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Experiment and Simulation Study on Silicon Oil Immersion Cooling Densely-Packed Solar Cells Under High Concentration Ratio

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Abstract: In order to solve the heat dissipation problem of densely-packed solar cells in high concentration photovoltaic (HCPV) system, a new cooling method of using silicon oil directly immerse the solar cells was proposed. The heat transfer performance of silicon oil immersion cooling the densely-packed solar cells with and without fin structure was investigated through experiment and simulation methods. The results of heat transfer performance of solar cells without fin structure showed that the simulated data was consistent well with data of experiment and the temperature could be lowered down in the operation range of solar cell. Furthermore, the heat transfer performance of solar cells with fin structure was researched using the model under different silicon oil inlet temperatures, inlet flow rates and the flow pressure drop was measured. The results indicated that the solar cells temperature declined and distributed well with silicon oil inlet flow rate increasing but the solar cells temperature raised linearly with silicon oil inlet temperature increasing. The optimized parameters of cooling receiver with fin structure were that: height of fin was 14 mm, number of fin was 50 and the thickness of substrate was 1.5 mm, with which the large amount of heat of densely-packed solar cells under high concentration ratio could be well controlled and make sure the power generation of HCPV system was high efficient.

Keywords: High Concentration Ratio, Densely-Packed Solar Cells, Silicon Oil, Immersion Cooling, Fin Structure

1. Introduction

With the development of photovoltaic technology and solar cells, the high concentration photovoltaic (HCPV) played an important role in power generation system. However, the thermal management of solar cells is an important issue need to be dealt with. Significant researches have been dedicated to cool HCPV system as reviewed in literatures [1-5]. It has been shown that the low system thermal resistance was difficult to satisfy because of the presence of traditional wall resistance between solar cells and heat sinks with conventional cooling approaches.

A new cooling method of direct contact liquid immersion cooling was proposed [6] to cool the solar cells in CPV system. With direct contact liquid immersion cooling, the bare solar cells were immersed in the circulating liquid directly. Thus, the traditional wall resistance between solar cells and heat sinks was eliminated to the boundary layer interface between the bulk liquid and the solar cells surface. Furthermore, the direct contact liquid immersion cooling provides an opportunity for heat to be taken away from both the upper and lower solar cells surface, which increased the heat transfer area by contrast with former cooling approaches. Our former study focus on liquid direct immersion cooling lower and medium CPV systems [7-13], furthermore, the attempt of using water immersion solar cells under 250X in dish CPV system had been done [14-15]. However, the water has some disadvantages and the proper immersion liquid was silicon oil [13, 16], meanwhile, the heat transfer performance of silicon oil direct immersion cooling solar cells under high concentration ratio has not been reported in literatures.

In this paper, silicon oil was chosen as immersion liquid to direct contact cooling the simulated solar cells model without fin structure. The heat transfer performance was investigated through numerical simulated and experimental methods, meanwhile, the CFD model was validated. Then the heat transfer performance of triple-junction solar cells model with fin structure was characterized by simulation method. Finally, the parameters of direct contact liquid immersion cooling receiver were optimized by simulation using the solar cells temperature and receiver pressure drop as evaluated targets.

2. Experimental

2.1. Experimental Setup and Procedure

Silicon oil was chosen as immersion liquid based on our former research. A stainless steel plate was designed to simulate the densely-packed solar cells and the electrical heated power of the plate simulated the solar concentration ratio under the premise that the power generation efficiency of triple-junction solar cells is 39.8% [17]. The liquid immersion receiver consisted of an electrical heating plate (EHP), two copper rods welded on EHP and flowing channel shaped by two iron plates and two teflon plates. The EHP consisted of four stainless plates with 40 mm length, 10 mm width, 0.28 mm thickness and 1 mm gap between each other. The flowing channel was 40 mm wide, 3.28 mm high and 200 mm long.

