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Preliminary Study of Solar Chimney Assisted Cooling System for SMART

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1. Introduction

After the NPP accident at Fukushima in Japan, the importance and necessity of the final passive heat removal system would be increased more and more. In this paper, the possibility of application for a complete passive final heat removal system using a solar chimney power plant for SMART NPP was estimated. Additionally the size of the cooling system was approximately calculated under the some assumptions.

2. SMART(System-integrated Modular Advanced ReacTor) & its final heat removal system concept

As shown in Fig 1, the single reactor pressure vessel of SMART contains all primary components such as core, steam generators, reactor coolant pumps and a pressurizer [1]. SMART was a small-sized integral type pressurized water reactor with a rated electrical power of 100 MW_e, which is yet to be built.

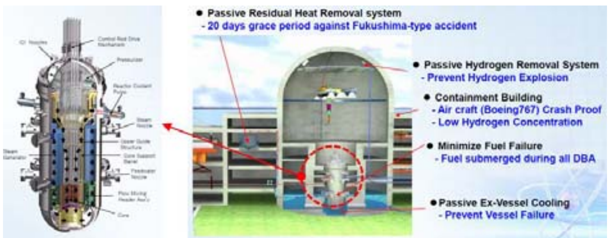


Fig 1. Simplified SMART layout

Therefore, its secondary heat removal system was not decided but analyzed as boundary condition. SMART can adopt a normal condenser using sea or river water. By the way, the situation may be different if SMART would be constructed in water shortage region like any Middle East area. In this case, a dry air cooling system could be likely applied for the final heat removal system as shown in Fig 2.

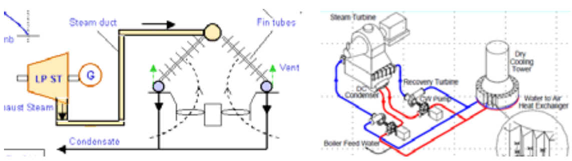
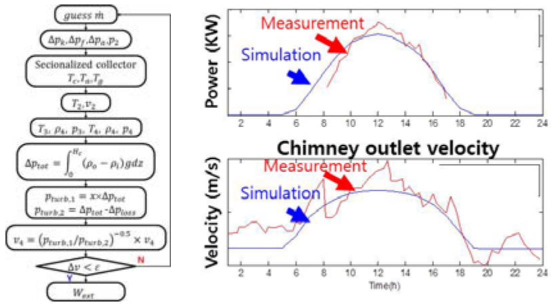


Fig 2. Dry cooling systems

3. New dry cooling concept for SMART

In this paper, we try to introduce new dry cooling concept for SMART, which can additionally even generate electricity by recovering the waste heat to be dissipated in atmosphere, named as SCPP (solar chimney power plant) [2,3]. SCPP in Fig 3 is consisted of the major three parts like a collector, chimney and turbine. We have numerically modelled and verified SCPP performance by comparison the simulation and experiment results in Fig 4.

Fig 3. Schematic diagram and experimental SCPP



(a) (b)

Fig 4. (a) Flow chart for numerical analysis and (b) its results (compared with experiments)

Main idea of this new dry cooling is replacing the A-typed cooling system or dry cooing tower shown in Fig 2 with SCPP mounted with an appropriately sized heat exchanger inside collector.

4. Analysis of SCACS(Solar Chimney Assisted Cooling System) for SMART

Boundary condition of secondary heat removal system for SMART

The condenser power to be removed in SMART is 230 MW_{th}. Using an energy balance, the mass flow rate in condenser tube side can be calculated as 3.65 Ton/s. Under an assumption of atmospheric temperature of 25 °C, T_{steam}, T_{hot}, T_{cold} could be 45°C, 43°C and 28°C, respectively.

Thermal analysis for SCACS

Now, it can be possible to calculate the number of pipe in heat exchanger which depends on the flow speed provided that pipe diameter would be fixed (1 inch in this case) as in Fig 5.

