Comparative Evaluation of Gas Side Heat Transfer Coefficient Across Finned Tubes Using Different Empirical Correlation

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***Abstract*—This paper presents the work undertaken in a boiler manufacturing company which produce boilers for combined power generation with Gas turbine. Heat Recovery steam Generators are widely used in cogeneration and combined cycle plants generating steam utilizing energy from gas turbine exhaust.This gas side heat transfer can be calculated in terms of heat transfer coefficient.Some local effects may be indicated in the course of the investigation.(i.e) the boundary layer thickness at the finned surface decreases with an increasing Reynolds number.In the course of parameter study heat transfer coefficient is calculated for fins, tube arrangements, type of flow.These studies, especially comparisons between measurement, results at global performance and numerical investigations of local heat transfer behaviour in a finned tubes rows, will provide further knowledge of the local thermal field and convective transport phenomena and will give a more complete understanding of the performance behaviour.**

Keywords— ***Gas turbine, Heat recovery steam generator, heat transfer coefficient, fin arrangement and flow.***

I. INTRODUCTION

Today's modern fast growing world is talking about an important word i.e., Energy conservation due to depleting energy sources. The two options available for the above purpose are either to use non-conventional energy sources or to improve effectiveness of conventional system. Though the former has vast amount of resources , it lacks due to economics and reliability. In most of the industries, large amount of heat is wasted. These losses are significant in the Gas turbine and Diesel engine exhaust, Process industries, Fertilizers industries, cement manufacturing units, sulfuric acid manufacturing units etc. HRSG is a steam-generating unit operated by recovering the sensible heat of flue gases from sources like Gas turbine exhaust and process industries. It is essentially a cross flow heat exchanger, which capable of generating steam at required pressures and temperatures conditions.

Increasing industrial activity world over and particularly in India in the recent years has emphasized the importance of power plants for meeting their electrical as well as heat energy needs and fast depletion of coal reserves and ever-increasing oil prices have forced Utilities/Designers to look for new energy sources. Energy from waste gases can be seen as an effective means of energy conservation, resulting in improved efficiency. Heat Recovery Steam Generator (HRSG) is one of the major equipment's which contributes towards meeting the modern day demand of energy conservation by recovering the potential heat from the waste gases and also improves overall cycle efficiency of the plant. The sources of these waste gases are in plenty such as open cycle gas turbine power plant, diesel engine exhaust, process industries etc.

II. LITERATURE SURVEY

G. Caruso, A. Naviglio[1]"EXPERIMENTAL INVESTIGATIONTHE PERFORMANCE OF A FINNED TUBE" is given asSeveral experiments on heat transfer phenomena are carried out at the University of Rome "La Sapienza" – DINCE. Theseresearches were undertaken mainly to support the development and qualification of passive cooling systems like that foreseenin the MARS nuclear reactor or in other process plants where heat has to be safely removed (as in chemical reactors whererunaway reactions could occur). This paper presents the results of an experimental analysis on the air-side heat transfercoefficient using finned tubes.A campaign of tests has been carried out to evaluate the air-side heat transfer coefficient using water in turbulent conditionsas heating medium flowing at different temperatures inside the tube. Petukhov's correlation has been selected to calculatewater heat transfer coefficient in the tube. The experimental data obtained have been compared with the Briggs & Young'scorrelation, obtaining a very good agreement in the same range of validity. The thermal contact resistance of the wrapped finson the tube has been considered in the evaluations.Thermofluidodynamic analyses of the experimental apparatus using the FLUENT code have been also performed.

Meeta Sharma, Onkar Singh[2]"Thermodynamic Evaluation of WHRB for it's Optimum performance in Combined Cycle Power Plants"Combined cycle power plants are being extensively used in view of their capability of offering high specific power output and thermal efficiency for same fuel consumption compared to other thermal power plants. Therefore, the studies for optimization of different systems in combined cycle power plant are of great significance. Waste heat recovery boiler (WHRB) being the interface between the topping cycle and bottoming cycle becomes one of the critical components. Present study is undertaken for thermodynamic analysis of waste heat recovery boiler for design change from spiral fin type to segmented fin type in 663 MW capacity gas/steam combined cycle power plant. Results obtained for combined cycle power plant with segmented fin type WHRB have been compared with the actual plant data of combined cycle power plant with spiral fin type WHRB. The conclusions presented in the study are useful for power plant designers.

