Very Large Steam Reformers

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INTRODUCTION

Recent forecasts of future natural gas requirements in the United States indicate that demand will exceed locally utilised production by 6,800,000,000,000 cubic feet during the year 1980 - (a 18,600,000,000 CFD deficit) (Reference - The Economist Intelligence Unit Ltd).

Japan similarly will have a deficit by 1980 for which estimates vary widely. The Economist Intelligence Unit forecast the figure for the year 1980 as 600,000,000,000 cubic feet (1,640,000,000 CFD).

Trans-oceanic transportation of natural gas in the liquid form (LNG) from countries with surplus supplies has been seen as one means of making up these deficits.

A major problem associated with the LNG scheme is the provision of transportation vessels. Cryogenic tankers are required which at present are on a 5 to 7 year delivery schedule and their costs are extremely high and still escalating rapidly.

An alternative means of transporting "natural gas" is now being studied in great detail. The idea is to convert the natural gas at its source to fuel quality methanol (or Liquid Chemical L.C.F) and to ship the methanol in conventional tankers for burning direct as fuel at the user location, or convert the methanol to SNG (Substitute Natural Gas) to supplement the locally produced natural gas.

Economic comparisons between the two schemes have been discussed elsewhere and the general opinion is that both types of plant will be built.

The plants to produce "methanol fuel" in economic quantities will be far larger than the methanol plants now being built for "chemical quality methanol".

LARGE PLANT

Contractors in the process industry and equipment vendors are being continually asked to supply larger plants in order that the chemical producer, refinery operator and fuel supplier, can keep pace with the ever increasing demand for more and cheaper product. For example, single stream ammonia plants have increased in size from 150 TPD of ammonia to 1,500 TPD in about one decade. The industry now faces a much larger increase in the size of methanol plants when the "fuel quality methanol" schemes proceed.

In a period from 1968 until 1975 we are expecting to see an increase in capacity of a methanol plant from 150 TPD to 25,000 TPD. In order to achieve the minimum production costs, this 25,000 TPD plant should be made up from the minimum number of single streams.

PROCESS ROUTE TO METHANOL FUEL

The natural gas which is currently being or that will be flared in areas such as the Middle East can be converted to methanol by the following process route. (See Fig. I).

The process consists of three basic steps:-

Steam reforming of desulphurised natural gas.
Compression to, and synthesis at, 100 atmospheres.
Dehydration to the required calorific value quality by distillation.

1 Reforming

Desulphurised natural gas is mixed with steam, reformed under optimised conditions in a tubular reformer, and then cooled.

2 Compression and Synthesis

Cold synthesis gas is fed by centrifugal compression to the synthesis loop where the methanol is formed.

Excess hydrogen is purged directly from the loop and burned in the reforming furnace, thus maintaining the overall plant efficiency at a high level.

3 Dehydration

Separation of water and dissolved gases from the L.C.F is achieved in a simple single-column distillation system.

THE STEAM REFORMER IS THE MAJOR PIECE OF EQUIPMENT IN THE METHANOL PLANT

The steam reformer is the most important and expensive single item of equipment in the methanol plant. It is therefore important to optimise the size and number of steam reformers required to produce 25,000 TPD of methanol within technical limitations. To date, the largest steam reformer is operating in a methanol plant at Clear Lake Texas (Celenese Chemicals Co) and contains 600 reforming tubes. This plant can produce 1,500 TPD of methanol by a similar route to that described above, or 1,800 TPD by slightly modified process route.

The following table shows the number of reforming tubes required for the range of methanol plants discussed.

Methanol Output TPD	Reformer Tubes (approx) 4" I.D; 40' heated length
150	60
1,500	600
5,000	2,000
25,000	10,000

OPTIMUM PLANT SIZE

The basis of this paper is that a single stream methanol plant can be built to produce 5,000 TPD of methanol. Five such identical plants will be required to produce 25,000 TPD. We are thus talking of a reforming furnace containing approximately 2,000 tubes, which is in excess of three times the world's largest operating single stream furnace.

Improvement to catalysts and reformer equipment are continually being implimented. Increases in output from these improvements are disregarded in this paper because they are insignificant with respect to the magnitude of the increase in output required for the economic production of L.C.F.

The reasons for selecting 5,000 TPD methanol plant are two fold:

1 Equipment other than the reformer is proven commercially at this sizing.

2 The increasing size of reformers over the years projected to 1976 show a progression to approximately 2,000 reforming tubes. (Figure II).

This paper continues with the description of a single stream 2,000 tube reformer.

