

SELECTIVE WATER SORBENTS, A NEW FAMILY OF MATERIALS FOR ADSORPTION COOLING/HEATING: STATE-OF-THE ART

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Abstract

This paper summarises the literature data concerning a new family of adsorption materials, so called Selective Water Sorbents, SWSs, which are composites "a salt confined in a porous host matrix". The materials demonstrate an intermediate behaviour between solid adsorbents, salt hydrates and liquid absorbents. The thermodynamic equilibrium with water vapour has been measured for twenty SWSs based on halides and sulphates confined to various matrices (silica, alumina, porous carbons, clays, MCM-41, etc.). It was shown that water sorption properties of SWS can be controllably modified in a wide range by varying a) porous structure of the host matrix, b) chemical nature of the impregnated salt, c) the amount of the confined salt, and d) preparation procedure. Among the measured dynamic properties of SWS are the thermal conductivity, specific heat and kinetics of water adsorption. Mathematical modelling of the thermodynamic cycle of adsorption heating/cooling machine showed that the SWS can effectively operate with cycles, the maximum temperature of which is about 85-95°C (for cooling) and 130-140 °C (for heating) that is lower than temperatures for other working pairs known so far. Recent study on the laboratory prototype of an adsorption chiller showed that the experimental values of COP \approx 0.6 are considerably higher than those reported for silica gel/water and zeolite/water systems at the same temperature of the heat source. Other practical applications of SWSs are briefly considered among which are the already commercialised gas dehumidification and the heat protection.

KEYWORDS

water, sorption, calcium chloride, lithium bromide, halides, sulphates, confinement to pores, adsorption heating, gas dehumidification, adsorption chiller, COP

INTRODUCTION

To make adsorption methods of heating/cooling competitive with traditional compression methods, it is necessary to look for or design new sorbing materials that have improved properties in comparison with traditional adsorbents (zeolites, activated carbon, silica gels). What does it mean to be "improved"?

First, new materials have to possess thermodynamic properties that would provide a higher COP and specific energy per cycle than the common materials. Second, they should have good dynamic properties with respect to heat and mass transfer for getting a high specific power of the unit operation. The first criterion is more theoretical while the second one is more practical, both being very important. These general criteria have to be formulated for each particular adsorption technology, such as chilling, deep freezing, heat pumping, trigeneration, etc. Thus, they should have optimal properties in a particular range of temperature and adsorbate pressure.

We have come to a question that is more general than the previous one: what is an optimal adsorbent that means the adsorbent which is the most suitable for a particular cooling/heating application? In the past, the question remained open because only traditional adsorbents were considered as commercially available and analysed for this application. Such an approach came from the thermal engineering side, that view an adsorbent as something already existed and consider its properties as they are declared in a property sheet.

A quite antithetical approach is coming from material scientists who ask "With which properties would you like to have the optimal adsorbent? Tell us, please, and we shall try to synthesise it." This looks fantastic, and this communication is directed to justify this approach and convince thermal engineers that it is, in principle, possible. Moreover, several examples are given confirming that this approach is quite efficient for applied thermal engineering and Several other applications.

Although there are many trade marks of adsorbents, only few types of commercially available materials are known and popular among thermal engineers. As a consequence, the most data in the literature are concerned to standard working pairs like "water – zeolite", "water – silica gel", "methanol – activated carbon", etc. Although many types of zeolites are commercially produced, just two of them are commonly studied for adsorption cooling/heating, namely, 4A and 13X, probably because they are large-scale products and, hence, they are available, well-characterised and cheap. Similar situation exists with silica gels: regular and high density silicas are mainly tested because their properties are quite different and represent two boundary situations. The property of other silicas lie between these extremes because the existing synthesis technologies allow a change in the sorption properties in a relatively narrow range. That is a general rule for single component adsorbents. Fig.1 demonstrates this range for the two mentioned silicas. The small pore silica adsorbs more water than the silica with larger pores, and the difference can reach the factor of two. Thus, for a single component systems the possibility to vary sorption properties is rather restricted.

