Research into the Possibility of Regenerating Silica Gel using Vacuum

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Abstract— *Gases used in industry must meet the required technological parameters for the production process, such as the content of gaseous impurities, moisture content and mechanical impurities. Their presence has a significant limiting effect for their further use in technical practice. One of the effective methods of removing moisture from gas is its adsorption, in which the gas passes through a bed of adsorbent, which subsequently binds this moisture on its surface. The article deals with the regeneration of this adsorbent, as it is advantageous from an economic point of view if it is possible to use this adsorbent repeatedly in the gas drying process. By reusing the adsorbent, there is an overall reduction in the cost of operating the equipment and the ecological burden caused by the production of a new adsorbent. The article primarily discusses the influence of the temperature of the dried medium on the speed of its regeneration using vacuum.*

Keywords— silica gel, adsorption, drying.

I. INTRODUCTION

The currently growing pressure to reduce energy and production costs forces manufacturers to increase the efficiency of production processes. One of the parameters for achieving the highest possible efficiency of the production process is the use of basic materials with the highest possible purity to prevent unwanted effects during production. Among the most used technical materials in all branches of industry are technical gases, which are subject to strict technical requirements. The amount of moisture contained in these gases indicates their quality. As the amount of moisture contained in the gas increases, its quality decreases and therefore it is necessary to subject them to a drying process.

The drying process is a complicated physical process in which the liquid content of the substance is reduced by the effects of heat, without changing its chemical composition.

The essence of drying is the migration of moisture in the opposite direction to the sorption process. During the general drying process, moisture moves from the porous core of the material to the surface layers and into the surrounding environment, whereupon the moisture meets the drying medium, which carries it away.

To determine the most optimal drying conditions, it is necessary to know the physical laws and quantities that affect drying in the individual phases of the entire process, the input parameters and the required performances.

II. SILICA GEL AS ADSORBENT

The principle of adsorption is the ability of some porous solid substances to bind gas particles or liquid substances on their surface. The adsorbed amount depends not only on the nature of the adsorbing medium, but also on the nature of the solid substance (adsorbent), on the size of its surface, on the partial pressure of the adsorbing component in the gas phase and on the temperature. During adsorption, it is important that the adsorbent has as large an active surface as possible. Trapped substances are released by desorption and the adsorbent can return to the drying process.

Known adsorbents used in removing moisture from gases include silica gel. It is a granular, porous form of silicon dioxide (SiO2), produced synthetically from sodium silicate and sulfuric acid in the form of hard irregular grains or regular balls. The porous structure of interconnected cavities provides a very high surface area (up to 800 m2·g-1), which allows water vapor to be easily adsorbed. Ordinary silica gel binds an amount of water corresponding to approximately 20% of its weight. Even when saturated with water vapor, silica gel still has the appearance of a dry product and its shape remains unchanged.

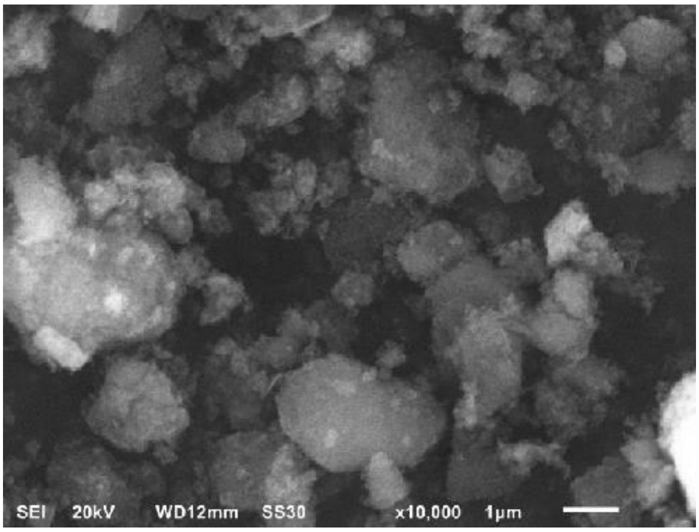

FIGURE 1: Structure of silica gel [8]

Silica gel is non-toxic, non-flammable and chemically highly inert. Sometimes it comes with a moisture indicator admixture that will change its colour whenever it is wet.