The silicon oil was pumped from the liquid tank and flew through the rotor flowmeter and injected in the liquid immersion receiver, and finally was driven back to the storage tank, in which there was a coil cooler to make sure the inlet temperature of silicon oil was fixed. The inlet flow rate of silicon oil was adjusted by a valve, and the temperature of simulated densely-packed solar cells was measured by K-type thermocouples that welded on the EHP surface. The experimental setup was shown in Fig. 1.

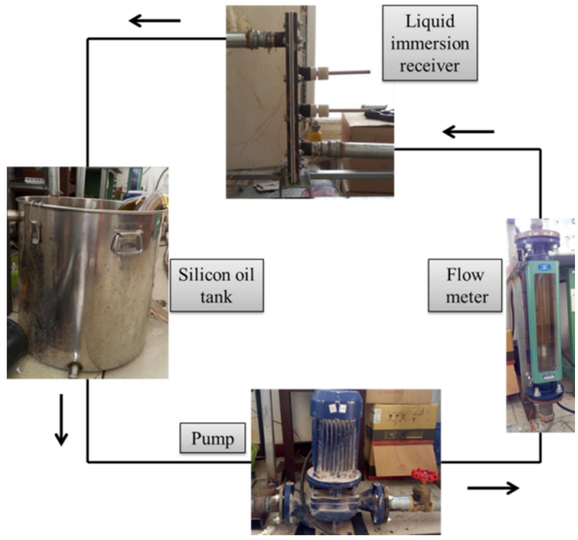

Fig. 1. *The experimental setup.*

2.2. CFD Models

The CFD model of liquid immersion receiver with simulated densely-packed solar cells without fin structure was designed, as Fig. 2a shown. The geometry dimension of receiver was 128 mm×24 mm×12 mm, the thickness of up and down flow channels was both 5.0 mm.

The CFD model of liquid immersion receiver with 64 triple-junction solar cells were densely-packed as 8×8, which were welded on the Aluminum substrate after insulation treatment. The geometry dimension of was 100 mm×100 mm×15.7 mm. Some fins were arranged on the back of substrates for heat dissipate enhancement, as shown in Fig. 2b.

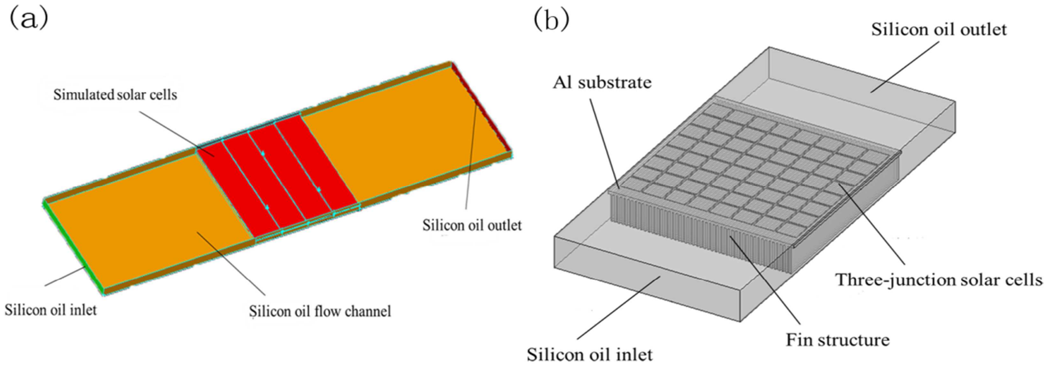

Fig. 2. *(a) The CFD model of liquid immersion receiver with simulated densely-packed solar cells without fin structure, (b) the CFD model of liquid immersion densely-packed solar cells with fin structure.*

3. Results and Discussion

3.1. Validation of Numerical Simulated Model

The temperature contour of simulated densely-packed solar cells was shown in Fig. 3a when inlet flow rate and temperature of silicon oil was fixed at 4.2 m^3/h and 50°C, respectively. It can be seen that the temperature of the main body was relatively uniform, the highest temperature was 70.31°C and the average temperature was 63.32°C. However, the temperature of the edge varied greatly, there was obvious temperature gradient along the flowing direction of silicon oil.

