To optimise air preheater design for better performance

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This paper presents an approach for the optimisation of air preheater design with inline & staggered tube arrangement. The poor performance of an air preheater in the modern power plants is one of the main reason for higher unit heat rate & is responsible for deterioration in boiler efficiency. The main problem of air preheater is the leakage of air to the flue gas side & thereby resulting in poor thermal performance.The higher ash content in Indian coal also adds to the problems associated with tubular air preheater. Air preheaters are designed to meet performance requirements with consideration of highly influencing parameters viz. heat transfer, leakage and pressure drop. In the present work the performance of tubular air preheater is evaluated with the help of CFD analysis for In-line & staggered tube arrangement with the latter being more thermally efficient. The model can also be used while selecting a new type of surface geometry for optimising the design of air preheater.

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1 Introduction:

Heating combustion air can raise boiler efficiency about 1% for every 40F (22°C) in temperature increase. The most common way to preheat the air is with a heat exchanger on the flue exhaust. With the increasing price of fuel and technology improvements, the size of a boiler that can be economically equipped with a pre-heater should become smaller. Although still a technology most applicable to large boilers, high energy prices will certainly motivate innovative new applications for economical combustion air pre-heaters on ever smaller boilers.Air heaters can also use extraction steam or other sources of energy depending upon the particular application. These units are usually employed to control air and gas temperatures by preheating air entering the main gas-air heaters.The hot air produced by air heaters enhances combustion of all fuels and is needed for drying and transporting the fuel in pulverized coal-fired units.Industrial units fire variety of fuels such as wood, municipal refuse, sewage sludge and industrial waste gases as well as coal,oil and natural gas. As a result, many air heater types are used. In the small units tubular, plate and cast iron heaters are widely used. [3]

Fuels fired on stoker grates, such as bituminous coal, wood and refuse, don’t require high air temperatures, therefore water or steam coil air heaters can be used. Tubular preheaters consist of straight tube bundles which pass through the outlet ducting of the boiler and open at each end outside of the ducting. Inside the ducting, the hot furnace gases pass around the preheater tubes, transferring heat from the exhaust gas to the air inside the preheater. Ambient air is forced by a fan through ducting at one end of the preheater tubes and at other end the heated air from inside of the tubes emerges into another set of ducting, which carries it to the boiler furnace for combustion. Steam coil and water coil recuperative air heaters are widely used in utility steam generating plants to preheat combustion air. Regenerative air heaters are relatively compact and are the most widely used type for combustion air pre heating in electric utility steam generating plants. Air to gas leakage can be controlled by cold-presetting axial & radial seal plates to minimize gaps at the hot operating conditions, or using sacrificial material.[1]

2 Traditional strategies for Air Preheater design

In a typical tubular air heater, energy is transferred from the hot flue gas flowing inside many thin walled tubes to the cold combustion air flowing outside the tubes. The unit consists of a nest of straight tubes that are roll expanded or welded into tubesheets and enclosed in a steel casing. The casing serves as the enclosure for the air or gas passing outside of the tubes and has both air and gas inlet and outlet openings. In the vertical type tubes are supported from either the upper or lower tubesheet while the other (floating) tubesheet is free to move as tubes expand within the casing. An expansion joint between the floating tubesheet and casing provides an air/gas seal. Intermediate baffle plates parallel to the tubesheets are frequently used to separate the flow paths and eliminate tube damaging flow induced vibration. Carbon steel or low alloy corrosion resistant tube materials are used in the tubes which range from 38 to 102 mm in diameter and have wall thicknesses of 1.24 -to 3.05 mm. Larger diameter, heavier gauge tubes are used when the potential for tube plugging and corrosion exists. The most common flow arrangement is counterflow with gas passing vertically through the tubes and air passing horizontally in one or more passes outside the tubes. A variety of single and multiple gas and air path arrangements are used to accommodate plant layouts. Designs frequently include provisions for cold air bypass or hot air recirculation to control cold end corrosion and ash fouling.[3]

Pressure drop:

In recuperative air heaters, gas- or air-side pressure drop arises from frictional resistance to flow, inlet and exit shock losses and losses in return bends between flow passes. Pressure drop is proportional to the square of the mass flow rate.[5]

Leakage:

Recuperative units may begin operation with essentially zero leakage, but leakage occurs as time and thermal cycles accumulate. With regular maintenance, leakage can be kept below 3%. Approximate air heater leakage can be determined based on gas inlet and outlet oxygen (O2) analysis (dry basis).[6]

Plugging and cleaning:

Plugging is the fouling and eventual closing of heat transfer flow passages by gas-entrained ash and corrosion products. It can occur at the air heater hot end but is most common at the cold end where ash particles adhere to acid moistened surfaces. Plugging increases air heater pressure drop and can limit unit load when fan capacity is reached at less than full load. In cases where low pressure washing is not effective, high pressure washing is done. Power plant operators employ air heater washing specialists and equipment with water jets at nozzle pressure above 5000 psi (34.5 MPa). Special care must be taken to avoid breaking and/or flattening regenerative element plates.

Erosion:

Heat transfer surfaces and other air heater parts can suffer erosion damage through impact of high velocity, gas-entrained ash particles. Erosion usually occurs near gas inlets where velocities are highest. The undesirable effects of erosion are structural weakening, loss of heat transfer surface area and perforation of components which can cause air to gas or infiltration leakage. Erosion rate is a function of velocity, gas stream ash loading, physical nature of ash particles and angle of particle impact. It is controlled by reducing velocities, removing erosive elements from the gas stream, or using sacrificial material. In the design stage, air heaters used with fuels containing highly erosive ash can be sized to limit gas inlet velocities to 50 ft/s (15 m/s). Inlet flues can also be designed to evenly distribute gas over the air heater inlet to eliminate local high velocity areas. In existing problem air heaters, flow distribution baffles may be installed to eliminate local high velocities, sacrificial materials such as abrasion resistant steel or ceramics may be placed over critical areas, or parts can be replaced with thicker materials for longer life.

3 Performance analysis of Air Preheater

The air heater is the last heat transfer component before the stack. The air heater, when sized properly, will have sufficient surface to provide the required air temperature to the fuel equipment (burners, pulverizers, etc.) and lower the gas temperature to that assumed in the combustion calculations. For the air heater, the heat transfer rate is determined as follows:

$q = m_g C_p (T_1-T_2)$ (1)

Where,
q= Heat transfer rate, Kcal/hr
m_g= Mass flow rate of flue gas, kg/hr
C_p = Approximate mean specific heat of gas, KJ/kg K
T_1 = Gas temperature entering the air heater, °C
T_2 = Assumed air heater exit temperature, °C

For the air side, the temperature rise is:

$T_2' = T_1' + q / (m_a C_p)$ (2)

Where,
T_1' = Air temperature entering air heater, °C
T_2' = Air temperature leaving air heater, °C
q= Heat transfer rate, Kcal/hr
m_a = Mass flow rate of air, kg/hr
C_p = Approximate mean specific heat of air, KJ/kg K

For cross flow arrangement , the log mean temperature difference is determined as follows:

$LMTD =[(T_1-T_2') - (T_2-T_1')] \times F / [\ln (T_1-T_2') / \ln (T_2-T_1')]$ (3)

In an air heater, gas & air film heat transfer coefficients are approximately equal. Film temperatures are approximated by the following calculations.[4]

Gas : $T_f = (T_1+T_2) /2 - LMTD/4$ (4)

Air : $T_f = (T_1' + T_2') / 2 + LMTD/4$ (5)

The gas mass flux is given by,

$G_g = m_g / A_g$ (6)

Where,
m_g= Mass flow rate of flue gas, kg/hr
A_g = Flue gas flow area, m^2

Gas Reynolds number is given by,

$Re = K_{Re} G_g$ (7)

Where,
K_{Re} = Gas properties factor, m^2 hr/ Kg
G_g = gas mass flux, Kg / m^2 hr

Gas film heat transfer coefficient is the sum of the convection heat transfer coefficient from the longitudinal gas flow inside the air heater tubes & a small gaseous radiation component from within the tube. To properly account for the fly ash layer inside the tubes, the gas side heat transfer coefficients will be multiplied by a cleanliness factor in the overall heat transfer calculation.

