Current status and development trend of dehumidification technology in low-humidity industries

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Abstract—There are few studies on dehumidification of low-humidity industries which are closely related to production, especially emerging industries. In this paper, the dehumidification demands of low-humidity industries are investigated and analyzed, and the necessity of maintaining low humidity of each industry was emphasized. It introduces the common dehumidification technologies and their applicability in different applications, and on this basis summarizes the application scope division diagram of dehumidification system for low-humidity industries, which can be used as a reference for the initial scheme selection. In the future, the research direction of humidity control technology in low-humidity industries should focus on the development of new desiccant materials, the integration of multiple dehumidification technologies and the complementarity of their advantages and disadvantages, and the development of pilot projects to determine the potential for system transformation. Finally, the existing problems are introduced to ensure that the dehumidification work of the low-humidity industries can be carried out effectively in the future.

1. Introduction
Humidity is closely related to the production and life of human society. Current research work on dehumidification focuses on the comparison of energy consumption and economy of different dehumidification methods[1-4], development of new dehumidification devices and energy-saving operation strategy[5]. The objects studied are mostly civil buildings[5-8] and industrial plants[9,10] that do not have strict humidity requirements and less attention is paid to applications in low-humidity industries. With the acceleration of industrialization, more and more new industries are emerging. Many industries, especially the food industry, the pharmaceutical industry, the lithium battery industry, increasingly need dehumidifiers to control the humidity, so as to make the products qualified. Low-humidity environment is an important guarantee for the effective development of the industry and needs more attention.

In some literatures[12, 13], relative humidity is used to describe low-humidity environment. However, relative humidity often varies with temperature change, so it is not appropriate to use relative humidity to represent the demands of low-humidity industries, and the humidity ratio representing absolute humidity should be considered. It is inconvenient to test the humidity ratio, and since the moisture content in the air is proportional to the logarithm of the dew point temperature, the dew point temperature is used in practice to indirectly represent the low-humidity requirements of the industries[14, 15].
2. Humidity requirements in low-humidity industries

2.1. Low-humidity requirements in lithium battery industry

To reduce the environmental pollution brought by traditional motors, break through the technological fortress and realize the overtaking of brands on the curve, the new energy vehicle industry is highly valued by the Chinese government and has become the strategic emerging industry and the key field of "Made in China 2025". With the expansion of the new energy vehicle market, the demand for lithium battery is growing. Hundreds of lithium battery enterprises have been established in China, and their production capacity is still expanding. From 2015 to 2018, the scale of China's lithium battery industry increased from RMB 98.5 billion to 172.7 billion, with a compound annual growth rate of 20.58%. It is expected that by 2025, the scale of China's lithium battery industry will exceed RMB 600 billion [16].

The technological process of cylindrical power lithium battery is shown in Fig.1, the production process of lithium battery can be divided into three stages: pre-process, mid-process and post-process. The pre-process completes the preparation of positive and negative electrodes of lithium battery. In this process, PVDF is often used as a binder for the preparation of positive slurry, PVDF will generate gelatinous substances when encountering excessive water, resulting in poor fluidity of slurry [17].

The requirement of humidity for electrolyte injection and sealing in the mid-process is stricter. As LiPF₆ is contained in the electrolyte, hydrofluoric acid and gas are produced when water is encountered during the injection process. The generated gas will increase the internal pressure of the battery, when the internal pressure is too high, the battery will burst and cause electrolyte splashing; Hydrofluoric acid can corrode the metal parts inside the battery, which can cause leakage. Leakage means a rapid decline in battery performance, also the leaking electrolyte can corrode nearby machines, leading to more dangerous failures. Therefore, the electrolyte injection should be carried out in the environment of dew point temperature less than -30 ℃, and the battery should be sealed immediately after the injection to prevent the battery interior from contacting the air.

Formation is an important process in the post-process, electrode material reacts with electrolyte at solid-liquid interface to form a passivation layer covering the surface of electrode material, which is called "solid electrolyte interface film". When the humidity exceeds the normal value, the SEI film will be locally non-compact and uneven, and eventually lead to accelerated battery life attenuation. The formation process requires not only the indoor temperature to be above 40 ℃, but also the dew point temperature to be less than -30 ℃.

