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Developing an Automated System for Pressure Monitoring and Leak Detection in an Independent Oxygen Generation Plant

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***Abstract*— Oxygen is considered the most important gas on Earth, making up about 21% of normal air under normal conditions. It is used in respiratory therapy and anesthesia, and has the ability to support life and combustion.**

In this research, we studied the components of an oxygen generation plant and worked to raise its efficiency and safety level by using pressure sensors in the various stages of the oxygen generation plant and linking them via a programmable logic controller (PLC) with a control and monitoring system (SCADA) to monitor the pressure of oxygen gas inside the plant, in addition to triggering alarms in cases of low or high pressure, as well as detecting gas leaks that may occur within the pipes and informing officials to intervene in critical cases, which helps in monitoring the plant in order to avoid the risks that may be caused by gas leaks.

Several tests were conducted on the system to ensure its readiness for service, and we observed that alarms occurred on the implemented (SCADA) interface in the event of a decrease or increase in pressure in any part of the station, in addition to alarms in the event of a leak in any branch of the station when there is a difference in pressure between the beginning and end of the branch.

***Keywords*— Oxygen generation plant, Scada, PSA process, gas pressure.**

I. INTRODUCTION

The use of oxygen by the US military can be traced back to World War II, where it was delivered to cyanotic patients at a rate of (4-5 L.m). In 1983, the US military began investigating oxygen generation in the field hospital [1], where oxygen generation plants are built to provide a reliable source of oxygen supply. These compressed gases are used within hospitals in operating rooms, intensive care units, pediatric units, emergency rooms, and patient rooms. [2]

The importance of oxygen gas is evident not only in the medical field, but also in the production of metals and steel, in the manufacture of chemicals, and it is also used in the treatment of sewage, and in many uses in the field of industry and research. Therefore, it was important to conduct many researches that serve the process of producing oxygen gas safely.

Modern oxygen production methods require highly precise gas pressure control to obtain a high-quality product. Furthermore, oxygen generation plants often lack adequate safety measures during production, as gas leaks can cause large explosions and result in fatalities among plant workers.

In 2020, Joshi et al. designed a system for monitoring and controlling oxygen distribution network parameters using a PLC controller connected to a number of sensors (temperature, flow, pressure). The system was able to monitor oxygen through a SCADA interface [3].

In 2019, Nur Hudha Wijay et al. presented a system for monitoring oxygen gas pressure in hospital oxygen cylinders using an Arduino controller, a pressure sensor (MPX5700), and an LCD screen. The system monitors pressure values, and when the value falls below the permissible limit or rises above it, an alarm is triggered. This system successfully monitored pressure readings accompanied by an alarm sound [4].

In 2017, Hesham et al. were able to design a fully automated system for monitoring medical gases in hospitals using the Internet. This system was successful in monitoring up to five gas generation stations in different hospitals, and this system was installed in Egypt (Al-Mujamma Hospital - Cairo) [5].

In 2025, Velicka et al. presented a monitoring system for continuously measuring oxygen concentration in intensive care units using Internet of Things technology. This pilot study demonstrated the effectiveness of the sensing system for continuously monitoring oxygen concentrations in hospital environments [6].

In 2023, Chin et al. conducted a comprehensive theoretical study of the pressure swing adsorption process, highlighting its applications in the production of industrial oxygen gas. The result showed that the continued development of the PSA system would contribute significantly to a wide range of chemical industries in the near future, whether for oxygen production or other gas separation applications [7].

In 2021, Nugraha et al. designed a system that can be used to control and monitor medical gases in hospitals in an integrated and automated manner. This system uses an Arduino microcontroller to read the pressure sensor on the oxygen tube, as well as to read and control the valve status. As a result, the system succeeded in reducing the risks of delays in providing oxygen gas [8].

In 2018, researcher Mai Xu et al. presented a model to simulate the pressure swing adsorption (PSA) process using MATLAB software, resulting in achieving an oxygen purity of 98.21% under optimal conditions [9].

No previous research has addressed the problem of gas leaks, which have caused serious accidents in some countries, including fires and explosions. Therefore, this study automates the monitoring system for an oxygen generation plant using a SCADA interface. This interface displays all conditions and

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problems that may occur during the production process (pressure drops and rises, leak detection and location, and issuing alarms in case of errors). We connected the SCADA interface to a PLC (Programmable Logic Controller) and implemented the program that will send commands to the alarm and monitoring devices to perform the aforementioned tasks.