STEAM REFORMER

A steam reformer contains a number of reforming tubes which are basically heat transfer tubes filled with catalyst. The process reactants, (steam and hydrocarbon) are passed through the tube where they react endothermically. These tubes are held vertically in a direct fired furnace box. The output of the plant is dependent on the following:

1 The number of tubes.

2 The physical dimension of the tubes.

3 The operating conditions.

4 The analysis of the total feed to the reformer.

5 The activity of the catalyst.

TUBE DESIGN PARAMETERS

Some of the important design parameters of the reforming tubes and the limitations imposed upon them are as follows:

Tube Length

It is possible to increase the output of a furnace by lengthening a given number of reformer tubes and thereby increasing the volume available for catalyst.

Actual costs prove it is more economical to increase the length of a given number of tubes than to maintain tube dimensions and increase the number of tubes. Benefits from increasing the length are available until limited by one of the following factors.

a Pressure Drop through the catalyst packed tube.

In order to limit the pressure drops through the plant to an acceptable level, the maximum heated length of a tube, currently being considered, is 50 feet giving a pressure drop through the tube in the order of 70 psi.

b Thermal Expansion.

As the reformer tubes operate at elevated temperatures, the tubes expand when heated from the ambient to operating temperatures. This expansion has to be taken up by the adjoining pipework, making its design rather cumbersome.

c Compression Load at elevated temperatures.

It is necessary, due to the length and relative small diameters of the tubes, to minimize the self weight compressive load on the tube. This is done by partially supporting the tube at the top by either counter-weights or by tensioning springs. Whichever method is used, a tube length from 40-50 feet seems to be the optimum.

Tube Diameter

Increasing the diameter of the tube achieves a larger volume available for catalyst for a given number of furnace fittings, as does lengthening the tube. Although in increasing this dimension consideration must be given to the following:

a Increasing the hoop stress in the tube.

This will increase the thickness of the tube wall, offering a higher resistivity to heat transfer, resulting in higher tube wall temperatures. The higher tube wall temperature again increases the wall thickness and therefore an economic optimum diameter must be chosen.

b Decreasing the tubes' heat transfer surface area for a given volume of catalyst.

This increases the tube wall metal temperatures and hence the tube wall thickness resulting from the higher heat fluxes required to pass the heat of reaction.

c Reduction in the gas side heat transfer coefficient.

Resulting again in higher tube wall temperatures and hence thicker tube walls.

The cost of tube material in its fabricated form is approximately $1.25 per pound weight (compared with $0.25 per pound for carbon steel), the need for optimisation then is critical on reformers containing 2,000 tubes.

Taking into account the above, also the heat flux and catalyst loading limitations imposed by the catalyst suppliers, the economical diameters for reformer tubes vary between 3½" and 4½" ID dependent upon operating conditions.

Tube Pitch

Take one row of tubes firstly it is necessary to select the tube pitch. This choice is governed by mechanical limitations of how close together tubes can be placed and an economic evaluation of tube wall thickness against the pitch selected. In general terms, the closer the tubes are together, the hotter the tubes will be for a given set of operating conditions. As the metal thickness of the tube is highly dependent upon the metal temperature of the tube an economic tube pitch is essential on large furnaces. Tube pitches of 9 to 11 inches are normally chosen after economic optimisation.

Other Variables

Consideration must also be given to catalysts and their activity, the temperature and pressure of the reaction, the steam to hydrocarbon ratio, of the catalysts' loading: all of which can be optimised to give the best possible output from a given number of tubes.

The above considerations leads the designer to the dimensions of the tube and the proximity of the tubes to each other within a single row.

TYPE OF FURNACE

Secondly we must consider the basic type of furnace which is best suited to large steam reformers.

Furnaces are generally classified into two types:

i Vertically fired multirow furnaces.

ii Side fired furnaces.

Side Fired

The side-fired furnace relies upon the tube being bounded on two sides by a refractory wall. The heat is received by the tubes from the radiating refractory wall. This, in fact, limits a dimensional freedom when trying to increase the size of the furnace. As we have already discussed, the heated length of a tube is fixed at say 40'-50' and each tube must be bounded on two sides by a refractory wall : this leaves just one dimension for expansion.

Vertically Fired Furnaces

Conversely on an up-fired or down-fired furnace the heat to the tubes is supplied by the radiating products of combustion and not radiating refractory. This means that we can have more than one row of tubes within the furnace box. This then allows for two dimensions of freedom. (See Figure III).

Single cell multi-row steam reformer furnaces have been operating for many years. In fact the majority of reformers outside the United States are of this type. The choice between up and down firing of the multi-row furnace generally breaks in favour of down firing when the size of the furnace and its convection section is large enough to require an induced draught fan to ensure good operation. This breakpoint is generally a furnace containing about 10 tubes.

