

## Technical Article

## High Frequency Resistance Welded Finned Tubes Technologies in Heat Recovery Steam Generator Boilers

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### Abstract

In professional industries have taken an interest in being more environmentally friendly, it is important that all adopt a unified standard regarding environmental preservation. In this investigating the increase in demand for electricity in the world a continuous search for new sources of energy, engineering and technology solutions. Heat recovery system generator (HRSG) is obviously a very desirable energy source, since the product is available almost operating cost-free and increases the efficiency of the cycle in which it is placed, either for steam generation or for incremental power generation. Increasing thermal efficiency while reducing energy costs is possible through the use of finned tubes for heat exchangers. Welding contact currents frequency is a variation of resistance welding which uses high-frequency properties of the welded contact surface heating elements to melt temperature, and combinations thereof by pressure. Finned tubes used a HRSG is the core facility of a combined cycle thermal power plant that recycles thermal energy from a gas turbine and creates high temperature and high pressure gas. This paper presents the technologies of environment friendly industrial fin tube boiler, with particular emphasis on high-frequency resistance welded (HFRW) finned tubes.

*Keywords:* Finned Tube, High-Frequency, Resistance Welding, Heat Recovery Steam Generator.

### 1. Introduction

Heat recovery system generator (HRSG) is the standard term used for a steam generator producing steam by cooling hot gases. HRSG can regain energy from waste-gas streams, such as incinerator gases, furnace effluents or most commonly the exhaust of a gas turbine. In modern operation of heat transfer equipment such as heat recovery steam generator, the exit gas temperature determines the amount of energy extracted from the flue gas stream of the gas turbine. Therefore, efforts are often made to lower the stack temperature as much as possible taken into consideration cost effectiveness and low temperature corrosion. The modifications of a single pressure HRSG to multi-pressures have also improve the energy efficiency of the heat recovery steam generator unit. HRSGs can be made up from a number of components, including evaporators, economizers, superheaters, reheater, integral deaerators and preheaters. Each of the heat transfer sections performs a specific task, and the one that is selected are generally dictated by the required steam conditions for process use or power generation, the type of power generation and/or the efficiency requirement, weighed against HRSG costs [1]. Heat recovery steam generator evaporator sections act to vaporize water and produce steam in one component.

A bank of finned tubes is extended through the gas turbine's exhaust gas path from a steam drum (top) to a lower (mud) drum. The gas turbine is a very satisfactory means of producing mechanical power [2,3]. Feed water is carefully supplied at the appropriate pressure to the upper drum below the water level, and circulates from the upper to lower drum, back to the upper drum by convection within the finned tube. The economizers are serpentine finned-tube gas-to water heat exchangers, and add sensible heat (preheat) to the feed water, prior to its entry into the steam drum of the evaporator. Different heat transfer applications require different types of hardware and different configurations of heat transfer equipment [4]. In single pressure HRSG, the economizer will be located directly downstream (with respect to gas flow) of the evaporator section. In multi-pressure unit, the various economizer sections may be split, and be located in several locations both upstream and downstream of the evaporators. The superheater is a separate serpentine tube heat exchanger which is located upstream (with respect to gas flow) of the associated evaporator. This component adds sensible heat to the dry steam, superheating it beyond the saturation temperature. In gas turbine heat recovery steam generator, its performance is dependent on the gas turbine exit temperature, inlet gas temperature, feed water temperature and steam pressure. The low exhaust gas temperature generates less steam on unit gas mass basis in the HRSG

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evaporator unit. The HRSG is widely used equipment in various industries to which include process, power generation, and petroleum industry. The development of HRSG as a component part of the combined power cycle and cogeneration has improved power production and enhanced costs effectiveness within the sector. Energy and materials saving consideration, as well as economical consideration have stimulated the high demand for high efficient HRSG. Meeting the growing requirement for cost-effective and undisturbed operation in today's economic environment drives power plants to reach for the best possible performance and higher availability. Power plants can no longer afford to operate without knowing the exact HRSG performances at all times or without taking immediate actions when problems occur. Even minor decreases in the HRSG efficiency and performance can cause significant financial and energy losses during the production phase of the plant. Aerial View of Combined Cycle Thermal Power Plant. (Fig. 1.)

Consideration is also required on the actual tubing utilised to form the gas to water/steam heat exchanger. The heat transfer rate between the tube and the high density water on the inside of the tube is far greater than the transfer rate between the tube and the low density flue gas passing on the outside. The outside heat transfer rate is said to be "controlling" and therefore responsible for the overall heat transfer rate. In the case of a HRSG this overall rate of heat transfer is lower in comparison with a fired utility boiler, due to the lower flue gas temperatures and the reduced effect of radiation. Therefore, in order to increase the rate of heat exchange in the HRSG tubes, the surface area on the outside of the tubes is extended by finning. There are many variations of fin design available. A commonly employed finning process is where the fin is fabricated from strip of metal. The longer leg of the strip is slit and the strip is wound and welded in a spiral around the tube. This result in the slits of the protruding long leg spreading out is wrapped around the parent tube [5].

## 2. HRSG Function

The Brayton cycle (gas turbine) and the Rankine cycle (steam turbine) are two venerable cycles that have served mankind well. However, the combined cycle, which combines the Brayton and Rankine cycles, has resulted in cycle efficiencies exceeding 60% on a lower heating value basis. This is a much higher efficiency than can be achieved by either the

Brayton or Rankine cycle alone. To combine these two cycles, a means to recover the waste heat from the gas turbine exhaust must be provided. The modern day HRSG has met this need and is the bridge between the two cycles. The versatility of the modern day HRSG has allowed great flexibility in combined cycle design: single pressure, double pressure, triple pressure steam levels; nonreheat, reheat; and supplementary firing. In addition, the adaptability in HRSG design has provided the prerequisite heat recovery for variants of the combined cycle.

