CFD Analysis on Entropy Generation Minimization of Pipe Bending

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Abstract- This project presents solution of a simple optimization problem of flow through circular bent channels. Six different bending angles of the pipe were taken for finding the effect of bending angle on the pressure drop. The diameter and length of all the pipes were taken same irrespective of the bending angles. The CFD model equations were solved to predict the hydrodynamic behavior of pipe. The models were solved by ANSYS Fluent 15.0 solver. The CFD models were validated by comparing the computed pressure drop with the analytically computed pressure as given in the previous literature. The entropy generation rate was compared and the optimum bending angle was found by taking pressure drop across the pipe as reference. The entropy generations in both isothermal and non-isothermal conditions were studied and compared mutually for a particular flow rate. An EGM analysis was carried out and a thermodynamically optimal solution was identified. It was also observed that as the bending angle increases the entropy generation decreases for a particular flow rate.

Keywords: CFD, Entropy generation minimization, Pipe bending

I. INTRODUCTION

Energy

Energy is everywhere. Anything we eat or use has energy in it. Everything that we process or every object we produce requires energy, and the economic growth of a country is related to the energy demands. But during an engineering operation most of the energy is not utilized so it transforms to another form and loss of energy occurs.

Entropy

Entropy is the degree to which energy is wasted. While the energy of a system is the maximum work possible during a process. So the amount of available work (or energy) depends on the amount of entropy produced. The amount of entropy generated can be directly used as an efficiency parameter of the system. Minimization of entropy generation in a thermodynamic system provides efficient use of energy that is available.

Entropy Generation Minimization (EGM)

The theorem of minimum entropy generation says that, under certain assumptions, the global entropy production rate of a given system attains a minimum value when the processes in the system become stationary. This method combines the most fundamental principles of thermodynamics, heat transfer, and fluid mechanics.

Bejan studied minimization of entropy generation in heat exchangers, insulation systems, storage system, power generation, refrigeration processes in brief. But later on many more detailed analysis of his work is carried out by many authors

Mass transfer Studies using EGM

Like in mass transfer operations, Barbosa et al. Have optimized the finned tube evaporator using the Entropy generation minimization (EGM) principle. While Özyurt et al. optimized evaporator for use in a refrigeration cycle. For condensation of gases in the presence of high non-condensable gases, in the design of fan-supplied tube-fin condensers and Refrigerant circuitry design of tube condenser different authors used EGM as efficiency parameter analyzed the EGM of absorption used entropy generation as a parameter to analyze the desalination process.

Nano-Fluid Flow and heat transfer Using EGM

In Nano fluid flow, Leong et al. analyzed entropy generation of three different types of heat exchangers studying the turbulent convection of nanofluids subjected to constant wall temperature. Theoretically investigated entropy generation of Nano-fluids convection and showed the existence of different optimal working points according to the flow features without considering the influence of particles diameter. Numerically developed turbulent forced convection flow in a square tube, subjected to constant and uniform wall heat flux of a water–Al2O3 nano fluid. Proposed a simple analytical procedure to evaluate the entropy generation and showed that it takes a good agreement with the numerical calculations.

Heat transfer and flow through a channel using EGM Considered a range of laminar streams at steady heat flux boundary condition and explored different pipe geometries to minimize the entropy losses. Among different geometries, when the frictional contribution of entropy generation are prevailing round geometry is the best. Dagtekin studied the effect of longitudinal blades of diverse shapes for laminar stream in a circular conduit and demonstrated that the cross-sectional region and the wall heat flux have extensive impact on entropy generation. For improved heat exchange surfaces of a tubular heat exchanger at steady wall temperature concentrated on liquid temperature variety along the length of exchanger by creating execution assessment criteria mathematical equations taking into account the entropy generation hypothesis.

II. PREVIOUS WORK

Pressure Drop in Channels

Hilbert et al. examined three bends: blinded tee, short radius elbow and long radius elbow experimentally. He found that from the standing point of the wear the blinded tee is the best bend followed by short radius elbow and long radius sweep is the least preferable one.

Entropy Generation analysis in Mass Transfer Applications

Lienhard et al. analyzed desalination process considering the separation work along with it lost work due to entropy generation. Entropy generated due to irreversibility in the separation process, along with the irreversible mixing of the brine with the ambient seawater and temperature disequilibrium of the discharge. The entropy generation due to chemical disequilibrium was found to be important for systems with high recovery ratios.

Entropy Generation analysis of Nano-Fluid Flow

Manca et al. Investigated the entropy generation in turbulent forced convection flow of Al_2O_3–water nano fluid at constant wall heat flux boundary condition. For a constant Reynolds number, nanoparticles were added to decrease entropy generation. The optimal concentration reduced with increase of Re.

Singh et al. Analyzed entropy generation of nanofluids of two different viscosity models, while considering conductivity, for laminar and turbulent flow. They have found that an optimum diameter at which the entropy generation rate was occurred was less for laminar flow in comparison to turbulent flow.