The fundamental difference between a side-fired and vertically fired furnace is that the former requires refractory wall to effect heat supply to the tubes whilst the latter relies upon radiant heat transfer from the combustion gases. Thus multirow vertically fired furnaces are constructed without inter-row refractory walls.

Side Fired or Top Fired Furnaces for very large Steam Reformers

The maximum number of tubes than can be satisfactorily contained within a single cell side-fired furnace is approximately 150. This means about 13 radiant boxes would be required to produce 5,000 TPD of methanol and 65 boxes to produce 25,000 TPD.

The largest multi-row furnace now operating contains 600 tubes* which reduces the radiant box requirements to 4 and 16 for the 5,000 TPD and 25,000 TPD plants respectively.

Furnaces of the multi-row type containing 2,000 tubes will reduce the radiant box requirement to only 1 and 5 respectively.

*This 600 tube furnace was designed on the Modular concept (detailed description to follow) such that by repeating proven modules any number of tubes can be accommodated.

Summary of Number of Radiant boxes required by the different furnaces.

	Number of Radiant Boxes.		
Output (Methanol)	Side Fired. 150 tubes per radiant box	Top Fired. 600 tubes per radiant box	Top Fired. 2,000 tubes per radiant box
5,000 TPD	13	4	1
25,000 TPD	65	16	5

This table shows the magnitude of the variance in designs when applied to very large reformed gas requirements.

The economic and operational advantages of selecting a low number of radiant boxes are considerable. Each radiant box will have its own piping, valving, instrumentation, burners and flue gas exhaust fan and all will require attention from plant operators.

MODULAR FURNACE

A radiant box containing approximately 2,000 tubes is the economic design for the proposed 5,000 TPD methanol plant, we now describe the Davy Powergas Modular Steam Reformer. The "MODULAR" concept that allows for an almost limitless expansion of the reformers.

This design has been developed over many years and is based upon the experience gained by our company in supplying over 170 steam reformers.

PRIMARY REFORMER (RADIANT SECTION)

General (See Figure IV)

The modular reformer is basically a box shaped refractory lined chamber, encasing the tubes.

The reformer tubes are supported vertically in straight rows and are connected to the feed stock header and reformed gas header systems by means of small bore tubes called pig tails. These pig tails protrude from the top and bottom of the furnace respectively.

The feedstock and steam flow downwards inside the catalyst filled reformer tubes. The heat for reaction is supplied by the products of combustion passing co-currently down the furnace outside the tubes.

The flue gases from the furnace flow into flue gas coffins or chambers of firebrick construction which run the entire width of the furnace. These are situated between the rows of tubes. The openings or ports in these coffins offer a resistance to flow which ensures even distribution of the flue gases within the furnace box.

The flue gas coffins empty into a refractory lined collecting duct which is located along the entire length of the furnace. This duct transfers the flue gases to the Convection section. See Figure IV.

MODULAR CONCEPT

The MODULAR concept entails the detailed design of a standard module or section of the steam reformer which is repeated until the reformer is of the required size. The module consists of 2 rows of reforming tubes and their associated burners. It can contain up to 74 tubes and is designed such that it may be repeated with respect to process, mechanical, and structural considerations. It is the prime requirement of the concept that extrapolation of the basic design is eliminated.

Reformer Tube

The reformer tubes packed with catalyst are simply guided and part supported on steel work below the furnace hearth plate.

The tubes are generally centrifugally cast 25% Cr - 20% Ni - 0.4% Carbon alloy steel. 24% Cr - 24% Ni - 1.5% Niobuim steel which has a higher stress valve may be used in place of the above material but the economics must be calculated on a case by case basis.

Burners

The burners are arranged in rows on each side of the tube lines and are fired vertically downwards. The burners can be designed to fire either liquid, or gaseous fuels or combinations of both. Normally forced draught combustion air (either ambient or heated) is used. With gaseous fuels the burners can be designed to be self inspirating.

Inlet and Outlet Header System

The inlet and outlet header systems consist of a number of subheaders arranged symmetrically about the furnace and these headers are connected to the tubes by inlet and outlet pigtails.

Each inlet header is connected to one row of tubes by small bore pipes called pig tails. These pigtails are designed to absorb, the horizontal expansion of the headers, the vertical expansion of reformer tubes and self expansion. These small bore pipes also assist even feedstock distribution to all reformer tubes by having a significant pressure drop through them.

Each outlet header is connected to two rows of tubes by small bore tubes called outlet pigtails made from 32% Ni - 20% Cr (Alloy 800). These pigtails are designed to accommodate both vertical and horizontal expansions of outlet headers and self expansion of the pigtail.

The reactants outlet sub-headers are fabricated from 32% Ni - 20% Cr material. Each subheader has a central tee connection and transition piece to the refractory lined main which transfers the product to the next process unit downstream of the reformer.