Because the flow condition of silicon oil was changing by the contact and detachment of silicon oil and simulated solar cells in the edge, the heat transfer was enhanced by the local fluid disturbance, leading to lower temperature in the edges. Hence, the edge effect was a main factor to consider when the liquid immersion receiver was developed. The comparison of simulated and experimental temperature under same condition was shown in Fig. 3b, which illustrated that the results kept well and there were only 2°C to 3°C temperature differences. Thus, it was reasonable and feasible to investigate the heat transfer performance of liquid immersion cooling densely-packed solar cells by numerical simulation method.

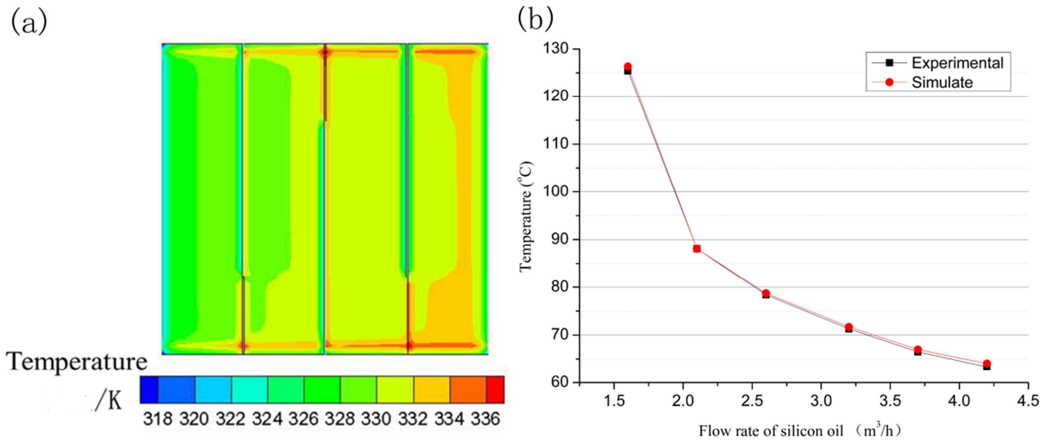

Fig. 3. *(a) The temperature contour of simulated densely-packed solar cells, (b) the comparison of simulated and experimental results.*

3.2. Heat Transfer Performance of Silicon Oil Immersion Cooling

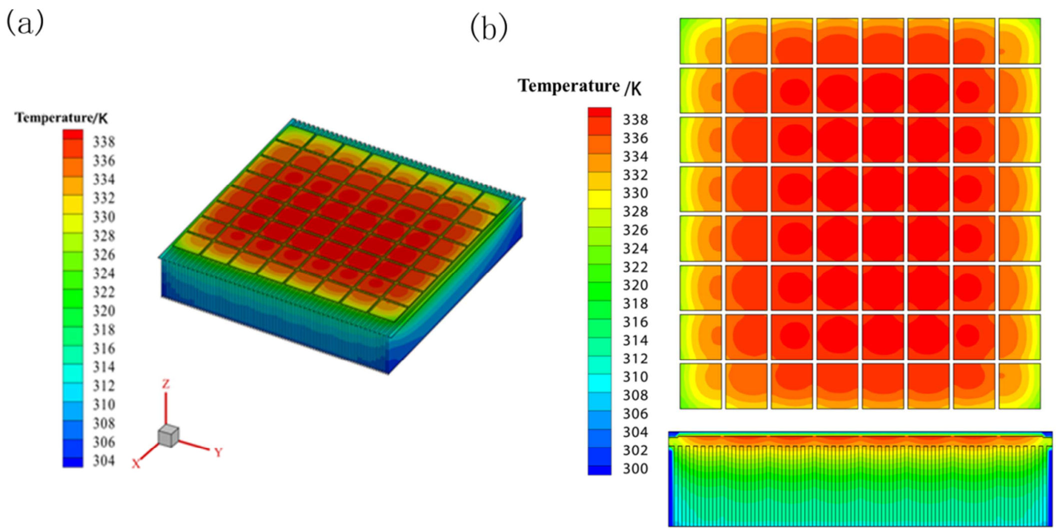

Fig. 4. *(a) The temperature distribution of solar cells model, (b) the positive surface and axial temperature distribution of solar cells model.*