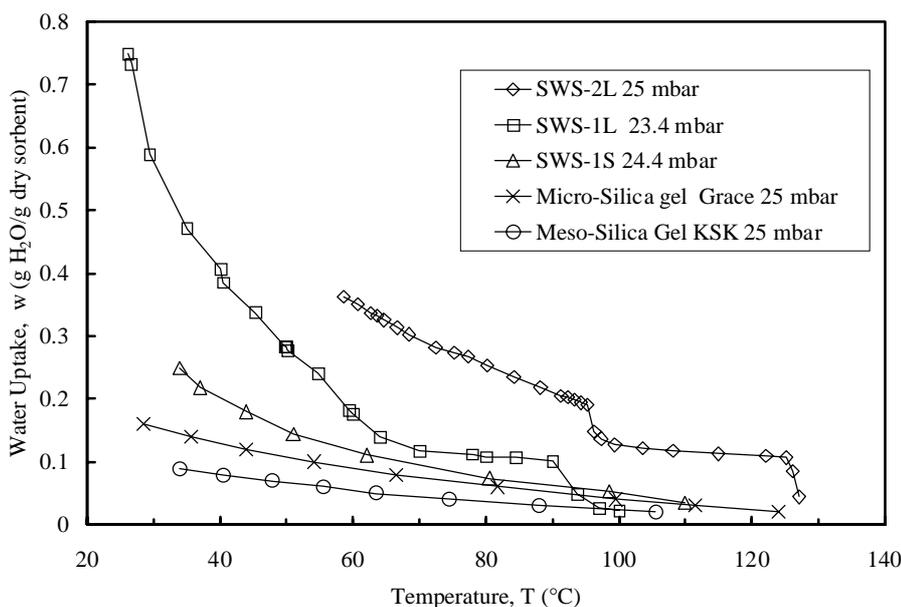


Fig. 1. Comparison of the 25 mbar isobars of pure silicas and composite sorbents (taken from [1]).

An idea to produce the two-component adsorbent like "active substance in porous host matrix" opens new opportunities in varying the sorbent properties. Indeed, since 1929 a composite "CaCl₂ in porous alumina" was patented as a dehydrating material [2]. Then other two-component composites have been proposed for this application. No comprehensive study was done to investigate properties of the composites because the aim of those studies was very narrowly focused and restricted to the particular conditions of gas drying. Anyway, it became clear that the modification of common adsorbents by hygroscopic salts can be a tool for modifying sorption properties. The idea was then forgotten.

Recently, a new impact has come from the material science to promote this concept. It was originated from a basic study of ultradispersed solids and was aimed to answer the question "How do sorption properties of a salt change if it is dispersed inside a porous host matrix and which factors do influence these changes?". The answer had required a detailed study of the problem that was done in a set of publications on the new materials, "halides inside porous matrix", performed since 1995 at the Borskov Institute of Catalysis, Novosibirsk, Russia [1, 3-36]. These materials have been called Selective Water Sorbents (SWSs).

In this paper we review a state-of-the art on SWSs and discuss their application for applied thermal engineering.

PREPARATION OF TWO-COMPONENT (COMPOSITE) SORBENTS

The general idea of a composite sorbent "salt inside porous host matrix" is to modify a common adsorbent like silica, alumina, porous carbons, etc., to make changes in its sorption properties in a

desirable direction. Hence, it is important to develop efficient practical procedures to vary sorption properties of the two-component sorbent in a wide range.

Generally, the synthesis procedure looks very simple:

- a) host matrix pre-treatment by its drying at 120-180°C,
- b) impregnation of the matrix with a salt solution,
- c) removal of water at 120-150°C.

Evidently, the preparation process is rather complicated and includes a formation of double electrical layer in the salt solution near the matrix wall, salt cation adsorption on the surface, salt nucleation and formation of amorphous or crystalline salt aggregates on the matrix surface. During drying stage the migration of the salt and its spatial redistribution inside the sample can take place. All these points are out of consideration in this communication and will be a subject of separate publications.

Here, we just mention that, in principle, there are at least five factors that can influence sorption properties of the two-component material "salt inside porous matrix", namely,

- a) a chemical nature of the modifying agent (the salt),
- b) a content of the modifying agent,
- c) a chemical nature of the host matrix,
- d) a porous structure of the host matrix,
- e) synthesis conditions.

Several examples of such influence are given below. So, many available tools open new ways to make a strong modification to enhance sorption properties of the (host matrix. Moreover, a knowledge on how each factor mentioned above influences the properties allows to formulate even more complicated and attractive target, which has been mentioned in the Introduction, namely, to design an adsorbent with pre-fixed sorption properties that, we believe, will be done in the nearest Future.

