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Application of Molecular Sieve Oxygen Generation Mini-plant under Harsh Environment

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ABSTRACT

Pressure Swing Adsorption (PSA) oxygen generation mini-plant is widely used in all various hospitals for its fast, convenient, and cost-effective features. However, considering the landscape of global markets, the PSA medical oxygen generation mini-plant design basis varies from location to location. Therefore, it forces the manufacturer to design and build the PSA oxygen generation mini-plant more flexibly to enable its compatibility in different extreme ambient conditions (temperature, humidity, pressure, cleanliness) of installation location. For the sake of these concerns, this paper employs the concept of modularity as an approach to PSA medical-grade oxygen generation mini-plant design and application and elaborates 10 key components for 4 modules of PSA medical-grade oxygen generation mini-plant, namely (a) air compressor module; (b) PSA module; (c) oxygen compressor module; (d) smart control module. Under this modularized design approach, this paper investigates the technical features and the design criticality of modular and key components in fulfilling the expected performance, finally achieving and maintaining the overall performance of PSA oxygen generation mini-plant with the selected modules which may be installed worldwide. This paper helps to highlight the variability of PSA oxygen generation mini-plants in harsh environments in four dimensions (temperature, humidity, pressure, cleanliness) and briefs the methodology of the phase gate model for modular approach in oxygen generation mini-plant. It contributes to the literature on this important subject in the modularized design method, adsorption technology, air separation process, etc.

Keywords – *PSA Oxygen Generation Mini-plant; Harsh Environment; Modularized Design; Process Design; medical-grade oxygen .*

INTRODUCTION

Oxygen for industrial purposes is generated through several techniques such as cryogenic air separation units, and membrane-based or adsorption technology. Therefore, it is vital for industrial production, environmental management of food & and beverage, and healthcare. As of 2021, the global annual oxygen turnover has reached USD 46.24 billion and will steadily increase.[1]

Since the first mention of oxygen therapy in the medical journal; *The Principles of Medicine* by Dr. William Osler in 1898, the rapid growth of medical oxygen is continuously driven by innovative technology and capital, today medical-grade oxygen is an indispensable part of medical care in hospital and at home, which the importance and criticality of it have been demonstrated in the context of COVID-19.

Air separation by adsorption to produce oxygen for medical-grade applications represents one of several important commercialized adsorption processes: adsorptive air separation technologies, nitrogen-selective zeolite technologies, and intensification technologies. Furthermore, owing to the development of synthetic molecular sieves, the pressure swing adsorption (PSA) technology, thus the PSA oxygen generation mini-plant is widely used in all various hospitals for its fast, convenient, and cost-effective features.

In this paper, we have drawn the modularity concept and cascaded the PSA oxygen generation mini-plant into 4 modules. Next, 10 key components (units) are defined and elaborated with their respective functionality. Thirdly, we discuss how the module approach demonstrates flexibility to meet the various ambient conditions with its outstanding technical features. Lastly, we introduce the phase-gate review to ensure the module approach achieves the overall PSA oxygen generation mini-plant performance. This paper contributes to the literature on the modularized design method, adsorption technology, air separation process, etc.

DESIGN CONCEPT

Adsorption air separation technologies can generate oxygen from the ambient air in the range of several kilograms to hundreds of tons of Per Day Oxygen (TPDO, normally limited to 300 TPDO) at a purity of 93%±3%. Such oxygen purity levels are simply because the heavy component (nitrogen) accounts for ~78% of the feed air. Other elements, such as argon and moisture, must be pretreated or integrated into the separation process. Therefore, it is understood that adsorption technology's basis is the adsorbent's variable absorptive capacity, depending on the consumption scale of hospitals and medical institutions and the characteristics of their oxygen therapy. Further, as a pressure swing cycle is tailored to the characteristics of the adsorbent, the final capacity very much relies on the temperature, pressure, and other ambient conditions such as humility and cleanliness of the feed air.

