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Solar air dehumidification systems

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Abstract. The solar air dehumidification system permits dehydration of air inside buildings using thermal energy. With thermal energy storage it is possible to organize the continuous process of air dehumidification even in the night time. Recently we have developed low cost solar concentrators that can be used for air dehumidification. The concentrators of this type contain a large number of flat triangle mirrors. The support frame for these mirrors has a shape of a parabolic dish. The experiments with two prototypes of flat mirror solar concentrators show that a stagnation temperature of more than 300ºC can be obtained. This temperature is sufficient to regenerate almost all desiccants that are used for air dehumidification. We estimate the cost of flat mirror concentrators in mass production as 20-30 USD per square meter. This cost permits creation of dehumidification systems for residential and district applications.

Key words

Air dehumidification, flat mirror solar concentrator, desiccant regeneration.

1. Introduction

Many tropical regions have such high air humidity that normal air conditioners cannot correct it to the normal level. In this case it is possible to use solar powered dehumidifiers [1], [2].

Special substances are used to eliminate the excessive humidity. Some of them have active surfaces that can adsorb the water vapour from the air. To regenerate the adsorption property of the substances, they need tube heated to high temperature. For this purpose it is possible to use hot air generated with a solar concentrator.

Another method of dehumidification is based on using water vapour absorbents. One of them is a concentrated water solution of $CaCl_2$. This absorbent extracts the water vapour from the air and decreases the concentration of the solution. To restore the solution concentration it must be heated. For heating we propose to use thermal energy obtained with solar concentrators and stored in thermal energy storage. One of the problems of the $CaCl_2$ solution is the necessity to obtain a large area of contact with the air with this solution. To obtain a large contact area normally the spraying method is used. But $CaCl_2$ solution is a very corrosive substance, moreover it is dangerous for human health.

In this article we propose a device that gives large contact area without spraying. So $CaCl_2$ crystals do not appear in the air.

Low cost flat facet solar concentrators and gravel based thermal energy storage are proposed for the dehumidification system feed.

2. Flat facet solar concentrator and thermal energy storage

We have developed several prototypes of flat facet solar concentrators [3], [4]. The main problem with these prototypes was the large number of bars and nodes in the concentrator support frame. The last prototype [5] was developed to avoid this drawback. It is shown in Fig. 1.

The support frame contains six triangular support cells. Each support cell has lower level and upper level triangles that are connected with vertical bars. The upper level triangle contains several parallel bars to support triangular flat mirrors. The vertices of the mirrors are placed on special adjustment nuts. The positions of the nuts are adjusted to approximate the parabolic dish shape. This is performed with a special parabolic gauge [6]. The spaces between the parallel bars form zones shown in

Fig.1. The number of zones is equal to the number of parallel bars in the upper level of the triangular cell.

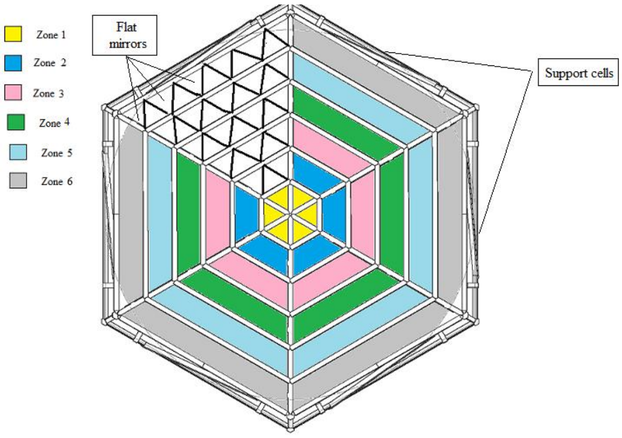

Fig.1. Solar concentrator prototype

To calculate the number of triangular mirror let us consider one sector of the concentrator (Fig.2).