Leong et al. analyzed the entropy generation of nanofluid. As the volume fraction of the nanoparticle was increased total dimensionless entropy generation was decreased. When Titanium dioxide nanofluids and alumina nano-fluids were compared for lower dimensionless entropy generation value, titanium dioxide nanofluids showed good results.

Flow through Microchannels

Ibáñeze et al. optimized various flows in a parallel plate micro channel having finite wall thickness using the entropy generation minimization method. An optimum slip velocity was obtained which was leading to a minimum entropy generation rate and they analyzed effects of slip velocity on the optimum values of some other parameters. Besides all these the Nusselt number was also calculated and analyzed. An optimum value of the slip length for which the heat transfer was maximized was derived.

Anand et al analyzed the thermally fully developed flow with viscous dissipation of a non- Newtonian fluid through a micro channel. The effect of slip on heat transfer and entropy generation was important and could not be neglected, especially for shear thickening fluids ($n > 1$) the curves for velocity distribution and temperature distribution had higher slopes, especially towards the centerline of the channel, in comparison to shear thinning fluids. The slip parameters only affected the advection of fluid momentum and not its diffusion for symmetrical slip boundary conditions.

Huai et al. numerically investigated the effect of viscous dissipation on total entropy generation for curved square micro channels in the laminar flow region by using two different working fluids. The working fluids were aniline and ethylene glycol. The effect of viscous dissipation was studied and analyzed to calculate the total entropy generation number and heat transfer entropy generation number.

EGM analysis for pipe or channel flow

A number of studies have been done on entropy generation in fluid flow and heat transfer problems. Bejan showed that the entropy generation is due to heat transfer and viscous friction for forced convection viscous fluid flow in a channel.

Bertola and Cafaro reviewed the principle of minimum entropy production of fluid at rest by the heat conduction and the combined effect of heat conduction and shear flow in an incompressible fluid flow. This theorem was a best approximation method and as the system converged to equilibrium it converged to the exact solution. And for a system in a stationary state the entropy production was approximately zero.

Sahin et al compared entropy generation and pumping power required for different duct geometry for optimum shape with constant wall temperature boundary condition. Duct geometries used are: square, circular, rectangle, equilateral triangle, and sinusoidal.

Vučković et al. studies on the numerical simulation of local entropy generation rate in flow meter and pipeline curve. The results of numerical simulation show good agreement with measured data in regard to temperature.

Sahin et al studied numerically the entropy generation rate in a developing laminar viscous fluid flow in a circular pipe with variable viscosity and constant heat flux boundary condition. The entropy generation rate is higher near the wall and decreases along the radius away from the surface of the pipe as the temperature and viscosity gradient are high near the wall of the pipe.

Abolfazli and Alizadeh have also studied the thermodynamic optimization of geometry in convective heat transfer at constant temperature at the wall by considering laminar flow. They found out the effects of different parameter on the pumping power and Entropy generation. They also introduced a proper correlation for the optimum design of the tube.

Sahin et al wrote the dimensionless entropy generation and pumping power to heat transfer ratio as functions of three dimensionless numbers, using an average heat transfer coefficient and a friction factor at average bulk temperature. The entropy generation per unit heat transfer rate decreased with duct length, while the entropy generation per unit capacity rate increased.

III. RESEARCH OBJECTIVES

1. Validation for pressure drop across the pipe inlet and outlet for various Re number.

2. To find out the effect of Re on pressure drop across the pipe ends.

3. To find out the effect of Re on entropy generation for ISO-thermal (constant temperature and sale of liquids and wall) problems.

4. To find out the effect of Re on entropy generation for constant heat flux boundary condition case.

5. To find out the effect of Re on entropy generation for non-isothermal constant wall temperature case.

IV. PROBLEM SEPECIFICATION AND GEOMETRY DETAILS

Consider a steady state fluid flow through a pipe for different angle of pipe bending α" shown in the figure 1 and 2. The diameter and length of the channel are 2.5cm and 3.0 m respectively. The inlet velocity range is 0.0401923m/s to 1.004809m/s, which is constant over the inlet cross section. Pipe outlet is at pressure of 1 atm. As the fluid flows through the pipe, for a particular Reynolds number its corresponding average velocity is applied to the inlet of the pipe. For the case of isothermal, entropy generation is only due to viscous dissipation only. And for non- isothermal cases entropy generation is due to both viscous dissipation and thermal dissipation. So for each case its value is calculated and plotted and compared.

The computational domain of the cylindrical channels is represented in three dimensional (3D) by a cylinder the geometry consists of a wall, inlet and outlet.