To fulfill the customer's requirements flexibly while managing balance of quality and costs, a product management methodology is introduced to ensure a consistent product portfolio across all markets and drive the standardization and modularization of PSA oxygen generation mini-plants for medical applications. It combines standardization and modularization, such as standardized components designed to ensure exchangeability. Meanwhile, the whole mini-plant is organized by combining several fixed & adapted modules engineered on a project basis to improve its constructability, as it is usually pre-assembled and skid-mounted.

The concept of modularity

Modularity is very popular in design and manufacturing, and it is widely used in medical devices for its compatible assembly and flexible adaption to various applications. Modularity generally refers to breaking down complex product systems into simpler units called modules that may function independently. Specifically, modules are self-contained functional units that connect with other units, but do not rely on those other units for their own stable operation.[2]

The properties of modularity

The modular approach featured four defined key properties. When defined in terms of these properties, modularity is not an all-or-nothing feature of designs but can be described in degrees.[3]

1. **Partial decomposability.** It refers to the notion that a complex system may be partially divided into smaller meaningful functional units – modules.[4] Depending upon the complexity of product systems and the necessity of product management, it can be divided from 3–5 modules to hundreds of modules with clear boundaries called battery limits.
2. **Proper functioning.** It signifies that the operation of each module in the design is expected to produce the intended result. This intended result is an integral part of the whole function of the designed complex system. For instance, the air compressor module generates the compressed air to feed gas into PSA module with the proper technical specifications range of pressure, temperature, and dew point.

3. **Standardized interface.** It denotes that modules within the design can connect or communicate with each other in a structured fashion. Interface management systematically controls all communications that support a process operation. In the most basic sense, this property is similar to the property of children's LEGO building blocks – pieces are designed so that one can plug into the next.
4. **Information hiding.** It is also known as "encapsulation" and refers to keeping the specific operation details within a module.[5] For example, the smart control module aims to control the whole product system. But its control philosophy, logic, process parameter, and value are not disclosed to others unless specified.

SKETCH OF MOLECULAR SIEVE OXYGEN GENERATION MINI-PLANT

PSA oxygen generation mini-plant has been developed steadily over the last four decades since Praxair built the first small-scale prototype in 1985.[6] which turned out from early progress driven primarily by large-scale industrial application. This development contributes to the on-site medical oxygen supply solution that prevails in hospital and other medical institutions. To fulfill the more flexibly designated function of the PSA oxygen generation mini-plant, the concept of modularity is applied and fixed modules and adapted modules were developed. Further, to make the modules more stable and minimize the cost, the components forming these modules are standardized, which could be sourced from off-the-shelf market or in-house manufactured.

Modules Definition

Considering the definition of modularity and the proper functioning above, we have described 4 modules of the PSA medical oxygen generation mini-plant, 3 of them are mechanical, and 1 module is instrumentation & control related. Their functionalities are introduced as follows:

1. **Air compressor module.** The system compresses atmospheric air by a screw-type air compressor to a required pressure and cools to ambient temperature through refrigerating drier. The condensed moisture is drained out automatically from the air receiver through an automatic drain valve. As a meaningful functional unit, it has clean compressed dry air as feed gas at 7–8 bar, with air quality that optimally fits the oxygen generator.
2. **PSA module.** The compressed air at constant pressure is passed through filters set and then passed through twin tower PSA module packed with special grade Zeolite molecular sieves, where compressed air is separated to oxygen at the purity of 93%±3% and at a pressure range of 4.5–6 bar. In a few cases, it can be directly delivered to the downstream user.
3. **Oxygen compressor module.** The produced oxygen is filled in the oxygen buffer tank and then boosted by an oxygen compressor to higher pressure. It typically has two configurations: (i) it is boosted to 6–8 bar to achieve oxygen reservation, then delivered to the central pipeline system; (ii) it is additionally pressured to 150 bar for filling oxygen cylinders; however, this is not allowed in China.
4. **Smart control module.** The system has a 7" color touch screen control panel with an integrated oxygen monitor. The touch screen provides a normal user interface for the start-up system, monitors/controls the operation of the process valves, monitors signals coming from the pressure transducers, and provides an alarm system when conditions require it, as well as a fail-safe shutdown mode. This control panel also features diagnostic capabilities and remote monitoring of process parameters.