2.2. Low-humidity requirements in pharmaceutical industry

Pharmaceutical industry, as an important pillar of China's national economic development, has achieved
rapid development in recent years. China's pharmaceutical market accounted for 11% of the global pharmaceutical market, becoming the second largest pharmaceutical market after the United States; The size of China's pharmaceutical market is estimated to reach RMB 2.2873 billion in 2025\[^{18}\]. Highly influenced by policies and institutions, the pharmaceutical industry has now reached a critical period of development. The emerging pharmaceutical industry is rising and growing rapidly, and a batch of new pharmaceutical production bases are being built or will be built soon\[^{19}\].

Pharmaceutical production plant is the main place of pharmaceutical production and the key step of drug development. Conventional drugs have no special requirements for the manufacturing environment, as long as they comply with GMP regulations and maintain the indoor temperature of 18~26 °C and dew point temperature of 9.56~15.15 °C\[^{20}\]. But for some special dosage forms of drugs, as shown in Fig.2, there are special requirements on environmental humidity for their production and storage.

Take effervescent tablets and soft capsules as examples. The production of effervescent tablets involves multiple processes such as granulation, drying, mixing, tablet pressing and packaging. The problem in the production process is that the effervescent tablets is not only easy to absorb moisture, but also easy to appear sticking during tablet pressing. If the ambient temperature in the granulation and tablet pressing is too high, it will also lead to stickiness. Therefore, the production environment of effervescent tablets must be strictly controlled as normal temperature and low humidity: dew point temperature -7.28~-1.27 °C, temperature 15~22 °C\[^{21}\]. Soft capsules are mostly used for non-water-soluble, light sensitive, unstable in heat and humidity, easy oxidation and volatile drugs. Their production process is relatively complex and needs to go through multiple processes such as batching, gelatinization, pill pressing, shaping, pill selection, drying, internal packaging, external packaging and finished products. Soft capsules have strong hygroscopicity, if the humidity of the production workshop is not well controlled in the process of pill pressing and shaping process, the capsules will absorb a large amount of water, adhesion and rupture occur, and destroy the molding and property of the capsules\[^{22, 23}\]. Soft capsules should be kept at 18~22 °C and dew point temperature -3.8~5.4 °C.

### 2.3. Low-humidity requirements in food industry

Since 2017, China has successively issued a number of policies related to the food industry, as shown in Table 1. The implementation of relevant policies has raised access threshold of the food industry to a certain extent, reduced the risk of inferior products disrupting the market, and ensured the rapid development of the food industry. The development of the food industry has also attracted attention to food safety. It is a problem that food processing enterprises need to face and solve to accurately control the humidity of food processing workshop within a reasonable range, ensuring the quality of food processing.

| Date   | Policy                                                                 | Content                                                                                                                                                                                                 |
|--------|-------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 2021.3 | The 14th five-year (2021-2025) plan for national economic and social development of the People's Republic of China and the outline of long-term objectives for 2035 | Vigorously develop and support the construction of green food industry and other projects; Improve the food and drug quality and safety traceability system; Accelerate the development of the food manufacturing industry, expand the green food industry and form a trillion-level industrial cluster. |
To make detailed provisions on the application, examination, management, supervision and inspection of food production license, and further improve the food safety laws, regulations and standard system.

By 2035, China's food safety standards will be among the highest in the world. The food safety risk management ability reaches the international advanced level; The food safety situation has improved fundamentally.

Firmly establish and implement the concept of innovative, coordinated, green, open and shared development; Adhere to the implementation of food safety strategy; Promote the development of a modern food safety management system.

Focus on improving food quality and safety, take innovation-driven supply-side structural reform as the main line, improve the quality and efficiency of food supply, promote the transformation and upgrading of the food industry, improve the food consumption structure, and meet the higher food demand of urban and rural residents.

As a typical representative of low-humidity environment in the food industry, the general process of meat processing workshop mainly includes slaughter and scalding, carcass front section processing, visceral processing, head and foot primary processing, head and foot finishing, carcass back section processing, packaging, high-quality packaging, etc., and according to the order of the technological process, temperature and humidity requirements are gradually increasing[24]. Regarding the first and second level cutting workshops and packing rooms, 《Code for design of pig’s slaughtering and cutting rooms》GB50317-2009[25] only stipulates that the indoor design temperature in summer should not be higher than (10±2) ℃, and there is no limit on workshop humidity. However, high humidity not only increases the bacterial number produced by human body, but also causes microbial reproduction, which is the main factor inducing biological pollution. In addition, in this low-temperature environment, excessive humidity will cause the formation of condensed water, which will drip on the food, resulting in too many bacterial colonies and food safety problems. The dew point of the low-temperature food processing workshop is suggested to be -6.02~2.6 ℃.

