

# Desiccant materials for air conditioning applications - A review

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## ABSTRACT

Desiccants are a group of adsorbent materials that have a great affinity for water vapour. Due to this merit, desiccant material can produce hot and dry air which can be used for the drying process as well as in air-conditioning applications to minimize the latent heat load. A good desiccant must have better moisture absorption capability as well as lower regeneration temperature. The moisture absorption capability basically depends upon the desiccant characteristics like pore volume, apertures size and void fraction. Depending upon normal physical state, desiccants can be either solids or liquids. Solid desiccant materials such as silica gel, natural zeolites, molecular sieves, activated alumina, synthetic polymers are highly porous in nature and adsorb water by using mechanisms of chemical adsorption. Liquid desiccants such as Calcium chloride, tri-ethylene glycol, and lithium chloride are generally very strong solutions of ionic salts and their behaviour is controlled by changing its temperature and concentration. This paper presents a detailed study on different solid, liquid and composite desiccant which combine two or more desiccant materials for better properties and performance. This review has a great significance for the research and technical development in the field of desiccant dehumidification and air-conditioning technology.

*Keywords: solid desiccant, liquid desiccant, regeneration, dehumidification, air-conditioning*

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## Nomenclature

COP	– Coefficient of Performance
DDAC	– Desiccant Dehumidification and Air Conditioning
FAM-Z	– Functional Adsorbent Material Zeolite
FSM	– Folded Sheet Mesoporous Material
HKUST	– Hong Kong University of Science and Technology
IUPAC	– International Union of Pure and Applied Chemistry
KIT	– Korea Advanced Institute of Science and Technology
MCM	– Mobil Composition of Matter Number
MIL	– Materials of Institute Lavoisier
RD	– Regular Density
SBA	– Santa Barbara Amorphous
VC	– Vapour Compression

## 1. Introduction

With the amplified thermal conditions, standard of living and comfort demands of occupants, the demand for air-conditioning has increased and the recent statistics estimate that the energy consumed for air-conditioning, both commercial and domestic, is about 45% of the total energy consumption [1]. In the meantime, because of the increasing global warming and extinction of fossil fuels, challenge for development of new air conditioning technologies has also been increased, for the assistance or replacement of conventional Vapour Compression (VC) systems and one of the best alternative is Desiccant Dehumidification based Air Conditioning (DDAC) [2]. These DDAC systems were initially adopted and were being used for a long time in industrial and agricultural field applications, like humidity control in fabric mills and low temperature post-harvest crop drying in stores. Later, they became more protuberant in air conditioning field as they make complete use of surface vapour pressure difference for humidity transfer between the process air and desiccant material [3]. The DDAC systems are most efficient as they are advantageous in many ways, as [2,4-8]:

1. The desiccant materials are capable of removing impurities from the air stream to improve supply air quality.
2. In DDAC system, the regeneration process can be powered by renewable energy sources like solar energy, geothermal energy etc. and also low grade energy like waste heat which makes the system more economical.
3. The desiccant material in the DDAC system will dry the process air stream and this reduces the corrosion of piping and clogging of valves and capillaries by ice crystals which occurs in case of VC system.
4. The DDAC system uses zeolites and silica gels as desiccants which are environment friendly unlike CFC's and other refrigerants.
5. DDAC systems are capable of handling air below dew point temperatures like  $-40^{\circ}\text{C}$ .
6. Desiccant dehumidification completely eliminates processes of evaporation and condensation, which are prevalent in VC system and reduces the growth of disease causing microbes.
7. In DDAC systems, increase in humidity of process air is not a problem, as it is handled by the desiccant wheel before being transferred to the conditioned space.
8. Environment cooling can be used for handling of sensible load, as ambient air is mostly used as the process, which reduces the energy consumption of the system.