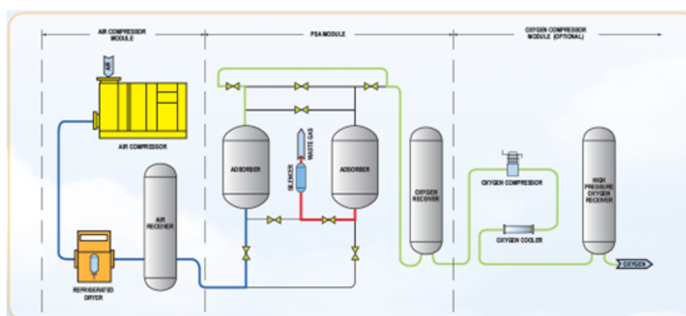

FIGURE 1. Typical PSA Medical Oxygen Generation Mini-plant

Standardized components

The total 10 key components are standardized in series:

- **(1-a) Feed air compressor system.** The mechanical compressor is the essential component in the Generation mini-plant. It gives the compressed air at 7–8 bar for air separation. It typically consumes more than 90% of the generation mini-plant's power and generates most of the noise and vibration. It is either oil-free or oil-injected rotary screw type and air-cooled. It should have a built-in oil separator and air filter; its controls are suction throttle valve type with on-off line control and motor stopper start control. Normally, the advanced compressor should be provided with a soft start or variable speed drive and have a digital display indicating failure, LCD display, and records at least 24 hours of operational data.
- **(1-b) Air dryer.** This is a refrigerant-type capacity air dry with a dew point of <+3°C and pre-filters with automatic drains. The alternative is a desiccant type with auto-regenerating. It removes more than 90% of water in compressed air from the compressor to protect the molecular sieve and piping.
- **(1-c) Air receiver tank.** There is at least one set of air receiver tanks after the compressor. It is made of painted carbon steel with a capacity of at least 1000 L, depending on the compressor. It is equipped with a pressure gauge to indicate the vessel pressure, a safety valve, and a level-sensing auto drain valve.
- **(1-d) Filter system.** A three-stage air filter removes the compressed air's dust, oil, and other impurities. The micro and active carbon layers remove oil and dust up to < 0.01 mg/m^3. The filtration level should comply with ISO Standard 8573-1:2010.1.4.1.
- **(2-a) PSA oxygen generator.** The duplexed tower PSA oxygen generator packed with special Zeolite molecular sieve is skid mounted. It produces 93±3% oxygen from compressed air with a capacity of 3 Nm^3/h to 60 Nm^3/h and usually not less than 4 bar outlet pressure.
- **(2-b) medical grade oxygen receiver tank.** The oxygen is separated through a PSA generator and received in an oxygen tank with less than 1000 L capacity with a bacterial/sterile filter. The oxygen receiver tank should be equipped with a pressure sensor. As aforesaid, the oxygen can be supplied to the central pipeline system.
- **(3-a) Oxygen booster.** The oxygen booster is configured for dynamic oxygen reservation. This has two primary purposes: backup to a short-time turndown case or adjusting the peak oxygen demand. In this scenario, a medical oxygen compressor with an aftercooler is required to boost the oxygen pressure back to 8 bar at a similar feed-in temperature. After that, the boosted oxygen is connected to the high-pressure oxygen receiver with a capacity of 1000–3000L.
- **(3-b) Cylinder filling station.** This component is optional and could be added at the client's request and as local regulations allow. The system comprises an oil-free oxygen-filling compressor at 150 bar pressure and a filling ramp for cylinders to be connected simultaneously. For filling the cylinder, wall-mounted racks shall be on the other side of the wall of the PSA mini-plant room.
- **(4-a) Measurement devices.** Several technical parameters are measured, such as the process's temperature, pressure, and flow rate. The measurement devices are installed in-field for easy checking. They are also transmitted to the centralized control system. Further, there is an integrated and continuous oxygen quality monitoring unit with the following alarm setting: Carbon monoxide (CO) @ 5 ppm, Carbon dioxide (CO_2) @ 300 ppm, water vapor (H_2O) @ 67 ppm, Oxygen (O_2) @ 90%.
- **(4-b) Smart control system.** With the installed sensor and transmitter of in-field measurement devices, the process data is automatically collected, recorded, and self-diagnosed under configured program embedded with the control philosophy and algorithm. Considering the tolerance of normal operation, alarm, and trip, as the three safety zones are pre-defined, the control system will be automatically triggered once the collected data is out of the normal operation range to protect against the potential damage of the PSA oxygen generation mini-plant. Consequently, the oxygen supplies will be shifted to other oxygen sources immediately.