$h_{cg} = h_l' \times F_{pp} \times F_t \times Di/ Do$ (8)

Where,
h_{cg} = The gas convection heat transfer coefficient, Kcal/m^2 hr °C
h_l'= Basic convection velocity & geometry factor for longitudinal flow
F_{pp} = Physical properties factor
F_t = Temperature factor
Di = Tube inside dia., mm
Do = Tube outside dia., mm

Gas side radiation heat transfer coefficient is given by,

$h_{rg} = h_r' \times K$ (9)

Where,
H_{rg} = The gas side radiation heat transfer coefficient, Kcal/m^2 hr °C
h_r' = Basic radiation heat transfer coefficient, Kcal/m^2 hr °C
K = Fuel factor

The air mass flux is calculated as,

$G_a = m_a / A_a$ (10)

Where,
m_a= Mass flow rate of air, kg/hr
A_a = Air flow area, m^2

Air Reynolds number is given by,

$Re = K_{Re} G_a$ (11)

Where,

K_{Re} = Gas properties factor, m^2 hr/ Kg
G_a = Air mass flux, Kg / m^2 hr

The crossflow convection heat transfer coefficient for air is obtained from following equation:

$$h_{ca} = h_c' \times F_{pp} \times F_a \times F_d \qquad (12)$$

Where,
h_c' = Basic convection velocity & geometry factor for crossflow
F_{pp} = Physical properties factor
F_a = Arrangement factor for in-line tube banks
F_d = Heat transfer depth factor

Assuming negligible wall resistance, the overall heat transfer coefficient is:

$$U = [\, F_{FR} (h_{cg} + h_{rg})\, h_{ca}] / [\, F_{FR} (h_{cg} + h_{rg}) + h_{ca}] \qquad (13)$$

The cleanliness or fouling resistance factor, F_{FR}, is empirically derived from field test data; 0.9 is representative of bituminous coal.

The total heat transfer rate for the air heater is:

$$q = U \times A \times (LMTD) \qquad (14)$$

Where,
A = Heating surface area in m^2

Air heater exit gas temperature is calculated to be:

$$T_2 = T_1 - [\, q / (m_g \times C_p)\,] \qquad (15)$$

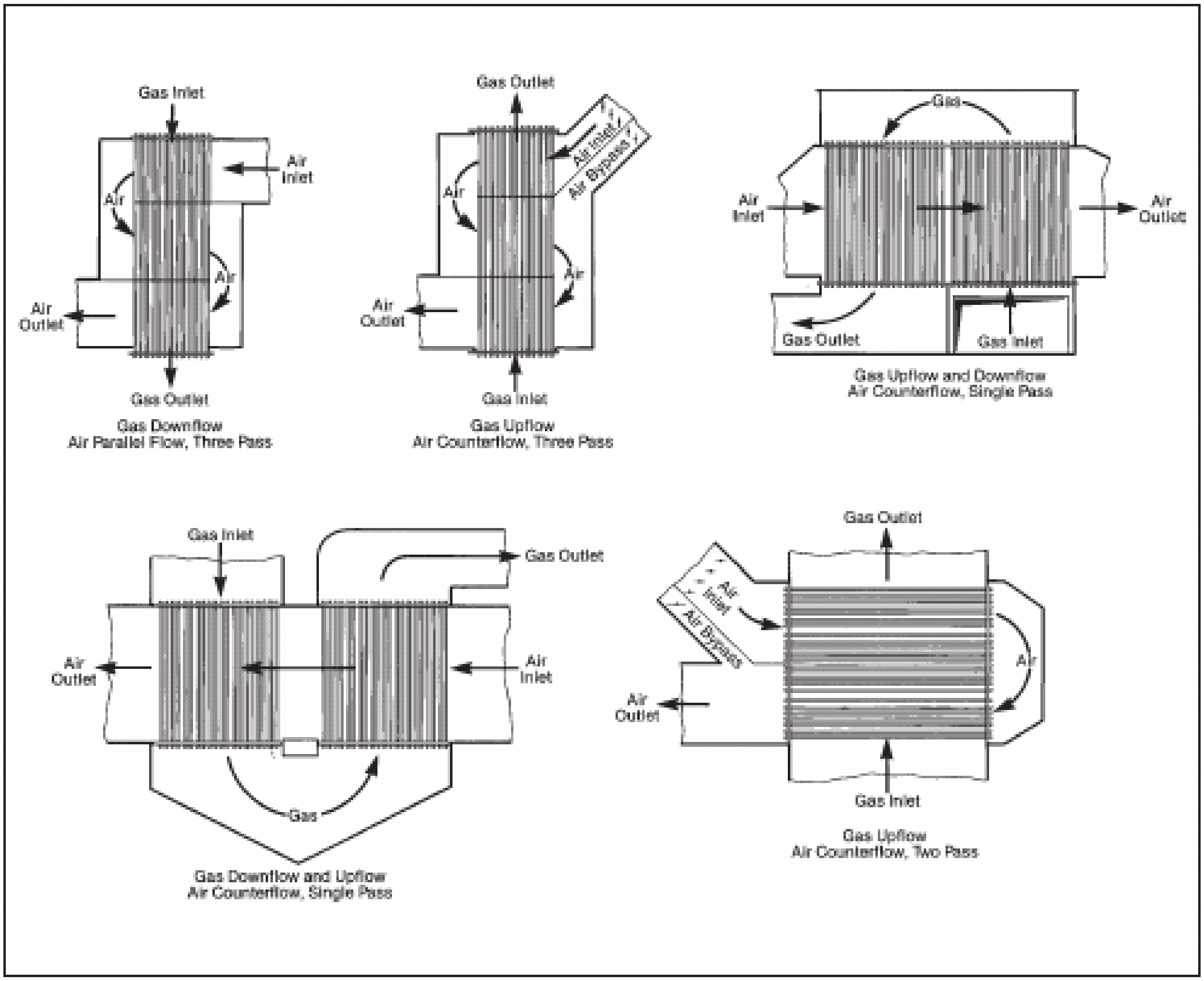

Fig. 1 Various tubular air heater arrangements

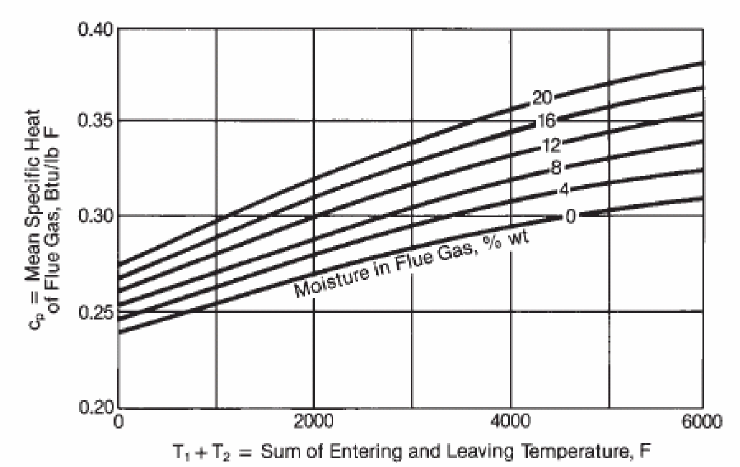

Fig. 2 Approximate mean specific heat, Cp, of flue gas

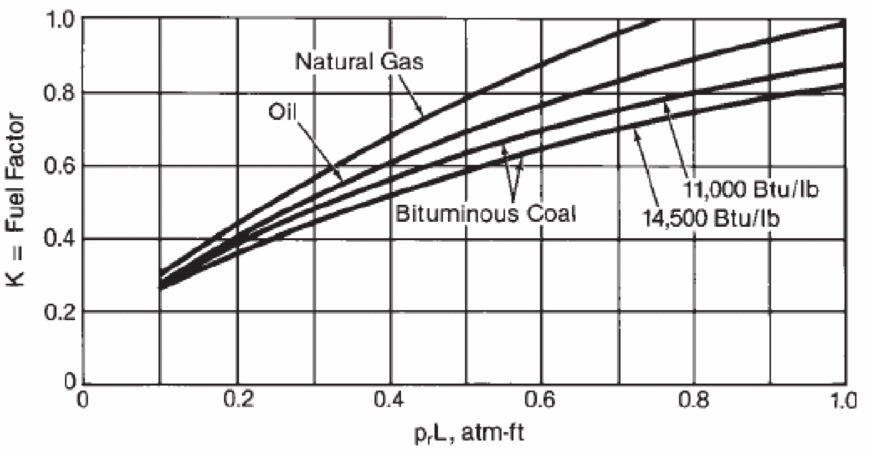

Fig. 3 Effect of fuel, partial pressure on radiation heat transfer coefficient

