ABSTRACT

The increasing energy demand of the world and the depletion of conventional energy resources triggered the need to find new alternative and sustainable energy sources. With the advent of new energy production technologies and the raising concern for the safety of environment, nuclear energy (nuclear fission and nuclear fusion) is proved to be the best alternative source of clean energy. Unlike nuclear fission, nuclear fusion is eco-friendly since there is no need to deal with hazardous radioactive waste. The International Thermonuclear Experimental Reactor (ITER) tokomak is one of the fusion machines used to confine hot plasma, generating nuclear fusion reaction. Confinement of plasma is possible using different superconducting magnets namely Toroidal Field (TF) Coil, Poloidal Field (PF) Coil and Central Solenoid (CS) Coil. These large scale superconducting magnets are constructed using cable-in-conduit conductors (CICC) operating at as high currents as 68kA and operating at high magnetic fields of nearly 12T. Supercritical Helium (SHe at 4.5K & 0.5MPa) is used to cool these conductors internally for maintaining superconductivity. Temperature dependent properties of Supercritical Helium (SHe) and temperature dependent properties of solid materials (CICC jacket, central spiral and superconducting strands) at cryogenic temperatures made the design of CICC more interesting and complex. Estimation of pressure drop and pumping power of cryogen required to cool the CICC by taking into account all the losses due to flow including the turbulence, is a challenge in the design of CICC. The challenge also lies in the estimation of heat transfer due to forced convection between the bundled conductors (porous annular region of dual channel CICC) and the coolant.

The present work is focused on optimizing the mass flow rate through dual channel CICC using entropy generation minimization technique. In order to estimate the entropy generation, velocity gradients and thermal gradients are evaluated by CFD analysis. In addition, pressure drop, pumping power, friction factors and heat transfer in dual channel CICC are estimated. The results of friction factors, pressure gradients and heat transfer coefficients obtained from CFD simulations are validated with the experimental results available in the literature. It is found that the results of simulation are in good agreement with experimental results. Furthermore, the energy associated with eddies, named as turbulent kinetic energy (TKE) due to turbulent flow through dual channel CICC is estimated along with its rate of dissipation, while eddies are transported through the flow using $k - \varepsilon$ turbulence model. An analysis on entropy generation is done in order to estimate the exergy losses during the operation of dual channel CICC. Few parametric analyses addressing the effect of porosity and inlet temperature of the coolant on pressure drop, pumping power, heat transfer coefficient, turbulent kinetic energy, turbulent dissipation rate and entropy generation rate are also done. These parametric analyses are helpful in choosing the operating mass flow rate of She judiciously depending upon the temperature of the coolant at the inlet and also according to the porosity of the dual channel CICC.

Keywords: CICC, Pressure Drop, Heat Transfer, Porous Medium, Turbulent kinetic energy, entropy generation minimization, Supercritical Helium, Computational Fluid Dynamics, FLUENT.