DEVELOPMENT OF A THERMAL STORAGE SYSTEM BASED ON THE HEAT OF ADSORPTION OF WATER IN HYGROSCOPIC MATERIALS.

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ABSTRACT

A thermal storage system based on the heat of adsorption of water in hygroscopic materials has been studied as a component of a solar space heating system. The aim of this project is to decrease the storage volume in comparison with a rock-bed storage system by increasing the stored energy density.

The measured stored energy density for several adsorbents are given. Further some system modifications are discussed with regard to a solar space heating system using a rock-bed storage sytem. The solar contribution of the system with an adsorbent bed, which has been calculated with our TPD computer simulation programme of a solar heating system, is given for the several adsorbents and has been compared with the solar contribution of the same system having a rock-bed storage system.

The project is carried out in the frame work of both the European and the Dutch Solar Energy Program and in co-operation with a Dutch firm.

1. INTRODUCTION

In the Dutch climate space heating is one of the possible applications of solar energy. The main components of a solar space heating system are the solar collectors, the heat storage system, an auxiliary heater and the heat distribution system. The purpose of the short term heat storage system is to store a surplus of collected heat for the night and for a next cloudy day.

A solar air heating system (see fig. 1) is one of the possible systems. Usually such a system consists of a solar air collector, a rock-bed heat storage system and an air distribution system. To charge and discharge the storage system air is passed through the rock-bed. An advantage of this solar heating system is the possibility to transfer the collected heat directly into the house: cold air from the house is passed through the collector and is transferred into the house.

So the collector can operate at a low temperature level. Only if there is a surplus of collected heat, the heat is stored. In a solar air heating system usually a rock-bed storage has been included because of its large internal heat exchange area between the transfermedium and the storage medium. This large heat exchange area is needed because of the low thermal conductivity of the transfer medium air. A disadvantage of a rock-bed storage system is the low stored energy density: in a water storage system the stored energy by heating the material from 20-80 ^{o}C is 250 MJ/m^3; in a rock-bed (bed porosity = 40%) only 75 MJ/m^3

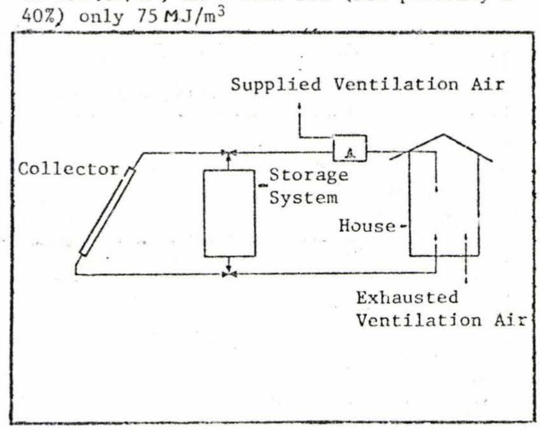

Fig. 1. Diagram of A Solar Air Heating System

For Dutch climatological circumstances a well designed solar heating system for a 9 kW-house consists of about 30 m^2 of collector area and 6 m^3 rock-bed storage system.

A possibility to decrease the storage volume seems to be a packed-bed of an adsorbent material. According to Close and Dunkle [1] the stored energy density will be 10-20 times higher than in a rock-bed. Therefore, it seems promising to find a compact practical storage-unit, which, if integrated in a solar heating system, takes good advantage of this physical principle.

2. ADSORBENT MATERIALS

2.1 Theory

An adsorbent material is a hygroscopic material, which can bind water physically. If water from the vapour-phase is adsorbed by the adsorbent material heat is liberated: the heat of adsorption. For the inverse process (drying of the adsorbent) the same amount of heat is needed. So by drying an adsorbent heat can be stored.
The heat of adsorption (r_a) is somewhat higher than the heat of evaporation (r_v) and depends on the water content of the adsorbent: at higher water contents the heat of adsorption approximates the heat of evaporation (see fig. 2).