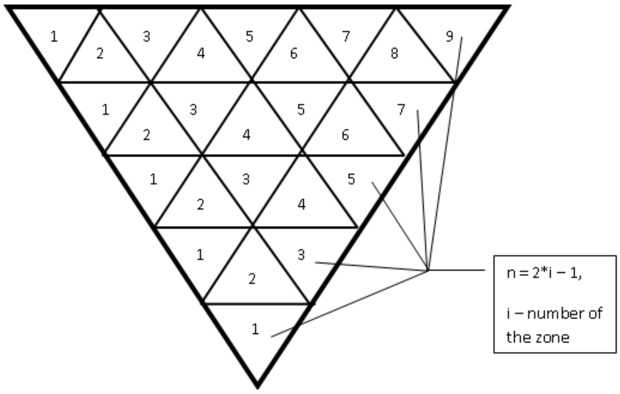

Fig. 2. Number of flat mirrors in one triangular sector

In this figure the triangular mirrors of each zone are sequentially numerated. It can be seen that the number of mirrors *n* in the *i*-th zone is equal to:

$$n = 2 * i - 1\,. \tag{1}$$

The total number of mirrors N_s in the sector that contains *Z* zones can be calculated as a sum of arithmetical progression:

$$N_s = (n_1 + n_Z) * \frac{Z}{2} = (1 + 2 * Z - 1) * \frac{Z}{2} = Z^2\,. \tag{2}$$

The number of sectors in the concentrator is 6. So the total number of mirrors in the concentrator is:

$$N = 6 * Z^2\,, \tag{3}$$

where *Z* is the zone number.

A rough estimation of the concentration rate (the coefficient of solar concentration) is possible based on the ideal brightness picture in the focal plane of the solar concentrator (Fig.3). In this ideal picture each triangular mirror gives in the focal plane triangle a bright imprint of size equal to the size of the triangular mirror. There are two possible orientations of the triangles (Fig.3). In the first orientation of the triangle has the upward position of the vertex.

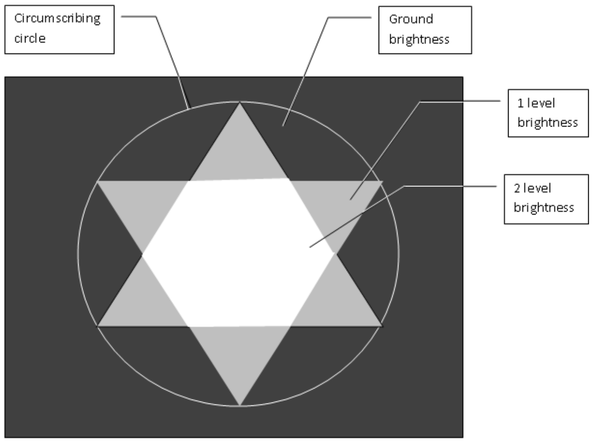

Fig.3. Brightness picture in the focal plane of solar concentrator

The second orientation is a downward position of the vertex. We calculate the concentrator brightness *S* as average brightness within the circumscribing circle of the picture in the focal plane (Fig.3). The diameter of the circumscribing circle is calculated as

$$d_{cc} = \frac{a}{\cos 30°} = \frac{2a}{\sqrt{3}}\,, \tag{4}$$

where *a* is a triangle mirror side. The area of one mirror can be calculated as

$$A_1 = \frac{\sqrt{3}}{4} * a^2\,. \tag{5}$$

The internal area of the circumscribing circle is

$$A_{cc} = \frac{\pi}{4} * d_{cc}^2 = \frac{\pi * a^2}{3} \tag{6}$$

If we consider an ideal mirror with reflection coefficient of 100% the average brightness from one mirror can be calculated from the equations (5) and (6) as:

$$B_1 = \frac{A_1}{A_{cc}} = \frac{3\sqrt{3}}{4\pi} = 0.414 \tag{7}$$

So the ideal concentration rate of one mirror in our concentrator is 0.414 suns. If the concentrator has a number of mirrors *N* (equation (3)) the concentration rate is

$$\gamma = 0.414 * N = 2.48 * Z^2 \text{ suns,} \tag{8}$$

where *Z* is the zone number.

