IOSR Journal of Agriculture and Veterinary Science (IOSR-JAVS)
e-ISSN: 2319-2380, p-ISSN: 2319-2372. Volume 16, Issue 2 Ser. II (February. 2023), PP 01-06
www.iosrjournals.org

Analysis of silica production and drying processes

Zongguang, Hu; Yongpeng, Chen; Laining, Zheng; Mingzhi, Cheng；Peng,Wang

(School of Agricultural Engineering and Food Science,Shandong University of Technology, Zibo,255000,China)

ABSTRACT:
Silica is widely used in industry, agriculture, medicine and many other fields due to its wide range of raw materials and excellent properties. The main industrial production methods for silica in China today are precipitation, vapour phase and dissociation. In the production of silica by precipitation and dissociation, drying is an essential part of the process, and the design of a reasonable silica drying method is essential to improve the production efficiency and economic effectiveness of silica.

Key words: *Silica; Industrial production ;Secondary dryin*

Date of Submission: 12-02-2023 Date of Acceptance: 24-02-2023

I. Introduction

Silicon is found in nature mainly in the form of silica and silicates, and is the second most abundant element in the earth's crust with 27.6% of the total.As a result, research into the production and application of silicon compounds is developing extremely rapidly, and this is particularly true of inorganic silicon.Silica is one of the early inorganic compounds of silicon

Silica ($SiO_2.nH_2O$) is an inorganic chemical material, also known as nano-silica, amorphous white powder or flocculent powder, non-toxic, odourless, non-polluting[1].Silica microstructures are spherical with porous, flocculent and reticulate quasi-particle structures, and are widely used in industry, agriculture, medicine and many other fields for their small particle size, large specific surface area, light texture, high temperature resistance, strong adsorption capacity and good dispersion properties[2].

Research began in the mid-1930s in the Soviet Union, the United States and Germany, and by the late 1940s it was in industrial production[3].China's silica industry started in the 1960s.The silica industry started late and failed to form a systematic industrial chain, a problem that has plagued China for a long time.Therefore, the development of new products and application areas and the continuous improvement of the production chain are the core tasks of the current silica industry development.

The main domestic industrial production methods for silica are precipitation, vapour phase and dissociation[4].The three production methods have their own advantages and disadvantages: namely, the precipitation method has become the mainstream of industrial production of silica with its low investment and high rate of return; the fumed method has occupied the high-end market of the silica industry with its high quality products of small particle size and high purity; the dissociation method is a method of preparing silica using non-metallic ores, graminaceous plants and industrial by-products recycling, which is currently small in overall scale and has not formed a complete system of process methods.

There are strict requirements for the moisture content of silica products in the production of silica using different process methods.The core element of controlling the moisture content of silica products is to control the drying process, using reasonable drying methods can greatly improve the quality of the product and production efficiency.A well-designed drying system and control system for real-time monitoring of the drying process and real-time control of the drying process is a fundamental way to improve the efficiency of silica production.The integration and improvement of advanced control theories and methods with existing control systems, the promotion of production efficiency and product quality, and thus the improvement of the competitiveness of industrial products in the domestic and international are the core of the current industrial chain upgrading and development direction.

II. Silica applications

Silica products have superior properties and are widely used in rubber, agriculture, household products and many other applications.

II.I. Silica in rubber products

In the rubber industry, silica is widely used in rubber and plastic products as reinforcing filler to enhance the performance of rubber and plastic products. Silica rubber products are mainly used in various types of agricultural tyres, load tyres and car tyres. For conventional bias tyres, the use of silica can make the tread have better anti-tear characteristics and guarantee good adhesion between rubber and cord, which can effectively reduce the resistance of the production tyre and improve the tyre's wear resistance and wet-slip resistance[5] Along with the increasing concern for environmental protection and comfort in the use of tyres, silica has become a key material in the manufacture of tyres,

Silica can also be used in the production of silicone rubber to enhance the performance of silicone rubber and reduce production costs. The heat resistance, cold resistance, ozone resistance and electrical insulation properties of silicone rubber are outstanding, and the water absorption of silicone rubber is also relatively small, which makes this rubber material can be used in wet environments for a long time[6].