For the past few decades, experimental researches in development of simulation models [9-14], desiccant materials [15-20] and improvement of systems and cycles [21-24], etc. were carried out in the field of DDAC systems. The DDAC systems mainly depend on the desiccant materials opted, as its characteristics (regeneration temperature, adsorption isotherms, etc.) significantly affect the performance of the system [25]. With advancement in material science, various desiccant materials have been explored and technologically advanced. Researches are also being carried out in the fields of development of advanced desiccant materials with improved long-term stability, adsorption characteristics and regeneration capacity.

## **2. Desiccants**

Generally, the materials which have the ability to attract and hold other gases or liquids are termed as sorbents. These sorbents are mainly used in chemical separation processes and are used for absorbing gases or liquids other than water vapour. Desiccants are a subset to the sorbents, which specifically have affinity for water. This process of absorbing and holding water vapour by the desiccants may be defined as either absorption or adsorption depending on whether the desiccant material undergoing chemical change on attracting moisture (absorption) or not (adsorption). Materials like wood, natural fibres, clays and various synthetic materials can also attract and hold water vapour, but they have less holding capacity. Generally, a desiccant attracts between 10 to 1100% of its dry mass of water vapour depending on the moisture content available in the surroundings and the type of desiccant material used. Desiccants continuously attract moisture, even from the dry air, until it reaches equilibrium with the environment. Moisture is removed by heating the desiccant material to temperatures from 50° to 260°C and exposing to a regeneration airstream. After the desiccant is completely dried, it should be cooled so that it can attract water vapour again [4]. The desiccants are available either as solids or liquids, namely, solid desiccants and liquid desiccants. Mostly adsorbents are solids and absorbents are liquids.

## **3. Solid Desiccants**

Solid desiccants are highly porous materials which adsorb water by various mechanisms like chemical adsorption onto the walls of pores or consecutive layered physical adsorption of water molecules or capillary condensation into the pores. These have large internal surface area per unit mass, as large as 4600 m<sup>2</sup> and the surface area which attracts water is always in the crystalline structure of the material. These materials attract moisture because of electrical field present at the desiccant surface, which utilizes the atomic and electrostatic forces to attract water molecules into the microscopic pores of the desiccant surface [4, 26]. Solid desiccants are generally classified into following classes.

### *3.1. Silica Gels*

Silica Gel is a naturally available mineral which is non-toxic, odourless and generally processed into beaded form. Its porosity is greater than 70% of its surface area and is as high as 650m<sup>2</sup>/g with pore size of 2-3 nm (type A) to 0.7 nm (type B) and it has a heat absorption capacity of about 2800 kJ/kg [27]. Silica gels are mainly of two kinds namely, macro-porous and micro- porous. Macro porous silica gel saturates readily with the surroundings whereas micro porous silica gel absorbs water for a long time. Silica gel generally requires temperature between 90° to 150°C as regeneration temperature to remove the moisture from it [28,29].

### *3.2. Zeolites*

Zeolites are aluminosilicate minerals of alkali and alkaline earth metals like sodium, potassium and calcium. They have crystalline lattice which are wide open that makes ease of holding water vapour like in a cage and have porous structure to accommodate the alkali and alkaline earth metal ions. Water vapour can be

removed by heating the material, leaving unchanged aluminosilicate skeleton with a void fraction ranging from 0.2 to 0.5. After heating, the size of apertures of the skeleton ranges from 3 to 8 Å<sup>0</sup> for further adsorption of water vapour [30]. Generally, zeolites will be contacted with aqueous solutions of appropriate cations (practically 0.1M) at a temperature of 60-70°C at solid to liquid (S/L) weight ratios ranging from 1/20 to 1/50, for cation exchange [31]. Analcime, Clinoptilolite, Heulandite, Natrolite, Phillipsite and Stilbite are some of the common zeolite minerals. These zeolites are also used in some of the industrial chemical processes like gas separations, ion exchanges, water treatment and catalysis [32].