Table 1: A list of SWSs materials synthesised and studied so far

Salt	Host matrix	Water sorption, g/g	Remarks	Reference
CaCl₂	silica gel KSK	0.70	SWS-1L	[1, 4]
	silica gel KSM	0.25	SWS-1S	[5]
	aerogels	1.0-1.50	SWS-1Aero	[9,14]
	carbon Sibunit	0.57	SWS-1C	[34,36]
	Al ₂ O ₃	0.52	SWS-1A	[34,36]
	vermiculite	1.13	SWS-1V	[24]
	MCM-41	0.56	SWS-1MCM	[30]
LiBr	silica gel KSK	0.77	SWS-2L	[8,12,35]
	silica gel KSM	0.25	SWS-2S	[35]
	aerogels	1.10-1.60	SWS-2Aero	[19]
	carbon Sibunit	0.60	SWS-2C	[25]
	Al ₂ O ₃	0.55	SWS-2A	[25]
	Expanded graphite	1.85	SWS-2Gr	[25]
MgCl₂	silica gel KSK	0.72	SWS-3L	[35]
LiCl	silica gel KSK	0.70	SWS-4L	[35]
MgSO₄	silica gel KSK	0.65	SWS-5L	[32,34]
	Al ₂ O ₃	0.50	SWS-5A	
NaSO₄	silica gel KSK	0.62	SWS-6L	[32,34]
CuSO₄	silica gel KSK	0.58	SWS-7L	[32,34]

Table 1 collects SWS-type materials already synthesised and studied. Four salts present a class of halides, three others are sulphates. Halides are very hygroscopic but also corrosive. Sulphates are

almost non corrosive, however, still attract a large amount of water. Salt content in the anhydrous samples was varied from 5.0 to 63 wt.%.

Host materials are mostly porous oxides (silica and alumina) that are commercially available and cheap. Even more cheap are mineral clays like vermiculite and bentonite. Rather exotic is a synthetic mesoporous mesophase silicate MCM-41 with mono-sized mesopores. All these matrices are hydrophilic. Hydrophobic matrices are presented by the synthetic carbon Sibunit and expanded graphite. According to the IUPAC classification the graphite and vermiculite are macroporous materials, while the others are mesoporous ones.

SORPTION PROPERTIES OF SWSs

Thermodynamics and kinetics of water adsorption on SWS are of the main interest to analyse its potentialities for adsorption cooling/heating and other applications. More than 20 sorbents have been studied so far, and general regularities of the water sorption on SWSs are revealed. They will be discussed below taking as an example few materials, SWS-1L, SWS-1S and SWS-2L.

Water sorption equilibrium

The amount of water sorbed by the samples was measured with a CAHN C2000 (in vacuum) or Rigaku Termoflex (under air flux) thermal balances in the temperature range of 293 - 423K at different partial pressures P_{H_2O} ranging from 8 to 133 mbar. The details can be found elsewhere [4,5,8,34-36]. The water content was calculated as $w = m(P_{H_2O}, T)/m_0$ where m_0 is the dry sample weight. As the water sorption by the host matrix was found to be less than 6-7 % of the total sorption, the calculation of the equilibrium number of water molecules with respect to 1 molecule of calcium chloride was another convenient way of the data presentation:

$$N(P_{H_2O}, T) = (m(P_{H_2O}, T)/\mu(H_2O))/(m(\text{salt})/\mu(\text{salt})), \text{ where } \mu \text{ is a molecular weight.}$$

CaCl₂ confined to the silica gel KSK mesopores (SWS-1L)

Water sorption isobars for SWS-1L are presented in Fig. 2a as a $N(T)$ dependence at different partial pressures P_{H_2O} . All the curves were found to be similar but shifted and partially extended along the temperature axis. Each curve has a plateau corresponding to $N = 2$, which indicates the formation of solid crystalline hydrate $CaCl_2 \cdot 2H_2O$. It is clear that under these conditions the majority of water is absorbed by the salt rather than by the host matrix. The dihydrate is rather stable and shows a *monovariant* type of sorption equilibrium typical for **solid absorption** processes. This hydrate was directly recorded by an X-ray diffraction technique. At high temperature this hydrate undergoes decomposition to form the crystalline hydrates $CaCl_2 \cdot H_2O$ and $CaCl_2 \cdot 0.33H_2O$ and, finally, the anhydrous salt. At low temperature, the amount of sorbed water increases and reaches 0.7-0.8 g/g, that is much higher than that for pure (non-modified) matrix (Fig. 1). At temperatures lower than that of the left boundary of the plateau, water sorption depends on both temperature and partial vapour pressure, so that the equilibrium becomes *divariant* which is typical for a **liquid absorption**.