MATRIX OF DESIGN BASIS COVERING HARSH ENVIRONMENT

The performance of the PSA oxygen generation mini-plant is determined by the adsorption and desorption process, which takes place in the duplexed adsorbers. The key variables for the adsorption and desorption process are multi-component thermodynamics and kinetics. Therefore, how to select and optimize those key variables are heavily linked to the physical properties of the adsorbent particles.[6] Moreover, their operating environment is even more discrete when exporting them to the global market. Therefore, a design basis rooted in local operation conditions has to be seriously considered to capture these key variables.

Matrix of Design Basis

The landscape of China from the eastern coast to western Tibet is totally different, and the operating condition of PSA oxygen Generation mini-plant is remarkably changed. Assuming this PSA oxygen Generation mini-plant will be installed not only in China but also for global marketing, the full range of design basis has to be assured. The actual operating condition is very complicated, but in this paper, we focus on the four main factors: temperature, humidity, atmospheric pressure, and cleanliness. While optimizing the cost and balancing the design standardization, we define that the normal case shall cover 80% of application cases and extend to the extreme case in the remaining 20%. Ultimately the design basis is specified as follows in Table 1.

TABLE 1. Matrix of Design Basis

Ambient Condition	Temperature	Humidity	Pressure	Cleanliness
Normal	5–35 °C	40–80%	0.09–0.1 MPa	≤10 mg/m^3
Extreme high	55 °C	95%	(Not applicable)	400 mg/m^3
Extreme low	−30 °C	(Be better)	0.059 MPa	(Be better)

Ambient Temperature

In the normal design, the ambient temperature is in the range of 20°C±15°C. As the suctioned air as feed gas is compressed, the temperature will be increased, and an air-cooled aftercooler is installed to ensure the discharged compressed air temperature is less than 10°C rising to the original ambient temperature. Further, the air dryer will continue to cool down to the pre-defined temperature before entering the PSA module. This cooling-down will generate cold, dry air for the temperature and minimize feed-gas moisture.

There are two sources for the extremely high ambient temperature. One is the high ambient temperature originating from hot summer land, a common understanding. However, another source actually comes from the air compressor. The heat radiation leads to heat accumulation, thus, high temperature. Therefore, ventilating fan and pipe duct shall be connected to the compressor's terminal to remove discharged hot air to minimize the negative compact on the ambient temperature of feed gas. In addition, an air conditioner shall be added for the area with the highest ambient temperature over 35°C.

However, heat preservation is required in cold areas in winter to maintain indoor temperatures above 5°C. Therefore, the discharged air of high temperature could somehow be utilized to warm the feed gas to meet the minimum requirement of 5°C. Therefore, in case of the gap to the normal range of 5–35°C is still extant after all heat balance and recycle measures, then a heater as an auxiliary facility shall be added and switched on in case the indoor temperature of the mini-plant house is lower than 5°C.