In the south of China, mildew is common at the bottom of fermentation tank and the ring beam at the top of floor slab in brewery production workshop under hot and high humidity environment. On the one hand, the cleaning work of the tank at the top is not in place, and it is in the dead corner of ventilation, resulting in cumulative pollution; On the other hand, the higher the indoor air humidity, the easier it is to form condensed water, promoting the propagation of mold, and the dead corner of ventilation makes it easy for mold to adhere and reproduce. In order to ensure pollution-free beer production process, the demand for air conditioning system in the brewery production workshop should be kept at room temperature of 10 ℃ and dew point temperature of -2.63 ℃[26], which belongs to the category of low temperature and humidity.

2.4 Low-humidity demand of storage industry
The storage industry will also emphasize low-humidity control. Archives storehouse is the base of permanent storage of archives, the preservation life of archives is closely related to the temperature and humidity conditions of the preservation environment. However, many existing archives were not designed according to relevant specifications in the early stage of construction, resulting in poor load and heat insulation of the envelope structure, and it is difficult to control the indoor temperature and humidity constantly. In the master film library and audio-visual library of the archives, the high humidity environment will cause the technical archives and video data mildew, so it is necessary to maintain a low temperature and low humidity environment all year round.

Similarly, as a large country of grain production and export, China has suffered huge economic losses
due to the backlog of seeds and improper storage measures. Therefore, it is particularly important to control the environmental humidity of seed storage. Reducing the concentration of water vapor can delay the germination of seeds, discharge the water produced by seed respiration, and maintain the life activity of seeds for a longer time, prolong the storage period and avoid mildew. According to the investigation, the indoor environment of master film library generally maintains the indoor temperature of 13~15 ℃ and dew point temperature of -1.02~2.46 ℃[27]. The indoor environment of the seed warehouse is generally kept at 0~10 ℃ and -11.95~4.09 ℃, which also belongs to the category of low temperature and humidity[28].

Low-humidity industries cover a wide range of dew point temperature according to different process requirements in different fields. Understanding the actual requirements of the process and selecting the dehumidification method suitable for its working environment is the premise to ensure the smooth progress of the production and storage process. The dew point requirements of the above four typical industries are summarized in Table 2.

### Table 2. Summary of low-humidity demand in low-humidity industries

| Industry                  | Typical representative                  | Dew point temperature | Temperature | Category                          |
|---------------------------|----------------------------------------|-----------------------|-------------|-----------------------------------|
| Lithium battery industry  | Coating and rolling slitting           | -26.13~ -1.01 ℃      | 18~28 ℃    | Normal temperature and low humidity |
|                           | Drying and electrolyte injection       | -60~ -30 ℃           | 18~28 ℃    | Normal temperature and ultra-low humidity |
|                           | Formation                              | -60~ -30 ℃           | 40~50 ℃    | High temperature and ultra-low humidity |
| Pharmaceutical industry   | Effervescent tablets                   | -7.28~ -1.27 ℃       | 15~22 ℃    | Normal temperature and low humidity |
|                           | Soft capsules                          | -3.8~ 5.4 ℃          | 18~22 ℃    | Normal temperature and low humidity |
| Food industry             | Meat processing workshop               | -6.02~ 2.6 ℃         | 8~12 ℃     | Low temperature and low humidity  |
|                           | Brewery production workshop            | -6.02~ -2.63 ℃       | 8~12 ℃     | Low temperature and low humidity  |
| Storage industry          | Master film library and audio-visual library | -1.02~ 2.46 ℃     | 13~15 ℃    | Low temperature and low humidity  |
|                           | Seed warehouse                         | -11.95~ -4.09 ℃      | 0~10 ℃     | Low temperature and low humidity  |