A. COMPONENTS OF AN OXYGEN GENERATION PLANT

For the purpose of extracting oxygen, the deep cryo-distillation method using industrial air separation units (ASU) was initially used on a large scale as a commercial production process for high-purity nitrogen and oxygen [10].

Oxygen can also be produced electrochemically, where simple electrolysis of water produces oxygen at the positive electrode and hydrogen at the negative electrode. This method is used to produce oxygen for breathing on board nuclear submarines [11].

The most common method for extracting oxygen gas is Pressure Swing Adsorption (PSA), a mechanically simple process widely used to separate a variety of gases. Because this process occurs at modest temperatures and pressures, it starts producing oxygen quickly and is relatively easy to operate and maintain [9].

Figure (1) shows the general layout of an oxygen generation plant that uses PSA technology and consists of:

1. Compressor
2. Centrifugal filter and linear filter
3. Dryer
4. Linear filter
5. Medical air tank
6. Pressure sensor
7. Granulated tanks
8. Oxygen tank
9. Bacterial filter
10. Oxygen purity meter

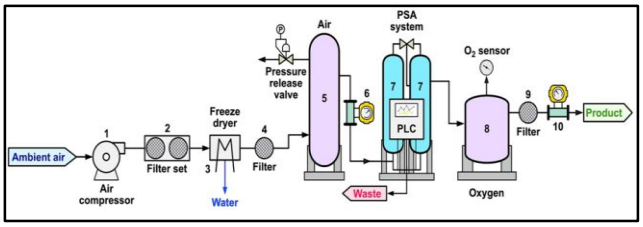


Fig. 1. Components of an oxygen generation plant [12].

1. Compressor:

A compressor is a mechanical device for raising the pressure of gases or a mixture of gases (air) from a low pressure to a high pressure [1]. Atmospheric air enters from the compressor's suction line at atmospheric pressure, which is approximately (1 bar kg/cm), and the compressed air used in pneumatic control exits from the compressor's discharge line at pressures ranging between (5-10 bar). Air compressors are usually driven by electric motors, internal combustion engines, or gas turbines.

2. filters:

Contaminants can enter a compressed air system from three sources: the atmosphere, the compressor, and the piping distribution system. Each potential source must be taken into account when determining the type and location of air handling equipment. Filtration equipment may include primary filters, amalgamation filters, absorption equipment, carbon filters, particulate filters, molecular filters, and any other additional filtration equipment necessary to ensure product quality.

Centrifugal filters: These filters purify the air from impurities.

Linear filters: help to purify the air from dust, oils and water droplets to protect the compressor and the equipment that operates it.

Bacterial filter: This filter purifies the air from bacteria that accumulate in the pipeline and thus prevents them from reaching the vacuum tank, thereby ensuring cleanliness [13,14].

Figure (2) shows some of the linear filters used in oxygen generation plants. The filter may become clogged as a result of dirt accumulation, so it must be cleaned or replaced.



Fig. 2. Linear filters

3. Dryer:

Compressed air is dried to remove atmospheric moisture and to avoid the following problems in the system:

- Rust in pipes, cylinders, and other parts, leading to corrosion and increased maintenance costs.
- Oil burning inside cylinders.
- Valves becoming ineffective and unable to function properly.
- Contamination and damage at points where compressed air comes into contact with sensitive materials.[15]

4. Medical air tank:

After the air passes through the filtration and drying stages, it reaches the medical air tank clean, pure, free from impurities, moisture, and small particles, suitable for consumption when needed, and maintains a certain pressure. Usually, the tank is connected directly to the compressor, and the tank usually contains several elements, including a pressure gauge, a temperature gauge, a valve for drawing condensed water, a vent valve, and a maintenance port [17].

5. Granulated tanks:

This is one of the most important stages that the air goes through, during which oxygen is separated from the compressed

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air using a special selective adsorption technique called pressure swing adsorption (PSA). It consists mainly of two adsorption tanks containing zeolite granules that retain nitrogen molecules and allow the oxygen in the compressed air to flow through them [7-11].

