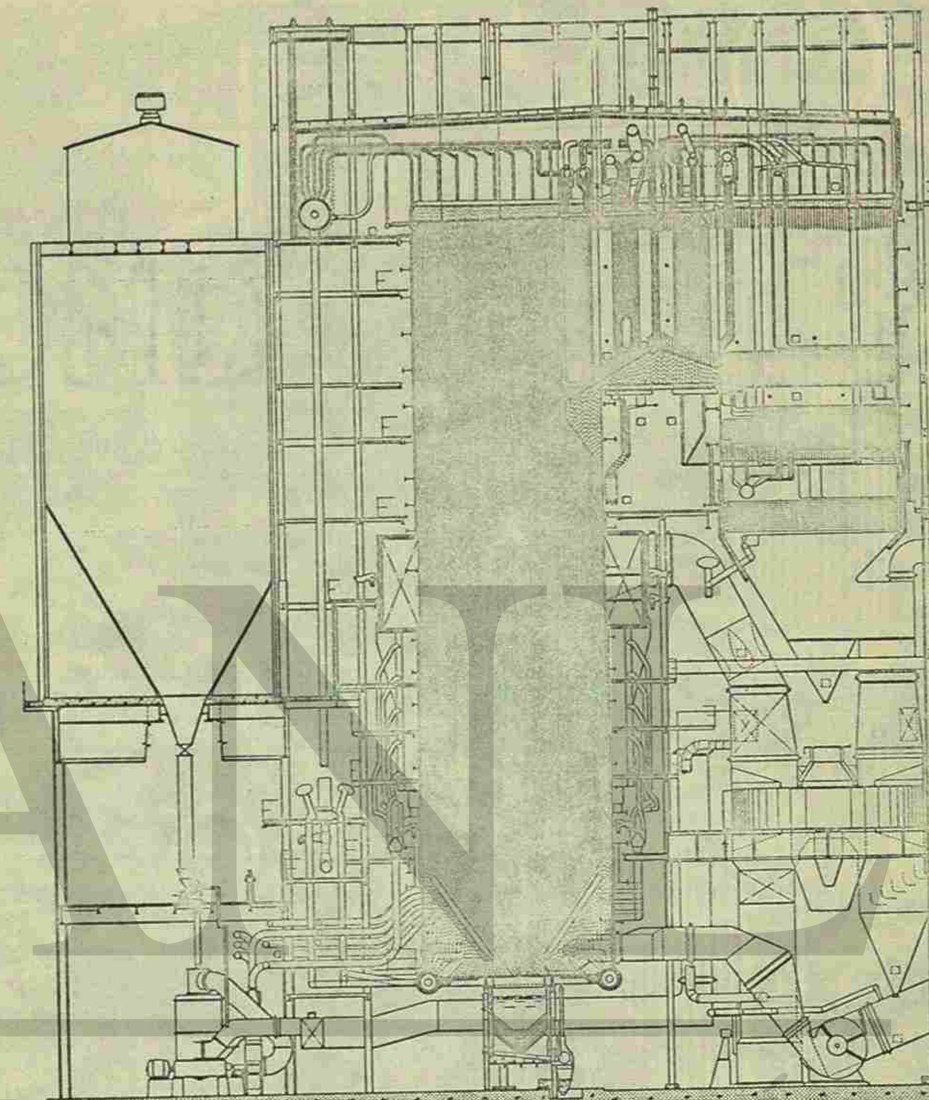


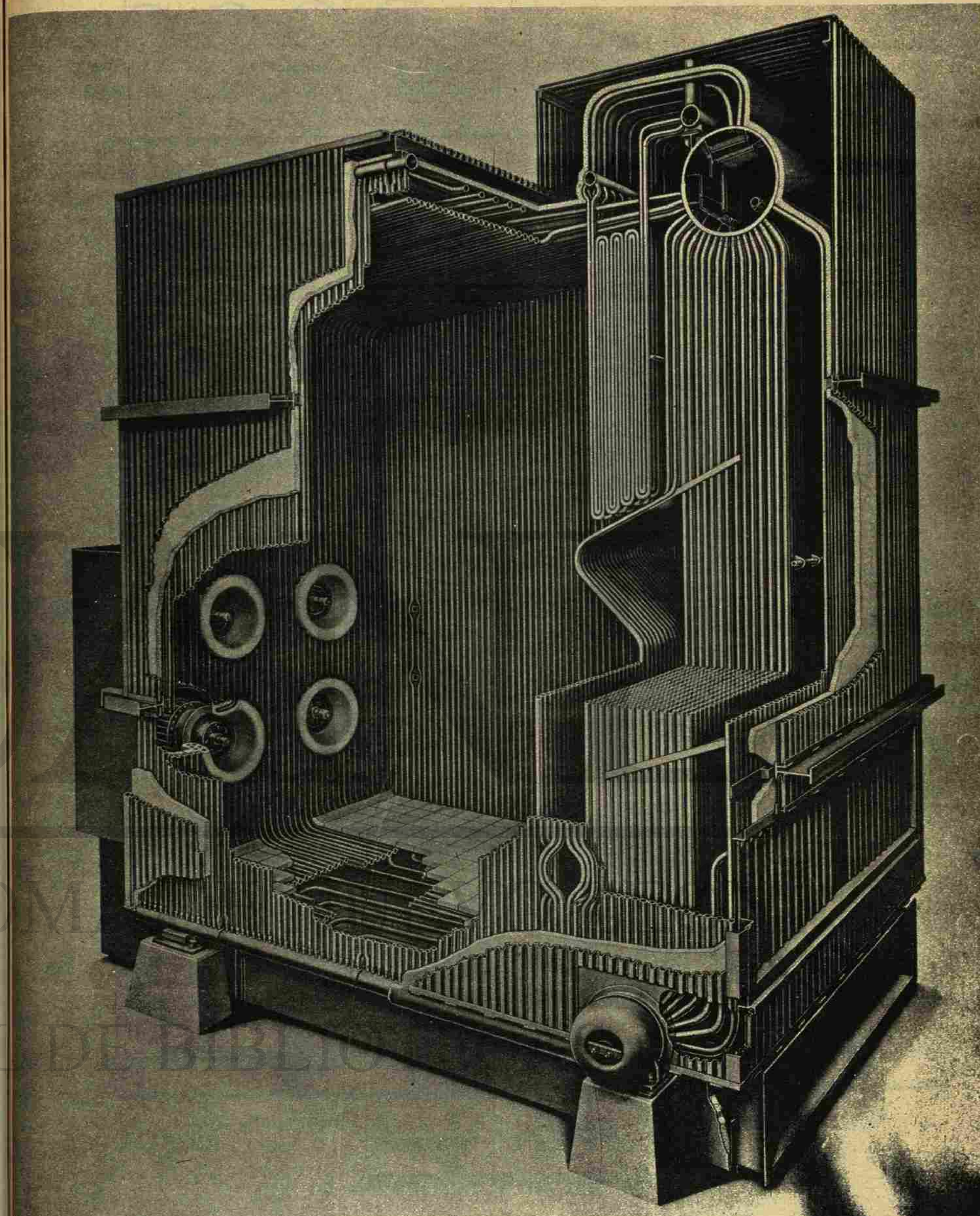
Fig. 5

