Efficient energy harvesting by switchable terrestrial solar heating and radiative cooling

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Introduction

The hot sun (~6000K) and the cold universe (~3K) are the ultimate heat sources and heat sinks for the Earth, and they can be regarded as huge renewable resources for clean heat and cool harvesting. In the past, most reported works focused on energy harvesting from the hot sun or the universe, including solar heating and radiative cooling. Interestingly, a new concept that simultaneously harvests energy from the hot sun and the cold universe is proposed to achieve efficient renewable energy utilization, which relies on adaptive absorbers/emitters, Janus structures, and spatially coupled devices.

Harvesting energy from both the hot sun and the universe is a new topic for the renewable energy field, and thermodynamic analysis is urgently needed. In this work, a thermodynamic analysis is conducted for the terrestrial solar heating and radiative cooling process, considering the effect of atmospheric radiation and dynamic spectrum properties.

Thermodynamic Analysis

A thermodynamic analysis model is developed for the terrestrial solar heating and radiative cooling process. Fig. 1 shows the thermodynamic schematic of energy harvesting from the sun and the universe. In solar heating mode, the solar absorber is fixed between the sun and the Carnot engine to absorb solar irradiance for power generation, with waste heat dissipated into the surroundings. In radiative cooling mode, the radiative emitter is fixed between the universe and the Carnot engine to radiate waste heat from the Carnot engine into the universe, and the surroundings are regarded as a heat source. During model development, several assumptions are made: i) Spectral-dependent spectral properties of the absorber and emitter are considered, and ii) the Earth's temperature is constant since the heat capacity of the Earth is huge.

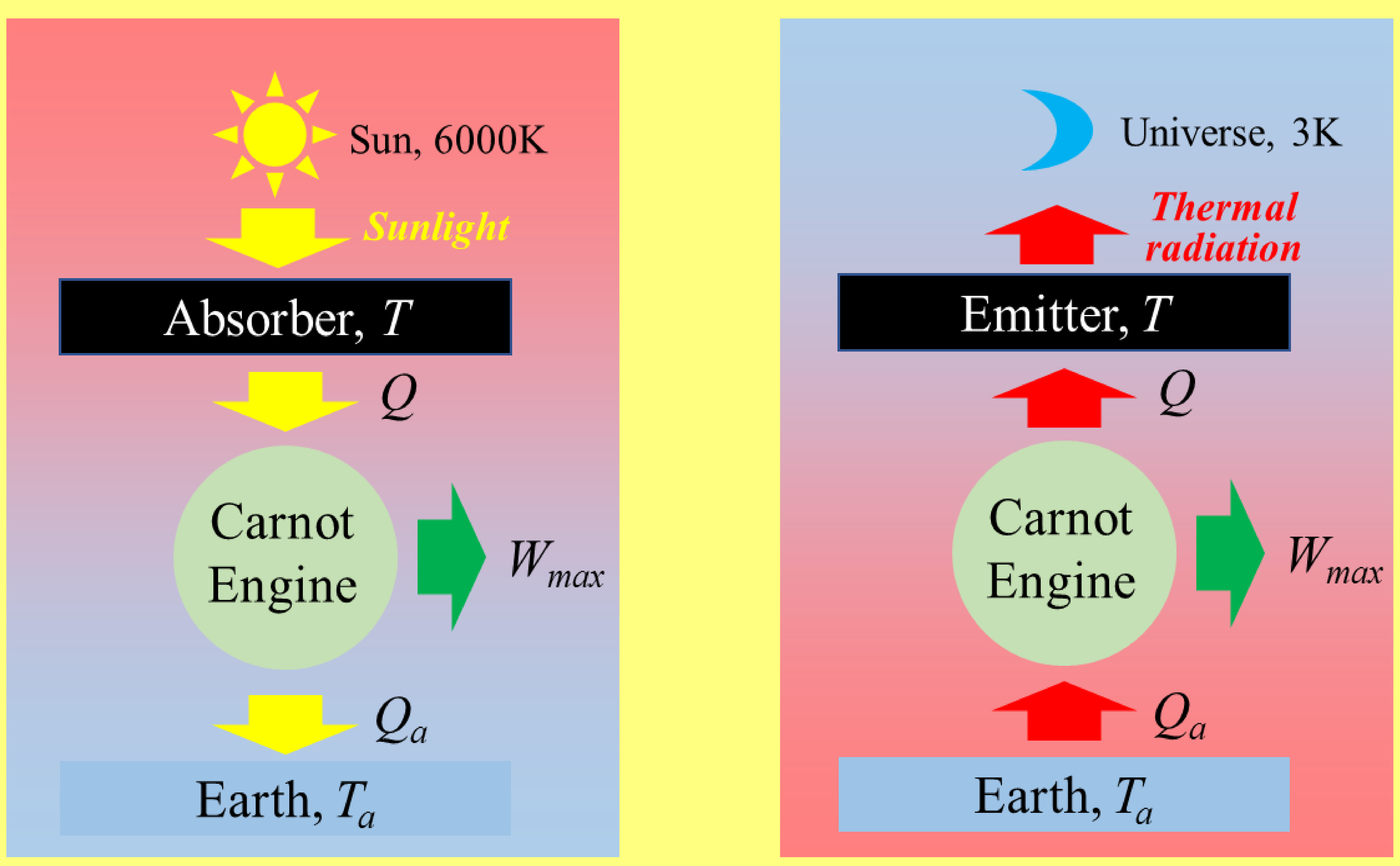

Fig.1. Thermodynamic schematic of energy harvesting from the sun and universe.