CONVECTION SECTIONS FOR LARGE REFORMERS

With increasing capacities of reforming furnaces the convection section duties have increased proportionately. The steam generation on a 5,000 Te/day Methanol plant can be as much as 1,500,000 lb/hour.

During the last decade, maximum steam pressures on reforming plants have increased from 400 to 1500 psig. Due to the above factors, convection sections have changed and are now in design similar to conventional type of power station boiler plant.

Convection sections must be "purpose" designed to meet the individual mechanical requirements and operational flexibility of the individual plant.

In determining the performances of convection sections the following factors must be considered.

i Thermal Design

Correct thermal design is most important, operational problems are encountered with oversurfacing while undersurfacing means a lack of performance.

ii Cavity Radiation

Cavity Radiation emitted by the furnace refractory and the flue gases coming from the radiant box are directed at the first heat transfer unit in the convection section. This radiation is dependant upon the flue gas temperature and the volume of the cavity upstream of the first unit, but is independent of the output of the plant. It is then necessary to safeguard convection units with varying operating duties from this constant source of cavity radiation.

If the first unit in the convection section was a process steam superheater, this unit would have a varying heat load dependant upon the process requirement. When the plant is operating at reduced loads or a plant start-up it would be subjected to the full radiation causing high metal temperatures. This results in the choice of higher alloy for the fabrication of the unit which increases the cost and may introduce metallurgical problems not experienced with the lower temperatures and alloys.

Radiant Shield Water Tube Boilers are therefore installed to absorb cavity radiation, and their purpose is:

a To absorb high radiant loads providing the flexibility to include auxiliary firing within the furnace collecting duct. This is sometimes necessary for steam raising and/or process control.

b Protection of downstream units.

iii Flue Gas Distribution

Natural draught furnaces have known problems of gas distribution in furnace "bridging" sections due to relative low gas velocities. With the MODULAR furnaces induced draught is provided, giving higher gas velocities which offer ideal gas distribution and the elimination of unbalanced gas temperature streams.

iv Induced Draught

Higher rates of heat transfer are achieved with an induced draught system offering more compact designs. Convection sections need not conform to the radiant box dimensions, and can be designed to suit the individual plant requirements.

In the Modular furnace waste gases are collected in a separate duct, elsewhere and the convection section is independent of main point.

v Compact Tube Banks

Economic use of tube configurations and pressure drop evens out irregular flow patterns or irregular firing of auxiliary burners in modular furnace collecting duct.

This is a particular problem area in side-fired furnaces. Normally their design constraints result in the supply of units that are both long and narrow, and have large bore heat transfer tubing which can give maldistribution of flue gases and uneven metal temperatures.

vi Circulation

Boiler Water circulation is a most important factor. Usually failures of boiler systems can be attributed in one form or other to circulation problems eg:

a Pump failure in forced circulation systems.

b Dry-out caused by water loss.

c Interference with circulation by extraneous matter.

d Water chemistry causing build up of deposits, or corrosion in high flux zones with subsequent failures.

Circulation can be either Natural or Forced.

Natural Circulation Systems are preferred as they do not require any "prime movers", circulation is maintained by the "thermodynamics" of the system. Higher circulation rates exist with Natural Circulation Systems than with Forced circulation Systems.

With modular designed furnaces, the natural circulation systems is always offered.

vii Materials

Careful selection of materials to cater for all conditions of operation and start up duties. As stated in this text the design of the Modular furnaces convection section assist in reducing the serverity of the various operating conditions and makes for safer designed units.

viii Steam Drums

Steam drums must be adequately sized, not only to provide steam of high quality demanded by modern chemical plant, but, also to provide a sufficient reserve of water "hold up" to maintain circulation to "radiant" steam generators during emergency conditions.

ix Air Preheat

Combustion air preheaters improve the overall efficiency of the units, and these are becoming increasingly important as fuel prices continue to rise. For large reforming furnaces, rotary regenerative airheaters are economically more attractive than the conventional shell and tube types.

x Flexibility of Operation & Control

Controlled supplementary firing in furnace collecting ducts can be incorporated to produce additional steam which may be required to obtain the optimum steam/power balance.

The control of steam superheat is by adjustments of firing rates and/or the use of spray water attemperators at an intermediate stage in the steam superheater.

The facility for bypassing flue gases around heat transfer units is incorporated in the design.

Further supplementary firing at intermediate points in recovery duct is a further method of control which is sometimes incorporated.

Manufacture

Where possible, units should be designed to minimise field erection. During shop manufacture more stringent control can be applied to material identification, workmanship, inspection and non-destructive testing. Field erection costs are usually more expensive than "shop" charges.