For *Z*=3, *N*=54 and γ =22.4 suns. For *Z*=10, *N*=600, and γ =248.4 suns.

The real concentration rate is lower due to several reasons. The first one: the reflection coefficient of mirrors is lower than 100%. Usually it has a value of 90-

92%. The second reason: the mirrors that approximate the parabolic surface are not perpendicular to the incident light. This decreases the efficient area of the mirror and increases the size of focal circumscribing circle. The third reason: sun light beams have divergence due to the finite angle size of the sun disk in the sky. For these reasons, more precise evaluation of concentration rate was performed in [3]. According to these calculations the coefficient of solar concentration for three zones is 11.5 suns and for ten zones is 122 suns. As a first approximation it is possible to accept this coefficient γ equal to $N/5$. A concentrator with more than three zones gives a stagnation temperature of more than 300°C. We estimate the cost of the solar concentrator as 20-30 USD per square meter.

3. Residential dehumidification system

A residential dehumidification system contains the solar concentrator field, gravel based thermal energy storage, and a powerhouse (Fig. 4).

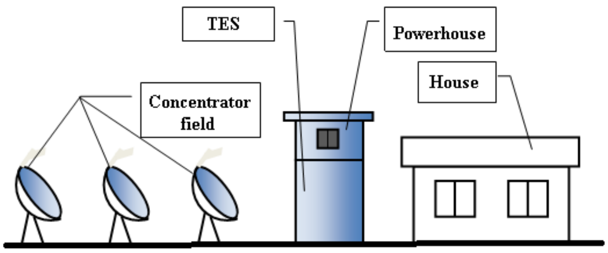

Fig. 4. Residential dehumidification system

The thermal energy storage and powerhouse can be shared with the residential cooling system [7]-[9]. The solar concentrator field collects solar heat energy and sends it to the thermal energy storage that has capacity to store this energy during 24 hours. If the direct sun beams are absent more than 24 hours the heat energy storage can be fed with fossil fuel burning. The powerhouse contains the system for heating the $CaCl_2$ solution that regenerates its high concentration. The concentrated solution is sent to the residential house where it serves for air dehumidification. To avoid solution spraying a special device is used. This device (Fig. 5) contains a multitude of capillaries of triangular or rectangular shape.

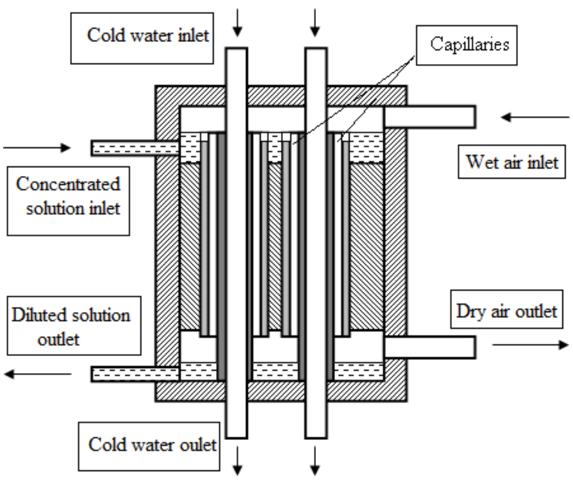

Fig. 5. Water vapour absorption device

The high concentration solution flows at the vertices of capillaries (Fig. 6) and the air that contains the water vapour flows at the centre of capillaries.