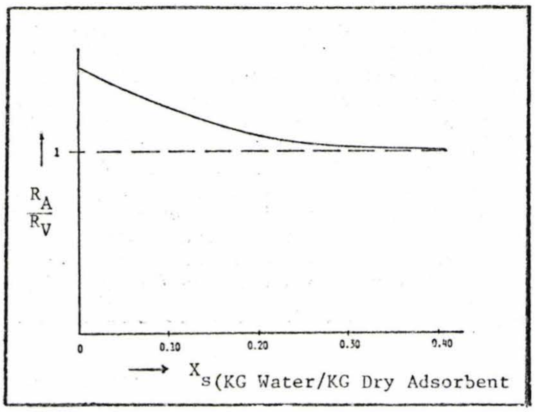

Fig. 2. The Heat of Adsorption R_A as a Function of the Water Content X_s of the Adsorbent. R_V is the Heat of Evaporation.

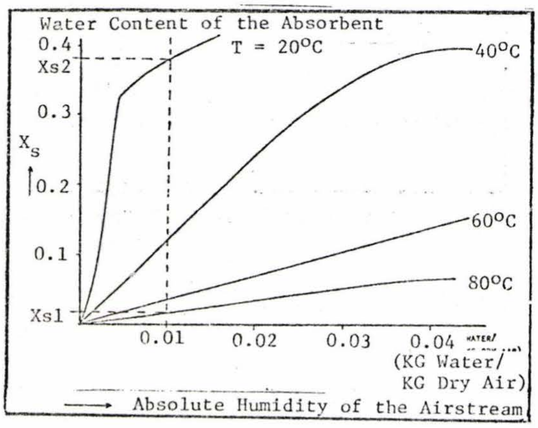

Fig. 3. Curves of the Equilibrium States Between the Adsorbent and the Airstream

An adsorbent heat storage system is charged by dry hot air and discharged by wet cold air. The quantities of water transferred to or from the bed material depend on the properties of the adsorbent material, the state of the adsorbent material and the state of the entering airstream. In fig. 3 the equilibrium states between the adsorbent and the airstream are given for a certain adsorbent.

2.2. The stored energy density of the several adsorbents

The stored energy density is defined as the amount of energy which has been stored per m^3. In an adsorbent storage system energy is stored both in the form of sensible heat and in the form of heat of adsorption.
The amount of heat which is stored in the form of heat of adsorption depends on the water adsorbing capacity (kg water/m^3) and on the heat of adsorption (kJ/kg water) in the operating range:

$$Q_{ads} = \rho_s \cdot V \cdot \int_{X_{s1}}^{X_{s2}} r_a\,(X_s)\, dX_s$$

with:
Q_{ads} = amount of heat stored in the form of heat of adsorption
ρ_s = density of the dry adsorbent
V = storage volume
ra = heat of adsorption
X_s = water content of the adsorbent

In order to make a clear comparison between the several adsorbents the operating range is defined as follows:

1. The stored energy is zero if the adsorbent is in equilibrium with air of temperature 20 °C and of absolute humidity 0.010 kg water/kg dry air
2. The stored energy is Q(T) if the adsorbent is in equilibrium with air of temperature T (> 20 °C) and of absolute humidity 0.010 kg water/kg dry air

The temperature 20 °C and the absolute humidity 0.010 kg water/kg dry air (R.H. = 70% at 20 °C) are realistic values for the state of the atmospheric air, which is available for charging and discharging of the storage system of a solar space heating system.
With the measured heat of adsorption and the measured equilibrium curves the stored energy density of five adsorbents in the operation range 20-80 °C have been determined (see table 1).

Sorbead R has the highest stored energy density in this operation range. With regard to a rock-bed the stored energy density of an adsorbent bed is 7-11 times higher.