M. R. Jafari Nasr and A. T. Zoghi[3] **"FULL ANALYSIS OF LOW FINNED TUBE HEAT EXCHANGERS".** In this paper, first the governing parameters characterizing low-finned tubes are reviewed. Second, the more important of the available performance correlations are compared with the available experimental data. The most reliable one can be employed to develop a pressure drop relationship, which has already been used in an algorithm for exchanger sizing. Also a means for the identification of advantages of low-finned tube heat exchangers over plain tube units has been developed. It has been recognized that for low-finned tube units there are some potential benefits to place certain liquids, particularly with high viscosities, in the shell side of heat exchangers rather than the tube side. These benefits can be obtained in both reduction of surface area and the number of shells required for a given duty. They result in heat exchangers, which are more compact and are also easier to construct. The performance evaluation of low-finned units, in terms of area benefits is not discussed in this paper. However, the results of this study will complete the author's investigation for low-finned tubes heat exchangers.

III. CASE STUDY

The selected boiler manufacturing company is the leading manufacturer of boilerin India and one of largest manufacturer of boiler in Asia. The company was established in 1964 at Trichy. It is an ISO 9001: 2000 certified company and also holds a BS OHSAS 18001:2007 certification. Here the tubes used in the boiler may be of following types:

A. Serrated

Serrated fins are mostly used in the boiler tubes because the heat transfer coefficient of the serrated fins are more than the other type of tubes.

Fig 1. Serrated and solid fin

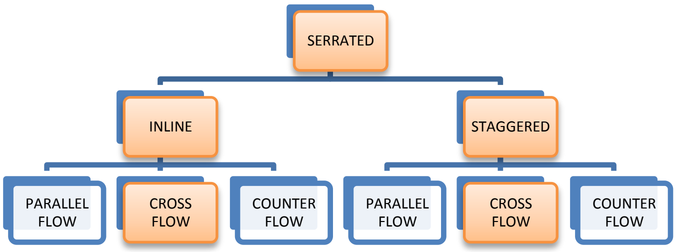
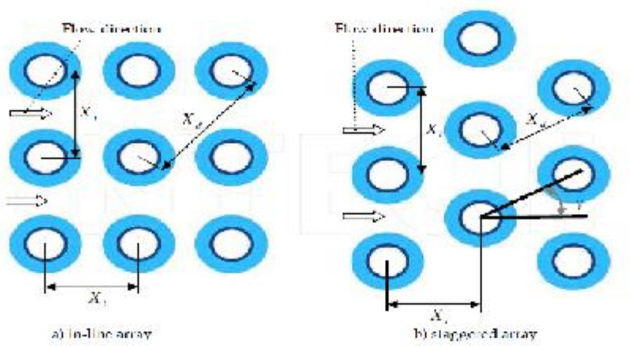


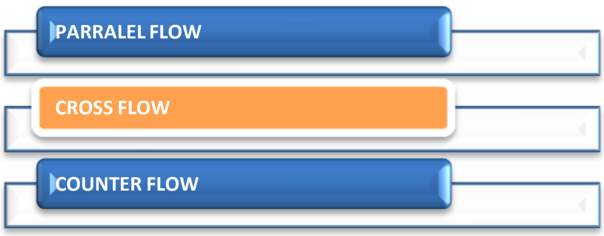
Fig 2: Flow chart of flow of flue gas

B. Arrangements:

There are two types of arrangements are made in the boiler used serrated tubes. They are inline and staggered.



C. Flow types:



Based on the data obtained from the process, it was found that the mostly the boiler is designed for the serrated finned tubes in both inline and staggered arrangements using flue gas in cross flow.