### 3. Application status of dehumidification technology in low-humidity industries

Cooling dehumidification uses the dew point method principle, through the cooling coil to cool the air below the dew point temperature, remove the excess water in the air. The cooling medium in the cooling coil can be refrigerant, chilled water or glycol/salt water, depending on the desired dew point temperature. In single dehumidification technology, cooling dehumidification has obvious advantages in initial investment with dew point temperature above 3.3 ℃. Li et al.[29] compared the cost of different dehumidification technologies and found that the initial investment of cooling dehumidification can be reduced by 8.52 million yuan compared with desiccant wheel dehumidification. In terms of operation cost, the liquid desiccant dehumidification combined with heat pump is more energy-saving. Ma et al.[12] conducted economic analysis on four kinds of dehumidification air conditioning with all fresh air for a low-humidity pilot workshop with the dew point requirement of 10.5 ℃ in Shanghai. The results showed that the heat pump assisted liquid desiccant dehumidification air conditioning system had the lowest electricity consumption in summer, followed by the parallel system of two refrigeration systems and the electricity consumption of hybrid solid desiccant wheel dehumidification system (cooling dehumidification + desiccant wheel dehumidification) is the largest, which is more than two times of the former. Under the same dew point requirement, the energy consumption of desiccant wheel based composite air conditioning system and cooling dehumidification system were compared by Liu et al.[30]
and found that the energy consumption of the desiccant wheel compound system is greater than that of the cooling dehumidification system in summer, but less than that of the cooling dehumidification system in the transition season. This is because the indoor heat load and dehumidification may be required at the same time in the transition season, which leads to the disadvantages of cooling dehumidification cold and heat offset more prominent. Therefore, the choice of dehumidification scheme also needs to consider outdoor meteorological parameters and indoor temperature requirements, which also determines the energy consumption of different systems.

Obviously, when the indoor air dew point is required to be below 3.3 °C, the desiccant wheel based hybrid air conditioning system will undoubtedly become the first choice for its superior performance in realizing low humidity environment. The wheel in the system consists of a corrugated medium uniformly loaded with a solid desiccant. Fig.3 shows the dehumidification principle of the dehumidification wheel. The wheel rotates between two different streams of air. Due to the difference in vapor concentration between the process air and the hygroscopic material, the treatment area of the wheel removes water from the process air flowing through it. The specific surface area of the wheel is very large, and the desiccant immersed on it has strong water vapor adsorption capacity, so the dehumidification efficiency is very high[31]. Ouyang Kunze et al.[32] proved that for glass lamination room (temperature 22.5 °C, dew point temperature 0.33 °C), the dehumidification scheme of fresh air to be cooled and dehumidified by cooling coil first, then mixed with return air and finally dehumidified by rotating wheel is much smaller in initial investment and power consumption than using desiccant wheel only. Weng et al.[33] comprehensively considered the energy saving and reliability of the air conditioning system in the soft capsule production workshop, and believed that the cold water dehumidification within the range of cooling dehumidification was more energy saving, and the desiccant wheel dehumidification could ensure more reliable operation of the system. Therefore, the fresh air humidity should be treated as low as possible during the pre-cooling dehumidification process. The fresh air after treatment is mixed with primary return air, then cooled by the middle cooling coil and finally dehumidified by the desiccant wheel after mixed with secondary return air. The air temperature after dehumidification by the desiccant wheel is higher, and it still needs to be cooled by the post cooling coil before being sent into the room, as shown in Fig.4. According to calculation, this scheme saves about 45% energy (room temperature 21 °C, dew point 0.51 °C) compared with the cooling dehumidification and reheating method. Similar composite dehumidification scheme has also been proven to maintain temperatures of 15~22 °C and dew point temperature of -7.47~1.59 °C in tableting room of effervescent tablet[21].

Fig.3 Principle of desiccant wheel dehumidification
Although the dehumidification ability of the desiccant wheel based hybrid air conditioning system is satisfactory in the dew point range of -30~3.3 ℃, its large regeneration energy consumption is still a critical factor restricting the application of the system. How to optimize the system and reduce the energy consumption has become the focus of research. In the hybrid system, the cooling coil for pre-cooling always provide chilled water of 7 ℃, which failed to make full use of their respective advantages. Huang et al.[34] proposed the optimal design method of low temperature and large temperature difference to optimize the system, namely, reducing the temperature of chilled water to 4 ℃ and increasing the temperature difference between supply and return of chilled water. The optimized system energy consumption can be reduced in two aspects: (1) The specification of the wheel is reduced, so as to reduce the regeneration energy. (2) As the temperature difference increases, the chilled water flow decreases, reducing the energy consumption of the chilled water pump and the procurement cost of related accessories. Yao et al.[35] analyzed the energy consumption of the all fresh air constant temperature and low humidity air conditioning system of a certain plant, and explored various methods of preheating regeneration air. The results show that the scheme of heating regeneration air with condensation heat of secondary refrigeration system is the most feasible, and it can save 13803 kWh of electricity every year, accounting for 4.13% of the total annual electricity consumption.

