Proceedings of IOE Graduate Conference, 2019-Summer
Peer Reviewed
Year: 2019 Month: May Volume: 6
ISSN: 2350-8914 (Online), 2350-8906 (Print)

Numerical and Experimental Analysis of Efficiency Enhancement in Fire Tube Boiler using Turbulators

Vijay Raj Giri [a], Ajay Kumar Jha [b], Tri Ratna Bajracharya [c]

[a, b, c] *Department of Mechanical Engineering, Pulchowk Campus, Institute of Engineering, Tribhuwan University, Nepal*
Corresponding Email: [a] 068bme648@ioe.edu.np, [b] jhaajaykumar@live.com, [c] triratna@ioe.edu.np

Abstract

This study presents Numerical modeling and Experimental analysis of enhancement of gas-side convective heat transfer coefficient of plain fire-tube boiler using turbulators. Insertion of twisted tape and coil wire turbulators served to arrest the thermal boundary layer formation on the 2^{nd} and 3^{rd} pass of the 3-pass fire tube boiler by preventing transition of hot flue gases from turbulent to laminar region and sustaining gaseous turbulence intact. This increased the pumping power inside the tubes, but the enhancement achieved by integrating turbulators exceeded the increment in friction factor by great extent.

The geometry of the heat exchangers was constructed in CATIA® v5R20 and the meshing was performed in ICEM CFD 17.0. The computational simulation was carried out by ANSYS® CFX 17.0 solver using Finite Element Approach. For experimental verification, experimental testing procedure with equipment was established. The results from CFD showed 1.26-1.78 times enhancement in heat transfer for twisted tape turbulators and 1.17-1.93 for coil wire turbulators. Similarly, the experimental results depicted 1.2-1.83- and 1.32-2.08-times augmentation for twisted tape and coil wire turbulators respectively.

The reduction in stack temperatures for twisted tape and coil wire turbulators were found to be 73℃ and 117℃ respectively. The combined effects of enhancement of heat transfer and reduction in stack losses was observed as 3.4% and 5.7% increment in energy efficiency for twisted tape and coil wire turbulators respectively. Consequently, the evaporation ratio for conventional plain fire tube boiler increased from 13.39 to 13.96 for twisted tape turbulators and 14.34 for coil wire turbulators using diesel fuel.

Keywords

Coil Wire, Efficiency, Fire Tube Boiler, Heat Transfer Enhancement, Turbulator, Twisted Tape

1. Introduction

A boiler is an enclosed pressure vessel that provides a means for combustion heat to be transferred into water until it becomes heated or steam [1]. Fire-Tube Boilers generate hot-water upto 3000 kW or saturated steam ranging up to 25 Tonnes/hr at pressure of 17.5 kg/cm^2 [2].

The efficiency of the first design of FTB until 1985 was very low, up to 70% due to utilization of several tubes, excessive refractory materials, and in many cases inadequate furnace. After 1985, new FTB design started leading to consciousness of energy saving potential and reduction of fuel consumption [3]. Radiation is the major mode of heat transfer in furnace while, 95% of the heat exchange in hot gas tubes is achieved from convection [4].

Normally, enhanced HTC techniques in FTB is used with the reversed flame furnace, because temperature of exit flue gases from the reversed furnace range between (600°C-700°C) which assists to use turbulator material as a cheaper option to reduce stack losses. Additionally, low overall pressure drops and greater enhancement in heat transfer coefficient makes it an economical choice [5].

Turbulators used inside tubes of FTB serves to improve the convective heat transfer coefficient in the gas-side by preventing formation of thermal boundary layer [6]. Turbulators are the turbulence generators that produce swirl, vortex or eddies leading to flow separation and sustaining the flue gases within turbulent regime. The overall objective of integrating turbulators in FTB is to improve the boiler efficiency, although other factors such as pressure drop, air-fuel ratio, change in water-side convective heat transfer coefficient, fouling, etc. are also important. Turbulators appeared in different shapes, like: twisted tape (helical), coiled-wire (spiral), bent-strip, bent-tab, louvered strip, conical ring, truncated half-cylindrical surface, etc [7]. However, an inappropriate assessment of a turbulators have impact on pressure drop and can cause the choking of burner because its fan would be unable to overcome the increased pressure drop in the boiler due to an inaccurate assessment of turbulators' combined effect on heat exchanger and pressure drop [8].

Most of the 3-pass fire-tube boiler uses plain tubes for heat exchange between hot flue gas and water. However, the efficiency of heat exchange in the second and third pass is not fully realized due to transition of hot flue gases from turbulent regime to laminar flow regime and formation of thermal boundary layer. This results in flue gas exiting the chimney at higher temperatures (stack losses) thereby lowering the thermal efficiency of the fire-tube boiler.