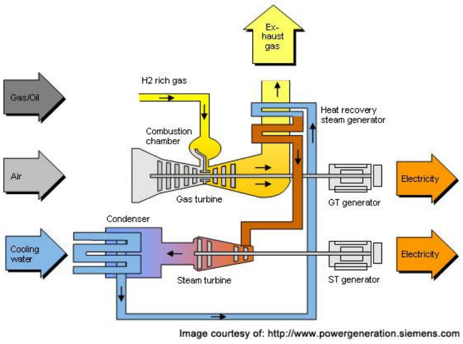


Fig 3. Combined cycle power plant.

IV. NOMENCLATURE.

Table 1: Nomenclature

Fin height	hf	M
Fin spacing	Sf	M
Fin thickness	Tf	M
Tube outside diameter	Do	M
Transverse tube pitch	Xt	M
Longitudinal tube pitch	Xl	M
Number of rows	n	
Fin diameter	Df	M
Air velocity	v	m/s
Density	ℓ	kg/m3
Viscosity	µ	kg/ms
Thermal conductivity	k	W/Mk
Specific heat	cp	J/kg-K
Inlet temperature	Ti	℃
Outlet temperature	To	℃
Mass flow rate	m	kg/s
Number of tubes	N	
Fin pitch	fp	M
Reynolds number	Re	
Prandtl number	Pr	
Viscosity at inlet temperature	µTi	Ns/m2
Viscosity at outlet temperature	µTo	Ns/m2
Overall heat transfer area	A	m2
Outside tube area	At	m2

V. PROCESS

This project implies that the need of finding the heat transfer coefficient across finned tubes using different empirical correlations because the convective heat transfer coefficient can be find using the following formula:

$$Q = hA\nabla T$$

For finding the 'h' value we used different empirical correlations because the other parameters can easily find but heat transfer coefficient cannot find until the values are known So the calculations were done on the system to find the values based on the collaborated correlation given for the company to design the boiler.

These correlations are based on the function of Nusselt number

$$Nu = \frac{hD}{k}$$

Here Nusselt number is a function of Reynolds's number and prandtl number.

VI. SOFTWARE USED

The HRSG's Vogt Power International provides are designed applying proven standards and also specializes in the design, manufacturing and supply of Heat Recovery Steam Generators (HRSG)and aftermarket related services.

To meet customer performance requirements they utilizes design software that incorporates the experience of more than 100 previously built units. Then, on a continuous bases, performance test measurements are compare to projected values generated by our software's to ensure that outcomes meet expectations, long before construction begins.

Vogt developed one of the first thermal rating and designed programs for heat recover steam generators over 30 years ago. Program was originally written in Fortran, then migrated to Wang Basic, Turbo Pascal and Microsoft DOS. Program is still in use today. Currently they have written new Microsoft Windows, Visual Basic 5 version of HRSG rating and design program.

VII. METHODOLOGY

Approach to the problem:

In order to find a suitable procedure for the analysis of the available heat transfer coefficient, a literature study was done searching for the methods other authors had used. The following are the different empirical correlations for calculating heat transfer coefficient over finned tubes bundles. Most of the heat transfer coefficient results are presented in dimensionless terms via Nu number defined by equation.