Silica plays an important role as an additive in the production of plastic products. Polyvinyl chloride (PVC) is one of the most widely used plastic materials, and as one of the leading general-purpose plastics, PVC pipes make a significant contribution to economic development and national infrastructure construction, and are widely used in various water supply and drainage systems. The addition of silica in the production of PVC materials can effectively improve the tensile and impact resistance of the material, increase the strength, rigidity and dimensional stability of the material and reduce the production cost, which effectively expands the application market of PVC materials[7].

II.II. Silica applications in agriculture

Silica is currently used in agriculture, mainly for efficient pesticide spraying and fertilizer application, animal feed additives, etc. In pesticide and efficient fertilizer application, silica can improve the efficiency of pesticide use and fertilizer application. Silica is used in pesticides and high efficiency spray fertilizers, mainly for its ultra-high surface area, its surface has a very strong adsorption and the particles are easy to suspend, have good affinity and chemical stability characteristics to improve the suspension rate of pesticides and fertilizers. Silica can also be used as an additive and dispersant for pesticides and as a carrier for different types of pesticides and highly effective spray fertilisers.

In the livestock industry, silica is used in feed as an additive to remove harmful substances from the gastrointestinal wall of animals to facilitate digestion and absorption. In livestock forage fertilizers, silica can act as an anti-caking agent.

I.III. Other applications of silica

Silica is used in a wide range of applications, in everyday chemicals, paper making and in many areas of new materials.

In daily chemical products, silica as toothpaste filler and abrasive, because silica and fluoride have good compatibility, can avoid the disadvantages of calcium salt as abrasive produce insoluble salt, add silica toothpaste has good flexibility, dispersion, paste smooth, soft, good abrasive, not abrasive toothpaste tube body and other advantages. Fumed silica has a strong UV-reflecting ability, good stability, does not decompose after being exposed to UV light, does not change colour, and does not react chemically with other components in the formulation, and as a new type of additive for sunscreen cosmetics, it has promoted a change in cosmetics.

Silica as paper filler can improve the ink transmission resistance and mechanical strength of paper, increase whiteness and reduce unit weight. It can effectively achieve paper lightweighting, reduce production costs and improve paper performance. Silica can also be used in organic light emitting devices (OLED), resin composites, ceramics, glass and steel products, antibacterial materials and many other new materials, playing a vital role in the development and research of new materials.

III. Production of silica

According to a survey of domestic and international data, the results show that there are currently three mainstream methods of silica production, namely precipitation, vapour phase and dissociation. Each of these three production methods has its own advantages, but the precipitation method occupies the mainstream of the silica market with its own advantages of low raw material prices, easy availability, simple production processes and production equipment, and low product prices compared to the fumed method. The production processes and techniques of the three silica preparation methods are now briefly described.

III.I. Silica production by precipitation

The precipitation process, also known as the "wet process", is based on quartz sand, industrial soda ash, industrial hydrochloric or sulphuric acid or nitric acid or carbon dioxide. The process route of precipitation method is generally: first use fuel oil or high quality coal at high temperature to react quartz sand with soda ash to make industrial water glass, the industrial water glass will be configured with water to a certain concentration of dilute solution, and then under certain conditions to add a certain acid, so that the silica precipitation out, and then after cleaning, filtering, remove the excess product by-products and excess water to get the preliminary products, and then drying to reduce the moisture content of the product, to get the product in line with the finished moisture requirements, and then crushed, to get the silica products[8].

Precipitation method of silica production process and production equipment is relatively simple, easy to achieve industrialization, so it is the most common production method used by domestic and foreign related production enterprises. The purity of industrial water glass, an intermediate product of the silica production process using precipitation, is relatively low and contains a large number of metal impurities, making it difficult to obtain high purity silica products. According to the traditional precipitation method of silica products prepared in the mass fraction of silica in about 90%, the production process is not highly controllable, resulting in the production of products with high hydroxyl content on the surface, product activity is not high and easy to agglomerate poor affinity, resulting in product activity is not high, particle size is not easy to control and other problems

The technology of industrial precipitation silica production is constantly being improved, and the industrial production of silica can now be carried out by means of a modified secondary crystallisation method, which allows the mass fraction of silica in the silica product to reach more than 94%, with a significant reduction in the impurity content, and a significant increase in the specific surface area and particle size, even to the nano level. Today's precipitated silica products have evolved to the stage of "highly dispersible silica with a unique structure", with good dispersibility and reinforcement.