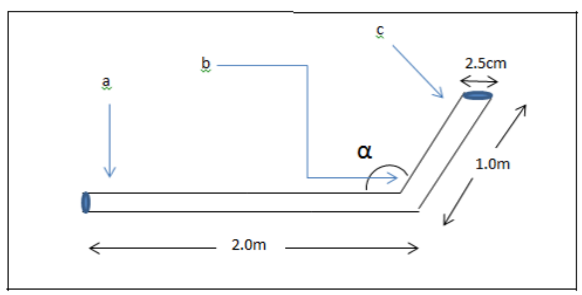

Figure 1: Geometry of the Pipe

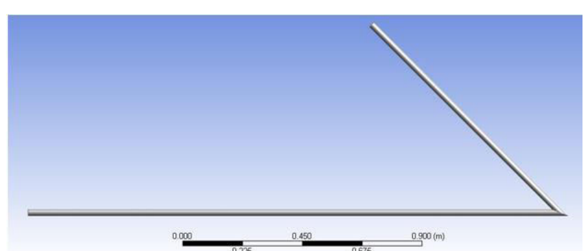

Figure 2: Geometry for $\alpha = 60^0$

The property of fluid is assumed to be constant for all the cases. Water based fluid properties:

Table 1: Property of fluid water

K_f (thermal conductivity, W/mK)	0.6
(viscosity, kg/ms)	0.001003
(density, kg/m^3)	998.2
C_p(specific heat, Kj/kg K)	4.182

Boundary Conditions:

- At the wall: Vr= 0, Vz=0
- At inlet where Vx0 is a constant: Vr= 0, Vx= Vx0.
- At the outlet section providing a fully developed flow condition:
- ISO-thermal flow no thermal boundary condition
- Non-iso thermal case, constant heat flux and constant wall temp are applied
- Where Vr is the velocity in radial direction and Vx is the velocity in x direction.

V. RESULTS

Pipes and pipe bendings contribute to major part of pressure drop as well as energy consumption. So it is better to know pressure drop in a piping system.
Simulations have been done for the 1-weld mitered bend pipe for α equals to 45^0, 90^0 and 180^0 straight pipe and pressure drop over pipe is calculated for different Reynolds number. Fig. 4, 5 and 6 comparing the pressure drop in fig 4 it is clear that the 180^0 shows the lowest pressure drop. The angle 45^0 bending pipe shows the highest pressure drop for a particular Reynolds number and the angle 90^0 bending have the pressure drop in between them.

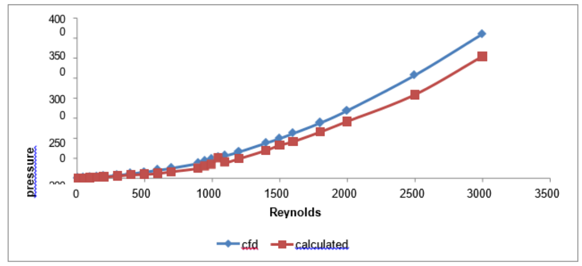

Figure 4: Pressure drop versus Reynolds number plot for α =45^0

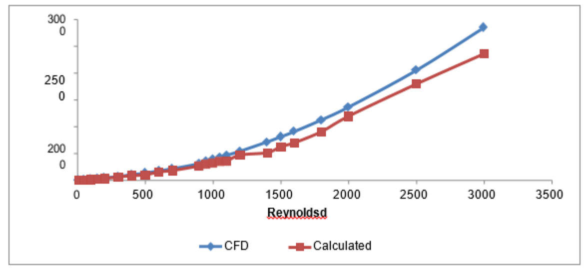

Figure 5 Pressure drop versus Reynolds number plot for α =90^0

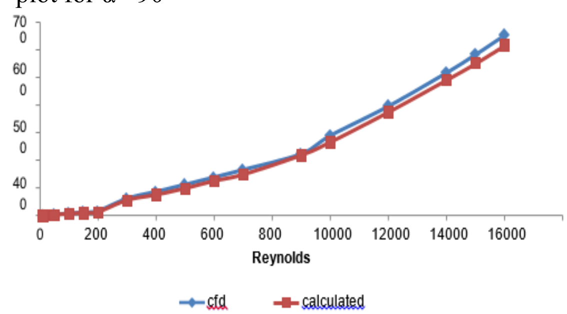

Figure 6: Pressure drop versus Reynolds number plot for α =180^0

VI. CONCLUSIONS

Entropy generation is studied for the flow through a pipe with varying parameter α for three different cases (I) iso-thermal case, (II) isoflux (III) constant wall temperature case.

1. As the Reynolds number increases the pressure drop also found to be increased accordingly and it justifies all the pressure drop and velocity co-relations.
2. For isothermal (constant temperature throughout) case the entropy generation is due to frictional irreversibility only. The entropy generation value increases with increase in Re. with increase in Re the frictional forces increases and hence the velocity gradient.

The frictional component has two components. One is viscous dissipation and another one is turbulence dissipation rate. Turbulence dissipation rate only occurs when the flow is turbulent.

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