$$Nu = \frac{hD}{k}$$

S.No	Author	Correlation
1.	BRIGGS AND YOUNG'S	$Nu_d=jRe_dPr_d^{1/3}$ $j=0.134Re_d^{-0.319}\left(\frac{g_f}{L_f}\right)^{0.2}\left(\frac{g_f}{\delta_f}\right)^{0.11}$
2.	E.MARTINEZ	$Nu=0.023Re^{0.85}\left(\frac{k}{Do}\right)\left(\frac{\mu_{Ti}}{\mu_{To}}\right)^{0.06}Pr^{0.33}$
3.	RABAS ET AL	$Nu=0.183Re^{0.73}\left(\frac{f_s}{f_h}\right)^{0.36}\left(\frac{P_Y}{d_f}\right)^{0.06}\left(\frac{f_h}{d_f}\right)^{0.11}Pr^{0.36}$
4.	HEWITT	$Nu=0.19\left(\frac{a}{b}\right)^{0.2}\left(\frac{s}{d}\right)^{0.18}\left(\frac{h}{d}\right)^{-0.14}Re^{0.62}Pr^{0.33}$
5.	ZUKAUSKAS	$Nu=0.044\left(\frac{S_T}{S_L}\right)^{0.2}\left(\frac{s}{d}\right)^{0.18}\left(\frac{h}{d}\right)^{-0.14}Re^{0.82}$
6.	STASIULEVI – CIUS	$Nu=0.19\left(\frac{a}{b}\right)^{0.2}\left(\frac{s}{d}\right)^{0.18}\left(\frac{h}{d}\right)^{-0.14}Re^{0.65}Pr^{0.33}$
7.	RYAN'S	$hc=0.026Re^{0.85}Pr^{0.4}\left(\frac{k}{Do}\right)$
8.	CHATO'S	$Nu=0.176Re^{0.50}Pr^{0.33}\left[1+\left(\frac{2.22}{2(Xt)^{0.72}}\right)\right]\left[\frac{Sf}{hf}\right]^{0.34}$
9.	PETUKHOV-KIRLLOV	$Nu=0.248Re^{0.42}Pr^{0.73}\left(\frac{Xt}{Xl}*\frac{1}{Do}\right)^{0.3}\left(\frac{fp}{Df}\right)^{0.18}\left(\frac{hf}{Do}\right)^{-0.41}$
10.	WARMEATLA'S	$Nu=0.356Re^{0.54}Pr^{0.33}\left(\frac{Xt}{Xl}\right)^{0.6}\left(\frac{Do}{hf}\right)^{0.42}$
11.	HOFMANN'S	$Nu=4.69Re^{0.26}Pr^{0.21}\left(\frac{Xt}{Xl}\right)^{0.4}\left(\frac{Do}{hf}\right)^{0.36}$
12.	PERRY'S	$Nu=0.183Re^{0.66}\left(\frac{S_f}{h_f}\right)^{0.2}\left(\frac{X_t}{Df}\right)^{0.18}\left(\frac{1}{df}\right)^{-0.14}$
13.	HOLMAN'S	$Nu=1.62Re^{0.59}\left(\frac{X_t}{D_o}\right)^{-1.53}\left(\frac{X_l}{D_o}\right)^{-0.48}\left(\frac{h_f}{D_o}\right)^{0.78}$
14.	SCHMIDT	$Nu=0.45\left(\frac{A}{A_t}\right)^{-0.375}Re^{0.9}Pr^{0.33}$

Table 2: Correlations for inline flow.