Thus, a venture for passive heat enhancement techniques that improves gas-side convective heat transfer coefficient, overall thermal efficiency as well as significant reduction in stack temperature (at exit of chimney) is growing. Integration of turbulators of varying shape and sizes in fire-tube boilers proves to be the viable solution to this problem.

An assessment of 'loose fitting' and gently twisted (1 turn in 3 meters) tapes in the 1 meter long horizontal tubes of a 74.57 kW boiler led to the saving of fuel as much as 8% [9].

An electrically heated air with temperatures varying from 249°C to 605°C was allowed to flow through a tube of 0.059 m I.D. and 0.167 m length. Nine different twisted tapes were stimulated to actual boiler conditions. The results obtained show that pitches larger than about 0.51 m had very little influence on the heat transfer. [10].

Colburn and King (1931), investigated effects of twisted tapes on heat transfer. Data were taken for inlet air temperatures ranging from 109°C to 392°C and inlet tube wall temperatures from 9.3°C to 12.3°C. The results were presented both graphically and tabularly as h_a/c_{pa} and frictional pressure drop as functions of mass velocity through the test section [11].

Kirov (1949), fitted an Economic Boiler having 1.9-0.07 meters I.D. tubes with 63.5 mm width twisted tapes of 1 turn in 356.62 mm. With full-length tapes, the increase in boiler efficiency was 5 to 7 percentage, which was equivalent to a fuel saving of 7-10% [12].

Twisted Tapes of 0.064 m width, pitches of 0.177, 0.228, 0.304 and 0.335 m, were tested in a 2.438 m long by 0.076 m I.D. test section. Inlet air temperature was approximately 418°C, while inlet Reynolds numbers varied from about 3,000 to 13,000. Results are presented as curves of convective heat transfer coefficient and pressure drop as functions of Reynolds number for different twisted tapes [13].

Thorsen and Landis (1968), reported the effects of twisted tapes on cooled air flows. Air was supplied at temperatures up to 277°C to a 0.0254 m I.D. water cooled tube. Pitches were 0.8, 0.131, and 0.203 m, and the tube-tape gap was about 0.076 mm. A major concern of this work was assessment of the effects of variable properties. A temperature ratio correction factor was determined primarily from heating data due to the limited values of (T_s/T_b) that could be attained in cooling. Best correlation of the cooling data was achieved by ignoring the temperature-ratio correction [14].

A literature search on the effects of tube inserts of various types suitable for augmentation of gas-side heat transfer coefficients in fire tube boilers was conducted using Computerized Bibliography on Augmentation of Convective Heat and Mass Transfer [15]. A study conducted for DOE at Brookhaven National Laboratory found that the addition of turbulators to residential oil-fired boilers resulted in fuel savings of 2-8% [16].

Usui et al. (1986), investigated the heat transfer at internally grooved rough tube with the twisted-tape insert using water and 40-60% aqueous solution of glycerin. The highest enhancement of heat transfer was achieved when the ribbing and the twisted-tape were positioned in opposite direction, and when the relative height of ribs was $e/D_0 = 0.022$ [17].

Zimparov (2002), investigated the combined design of the heat transfer enhancement technique with water. The heat transfer was investigated for Re = $4*10^3$ - $6*10^4$ and Pr = 1.9-3.7 and implemented a uniform wall temperature boundary condition. Zimparov observed that with the combined use of single start spirally corrugated tube and with the twisted-tape insert an additional increase of the heat transfer could be achieved. After installation of a spiral tape insert with the relative twist ratio y = 3.95, an increase in the heat transfer (about 3.5-4.4 times) was reported at a simultaneous increase of friction factor 7.9-10.2 times [18].

As air in the working fluid, for effectively and efficiently enhancing the in-tube heat transfer, the proposed e/d and p/d values of the wire coil as 0.101 and 2.319, respectively; the heat transfer enhancement index (Nu/Nu_0) of value larger than 2.0 and the pressure drop within acceptable range was obtained [19].

The major objective of this study was to evaluate and assess the enhancement in gas-side convective heat transfer coefficient, reduction of stack losses and increase in overall thermal efficiency of fire-tube boilers using coil-wire and twisted-tape turbulators.

2. Methodology

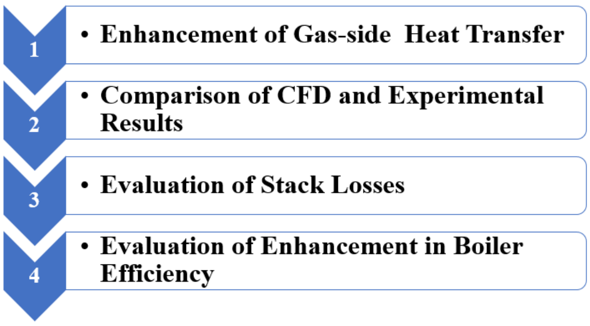

Figure 1: Research Methodology for the study

2.1 Assessment of Enhancement of Gas-side Convective Heat Transfer Coefficient

In order to simulate the heat transfer rate on the last pass of the 3-pass fire-tube boiler, the CFD analysis and experimental verification on enhancement of thermo-hydraulic performance factor is done. For a particular Reynolds number, the thermo-hydraulic performance of an insert is said to be good if the heat transfer coefficient (or Nusselt number) increases significantly with a minimum increase in friction factor [20].

