Sensing Methodology of Heat Flux for Detecting Structural Defects in Spent Fuel Dry Storage Cask

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1. Introduction

The nuclear power plant is one of the energy harvesting systems. After the management of spent fuel in the pool for certain years, the spent fuel should be handle appropriate method. The dry storage cask is one of the methods to ensure safely store the spent fuel. However, the spent fuel has yet heat source by low level of nuclear fission. Under the accident cases, decay heat generated by spent fuel is transported to outer wall of dry storage cask. Basically, working fluid which is air enters the narrow passage near the bottom of the cask and then circulate the passage by the principle of buoyancy driven natural convection. The cooler air absorbs the decay heat and dissipates the heat by natural convection through flow channel. The outer wall of dry storage cask can be overheated if the system has problem like a thermal concentration by crack inside the wall. Therefore, it is important to maintain the temperature of working fluid in a certain range to prevent from occurring a nasty accident.

In this study, we suggest the approach how to detect the accident or incident situation and deal with the problem using thermoelectric device for safety management of systems and present the possibility of harvesting energy in normal operating case. Also, we present the possibility of the Dry storage cask - Thermoelectric system applying to another field in nuclear power system.

1.1 Considering thermoelectric device for the spent fuel storage cask

Previous existing systems use the temperature sensor which could be a RTD or thermocouple to detect the temperature of dry storage cask. However, these systems additionally need energy to power the sensor. Also, there is a place which can't connect the power lead to temperature sensor. Consequently, these systems need another battery for supplying the power to systems and can't be installed inside the dry storage cask. On the other hand, the thermoelectric systems need no longer extra power source for detecting the temperature inside the dry storage cask and can save the energy to operate the sensor in normal condition. Also, thermoelectric Therefore, the thermoelectric systems doesn't need more any extra lead to power the systems.

2. Dry storage cask - Thermoelectric model

Thermoelectric(TE) unit couple consists of single p-type and single n-type thermoelectric elements which can directly convert heat into electricity and vice versa.[1] Thermoelectric element material can be selected depending on target range of temperature. There are three effects in thermoelectric (Seebeck, Peltier, Thomson). Seebeck effect is a converting effect which generate voltage by temperature difference of thermoelectric materials. Peltier effect refers to the phenomenon that when a current flow through the thermoelectric materials, heat is moved to other side as shown in Figure 1.

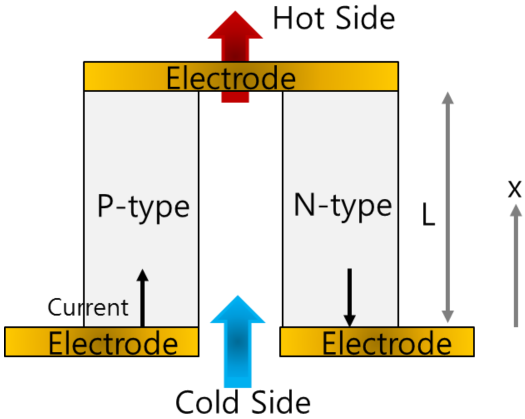

Figure 1 Thermoelectric Peltier Effect

Thomson effect is normally ignored. Thermoelectric module same as a heat engine that consist of solid state P and N type legs connected electrically in series and thermally in parallel. Considering all of the conditions, TE module can be used to generate power supplying to small electronic devices need microwatts or can be used to cool down the object. Applying TE module for handling the emergency situation is also possible for safety in dry storage cask. From Seebeck effect's point of view, first, TE module can be used to detect the emergency situation and alert signals in case of state of emergency like a sudden rising temperature. Second, TE module can be used to harvest energy on outer wall of dry storage cask using heat pipe in case of normal operating conditions to power the sensor which requires small energy or to save auxiliary energy[2]. Given that the temperature of canister is high and heat pipe transport heat, the place on the heat pipe is suitable place for installation of TE module.

2.1 Normal operating region

In normal case, the maximum temperature of the cask is 93.3℃ under normal conditions[2,3,4] and ambient temperature is around 20~30℃. That means, the voltage is continuously generated by temperature difference between hot side and cold side. In other words, the dry storage cask-TE systems continuously generate the energy which can be used to power the sensor detecting the temperature or the module transmitting the information inside the dry storage cask for safe and reliable management of systems. The spare energy can be saved into battery for purpose of automatic cooling system. Basically, the component of the system and operating principle is same as abnormal case. So, this compound systems always use useless energy at all times.

2.1 Emergency operating region

Natural convection in the flow channel plays a very important role in controlling the temperature inside the wall of the dry storage cask. The heat can be leaked to outer wall of dry storage cask through the crack inside the wall and make non-stability of system by the thermal concentration if the abrupt accident occurs. The maximum acceptable temperature of the steel canister was 570℃ and the maximum acceptable temperature of top lid was 176.6℃ under accident conditions[2,3,4]. When the abrupt accident occurs inside the canister, we should notice the signal promptly. So it is important not only pay attention to the possible damage caused by thermal stress and design the structural in terms of the efficiency of flow channel but also notice the signal of abrupt accidents for safe and reliable management system. TE module is installed on the heat pipe which transports the heat caused by nuclear decay in the canister to ambient. TE module on the cold side basically exposures to ambient around 20~30℃ and natural convection conditions. So it can be assumed that maintains in a certain temperature range in normal conditions. The heat comes in from the nuclear decay through the heat pipe goes through the TE module on the hot side. In case of the abnormal condition, the temperature inside the canister rises up to more than twice, the voltage signal abruptly rises up proportionately difference of temperature between hot side and cold side. In this case, we can quickly notice the problem and handle the problem by operating extra coolant circulation loop driven by the force convection.

3. Conclusions

Dry storage cask-TE systems are expected to generate the power around a few watt energy which can power the sensor and other module in normal operating condition. In abrupt state of emergency, a proposed system can be detected the emergency state in the dry storage cask like a thermal stress by the crack on the outer wall.

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