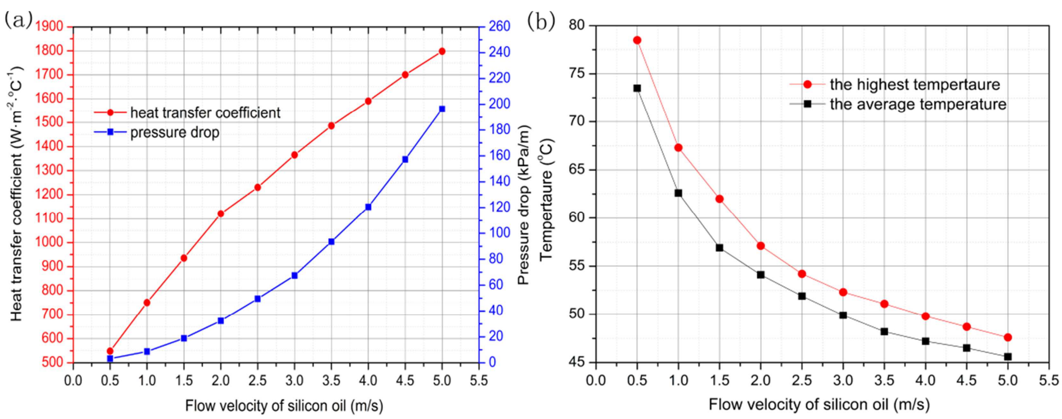

Fig. 5. *The heat transfer performance of solar cells model with different silicon oil flow velocities.*

The temperature distribution of densely-packed triple-junction solar cells with fins structure were shown in Fig. 4 when inlet flow velocity and temperature of silicon oil was 1.0 m/s and 25°C, respectively. The thickness of aluminum substrate was 1.5 mm, the height and amount of fins were 14 mm and 50, the thickness of liquid layer was 1.0 mm and the concentration ratio was 500X. The negative direction of X axis was silicon oil flowing direction. It can be seen that the highest temperature was lower than 70°C and the temperature distributed well uniform.

The varying trend of average temperature, highest temperature, heat transfer coefficient and pressure drop with silicon oil inlet flow velocity increasing was shown in Fig. 5. It was shown that the highest temperature was lower than 70°C, the average temperature was 63°C, the heat transfer coefficient was 750 W/(m^2 °C) and the pressure drop was lower than 10 kPa/m when inlet flow velocity and temperature of silicon oil was 1 m/s and 25°C. In order to further testify the heat transfer performance of silicon oil immersion cooling, the inlet flowing condition varied from 0.5 m/s to 5.0 m/s. The results showed that highest and average temperature decreased with inlet flow velocity increasing. The heat transfer coefficient and pressure drop increased with inlet flow velocity increasing. The direct contact of silicon oil and solar cells eliminated the traditional wall resistance and the heat transfer coefficient was improved from 451 W/(m^2 °C) at 0.5 m/s to 1800 W/(m^2 °C) at 5.0 m/s. However, the parasitic energy consumption increased with inlet velocity increasing, so the proper flow velocity of silicon oil was important for direct contact liquid immersion cooling receiver.

The varying trend of solar cells temperature with inlet temperature was shown in Fig. 6. It showed that the temperature of solar cells increased linearly with inlet temperature increasing. The temperature of solar cells increased from 26°C to 97°C when inlet temperature increased from -15°C to 65°C. The maximum temperature difference was within 4°C to 5°C under fixed inlet temperature, the reason of which was the liquid turbulence played a main factor in influencing the heat transfer. Thus, the lower inlet temperature was reasonable and better to obtain lower solar cells temperature.