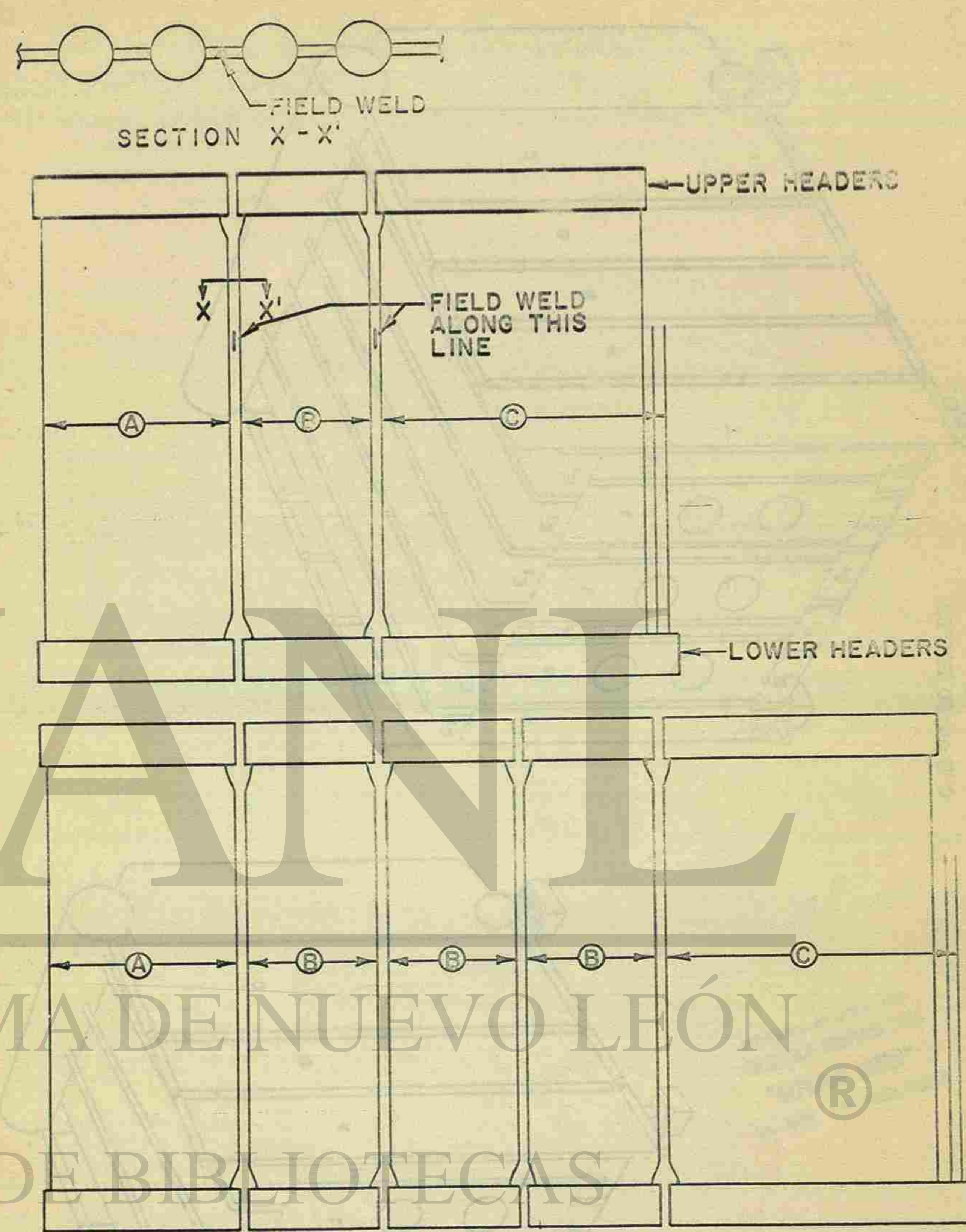


C-E CONTROLLED CIRCULATION UNIT

370 MW 2500 PSIG 1005/1005 F

Fig. 7

