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Feasibility Study of Modified Three Pass Dry Back Reversal Chamber Fire-Tube Boiler

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Abstract—***A well designed, operated and maintained boiler is the heart of an efficient steam plant. Research data shows that extensive research work on improving the efficiency and to quicken the steam formation from fire-tube boilers has been done all across the globe. Steam once formed cannot be stored in any container; it has to be simultaneously regulated in the required section of the plant. So a continuous and constant input of steam is desired in industries. The existing three pass dry back reversal chamber industrial boiler consists; well defined passes of fire tubes surrounded all over by water within a boiler shell. The authors have proposed another set of tubes inside the boiler shell; which introduces water inside the shell upon the fire tubes. Researchers have come up with the designs of fire-cum-water tube boilers; in which water in tubes is present in the fire chamber of the fire tube boilers to increase efficiency, minimise losses and to quicken the steam formation. The authors have mainly focused on developing a three pass fire tube boiler which compiles to minimise water loss and quicken steam formation as stated above.***

Keywords— ***Boilers, intermediate water tubes, nozzles, steam***

I. INTRODUCTION

Surface area plays a vital role in transfer of heat from one body to another body or medium; for instance let us take 1L of hot water in two different containers with cross-sectional area A1 and A2, such that A1>A2. The transfer of heat will be faster in the container with area A1 because larger mass is exposed to the atmosphere with a greater surface area at any particular time. Now considering another fact, if a drop of water is sprinkled on a heated rod it will vaporize quickly. Continuous spray of water droplets on the heated rod would result in faster rate of vaporization than what it would be if the heated rod is placed in the pool of same quantity of water at same temperature and pressure conditions.

In the existing three-pass steam boiler the tubes through which the hot flue gases pass are submerged in water which is meant to form vapours that is steam.

But in this case, the authors have introduced another set of tubes, arranged within the boiler drum. These tubes are named as intermediate water tubes (IWT); these tubes have a series of specially designed nozzles. Water via these intermediate water tubes is introduced inside the boiler drum just when the flue gases start originating from fire chamber through the first pass fire tubes. Water from the nozzles on water tubes is released on the fire tubes in the form of small droplets of water. This process is somewhat similar to atomizing the water flow.

There are two water level indicators (WL1 & WL2) in the boiler drum. When viewed from top, one (WL1) is just below the first phase of second pass fire tubes and another (WL2) is in between the two phases of the third pass fire tubes. These indicators would automatically sense the level of water inside the drum and operate the water drainage valve present at the bottom, which is below the first pass/ fire chamber. In this case, the inflow of water inside the boiler drum is continuous thus; its level is needed to be regulated. When the water level touches the WL2 the drainage valve opens and the hot water is drained out to the water reservoir. This reservoir is the same from where the water was pumped in initially to the Boiler drum via intermediate water tubes. This drainage lowers the water level in the boiler drum and when the level reaches WL1 the drainage valve gets closed automatically. All this is controlled by a sensor control system.

The rest of the boiler unit is kept same as it is in an existing three pass fire tube boiler.

TABLE I

TECHNICAL SPECIFICATIONS [3], [5]

specification	**unit**	**details**
steam output f&a @ 100 degree Celsius	kg/hr	500
	kwh x 106	314
	kcal/hr x 106	0.270
metric dimensions	height (mm)	2115
	width (mm)	1500
	length (mm)	3200
recommended flue dia.	size mm	190
standard working pressure	kg/cm^2	10.55
safety valve exhaust size	size nb	50
main steam stop valve size	size nb	40
air vent valve size	size nb	15
blow down valve size	size nb	25

TABLE II

PHYSICAL CHARACTERSTICS OF THE FURNACE OIL [3]

ncv	9650 kcal/kg
gcv	10200 kcal/kg
flash point	66 deg
pour point	20 deg
density	0.89-0.95
sediments	0.25%
water content	1.0%
sulpher content	3.5%-4%
ash content	0.1%-0.5%
carbon content	84.0%
hydrogen content	11%

II. METHODOLOGY OF WORKING

Water at normal temperature (27^0C) from the water reservoir unit is pumped to the intermediate water tube web where another centrifugal pump (6kg/cm^2) is connected (absent in existing model). This pump increases the pressure of the inflow water. This high pressure water flow spreads into the different water tubes (connected to web) and into the boiler drum. As the boiler capacity is 500 kg/hr with standard working pressure of 10.5 kg/cm^2; the inflow water pressure has been modified than the usual boilers. The water via nozzles sprinkles out onto the third pass fire tubes first and then starts accumulating inside the boiler drum around the fire chamber and second pass. The steam formed due the conductive and convective heat transfer between the hot fire tubes and the surrounding water starts moving up and gets accumulated near the dome shaped steam-ejection point, from where the steam is extracted out. When the WL2 water level sensor raises the alarm the drainage valve automatically opens and the heated water (temperature is above 27^0 c) is drained with action of gravity to the water reservoir. When the WL1 raises the alarm the valve closes. This complete operation helps to keep the water warm. During the second cycle water at higher temperature will be sprinkled from the nozzles on the fire tubes which will further speed-up steam formation. Consider the example that during the first cycle water from 27^0 C gets heated to 65^0 C before it leaves the boiler drum then when it re-enters the drum its temperature (considering heat loss in between passages) will be higher than 27^0C somewhere around 50^0C. Thus it will attain the temperature of 100^0C faster than normal. The steam at 174^0 C is attained under described working conditions for the existing model.[3]

This boiler is a dry back reversal chamber three pass boiler so the intermediate water tubes will not come in contact with the flue gases inside the boiler drum.