S.No	Author	Correlation
1.	BRIGGS AND YOUNG'S	$Nu_a=\frac{\left(\frac{\bar{f}}{8}\right)Re_a^{0.53}Pr_a^{0.26}}{k+12.7\sqrt{\left(\frac{\bar{f}}{8}\right)}\left[Pr_a^{2/3}+1\right]}$ where, $\bar{f}=(1.82\ln Re_a^{-1.64})^2$ and $k=1+\frac{900}{Re}$
2.	E.MARTINEZ	$Nu=0.021Re^{0.85}\left(\frac{k}{Do}\right)\left(\frac{Ti}{To}\right)^{0.5}Pr^{0.4}$
3.	RABAS ET AL	$Nu=0.036Re^{0.82}Pr^{0.33}\left(\frac{D_o}{h_f}\right)^{0.055}$
4.	HEWITT	$Nu=0.32\left(\frac{a}{b}\right)^{0.2}\left(\frac{s}{d}\right)^{0.18}\left(\frac{h}{d}\right)^{-0.14}Re^{0.57}Pr^{0.4}$
5.	ZUKAUSKAS	$Nu=0.067\left(\frac{S_T}{S_L}\right)^{0.2}\left(\frac{s}{d}\right)^{0.18}\left(\frac{h}{d}\right)^{-0.14}Re^{0.78}$
6.	STASIULEVI - CIUS	$Nu=0.05\left(\frac{a}{b}\right)^{0.2}\left(\frac{fp}{Do}\right)^{0.18}\left(\frac{1}{Do}\right)^{-0.14}Re^{0.8}Pr^{0.4}$ where, $a=\frac{Xt}{Do}; b=\frac{Xl}{2Do}$
7.	RYAN	$hc=0.23\overline{Cp}Re^{-0.28}Pr^{-2/3}\left(\frac{m}{A}\right)$
8.	CHATO	$Nu=0.023Re^{0.62}Pr^{0.4}\left[1+\left(\frac{2.22}{Xl^{0.89}}\right)\right]\left[\frac{Sf}{hf}\right]^{0.2}$
9.	PETUKHOV-KIRLLOV	$Nu=0.356Re^{0.54}Pr^{0.33}\left(\frac{Xt}{Xl}\right)^{0.6}\left(\frac{Do}{hf}\right)^{0.42}$
10.	HOFMANN'S	$Nu=0.356Re^{0.54}Pr^{0.33}\left(\frac{Xt}{Xl}\right)^{0.6}\left(\frac{Do}{hf}\right)^{0.42}$
11.	PERRY'S	$Nu=0.036Re^{0.8}\left(\frac{S_f}{h_f}\right)^{0.45}\left(\frac{X_t}{Df}\right)^{0.14}\left(\frac{1}{Df}\right)^{0.28}$
12.	ESCOA'S	$hc=jC_pPr^{-2/3}Re^{0.23}$ where $j=C_1C_3C_5\left(\frac{D_f}{D_o}\right)^{0.5}\left(\frac{T_i}{T_o}\right)^{0.25}$ $C_1=0.25Re^{-0.35}$ $C_3=0.35+0.65e^{-0.25\left[\frac{h_f}{S_f}\right]}$ $C_5=\left[0.7+\left[(0.7-0.8e^{-0.15n^2})\right]\left[e^{\frac{-X_l}{X_t}}\right]\right]$
13.	HOLMAN'S	$Nu=2.12Re^{0.57}\left(\frac{X_t}{D_o}\right)^{-0.83}\left(\frac{X_l}{D_o}\right)^{-0.94}\left(\frac{h_f}{D_o}\right)^{0.71}$
14.	SCHMIDT	$Nu=0.30\left(\frac{A}{A_t}\right)^{-0.375}Re^{0.95}Pr^{0.33}$

Table 3: Correlations for staggered flow.

VIII. INPUTS.

Based on the site data, inputs are given to the correlations which are countered here. Because it is essential to check the site data until it reaches the nearby value to the values taken from the software analysis.

Fin height	hf	m	0.0159
Fin spacing	Sf	m	0.004
Fin thickness	Tf	m	0.00125
Tube outside diameter	Do	m	0.051
Transverse tube pitch	Xt	m	0.11
Longitudinal tube pitch	Xl	m	0.133
Number of rows	n		8
Fin diameter	Df	m	0.0828
Air velocity	v	m/s	27.258
Density	ℓ	kg/m3	0.423
Viscosity	µ	kg/ms	0.000036148
Thermal conductivity	k	W/mK	0.06075
Specific heat	cp	J/kgK	1107.553
Inlet temperature	Ti	˚C	569.34
Outlet temperature	To	˚C	471
Mass flow rate	m	kg/s	131.47
Number of tubes	N		40
Fin pitch	fp	m	0.133
Reynolds number	Re		16267.479
Prandtl number	Pr		0.659
Viscosity at inlet temperature	µTi	Ns/m2	0.000036148
Viscosity at outlet temperature	µTo	Ns/m2	0.000035279
Overall heat transfer area	A	m2	34.9824
Outside tube area	At	m2	0.002042821

Table 4: Inputs

IX. RESULTS AND DISCUSSION

In this project steps were taken to improve the efficiency of the Gas Turbine using HRSG. The inputs are feed inside the Vogt software given by the collaborator and the outputs were seen. Now the heat transfer coefficient value calculated from the countered correlationsare compared with the software's output. So the value of heat transfer coefficient across finned tubes taken from the software output is compared and some related values are matched. Due to this, the value which is nearly equal to the correlations are been taken and used for the company, to create a new software by their own and they develop their own boiler with the proper correlation.
Here for the given inputs the Vogt Software has given the value forinline and staggered (i.e.)

