THERMODYNAMIC DESIGN AND ANALYSIS OF WATER CHERENKOV DETECTOR AND CFD ANALYSIS OF A SUBMERGED, TURBULENT, ISOTHERMAL JET LOCATED BETWEEN TWO IDENTICAL JETS USING THE k-ω TURBULENCE MODEL

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Abstract

A massive water Cherenkov detector is being designed for the Deep Underground Science and Engineering Laboratory (DUSEL), to be constructed in the Homestake Gold Mine in Lead, South Dakota, USA, with the purpose of revamping the United States' neutrino physics program. The long-term goal of the water Cherenkov detector is to determine the neutrino mixing angle θ_{13}, which will assist physicists in updating the Standard Model of particle physics.

There are two design requirements from a thermodynamic and hydrodynamic standpoint in order to accurately collect data. The first requirement is to design the vessel water system to have a residence time of at maximum a month. The second condition is to create a vessel water system that is uniformly mixed, yet as stagnant as possible.

This thesis is divided into thermodynamic and hydrodynamic sections. The thermodynamic section evaluates both analytically and numerically all of the known external heat additions to the vessel in order to size the water chiller required to maintain the water at a set temperature. The hydrodynamic section utilizes several non-dimensional numbers to characterize the flow in an attempt to predict what to expect in the motions of the fluid.

A computational fluid dynamic (CFD) model of a submerged, turbulent jet is then solved using the k-ω turbulence model in the commercial program COMSOL Multiphysics. The jet is modeled as located between two identically discharging jets, the distance between which is varied in order to assess how the motion of the fluid changes.

The results from the analyses show that the amount of thermal energy added to the vessel is highly dependent on the operating temperature of the vessel. For this reason, the addition of thermal insulation on the deck could prove to be cost-effective; however thermal insulation on the air dome is not recommended. The Rayleigh number and Richardson number as calculated for this system point to a highly turbulent, naturally convecting flow despite the system being relatively isothermal.

A vessel water chiller with a flow rate of 1200gpm is recommended in order to create a vessel water residence time less than a month.

The results from the CFD analysis revealed that closer jet spacings will result in smaller convection eddies located at the bottom of the vessel. Smaller jet spacings also correspond to quicker dissipation of the jet at lower vessel heights, but also correlate to a faster average upward velocity of the fluid.