Numerical Simulation of Cooling System for Solar Simulator

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Abstract. The cooling system for the solar simulator was introduced, which contained wind-cooling system, water-cooling system, and refrigeration system. Then the numerical simulation of the wind-cooling system was numerical simulated. The solar simulator with 13 xenon lamp was modeled, and the flow and the heat transfer in the solar hood was simulated by the FLUENT. The flow field in the solar hood was studied, especially the flow near the xenon lamp and the collector. The result showed that the velocity of the most area in the solar hood was slow, but the area near the xenon lamp, because the flow area suddenly decreases, the velocity of the gas increased significantly, which is conducive to the heat exchange between the xenon lamp and the gas. The temperature of the xenon lamp was lower than 328 K, and the velocity on the surface of the xenon lamp was higher than 17 m/s, which met the operating requirement of the xenon lamp, and the temperature of the collector was lower than 308 K, and meet the operating requirement of the collector.

1. Introduction
Two methods has been applied to simulate the space heat flux during the thermal vacuum test: infrared radiation simulation method and solar simulation method [1-3]. In the solar simulation method, the energy radiated on the spacecraft from the sun is simulated by the solar simulator, which doesn’t introduce any hypothesis, so the test results are reliable, and it is suitable for satellites with complex shape or large variations in surface optical properties.

Cooling system is a main subsystem of the solar simulator, to cooling the solar lamps and other optical modules, including the cathode and anode of the solar lamps, collectors, solar hood, water cooling plate, multiple lens units, etc.

2. System composition
The cooling system contains three subsystem: wind-cooling system, water-cooling system, and refrigeration system.

2.1. Wind-cooling system
Wind-cooling system is applied to cool the modules in the solar hood and the multiple lens units, including solar lamps and collectors. The flowchart is shown in Figure 1, it contains fan, heat exchanger, filters, valves and pipes, etc. The GN2 (Nitrogen gas) exchange heat with the cool water in the heat exchanger, the cooled GN2 is send to the solar hood and multiple lens units by the fan to cool
the optical modules, the high temperature GN2 flow into the heat exchanger again to form the cycle. Two filters are applied to ensure the cleanliness of the GN2.

2.2. Water-cooling system

Water-cooling system is applied to cool the solar hood, water cooling plate, and multiple lens units. As shown in Figure 2, the water cooling system is a closed cycle, and contains pump, heat exchanger, filter, tank, valves and pipes, etc. The pump can provide the power of the cycle, and the heat exchanger can cool the water in the system, and the tank can stabilize the pressure and supply water when turn on the pump.

2.3. Refrigeration system

Refrigeration system contains pumps, refrigeration module, tanks, valves and pipes, as shown in the Figure 3, which can provide cold water to the heat exchangers of the wind-cooling system and water-cooling system to take away the heat from the solar simulator.
3. Modeling
The wind cooling system not only need take away all the heat of the xenon lamps, but also need ensure the cooling effect of every xenon lamp, especially the temperature and velocity around every xenon lamp. As the requirement of the solar simulator, the temperature of the xenon lamp should be lower than 503 K, and the velocity around xenon lamp should be faster than 17 m/s, and the temperature of the collector should be lower than 323 K. So the cooling effect should be numerical simulated, and the medium is GN2, the flow rate of the GN2 is 11000 m$^3$/h, the thermal load of the xenon lamps is 45 kw, and the thermal load of the collectors is 5 kw.