STRUCTURAL DESIGN OF LARGE STEAM REFORMING FURNACES

Radiant Section

The structure forming the radiant section of the Modular Reforming Furnace can be considered in three separate parts :-

1 Top Housing - supporting and providing weather protection to the process pipework the burners and to the suspended refractory brickwork.

2 Casing - supporting the refractory brickwork, burners and reforming tubes, and providing weather protection to the brickwork forming the walls.

3 Sub-frame - supporting the casing and providing a rigid "table" over which the casing is free to thermally expand. This thermal expansion takes place radially from an anchor point and movement is guided on the rectangular axes of the furnace.

All the design methods and fabrication techniques used for the structural steelwork of the radiant section are as specified in standard structural codes.

In accordance with the modular concept the major part of the structural steelwork of the radiant section is formed by assembling a series of standard designed and shop fabricated units. Included in this category are all hearth frames, side and end casing panels, intermediate columns, beams supporting the suspended refractory roof and the top housing members. By using standardised units, fabrication time and erection periods are minimised and the possibility of fabrication errors reduced.

The maximum size of the radiant section is not governed by steelwork design, considerations. The modular concept has eliminated almost all the structural design problems which are encountered in designing large conventional furnaces.

Convection Section

The structural steelwork of the convection section duct is of similar construction to that of the radiant section although it is purpose designed. Prefabrication is maximised to reduce the erection period.

When designing the structural steelwork arrangement for the duct, consideration is given to the initial installation of boiler and superheater units; also to their removal and replacement should there be a failure during operation.

Sections of steelwork are provided which can be easily removed, normally complete with the refractory insulation.

As with the radiant section, thermal expansion of the steelwork of the duct is catered for by the provision of expansion joints at strategic places and PTFE sliding bearings in the case of a horizontal duct. Spring suspension systems are installed where the convection section is a vertical duct.

Conclusion

The energy shortage in certain areas of the world is leading the suppliers to investigate various methods of transporting the readily available natural gas from areas such as the Middle East to these areas in need of energy.

One method that is gaining interest and support is to produce and transport "fuel quality methanol".

Economic studies indicate that 5,000 TPD methanol plants are the optimum size. The critical item in these plants is the steam reformer and this paper discusses the various types of reformer available. Side fired furnaces are considered unsatisfactory for this duty due to their basic design precluding this type of furnace from increasing in physical size.

The vertically fired modular type furnace as developed by Davy Powergas, has the design capability to increase in size. The worlds largest furnace is designed to this concept, and from the design, erection and operating experience gained from this furnace we describe a steam reformer satisfactory in all aspects to meet the new requirements in the production of fuel quality methanol.