a) Type N – normal grains **b) Type WS – water resistant grains** **c) Type Orange gel – indicator grains**

FIGURE 2: Types of silica gel

The basic advantage of silica gel is its simple regeneration by increasing the temperature of the adsorbent, which removes the moisture stored in it. A decrease in the energy requirements for such drying can be achieved by reducing the pressure in the system, thanks to which the temperature required to remove moisture from the silica gel will also decrease. Pressure reduction in the adsorbent regeneration system is possible by creating a vacuum. Vacuum drying of silica gel is a suitable drying method, as the lower temperature during regeneration reduces the risk of silica gel degradation. After the drying process, it is necessary to cool the adsorbent in order not to deteriorate its adsorption properties in the gas drying process, as the amount of adsorbed water molecules on its active surface decreases with its increasing temperature.

III. DESCRIPTION OF THE MEASUREMENT PROCESS AND DESIGN OF EXPERIMENTAL EQUIPMENT FOR VACUUM DRYING OF SILICA GEL

An experimental device was designed for the regeneration of silica gel using vacuum drying, including a device for heating the heat-carrying medium and a chamber for humidifying the supplied gas to the drying chamber with silica gel.

For the purposes of the experiment, spherical silica gel EINECS: 231-545-4 was used. Hydrogen with a purity of 99.95% was used as the dried medium.

Fig. 3 shows the basic scheme of the experimental device, which consists of a segment for gas humidification (2), a tank containing silica gel (9), in which the humidified gas is dried, and then a part for heating the heat-carrying medium (5), which serves for regulation temperature in the tank with silica gel. Between the individual parts of this column, there are units for the analysis of humidity and temperature of the driving gas (1), (8), (11). Resistance thermometers (Thermistor 10K) are placed in the tank with silica gel and in the tank used to heat the water ensuring the required temperature of the silica gel. A vacuum pump (rotary vane pump RE 2.5) is connected to the tank with silica gel, which ensures the required pressure drop during the regeneration process.