Interestingly, almost complete desorption of water (except last 0.1 g/g) can be performed by heating the sorbent by some 40-60°C (Fig. 2) that makes the material promising for utilisation of low grade heat (80-130°C).

Based on isobaric curves, water sorption isosteres are plotted for $N = 1 - 10$. They appeared to be straight lines $\ln(P_{H_2O}) = A(N) + B(N)/T$, with a slope depending on the water content N and giving an isosteric water desorption heat $\Delta H_{is}(N) = B(N) \cdot R$, where R is the universal gas constant (Table 2) [4]. For $N > 2$ this value (43.9 ± 1.3 kJ/mol) is close to the water evaporation heat from aqueous $CaCl_2$ solutions. A significant increase in ΔH_{is} at $N \leq 2$ is caused by the formation of solid hydrates where water molecules are bound stronger.

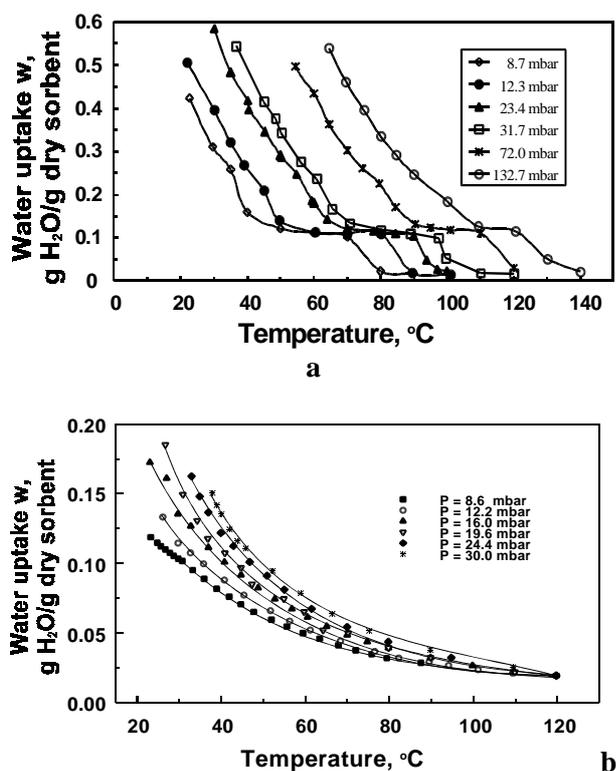


Fig. 2. Water sorption isobars measured for the SWS-1L (a) and SWS-1S (b) materials [4,5]

Table 2: Isosteric heat of water desorption ΔH_{is} (kJ/mol) for SWS-1L and SWS-1S [4,5].

N	mesoporous SWS-1L	microporous SWS-1S
1	63.1	-
2	62.3	69.0
3	42.2	62.3
4	43.9	56.0
5	45.6	50.2
6	44.7	46.0
7	44.3	43.9
8	45.6	-
9	45.1	-
10	43.9	-

Thus, two main mechanisms of water sorption take place on SWS-1L: a) solid absorption (or chemical reaction) that is responsible for about 10-15% of total sorption, and b) liquid absorption ($\approx 80\%$). Heterogeneous adsorption on matrix surface is responsible for 3-5% and can be neglected in the first approximation. The scheme of water interaction with the SWS-1L (and similar SWS materials) is displayed on Fig. 3 and indicates the consequent formation of various crystalline hydrates $\text{CaCl}_2 \cdot n\text{H}_2\text{O}$ (where $n = 1/3, 1$ and 2) and then of the salt solution which completely or partially fills the matrix pores. Namely, such volume filling of pores leads to the advanced sorption capacity of the SWS materials. This phenomenon is similar to the volume filling of micropores in zeolites and other molecular sieves. The difference is that the driving force for adsorption on SWS is an interaction of water with the salt molecules (in hydrates) or ions (in solution) instead of interaction with walls of zeolite nanopores. The approach of the Volume Filling of Micropores suggested by M. Dubinin [37] can be applied to describe the water sorption on SWSs thus giving a temperature-invariant curve of sorption in the N vs ΔF presentation, where $\Delta F = -RT \ln \eta$ is a sorption potential

(or free sorption energy) and $\eta = P/P_0$ is the relative pressure.