Liquid desiccant dehumidification can also easily meet the dew point temperature requirements above -2 ℃[36-38]. It relies on the vapor pressure difference between air and solution for dehumidification. As the equilibrium vapor pressure above the desiccant solution is lower than the vapor pressure of air, the steam in wet air is absorbed by the desiccant, and the desiccant becomes dilute solution after air absorption. Liquid desiccant dehumidification shows more favorable energy-saving characteristics when combined with low grade energy. Studies show that the liquid desiccant dehumidification air conditioning system driven by a heat pump as shown in Fig.5 has strong dehumidification capacity and stable performance[39]. The dilute solution is regenerated by the condensation heat of the heat pump system, avoiding the gas boilers and steam pipes required by the desiccant wheel, which saves a lot of high-grade energy. The operating cost in summer can be reduced by RMB 37 ten thousand, and the increased initial investment can be recovered in 0.8 years. Zhang et al.[40] designed a lithium bromide solution desiccant deep-dehumidification unit driven by a heat pump, which includes three heat pump systems, three-stage dehumidification and regeneration. The test results show that when the outdoor temperature is 25~32 ℃ and the outdoor dew point is 23.24~25.72 ℃, the unit can achieve the air supply temperature of 3.2~4.0 ℃ and the dew point temperature of -1.25 ~-0.57 ℃. At present, there are few engineering applications of liquid desiccant dehumidification in low-humidity industries, which is related to the corrosiveness of liquid desiccant and the tendency to produce liquid droplets, leading to the research on liquid dehumidification mostly remaining in numerical simulation or laboratory-scale experiments[41, 42]. But now these disadvantages can be eliminated by some means, so in the future liquid desiccant dehumidification is expected to be more widely used in low-humidity industries.
For low-humidity industry with dew point temperature less than -30 °C such as lithium battery drying room, the general dehumidification system, namely single desiccant wheel dehumidification system or liquid desiccant dehumidification system, is difficult to meet this demand. In this regard, many scholars [17, 43, 44] advocate the adopt of two-stage desiccant wheel dehumidification system as shown in Fig.6 to achieve ultra-low humidity requirements and the secondary wheel’s outlet regeneration air is used to regenerate the primary wheel, which can maximize the saving of steam or regeneration electric energy. However, this system also has many disadvantages: (1) The air flow of the primary wheel is larger than the required fresh air, leading to the operation cost is high. (2) The regeneration temperature of the primary desiccant wheel is about 110 °C, and that of the secondary wheel is 140 °C, which means the regeneration energy consumption is large. (3) The complex system structure leads to the difficulty of debugging. In order to solve the above problems in the existing two-stage wheel system, Wan et al. [45] proposed a new ultra-low dew point dehumidification system, which made the primary and secondary wheel relatively independent and the air flow of primary wheel was exactly the amount of fresh air needed in the workshop. The test results show that the regeneration temperature of the primary wheel is 100 °C, the secondary wheel regeneration temperature is reduced to 80 °C, and the total heat load of the new system is reduced by 46.7% compared with the existing system, which not only greatly reduces the regeneration energy consumption, but also extends the life of the secondary desiccant wheel.

The industrial application scope of various dehumidification systems is divided as shown in Fig.7,
as well as the demand scope of some emerging low-humidity industries described in Chapter 1. Fig.7 can provide some reference for suppliers of low-humidity solutions and related enterprises in the selection of dehumidification schemes in low-humidity industries. For example, it can be seen from the figure that both liquid desiccant dehumidification system and desiccant wheel based hybrid system can achieve most low-humidity requirements in food industry. On this basis, considering the liquid dehumidification combining with heat pump technology can not only realize energy-saving, but also its sterilization effect on air is beneficial to food production, heat pump driven liquid desiccant dehumidification scheme can be preferred. In addition, the author believes that the application of dehumidification technology in low-humidity industries should focus on the following three aspects in the future: (1) Develop dehumidification materials with excellent adsorption performance and low regeneration energy consumption and optimize the structure of dehumidification equipment. (2) Explore the feasibility of coupling of a variety of dehumidification technologies to develop a new dehumidification system that is relatively energy-saving and has the advantages of high dehumidification rate and deep dehumidification to replace the existing dehumidification system with large energy consumption. (3) Carry out pilot demonstration projects, explore the feasibility of dehumidification system renovation scheme, compare with the dynamic operation data of existing projects, and promote the successful experience obtained in the pilot work in low-humidity industries.