The exhaust gas from the combustion turbine becomes the heat source for the Rankine cycle portion of the combined cycle. Steam is generated in the HRSG. The HRSG recovers the waste heat available in the combustion turbine exhaust gas. The recovered heat is used to generate steam at high pressure and high temperature, and the steam is then used to generate power in the steam turbine/generator.

The HRSG is basically a heat exchanger composed of a series of preheaters (economizers), evaporator, reheaters, and super heaters. The HRSG also has supplemental firing in the duct that raises gas temperature and mass flow.

This section is intended to provide turbine operators with a basic understanding of HRSG design and operation.

The HRSG absorbs heat energy from the exhaust gas stream of the combustion turbine. The absorbed heat energy is converted to thermal energy as high temperature and pressure steam. The high-pressure steam is then used in a steam turbine generator set to produce rotational mechanical energy. The shaft of the steam turbine is connected to an electrical generator that then produces electrical power.

The waste heat is recovered from the combustion turbine exhaust gas stream through absorption by the HRSG. The exhaust gas stream is a large mass flow with temperature. Most large HRSGs can be classified as a double-wide, triple-pressure level with reheat, supplementary fired unit of natural circulation design, installed behind a natural gas fired combustion turbine. The steam generated by the HRSG is supplied to the steam turbine that drives the electrical generator system. HRSG is the core facility of a combined cycle thermal power plant that recycles thermal energy from a gas turbine and creates high temperature and high pressure gas. (Fig. 2.).

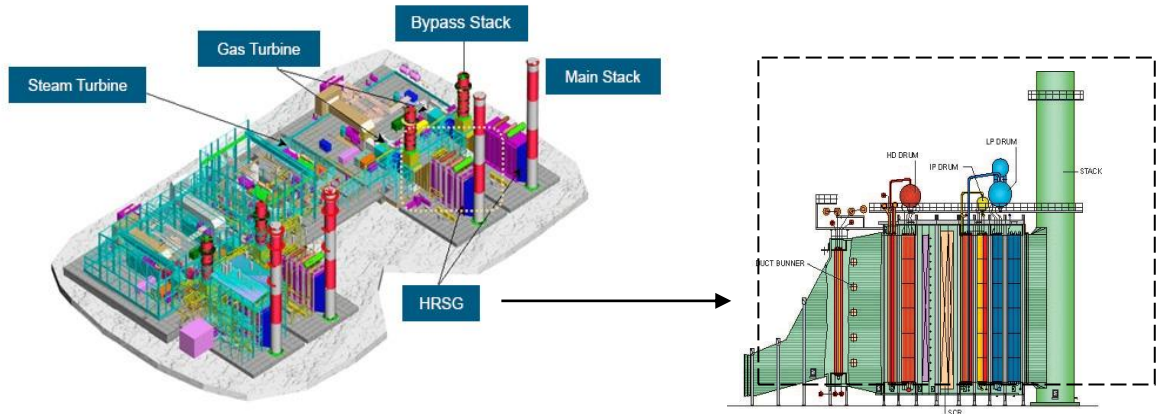


Fig. 1. Aerial View of Combined Cycle Thermal Power Plant [6].

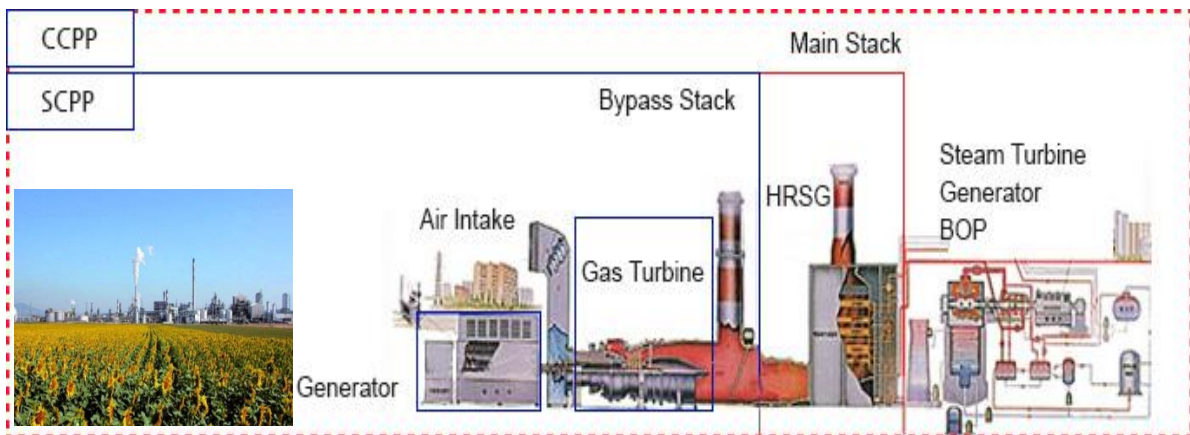


Fig. 2. Combined Cycle Thermal Power Generation System Diagram [6].

### A. Simple Cycle Power Plant (SCPP)

A single cycle power plant produces electricity by operating the gas turbine and generator using high temperature and high pressure gas generated by the combustion of compressed air mixed with fuel (NG, oil, etc.). In this case, the hot exhaust gas at around 650 °C is discharged into the atmosphere through the bypass stack, and the plant efficiency can be as much as 40%.

### B. Combined Cycle Power Plant (CCPP)

HRSG is a major component of a Combined Cycle Power Plant (CCPP). A combined cycle power plant recycles the hot exhaust gas from the gas turbine into HRSG to use it as the heat source to generate high temperature and high pressure steam to operate a steam turbine and generator to produce secondary electricity. A combined cycle power plant consists of a single cycle power generator that uses

a gas turbine and HRSG to maximize plant output and efficiency. CCPP can achieve plant efficiency of approximately 55% (Fig. 3.). [6]

### 3. HRSG Design

The function of the combined cycle HRSG system is to provide a method to extract sensible heat from the combustion turbine (CT) exhaust gas stream.