### 3.3. Activated Alumina

Activated alumina are hydrides and oxides of aluminium, generally prepared by thermal dehydration or activation of aluminium tri-hydrate or gibbsite. The structural characteristics of alumina can be controlled either by temperature and duration of the thermal process or by the gases used for producing them. Activated alumina, like silica gel, have greater capacity for water vapour than zeolites and surface acidity is the important property for adsorption as well as catalysis. Because of this surface acidity, Lewis acid sites (sites that accept electrons) are abundant on alumina and for fully hydrated alumina, Bronsted acid sites (-OH groups that donate proton) are present. These activated aluminas have surface area ranging from 150 - 500 m<sup>2</sup>/g and heat adsorption capacity as high as 3000kJ/kg. The pore configuration of the activated alumina mainly depends on the conditions of heat treatment and will be of size ranging from 1.5 – 6 nm [27,30]. Because of its high sorbent properties, it has been prominently used in desiccant dehumidification and cooling applications [33,34] and also in removal of oxygenates, Lewis bases, polar organic compounds and hydrogen fluorides from gases and liquids. Depending on the degree of hydration, the high temperature forms of alumina are  $\theta$ -alumina and  $\delta$ -alumina having only Lewis acid sites and  $\gamma$ -alumina and  $\eta$ -alumina having both type of acid sites (both Lewis and Bronsted).

### 3.4. Molecular Sieves

Molecular Sieves, which can also be termed as synthetic zeolites, are crystalline aluminosilicates which are obtained by isomorphous substitution of aluminium or silicon from zeolite framework with other elements in thermal process. Compared to zeolites, molecular sieves are advantageous for their large pores or channels and catalytic sites in place of acid sites. The structure and surface features are mainly controlled by the temperature of the process and composition of the ingredient materials. The largest windows of these synthetic zeolites are of order 8.1 Å<sup>0</sup> for a 12-membered oxygen ring pore system. Some of the commercial synthetic zeolites are VPI-5, a crystalline aluminophosphate with 18-membered oxygen rings; AlPO<sub>4</sub>-8, contains 14-membered oxygen rings and Cloverite, a gallo-phosphate consisting of 20-membered oxygen rings as well as 8-membered oxygen dual rings as pore systems [30]. Because of its pore system, it has great affinity in adsorbing water vapour resulting in its application in dehumidification and air-conditioning systems [35-38].

### 3.5. Activated Carbon

It is one of the most widely used adsorbent because of its huge micropore and mesopore volumes and higher surface area of 300-4000m<sup>2</sup>/g. Activated carbon is generally prepared by low temperature carbonization (400-500°C) to remove the volatile matter, followed by activation process, either gas or chemical, where partial gasification (800-1000°C) to develop surface area and porosity. Commercial activated carbon is generally available in both liquid and gas phase. The liquid phase activated carbon has a pore volume with pores having diameter larger than 30 Å<sup>0</sup> and gas phase activated carbon has pores of size 10-25 Å<sup>0</sup>, so based on the application the phase of activated carbon is selected [30]. Apart from the activated carbon available as

powder or granules, activated carbon fibres have better adsorption characteristics. These activated carbon fibres are prepared by taking synthetic fibres like poly-acrylonitrile, coal tar, viscose rayon and phenolic resin as precursors. Similar to activated carbons, these precursors are also carbonized at high temperatures in inert atmosphere and activated by steam at temperatures of 200-300°C followed by the calcination at 400-1000°C in inert atmosphere. Stabilized fibres with desired properties are activated at 800-1000°C. The pore volume of the activated carbon fibres is of range 0.5-1.4 ml/g with average pore diameter of 1.2-3.0 nm and specific surface area of 700-2500 m<sup>2</sup>/g. Due to these properties, the adsorption characteristics of activated carbon fibres is better than the activated carbon powder or granules [39].

### 3.6. Polymer Desiccants

A polymer can be termed as a substance which is made of macromolecule [40,41]. Desiccants based on polymers are mainly investigated because of their ability to adsorb water vapour upto 80% of its own weight and potential to reach the desired water adsorption characteristics. Following are some of the polymer desiccant materials on which experimental investigations are largely carried out.

