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Advances in low to medium temperature non-concentrating solar thermal technology

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ABSTRACT

Solar thermal applications are an emerging technology with increasing attention in the renewable energy research for their high energy conversion efficiency and energy storage density. The scope of this review is to demonstrate the state-of-the art non-concentrating solar thermal systems. This paper begins by describing the current design criteria and material selection followed by different research results, including their limitations, financial benefits and possible improvements.

1. Introduction

The solar energy widely used since ancient time by the Greeks and Chinese to orient their buildings towards the south to gain access to light and passive heating [1]. The solar power is at the front of an energy revolution which is bound to change power generation in the coming years. Passaro [2] stated that the geopolitical unstable supply area or supply lines and increasing trend of environmental awareness are putting strains on traditional energy use. As a result, the demand for renewable energy sources is increasing. The world total renewable power capacity is 1849 GW [3].

The annual average energy use per capita, considering a human population of 7 billion, is 23.25 MW h a year [1]. Today the world's energy use is approaching 14,000 Mtoe [4]. EIA [5] projects 48% increases in world energy consumption by 2040. As supply rises, GHG emissions from fossil fuels have increased each year since the IPCC 2001 third assessment report (TAR) [6]. Without introducing effective policy, the combustion related GHG emissions will increase by 50% in 2030 and Mitigation will become more challenging [7]. Today solar thermal (ST) is an indispensable and a crucial pillar of the present and future energy demand for heating and cooling. The non-concentrating solar thermal technology can reduce conventional fuel consumption and reduce peak electricity loads. Such system has unique and some specific benefits [8]:

(i) It leads to a direct reduction of primary energy consumption;
(ii) It can be combined with different type of back-up heat sources;
(iii) It does not lead to a significant increase in electricity demand, which could imply substantial investments to increase power generation and transmission capacities;
(iv) It is available nearly everywhere and can be largely modified depend on storage space and latitudes.
(v) It prices are highly predictable, since the largest part of the investment occurs at the construction stage, and therefore does not depend on future fuel price;
(vi) The life-cycle environmental impact of ST systems is extremely low.

The yearly global average heat power produced by per unit area, normal to the Sun's direction, is shown in Fig. 1.

Weiss et al. [10] estimated that the demand of solar thermal collector is growing by 20% per year. This system widely used in domestic hot water installations, heating of space/swimming pools, crop drying, cooking stoves, etc. In most cases, the annual solar thermal energy use depends on the collector working area, availability of the solar radiation throughout the year and type of solar collectors such as both glazed and unglazed systems. Most of the swimming pools in USA and Europe are used unglazed solar collectors that represented about 28 million m^2 in 2003.

However, by the end of 2014, an installed capacity of 410.2 GWth, corresponding to a total of 586 million square meters of collector area was in operation worldwide [11]. The breakdown of the cumulated operational capacity in 2014 by collector type is 22.1% glazed flat-plate collectors, 71.1% evacuated tube collectors, 6.3% unglazed water

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Nomenclature

I_T	total radiation incident on the tilted surface;
I_b	beam (or direct) radiation on a horizontal surface;
I_d	diffuse radiation on a horizontal surface;
I	total radiation on a horizontal surface (W/m^2);
G	solar intensity of solar radiation (W/m^2)
R_b	ratio of beam radiation on a tilted surface to beam radiation on a horizontal surface.
ρ_g	fraction of radiation incident on the ground which is reflected (0.2 for grass);
A	solar collector having a collector surface area (m^2)
$Q_c(t)$	solar radiation absorbed by the cover (W)
L	length (m)
e	thickness (m)
T	temperature (°C)
M	material mass (kg)
C	specific heat (J/kg K)
C_a	concentration ratio
V_w	wind speed (m/s)
N_u	Nusselt number
P_r	Prandtl number
G_r	Grashof number
R	radius of the cylindrical absorber (mm)
t	time (s)
CR	ratio of the area of the aperture to the area of the absorber
θ_{cpc}	half acceptance angle of CPC
I_{dr}	direct incident solar radiation (W/m^2)
Q_{abs}	solar radiation absorbed by the tube (W)
η_{opt}	optical efficiency
Q	heat (W)
C_p	specific heat at constant pressure (j/kg °C)
$\dot{m}$	mass flow rate (kg/s)
p	pressure (kPa)
R	molar gas constant (KJ/kmol K)
(−)	not available
*	approximate
MX	solid chemical reactant/liquid absorbent
G	gas reactant
p	equilibrium pressure of the solid–gas pair
R_i	reactants (endothermic part)
P_i	products (exothermic part of the reversible reaction)
d	interest/market discount rate (%)
N	number of years (equal instalments)
HST	hexagon shaped tubes
RST	round shaped tubes
ERST	extruded rectangular shaped tube
ETC	evacuated tube collector
AP	air passage
VT	vacuum tubular
VC	vacuum cusp
VHF	vacuum horizontal fin
VVN	vacuum vertical fin
HHF	horizontal half fin
VVF	vacuum vertical fin
HTF	heat transfer fluid
TC	thermal conductivity
SH	specific heat
HF	heat of fusion
MT	melting temperature
SM	storage material
WLSC	water level sorption capacity
HSC	heat storage capacity

Greek symbols

β	slope of the surface.
α	absorptance
ρ	reflectance
τ	transmittance
σ	Stefan-Boltzman's constant (W/m^2 K^4)
ε	emissivity
λ	fluid thermal conductivity (W K/m).
ψ	inclination angle
Δ	reaction

Subscripts

am	ambient
c	cover
r	receiver (cylinder tank)
m	mirror
sky	sky
w	water
a	area
l	loss
u	useful
abs	absorbed
rad	radiation
og	outer glass
conv	convection
cond	conduction
ig	inner glass
out	outlet
in	inlet
1	at the beginning
2	at the end
H	enthalpy
S	entropy
V	volume
λ	latent heat fusion
s	solid
liq	liquid
M	melting point

collectors, and 0.4% glazed and unglazed air collectors. The vast majority of the total capacity in operation was installed in China (289.5 GWth) at the end of 2014. According to Philibert and Podkanski [12], due to the high potential energy savings compared with conventional electric vapor-pressure air-conditioning systems, more than 100 commercial solar cooling systems with a cooling power of 9 MWth exist in Europe. The aim of this paper is to present a review of low to medium temperature non-concentrating solar thermal systems associated with the latest heat storage materials. The thermophysical properties of the heat storage material along with different heat storage methods and economic analysis are also discussed in this paper.

2. State-of-the art development stage

2.1. State of the art – before 2000

Khanna [13,14] studied design data of a heat exchanger for solar heating of air with natural and forced heat transfer modes and then constructed a shell-tube heat exchanger for use in drying a specific material and space heating of a living room. Ramsey et al. [15] developed a 122 cm×122 cm×15.2 cm collector for cooling of 93 °C inlet fluid temperature at a 27 °C ambient temperature and 1009 W/m^2 incident flux. The backside of the absorber plate of the collector has