Ambient Humidity

In the normal design, the relative air humidity ranges from 60±20%. The air that leaves a compressor reaches 100% humidity as the air is compressed and has a higher temperature. Unfortunately, the compressed air also contains limited oil (unless you use an oil-free compressor) and solid particles. Together, they form an abrasive, often acidic, oily sludge. Without air treatment, this murky mix will enter the PSA module, harming the molecular sieve adsorbents, corroding pipework, damaging pneumatic tools, and potentially compromising oxygen products.

The air treatment typically includes three parts. Firstly, the condensate shall be drained out by the steam traps.

Although an automatic trap is usually mounted, in some cases, a manual trap also makes sense, depending on the amount of condensate. In addition, a humidity sensor is recommended to install to capture the failure of condensation prevention. Secondly, as a partial air dryer, the saturated air with 100% humidity is cooled down to dewpoint; thus, the moisture in the compressed air is removed.

As aforesaid, there are two types of air dryers. One is a refrigerant type with a pressure dewpoint of <3°C (100% relative humidity at 20°C), and another is a desiccant type with auto regenerating. In the normal case, both are suitable. However, if the ambient humidity is high, the refrigerant type is strongly recommended to ensure its higher reliability. Further, to meet the high humidity, the sufficient design margin of the air dryer shall be considered. For instance, 130–150% of the calculated capacity shall be configured.

Atmosphere Pressure

When addressing the pressure, it refers to the plateau area where the atmospheric pressure is less than 0.1 MPa. In the normal design, the mini-plant is assumed to be installed at an elevation no more than 1000 meters, which equals its atmosphere pressure in the range of 0.09-0.1 MPa. Therefore, when the atmospheric pressure decreases by 0.01MPa, the compression ratio of the air compressor will increase by 6~8%, and the compression energy consumption will increase accordingly. In addition, the reduction of atmospheric pressure will reduce the displacement of the air compressor, and the corresponding oxygen production will also be reduced.

To maintain the feed-air to the PSA module at the optimum pressure, the logical thinking is to enlarge the compressor's power to compensate for the insufficient pressure from the atmosphere. Adjustment to the atmospheric pressure by selecting the suitable compressor model is possible, while it should keep in mind that each compressor has a maximum compression ratio that cannot be exceeded. Further, for the compressor and its auxiliary equipment, in practice, it will have a significant impact on power consumption and air consumption. Meanwhile, changes due to altitude will also affect the rated power provided by the motor and internal combustion engine.

External Cleanliness

Cleanliness is very crucial for the oxygen industry. There is a significant issue regarding internal surface cleanliness resulting from machine and equipment, process-compatible coatings, and, more important, the grave consequence of molecular sieve pulverization. This is a profound issue that can be addressed in another special edition. In this paper, we only concentrate on external cleanliness, which is affected by the external environment, such as the oil, grease, particles, and liquid moisture in the feed air.

Therefore, it is heavily linked to two portions: (1) the inlet self-protected dust filter by the compressor. It is designed to remove dust and other physical impurities from the ambient air before it is further compressed in the air compressor; (2) the three-level filtration system for compressed air. Untreated compressed air can be contaminated by dust, water, and oil. This makes filtration a crucial component in the air compressor module. Depending on the external cleanliness, a series of filtration solutions are needed to protect the air-proceeded equipment and the final oxygen products. For instance, wrapped media for wet particles, pleated media for solid particles, macro-structured activated carbon for oil vapors, cyclone for moisture, etc.

DISCUSSION

The adsorption and desorption processes within the duplexed adsorbers are affected by pressure and pressure drop, heat and mass transfer, temperature gradients, and airflow velocity of the feed gas. These elements jointly determine the dense packing of the adsorbents and their fluidization for achieving optimum oxygen production. Taken individually, many of these elements may seem to be conceptually straightforward. However, integrating them to achieve a high-performance process concerning high oxygen purity, high oxygen productivity, and low power consumption at a competitive cost is not trivial.