#### 3.6.1. Polyelectrolytes

A polyelectrolyte is a polymeric material which consists of large portion of its repeating units having ionic or ionisable groups, or both [41]. These polyelectrolytes have been employed as desiccant materials for a long time because of their ease of regeneration, high adsorption capacity and adjustable functionality [42-44]. The hydrophilicity of the polyelectrolytes can be varied by introducing hydroxyl and carboxyl groups into them but the exchange of cations affects the water adsorption characteristics [45,46]. The tremendous development in material synthesis made possible the development of polyelectrolytes with higher adsorption capacities and durability and employed in dehumidification [47-50]. Joohyun Lee and Dae-Young Lee [51] developed a polymeric desiccant by ion modification of sodium salt of polyacrylic acid and fabricated it into desiccant wheel whose experimental results showed 2-3 times higher adsorption capacity than silica gel. White et al. [52] conducted experimental investigation on desiccant wheel made using a polymeric desiccant developed by ion modification of polyacrylic acid and results were compared with two desiccant wheels made of silica gel and FAM-Z01. The results indicated 10-20% more dehumidification than the other two desiccant wheels at low regeneration temperature of 50°C.

#### 3.6.2. Metal-Organic frameworks

According to IUPAC, metal-organic frameworks are coordination polymers or networks that have potential voids in the open framework [53]. They have large surface area, high pore volume and exceptional physiochemical variability leading to its variable composition [54-56]. These properties of metal-organic frameworks lead their application to catalysis [57-59], gas storage [60-63] and gas separation processes [64-67]. Most of the metal-organic frameworks used in desiccant dehumidification processes have a specific pore volume of 2 cm<sup>3</sup>/g and surface area as high as 6000 m<sup>2</sup>/g [68-71] and some of the MIL type compounds like MIL-100(Cr) and MIL-101(Cr) have water adsorption capacities as high as 1.43g/g and inimitable hydrothermal stability [72-75]. Seo et al. [76] conducted experiments on MIL-101(Cr) and MIL-100(Fe) and the performance results were compared with that of silico-alumino-phosphate molecular sieve and alumino-silicate zeolite as reference materials. The MIL-101(Cr) and MIL-100(Fe) exhibited more than 1.5 g/g and 0.84 g/g water capacity respectively, which were 6.0-11.5 times that of the reference materials. Akiyama et al. [77] investigated on a MIL material consisting of substituents like -H, -NO<sub>2</sub>, -NH<sub>2</sub> and -SO<sub>3</sub>H as ligands and observed that they exhibit higher water capacities of 0.8-1.2 g/g and water adsorption trapping pressure could be controlled by changing substituents or their hydrophobicity. Henninger et al. [75] investigated on

the properties of three materials namely, HKUST-1(Cu), MIL-53(Al) and MIL-100(Fe). He found that of all the three materials, MIL-100(Fe) showed higher water adsorption capacity of 0.6 g/g. Similarly, Rezk et al. [78] investigated and reported that MIL-100(Fe) had 78.6% more adsorption capacity than silica gel RD-2060 at 20°C and P/P<sub>0</sub> of 0.9.

### 3.7. Composite Desiccants

Composite materials are generally formed by the impregnation of hygroscopic salts into the pores of the host, i.e., a porous desiccant material in this case. The hygroscopic salts (nitrates, sulphates and haloids etc.) possess high water adsorption characteristics but they are unstable at higher humidity ratios due to lyolysis, so porous desiccant materials with stable characteristics like silica gels, activated carbon, mesoporous silicates and natural rocks are used as host material. Aristov [79], Gordeeva and Aristov [80] investigated on some composite desiccants for cooling applications and reported that the composite desiccants achieved high COP as well as water adsorption characteristics. Some of the composite desiccants used in dehumidification and cooling applications are discussed below.

