ABSTRACT: A steam generator arrangement is provided whereby various components may be independently designed and positioned to reduce or eliminate intercomponent dependency disadvantageously affecting efficiency and economy, and enabling component standardization and prefabrication with minimized field assembly. The key structural features pertain to elimination of direct connection of boiler tubes to drums, with the boiler section comprising modular boiler units including headers in the flow path between the steam drum and the boiler tubes. The lower mud drum is completely eliminated and the steam drum is positioned exteriorly of the combustion gas path.
MODULAR STEAM GENERATOR

The present invention relates to steam generators, and more particularly to an arrangement whereby certain steam generator components may be separately and individually designed and constructed to achieve optimum standards. More specifically, the basic concepts of the invention seek to obviate certain intercomponent dependencies and the structural and operational limitations associated therewith.

Individual steam generator components are to a significant degree limited with regard to size, arrangement and operational characteristics because of dependency upon other components. The depth or width of a steam generator furnace may be as significantly limited and determined by factors such as the length of the steam drum as by performance factors such as fuel characteristics or output requirements. Such intercomponent dependency and limitations, moreover, may extend to between other steam generator components in addition to the furnace and the steam drum. The boiler section and the superheater section, as well as other steam generator components including other heat recovery elements, may likewise be subject to limitations because of intercomponent dependency. The effects and disadvantages of such interdependency may impose design and operational limitations which require that individual components be constructed and formulated to operate at less than optimum efficiency and economy.

Accordingly, it would be of significant advantage if certain undesirable effects and limitations of intercomponent dependency in steam generators could be eliminated or significantly reduced to enable more individual and independent design and construction of steam generator components; i.e., furnace, boiler section, steam drum, superheater, etc., with each component operative at optimum component efficiency and constructed for optimum economy.

Accordingly, it is an object of the present invention to provide an improved steam generator arrangement reducing or eliminating certain disadvantageous intercomponent dependencies and limitations.

Elimination of certain aspects of component interdependency can also give rise to additional heretofore unavailable benefits relating to standardization and prefabrication of steam generator components. In addition to elimination of the aforementioned disadvantageous limitations, the present invention contemplates enablement of techniques of steam generator design, manufacture and assembly whereby steam generator components may be prefabricated as standardized modular elements, with individual prefabricated modular elements being adaptable for utilization and field assembly in a variety of specific steam generator unit designs. Thus, it would be possible, in accordance with the present invention, to maintain an inventory of prefabricated modular steam generator components; e.g., boiler sections, furnaces, superheaters, which could be selectively field assembled in accordance with required steam generator operating characteristics.

Accordingly, it is a further object of the present invention to provide a modular steam generator construction wherein components may be standardized and prefabricated for field assembly.

One of the most significant structural aspects of presently known steam generator constructions affecting intercomponent dependency is the construction and arrangement of the boiler section. Traditionally, boiler sections are comprised of an upper steam drum and a lower mud drum with boiler tubes extending directly therebetween. Inasmuch as every boiler tube is directly connected to both the steam drum and the lower drum, the length of the boiler section is determined by the length of the tubes. This interdependency affects not only the length of the drums, boiler section, and superheater arrangement, but it may further affect other structural and operational relationships pertaining to other steam generator components. For example, depending upon the specific furnace arrangement and the direction of burner orientation and flame travel, a certain minimum furnace depth may be mandatory based upon length of flame travel. In some particular steam generator arrangements, furnace width or depth will determine steam drum length which in turn would determine boiler section length. Thus, a particular boiler section length would become mandatory regardless of other aspects of the requirements of the unit thereby introducing a potentially adverse affect upon optimum efficiency and economy.

The most important structural aspects of the present invention pertain to the arrangement and construction of the boiler section of a steam generator. Thus, a particular boiler section, a boiler section may be constructed in individual modular units each comprising an upper and lower header with boiler tubes extending therebetween. The headers may be appropriately connected to other steam generator components including the steam drum thereby eliminating direct connection between the boiler tubes and the steam drum and consequently eliminating the interdependency between drum length and boiler section length. Furnace water wall tubes may similarly be routed into headers for interconnection with the steam drum thereby further reducing component interdependency.

By a further aspect of the present invention the lower mud drum is completely eliminated and the steam drum is located outside of the gas path thereby effecting further improvement in unit efficiency and economy.