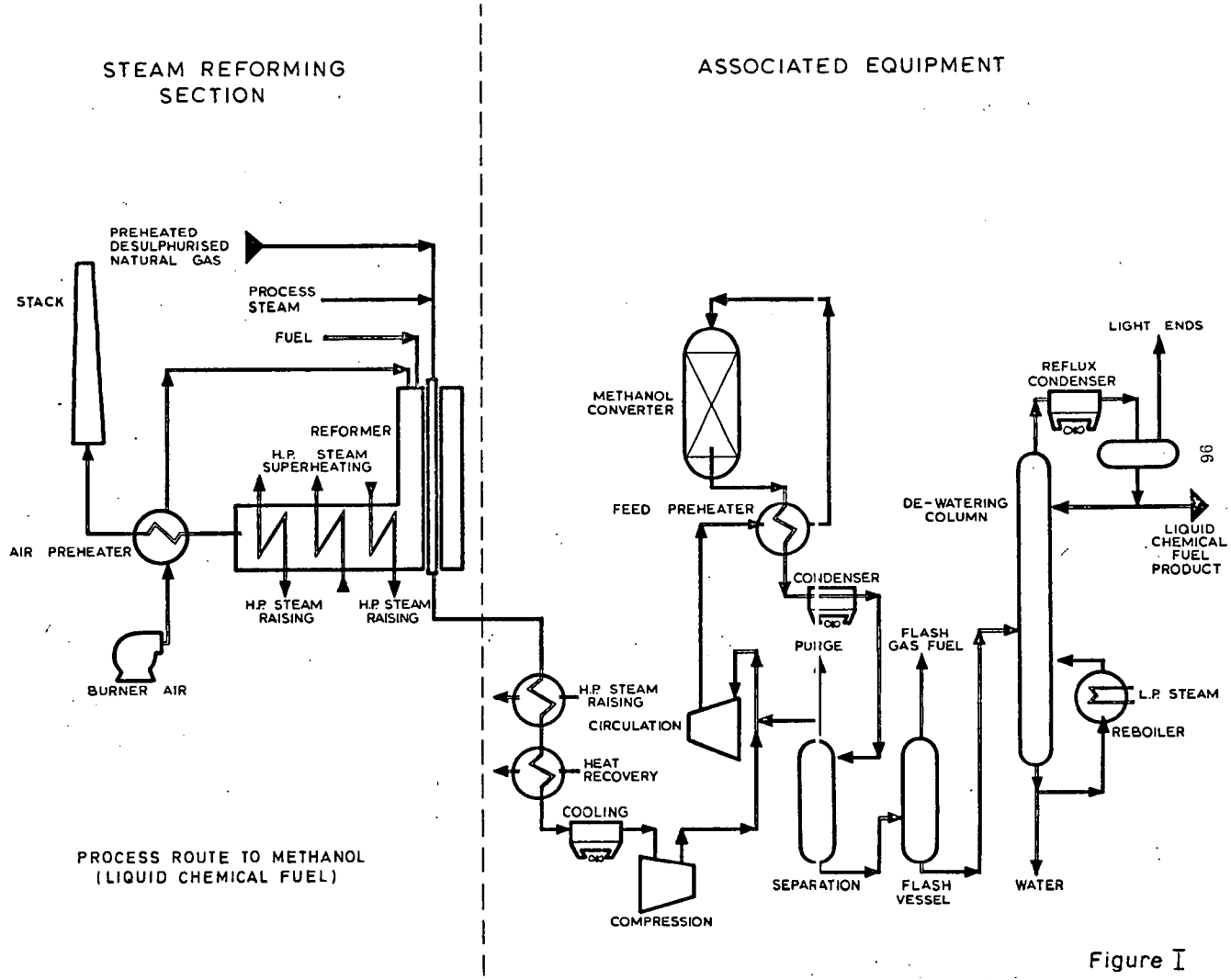

STEAM REFORMING SECTION
ASSOCIATED EQUIPMENT
PREHEATED DESULPHURISED NATURAL GAS
STACK
PROCESS STEAM
FUEL
REFORMER
H.P. STEAM SUPERHEATING
AIR PREHEATER
H.P. STEAM RAISING
H.P. STEAM RAISING
BURNER AIR
METHANOL CONVERTER
FEED PREHEATER
CONDENSER
PURGE
H.P. STEAM RAISING
CIRCULATION
HEAT RECOVERY
COOLING
COMPRESSION
SEPARATION
FLASH GAS FUEL
FLASH VESSEL
DE-WATERING COLUMN
REFLUX CONDENSER
LIGHT ENDS
LIQUID CHEMICAL FUEL PRODUCT
L.P. STEAM
REBOILER
WATER
PROCESS ROUTE TO METHANOL (LIQUID CHEMICAL FUEL)