The heat is converted into usable steam by the heat transfer surfaces within the HRSG. The usable steam is generated in three separate and different pressure levels for use in a steam turbine (ST) generator set and for power augmentation of the CT. The pressure levels and their associated components are (Fig. 4.):

- High pressure (HP)
- Intermediate pressure (IP)
- Low pressure (LP)
- Reheat (RH)
- Feed water preheater (FWPH)

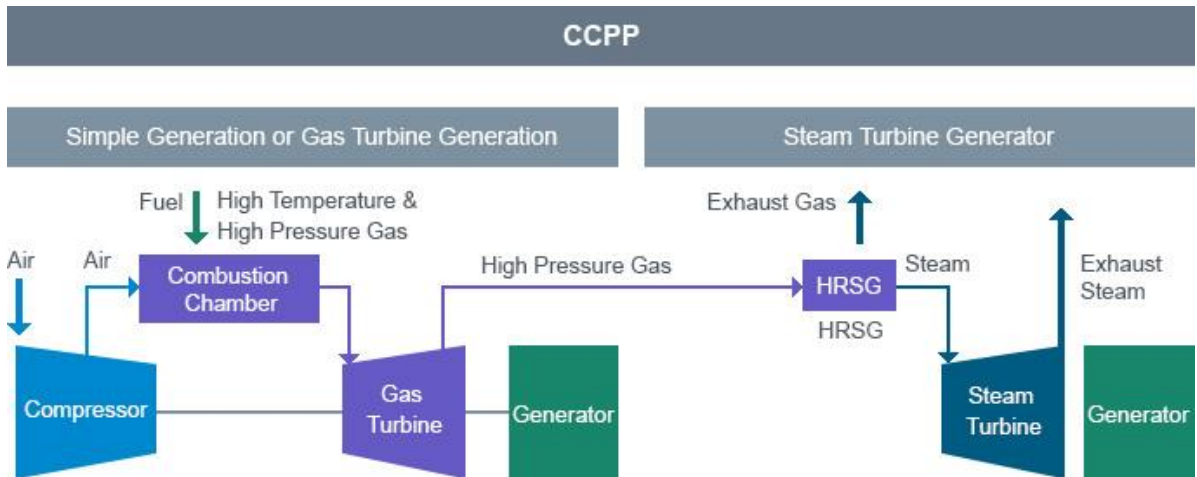


Fig. 3. Combined Cycle Power Plant (CCPP) System Diagram [6].



Fig. 4. Typical General Arrangement of Heat Recovery Steam Generator [7].

All generated steam from the HP, RH, and LP systems is supplied to the steam turbine, except for some LP steam used for deaeration, The IP steam is mixed with the cold RH return loop prior to being admitted to the steam turbine.

Typical heat recovery steam generator circuits have four major components (Fig. 5.):

- Super heaters
- Evaporators
- Economizers
- Drum

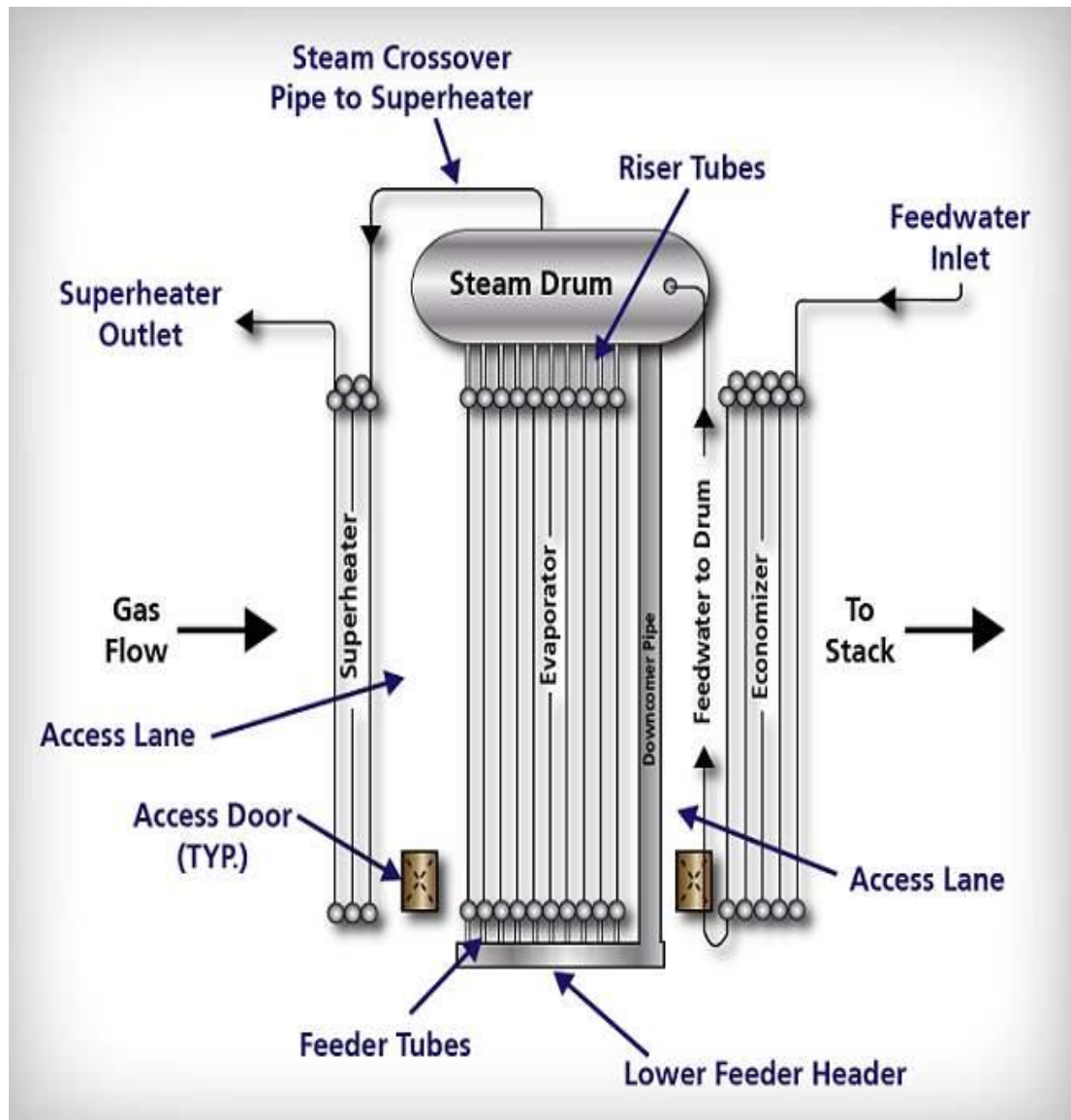


Fig. 5. Heat Recovery Steam Generator Components [7].