Another way to describe the sorption by one parameter instead of two is to present it directly as a function of the relative pressure η (Fig. 4) [4]. Such presentation allows a comparison between the sorption properties of the dispersed and bulk calcium chloride. For KSK silica pores, the properties of CaCl_2 solution appeared to be essentially the same both in bulk and dispersed state that means the water - salt interaction in solution is likely to be much stronger than the interaction of water with the host matrix. The salt hydrates are more sensitive to the confinement to pores and change their properties. *First*, the formation of $\text{CaCl}_2 \cdot 2\text{H}_2\text{O}$ in KSK pores is observed at the relative pressure of about 2-3% that is much lower than at the bulk state (13-14%) [4]. The quantitative explanation of the effect was done in [10]. The practical consequence is the higher adsorption capacity of the confined salt at low humidity of inlet gas as well as the lower Dew point of outlet gas. New efficient adsorbents for gas dehumidification have been developed based on this phenomenon. *Second*, a crystalline CaCl_2 hexahydrate which is well known in bulk was not found in pores because its melting temperature in KSK pores appears to be depressed down to 18°C [6]. Important conclusion is that the confinement of hygroscopic salt (like CaCl_2) inside mesoporous matrix (like silica KSK) can result in changing salt sorption properties due to the influence of the host matrix.

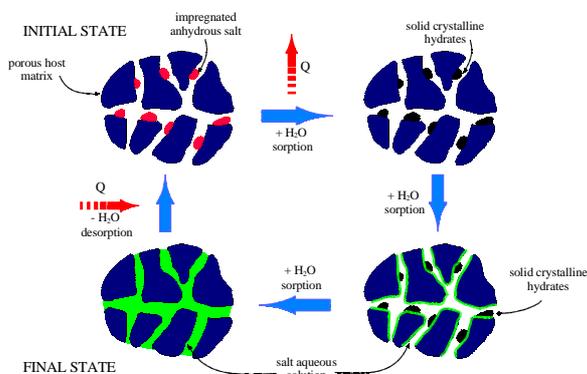


Fig. 3. Scheme of water sorption on SWS-1L.

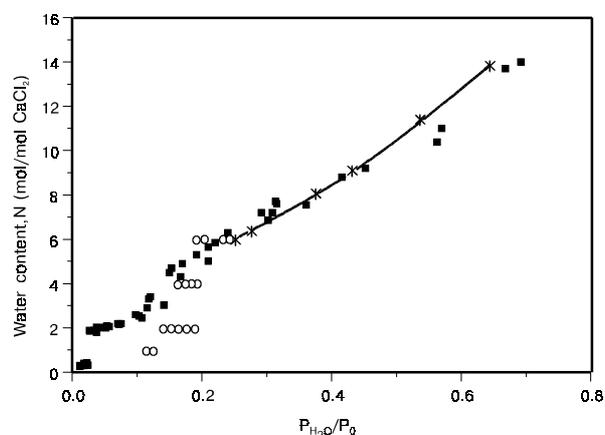


Fig. 4. Temperature-invariant curves of water adsorption on SWS-1L (v), bulk salt (μ) and salt solution (solid line) [4].

This effect increases for KSM silica which has the same chemical composition as KSK but much smaller pores of 3.5 nm diameter. Confinement of CaCl_2 in these pores completely changes the isobars of water sorption compared to those in the SWS-1L or bulk state (Fig. 2b). No hydrates formation was found, and the sorption equilibrium is divariant even at $N \leq 1$ that indicates that the hydrated salt can continuously change its composition. It is typical, for instance, for aqueous salt solutions or hydrates with vacation structure. Detailed study of this unusual salt state is of top interest for future research.

Thus, the sorption properties of the composite "CaCl₂ + host matrix" is not a linear superposition of the properties of single components, but rather a result of their mutual influence. Change of host matrix porous structure can strongly influence the properties of the confined salt and hence the composite properties.

Another rather obvious but efficient tool for modification of SWS properties is to change the chemical nature of a confined salt. Indeed, introduction to the same matrix of the same amount of LiBr (SWS-2L) leads to the composite that at low temperature absorbs water much better than SWS-1L (Fig. 1) however has to be regenerated at higher temperature [8,12,35].