Modular approach

The modular approach is widely used for complex product systems, including process plants. However, how to define the modular boundaries, the input and output of the modules, and their coordination interface become more important.

Before applying and executing a project, a phase gate review is recommended to ensure the standardized components are properly selected and maintained in due time. Specifically, the phase aligns with the project's time frame, and the gate has a strictly defined project quality. For example, for successfully applying modules for PSA oxygen generation mini-plant, we recommend splitting them into the following phases: conceptual design, basic engineering, and detailed engineering. For the gate review, the gate requirement is specified in advance in Table 2.

TABLE 2. Phase Gate Review for Modular Approach in Oxygen Generation Mini-Plant

Phase	Gate	Typical Gate Requirement
Conceptual Design	CD	• Process topology defined • Utility consumption estimated • Process and environmental safety concepts prepared • Process flow diagram released for basic engineering
Basic Engineering	BE	• P&ID released for mini-plant design • Plot plan completed • Mechanical datasheet/inquiry spec completed • Mechanical tie-in data, installation dimension, and weights fixed • Basic requirements for operation and automation completed
Detailed Engineering	DE	• P&ID released for construction and commissioning • Electrical and instrumentation materials ordered • Equipment foundation completed • Isometrics drawing completed • Factory acceptance test (FAT) for key equipment completed

Temperature

Ambient temperature is a key parameter influencing the performance of oxygen generation mini-plant. The ambient temperature will have three impacts on the mini-plant's performance, finally determining its uptime in the harshest conditions and its build-up cost. Firstly, each compressor has an ideal operational range, reflecting the operation temperature, pressure, and flow rate. Thus, the model selection shall be fixed during the conceptual design, and the deviation from the optimal operating temperature will decrease the compressor efficiency. When the ambient temperature rises, the discharge flowrate of the air compressor will decrease, which means that the shaft power will increase. The record shows that the shaft power increases by about 1% for every 3°C increment in ambient temperature.

Secondly, increasing the ambient temperature will also increase the exhaust temperature of the air compressor, which requires more refrigeration capacity to compensate for the cooling loss, ultimately leading to increased energy consumption. Furthermore, the higher ambient temperature will also decrease the efficiency of the air dryer by 10% for every 5°C and leads to a higher dew point of compressed air, which will have a grave consequence of molecular sieve pulverization. Therefore, the high ambient temperature needs more heat exchange by the pre-cooler or aftercooler of the air compressor. Therefore, it is calculated and additionally configured. Alternatively, a higher-capacity of air dryer is also possible.

Thirdly, the low ambient temperature will decrease adsorption efficiency and oxygen purity in northern winters, especially in extremely low-temperature conditions. Further, in the winterization, the electrical and instrumentation parts, including in-field measurement devices, could be blocked or malfunction, and the safety of the mini-plant could be destroyed.

In summary, besides the process engineering calculation and modules matching as a basis, additional measures should be tailored to the local conditions of hot/cold are assumed. For instance, the air conditioner, ventilating fan and/or electric heater shall be installed indoors to reduce ambient temperature deviation. In addition, of course, the manual assistance to keep the door of the mini-plant house full-open, half-open, and full-close (if still possible to guarantee its safety) is helpful to maintain the normal range of 5–35°C and save power.

Humidity

As aforesaid, the murky mix caused by high humility could harm the downstream units by grinding, corrosion, and polluting the process air. Secondly, it also could influence electric insulation seriously. Thirdly, it will increase power consumption, leading to a high-pressure drop resulting from a block by water vapor or moisture. Last but not least, high humidity will increase the operating load of the air filter at the compressor inlet and increase the replacement cycle.

Although the air that leaves a compressor reaches 100% humidity, the remaining humidity in compressed air turns into water as the air cools while it moves through the system. Because water causes corrosion and damage, proper drains function must be installed, whether automatic, electronic, or manual, to keep downstream equipment working optimally.