Figure I

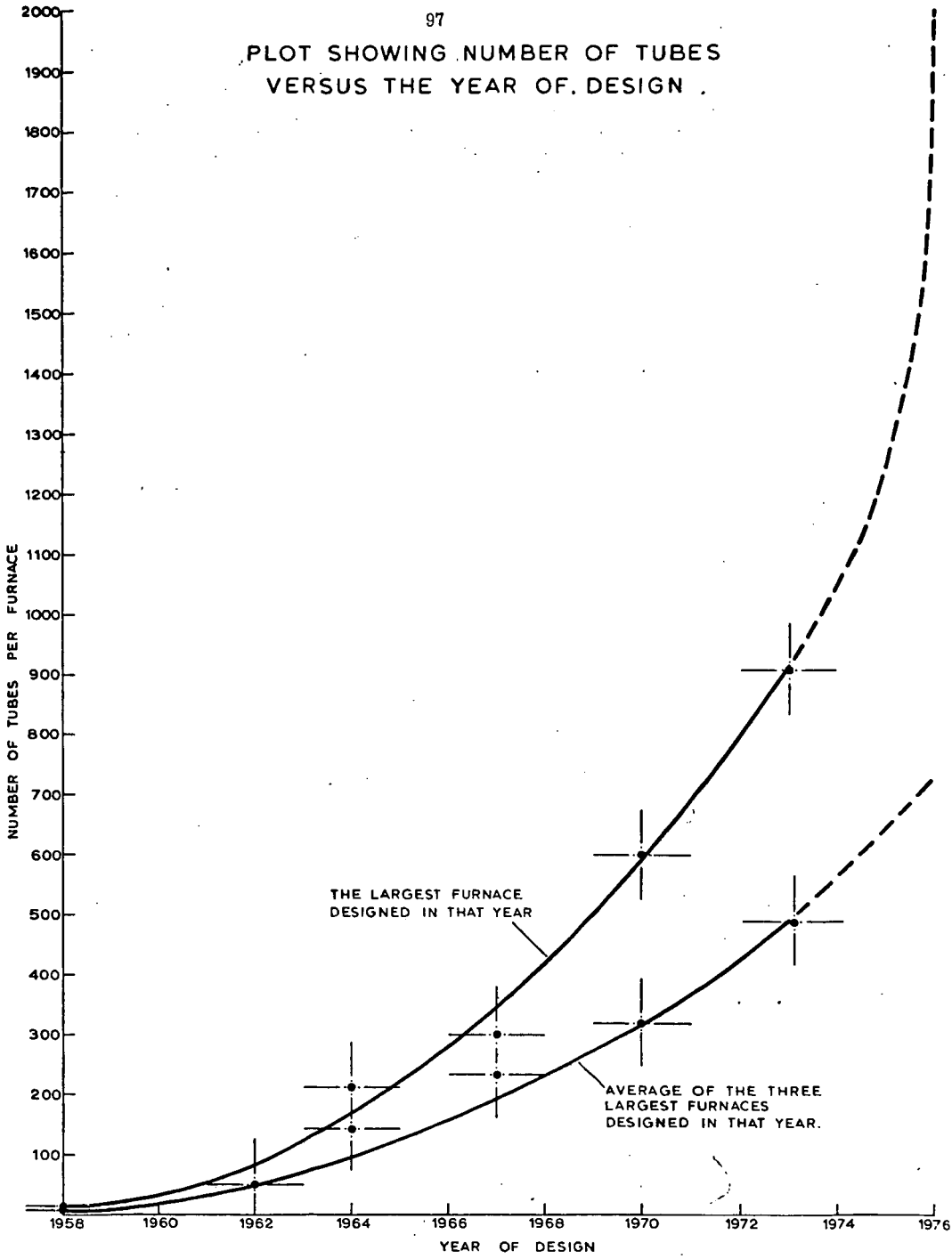
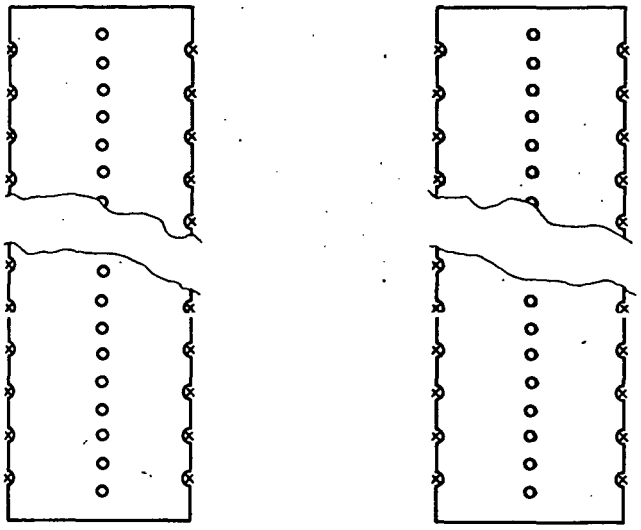
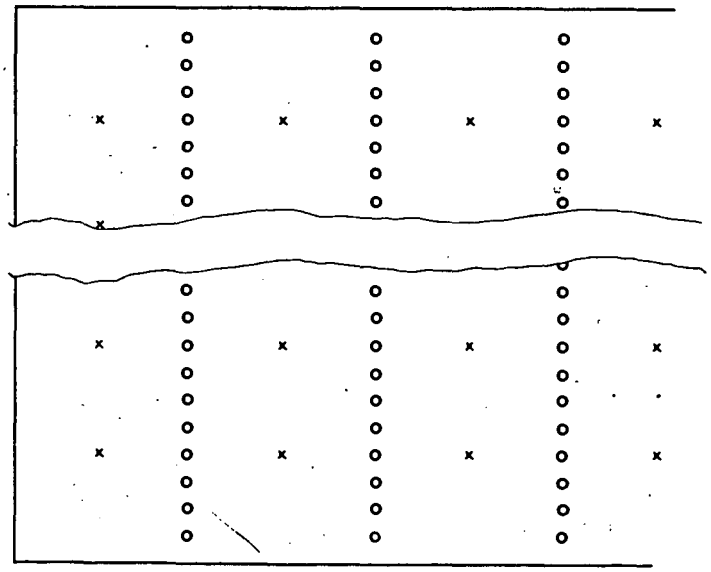

PLOT SHOWING NUMBER OF TUBES
VERSUS THE YEAR OF. DESIGN .
NUMBER OF TUBES PER FURNACE
2000
1900
1800
1700
1600
1500
1400
1300
1200
1100
1000
900
800
700
600
500
400
300
200
100
1958
1960
1962
1964
1966
1968
1970
1972
1974
1976
YEAR OF DESIGN
THE LARGEST FURNACE
DESIGNED IN THAT YEAR
AVERAGE OF THE THREE
LARGEST FURNACES
DESIGNED IN THAT YEAR.