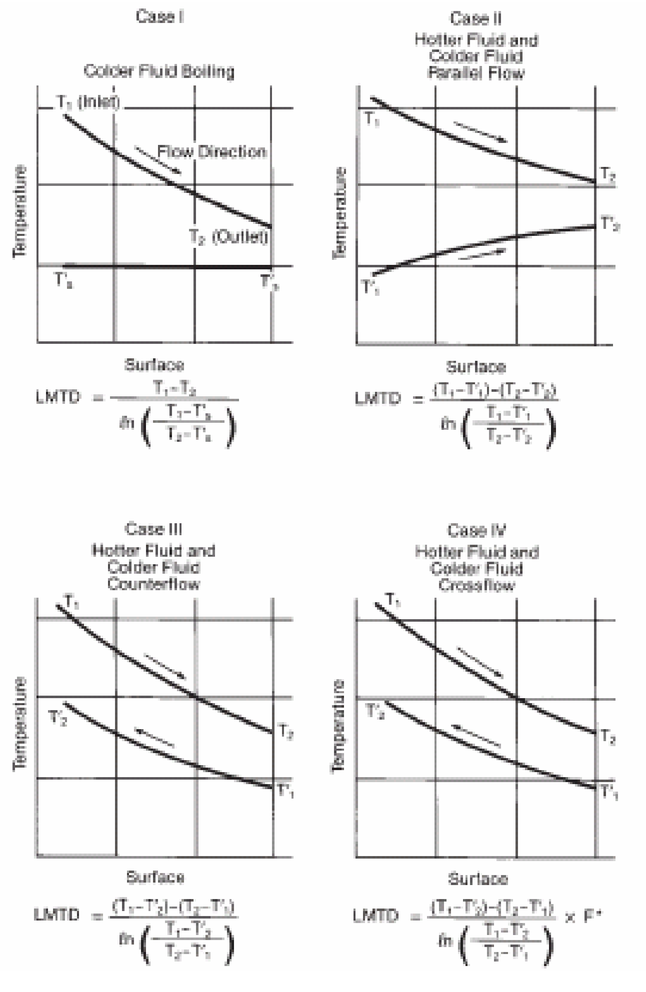

Fig. 4 LMTD for selected heat exchanger configurations

4 CFD analysis of Air Preheater

Input parameter:

Flue gas inlet mass flow rate = 193.6 Kg/s
Flue gas inlet Temperature = 285^0C
Back pressure at outlet = -154 mmWC
Gas composition (volume fractions)

