A Comparison and Sustainability Analysis of Solar Thermal Receivers

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Abstract:
Solar Thermal receivers are major component in applications, such as solar water heater for generating hot water for commercial and domestic purpose, solar space heating, concentrating solar power, or solar assist heating, ventilation and air conditioning. There are evacuated tubes and aerogel based solar receivers. A receiver should ideally absorb and convert incident sunlight into heat. For high efficiency receiver should not loss much heat out of its boundary. However, some radiation and convection heat loss occur in every receiver. In this paper comparative analysis of two type high efficiency receiver, evacuated tube and aerogel receivers has been done based on the parameters like sustainability, effectiveness, efficiency, and life cycle. A mathematical model of each receiver has been developed with other comparison parameter. Upon analysis it could be predict that aerogel receiver more sustainable and overall impact than vacuum or evacuated type receiver. Aerogel receiver also gives flexibility of design, geometry and temperature.
Keywords: Solar Energy, Solar Thermal, Aerogel, Energy storage, Solar receivers

1. Introduction

Solar energy harness and utilization at thermal energy end is efficient and reliable, for that solar receivers used as converting device as solar radiation energy to thermal energy.Energy equation for heat transfer of two-dimensional fluid flow can be applied to measure efficiency, heat removal factor, overall heat loss coefficient [1]. Aerogels arematerials having thermal insulation characteristics and heat absorbertoday available in the market. They are resistant to fire and materials behave as glassoffering low values thermal conductivity as 0.012 to 0.018 W/mK without use of any vacuum or gas sealed systems[2]. The main disadvantages are high production costs and less matured with respect to commercialization of these absorbers [3]. But transparent characteristic of aerosol makes it choice to select as a solar thermal receiver. There are a couple of aerogel insulation materials of fibre reinforced type available within the commercial market, and therefore with decrease in production cost, the market share is predicted to increase [4].

The development of products like absorber with aerosol and vacuumed based receiver is highly interesting and there is scope of choice of selection. In this theme, the development and manufacturing of products having layers integrated with aerogel is highly recommended. Vacuumed receiver also got attention from last few years as receivers as they offers high heat carrying capacity with lowered loss[5]. Aerogel insulating material may be overlaidinto the airblockade or incorporated intostructureequipment, like window frames, door frames and masonry bricks. This incorporation methodprovidesan additional advantages of substrate to compensate for the aerogel insulation havinglessertensile strength and also reduce the number of operations required on the construction site[6]. In the present article,

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we have carried out comparison between evacuated and aerogel receiver based on parameter like sustainability, cost, efficiency, and life cycle.

2. Mathematical Modeling

2.1. Materials

Aerogel insulating mats or blankets which are commercially available are basically acomposite materialconstitute of silica aerogel, polymer fibres, glass fibres and carbon black. Typically, the aerogel mats are manufactured by pervade a fibre fleece with the support of silica precursor sol-gel.These mats are then gelled together and dried under the recommended environmental conditionwhich lead to the formation of aerogel. A naturally-occurring form of crystalline carbon,Graphite,which act as a thermal insulation, is added in gel to minimize radiative heat transfer with the surrounding. Another method of manufacturing of solid insulation mats is by compressing aerogel grains with an organic binder in addition offinely dispersed fibres[7-8]. They are generallyavailable in the commercial market in the form of rolls, and depending upon the amount of graphite added its colourvary from white to dark grey[9].

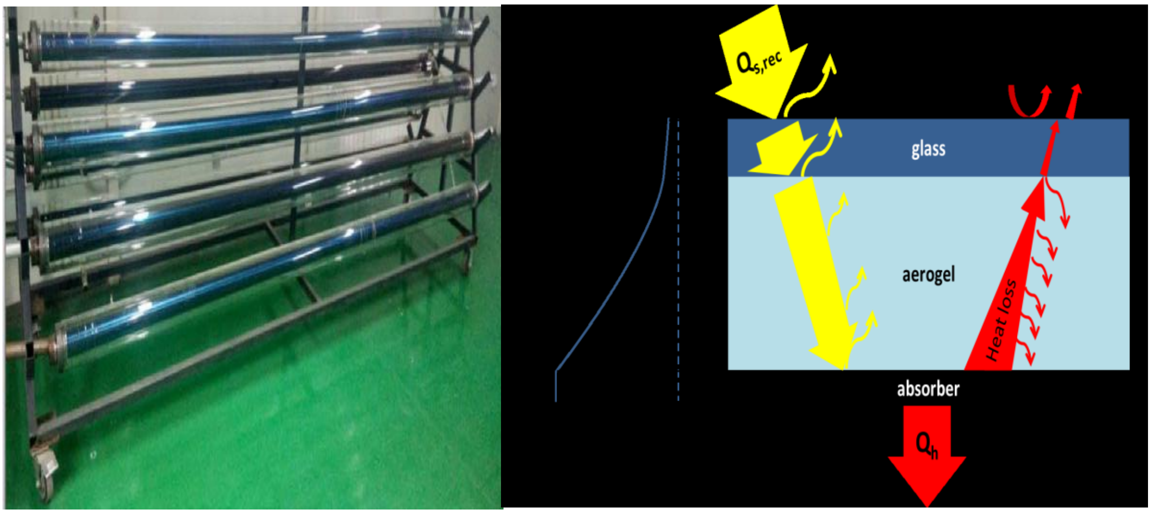

Fig. 1: Vacuum based receiver and aerogel based receiver[8,9]