III.II. Fumed silica production

The main method of production of fumed silica is chemical vapour deposition. This process is also known as the pyrolysis, dry or combustion method. Its main raw material is siloxane, mainly hexaethylsiloxane, silicon tetrachloride and methyltrichlorosilane.The production process of fumed silica is to send the raw material to the distillation tower for distillation treatment and then to be heated and evaporated in the evaporator and sent to the synthetic hydrolysis furnace with dried and filtered air as carrier. After gasification at high temperatures, the silicon tetrachloride is hydrolysed with a certain amount of hydrogen and oxygen or air at a high temperature of around 1800°C. The silica produced by the gas phase hydrolysis is extremely fine and the reaction gases form aerosols which cannot be aggregated[9]. Therefore, the silica aerogel in the gaseous phase is first aggregated into larger silica particles in an aggregator, and then the produced silica semi-finished products are collected in a cyclone separator and sent to a deacidification furnace, where the finished fumed silica is obtained by blowing the silica with air containing ammonia to a pH of 4-6.

The production process of fumed silica is relatively simple, the reaction conditions are easy to control, and the purity of the silica product obtained is high, reaching a very high purity of 99.8%. The specific surface area of the product is high, reaching 300m2/g, and the product has high reactivity, but the number of hydroxyl groups on the surface is low, which is suitable for the production of high purity silica[10]. The disadvantage of this production is the presence of active hydroxyl groups on the surface, adsorbed water and the preparation process resulting in an acid zone on its surface, making the fumed silica product hydrophilic and difficult to infiltrate and disperse in the organic phase. Fumed silica also has a variety of special features such as a small burn vector, thickening and thixotropy of liquids, prevention of solid phase deposition in suspensions, increased fluidity of powder products, prevention of caking and matting. However, the vapour phase production process is complex and has high requirements for raw materials, equipment and process parameters.

The production process of silica in industrial production using the fumed method is relatively simple, but the preparation process is complex and requires high requirements for raw materials, equipment, temperature and pressure and other process parameters, and the specific operational control of the production process is difficult. In the production of some high grade products, the requirements for heat dissipation in the synthesis furnace, the control of the operation of the high efficiency separator and the absorption of hydrogen chloride gas are very strict and the corresponding production costs are relatively high. In view of the various factors, the fumed silica process is currently only used in the production of high quality silica.

III.III. Silica production by dissociation

There are two main types of silica preparation by dissociation. One uses the dissociation method to produce silica products by dissociating silicon from non-metallic ore by-products using non-metallic ore waste and post-combustion products as a silicon source[11]. The other is to use biomass ash, mainly rice husk combustion products, as a silica source, and to extract silica products from biomass ash by sieving, alkali dissolution and acid precipitation[12].

The production of silica by dissociation is actually a way of reusing industrial products to produce high value-added products. At present, the production of silica by dissociation is mostly at the stage of experimental research for large-scale industrial production, through which higher purity silica can be prepared, but productivity is low and further research is needed to improve production efficiency. This method allows for the secondary use of industrial by-products, saving a large amount of resources for the disposal of industrial waste, and at the same time allows for the production of high value-added silica products, which is quite effective and worthy of study and widespread promotion.

IV. Drying for silica production

The drying and dewatering process is an essential part of the production process of silica using different methods. The precipitation and dissociation methods are used in the production of silica to reduce the moisture content of the semi-finished silica liquor by drying and dehydrating it to produce finished silica that meets the product requirements. Fumed silica is produced using a cyclone separator to collect silica particles in aerogel form, which are dried using ammonia-containing air while the pH of the semi-finished product is adjusted to produce the finished silica.

The rational design of the silica drying process is related to the quality of the silica production products and the qualified rate of the produced products. When using different drying methods such as freezing, spraying, vacuum and oven drying to dry silica, there will be different effects on the physical and chemical properties such as particle size, oil absorption value, specific surface area and microscopic morphology of the dried silica, which is mainly caused by the differences in drying methods that make the discrete silica particles in the drying process will have a greater degree of bonding[13]. In the industrial production of silica, taking into account the efficiency of the drying process, product qualification rate and cost, the economical and efficient combination of spray drying and fluidised bed drying, using the drying and dissociation method for silica production is currently the most economical production method and is most widely used in many enterprises.