#### 3.7.1. Silica gel-host composites

Silica gel is one of the host material which is widely used in composite desiccants because of its low regeneration temperature [81] and composite desiccants in which hygroscopic salts are impregnated into silica gel, have enhanced water adsorption characteristics [82-84]. Many investigators developed various silica gel-host composites and studied their properties. Jia et al. [85] synthesized a silica gel host-composite desiccant where saturated LiCl solution was impregnated into the pores and results showed that the adsorption capacity was 2-3 times higher than that of pure silica gel. The desiccant wheel of the above composite desiccant resulted in 20-40% more dehumidification than the silica gel desiccant wheel [86]. Simonova et al. [87] developed a composite desiccant by impregnating saturated aqueous Ca(NO<sub>3</sub>)<sub>2</sub> solution into silica gel and experimentally determined that the material had an adsorption capacity ranging from 0.15-0.17 g/g at a desorption temperature of 75-80°C. Aristov et al. [88] experimentally determined that a source temperature of 65-75°C was sufficient for regeneration of LiNO<sub>3</sub>-Silica gel composite desiccant. Bu et al. [89] prepared three CaCl<sub>2</sub>-Silica gel composite desiccants with different pore sizes of 2-3 nm, 4-7 nm and 8-10 nm and found that the composite desiccants of 4-7 nm and 8-10 nm exhibited enhanced water adsorption capacities with the concentration of CaCl<sub>2</sub>. Similarly, Gordeeva et al. [90] also proved that the adsorption capacity of MgSO<sub>4</sub>-Silica gel composite desiccant could be increased with increasing the concentration of MgSO<sub>4</sub>. Cortes et al. [91] investigated on three composite desiccants, namely, CaCl<sub>2</sub>-Silica gel, MgCl<sub>2</sub>-Silica gel and LiBr-Silica gel and found that the CaCl<sub>2</sub>-Silica gel had the highest water adsorption capacity and MgCl<sub>2</sub>-Silica gel had the lowest. Mrowiec-Bialion et al. [92] synthesized a CaCl<sub>2</sub>-Silica gel composite desiccant using sol-gel method and found experimentally that the water adsorption capacity of the composite desiccant was higher than 1 g/g. Similarly, using sol-gel method, Sukhyy et al. [93] developed Na<sub>2</sub>SO<sub>4</sub>-Silica gel composite desiccant whose water adsorption capacity was reported to be 0.85 g/g.

#### 3.7.2. Mesoporous silicate-host composites

After the discovery of MCM-41 [94,95] and FSM-16 [96], a family of mesoporous silicates emerged, which are prepared by hydrothermal synthesis of silica gel in the presence of long chained surfactant templates. Later, this lead to the discovery of more of these kind like MCM-48, MCM-50, KIT-1, SBA-15 and many others [97,98]. They have microporous distribution, high surface area (> 500m<sup>2</sup>/g), regular structures and abundant silanol groups resulting in higher water adsorption characteristics than original silica gel [99]. These mesoporous silicates exhibit type V adsorption isotherm characteristics which makes them a better



host material for composite desiccants [100,101]. Many researchers developed these mesoporous silicate desiccants with enhanced adsorption properties. Ponomarenko et al. [102] developed a composite mesoporous silicate by impregnating  $\text{CaCl}_2$  in SBA-15 and observed experimentally that the adsorption capacity as high as 0.47 g/g could be achieved. Glaznev et al. [103] synthesized two composite desiccants of  $\text{CaCl}_2$ -SBA-15 with 8.1 nm and 11.8 nm pore sizes and found that the desorption was achieved at a low temperature of 88.5°C for larger pore size and was 6°C lower than that of the smaller pore size desiccant. Zhang and Pei [104] developed three mesoporous silicate desiccants with sodium polystyrene sulfonate, sodium polyacrylate and sodium malate as impregnating salts and found that the desiccant with sodium malate had exhibited higher water adsorption characteristics and the water intake was double than that of the pure mesoporous silica at 25°C.