2.2. Characterization

The material is having an apparent thermal conductivity λ W/mK which was measured with the help of a heat flow meter apparatus under the conditions defined in EN 12667 the governing standards [10]. The workpiece wastreated at the temperature of 10 ºC and relative humidity of 50 percent for a minimum period of 12 hours before the measurement of apparent thermal conductivity in the heat flow meter. Specimens were preparedhavingdimensions of 600 mm x 600 mm and were measured for each of the blankets of aerogel insulation. The sensor was employed in the gap size containing the specimen in the heat flow meter apparatus[11]. The gap size was set to the nominal thickness of the aerogel insulation blanket,thethermal conductivity of AB1 was determined. Since the nominal thickness was not reported by the manufacturer,the gap size for AB2 and AB3 was set according to measured thickness of specimen. By compressing the aerogel blankets in the heat flow meter apparatus in each steps of 0.2 mm, the effect of axial compression on thermal conductivity was measured for AB1 and AB2, and the thermal conductivity data was measured after achieving the steady-state [11].

2.3 Analysis Model:

A model based on comparison of two receivers vacuumed and aerogel developed:
Receiver efficiency can be defined as [8]:

$$\eta_{rec} = \frac{Q_h}{Q_{s,rec}} = \frac{Q_{abs} - Q_{loss}}{Q_{s,rec}} = \frac{Q_{abs} - Q_{loss}}{CQ_{sol}}$$

Where

Q_h is the heat deliver,

Q_{abs} is the sunlight absorb, and

Q_{loss}isthetotal of all thermal losses

CQ_{sol} = solar flux (standard) considering Airmass.

Overall effective absorptance is[11]:

$$\alpha_{eff} = \frac{Q_{abs}}{Q_{s,rec}}$$

Ideally, the radiation shieldsaresufficient to hide all the radiationenergy emitting from the absorber material; heat lost from the absorber material is the only heat conduction through the aerogel. The amount of sunlight is a decaying in exponentially to aerogel thickness when transmitted through the aerogel. The receiver efficiency can be calculate considering above concepts [12]

$$\eta_{rec} = \frac{Q_{s,rec} T_g e^{-\alpha_a L_a} \alpha_{abs} - k_a \frac{T_h - T_{g,i}}{L_a}}{Q_{s,rec}}$$

Where

T_g= transmittance of the glass,

T_a=aerogel's effective absorptance,

La = thickness of aerogel,

α_{abs} =absorptance of the absorber,

K_a=aerogel's thermal conductivity.

$T_{g,i}$ = temperature of glass's inside surface

Table 1: Comparative analysis of collectors [13–16]

Parameters	Glass based collector	Vacuum Collector	Aerosol Based collector
Efficiency (η)	30-35	60-80	70-85
Cost (Rs.)	5000-7000	25000-30000	15000-20000
Temperature range (°C)	60-90	100-300	80-200
Maturity	High	Medium	Low
Sustainability	High	High	High

3. Results and discussion

Based on the literature survey, we had developed the analysis on comparison of solar collectors including emerging aerogel based solar collectors. It is strong justification from Table 1 that aerogel-based collector highly efficient and low cost but still not matured till date to commercialize. However more research required on policy based is required especially in India. Because as potential indicates that solar energy harness at the end user levelcan be sustainable and very feasible solution to utlise solar throughout country.

These new and emerging technologies can be adapted directly in developing countries with modification in policies. It can also be said that application like solar water heater, air heater, industrial process heat, cooking etc. are needs integration with these solar collectors.

Furthermore, the average sustainability of all the collectors are high, so it is that all collectors follows the environmental standards, but cost and maturity defines.

4. Conclusion:

After analysis and comparison based on parameters taken like efficiency, sustainability and life cycle it is found that aerogel-based receivers are more competitive and potential to commercialize. This analysis and comparison will be useful when selecting and considering either the solar collectors individually or the whole system to identify base on need and availability of location.

As solar receivers are an essential component when considering the sustainabilitydesigns, and exergy analysisgives a moreaccurate performance evaluation and is one of theprovedmethods toassessand obtained the best possible configurations of these systems.

It can also be predicted that solar receivers based on aerogel could replace conventional evacuated tube type receivers, such as those evacuated tube type receivers used for domestic hot water and solar troughs which are having high-efficiency but the deciding factors will be reliability and price of system. Aerogel-based receivers provides the high efficiencysince they do not need to be evacuated, as in case associated with evacuated tube type receivers to additional form factor receivers as in case of panels.

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