Since we are operating a triple-pressure system of HP, IP, and LP, we have these components for each associated pressure. These components (with the exception of the drum) are arranged in series in the gas flow path within the HRSG. Essentially, this means that the heat transfer boiler circuits are not in parallel with one another with respect to CT exhaust gas flow. The gas, after having been used to heat the water/steam in the HRSG is released to the environment through a stack.

### 3.1. Vertical and Horizontal Types

Classification is on the construction or design of the HRSG. Based on the gas flow it can be vertical or horizontal. (Fig. 6 and 7.). As well as Fig. 8. Show that the comparison of the two HRSG isometric view installed at the Power Station.

1. Vertical types have gas flow vertically upward with coils placed horizontally.

2. Horizontal types have gas flows horizontal with coils placed vertically.

From the performance and cost point of view both are the same. More than the technical issues it is a proprietary design of individual manufacturers or client preferences. Some of the differences are [7]:

1. Horizontal types require a 30 % larger footprint area.

2. More expansion joints are required in horizontal units.

3. Structural requirements are higher in vertical types.

4. Horizontal types are more difficult for maintenance and inspections.

5. Overall cost may be same in both types.

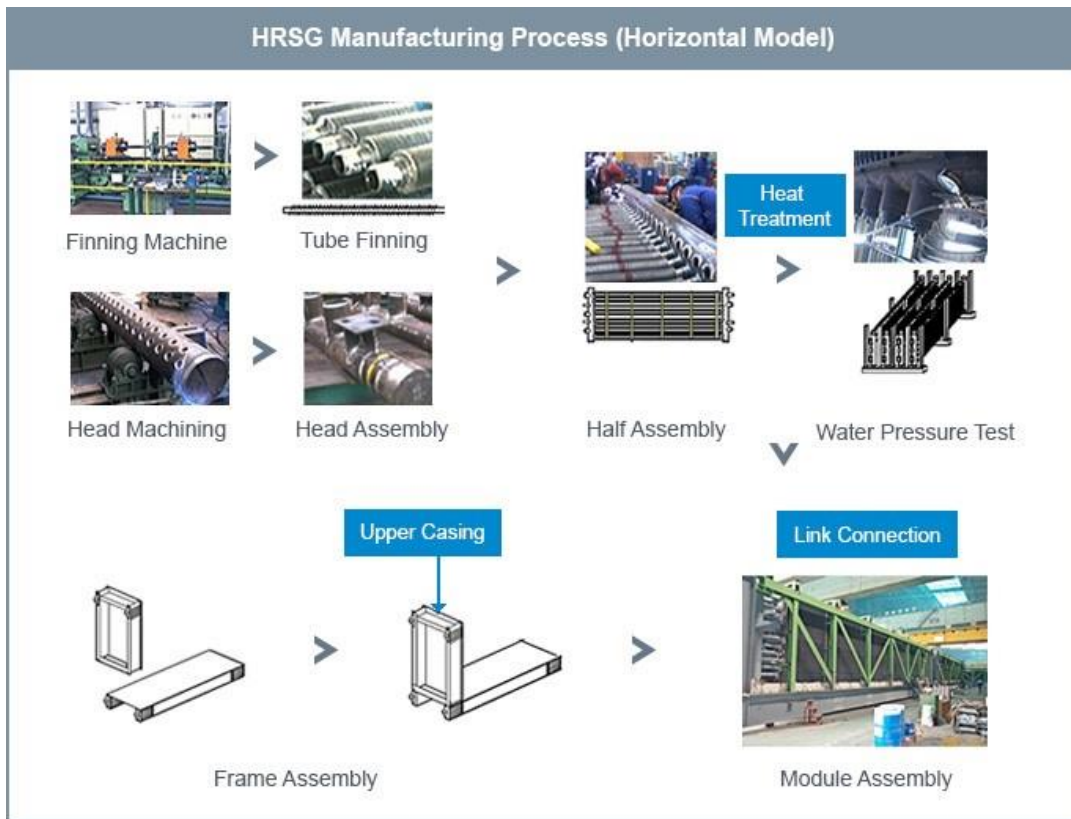


Fig. 6. HRSG Manufacturing Process (Horizontal model) [7].



Fig. 7. HRSG Manufacturing Process (Vertical model) [7].