2.1.1 CFD Methodology for evaluation of heat transfer enhancement

Construction of Model Geometry: The assembly products for counter-flow heat exchanger was designed in CATIA v5R20 to simulate the heat transfer scenario inside smoke tube of the fire tube boiler. Three such assemblies were generated to represent three cases for this study namely, plain fire tube, plain fire tube with TT and CW Turbulator inserts.

Discretization of the Computational Domain: The necessary domain of the computational field was discretized by using ANSYS ICEM CFD v17.0. The mesh was first made coarse with large element size and was refined according to the error between various computations. The size of the element was made smaller by a factor of 1.5 between each computation, which was performed in the grid independence test.

CFX Simulation: The mesh created by ANSYS ICEM CFD v17.0 was imported to CFX and the setup was done. During the setup of the simulation, the fluid properties and the model of equations were chosen and the flow velocity and pressure values were supplied using the boundary conditions at various surfaces. Then the solver was run and the necessary Root Mean Square (RMS) value of the residual was set as the convergence criteria. At last the result was post-processed in CFD-POST, and various necessary parameters were viewed in CFD-POST.

CFX Setup Parameters: For the relevant comparison of different geometry, CFX setup parameters were kept same for each of the three cases. The model selected were as follows:

- k-ε Turbulence model
- Material: Air at 25°C, Water and Copper (with 0.5 mm thickness) as the wall material
- Viscosity: Constant
- Buoyant Model with Total Energy Analysis

Post-Processing: With CFD-Post's flexible & state-of-the-art post-processor, various contours, planes and streamlines were generated along with formula to calculate Nusselts number, Reynolds number and friction factor.

2.1.2 Experimental Methodology for evaluation of heat transfer enhancement

An experimental setup depicted in Figure 3 has been developed to determine the thermal-hydraulic performance of various turbulator inserts with cooling of air. The test-rig consists basically of a blower suitable to produce Reynolds number in the range of 5,000 to 25,000, a heater box with electric heater in it to heat the air to about 170°C temperature, and the actual test section where the performance of the inserts is to be evaluated. The cooling water jacket of the test section simulates fire-tube boiler conditions while serving as a calorimeter.

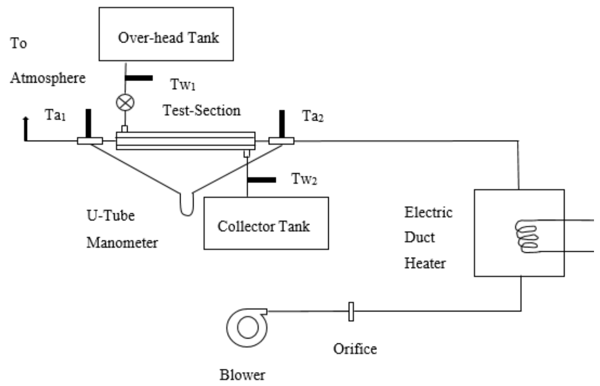

Figure 2: Experimental Routing Setup

Mathematical Procedure for Experiment: The detailed mathematical procedure for the experimentation of enhancement of heat transfer is listed below: [21]

Calculation of air mass flow rate

$$\dot{m_a} = \rho_a * C_D * \sqrt{\frac{P_{or}}{\rho_a}} \quad (1)$$

Calculation of Energy Gain by Water

$$q_w = \dot{m_w} C_{p,w}(T_{w2} - T_{w1}) \quad (2)$$

Calculation of Energy Gain by Calorimeter

$$q_c = k_t A(\frac{\Delta T_t}{\Delta x}) \quad (3)$$

Calculation of Corrected Energy Gain by Water

$$q_{w,c} = q_w - q_c \quad (4)$$

Calculation of LMTD

$$\Delta T_{LMTD} = \frac{(T_{a1} - T_{w2}) - (T_{a2} - T_{w1})}{ln(\frac{T_{a1} - T_{w2}}{T_{a2} - T_{w1}})} \quad (5)$$