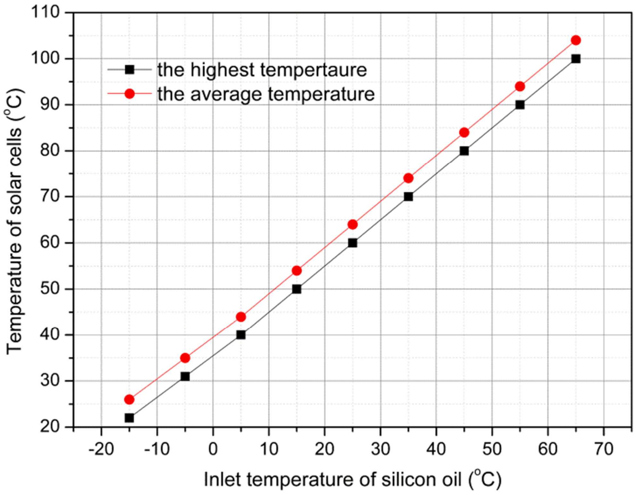

Fig. 6. *The temperature of solar cells model under different silicon oil inlet temperatures.*

3.3. Optimization of Silicon Oil Immersion Cooling Receiver

The thickness of liquid layer, fins structure and substrate thickness were main parameters of liquid immersion cooling receiver. The lower solar cells temperature and lower parasitic energy consumption were targets to optimize the parameters of receiver under concentration ratio of 500X.

3.3.1. The Effect of Liquid Layer Thickness

The thickness of liquid layer should be less than 6.3 mm when using silicon oil as immersion liquid according to our former research results [13]. The heat transfer performance and pressure drop were measured when liquid thickness ranged between 1 mm and 5 mm, the results were shown in Fig. 7. It can be seen that the temperature decreased with liquid layer thickness increasing and the thickness of the receiver increased with the liquid layer thickness increasing and the pressure drop decreased, which would decreased the parasitic energy consumption under fixed inlet flow velocity. Considering the results, the proper liquid layer thickness was 1 mm.

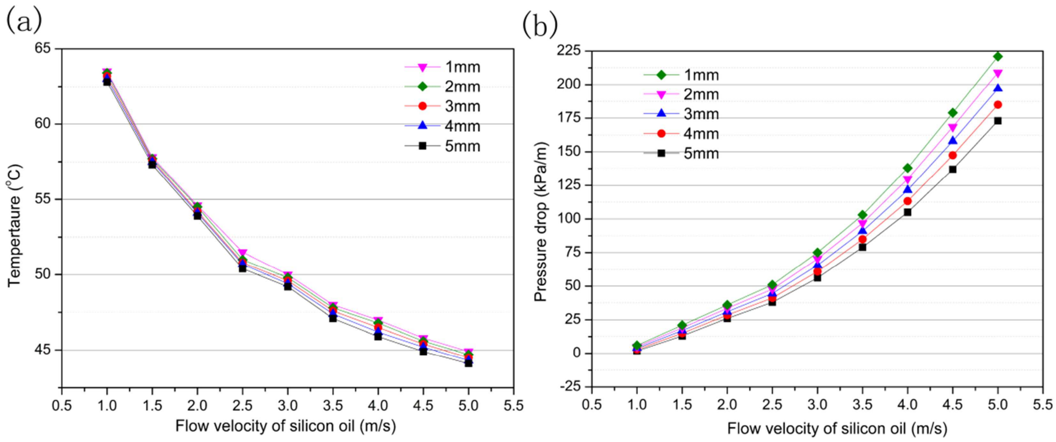

Fig. 7. *The solar cells temperature and pressure drop under different liquid thickness.*

3.3.2. The Effect of Height of Fins

The height of fins effect on solar cells temperature and pressure drop were evaluated under different inlet velocities of silicon oil. The height of fins ranged between 6 mm and 22 mm. The results were shown in Fig. 8.