One of the most important issues is that the compressor shall be equipped with an aftercooler. It cools the air, turning up to 70% of the humidity into water, which is immediately drained. However, production facilities with extremely high ambient temperatures might need additional cooling, meaning double capacity or add-on aftercoolers in parallel, preventing excess moisture from entering the downstream equipment.

Pressure

When addressing the pressure, it often refers to the plateau area. There are two related two issues. One is the atmospheric pressure in a plain area or plateau area. In the plateau area, lots of atmosphere pressure-related factors shall be considered. For instance, is a specific mass flow or volume flow required? Can the compression ratio, absolute pressure, or gauge pressure be measured? Is the temperature of compressed air significant? But of course, the most crucial factor is that the suction pressure of feed air varies with the altitude. For example, a compressor with a compression ratio of 8.0 at sea level will increase to 11.1 at 3000 meters above sea level.

Furthermore, the atmospheric pressure also depends on the weather. For a specific place, seasonal temperature changes can also affect the pressure value by up to 5%. By the way, high altitude locations always lead to low atmospheric pressure and temperature, which shall be considered in advance. For the details, please refers to the section on "temperature."

Another issue is the process pressure inside the mini-plant, precisely the working pressure of the adsorption and desorption process, which is jointly determined by atmosphere pressure, compressed air, and the pressure drop in the process. There are two main adsorption technologies for air separation by adsorption: PSA and Temperature Swing Adsorption (TSA). PSA methods require electricity to be supplied to the compressor or vacuum pump, while the TSA method involves heating the adsorption bed during the regeneration stage. Here is just a short discussion on PSA pressure setting. For Pressure ratio (PH/PL) is determined from the pressures at the end of the feed step (PH) and at the end of the desorption step (PL). These end pressures establish the boundaries for the N_2 and O_2 working capacities. Selecting PH, PL and PH/PL is a compromise between O_2 recovery and energy consumption, all within the constraints of the available compression equipment.[7]

Cleanliness

Filtration is essential, so the diversified filter types offer a range of purity grades to meet the specific requirements for removing the smallest contaminants, including bacteria and viruses. However, three negative impacts shall be considered when selecting the suitable solution for every application: the pressure drop, the contamination, and the cost of spare parts for filter elements.

In the heavy industrial zone, the inlet filter has to be reinforced, which leads to a pressure drop rising and increases the motor's load; otherwise, too many impurities in the air will increase the purification load of the molecular sieve adsorber and filters. If the purified air fails to meet the expectation, it will also affect the production efficiency of the PSA system and the production quality of oxygen.

CONCLUSION

This paper introduces the PSA oxygen generation mini-plant, a small-scale complex product system widely used in various hospitals, which was neglected in innovation. It addresses how to design and build the PSA oxygen generation mini-plant more flexibly to enable its compatibility in different extreme ambient conditions (temperature, humidity, pressure, cleanliness) of installation location.

Specifically, this paper employs the concept of modularity and elaborates 10 key components for 4 modules of PSA medical oxygen generation mini-plant, namely (a) air compressor module; (b) PSA module; (c) oxygen compressor module; (d) smart control module. Under this modularized design approach, this paper further investigates the technical features and the design criticality of modular and key components in fulfilling the expected performance, finally achieving and maintaining the overall performance of PSA oxygen generation mini-plant with the selected module installed worldwide.

This paper helps to illuminate the variability of PSA oxygen generation mini-plants in a harsh environment in four dimensions (temperature, humidity, pressure, cleanliness) and briefs the methodology of the phase gate model for modular approach in oxygen generation mini-plant. Furthermore, it contributes to the literature on modular design methods, adsorption technology, air separation process, etc.

RECOMMENDATIONS

PSA oxygen Generation mini-plant has been widely used in all-levels of hospitals and medical institutions. To overcome the harsh environment, a new product development process has been established and optimized via S/M/P (standardization/modularization/platform) approaches to ensure product portfolio management and successful application with the selective serialized & standardized components.

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