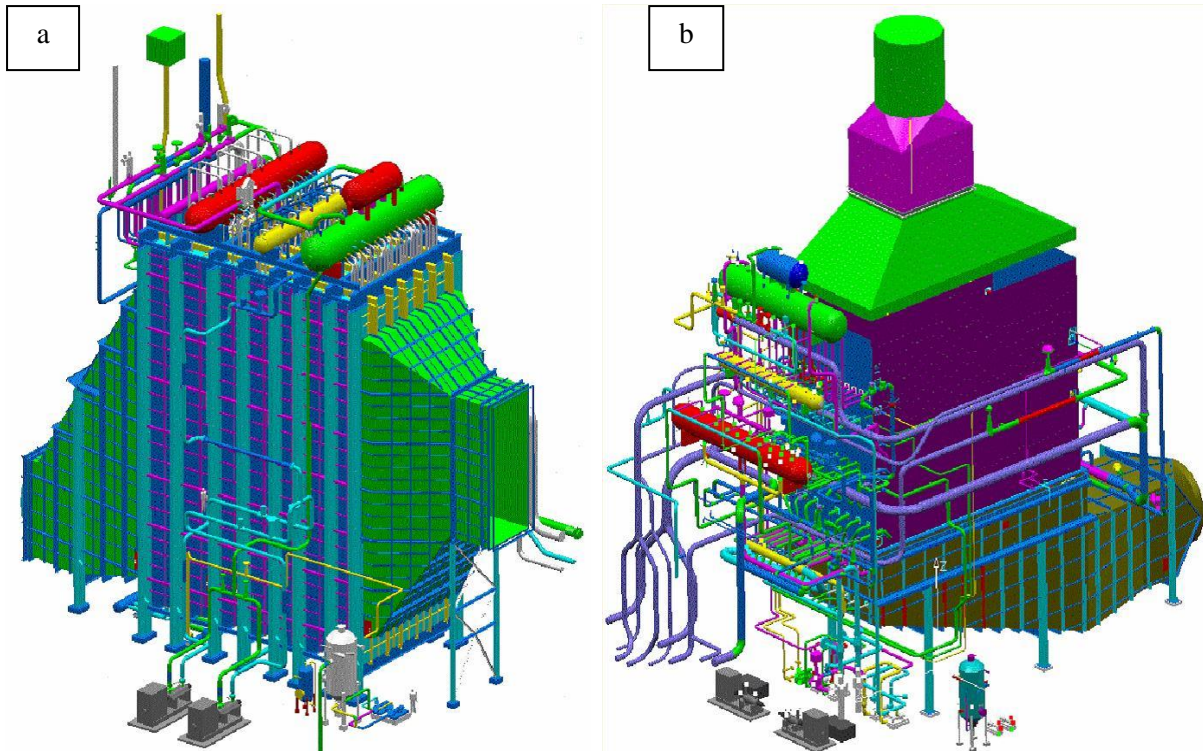


Fig. 8. Classification is on the construction or design of the HRSG, (a) Horizontal HRSG isometric view, (b) Vertical HRSG isometric [8].

#### 4. Manufacturing Finned Tubes Welding Technologies

The oldest patented method of producing cross-finned tube with a full connection is a plastic working. In the process of cold rolling formed monometallic and bimetallic tubes. For the production of pipes are used tri-axial angular contact rolling (Fig. 9a). Each roll contains the right amount of disk utilities variable geometry part of the work, and on the number of fins per meter depends on their thickness. In this technology can be divided into two types: depressing and grading method. Depressing method involves inflicting deformation using the tool disk of increasing diameter and height of the ribs is achieved by a gradual penetration of the surface pressure and the working tools. This technology is used for the production of low finned tubes. In method grading with strong clamps and tools for working with thicker walls of the tube base is obtained while thinning the cross ribs and increase its diameter. This method is applicable to the production of high-finned pipes (Fig. 9b). The materials used in the production of bimetallic pipes on the base pipe can be continuously boiler, austenitic stainless steel, brass, copper and its alloys, while the external fins of the tube is used in aluminium, copper and their alloys. Due to the differences in the thermal properties of the materials used pipe can be applied to most chemically

aggressive media and the operation to a temperature of 200 ° C [9, 11].

Another method of manufacture of finned tubes is to use the hot rolling process. This technology involves winding the tape and clamping it in before the notched groove in the base pipe (Fig. 10a). Difficulties occur in the production of stainless steel pipes. Willing stainless steel to strengthen is much higher and the groove in the base pipe cause a reduction of its thickness, which makes the production of pipes in this technology becomes uneconomic. In the case where the base pipe is made of ordinary steel, the wall thickness does not significantly affect the price of the heat exchanger. Finned tubes produced with this technology are applied to a temperature of 450° C in the case of aluminium fins and 500° C in the case of stainless steel ribs [9,10].

Another manufacturing technology finned tubes is applied to the base pipe and the webs of sheet welding or soldering the ends of the tube webs (Fig. 10b). The configuration webs creates a form of a helical spring, which is tightly applied to the pipe acts as a heat sink. Dissolve the sheet in this manner causes the tape is heavily creased, thereby increasing the contact area between the base of the finned tube and the thermal surface and the air flowing over the turbulent motion. For the production of such pipes can be used, almost all commercially available materials [11].

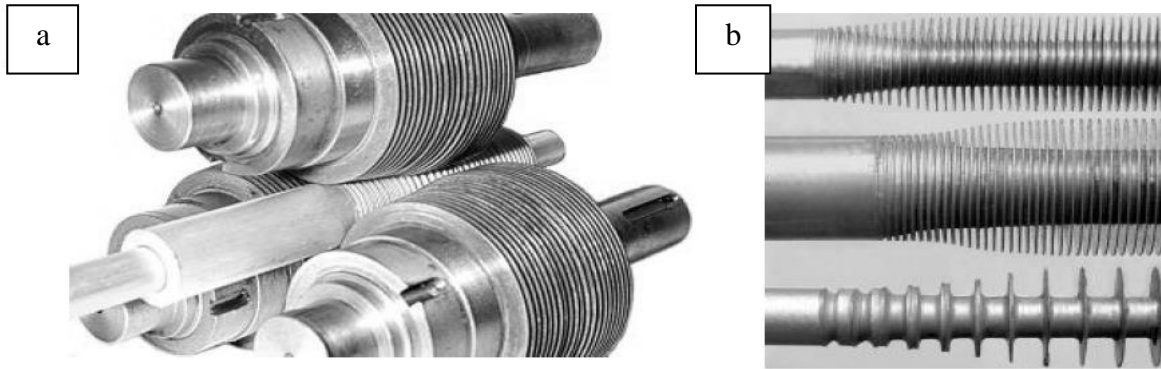


Fig. 9. The manufacturing process of finned tubes. (a) A set of three rolls of rolled tube, (b) High finned tube manufactured by depressing and grading [11].