A better understanding of the invention may be had by reference to the following detailed description of a preferred embodiment thereof taken in connection with the accompanying drawings wherein:

FIG. 1 is a view in perspective partially schematic and broken away of a steam generator arrangement embodying the principles of the present invention;

FIG. 2 is a front elevational view partially broken away and in cross section showing the modular boiler unit of the invention;

FIG. 3 is a side elevational view of the modular boiler unit of FIG. 2;

FIG. 4 is a graph which plots furnace Effective Projected Radiant Surface in square feet against Unit Series Number;

FIG. 5 is a graph which may be utilized in conjunction with the graph of FIG. 4 to obtain certain steam generator parameters based upon a particular Unit Series Number; and

FIG. 6 is a schematic plan view of the steam generator of FIG. 1 showing the flow path of the combustion gases.

Referring to the drawings, the steam generator of the present invention is shown as basically comprising a furnace section 10, a superheater section 12 and 35 and a boiler section 14. Burners 16 mounted in the front wall 18 of furnace 10 are directed rearwardly as indicated by arrows 20 in FIG. 6 and are equipped to provide fuel combustion for the steam generator, with gases which are the product of such combustion being directed into the furnace. As depicted in FIG. 6, the combustion gases travel in the direction of arrows 20 to the rear of furnace 10 and then through a furnace exit screen 23 into the convection pass formed by superheater 12 when required and boiler section 14 as indicated by arrow 22. The gases leave the unit at the front of the boiler section 14 in the direction of arrow 24.

The structural details of furnace 10 may be in accordance with well known principles that should be apparent to those skilled in the art. Accordingly, the furnace 10, like other well known structural features, is shown schematically as comprising tubular elements 26 which form a front furnace water wall 18, sidewalls 28L and 28R, and a rear wall 30. The furnace roof 32 also comprises water tubes 26, but as will be explained hereinafter, some of these tubes may be diverted to pass steam therefrom to result in forming a radiant superheater section (when required).

Feed water is initially supplied to the unit by any known means (not shown) into the steam drum 50 which may be generally constructed utilizing many appropriate known features and which comprises drum internals 52 including liquid vapor separator means well known to those skilled in the art.
Although the steam drum 50, as to many of its structural details, is constructed in a known manner, several important aspects thereof, such as the specific location and size, particularly the length, of the drum are very important aspects of the present invention, as will appear from the disclosure which follows.

Water flows between the drum 50 and the boiler section 14. The structural configuration and arrangement of the boiler section 14 is the key element of the present invention and gives rise to many of the attendant advantages. As depicted in Figs. 1, 2, and 3, the boiler section 14 is comprised of modular boiler units 40, there being five such units depicted in the steam generator of Fig. 1. Each modular unit 40 takes the form of an open-ended box frame comprised of refractory sidewalls 41 and an upper header 42 and a lower header 43 with boiler tubes 45 extending in flow relationship therebetween. Each upper header 42 is connected to the steam drum 50 by a riser tube 33 and a downcomer tube 34. Thus, water from drum 50 may flow into the modular units 40 of boiler section 14 through downcomers 34, with a flow of heated water returning to drum 50 from boiler section 14 through risers 33. The water from the drum 50 flows into headers 42 and then through boiler tubes 45 of side walls 41 in which it is heated by the heat exchange, which takes place with combustion gases flowing through boiler section 14 across tubes 46. As seen in Figs. 1, 2, and 3, the open cross-sectional areas of the frames are progressively smaller from one frame to the next in the direction relatively away from the furnace. Thus, the combined area of the narrow, vertically elongated openings and cross-sectional areas of the sidewalls 41 in each unit, is progressively smaller from one unit to the next in this direction, so that the mass flow through the units is increased as the convection path becomes progressively more remote from the furnace. Some of the heated water flows back to drum 50 in form of water-steam mixture through risers 33 with the remaining portion flowing down into lower header 44 and through downcomer tubes 36 into the furnace water wall lower headers 39 from where it flows upwardly into water wall tubes comprising the furnace walls 18, 28, and 30 for further heating by heat exchange with the products of combustion within the furnace 10.