4. The existing problems of low-humidity industry

The production environment requirements of low-humidity industries are extremely strict, any deviation in the design and construction of any part, from the dehumidification scheme design to the field operation, will cause the indoor low-humidity requirements are not up to standard, which will affect the production quality of products and bring inestimable losses.

The rationality of dehumidification scheme directly affects the dehumidification effect. Therefore, dehumidification solution providers should pay attention to the building itself, construction difficulty, energy saving and many other aspects during the design process. At present, the domestic low-humidity industries are in the stage of rapid development, and the dust removal, dehumidification and purification links have not formed a perfect system, some enterprises tend to choose low-price solutions to save costs. However, such cost-saving approach at the beginning of system planning often results in more costs in
the actual operation. Therefore, at the initial stage of design, suppliers of low-humidity solution should understand the allowable range of temperature and humidity variation in low-humidity area, and choose the best low-humidity solution for customers from the aspects of capital cost, operation cost, maintenance cost and operation reliability; The enterprise itself should also strengthen the understanding of dehumidification, energy-saving equipment, environmental control system knowledge and technology, and change the enterprise management thinking.

A reasonable dehumidification scheme does not mean that the ideal dehumidification effect can be obtained. Outdoor meteorological parameters fluctuate greatly in a year, while indoor humidity needs to be maintained in a low level, so the dehumidification system needs to have the ability to adapt to the change of external environmental. This adaptability depends not only on the configuration of the components of the dehumidification system, but also on the necessary control system. The quality of the control system directly determines whether the humidity can be maintained within the desired range. In addition, the process conditions on site also affect the performance of the system. The author once experienced a project site where the indoor dew point was required to be -40 °C. After two years of on-site operation, it was found that due to the lack of regular cleaning, the air conditioning unit accumulated serious ash, and the final dew point temperature of the room could only be maintained at -27 °C. On the one hand, the system needs to be equipped with accurate and sensitive control system. On the other hand, the enterprise itself needs to pay attention to the cleaning and maintenance. During the operation of the dehumidification system, it is necessary to reduce the number of opening and closing of the room, and it is best to set up a low-humidity positive pressure buffer room, which is conducive to maintaining the stable dew point of the room.

The lower the humidity required by the low-humidity industry, the more energy the dehumidification system consumes, and the large energy consumption of the low-humidity system is a major challenge faced by all technical personnel. In order to reduce system energy consumption, it is far from enough to rely only on modeling analysis and laboratory testing, but also need to combine with the measured data of existing projects for analysis. Now most of the published literatures have not carried out in-depth research on energy saving of dehumidification system in low-humidity industries, and lack of relatively comprehensive operation data of such system. Therefore, relevant personnel should record the dynamic data of the dehumidification system and establish the dehumidification system database based on the existing projects, so as to establish data support for the later energy consumption analysis and select the dehumidification solutions suitable for different low-humidity industries.

5. Conclusion
This paper summarizes the low-humidity demands, dehumidification technology applications and existing problems of low-humidity industries. The main conclusions are as follows:

(1) Among the common low-humidity industries, the pharmaceutical industry belongs to the category of normal temperature and low humidity; Storage and food industry belong to low temperature and low humidity category; Lithium battery industry is special, including both low humidity and ultra-low humidity. Different low-humidity industries have different dew point requirements, and the selection of appropriate dehumidification method is the premise to ensure the smooth operation of the production process and storage process.

(2) Common dehumidification technologies include cooling dehumidification, liquid desiccant dehumidification and desiccant wheel dehumidification. In terms of application, in the case of dew point temperature above 3.3 °C, all three dehumidification technologies can meet the requirements. In the case of insufficient budget in the early stage, cooling dehumidification is preferred, followed by the heat pump driven liquid desiccant dehumidification system with obvious energy saving effect. When the dew point ranges from -30 to 3.3 °C, the desiccant wheel based hybrid system is mostly used, while when the dew point temperature is below -30 °C, the two-stage desiccant wheel system is needed to achieve ultra-low dew point. The application scope division diagram of dehumidification system in low-humidity field can provide initial reference for dehumidification solution suppliers and related enterprises. The application of dehumidification technology in low-humidity industries should focus on
the research and development of new adsorption materials in the future, development of new dehumidification system, pilot and spread new energy-saving renovation schemes.