Calculation of Overall Heat Transfer Coefficient

$$U = \frac{q_{w,c}}{A_c * \Delta T_{LMTD}} \quad (6)$$

Calculation of Convective Heat Transfer Coefficient

$$h = \frac{1}{\frac{1}{U} - \frac{D ln(\frac{D_t}{D})}{2k_s}} \quad (7)$$

Calculation of Nusselt's Number

$$Nu = \frac{h_a D}{k_a} \quad (8)$$

Calculation of Reynolds Number

$$Re = \frac{vD}{\nu} = \frac{4}{\pi} * \frac{\dot{m_a}}{\mu_a * D} \quad (9)$$

Calculation of Friction Factor

$$f = \frac{\pi^2}{16} * \frac{\Delta p}{\dot{m_a}^2} * \frac{\rho_a D^5}{L} \quad (10)$$

2.2 Comparison of CFD and Experimental Results

The results from CFD and the experimental part are then compared as plots of Nu Vs. Re, f Vs. Re and Performance Evaluation Criteria (PEC) Vs. Re where PEC is given as [22]:

$$PEC = \frac{(\frac{Nu}{Nu_P})}{(\frac{f}{f_P})^{1/3}} \quad (11)$$

For given Reynolds number, the error associated with CFD and Experimental data is evaluated from the expression below:

$$Error_{PEC} = \frac{|PEC_{EXP} - PEC_{CFD}|}{PEC_{CFD}} * 100\% \quad (12)$$

2.3 Stack Temperature Monitoring and Evaluation of Losses

Stack temperature refers to the temperature of the exhaust flue gas which exits the fire tube boiler through chimney. Generally, higher stack temperature points out energy conservation opportunities while too low stack temperature (below 100°C) is undesirable because it corrodes the inner walls of chimney due to condensation of moisture and oxides of Sulphur which is present in boiler fuels. Normally, when an economizer or an air preheater unit becomes too expensive an option to reduce stack losses and improve overall thermal efficiency of the boiler, the turbulator inserts might prove to economically viable substitution.

2.4 Evaluation of Enhancement in Boiler Efficiency

2.4.1 Evaluation of Direct Efficiency

Fuel and air temperatures at the entrance of the boiler are assumed to the ambient temperature, which is T_{amb}

= 19°C. Boiler efficiency is calculated by the amount of heat extracted from working fluid per hour which is Q_w, over heat load of fuel used. According to the first law of thermodynamics, boiler efficiency is calculated as follows [23]:

$$\eta_{Direct} = \frac{Q(H_s - h_w)}{q * GCV_f} \tag{13}$$

2.4.2 Evaluation of Indirect Efficiency

In order to calculate the indirect efficiency of boiler, calculation of theoretical air, excess air, Actual Air Supplied (AAS) and Dry Flue Gas Flow Rate are determined. After that, various losses associated with FTB namely, Dry Flue Gas Loss (L_1), Hydrogen Loss (L_2), Fuel Moisture Loss (L_3), Air Moisure Loss (L_4), CO Loss (L_5) and Radiation & Convection Losses (L_6) are evaluated. Finally, the indirect efficiency of boiler was calculated as:

$$\eta_{Indirect} = (100 - L_1 - L_2 - L_3 - L_4 - L_5 - L_6)\% \tag{14}$$

3. Results and Discussion

3.1 Heat Transfer Enhancement

3.1.1 CFD Results

f Vs. Re Plot: For Plain Fire Tube, the correlation obtained from f Vs. Re Plot of CFD results was

$$f = 0.1848 * Re^{-0.347}$$

Similarly, the correlations for Plain Fire Tube with TT and CW Turbulator inserts were

$$f = 0.787 * Re^{-0.356}$$

and

$$f = 4.1162 * Re^{-0.486}$$

respectively. In the range of 5,000 ≤ Re ≤ 25,000, the increment in friction factor index with reference to plain fire tube was found in the range of 3.69 - 4.12 for Twisted Tape Turbulator and 5.33 - 6.71 for Coil Wire Turbulator. Significantly, the pressure drop for coil wire turbulator was found to be larger than twisted tape turbulator inserts.

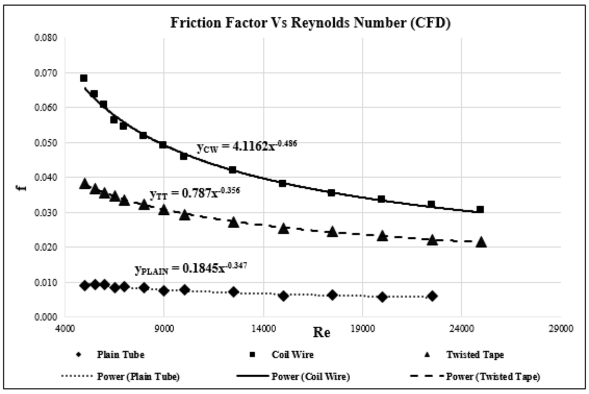

Figure 3: Plot of Comparison of f Vs. Re (CFD Results)