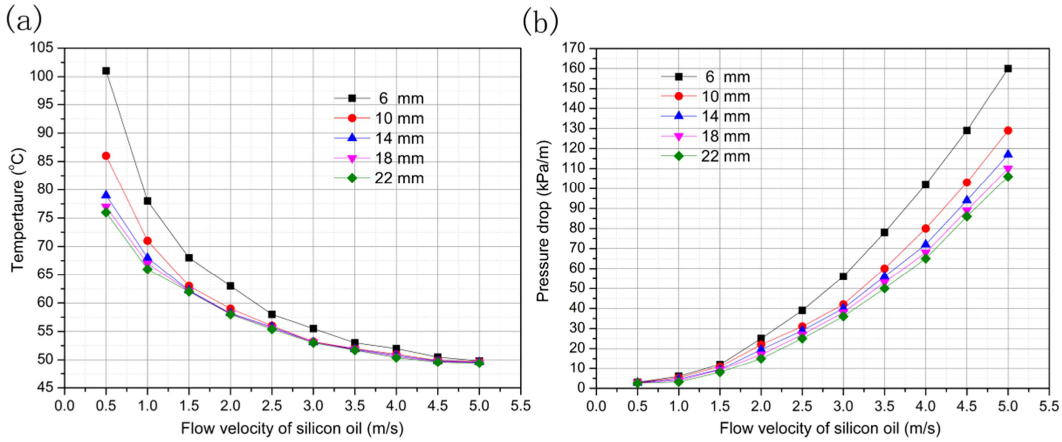

Fig. 8. *The solar cells temperature and pressure drop under different height of fins.*

It was shown that the solar cells temperature decreased from 100°C to 76°C with the fins height increased from 6 mm to 22 mm under inlet velocity was 0.5 m/s. The pressure drop decreased from 160 kPa/m to 107 kPa/m with the fins height increased from 6 mm to 22 mm under inlet velocity was 0.5 m/s. However, the decreased degree of temperature and pressure drop was not obvious when height of fins reached 18 mm and 22 mm, under which the velocity effect on solar cells temperature was little. Thus, the reasonable height of fins was 14 mm considering the solar cells temperature and pressure drop.

3.3.3. The Effect of Fins Amount

The effect of fins amount on temperature and pressure drop were measured under different inlet velocities. The fins amount ranged between 33 mm and 83 mm. The results were shown in Fig. 9. It was shown that the solar cells temperature decreased with fins amount increasing, the temperature decreased from 93°C to 48°C with fins amount increased from 33 mm to 83 mm under inlet velocity was 0.5 m/s/. The pressure drop increased with fin amount and silicon oil flow velocity increasing, but the pressure drop increased sharply when fins amount was higher than 50. The main reason was the heat transfer area increased with fins amount increasing but the liquid turbulence condition was also affected, which raised the parasitic energy consumption. Thus, the reasonable amount of fins was 50 considering the solar cells temperature and pressure drop.

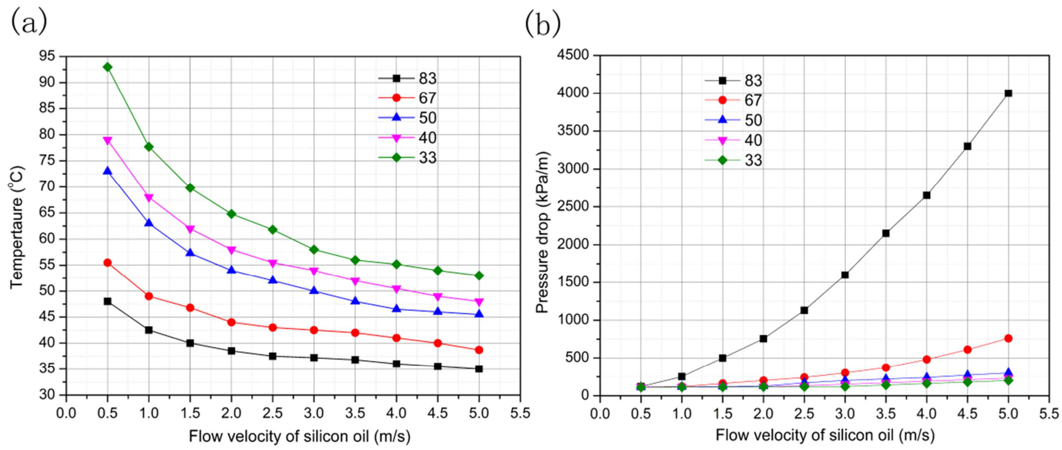

Fig. 9. *The solar cells temperature and pressure drop under different amount of fins.*