3.1. Mathematical modeling
The GN2 of the wind cooling system is restricted by the laws of conservation of mass, momentum and energy [4, 5].

$$\frac{\partial \rho}{\partial t} + \frac{\partial}{\partial x_i}(\rho u_i) = 0$$  \hspace{1cm} (1)

$$\frac{\partial}{\partial t}(\rho u_i) + \frac{\partial}{\partial x_j}(\rho u_i u_j) = \frac{\partial}{\partial x_j} \left( -\rho u_i u_j \right) + \frac{\partial p}{\partial x_j} + \mu \left( \frac{\partial u_i}{\partial x_j} + \frac{\partial u_j}{\partial x_i} - \frac{2}{3} \delta_{ij} \frac{\partial u_k}{\partial x_k} \right)$$  \hspace{1cm} (2)

$$\frac{\partial}{\partial t}(\rho E) + \frac{\partial}{\partial x_j} \left[ u_j (\rho E + p) \right] = \frac{\partial}{\partial x_j} \left[ \lambda \left( \frac{\partial T}{\partial x_i} \right) \right] + \mu \left( \frac{\partial u_i}{\partial x_j} + \frac{\partial u_j}{\partial x_i} + \frac{2}{3} \delta_{ij} \frac{\partial u_k}{\partial x_k} \right)$$  \hspace{1cm} (3)

3.2. Mesh of the solar simulator
The solar simulator contains 13 xenon lamps is analysed as the model, and the mesh is shown in Figure 4 and Figure 5.

**Figure 3.** Flowchart of the refrigeration system

**Figure 4.** The mesh of the solar hood.
Figure 5. The mesh around the xenon lamp.

4. The result of the calculation
The flow in the solar hood is simulated by the FLUENT software [6, 7], the distribution of the velocity in the solar hood and around the xenon lamp are shown in Figure 6 and Figure 7. Most velocity in the solar hood is very slow, but because the area of the channel suddenly becomes smaller, the velocity near the xenon lamp increases significantly. The increase of the velocity can enhance the convective heat transfer on the surface of the xenon lamp, which is helpful to carry away the heat of the xenon lamp and the collector.

Figure 6. The distribution of velocity in the solar hood.

Figure 7. The distribution of velocity around the xenon lamp.

The velocity along the xenon lamp is shown in Figure 8. Because of the shape of the xenon lamp, the front velocity and the back velocity on the surface of the xenon lamp is slow, but most velocity on the surface of the xenon lamp is higher than 17 m/s.
The distribution of the velocity on the surface of the xenon lamp is shown in Figure 8. The heat flux density of the xenon is high. The velocity near the xenon lamp is fast, so the convective heat transfer coefficient on the surface of the xenon lamp is large, which is conducive to the heat exchange between the xenon lamp and the gas.

The temperature along the surface of the xenon lamp is shown in Figure 9. Because the front velocity is faster, the convective heat transfer coefficient is larger, and the temperature of the gas is cooler, which makes the front temperature of the xenon lamp cooler. The back velocity is slower which makes the convective heat transfer coefficient smaller, and the gas temperature is higher after absorbing the heat of the xenon lamp and the collector, so the back temperature of the xenon is higher. As shown in the Figure 9 and Figure 10, the maximum temperature of the xenon lamp is 330 K, and the maximum temperature of the collector is 308 K, which meet the temperature requirement.
Figure 10. The temperature along the surface of the xenon lamp

5. Conclusion
The cooling system for solar simulator was introduced, and the wind-cooling system is numerical simulated by the Fluent. The simulation result show that, when the flow rate of the GN2 was 11000 m$^3$/h, the thermal load of the xenon lamps was 45 kw, and the thermal load of the collectors was 5 kw, the velocity of the most area in the solar hood was slow, but the area near the xenon lamp, because the flow area suddenly decreases, the velocity of the gas increased significantly, which make the convective heat transfer coefficient on the surface of the xenon large. The xenon is the main equipment generating heat, and the heat flux density of the xenon lamp is high, but the convective heat transfer coefficient is high, which is conducive to the heat exchange between the xenon lamp and the gas, and the temperature of the xenon lamp is lower than 328 K, and the velocity on the surface of the xenon lamp is higher than 17 m/s, and meet the operating requirement of the xenon lamp. The velocity near the collector is low, which made the convective heat transfer coefficient low, but the heat flux density of the collector is low, the temperature of the collector is lower than 308 K, and meet the operating requirement of the collector.

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