(3) Unreasonable dehumidification scheme and inadequate on-site maintenance will lead to the non-compliance of indoor low humidity requirements, which will affect the product production quality and bring inestimable losses. The solution of the problem requires the communication between the scheme designer and the enterprise to design an energy-saving and reasonable dehumidification system. The regular maintenance of the enterprise is also an important link to ensure the low humidity environment. In addition, the collection of performance data of dehumidification system in existing low-humidity industries is very necessary for energy consumption analysis and energy-saving transformation.

References
[1] Li N, Wang Y H, Zhang Q, et al. Energy consumption of household radiation air conditioning systems with different dehumidification modes [J]. Journal of HV&AC, 2021, 51(07):100-103.
[2] Zhang H M, Mao R Y, He B, et al. Research on the scheme of temperature and humidity independent control air conditioning system in Guiyang [J]. SHANXI ARCHITECTURE, 2021, 47(13):89-92.
[3] Gao J F. Economic analysis on different dehumidification methods of comfort-oriented air-conditioning system [J]. SHANXI ARCHITECTURE, 2021, 47(15):157-158.
[4] Wang L J, Yang C S. Energy consumption analysis and application of dehumidification air conditioning Units [J]. Equipment Manufacturing Technology, 2019, (08):84-86+91.
[5] Sun K. Energy-saving Analysis of fresh air deep cooling dehumidification air conditioning system in newly built clean operating room [J]. Chinese Hospital Architecture & Equipment, 2020, 21(06):114-116.
[6] Chen Y W, Gan Y L. Energy-saving analysis of the clean air-conditioning system based on fresh air deep dehumidification technology [J]. Contamination Control & Air-Conditioning Technology, 2020, (03):83-86.
[7] Wang W, Liang J, Zhang B T. Analysis of dehumidification mode in the temperature and humidity independent control air-conditioning system [J]. Contamination Control & Air-Conditioning Technology, 2019, (02):102-105.
[8] Chen J B, Han K H, Zhan J W. Comparison of energy consumption of high-rise residential buildings in hot summer and cold winter areas with different temperature and humidity separately controlled air conditioning systems in summer [J]. China Water Transport, 2020, 20(01):106-108.
[9] Qu X N, Wang C Q. Energy consumption analysis of liquid dehumidification direct purification air conditioning in different areas [J]. Energy Conservation, 2020, 39(07):23-25.
[10] An H P, Cui P, Fang L, et al. Energy consumption analysis of liquid dehumidification air conditioning in industrial plant [J]. Energy Conservation, 2017, 36(08):51-54.
[11] Yan W, Sun Y L, Liu S, et al. Analysis of air conditioning system reconstruction scheme for humidity control of plant [J]. Installation, 2021, (06):43-45.
[12] Ma X G, Cai L J. Technical and economic analysis on low humidity air-condition with all fresh air [J]. Building Energy Efficiency, 2013, 41(03):65-70.
[13] Wu N C. Low temperature and humidity air conditioning environment design [J]. Petrochemical Design, 1997, (02):7-12.
[14] Dai B Q. Dehumidification design of lithium battery operating room [J]. Battery Bimonthly, 1988, (02):4-8.
[15] Zeng R X, Yan C C, Li M. Dehumidification classification and advanced research in deep dehumidification technology [J]. Journal of Refrigeration, 2020, 41(06):12-21.
[16] Forward Industrial Research Institute. Analysis of market status and development prospect of China's lithium battery industry in 2020 It is estimated that the market scale will exceed 640 billion in 2025 [Z/OL]. 2020, https://bg.qianzhan.com/trends/detail/506/200211-4dd4534.html.
[17] Zhao L. Analysis and research on low-humidity air conditioning system for lithium cell production workshops [J]. Refrigeration and Air-Conditioning, 2020, 20(03):27-34.
[18] Fu R, Xiang S X. Statistical research on the development of China's pharmaceutical industry [J]. UNDERTAKING&INVESTMENT, 2020, (1):152-154.
[19] Lin R. New thinking of pharmaceutical industry development in China under new pharmaceutical policy [J]. The Merchandise and Quality, 2020, (3):5,7.
[20] Wang J M. Solution and design selection of fixed temperature and humidity in solid preparation workshop [J]. Mechanical and Electrical Information, 2015, (14):36-41,45.