3.3.4. The Effect of Substrate Thickness

The effect of substrate thickness on temperature and pressure drop was measured under different inlet velocities. The substrate thickness ranged between 0.5 mm and 2.5 mm. The results were shown in Fig. 10. It can be seen that the solar cells temperature and pressure drop changed little with substrate thickness varying, which meant the main function of substrate was support for densely-packed solar cells and 1.5 mm was proper substrate thickness.

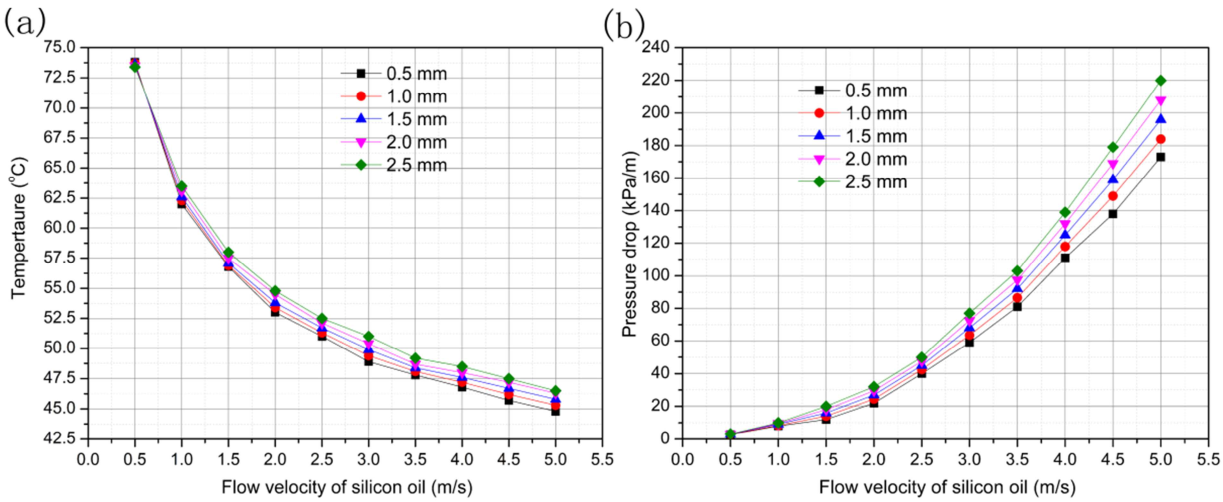

Fig. 10. *The solar cells temperature and pressure drop under different substrate thickness.*

Above all, the optimized parameters of liquid immersion cooling receiver were listed as follow: the thickness of liquid layer was 1.0 mm, the height and amount of fins were 14 mm and 50, the substrate thickness was 1.5 mm. The optimized silicon oil immersion cooling receiver would make sure the temperature of densely-packed solar cells distributed well uniform under 500X.

4. Conclusions

This paper mainly focused on the heat transfer performance of simulated densely-packed solar cells and optimization of liquid immersion cooing receiver. The conclusions were shown as follow.

1 The temperature could be controlled properly in the working range when using silicon oil to cool simulated solar cells model without fins structure under high concentration ratio. The results of simulated and experimental temperature of simulated densely-packed solar cells model were consisted well, which validated that the numerical simulation method was feasible to investigate the heat transfer performance of silicon oil direct immersion cooling solar cells.

2 The simulated results of densely-packed solar cells models with fins structure showed well temperature uniform. The temperature decreased and pressure drop increased with silicon oil inlet flow rate increasing. The model temperature increased linearly with silicon oil temperature increasing.