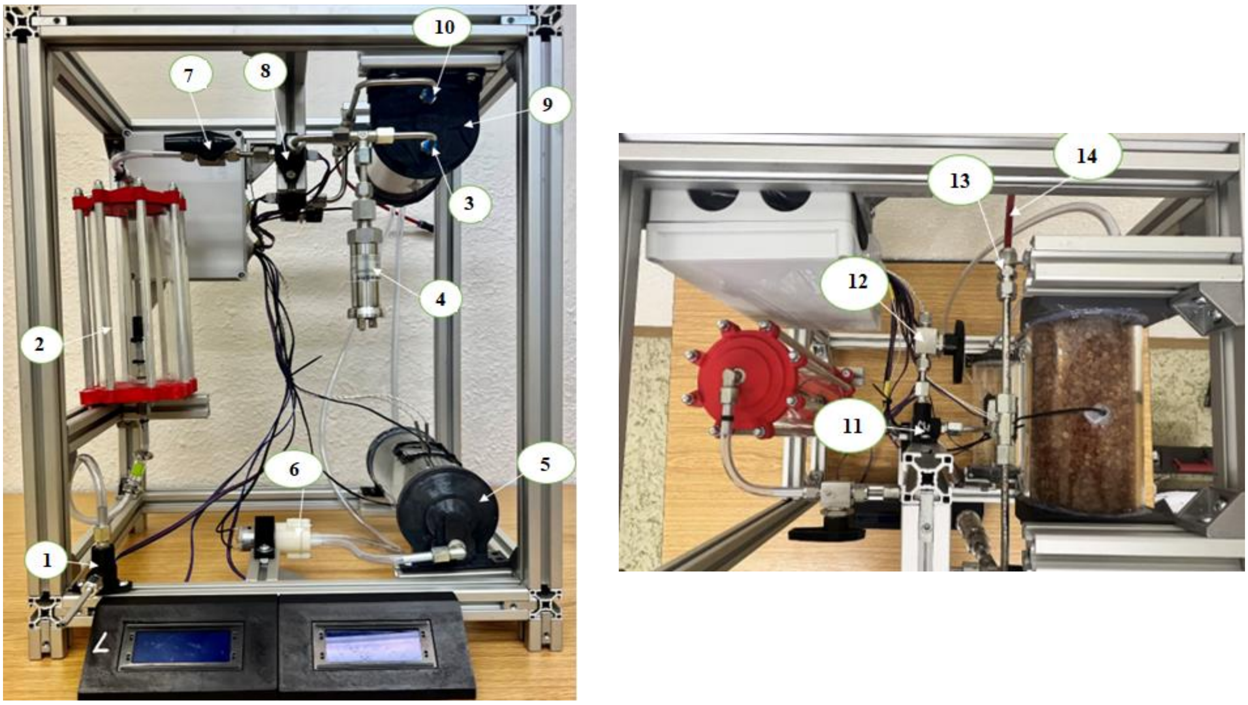

FIGURE 3: Model of experimental equipment

(1) (8) - SHT31 sensor (humidity and temperature sensor), (2) - hydrogen humidification chamber, (3) (10) - quick coupling, (4) - DMP331 pressure sensor during vacuuming, (5) - tank with heat exchanger liquid, (6) – pump ensuring water circulation to the container with silica gel, (7) – two-way valve Fitok Boss-ML6-05, (9) – tank with silica gel, (11) – sensor SHT31 (sensing humidity and temperature), (12) - two-way valve Fitok Boss-ML6-05, (13) - quick coupling, (14) - pipe for connecting the vacuum pump

From the pressure tank, the hydrogen is supplied to the humidification chamber, then it flows into the vessel with silica gel, where it dries and is released into the surrounding atmosphere. The heat source located on the tank transfers heat to the water, which circulates with the help of a pump to a spiral placed in a tank with silica gel, where thermal energy is transferred from the water to the adsorbent. After the heat has been transferred, the water returns to the storage tank. After finishing the process of drying wet hydrogen using silica gel, the silica gel regeneration process occurs by closing the circuit for the flow of hydrogen and connecting the vacuum system to the tank with silica gel.

IV. EVALUATION OF THE RESULTS FROM THE SILICA GEL REGENERATION PROCESS

Experimental measurement of silica gel regeneration took place in vacuum at four different temperatures (10°C, 25°C, 50°C and 70°C). To achieve a temperature of 10°C in a tank with silica gel, a Peltier cell (PC) with a power of 60 W was used. The PC was placed on an aluminium heat exchanger, which was in a tank with heat exchange liquid. The flow time of moistened hydrogen through the silica gel was the same for all measurements (15 minutes). The hydrogen pressure at the system inlet was set to a constant value to ensure the same volume flow during the measurement period. A constant temperature of the silica gel during the humidification process (approx. 25°C) was also ensured by means of a spiral located in the tank through which the heat-carrying medium flowed. The time to which the silica gel was exposed in the regeneration process was 40 minutes at all four considered temperatures. To determine the moisture removed from the adsorbent during the regeneration process, the silica gel was weighed before vacuuming and during the vacuuming itself. The absolute pressure during vacuuming was maintained at 0.4 bar.

Fig. 4 shows the weight loss of silica gel during vacuum drying at four selected temperatures.

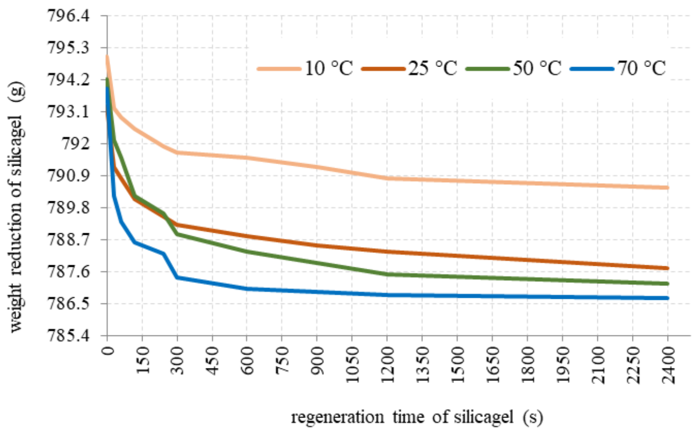

FIGURE 4: Regeneration of silica gel in vacuum at selected temperatures

From the graphic dependence, it follows that with the increasing temperature of the silica gel during the process of regeneration with the help of vacuum, there was a significant loss of moisture in it, for the same time interval.