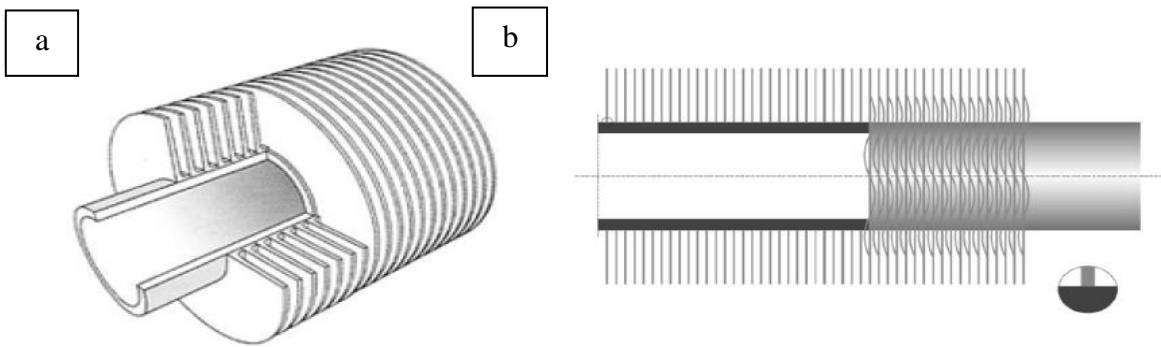


Fig. 10. Examples of finned tubes produced. (a) finned tube type G, (b) finned tube type Z [11].

The most commonly used in industrial manufacturing technology finned tubes is an automatic welding consumable electrode active gas welding (MAG). Connecting the ribs with the pipe is done using a fillet weld (Fig. 11.) or by performing a joint front in the ribs (Fig. 12.). The first method has a relatively low yield (linear welding speed 2m/min). However, in the case of the second technology cannot guarantee sufficiently high quality for use of connectors, due to the incompatibility unacceptable welding, such as lack

of fusion, adhesion, flooding and splashes (Fig. 12b). Welding contact currents frequency (HF) is a variation of resistance welding which uses high-frequency properties of the welded contact surface heating elements to melt temperature, and combinations thereof by pressure (Fig. 13.). In this method, it is important to fine-tune current switch position. The typical non-compliance includes local burnout and flooding the surface of objects and weld splatter of molten metal [12].

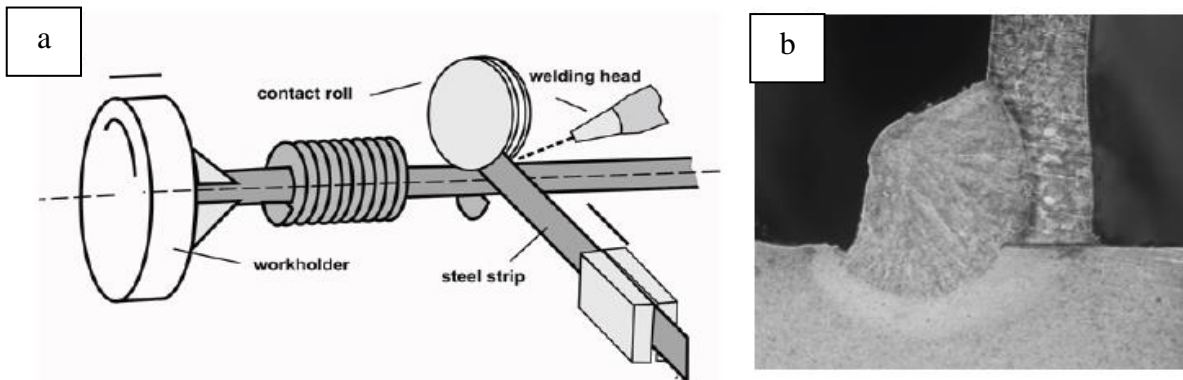


Fig. 11. Welding finned tubes fillet weld. a) Diagram of the process welding, b) The joint weld pipe - rib area (magnification 5x) [12].



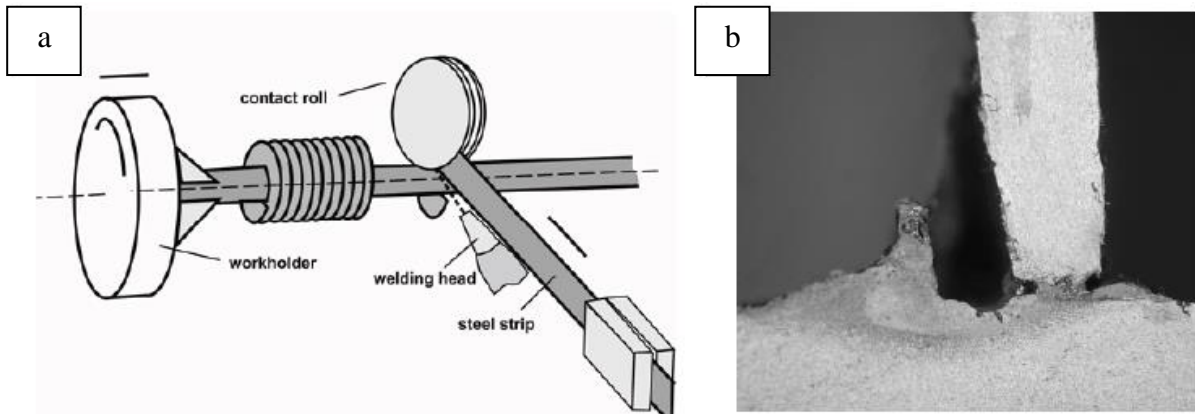


Fig. 12. Welding finned tubes in the ribs. a) A diagram of the process pipe welding in the ribs, b) Butt joint pipe - rib, ribs visible separation, magnification 5x. [12].



Fig. 13. The welding process currents of high frequency [13].