For the same salt and matrix the sorption properties will enhance at larger salt content confined to pores (Fig. 5), however the effect is not linear [32].

It is surprising but the influence of a chemical nature of the host matrix is found to be almost negligible. For instance, the SWS-1A based on hydrophilic alumina and SWS-1C based on hydrophilic carbon Sibunit have quite similar pore structure and sorption properties [25,35]. One more efficient tool is to change parameters of SWS synthesis that is discussed in [32,38].

APPLICATIONS

Accumulated fundamental knowledge about the structure of SWS and mechanisms of the water sorption recently allowed us to shift accents of the study to an analysis of SWS possible applications.

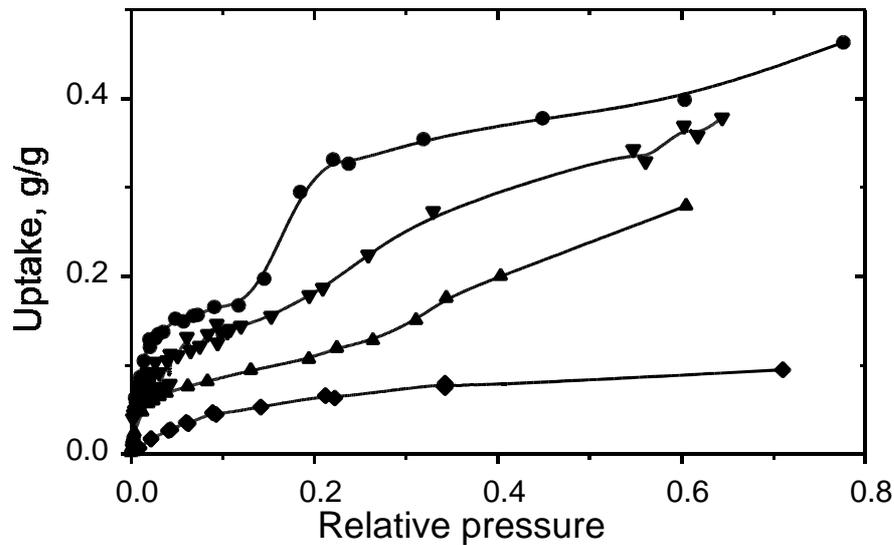


Fig. 5. Isotherm of water sorption for $\text{MgSO}_4(38\%)/\text{SiO}_2$ (●), $\text{MgSO}_4(24\%)/\text{SiO}_2$ (▼), $\text{MgSO}_4(13.5\%)/\text{SiO}_2$ (▲) and SiO_2 (◆) [32].

Today, two of these applications have been realised commercially in Russia. They are a) adsorptive drying of a compressed air that was implemented in twelve oil refinery plants and cryogenic stations in Russia (more than 100 tonnes of SWS-1A are in use) [39] and b) thermal protection of electronic memory chips ("black box") [27]. Other possible applications of SWS for obtaining water from air (BIC, Russia [28,29]; Institute of Refrigeration and Cryogenics, Shanghai Jiao Tong University, China, and for seasonal storage of energy (BIC, Russia) are under intensive investigation.

A



B



Fig. 6. Lab prototype of adsorption chiller built in the ITAE/CNR (A – view of the unit, B – the heat exchanger and adsorber) [33,40].

The most interesting applications of SWS in sorption heating/cooling technology are now at the stage of laboratory testing. In the ITAE/CNR (Italy) a laboratory adsorption chiller was assembled

and tested (Fig. 6) [33,40]. The adsorber of the chiller was filled with SWS-1L (calcium chloride in silica gel KSK). It is found that at $T_{\text{cond}}=35^{\circ}\text{C}$ and $T_{\text{evap}}=10^{\circ}\text{C}$, cooling COP achieves 0.6 at the low desorption temperature of 85-95°C (Fig. 7). This is a gross COP that is affected by heat losses, the heat capacity of the inert masses and the heat efficiency of exchangers, which will be optimised in the next unit. Of course, it can be further improved in a multi-bed system with internal heat recovery. So large COP achieved for a simple unit configuration shows the advantage of this new composite sorbent with respect to common commercial materials (zeolite or silica gel) at such a low regeneration temperature. Indeed, 85-90 °C can be easily obtained with a simple and cheap flat receiver of solar energy or from industrial waste heat. At present, other prototypes are also under construction for chilling and ice making.