Zeolite is a small, regular crystalline substance that is easy to penetrate. It is of two types, natural and synthetic. Natural is a group of minerals, which are mainly aluminum, sodium, and calcium silicates. They contain a large percentage of water, and the number of its types reaches about 40. As for synthetic zeolite, it has the same properties as natural zeolite, and there are some of them without a complete structural structure. The diverse properties of zeolite have made it possess great importance, and it has been aptly classified in many fields, including agriculture, industry, Medicine, and water treatment [6]. The unique feature of zeolite that makes it ideal for use in the oxygen separation process is its ability to release retained nitrogen gas once the pressure inside the tank is reduced. The general formula of zeolite can be written as follows:
M2/ nO, Al2O3, xSiO3, yH2O, where M is any alkali, or alkaline earth atom, n is the charge of the atom, and x is the ratio of silica and alumina [7,18].

The mechanical properties of zeolite were determined by measuring the crushing strength and the wear rate with temperature changes. Figure (2-7) shows the test results; the crushing strength increases with the sintering temperature, while the wear rate decreases with the sintering temperature. The effect of temperature on improving mechanical properties is more obvious when the sintering temperature is above 800 °C. At 1000 °C, the crushing strength of the zeolite grains achieves the highest value (596.39 N) and the wear rate reaches the lowest value (9.61%) [19].

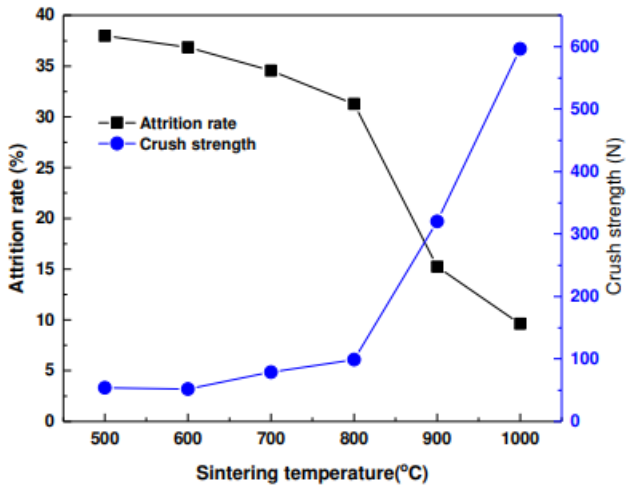


Fig. 3. Mechanical properties of zeolite grains at different temperatures

6. Oxygen tank:

The oxygen coming from the pellet tanks is collected in a special oxygen tank equipped with a safety valve, a pressure sensor to adjust the pressure to a value of 5 bar, in addition to an oxygen purity sensor, as medical facilities require that the oxygen purity not be less than 98%.

B. Adsorption Process:

It is the accumulation of nitrogen atoms or molecules on the surface of the zeolite material. In this process, a layer of molecules or atoms is formed that accumulates densely on the surface of the material [18]. To complete this stage, the adsorption tank is filled with molecular zeolite granules that retain nitrogen spontaneously and allow oxygen to pass through them. This selective adsorption process continues until the adsorption agitator reaches the point of maximum saturation at which the zeolite sieve cannot absorb any more nitrogen gas. It then begins to release the remaining nitrogen that was previously absorbed through the valve, and the zeolite is regenerated. These processes are repeated alternately in both tanks, and the pressure constantly oscillates between the high pressure during adsorption and the low pressure during regeneration [7].
Equation (1) describes the overall periodic processes of PSA and is called the mass equilibrium equation [11]:

$$\varepsilon \frac{\partial(yi\rho g)}{\partial t} - \varepsilon DL \frac{\partial^2(yi\rho g)}{\partial z2} + \frac{\partial(Qyi)}{\partial z} + (1-\varepsilon)\rho p \frac{\partial qi}{\partial t} = 0 \quad (1)$$

ε: Porosity of the absorbent layer
ρp: Absorbent body density
ρg: gas density
Z: Tank axis distance
yi: molar fraction of zeolite
qi: Molecular concentration of zeolite
∂: free oxygen
DL: Mass axial dispersion coefficient

$$D_L = 0.7D_m + 0.5\frac{dpQ}{\varepsilon\rho g} \quad (2)$$

dp: particle diameter
D_m: Molecular diffusion

The absorption rate of zeolite granules was described by the (3) relationship:

$$\frac{\partial qi}{\partial t} = k_{p,i}(qi* - qi) \quad (3)$$

k_p: Effective mass transfer coefficient

qi: It is the amount of the i^3component absorbed at equilibrium.