Nu Vs. Re Plot: The Nu Vs. Re Plot from CFD results gave the following correlation for plain fire tube

$$Nu = 0.0175 * Re^{0.8426} * Pr^{0.3}$$

which was in close kinship with Dittus-Boelter correlation. Similarly, the correlations for Plain Fire Tube with TT and CW Turbulator inserts were

$$Nu = 0.2032 * Re^{0.6679} * Pr^{0.3}$$

and

$$Nu = 0.4124 * Re^{0.607} * Pr^{0.3}$$

respectively. In the range of 5,000 ≤ Re ≤ 25,000, the increment in heat enhancement index with reference to plain fire tube was found in the range of 2.00 - 2.79 for Twisted Tape Turbulator and 2.15 - 3.45 for Coil Wire Turbulator. Evidently, the heat enhancement index for coil wire turbulator was found to be greater than twisted tape turbulator inserts.

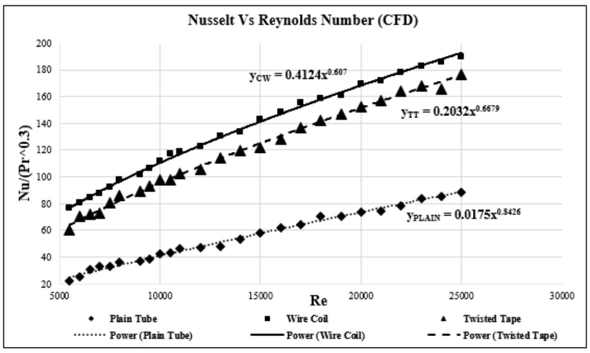

Figure 4: Plot of Comparison of Nu Vs. Re (CFD Results)

3.1.2 Experimental Results

f Vs. Re Plot: For Plain Fire Tube, the correlation obtained from f Vs. Re Plot of Experimental results was

$$f = 0.2198 * Re^{-0.354}$$

Similarly, the correlations for Plain Fire Tube with TT and CW Turbulator inserts were

$$f = 0.8166 * Re^{-0.372}$$

and

$$f = 4.8193 * Re^{-0.508}$$

respectively. In the range of 5,000 $\leq$ Re $\leq$ 25,000, the increment in friction factor index with reference to plain fire tube was found in the range of 2.53 - 3.13 for Twisted Tape Turbulator and 4.25 - 5.95 for Coil Wire Turbulator. Significantly, the pressure drop for coil wire turbulator was found to be larger than twisted tape turbulator inserts.

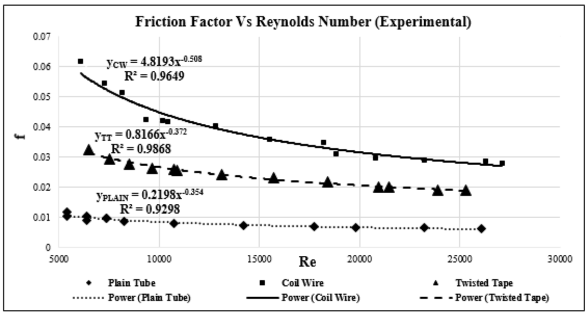

Figure 5: Plot of Comparison of f Vs. Re (Experimental Results)

Nu Vs. Re Plot: The Nu Vs. Re Plot from Experimental results gave the following correlation for plain fire tube

$$Nu = 0.0171 * Re^{0.8402} * Pr^{0.3}$$

which was in close kinship with Dittus-Boelter correlation. Similarly, the correlations for Plain Fire Tube with TT and CW Turbulator inserts were

$$Nu = 0.1931 * Re^{0.6623} * Pr^{0.3}$$

and

$$Nu = 0.5176 * Re^{0.5838} * Pr^{0.3}$$

respectively. In the range of 5,000 $\leq$ Re $\leq$ 25,000, the increment in heat enhancement index with reference to plain fire tube was found in the range of 1.68 - 2.63 for Twisted Tape Turbulator and 2.19 - 3.48 for Coil Wire Turbulator. Evidently, the heat enhancement index for coil wire turbulator was found to be greater than twisted tape turbulator inserts.

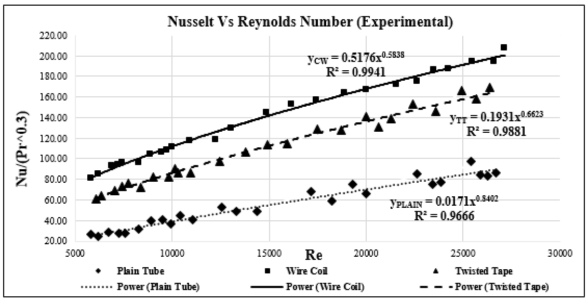

Figure 6: Plot of Comparison of Nu Vs. Re (Experimental Results)