Two different kinds of ideal surfaces are selected for thermodynamic analysis, including blackbody (BB) and switchable spectrum emitter (SSE). The spectral properties of the above surfaces are shown in Table 1 (SSE-SH and SSE-RC denote the switchable spectrum emitter that works on solar heating and radiative cooling mode). During simulation, the ambient temperature is set to 300 K, solar irradiance is set to 1000 W·m^{-2}, and atmospheric transmittance under Mid-latitude winter is applied.

Table 1: Spectral properties of the SSE and BB.

	Spectral emissivity(absorptivity)			
	0.3-3 μm	3-8 μm	8-13 μm	13-25 μm
BB	1	1	1	1
SSE-SH	1	0	0	0
SSE-RC	0	0	1	0

As shown in Fig. 2a, it can be found that the SSE-SH exhibits a better performance than the BB due to the low thermal emissivity. The maximal output power of the SSE-SH reaches 398.4 W·m^{-2} and a conversion efficiency of nearly 39.8% at the surface temperature of approximately 542 K, while that of the BB is just 75.2 W·m^{-2} with a conversion efficiency of 7.5% at the surface temperature of about 350 K, showing a relative difference of nearly 430%. Fig. 2b presents the output power in radiative cooling mode, and it is seen that the SSE-RC is superior to that of the BB. The maximal output powers (corresponding temperature) of the SSE-RC and BB are 4.3 W·m^{-2} (273 K) and 1.8 W·m^{-2} (290 K). The current mode is more appropriate for terrestrial weather conditions and general materials.

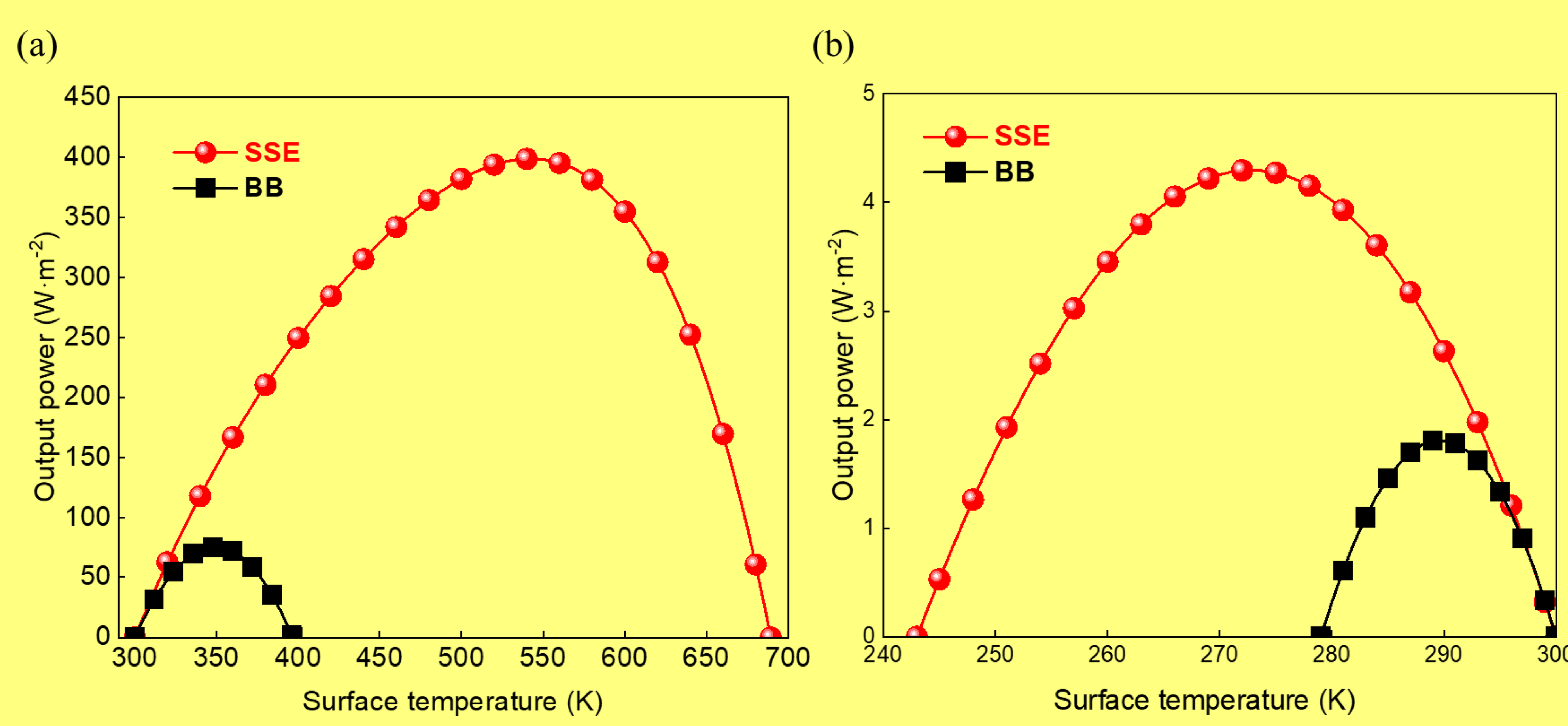

Fig.2. Thermodynamic schematic of energy harvesting from the sun and universe.

Acknowledgements

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