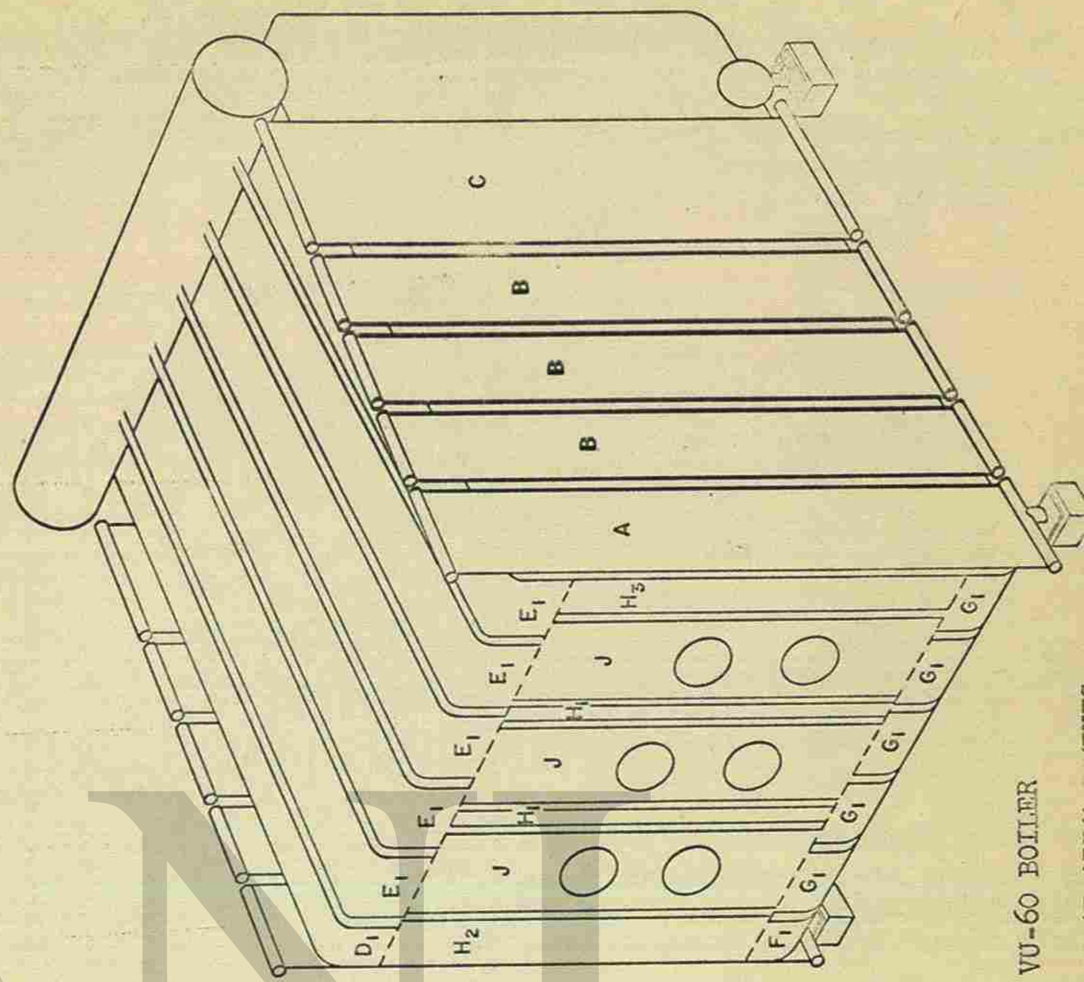


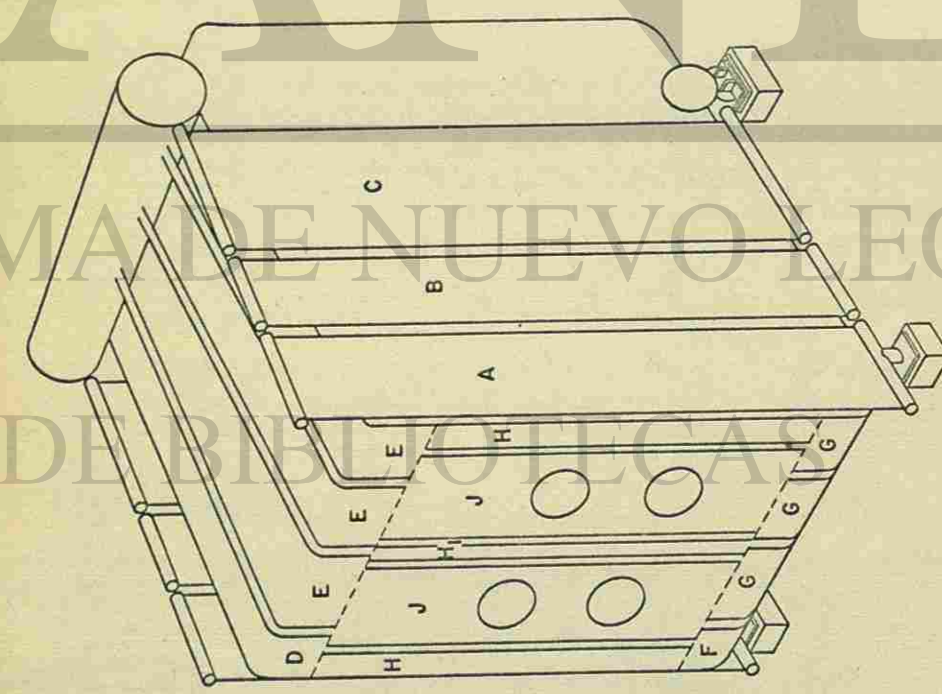


C-E VU-60 BOILER

FURNACE SIDEWALL MODULAR PANELS

Fig. 9





C-E VU-60 BOILER

TYPICAL MODULAR ARRANGEMENTS

Fig. 10