Serrated finned tubes and solid finned tubes are two types of spiral finned tubes used HF technology as illustrated in (Fig. 14.). Solid and serrated fins are widely used solutions for improving heat transfer in fired heaters. The important fact that designers or engineers often overlook while selecting the fins is that serrated fins can provide larger surface area and

significantly higher fin efficiency compared with solid fins. Chemical requirements for carbon steel and alloy steel tube illustrated in Table 1 and 2 (according to ASTM A192 and ASTM A213) [15,16]. As well as carbon steel and alloy steel coil strips shown in Table 3 and 4. ( according to ASTM A1008 and ASTM A240-TP409 ) [17,18].

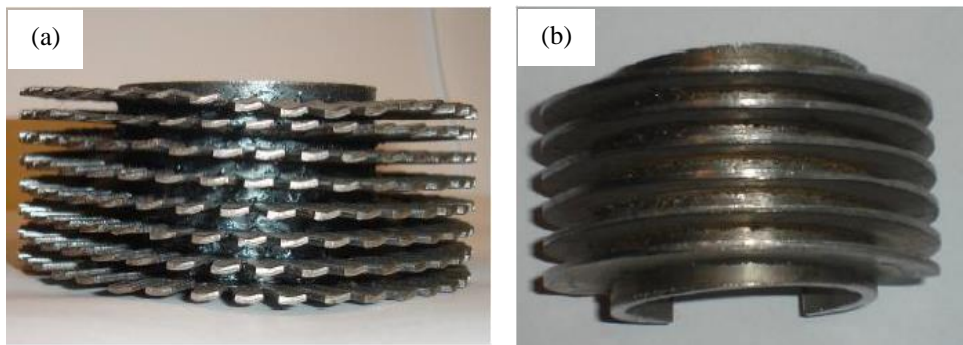


Fig. 14. Type of finned tubes HF technology. (a) Serrated finned tubes, (b) Solid finned tubes [14].

The fins greatly enhance the heat transfer surfaces, allowing the full optimization of heating surfaces of the boiler, which is achieved by reducing the dimensions of the boiler, and thus reducing its weight. The efficiency of the heat exchanger tube depends on the thermal conductivity between the pipe wall and the fluid and the surface area of the tube. For pipes of the finned heat exchanger surface can be increased by 30 times compared to the finned tube is not, and thus significantly increases thermal conductivity and the heat flux per unit increased by almost 300% as compared to compared to smooth

pipes, leading to an increase in overall efficiency of industrial boilers.

Manufacture heat exchangers with finned tubes, due to the increasing competition requires the implementation of new technological solutions in the production area. The technology of finned tubes is high frequency welding. In modern boilers are increasingly being used finned tubes made in the technology of HF. The use of concentrated high frequency power allows for a significant increase in connection speeds, ensuring the quality of the connection required by the technical regulations and standards [14].

**Table 1. Chemical requirements for carbon steel tube according to ASTM A192 (wt.%) [15].**

Grade	C	Mn	P	S	SI	Ni	Cr	Mo	V
A192 A	0.06–0.18	0.27–0.63	0.035	0.035	0.25	-	-	-	-

**Table 2. Chemical requirements for alloy steel tube according to ASTM A213 (wt.%) [16].**

Grade	C	Mn	P	S	SI	Ni	Cr	Mo	V
A213-T22	0.06-.015	0.30-0.60	0.025	0.025	0.50-1.0	-	1.90-2.60	0.87-1.18	-

**Table 3. Chemical requirements for carbon steel coil strip according to ASTM A1008 (wt.%) [17].**

Grade	C	Mn	P	S	Si	Cu	Ni	Cr	Mo	V	Cb	Ti
A1008 CS	0.10	0.60	0.030	0.035	-	0.20	0.20	0.15	0.06	0.008	0.008	0.008

**Table 4. Chemical requirements for alloy steel coil strip according to ASTM A240 (wt.%) [18].**

Grade	C	Mn	P	S	Si	Cu	Ni	Cr	Mo	V	Cb	Ti
A240-TP409	0.05-0.15	0.3-0.6	0.025	0.025	0.50	-	-	1.90-2.60	0.87-1.13	-	-	-

International standard for tests of high frequency resistance welded fins according ASME and ASTM used for metallography fusion weld ,tensile strength, hardness . Tube material specifications are Carbon Steel (C.S) such as SA192/SA178A , alloy steel such as SA213-T22 and Stainless Steel (St-St)such as SA213TP304 with outside diameter (O.D) sizes is usually 38.1mm or 50.8mm and minimum wall thicknesses (M.W.T) is 2.4mm to 5.0mm . After mock up test sample are prepared for metallography (C.S) with (Nital 2%) HCl+HNO<sub>3</sub>+CH<sub>3</sub>COOH and alloy steel HNO<sub>3</sub>+HCL+H<sub>2</sub>O according to ASTM E340-15 . Microstructure should be survey fusion weld and accepted accordance of standards specification. (Fig. 15.). [19]

Tensile tests shall be performed on finned samples. A section of one wrap of fin with a maximum width of 50% of bare tube diameter shall be placed in a tensile testing machine with suitable grips in accordance with ASTM A370-17 (ASME Boiler and Pressure Vessel Code, Section VIII, Division I, Part UG-8). (Fig. 16.) The fin shall be pulled radially from the tube and the maximum force, F, recorded. The tensile strength of the weld, S, is calculated as follows:

$$S = F / (T \times W)$$

Where:

S is the tensile strength, ksi (MPa)

F is the maximum tensile force, lbs. (N)

T is the measured fin thickness, inches (mm)

W is the width of the fin section inches (mm)

Value of minimum tensile strength applied in Table 5. [20].