### 3.7.3. Carbon-host composites

Activated carbon is widely used adsorbent due to its high pore volume and large surface area and also, it is a good host material for composite material as it exhibits type V adsorption isotherm characteristics with S-shaped curve [105]. Combining activated carbon with hygroscopic salts is one of the paramount ways for enhancing water adsorption characteristics of activated carbon. Huang et al. [106] synthesized a composite desiccant by impregnating activated carbon into  $\text{NaSiO}_3$  solution and found that the water adsorption characteristics were higher than the original activated carbon. Tso and Chao [107] developed a composite desiccant by impregnating both  $\text{CaCl}_2$  and  $\text{NaSiO}_3$  into activated carbon. The water adsorption capacity was found to be 0.805 g/g at atmospheric pressure and at temperatures of 25-115°C. They also observed that utilizing waste heat at temperature of 60°C as source heat for regeneration resulted in almost 80% of adsorption of water vapour.

### 3.7.4. Natural rock-host composites

The investigations on composites of chlorine salts and natural porous materials brought attention towards natural mineral clay hosted composites [108-111]. Chen et al. [112] synthesized a composite of  $\text{LiCl}$  and attapulgite clay and investigated on its properties. The results indicated that at 30°C temperature and 1.5 kPa pressure, the water adsorption capacity was 0.44 g/g, which was 6-7 times that of the original attapulgite clay, but with a regeneration temperature of 170°C. Butut et al. [113] investigated on a composite desiccant of Turkish bentonite and  $\text{CaCl}_2$  and found that it had water adsorption characteristics but it required regeneration temperature of 105-150°C. Sapienza et al. [114] synthesized a composite desiccant of vermiculite and  $\text{LiNO}_3$  and found that the water adsorption capacity was about 0.4 g/g where adsorption took place at 33-36°C and desorption at 62-65°C. Nakabayashi et al. [115] fabricated three desiccant composites by impregnating  $\text{CaCl}_2$ ,  $\text{NaCl}$  and  $\text{LiCl}$  into the pores of wakkanai siliceous shale. The investigation results indicated that the adsorption characteristics of composite desiccant with  $\text{NaCl}$  was 5-7 times that of the pure wakkanai siliceous shale at 25°C.

### 3.7.5. Binary salt impregnated composites

The research works mentioned above were based on the composite desiccants with single salt impregnations. Recently composite desiccants with double hygroscopic salts impregnation became more prominent in researches. Gordeeva et al. [116,117] synthesized two composite desiccants by impregnating  $\text{CaCl}_2 + \text{CaBr}_2$  and  $\text{LiCl} + \text{LiBr}$  into silica pores and found that the water vapour can be desorbed at 70°C by increasing the chlorine salt concentration in the binary salts. These binary salt impregnated composite desiccants were found to be having higher water adsorption characteristics when compared to single salt composite desiccants and low regeneration temperatures less than 100°C. The water adsorption

characteristics of these composite desiccants mainly depends on the concentration and categories the of salts [88,90,107,118], fabrication processes [83,84,91,92] and pore distribution of host material [86,101,106,110]. By varying these above characteristics, composite desiccants with desired and required adsorption characteristics can be synthesized.