3.1.3 Comparison with Existing Literature

The existing literature for correlation of heat transfer index (Nu Vs. Re) for plain tube is given by Dittus-Boelter as:

$$Nu = 0.023 * Re^{0.8} * Pr^{0.3}$$

The results obtained from this study is analogous to it. The correlations obtained from CFD and Experimental results for plain tube are respectively:

$$Nu = 0.0175 * Re^{0.8426} * Pr^{0.3}$$

and

$$Nu = 0.0171 * Re^{0.8402} * Pr^{0.3}$$

The correlations of heat transfer index for Twisted Tape and Coil Wire Turbulators are given by Junkhan, et. al. [21]

For Twisted Tape Turbulators: The correlation from existing literature is given as:

$$Nu = 0.2 * Re^{0.6} * Pr^{0.3}$$

The results obtained from CFD and Experimental results are respectively:

$$Nu = 0.2032 * Re^{0.6679} * Pr^{0.3}$$

and

$$Nu = 0.1931 * Re^{0.6623} * Pr^{0.3}$$

For Coil Wire Turbulators: The correlation from existing literature is given as:

$$Nu = 0.515 * Re^{0.584} * Pr^{0.3}$$

The results obtained from CFD and Experimental results are respectively:

$$Nu = 0.4124 * Re^{0.607} * Pr^{0.3}$$

and

$$Nu = 0.5176 * Re^{0.5838} * Pr^{0.3}$$

Very little literature for the correlations of pressure drop index (f Vs. Re) is available.

3.1.4 Performance Enhancement Criteria

Performance Enhancement Criteria (PEC) is the measure of net enhancement in gas-side heat transfer coefficient that has been attained by incorporating turbulator inserts. The PEC criteria for various inserts for CFD and Experimental part are illustrated below:

Twisted Tape Turbulator: The PEC for TT turbulator in the range of 5,000 ≤ Re ≤ 25,000 was found to be 1.26 - 1.78 from CFD results and 1.17 - 1.93 from Experimental results.

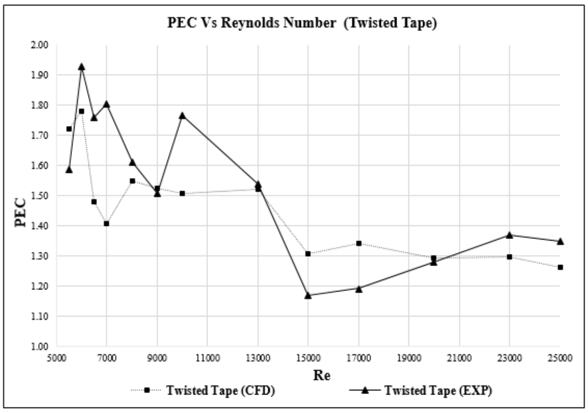

Figure 7: Plot of PEC Vs. Re for TT Turbulator

This indicates net maximum heat enhancement of 178% and 193% respectively from CFD and Experimental results for TT turbulator compared to conventional plain fire tubes. The errors associated with CFD and Experimental data for TT insert lies in the range of 0.93-28.11%.

Coil Wire Turbulator: The PEC for CW turbulator in the range of 5,000 ≤ Re ≤ 25,000 was found to be 1.2 - 1.83 from CFD results and 1.32 - 2.08 from Experimental results.

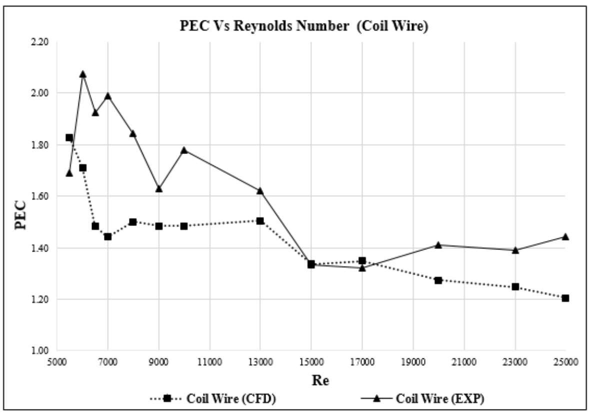

Figure 8: Plot of PEC Vs. Re for CW Turbulator

This indicates net maximum heat enhancement of 183% and 208% respectively from CFD and Experimental results for CW turbulator compared to conventional plain fire tubes. The errors associated with CFD and Experimental data for CW insert lies in the range of 0.17-37.86%.

3.2 Reduction of Stack Losses

Apart from enhancement in gas-side heat transfer coefficient in fire tube boilers, another evident augmentation that can be achieved by integrating turbulator inserts is reduction in stack temperature which serves to reduce stack losses and utilize fully the heat available from hot flue gases before discharging it via chimney. This improves overall thermal efficiency, evaporation ratio and ultimately reduces the consumption of fuel to produce an equivalent amount of steam.