Figure II

PLAN VIEW OF SIDE FIRED FURNACES
SHOWING NEED FOR 2 REFRACTORY SIDE WALLS
FOR EACH ROW OF TUBES



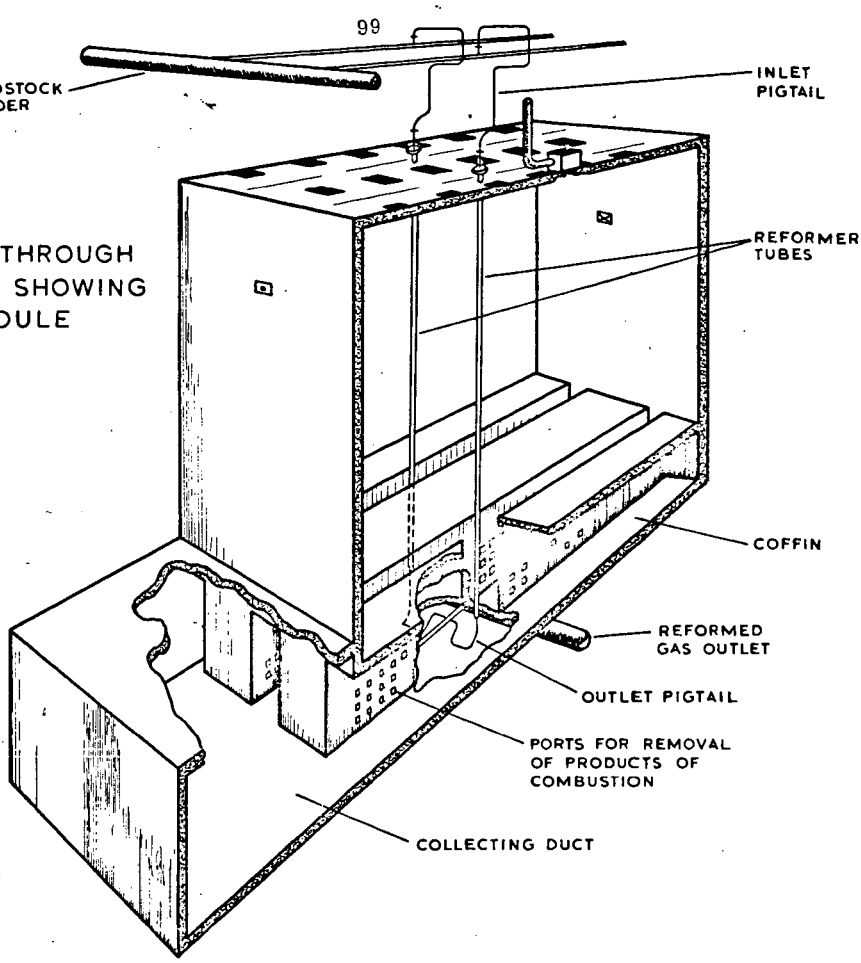
X BURNERS
O REFORMER TUBES

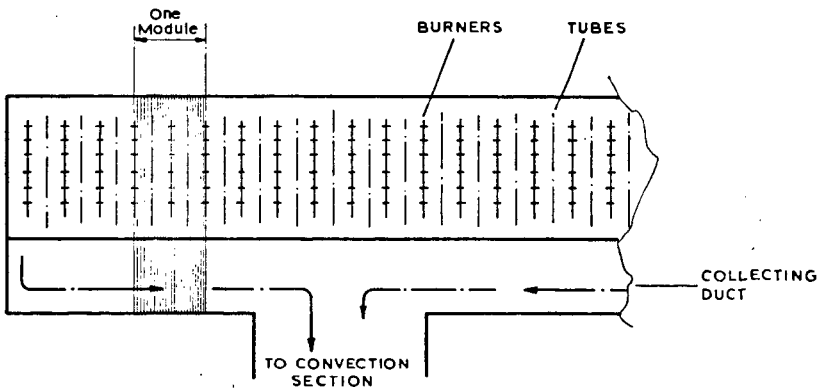


PLAN VIEW OF A VERTICALLY FIRED FURNACE
INTERMEDIATE REFRACTORY WALLS BETWEEN TUBE ROWS
ARE ABSENT FROM THE DESIGN

Figure III

SECTION THROUGH FURNACE SHOWING ONE MODULE





PLAN VIEW

Figure IV