#### **4. Liquid Desiccants**

Liquid Desiccants are generally strong ionic salt solutions whose behaviour can be controlled through varying their concentration, temperature or may be both. The control of temperature is handled by coolers or heaters, whereas concentration is handled by heating the desiccant to remove water vapour into the atmosphere or a scavenger airstream. In air washer, when air is passed through it, the dew point of the air supplied approaches the water temperature with which the machine is supplied. In this process, more humid air gets dehumidified and less humid air humidified. In the same way, the air is brought into contact with the liquid desiccant solution. Generally, the vapour pressure of liquid desiccant solution is lower than that of water at same temperature and the air gets dehumidified due to this vapour pressure difference, [4]. The selection of liquid desiccants depends on many parameters like density of energy storage, thermo-physical properties, vapour pressure, availability, regeneration temperature, boiling point temperature, cost, etc. and of all the above parameters, vapour pressure of the surface is of main concern. Some of the commonly used liquid desiccants, because of their low surface vapour pressure at low temperature and high concentration, are calcium chloride, lithium chloride, lithium bromide and triethylene glycol [3]. Thermodynamic properties of individual liquid desiccants are provided by many researchers like Uemura [119], Patil [120] and Ahmed [121]. Conde et al. [122] developed the formulae for determining the thermodynamic properties of calcium and lithium chlorides and Sun et al. [123] analysed and calculated vapour pressures, based on thermodynamic properties, of various liquid desiccants. Thermodynamic properties of aqueous lithium bromide solution are provided by McNeely [124]. Kaita [125] developed equations for determining thermodynamic properties of lithium bromide-water solutions for temperatures of 40-210°C and for concentrations of 40-60% weight. Ertas and Kiris [126] investigated and provided the properties of calcium chloride and lithium chloride at temperatures of 26.6-65.5°C. Recently, researchers like Lucas et al. [127] and Park et al. [128], started studying the properties of mixed liquid desiccants at appropriate proportions with lower surface vapour pressure and enhanced thermodynamic properties. Below is a brief discussion on commonly used liquid desiccants and their properties.

##### *4.1. Calcium Chloride*

Calcium chloride is a typical ionic halide which serves calcium ion in aqueous solution and at room temperature it is a solid. It is generally produced by direct reaction of limestone with hydrochloric acid but in large quantities it is produced as a byproduct of Solvay process. It has a boiling point temperature of 1395°C with 2.15 g/cc density. In  $\text{CaCl}_2\text{-H}_2\text{O}$  solutions, the crystallization line is complex because of the formation of  $\alpha$  and  $\beta$  tetrahydrates [129].

##### *4.2. Lithium Chloride*

Lithium chloride is an ionic salt that is widely used in air-conditioning systems. It has better hygroscopic properties and amazing solubility of about 83g/100 ml at 20°C in polar solvents. It has a boiling point temperature of 1382°C with 2.068 g/cc density. The crystallization line of  $\text{LiCl-H}_2\text{O}$  solution is an increasing mass fraction of LiCl and reducing water content [129].

##### *4.3. Lithium Bromide*



Lithium bromide is another lithium salt that is widely used as desiccant in air-conditioning applications. It is generally produced by treating lithium carbonate with hydrobromic acid and it can also be produced as a precipitate in water by treating lithium hydroxide with hydrobromic acid. It generally forms many crystalline hydrates comparative to other bromides of alkali metals. It is quite soluble in water, methanol, ethanol, ether and also slightly in pyridine. It has a boiling point temperature of 1265°C with a density of 3.464 g/cc [129].

## 5. Conclusion

The ability of a desiccant to attract water vapour depends on the difference in vapour pressure between its surface and the process air. All desiccants attract moisture until they touch equilibrium point with the surrounding air. The absorbed water vapour is usually removed from the desiccant by regeneration in which desiccant is exposed to a regeneration airstream having temperatures between 50 and 260°C.

Generally, the capacity of solid desiccant is less than the capacity of liquid desiccant but the use of composite desiccant materials may improve the moisture adsorption capacity. In case solid desiccant for air dehumidification with low grade waste heat as driving energy silica gel always performs better than other solid desiccant. Where as in case of liquid desiccant the most suitable is LiCl because of its lower vapour pressure but the major problem with LiCl is its high cost, this issue can be solve by combining it with cheapest desiccant  $\text{CaCl}_2$ . At the same time the composite desiccant of silica gel and LiCl has adsorption capacity 2-3 times higher than that of pure silica gel. The limitation faced by desiccant system is availability of regenerating heat to regenerate desiccant material. But the use of solar energy and waste heat for regeneration of desiccant material will make the system more economical. The use of desiccant system can solve lot of environmental problems well, as it can also minimise the high demand of electrical energy for conventional air-conditioning system and poor indoor air quality.

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