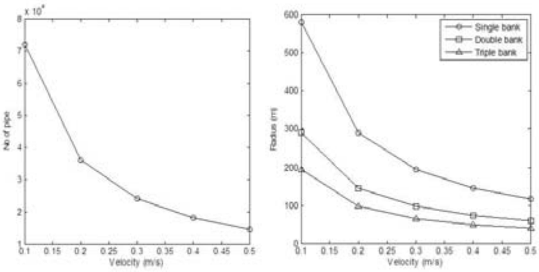


Fig 5. Number of pipe to be required in condenser

Next it was necessary to decide the pipe length so that the temperature difference between condenser inlet and outlet could be greater than 15°C. In order to satisfy the above constraint, 3D FEM simulation using COMSOL was done like in Fig 6 [4]. The water flow length was 0.1 m and fined typed pipe was modelled because of the cooling efficiency. As a result, the effectiveness in water cooling was inversely proportional to tube side speed in Fig 7(a). Fig 7(b) indicates that the effectiveness could be proportional to the air speed and inversely proportional to the water speed. From Fig 7(c), the pipe length which makes ΔT greater than 15°C can be determined.

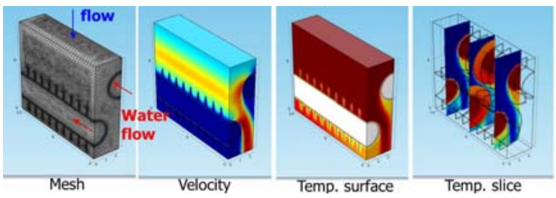
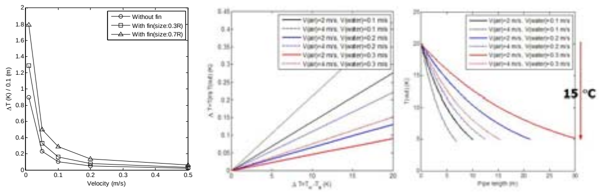


Fig 6. 3D model and simulation results

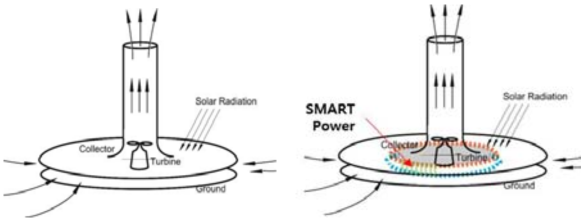


(a) (b) (c)

Fig 7. Thermal analysis for SCACS; (a) ΔT_w/0.1 m vs. water speed, (b) $\Delta T(=T_{in}-T_{out})$ vs. $\Delta T(=T_w-T_a)$, (c) T_{out} vs. pipe length

5. Results

The related all parameters satisfying the constraint of the final heat removal system for SMART were calculated. Using the constraint of the amount of heat to be removed from SMART, two kinds of SCPP performances were analyzed; one for a stand alone SCPP in Fig 8(a) and second for SCPP with SMART in Fig 8(b). As might be expected, the temperature jump around the secondary heat removal system inside collector would occur and displayed in Fig 10 which results in SCPP power up to about 2 MW.



(a) (b)

Fig 8. SCPP (a) stand alone (b) coupled with SMART

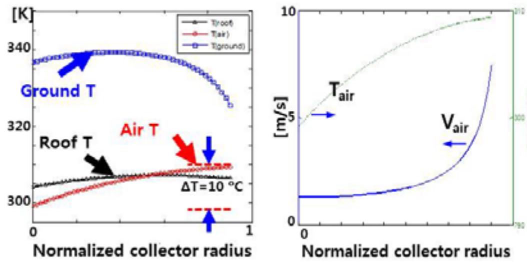


Fig 9. Temperature & speed for SCPP stand alone

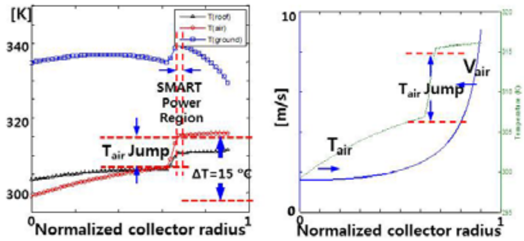


Fig 10. Temperature & speed for SCPP with SMART

6. Discussions & conclusions

Solar chimney power plant was numerically modelled and analyzed. Then its results were compared with the experimental data for SCPP in Spain Manzanares.

In order to estimate the applicability of SCPP as a complete passive secondary cooling system for SMART, we try to calculate the size of heat exchanger and simulate SCPP performance. As a result, it was found that SCPP could be coupled with SMART and some of waste heat could be recovered into electricity without any change in SCPP size.

REFERENCES

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[4] COMSOL Multiphysics, 4.2a