The normalized baseline temperature data for plain fire tubes showed chimney exit temperature of 237°C. After integrating TT and CW turbulators, the exit temperatures were reduced to 164°C and 120°C respectively.

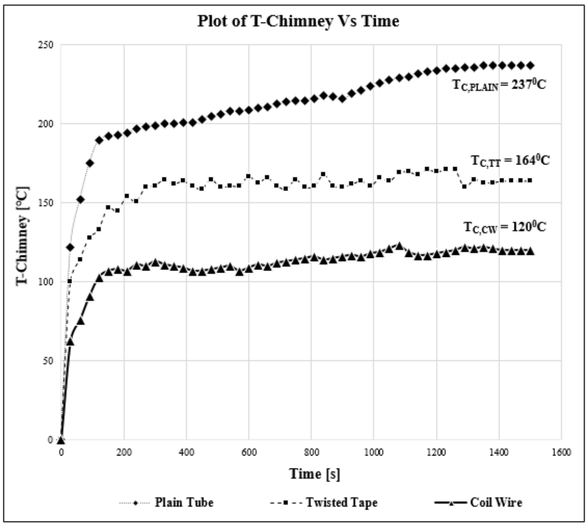

Figure 9: Time-Temperature Plots for exit flue gases

3.3 Augmentation of Boiler Efficiency

Direct Efficiency: The direct efficiency of the fire-tube boiler is calculated on the basis of reduction on fuel feed rate that has been achieved by introducing turbulator inserts. Results showed that the conventional plain fire tube efficiency of 80.09% was increased to 83.5% and 85.78% respectively upon integrating TT and CW Turbulator inserts respectively.

Indirect Efficiency: Various Losses that were encountered upon operating FTB with and without turbulator inserts are listed below in Table-1.

Thus, the indirect efficiency for plain tube, TT and CW turbulator inserts were found to be 80.143%, 83.541% and 85.840% respectively. Thus, the integration of TT turbulators generates an augmentation of about 3.4% on indirect energy efficiency of the system. In the meantime, the CW turbulators exhibit even promising results; which produces an enhancement of 5.7% on indirect energy efficiency of the conventional fire-tube boilers with plain tubes.

Table 1: Calculation of Losses for FTB

Losses	Plain	Twisted Tape	Coil Wire
L_1	9.92%	6.97%	4.95%
L_2	6.82%	6.49%	6.29%
L_3	0.03%	0.03%	0.03%
L_4	0.49%	0.34%	0.25%
L_5	0.49%	0.42%	0.39%
L_6	2.11%	2.19%	2.25%
$\eta_{Indirect}$	80.143%	83.541%	85.840%

Evaporation Ratio: The results for the Evaporation ratio of fire-tube boilers reveal a significant increase in steam output and/or reduction of fuel required to generate an equivalent amount of process output. By integrating Twisted Tape inserts, 570 kg/hr of additional steam output can be increased from one tonne/hr of the fuel feed rate. Similarly, 951 kg/hr of additional steam output can be produced from one tonne/hr of the fuel feed rate.

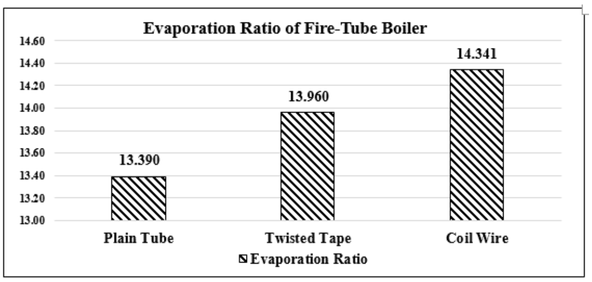

Figure 10: Plot for Evaporation Ratio of FTB

4. Conclusions

The Performance Enhancement Criteria (PEC) attained by integrating Twisted-Tape turbulators in plain fire-tubes were found to be in the range of (1.26 – 1.78) from CFD results and in between (1.17 – 1.93) from Experimental results in the range of $5{,}000 \leq Re \leq 25{,}000$. Similarly, for Coil-Wire turbulators, PEC ranged between (1.2 – 1.83) from CFD results and in between (1.32 – 2.08) from Experimental Results in the same range. The stack temperature of the conventional fire-tube boiler reduced from 237°C to 164°C upon incorporating TT turbulators and to 120°C upon intervening CW Turbulators. This combined effect of enhanced heat transfer and reduced stack temperature led to an increment of thermal efficiency of conventional fire-tube boiler by 3.4% with TT turbulators and 5.7% with CW Turbulators respectively. Moreover, the evaporation ratio of the conventional boiler improved from 13.39 to 13.96 with TT and to 14.34 with CW turbulators.