Table 1: The Stored Energy Density

MATERIAL	STORED ENERGY DENSITY (MJ/m³)		
	SENSIBLE HEAT	HEAT OF ADSORPTION	TOTAL
SILICAGEL	35	616	651
SORBEAD R	38	768	806
SORBEAD W	38	502	540
ACTIVATED ALUMINA	29	573	602
MOLECULAR SIEVE	32	119	151
ROCK	75	-	75
WATER	250	-	250

OPERATION RANGE : -TEMPERATURE 20-80 °C
-HUMIDITY CONSTANT
(0.010 KG WATER/KG DRY AIR:
R.H. = 70% AT 20 °C)

3. A SOLAR HEATING SYSTEM WITH AN ADSORBENT HEAT STORAGE SYSTEM

3.1. Set-up of the solar heating system

Fig. 4 shows a diagram of a solar heating system with an adsorbent heat storage system. This system shows some differences with regard to a solar heating system with a rockbed storage (see fig. 1):

a. The charge circuit is open (see fig. 5)
Dry air coming from the atmosphere is preheated in heat exchanger 1 and heated further by the solar collectors. Hot, dry air enters the storage system In the storage system the air is cooled and wetted by water from the adsorbent bed. In heat exchanger 1 the wet air is cooled further and transferred back into the atmosphere.
Of the collected heat only the net heat of adsorption (the difference between the heat of adsorption and the heat of evaporation) is stored in the storage system; the heat of evaporation is transferred to the atmosphere, but the adsorbent has, due to its "dryness" the capability to adsorb water vapour from atmospheric air. So in a later stage the heat of evaporation can be recovered.

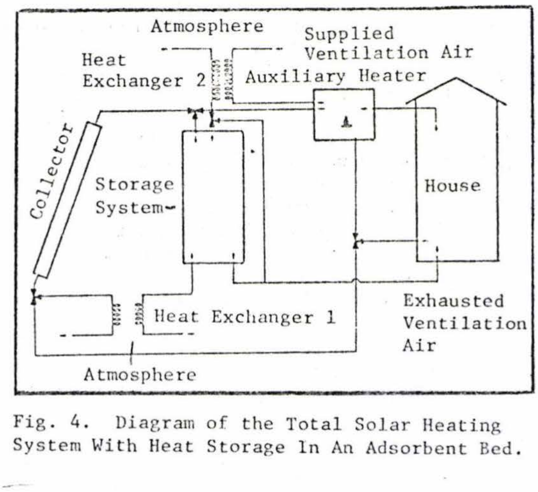

Fig. 4. Diagram of the Total Solar Heating System With Heat Storage In An Adsorbent Bed.

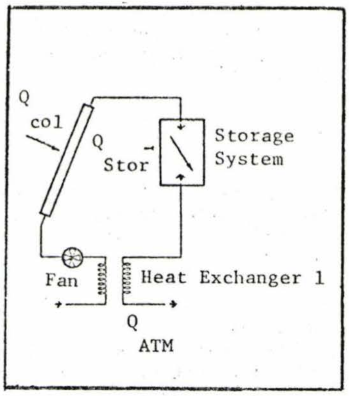

Fig. 5. The Charge Circuit

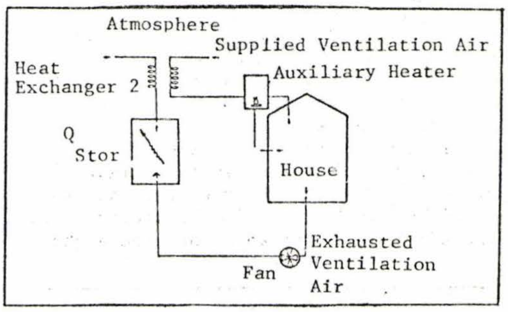

Fig. 6. The Discharge Circuit

b. The discharge circuit is completely different (see fig. 6)
The exhausted ventilation air is passed through the storage system.

In the storage system the air is dried and heated. In heat exchanger 2 heat is emitted to the supplied ventilation air.
This system-approach has been chosen because:
1. the system, in which air from the house is passed through the storage system and is transferred back into the house, water vapour is withdrawn from the house air. So the house air will be dried. To prevent this drying of the house air, the air has to be wetted. But in that case the heat of evaporation cannot be recovered from the atmosphere.

2. in the system, in which air from the atmosphere is passed through the storage system, the air has to be heated first by the storage system from ambient to room temperature. Only if the air temperature is higher than the room temperature heat can be emitted by the airstream to the house.