IV.I. Secondary drying methods

The two-stage drying method is to divide the drying process into two drying processes, by dividing the drying process into two to achieve the purpose of increasing the production capacity of the drying system and reducing the heat loss of the equipment. The most important application of the secondary drying method is in the drying process of protein reagents. The drying process of protein reagents is different from the traditional drying of low molecular mass drugs. When over-drying, proteins tend to lose their activity and various physical, mechanical and other properties will be changed. With the development and advantages of secondary drying technology, it is gradually being used in the production of more chemical and food products and many other fields.

The application of secondary drying methods in the industrial sector also varies considerably. In PVC drying a combination of airflow and boiling is used, in the dye industry there are thin film and airflow secondary drying units, and in the dairy industry a vibrating boiling dryer is arranged at the bottom of the spray drying tower[14]. In the drying process of silica production, spray drying is used for initial drying and fluidised bed drying as a secondary drying method for drying is the drying method that best meets the interest requirements of plant production.

In the process of preparing silica by precipitation and dissociation, the combination of spray drying and fluidised bed drying for the production of silica is currently a common production method used by domestic enterprises. This drying method not only saves energy, but also allows precise control of the moisture content of the silica and improves the productivity and efficiency of the product.

IV.II.Spray drying

The principle of spray drying is to atomise the material and water mixture through mechanical pressure, using the atomised material mass with a large contact surface area of hot air to quickly evaporate the moisture in the material and obtain a dried product[15]. The spray drying method can directly make the solution, emulsion and other materials can be eliminated evaporation, crushing and other complex links, directly dry into powder or granular finished products. Spray drying can be divided into three different drying methods: pressure spray drying method, centrifugal spray drying method and airflow spray drying method.

In the secondary drying process of silica, spray drying is carried out using a spray drying tower as the first drying link in the production process. The spray drying tower will be used to dry wet silica materials with a moisture content of about 80% to a moisture content of about 12%. In the spray drying tower using pressure spray drying method for drying, the drying process is to filter and heat the air into the air distributor at the top of the dryer, the hot air is spiralled evenly into the drying chamber, the silica material liquid through the high-pressure atomiser at the top of the tower, spray into a very fine mist liquid beads, with the drying tower in parallel contact with the hot air, heat transfer and moisture exchange, so that the silica material liquid in the The moisture content of the silica material is reduced to complete the initial drying of the silica production[16]. Through the drying tower dried silica part of the higher water content of the tower bottom discharge port collection into the next drying link, part of the lower water content of the cyclone separator by the lower end of the award cylinder collection directly collected to generate finished products. The exhaust gas generated by the drying is discharged by the fan, and a secondary dust removal device is installed at the outlet of the fan, which can achieve a recovery rate of 96% or more of the material and avoid polluting the air.

Spray drying has many advantages as the first level of drying in the secondary drying production of silica. The drying efficiency of spray drying is high, the surface area of the material liquid in contact with the air increases after atomisation, and the time to complete the drying is short, and the drying process can be completed within ten to tens of seconds. Secondly, the product produced by spray drying is spherical particles with uniform particle size, good fluidity, good solubility, high product purity and good quality. Spray drying also has many advantages such as simple and stable operation, convenient control and easy to realise automatic operation. However, due to the high efficiency of spray drying, the drying process is rapid and easy to cause low moisture content of the product, and the economic efficiency is reduced.

IV.III.Fluidised bed drying

Fluidized bed is also known as "boiling bed", the process of fluidized bed drying is that the bulk material is placed on the orifice plate and the gas is conveyed from its lower part, causing the material particles to move on the gas distribution plate and be in suspension in the airflow, producing a mixed bottom layer of material particles and gas, as if the liquid is boiling. Engineering on the basis of the ordinary fluidized bed dryer to modify, developed the vibration fluidized bed dryer[17], stirring fluidized bed dryer, centrifugal fluidized bed dryer, etc., to expand the scope of fluidized drying, improve the quality of fluidization, improve the intensity of heat mass transfer.

In the secondary drying process of silica, fluidised bed drying is used as the secondary drying link in the production process. When fluidised bed drying is used, the wet silica material with a moisture content of around 12% collected by spray drying is dried to a moisture content of around 7%. In the fluid bed drying process, the spray dried silica semi-finished products are fed into the fluid bed through the silo, and hot air is fed into the lower part of the fluid bed to dry the materials.

Fluidised bed drying applied to the drying production[18]of silica has the advantages of high heat and mass transfer rate, high drying rate, high thermal efficiency, compact structure, low basic investment and maintenance costs and easy operation. The use of fluidised bed drying in the drying production of silica allows precise control of the moisture content in the product and improves the economic efficiency of the production process.