H2O	11.81 %
N2	70.65 %
CO2	14.45 %
O2	3.09 %

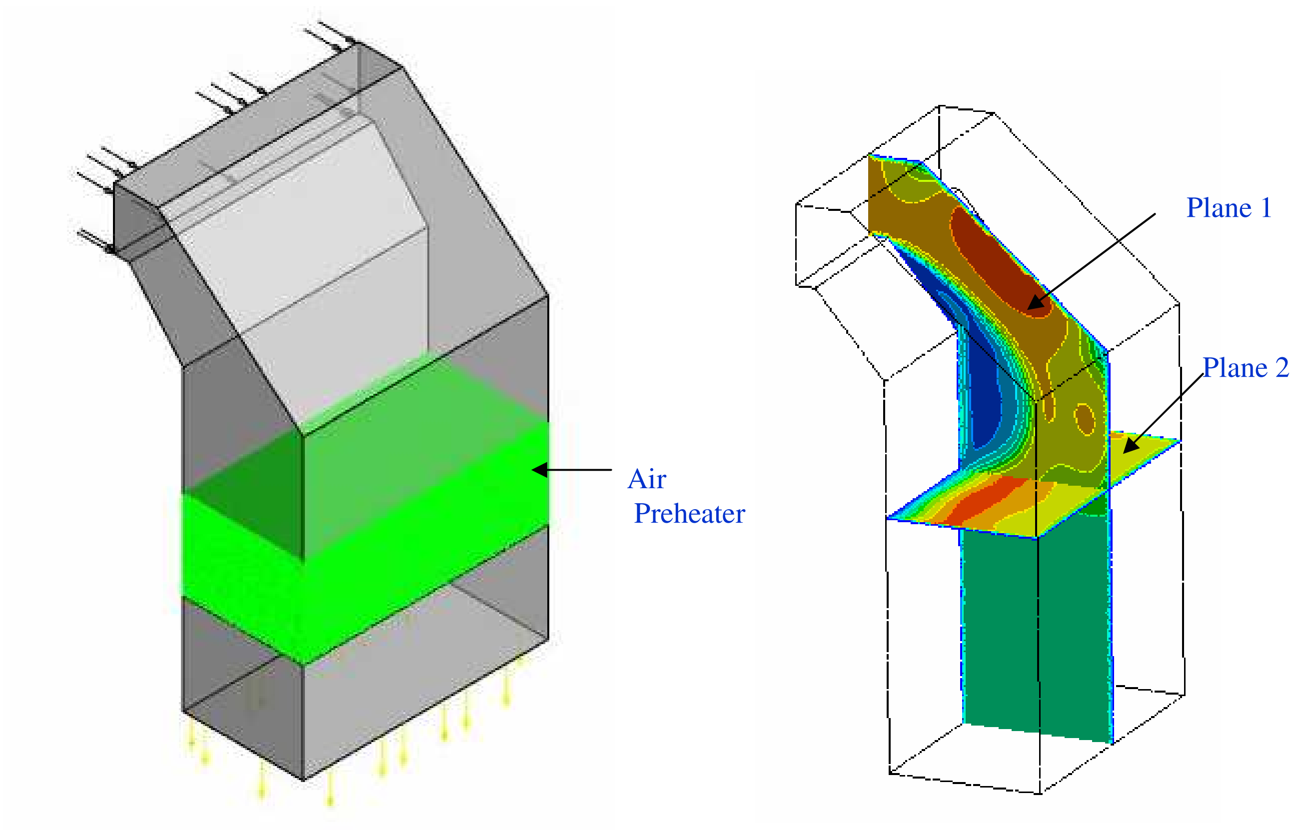

Fig. 5 3-D Model & plane locations for duct before Air Preheater

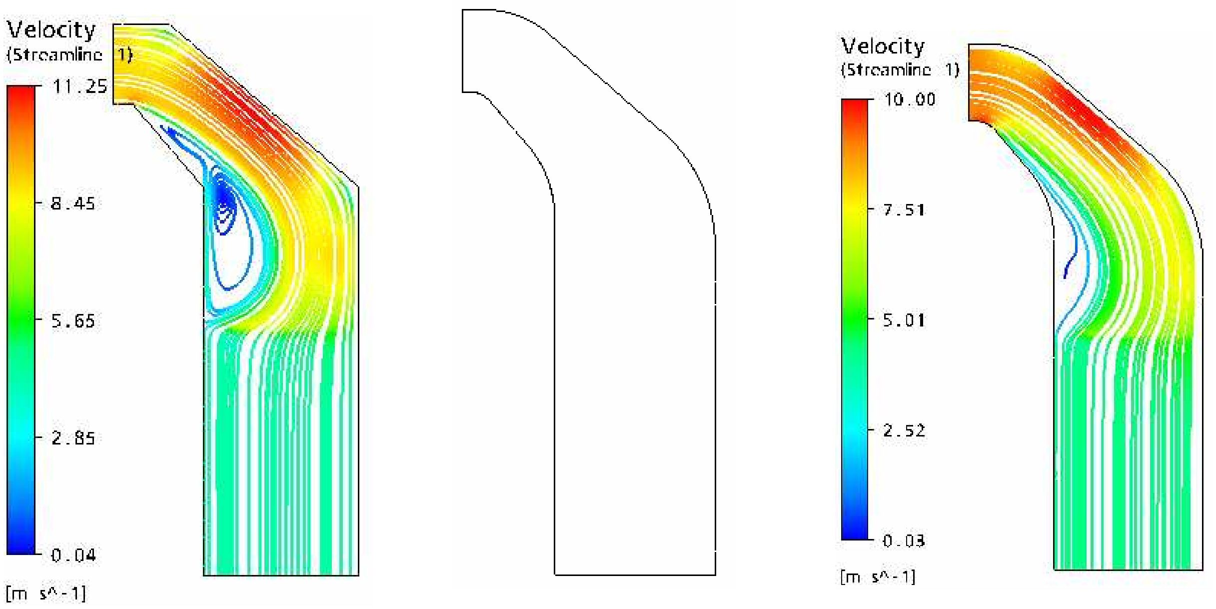

Fig. 6 Velocity contours on plane 1 & recommended modifications

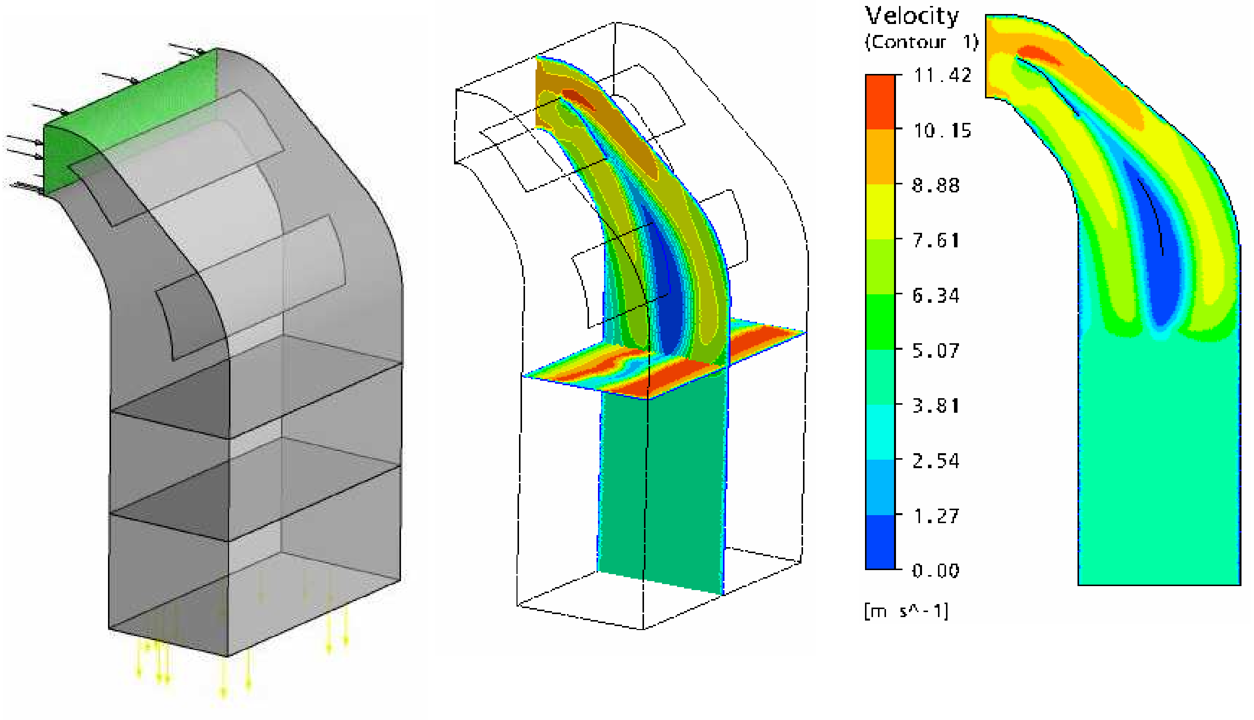

Fig. 7 Plane locations & velocity contours with addition of Internal baffles

Conclusion

In a recuperative heat exchanger, heat is transferred continuously and directly through stationary, solid heat transfer surfaces which separate the hot flow stream from the cold flow stream. The most common heat transfer surfaces are tubes and parallel plates. In case of tubular air heaters a variety of single and multiple gas and air path arrangements can be used to optimum performance. Modern tubular air heaters can be shop assembled into large, transportable modules. Erosion of air preheater parts can be controlled by reducing velocities, removing erosive elements from the gas stream, or using sacrificial material. The performance of tubular air preheater can be evaluated with the help of CFD analysis for In-line & staggered tube arrangement with the latter being more thermally efficient. The model can be used while selecting a new type of surface geometry in order to have uniformly distributed flow pattern for optimising the design of air preheater.

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