[21] He J Q. Design and realization of oral effervescent tablet laboratory production environment [J]. China Food Safety Magazine, 2015, (15):142-143.
[22] Wang L J, Dong H J, Yang J L, et al. Study on optimization of central air conditioning system in soft capsule production workshop [J]. Journal of Pharmaceutical Research, 2018, 37(4):245-248.
[23] Guo Y G. Discussion of rotary desiccant technology used in design of cleaning plant building for pharmaceutical soft capsule [J]. Chemical and Pharmaceutical Engineering, 2016, 37(3):32-37.
[24] Zhao C C. Design of low temperature clean air conditioning for meat processing workshop [J]. China Construction, 2021, (17):99-101.
[25] Code for design of pig's slaughtering and cutting rooms [M].
[26] Jiang M C, Pan Z B, Zhao S S. Discussion on dehumidification schemes of beer production workshops [J]. Heating Ventilating & Air Conditioning, 2021, 51(7):64-67.
[27] Bu Y, Wang H. Analysis on temperature and humidity control and adjustment of archive warehouse [J]. Inside and Outside Lantai, 2021, (6):16-17.
[28] Zhang X Y. Experimental study of dehumidification system for storage [D]; South China Agricultural University, 2016.
[29] Li B J, Deng L L. Design of low utmost humidity air-condition system by cooling dehumidification [J]. Building Energy & Environment, 2008, 27(06):50-52.
[30] Liu X B, Cao S W. With absorption dehumidification method to achieve year-round constant humidity of the air conditioning system [C]. National HVAC Refrigeration 1998 annual conference, 1998.
[31] Wang Q. Dehumidification in air conditioning system [J]. Journal of Guangdong University of Petrochemical Technology, 2013, (4):63-67.
[32] Ouyang K Z, Zou D Z, Xu X C, et al. Energy efficient design of the air conditioning and cleaning system in a glass production workshop [J]. Heating Ventilating & Air Conditioning, 1997, (S1):62-65.
[33] Weng Z J, Wan X. Application and research of the new development of the dehumidification system in low dew point process in the project [J]. Contamination Control & Air-Conditioning Technology, 2016, (3):98-101.
[34] Huang P X, Wu J S, Lin H S. Energy saving optimization design of air conditioning system in low humidity drying room [J]. China Science & Technology Overview, 2014, (8):2-2.
[35] Yao K D, Wu X P. Energy Consumption Analysis on an all fresh air conditioning system of constant temperature and low humidity for workshop [J]. SHANGHAI ENERGY CONSERVATION, 2010, (06):29-33.
[36] Liu X, Yi X, Jiang Y. Mass transfer performance comparison of two commonly used liquid desiccants: LiBr and LiCl aqueous solutions [J]. Energy Conversion and Management, 2011, 52(1):180-190.
[37] Yin Y, Zhang X, Chen Z. Experimental study on dehumidifier and regenerator of liquid desiccant cooling air conditioning system [J]. Building and Environment, 2007, 42(7):2505-2511.
[38] Bassuoni M. A simple analytical method to estimate all exit parameters of a cross-flow air dehumidifier using liquid desiccant [J]. Journal of advanced research, 2014, 5(2):175-182.
[39] Zhang W. Study on energy saving of temperature and humidity independent control air conditioning system [J]. Science and Technology of West China, 2014, (5):27-29.

[40] Zhang H Q, Liu X H, Jiang Y. Performance analysis of three-stage liquid desiccant deep dehumidification processor driven by heat pump [J]. JOURNAL OF SOUTHEAST UNIVERSITY (ENGLISH EDITION), 2010, 26(2):217-221.

[41] Qi R, Dong C, Zhang L Z. A review of liquid desiccant air dehumidification: From system to material manipulations [J]. Energy and Buildings, 2020, 215109897.

[42] Chen X, Riffat S, Bai H, et al. Recent progress in liquid desiccant dehumidification and air-conditioning: a review [J]. Energy and Built Environment, 2020, 1(1):106-130.

[43] Zhang Q. Application of rotating wheel dehumidification for lithium cell manufacturing shop in air-conditioning system [J]. Power Generation Technology, 2011, 32(5):14-17.

[44] Zhang L H. Discussion on the design of air conditioning system in lithium battery industry [J]. Urban and Rural Studies, 2021, (14):389-390.

[45] Wan X, Zhang X H, Li K W. Application of new type air-conditioning dehumidification system to project with ultra-low dew point process [J]. Refrigeration and Air-conditioning, 2016, 16(1):10-13.