Adsorption heating for floors, walls and rooms could be another application of SWSs. Interesting properties for this field could have SWS-2L (LiBr in silica KSK) which according to theoretical analysis of [1,15] can allow the COA as high as 1.6-1.7 at maximum desorption temperature 130-140 °C. Such low driving temperature for developing low-cost massive produced adsorption heaters that use a natural gas boiler (or preferentially waste heat) as a heat source. Final conclusion on SWS usability for heating will come soon after appropriate testing.

Despite the results of the investigations are published in more than 80 papers, abstracts and patents, only further testing of the prototypes can prove the worth of these sorbents in the applied thermal engineering.

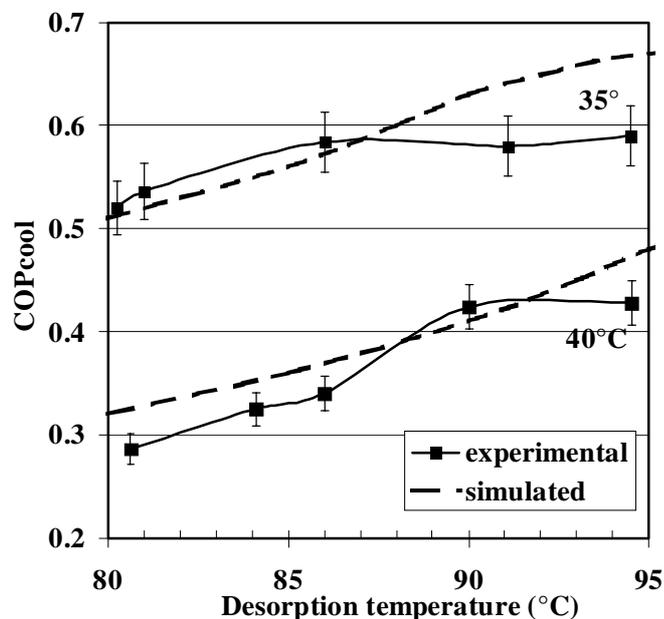


Fig. 7. Cooling COP as a function of desorption temperature at two condenser temperatures (35 and 40°C) [33,40].

SWS stability

On the way to practical application one of the most important questions is the SWS stability under multiple operating cycles. This information is still rather poor, and the SWS hydrothermal stability is being tested. No loss of the capacity was found for SWS-1A after 200 cycles of "complete saturation – complete drying at 150 °C" which is rather severe conditions [36].

Another fact confirming the SWS stability is the following one. Adsorbent IC-011-1 (on the basis of SWS-1A), which is commercially produced in Russia, is already utilised on the Omsk SIBNEFT refinery plant since 1999 being regenerated at 150 °C approximately each week. That means that the total amount of the cycles without loss in the activity has been more than 250.

Nevertheless, in ref. [41] it was mentioned that "The modified materials (SWS-1L) used in the experiments turned out to loose sorption capacity during cycling. These problems have not occurred under laboratory conditions and might come from contamination due to the gas originating from the internal coating." The authors tested this material for thermal energy storage under conditions which

are absolutely not suitable for SWS-1L. Indeed, the evaporation temperature was as high as 20 °C, while the minimum adsorption temperature was 30 °C. That means that the high relative humidity was 55-60%. The container with adsorbent was big (about 400 litres) and in its coldest part the temperature was probably even lower that could cause over-saturation of the sorbent and as a consequence the loss of the sorption capacity. Furthermore, in the same paper it was shown that the container filled with the sorbent was heated by an electric heater located at the centre of the vessel. That means that the material close to the heater could reach a temperature of few hundreds degrees C. This is another possibility for the wrong operating conditions for SWS.

Thus, for a proper usage of SWSs, we would recommend

- a) to organise the operating cycle in such a way to avoid extreme conditions, namely, the minimum uptake should be higher than that corresponding to the solid hydrate formation ($w = 0.11$ g/g for SWS-1L), while the maximum uptake should be far lower than the pore overloading threshold (that is 0.59 g/g for SWS-1L with 32 wt.% CaCl_2 (for salt content 25 wt. % the threshold is 0.69 g/g),
- b) an adsorber heat exchanger should be well constrained in order to ensure good thermal control inside the unit.