A disadvantage of the chosen system seems to be the low ventilation air flow ($\approx 200\ m^3/h$); the total air flow in the heat distribution system is about $1200\ m^3/h$.

An advantage is, that with an extra bypass the heat exchanger in the discharge circuit can be used for the heat recovery from the exhausted ventilation air.

3.2. The solar contribution of the system with an adsorbent storage system

With our computer simulation programme of a solar heating system the solar contribution of the above described system has been calculated [2]. For these calculations hourly weather data of the Dutch reference year have been used.
The calculations have been done for a solar heating system that consists of 25 m^2 collector area (spectral selective, single glazed) and a storage volume of 2.5 m^3.
For the solar contribution of other dimensioned systems see [2].

a. Comparison between the several adsorbents

In fig 7 the solar contribution of this system for several adsorbents is given as a a function of the annual heat demand of the house. The annual heat demand of one type of house is thereby determined by the insulation and the ventilation rate.
The solar contribution in this figure is divided into a "direct use" part and an "indirect use" part (via the storage system). The adsorbent "Sorbead R" has the highest contribution.

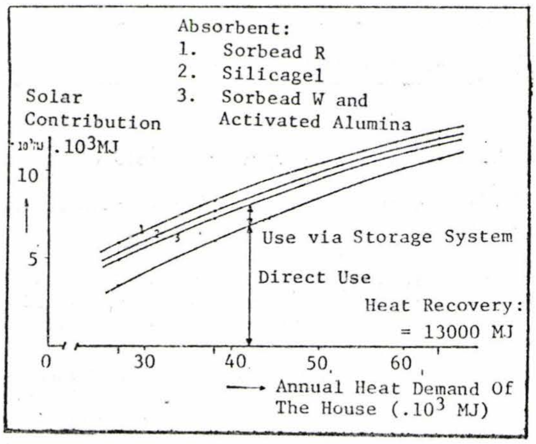

Fig. 7. Solar Contribution of the System For The Several Adsorbent Materials As A Function Of the Annual Heat Demand Of The House.

b. Comparison between a rock-bed and an adsorbent bed

For a clear comparison between a system with a rock-bed and a system with an adsorbent bed it is necessary, that the heat demand to the system is the same.

The extra heat recovery function of the heat exchanger in the discharge circuit of the adsorbent system makes that the heat demand to the solar part of the system is less compared to the system using a rock-bed (compare figures 1 and 4).
For the calculations the system with a rock-bed is therefore extended with heat recovery from the exhausted ventilation air too.

The "indirect use" part of the solar contribution of both systems is given as a function of the storage volume.(see fig. 8)
The adsorbent material is sorbead R. The total annual heat demand of the house is 26000 MJ.
An adsorbent system with about 2 m^3 storage volume has the same indirect contribution as a 6 m^3 rock bed.

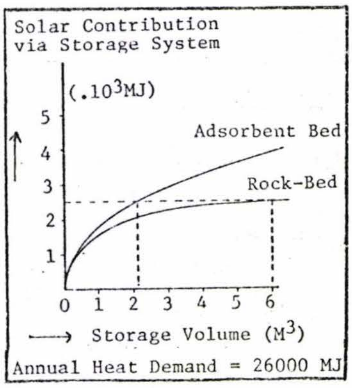

Fig. 8. Comparison Between A Rock-Bed and An Adsorbent Bed.

4. CONCLUSION

A solar heating system with an adsorbent storage system can be more compact than a solar heating system with a rock-bed storage system: the storage volume can be reduced with a factor 3. This factor of 3 becomes however, less important if we see that a rock-bed storage system with the same reduced storage volume has only a few precent lower solar contribution.
In a solar air heating system the part of the collected heat, which is "indirect used" (via the storage system) for space heating is less important than the "direct use" part. Questionable is whether a storage system is necessary in combination with air collectors. Maybe a somewhat higher thermal inertia of the house is sufficient. The adsorbent material can also be used for air conditioning purposes. The combination heating/airconditioning can be more efficient.

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