V. Conclusion and outlook

Silica is widely used as an excellent additive in agriculture and industry. In recent years, China has seen rapid development in many fields such as the pesticide industry, the feed industry and the tyre manufacturing industry[19], and the demand for silica in these industries is increasing[20].

The production technology of silica must be continuously upgraded to improve the real-time monitoring and control system for the production process of silica. In the design and improvement of the silica control system, some advanced control theories and control methods are applied to the system. Through the upgrading of silica production technology to improve production efficiency, reduce production costs and promote the development of related industries.

References

[1]. Chen Yanlin, Shen Yichun, Qian Yigang et al. Preparation and development trend of nano-silica[J]. Glass,2022,49(04):16-19.
[2]. LONG Jin-Fen, ZHANG Jia-Cheng, CHEN Cheng et al. Process research on preparation of silica from acid leaching slag of coal gangue[J]. Chemical Technology and Development,2022,51(05):55-58+77.
[3]. Li Yu-Fang, Wu Xiao-Ming. Production of silica and development prospects at home and abroad[J]. Chemical Industry,2012,30(07):25-29+37.
[4]. Han Xiushan. Production process and application of silica[J]. China Rubber,2005,(06):23-25.
[5]. Tan Dongyu. Status and development of precipitated silica for rubber[J]. Tianjin Chemical Industry,2022,36(03):65-67.
[6]. Yin Changjie, Zhang Qiuyu, Zhang Hepeng et al. Research progress of silicon dioxide reinforced diene non-polar rubber[J]. Synthetic Rubber Industry,2009,32(3):251- 256.
[7]. Chen H, Zheng JX, Xia Y et al. Application of silica in the modification processing of PVC pipes[J]. Plastic additives,2018,(01):21-23.
[8]. Li Yufang,Wu Xiaoming. Production of silica and development prospects at home and abroad[J]. Chemical Industry,2012,30(07):25-29+37.
[9]. WANG Xinyu, HE Zhixin, ZHENG Xingrong et al. Research progress on the preparation and application of nano-silica [J]. Guangdong Chemical Industry,2020,47(09):101-102.
[10]. Liu JL. Preparation of pre-modified silica and its application in green tire formulation[D]. Beijing University of Chemical Technology, 2020.
[11]. Hu D, Fang M, Zhang Q et al. Preparation of silica from solid waste and research progress[J]. China Resource Utilization,2020,38(10):107-109.
[12]. Liu YQ. Production of silica from rice husk and its application[J]. Renewable Resources and Circular Economy,2021,14(10):32-33.

[13]. Chen P.Y., Cheng N., Mi S.Y. et al. Effect of drying method on the performance of silica [J]. China Powder Technology,2017,23(03):30-33.
[14]. Chen Yan,Chen Zhiqiang,Ma Wei. Design of vibrating fluidized bed dryer for secondary drying of milk powder[J]. Journal of Qiqihar University,2000,(01):73-75.
[15]. Mao Wutao, Zhang Zixiang, Ni Ping, et al. Guidance scheme for the preparation of material papers by spray drying method[J]. Guangzhou Chemical Industry,2020,48(10):165-166+207.
[16]. Meng Q, Zhou SY, Li K et al. Construction of silicon/carbon composites by spray drying method and its electrochemical properties[J]. Guangzhou Chemical Industry,2019,47(21):32-36.
[17]. Zhang Binhai,Zhang Hongjian,Wang Peng et al. Design calculation of vibrating fluidized bed dryer [J]. Shandong Chemical Industry,2022,51(21):187-189.
[18]. Han Fei. Design and research of fluidized bed control system for silica drying[D]. Shandong University of Technology, 2021.
[19]. Bu Yifu, Kong Junjia, Wang Ruiqian, Zhang Yanxiang, Wan Shuailong, Wang Siqi. Study on the performance of diatomaceous earth/silica composite filler reinforced natural rubber composites[J]. Tyre Industry,2022,42(12):734-737.
[20]. Shao Qiang, Guo Yijiong, Zhu Chunyu. Current situation and outlook of precipitated silica industry in China[J]. Inorganic Salt Industry,2020,52(07):8-11.

Zongguang, Hu, et. al. "Analysis of silica production and drying processes." *IOSR Journal of Agriculture and Veterinary Science (IOSR-JAVS)*, 16(2), 2023, pp. 01-06.