ABSTRACT

Pipes in the process piping industry carry hazardous fluids at elevated temperatures and pressure. Seamless pipes are formed to the required pipe bend angle using pipe bending techniques complying with ASME B 31.3 standards rather than using pipe fittings and welding techniques. The pipe fittings and welding will eventually reduce the strength of the piping system at pipe bends which are incapable of handling high pressure and temperature limits of the fluid being transported. Rotary draw pipe bending is the most suitable method for forming smaller diameter pipe bends and three-roller pipe bending is suitable for forming larger diameter helical coils. During forming of pipe bends, the extrados experiences tensile force resulting in thinning of walls and simultaneously the intrados experience compressive force resulting in thickening of walls and results in the formation of ovality and wrinkles in pipe bend. The presence of these geometrical irregularities in pipe bends fails to meet ASME B 3.13 standards and hence these pipe bends are not qualified to be used for process piping applications. Ovality and wrinkles will have their dominant influence on the service life of the pipe bends which needs to be investigated to avoid premature failures.

In present study, an attempt has been made to explore the process parameters of rotary draw pipe bending and three-roller pipe bending methods using numerical simulation and experimental validation. The existing rotary draw pipe bending machine was studied and a numerical model of pipe bending setup was developed and finite element analysis was carried out to investigate the influence of process parameters on the quality of pipe bend produced. The dominant process parameters identified were friction between the pipe and other parts which are in contact with the pipe to be bent, boosting velocity of the pipe and speed of bending the pipe. Based

on the investigations, optimized process parameters were presented for obtaining pipe bends of improved quality.

An existing three-roller pipe bending machine, for forming copper helical coils used as a heat exchanger in a dry air generation application, was considered for investigation. The feed of the top roller during forming of helical coils and the velocity of the rollers were the dominant parameters that influence the quality of helical coils produced. The speed of the rollers was varied and the corresponding ovality was investigated. The maximum percentage ovality observed was 8.9% and the minimum ovality observed was 5.1%. The influence of the center distance between the rollers was varied from 300 mm to 650 mm and the maximum ovality was observed as 8.17% at 300 mm center distance and the minimum ovality was observed as 5.16% at 450 mm center distance. The optimum parameters to reduce the percentage ovality was presented from the numerical and experimental investigation.

The effect of wrinkles and ovality on the flow field of the helical coil was investigated by experimental and numerical analysis. In experimental analysis, a three-turn copper helical coil with wrinkles and ovality was investigated for estimating the global hydrodynamic characteristics inside the helical coil and the results were compared with the ideal geometry of the helical coil without wrinkles and ovality. The effect of wrinkles was assessed through friction factor and the corresponding equivalent surface roughness was found to be increased by 5.7 times owing to the presence of wrinkles in helical coils. Numerical simulation was carried out for exploring the pressure distribution along the length of a helical coil, velocity distribution and secondary flow inside the helical coil by considering three different cases and the numerical results were obtained with few inputs from experimental data. The percentage ovality was measured from three turn helical coils and it was observed that the maximum percentage ovality was 3.2%. The effect of wrinkles and ovality in the flow field was assessed by computing friction factors and it was found, that comparatively, wrinkles had a more dominant effect on the flow field than ovality. The critical section of the helical coil with multiple wrinkles was considered for the numerical simulation to explore the local effects of wrinkles on the flow field behavior. Subsequent local analysis in the vicinity of wrinkles exhibited recirculation and cavitation due to the negative pressure developed in the flow field.

The thermal investigation to quantify the effect of wrinkles and geometrical parameters of the copper tube-in-tube helical coil was considered for investigation. Air was considered as a working medium in the outer coil and r134a (Tetrafluoroethane) refrigerant was used in the liquid state as the working fluid in the inner coil. The helical coil was mounted vertically and counterflow was implemented between air and refrigerant. Experimental results were obtained for various flow conditions and the numerical investigation was established for ideal coil without wrinkles and coils with random wrinkles. The geometrical parameters of the helical coils, namely, pitch, diameter and pitch circle diameter were varied to study the influence of changes in geometrical parameters on the heat transfer characteristics of the helical coil. Based on the experimental and numerical investigation, it was observed that wrinkled pipes increase the turbulence of fluid inside and hence the heat transfer coefficient is increased by 30%. Wrinkled pipes have more heat transfer rate and their effectiveness is increased by 15% than the ideal pipe. An increase in pitch circle diameter of the helical coil decreases the heat transfer coefficient due to less curvature effect. The pitch of the helical coil has a negligible effect on heat transfer characteristics.

This study recommends the optimum process parameters for rotary draw pipe bending and three-roller pipe bending techniques and thereby obtaining pipe bends of higher quality. The service life of pipe bends with

geometrical irregularities and their influence on the premature failure of pipes were investigated and the results portray the severity of premature failure in high temperature and high-pressure applications.