5. Future Works and Recommendation

This study provides the CFD simulation and Experimental results for enhancement in heat transfer, reduction in stack temperature, and improvement in energy efficiency for only two types of turbulators namely, Twisted-Tape and Coil-Wire turbulators. There are several other complicated geometries like Wire Matrix Tube Turbulators, Flexible Turbulators, Nozzle Turbulators, Angle Turbulators, etc. Comparison and assessment of performance enhancement using these turbulators constitutes the future works for this study. Moreover, the variables like thickness of the strip, pitch ratio, no. of turns, etc. has been kept constant for this study. Alteration and assessment of effect of change in these parameters will establish framework and foundation for future works and continuity of this study.

References

[1] F.J. Gutierrez Ortiz. Modeling of fire-tube boilers. *Applied Thermal Engineering*, 31:3463–3478, 2011.

[2] C.D. Shields. *Boilers*. McGraw Hill Book Company, U.S., 1st edition, 1961.

[3] J.J. James. *Steam Boiler Operation*. Prentice-Hall Inc., New Jersey, 1980.

[4] A. Abene, A. Rahmani, R.G. Seddiki, A Moroncini, and R. Guillaume. Heat transfer study in 3-pass fire tube boiler during a cold start-up. *Software Engineering*, 5:57–64, 2017.

[5] K.I. Rashid and K.E. Amori. Investigation of twisted tape turbulator for fire tube boiler. *Journal of Engineering*, 17:694–713, 2011.

[6] N. Dmitri, O. Arvo, L. Jaan, and T. Toomas. Experimental investigation of various turbulator inserts in gas-heated channels. *Experimental Thermal and Fluid Science*, 28:877–886, 2004.

[7] D.A. David. Prediction of performance for a fire-tube boiler with and without turbulators. Technical report, U.S. Department of Commerce, 1984.

[8] P. Acharya, R. Mamadapur, and S. Dalvi. Effect of twisted tape insert on heat transfer in tube. *International Journal of Recent Advances in Engineering and Technology*, 4:2347–2812, 2016.

[9] J.M. Whitham. The effect of retarders in fire tubes of steam boilers. *Street Railway Journal*, 12:374, 1896.

[10] R Royds. *Heat Transmission by Radiation, Conduction and Convection*. Constable and Company, 1st edition, 1921.

[11] A.P. Colburn and W.J. King. Relationship between heat transfer and pressure drop. *Industrial and Engineering Chemistry*, 23:919–923, 1931.

[12] N.Y. Kirov. Turbulence promoters in boiler smoke tubes. *Journal of the Institute of Fuel*, 22:192–196, 1949.

[13] S.I. Evans and R.J. Sarjant. Heat transfer and turbulence in gases flowing inside tubes. *Journal of the Institute of Fuel*, 24:216–227, 1951.

[14] R. Thorsen and F. Landis. Friction and heat transfer characteristics in turbulent swirl flow subjected to large transverse temperature gradient. *Journal of Heat Transfer*, 90:87–97, 1968.

[15] A.E. Bergles, R.L. Webb, G.H. Junkhan, and M.K. Jensen. Bibliography on augmentation of convective heat and mass transfer. *AMES*, 1979.

[16] R.J. McDonald, J.E. Batey, T.W. Allen, and R.J. Hoppe. Direct efficiency measurement and analysis of residential oil-fired boiler systems. Technical report, Brookhaven National Laboratory, 1979.

[17] H. Usui, K. Sano, K. Iwashhita, and A. Isozaki. Heat transfer enhancement effects by a combined use of internally grooved rough surfaces and twisted tape. *International Chemical Engineering*, 26:97–104, 1986.

[18] V. Zimparov. Enhancement of heat transfer by a combination of three-start spirally corrugated tubes with twisted tape. *International Journal of Heat and Mass Transfer*, 44:551–574, 2001.

[19] J.Y. San, W.C. Huang, and C.A. Chen. Experimental investigation on heat transfer and fluid friction correlations for circular tubes with coiled-wire inserts. *International Communications in Heat and Mass Transfer*, 65:8–14, 2015.

[20] A. Bisetto, M. Del Col, and M. Schievano. Fire tube heat generators: Experimental analysis and modeling. *Applied Thermal Engineering*, 2015.

[21] J.H. Junkhan, A.E. Bergles, V. Nirmalan, and T. Ravigururajan. Test of turbulators for fire tube boilers. Technical report, Iowa State University AMES Heat Transfer Lab, 1982.

[22] P. Bharadwaj, A.D. Khondge, and A.W. Date. Heat transfer enhancement using 75-start corrugated tube with twisted tape inserts. *International Journal of Heat and Mass Transfer*, 52:1938–1944, 2008.

[23] R.K. Rajput. *Thermal Engineering*. Laxmi Publications Pvt. Ltd., New Delhi, 7th edition, 2012.