This statement can be clearly confirmed in fig. 5, where at an adsorbent temperature of 70°C during the drying process for 40 min. 7.2 g of moisture taken, while at a temperature of 10°C only 4.5 g.

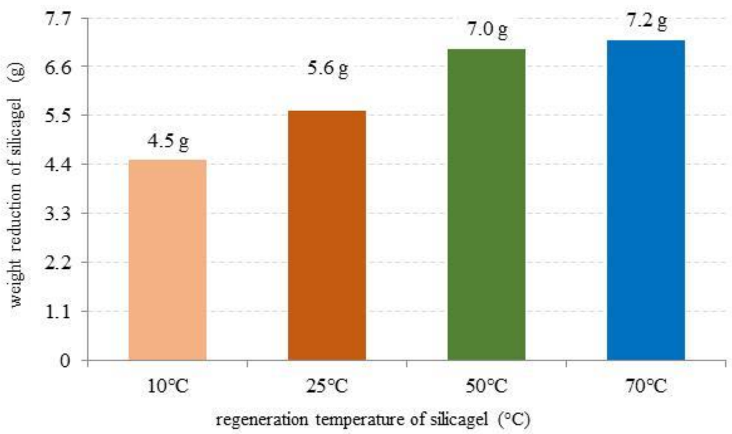

FIGURE 5: Loss of moisture in silica gel during its regeneration in vacuum at selected temperatures

In fig. 6, the time required for silica gel regeneration at 25°C and 70°C is investigated. From the dependence, it follows that at a temperature of 25°C, the adsorbent needs to be dried for up to 90 min to achieve a dryness comparable to that in the case of regeneration at a temperature of 70°C.

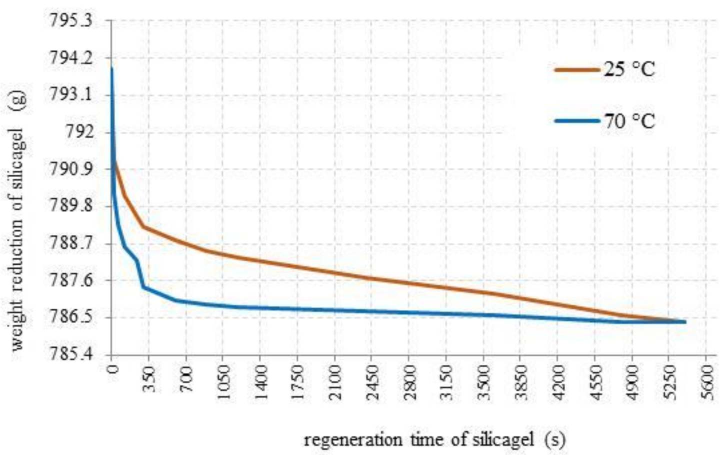

FIGURE 6: Comparison of the time required for the regeneration of silica gel at temperatures of 25°C and 70°C

Drying silica gel at higher temperatures, not only in a vacuum, ensures faster desorption of water molecules from its active surface. Regeneration of silica gel in a vacuum takes place faster compared to classic drying processes, as the amount of removed moisture per unit of time also increases by reducing the pressure in the system.

V. CONCLUSION

Vacuum drying wet material can significantly reduce its drying time due to the low-pressure environment. This lowers the boiling point of water, which accelerates the removal of free and bound moisture from the dried material. Thanks to lower temperatures, this method of regeneration prevents thermal damage or material degradation.

From the experiments presented in the article, it follows that vacuum drying is ideal for the desorption of moisture from silica gel at a temperature of 70°C, as the moisture bound on its surface is released faster. Lowering the temperature also results in an increase in the time required for the regeneration of the silica gel and its reintroduction into the gas drying process.

When designing a device used for the regeneration of silica gel using a vacuum, it is also necessary to consider the economic aspects of drying, as the provision of a vacuum system can mean significant financial costs, but the reduction of the drying temperature compared to classical methods gives the possibility of saving energy spent in the process of regeneration of silica gel.

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