Headers 54 receive the upflow of steam-water mixture from the furnace water wall tubes, and transmit this flow to steam superheater 20, which includes boiler tubes 26 forming the boiler section 14. Headers 54 are connected directly into headers 55 and by way of headers 54 are connected directly into a header 56 by way of headers 54 and by way of headers 55 and by way of headers 56 and by way of headers 56 and by way of headers 56 and by way of headers 56 and by way of headers 56. As depicted in Fig. 1, some of the water wall tubes, 26 which form side wall 28R are continuously integral with tubes forming roof 32 and are connected directly into a header 54. However, others of the tubes 26 in side wall 28R within that portion of roof that is radiant superheater are connected into an intermediate header 55, and disconnected from tubes 26 which form roof 32. This section of roof tubes will be also disconnected from header 54 and joined to headers 57 and 59. When it is desired to arrange a portion of the furnace roof 32 into a radiant superheater section, to adjust final steam temperature, it is merely necessary to disconnect a desired number of the roof tubes 26 from between headers 54 and wall 28R, and reconfigure the superheater section. It will be noted that auxiliary headers 58 and 59 and auxiliary forward end of headers 59 are shown in dotted form. This is to depict the fact that these headers are not needed unless a radiant superheater section is required. In such a case, header 59 may be extended by adding the auxiliary forward section shown dotted and auxiliary headers 58 and 59. Also, a connection between header 55 and drum 50 should be included to provide for flow into the drum of the steam-water mixture entering between two side walls 28R. When no radiant superheater is required, all the roof tubes 26 which would otherwise be connected between headers 57 and 59 will be integral with side wall 28R and terminate into header 54 as previously described.

Steam flow into the radiant superheater header 57 is provided from drum 50 by way of connecting tube 61 which is the rerouted branch of the tube system 58 which normally feeds steam to the convection superheater 12 when radiant superheater is not required. Steam from header 57 flows through the radiant superheater tubes 26 in the furnace roof 32 to header 59 where the steam flows through the convection superheater enclosure 35 and convection superheater 12 to the steam generator unit outlet 62.

As previously stated, the most important structural concept of the present invention resides in the arrangement of boiler section 14. In the typical boiler section construction heretofore known, all boiler section tubes are connected directly to an upper steam drum and to a lower mud drum, the steam drum being similar to drum 50. Because every boiler section tube, in prior art structures, is connected to two drums, the length of the drums and the length of the boiler section must necessarily be equivalent. Accordingly, a component interdependency would exist physically relating steam drum length directly to boiler section length regardless of whether optimum operational efficiency would require differing lengths. Furthermore, due to the number of individual tubes connected directly to the drum, the wall thickness of the drum must be maintained above a particular minimum. Additionally, both drums including the steam drum would have to be located within the path of the combustion gases which must flow across the boiler tubes to effect the necessary heat transfer. This is an additional factor preventing decrease of the cost and complexity of the steam drum construction due to the thermal stresses to which the drum is exposed.

By utilization of the present invention, these and other drawbacks may be overcome or eliminated. As will be apparent from the foregoing description, the necessity for a lower mud drum is completely eliminated. Furthermore, the steam drum 50 may be located completely outside the gas path and its orientation with respect to the boiler section, or other steam generator components, may be varied; i.e., it may be situated with its length parallel to the length of the boiler section as shown in the drawings, or it may be oriented in some other convenient juxtaposition. By arranging the boiler section in accordance with the present invention there results a significant decrease in the number of tubes which must be directly connected to the drum, thereby further enabling reduction in the thickness of material required for the drum. Also, less connections would produce a less complex structure and reduction in stress-producing aspects of the structure.
boiler section connections 33 and 34 may be located at virtually any location on the drum 50 and greater flexibility in locating these connections makes possible an arrangement whereby drum internals may be positioned on both sides of the drum 50 thereby nearly doubling the steam-water separation capacity per foot of drum length. It will be apparent that this will significantly reduce drum length for a given required capacity thereby further reducing substantially the cost of the unit. These and many other advantages and improvements made possible by utilization of the present invention will be apparent to those skilled in the art.

In addition to the advantages discussed herein and others too numerous to describe in detail, the present invention makes possible the very important and valuable achievement of a steam generator comprising standardized modular components. As shown in FIGS. 1, 2, and 3, the boiler section 14 is comprised of modular boiler units 40 which may be manufactured by prefabrication in standardized sizes. The units 40 may be constructed to include outer enclosing walls 41 including refractory material or other appropriate materials which would suitably thermally insulate the boiler section connection path. Depending upon the particular operational requirements of a steam generator unit, an appropriate number of suitably sized boiler units 40 could be selected from among a prefabricated inventory of standard sizes. The units 40 could then be assembled together utilizing known assembly techniques to connect the necessary water tubes by welding of the like, and to join together the outer wall portions 41 to form a continuous boiler section 14 made up of the appropriate number and size of units 40. Of course, it would be possible to totally field assemble the entire boiler section by onsite interconnection of boiler units 40.