For inline "h_c"value is "62.234w/m^{2}k".

For staggered "h_c"value is "79.3216w/m^{2}k".

CORRELATION	INLINE	STAGGERED
A.BRIGGS AND YOUNG'S	88.49551	107.5077
B.E.MARTINEZ	90.99926	88.41932
C.RABAS ET AL	114.8948	113.1444
D.HEWITT	99.59458	100.3201
E.ZUKAUSKAS	106.6822	110.2202
F.STASIULEVICIUS	93.33075	102.1554
G.RYAN'S	99.56939	83.80048
H.CHATO's	78.78613	103.2429
I.PETUKHOV-KIRLLOV'S	92.7295	100.9589
J.WARMEATLA'S	83.36779	84.45049
K.HOFMANN'S	89.80425	101.132
L.PERRY'S	112.6822	106.7962
M.WARMEATLA'S 2	83.61492	79.49252
N.ESCOA'S		82.02404
O.HOLMAN'S	46.21591	59.56682
P.SCHMIDT	74.47351	80.62627

Table 5:Outputs

Inline :

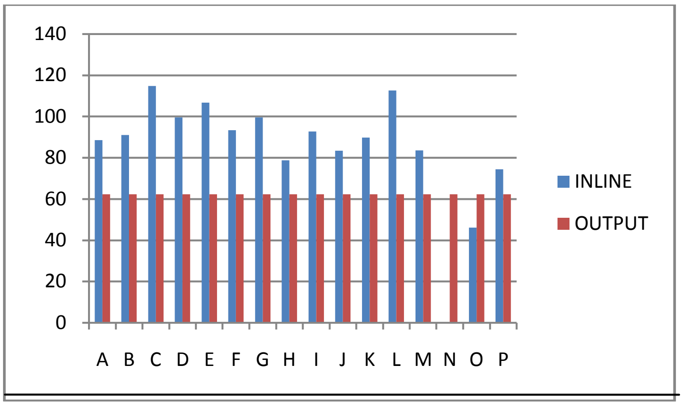


Table.6: correlation values vs software values

Staggered:

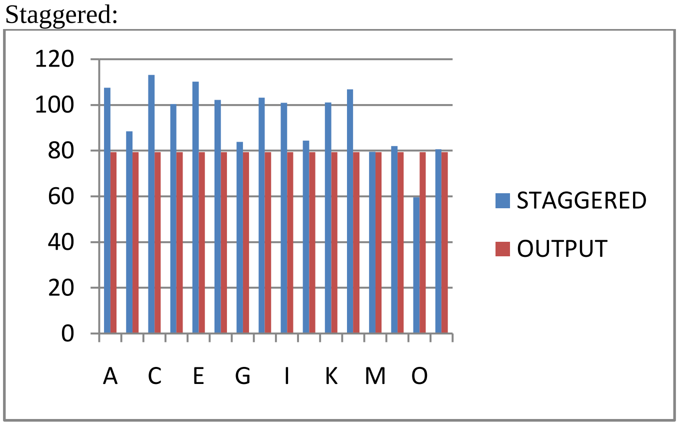


Table 7: correlation value vs software value

X. CONCLUSION.

The heat transfer coefficient evaluation on the gas side of serrated fin finned tube heat exchanger has been determined numerically. Using the present numerical investigation and with the given mechanical data, improved heat transfer coefficient correlations for the HRSG has been studied and provided for reference. The tubes in all bundles are of staggered arrangement or inline arrangement. The results of gas side heat transfer coefficient calculated by various correlations are graphed with software results. If the gas side heat transfer coefficient across HRSG experienced during operation is higher than the limit considered during design, it may attract penalty. Hence, for a typical HRSG designed by BHEL, the gas side heat transfer coefficient values have been predicted for HRSG using different empirical correlations as part of the project work will be useful for refining the gas side heat transfer coefficient calculations based on the site feedback. Therefore, this exercise of taking all these correlations into consideration and comparing it with the field data will be helpful for formulating suitable design strategy towards accurate prediction of gas side heat transfer coefficient across HRSG and optimized overall cost and plant performance.

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