The thickness of the fire tubes differs for second and third pass tubes which plays an effective role in heat transfer. The water initially hits the third pass and its temperature increases. The temperature of water further increases when it comes in contact with the second pass fire tubes. Finally, the water gets accumulated in the drum with the first pass or the fire chamber and second pass fire tubes fully submerged and forms steam.

Fig. 1 back view of the boiler shell

Fig. 2 front view of boiler shell

III. CHARACTERISTICS OF TUBES

Tube is generally manufactured to one of several international and national industrial standards. Tube is often made to custom sizes and a broader range of diameters and tolerances. Many industrial and government standards exist for the production of pipe and tubing. Water and fire tubes used are derived from AMERICAN STANDARDS OF MECHANICAL ENGINEERS (ASME); it is used as per rules and regulations set by IBR for FO fired fire tube boilers which states the use of SA516 GRADE 70 and SA106 GRADE B both with SCHEDULE 40 (3mm-5mm) pipes. [4], [5]

SA106 GRADE B is a seamless carbon steel pipe for high temperature usage. SA516 GRADE 70 is a carbon steel plate for moderate temperature usage

TABLE III

SPECIFICATION FOR SA106, TENSILE REQUIREMENTS [1], [6]

	grade a	grade b	grade c
tensile strength, min, psi (mpa)	48 000 (330)	60 000 (415)	70 000 (485)
yield strength, min, psi (mpa)	30 000 (205)	35 000 (240)	40 000 (275)

TABLE IV

CHEMICAL REQUIREMENTS, (Composition, %) [1], [6]

	grade a	grade b	grade c
carbon, max (a)	0.25	0.30	0.35
manganese	0.27–0.93	0.29–1.06	0.29–1.06
phosphorus, max	0.035	0.035	0.035
sulphur, max	0.035	0.035	0.035
silicon, min	0.10	0.10	0.10
chrome, max (b)	0.40	0.40	0.40
copper, max (b)	0.40	0.40	0.40
molybdenum, max (b)	0.15	0.15	0.15
nickel, max (b)	0.40	0.40	0.40
vanadium, max (b)	0.08	0.08	0.08

a- For each reduction of 0.01% below the specified carbon maximum, an increase of 0.06% manganese above the specified maximum will be permitted up to a maximum of 1.35%.

b- These five elements combined shall not exceed 1%.

TABLE V

SPECIFICATION FOR SA516 GRADE 70, TENSILE REQUIREMENT [2]

tensile strength (n/mm^2)	510/ 650
yield stress/ min (n/mm^2)	335

TABLE VI

CHEMICAL REQUIREMENTS, (Composition, %) [2]

carbon	0.10/ 0.22
silicon	0.6
manganese	1/ 1.7
phosphorous	0.03
sulphur	0.03
aluminium	0.02
chromium	0.3
copper	0.3
nickel	0.3
molybdenum	0.08
niobium	0.01
vanadium	0.02
titanium	0.03

The diameter and thickness of second and third pass fire tubes are (63.5 mm, 4.06 mm) and (63.5 mm, 3.65 mm) respectively. [4], [5]. This variation is another modification done in this boiler as compared to the existing fire tube boilers. A thicker tube will take longer time to get heated up than a thinner tube but once it gets heated; it will stay hot at a higher temperature for a longer period of time. Thus the thicker third pass tubes retain the heat for a longer period of time. As the second pass in this boiler is completely submerged in water nucleoid boiling will take place from the surface. Further the third pass tubes contain flue gases at lower temperature than second pass tubes and will not be submerged completely under water (in this boiler only) always, so its thickness has to be less than second pass tubes so that it heats up fast. The third pass tubes in this boiler has to prevent itself with factors like scaling and quenching as water is first introduced directly on its surface and then accumulates inside the boiler around fire chamber (first pass) and second pass tubes. The thinner tubes help the tubes to cool down quickly as the water level is automatically lowered. Thus when it is not submerged in water it will increase the temperature of the feed-water only but it will not get quenched. Further the water is in the form of small particles falling on the tubes as it is getting released from the special nozzles welded to water tubes which will reduce the effect of water quenching of third pass tubes. The intermediate water tubes; a modification in this boiler basically does not works like the usual water tube boilers as they do not come in contact with the flue gases inside the boiler shell. The water tubes are distinctively smaller in diameter and thickness than the fire tubes in this boiler. The outer diameter of the water tubes is 33.4 mm to 34.2 mm and thickness is 3.25 mm with a nominal bore of 1inch [5]. The intermediate water tubes have special designed nozzles attached to them which in a way helps to scatter the water flow into tiny droplets falling on fire tubes. These water tubes are at the top most position along the boiler shell but not touching it's inside surface.

The nozzle is basically a cylinder cup as shown in the figure; it is so designed to provide the incoming water flow a pre-whirl and is released through a net/mesh-like cover into tiny droplets, quite similar to the atomization of furnace oil.

Fig. 2 nozzle-cup showing the flanges which provides the necessary pre-whirl to water flow.

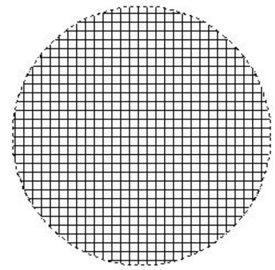

Fig. 1 the net/mesh cover on the face of nozzle

IV. CONCLUSIONS

Detailed theoretical analysis of the modified three pass dry back fire tube boiler was discussed and it was found from the feasibility study that the proposed model could be expected to produce continuous and constant steam input. It can be further expected to quicken the steam formation with higher efficiency and minimum water loses. This proposed modified boiler could be used in food processing units, textile units etc. with better productivity rates in future.

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