For instance, in the already mentioned paper [40], where SWS-1L was utilised for chilling cycle in which the sorbent extreme conditions were $T_{\max} = 95$ °C at about 70 mbar and $T_{\min} = 35$ °C at about 10 mbar, thus the water uptake changed between about 0.11 g/g and about 0.29 g/g. We performed more than 60 cycle and found no change of the SWS sorption properties. It is a partial result, but our opinion is that avoiding operating extreme conditions, the stability should be the same of that of a common silica gel.

Other SWS-type materials

Here we focus only on heating/cooling applications and shall not consider composites “salt inside host matrix” studied or patented for gas drying.

Two other materials of this type were suggested for adsorption thermal units:

- a) The first example concerns the materials “active carbon fiber “Busofit” + a metal chloride” which have been invented and developed in the Luikov Institute of Heat and Mass Transfer (Belarus) [42-45]. The chlorides were CaCl_2 , NiCl_2 and BaCl_2 . These sorbents were used as single storage systems with physical sorption (pure active carbon fiber “Busofit”), complex compound single stage systems with physical sorption and chemical reactions (active carbon fiber “Busofit” + CaCl_2), or a complex compound two stage systems (“Busofit” + BaCl_2 and “Busofit” + NiCl_2) with the internal and external heat recovery. It was found that the use of the salts allowed a considerably increase in the full heat output (with simultaneous raise of the reaction time from 12 min. up to 20-25 min.). For the “Busofit”- CaCl_2 combination, a full adsorption capacity is more than 0.85 kg of ammonia for 1 kg of a sorbent bed. On the contrary to the SWSs considered above, these materials demonstrate a combination of the physical sorption and chemical reaction, a contribution of the reaction between ammonia and the salt being only 25-40% (see Table 3), while for SWS almost the whole adsorption is attributed to the “water-salt” interaction. Another difference is that a granulated or consolidated SWS layer is homogeneous while the carbon fibers can be oriented in a preferable direction.

Table 3. Full adsorption capacity of Busofit and composite sorbent

Full sorption capacity, kg/kg of the sorbent	Busofit	Busofit + CaCl_2
Acetone	0.61	-
Ammonia	0.62	0.85
Ethanol	0.6	-
Methanol	0.55	-

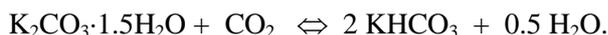
Another composite material, comprising either of a mixture of finely divided materials (expanded graphite, EG) and a solid reactant or of a compressed support (EG) and the reactant, was suggested in a set of patents (see [46] and references herein). The aim was to achieve the substantial improvement of the kinetics of the reversible gas/solid reaction and the increase in the thermal conductivity of the composite up to 20-30 W/(m K). One of the problems which the authors mentioned was the closed

porosity of such composite caused by the salt impregnation that can reach 60-70% at high salt content that is typical for hydrophobic supports. As the EG compressed support is a macroporous matrix with the average pore size 1-2 μm , it plays the role of a dispersing and heat transfer media rather than influences the sorption properties of the inserted material. It is out of the main line of this paper, which considers the composites the sorption properties of which are not a linear combination of those of the matrix and the filling.

Several composites “salt in host matrix” were suggested for CO_2 sorption [47-51]. The host matrices are alumina, silica, various porous carbons, vermiculite, etc. and the active salt is a potassium carbonate. The CO_2 is captured due to the following reversible chemical reactions



or/and



The dynamic sorption capacity of these materials can reach 0.09-0.11 g/g in the temperature range 20-50 $^\circ\text{C}$ [50] that could be an interesting alternative to common zeolites which lose the activity in the presence of water. On the contrary to the water sorbents (SWSs) for which the “salt-matrix” chemical interaction in most cases is negligible, for CO_2 -sorbents it can be rather strong (except carbon matrices) and leads to the formation of inactive surface compounds (for instance, potassium alumocarbonate $\text{KAl}(\text{CO}_3)_2$ in the case of alumina [49]) that could decrease the sorption capacity. Special regeneration procedure must be used to recover the sorbent [50].

Silicate host materials were suggested as porous containers for drugs (so called “drug delivery systems”) to improve the drug therapeutic efficiency and protect it against chemical and enzymatic degradation [52].

From this brief scanning it is clear that the term “Selective Water Sorbent” does not cover all applications of the composites “salt inside porous matrix” that are known so far, and more general term should be introduced to describe such materials. I would suggest here to call them “Salt inside Matrix” (SiM). The term SWS still can designate the particular class of SiM-materials aimed to water vapor adsorption.

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