3 The direct contact liquid immersion cooling receiver was optimized using numerical simulated method. The optimized parameters were as follow: the thickness of liquid layer was 1 mm, the height and amount of fins was 14 mm and 50, the substrate thickness was 1.5 mm. The solar cells temperature distributed well uniform and relatively lower pressure drop when using the liquid immersion receiver for cooling densely-packed solar cells under 500X.

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References

[1] Royne A, Dey CJ, “Design of a jet impingement cooling device for densely packed PV cells under high concentration,” Solar Energy, 81, pp. 1014-1024 (2007).

[2] Xu Z, Kleinstreuer C, “Computational Analysis of Nanofluid Cooling of High Concentration Photovoltaic Cells,” Journal of Thermal Science and Engineering Applications, 6, (2014).

[3] Geng wg, Gao L, Shao M, Li Xy, “Numerical and experimental study on cooling high-concentration photovoltaic cells with oscillating heat pipe,” International Journal of Low-Carbon Technologies, 7, pp. 168-173 (2012).

[4] Reeser A, Wang P, Hetsroni G, Bar-Cohen A, “Energy Efficient Two-Phase Microcooler Design for a Concentrated Photovoltaic Triple Junction Cell,” Journal of Solar Energy Engineering, 136, (2014).

[5] Barrau J, Perona A, Dollet A, Rosell J, “Outdoor test of a hybrid jet impingement/micro-channel cooling device for densely packed concentrated photovoltaic cells,” Solar Energy, 107, pp. 113-121 (2014).

[6] Wang Y, Fang Z, Zhu L, Huang Q, Zhang Y, Zhang Z, “The performance of silicon solar cells operated in liquids,” Applied Energy, 86, pp. 1037-1042 (2009).

[7] Han X, Wang Y, Zhu L, “The performance and long-term stability of silicon concentrator solar cells immersed in dielectric liquids,” Energy Conversion and Management, 66, pp. 189-198 (2013).

[8] Han X, Wang Y, Zhu L, Xiang H, Zhang H, “Reliability assessment of silicone coated silicon concentrator solar cells by accelerated aging tests for immersing in de-ionized water,” Solar Energy, 85, pp. 2781-2788 (2011).

[9] Han X, Wang Y, Zhu L, Xiang H, Zhang H, “Mechanism study of the electrical performance change of silicon concentrator solar cells immersed in de-ionized water,” Energy Conversion and Management, 53, pp. 1-10 (2012).

[10] Liu L, Zhu L, Wang Y, Huang Q, Sun Y, Yin Z, “Heat dissipation performance of silicon solar cells by direct dielectric liquid immersion under intensified illuminations,” Solar Energy, 85, pp. 922-930 (2011).

[11] Sun Y, Wang Y, Zhu L, Yin B, Xiang H, Huang Q, “Direct liquid-immersion cooling of concentrator silicon solar cells in a linear concentrating photovoltaic receiver,” Energy, 65, pp. 264-271 (2014).

[12] Xiang H, Wang Y, Zhu L, Han X, Sun Y, Zhao Z, “3D numerical simulation on heat transfer performance of a cylindrical liquid immersion solar receiver,” Energy Conversion and Management, 64, pp. 97-105 (2012).

[13] Xin G, Wang Y, Sun Y, Huang Q, Zhu L, “Experimental study of liquid-immersion III–V multi-junction solar cells with dimethyl silicon oil under high concentrations,” Energy Conversion and Management, 94, pp. 169-177 (2015).

[14] Zhu L, Boehm RF, Wang Y, Halford C, Sun Y, “Water immersion cooling of PV cells in a high concentration system,” Solar Energy Materials and Solar Cells, 95, pp. 538-545 (2011).

[15] Zhu L, Wang Y, Fang Z, Sun Y, Huang Q, “An effective heat dissipation method for densely packed solar cells under high concentrations,” Solar Energy Materials and Solar Cells, 94, pp. 133-140 (2010).

[16] Krauter S, “Increased electrical yield via water flow over the front of photovoltaic panels,” Solar Energy Materials and Solar Cells, 82, pp. 131-137 (2004).

[17] Tianjin Lantian Solar Technology Limited Company, www.tjsolartech.com.