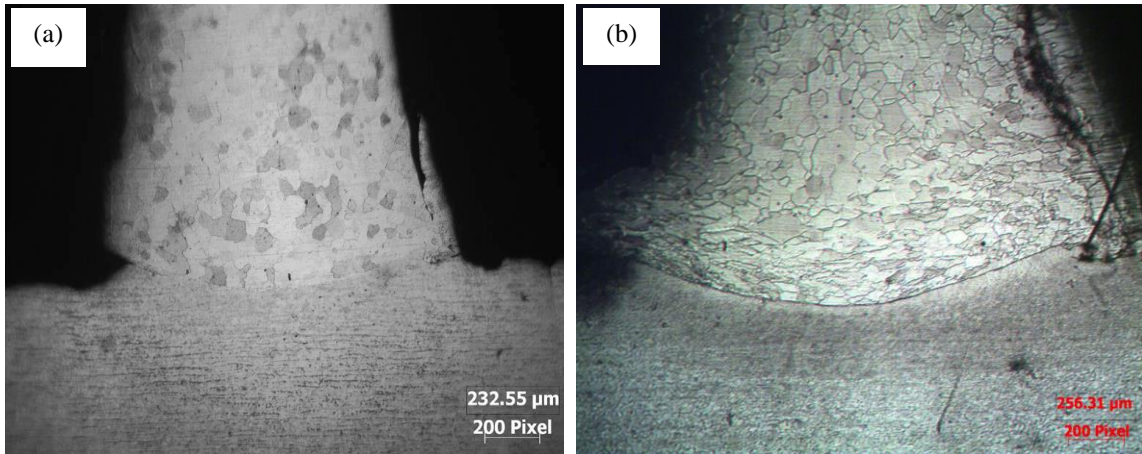


Fig. 15. Metallography fusion weld tests of HFRW tube to fins (a) Carbon Steel to Carbon Steel ( SA192 to A1008 C.S ) , (b) alloy steel to alloy steel (SA213T22 to A240-TP409 ) according to ASTM E340-15 [19].

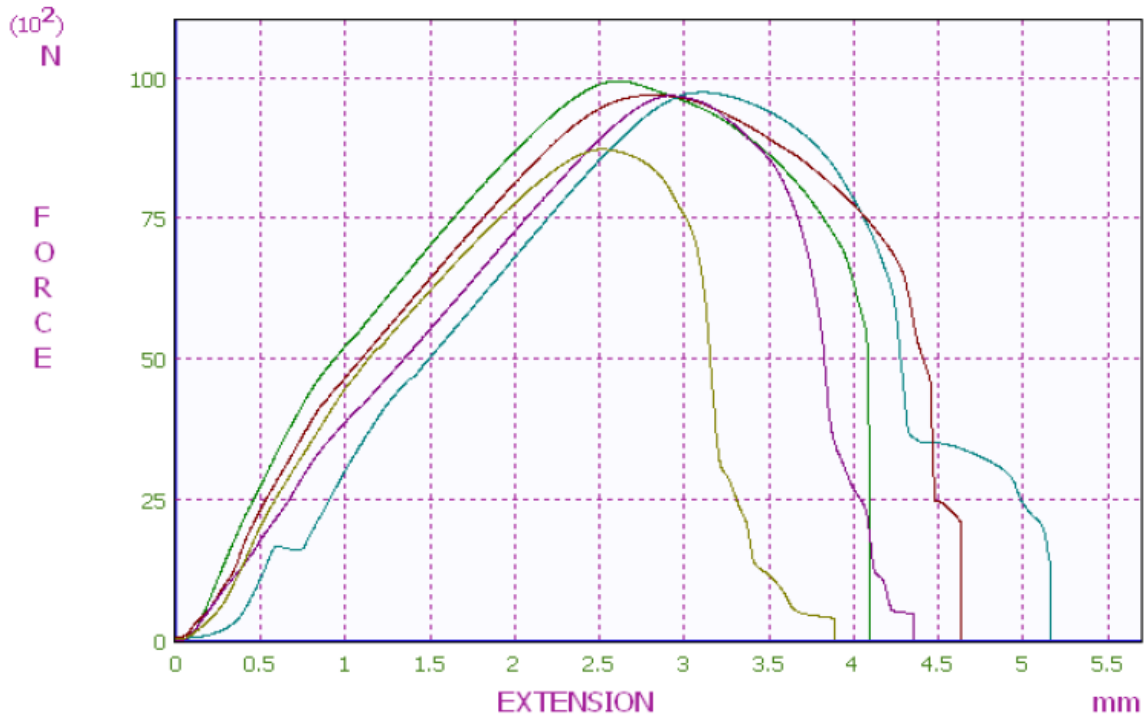


Fig. 16. Tensile strength tests of HFRW tube to fins according to ASTM A370-17 [20].

Table 5. Value of minimum tensile strength according to ASTM A370-17 [20].

Fin / Tube	Carbon Steel	Alloy Steel	Stainless Steel
Carbon Steel	25 ksi (172 Mpa)	25 ksi (172 Mpa)	25 ksi (172 Mpa)
Alloy Steel	25 ksi (172 Mpa)	40 ksi (275 Mpa)	40 ksi (275 Mpa)
Stainless Steel	25 ksi (172 Mpa)	40 ksi (275 Mpa)	55 ksi (379 Mpa)

Alloy steel and Stainless Steel are needs Micro hardness HV1 (Vickers diamond 136° indenter) according to ASTM E384-16. Hardness shall

not be over max. 400Hv, hardness at heat affected zone (HAZ) shall be under 150Hv for fin (tube) [21].

## 5. Conclusions

The HRSG is the core facility of a combined cycle thermal power plant that recycles thermal energy from a gas turbine and creates high temperature and high pressure gas. The use of welded finned tubes in the power equipment leads to savings in energy and cost savings in the operation of industrial boilers, heat recovery condensing and its deliberate use and minimizes energy losses by lowering the temperature of the flue gases. There are several technologies for production of finned tubes for the energy industry. The most important of these, high frequency resistance welded (HFRW) process. These methods, despite its advantages, which include :

- A combination of continuous tube-fin
- Significantly increases the thermal efficiency
- High productivity
- Low imperfections

In the company MAPNA has developed technology for high performance high frequency welding finned tubes, which ensures a level of quality welded joints increase in production efficiency that is unified standard and environmentally friendly. Made welded joints are characterized by continuous full penetration weld the entire length, which indicates that this technology can be qualified for use in the energy industry.

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