In a similar fashion, other section of the steam generator such as the convection superheater 12 integral with superheater enclosure 35, steam drum 50 and the furnace 10, could be prefabricated and/or field assembled in accordance with specific requirements, with the possibility that these sections could also be provided in a prefabricated inventory of standardized dimensions. Of course, in any case, the amount and degree of standardization, prefabrication and field assembly would vary with specific requirements, but it is important to note that due to the concepts of the present invention a great flexibility in sizing and arranging individual sections has been introduced with a resulting potential for a maximized prefabrication and a minimized field assembly. The furnace, the boiler section, the steam drum and the superheater may now be constructed and arranged with significantly reduced interdependency thereby enabling greater flexibility in the relative physical juxtaposition of the components as well as their independent sizing to meet optimum efficiency requirements, and their standardized prefabrication as modular components adapted for field assembly.

A specific example of standardization of steam generator components and assembly may be described by reference to FIGS. 4 and 5 which are graphic plots of steam generator characteristics. The approach to standardization depicted in FIGS. 4 and 5 proceeds upon the basis of a set series of steam generator units with each individual unit in the series being identified by a unit numerical designation. In the example described herein, a steam generator series comprising twenty designations exemplifies the selection of variously sized modular standardized steam generator elements. In FIG. 4 there is shown a curve plotting the Effective Projected Radiant Surface, EPRS, against the Unit Series Number. In the specific standardization technique herein described, it is assumed that twenty standardized units are sufficient. However, it should be apparent from the description which follows that this number could be varied depending upon specific requirements contemplated.

EPRS is a function of steam generator output requirements and, therefore, from a determination of the output requirements of a particular installation there may be derived the particular EPRS requirement. Knowing the square footage of EPRS required, there may be derived from FIG. 4 a particular Unit Series Number from 1 to 20 which represents the particular dimensional characteristics corresponding to the EPRS requirement.

FIG. 5 relates the Unit Series Number to unit dimensional characteristics, and, accordingly, knowing the Unit Series Number and projecting the appropriately designated line in FIG. 5 to the left there may be ascertained the Average Furnace Height in feet as indicated upon the diagonal line at the left of FIG. 5. Projecting the Unit Series Number to the right in FIG. 5 there may be ascertained the Furnace Width; by projecting vertically downward to the lower horizontal line designated Unit Width the intersection of the horizontal Unit Series Number line and the diagonal line labeled A; the Steam Generator Width, by projecting vertically downward to the lower horizontal line designated Unit Width the intersection of the horizontal Unit Series Number line and the diagonal line labeled B; the Convection Pass Width, which is the difference between the Steam Generator Width and the Furnace Width; and the Furnace Depth, by projecting the horizontal Unit Series Number line to the vertical line at the right of FIG. 5.

The data depicted in FIGS. 4 and 5 may be translated into tabular form, and the following Table I exemplifies a steam generator series comprising only the three standard units corresponding to Unit Series Numbers 1, 9, and 20.

<table>
<thead>
<tr>
<th>Unit Series Number</th>
<th>1</th>
<th>9</th>
<th>20</th>
</tr>
</thead>
<tbody>
<tr>
<td>EPRS, sq. ft.</td>
<td>62.6</td>
<td>1,690</td>
<td>6,410</td>
</tr>
<tr>
<td>Furnace length, ft.</td>
<td>15.6</td>
<td>20.8</td>
<td>24.0</td>
</tr>
<tr>
<td>Furnace depth, ft.</td>
<td>18.5</td>
<td>26.0</td>
<td>35.0</td>
</tr>
<tr>
<td>Furnace width, ft.</td>
<td>7.25</td>
<td>14.0</td>
<td>23.0</td>
</tr>
<tr>
<td>Convection pass width, ft.</td>
<td>3.5</td>
<td>5.5</td>
<td>8.5</td>
</tr>
<tr>
<td>Unit width, ft.</td>
<td>11.25</td>
<td>19.5</td>
<td>31.5</td>
</tr>
</tbody>
</table>

It should be apparent that a more extensive tabulation could be derived from FIGS. 4 and 5 to include additional Unit Series Number designations which could extend to twenty or exceed that amount.

Having made a determination of the convection pass width, modular boiler units 40 can be selected from among a group which would correspond to the convection pass width involved. The number and size of such modular units 40 would be determined by the operating requirements of the unit, such as exit gas temperature, but it should be clear that such a computation and determination may be readily made once required boiler capacity has been determined. Furthermore, other components, such as the steam drum and superheater, may be sized and arranged in a flexible manner to obtain optimum operational characteristics and adjustments would be possible depending upon the specific operational levels desired.

For example, the inclusion of a radiant superheater will depend upon the final steam temperature desired, with increased numbers of tubes 26 in roof 32 being diverted for use as radiant superheater tubes for increase in final steam temperature. Furthermore, the adjustability of radiant superheater capacity enabled by the ease with which individual tubes 26 in roof 32 may be interconnected between either headers 54, 55 or between auxiliary and the furnace header 59, enables very exact control of final steam temperature without variation in furnace exit temperature and most important without the necessity for altering heating surface area.