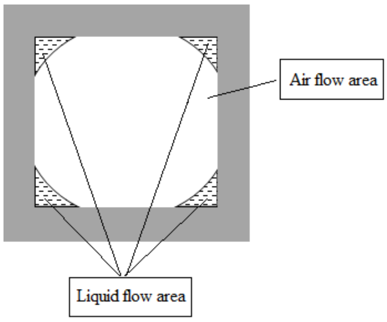

Fig. 6. Capillaries for water vapour absorption

This device permits us to obtain a large contact area of $CaCl_2$ solution with wet air and support the intensive absorption process without solution spraying.

We propose to make the capillaries from hydrophilic materials. For these small capillaries, for example 0.1-0.2 mm, the surface tension forces are much larger than the weight forces and a small quantity of the high concentration $CaCl_2$ solution sticks to the capillary vertices. At the same time the wet air flows at the center of the capillary and the friction forces between air and liquid set in motion the liquid with a speed that depends on the air flow speed, the relative viscosities of the liquid and air, the capillary geometry and some other parameters. The cross section of the liquid depends on the flow rate of the liquid that must be controlled in our device and from its speed that can be calculated using the finite elements method. Increasing the liquid flow rate it is possible to increase the cross section of liquid to obtain a circular shape of the air cross section (Fig.7). It is practically the upper limit of liquid flow rate for this capillary.

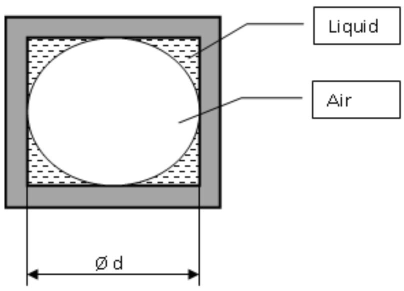

Fig.7. Capillary with air and liquid

The absorption process is always accompanied by heat release. For this reason the device is cooled with cold water. The speed of the air in the capillaries is selected in a way that does not permit the formation of solution droplets. So this device can be used in indoor conditions.

Let us consider the relation of liquid-air surface to the volume of the air. Let the diameter of the air channel be d (Fig.7). Correspondingly the side of the square capillary is also d. In this case the volume of the air in the capillary equals

$$v = \frac{\pi * d^2}{4} * L_c, \tag{9}$$

where L_c is the length of the capillary.

The air-liquid surface S_{al} for the case shown in Fig.7 can be calculated as

$$S_{al} = \pi * d * L_c \quad . \tag{10}$$

The relation of the air-liquid surface Ψ to the air volume is

$$\Psi = S_{al} / v = \frac{\pi * d * L_c}{\pi * d^2 * L_c} * 4 = \frac{4}{d}. \tag{11}$$

For example, for a capillary of 0.1 mm (10^{-4} m) the Ψ value is $4*10^4$ m^{-1}. If we compare with a flat air channel of thickness T_a=5 mm (Fig.8) that has $\Psi_1 = 1/5*10^{-3} = 2*10^2 m^{-1}$. The increase of factor Ψ in our design is

$$\Psi / \Psi_1 = 4*10^4 / 2*10^2 = 200. \tag{12}$$

So, we obtain the factor Ψ, 200 times better than usually obtained in flat box dehumidification devices.

Fig.8. Flat box dehumidifier

4. District dehumidification system

For the district dehumidification system much larger concentrator field and thermal energy storage systems are proposed to use. The size of thermal energy storage can be decreased if two storage tanks are introduced: one tank for high concentration $CaCl_2$ solution and another tank for low concentration solution. In the absence of direct solar beams the reserves of high concentration solution from the first tank are used to maintain a continuous process of the dehumidification and the low concentration solution is stored in the second tank. When a direct solar beams appears the process of high concentration solution regeneration is started and the first tank is filled with fresh solution of high concentration.

5. Conclusion

Low cost flat facet solar concentrators can be used for air dehumidification systems to restore high concentration of desiccant solution by heating it. To avoid the solution spraying a capillary dehumidifier is proposed. It permits us to obtain a large contact area of the desiccant solution with indoor air without generation of small droplets that can be highly corrosive and dangerous for human health.

Acknowledgement

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