1. A steam generator comprising a furnace, fuel burner means for generating heat in said steam generator by fuel combustion, liquid-vapor flow means in heat exchange relationship with products of said combustion, liquid-vapor drum means, said liquid-vapor flow means including boiler means...
connected to said liquid-vapor drum means with a flow path therebetween, and header means in said flow path inter-
mediate said boiler means and said liquid-vapor drum means, said liquid-vapor flow means including water wall tubes form-
ing a roof for said furnace comprising roof tube header means interconnecting said roof tubes, connecting tubes enabling liquid-vapor flow from said roof tube header means to said drum means, auxiliary header means, and auxiliary steam flow connecting means between said drum means and said auxiliary header means whereby selective interconnection of particular ones of said roof tubes from between said roof tube header means to between said auxiliary header means enables steam flow therethrough from said drum means thereby providing radiant superheater means.

2. A steam generator according to claim 1 wherein said boiler means comprise a plurality of boiler tubes directly inter-
connecting a pair of headers.

3. A steam generator according to claim 1 wherein said boiler means comprise a plurality of separately connected distinctly structured modular units, each of said units compri-
sing a plurality of boiler tubes interconnecting a pair of headers with each of said units having one of said headers connected in flow relationship with said liquid-vapor drum means.

4. A steam generator according to claim 1 wherein the drum means are comprised exclusively of said liquid-vapor type.

5. A steam generator according to claim 1 wherein said drum means are located outside the path of the products of said fuel combustion.

6. A steam generator according to claim 3 wherein said modular boiler units are of varying size.

7. A steam generator according to claim 1 wherein said modular boiler units are of a standardized size selected from among a specific predetermined number of such standardized sizes.

8. A steam generator according to claim 3 wherein each of said modular units comprises an upper header having connect-
ing tubes permitting liquid flow from said drum means and connecting tubes permitting liquid flow to said drum means.

9. A steam generator according to claim 8 wherein said liquid-vapor flow means include water wall tubes located within said furnace and wherein said modular units comprise a lower header with connecting tubes permitting liquid flow from said lower header to said furnace water wall tubes.

10. A steam generator according to claim 3 wherein said modular units include heat insulative outer walls adaptable to interconnect with similar walls upon other of said modular units to form a continuous heat insulative convection gas path in said steam generator.

11. A steam generator according to claim 1 wherein the number of said particular ones of said roof tubes which are connected between said auxiliary header means may be selec-
tively varied.

12. A steam generator according to claim 1 wherein said furnace is of a standardized size selected from among a specific predetermined number of standardized sizes.

13. In a steam generator, a furnace for generating a mass of combustion products by burning a fuel therein, conduit means having top, bottom and side walls defining an elongated con-
vection path for the passage of the combustion products in a direction relatively away from the furnace, drum means spaced apart from the conduit means for holding water, and heat transfer means defining a plurality of spaced, parallel boiler tubes which are disposed upright in the convection path and interconnected with the drum means so as to heat said water therein by circulating it through the conduit means in heat transfer relationship with the combustion products, said boiler tubes being arranged in crosswise planes of the conduit means at intervals along the length of the convection path, and spaced apart from the sidewalls of the conduit means so as to form a series of successively interconnected boiler units which have narrow, vertically elongated openings in the aforesaid planes thereof that are coextensive with the tubes and sidewalls of the respective units for the free passage of the combustion products therethrough in a course generally paral-
lel to the top and bottom walls of the conduit means, the combined area of the openings in each respective unit being progressively smaller from one unit to the next in the aforesaid direction relatively away from the furnace, so that the mass flow through the units is increased as the convection path becomes progressively more remote from the furnace.

14. The steam generator according to claim 13 wherein each unit has a plurality of tubes in the plane thereof, and the tubes of each respective unit are interconnected with the drum means by a pair of headers connected to the upper and lower ends thereof.

15. The steam generator according to claim 12 wherein the conduit means includes a series of open-ended box frames which are disposed end-to-end with one another and have the boiler tubes arranged crosswise therewithin, the open cross-
sectional area of the frames being progressively smaller from one frame to the next in the aforesaid direction relatively away from the furnace.

16. The steam generator according to claim 15 wherein the top and bottom walls of the frames form headers for the boiler tubes, and the headers are interconnected with the drum means for the supply and return of the water to and from the tubes.

17. The steam generator according to claim 15 wherein the box frames have a common width but progressively smaller heights in the aforesaid direction relatively away from the furnace, and there are means for closing the peripheral gaps between the ends of the frames at each juncture therebetween.