$k_{p,i}$: Effective mass transfer coefficient of component i (1/s).

The absorption rate was represented by equation (3), where the absorption rate increases abruptly at about 20 minutes for all temperatures as shown in Figure (4), where the amount of oxygen produced was represented.

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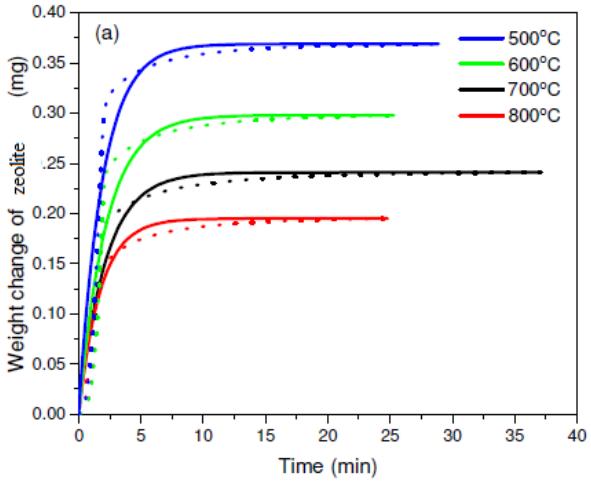


Fig. 4. Absorption rate curves [18].

as shown in Table (1) by the change in the weight of the absorbent material (zeolite granules) [20].

TABLE I. THE VALUES OF THE COEFFICIENTS IN EQUATION (3):

Temperature (°C)	$K_{o2,sorption}$ (1/s)	$K_{o2,desorption}$ (1/s)
500	0.523	0.0465
600	0.454	0.0576
700	0.463	0.0618
800	0.574	0.0464

II. STUDY OF CONTROL SYSTEMS:

In this study, we designed a system capable of monitoring oxygen gas pressure at various stages of an oxygen generation plant, where the programmable logic controller reads and processes the pressure values and then sends them to the computer to display the data to be monitored via the SCADA interface.

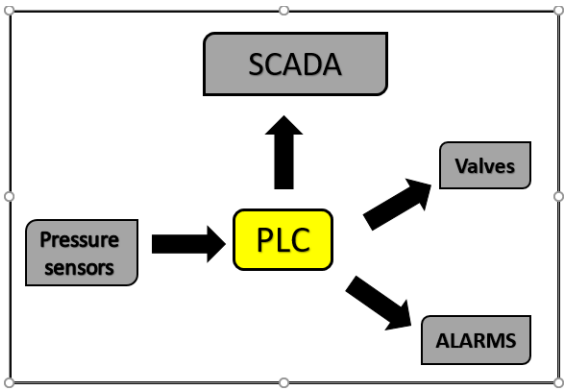


Fig. 5. Proposed system diagram

The system diagram shown in Figure (5) includes the equipment required to configure the proposed system, which is:

A. *programmable logic controller*

A programmable logic controller (PLC) is an electronic device widely used in industrial automation. It can control the logic of the operation of machines, factories, and industrial processes. It receives and processes digital and analog signals, through which control strategies can be applied. This type of equipment is found in industrial environments [16,21].

In this experiment, we used a Delta SX2 PLC, which features four analog inputs and two analog outputs, in addition to eight digital inputs and six digital outputs, as shown in Figure (6):

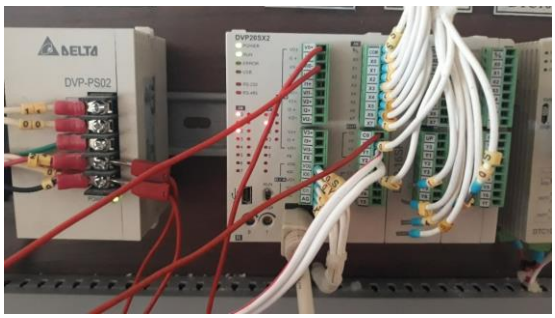


Fig. 6. PLC SX2

B. *SCADA System*

A SCADA system is a system for collecting, monitoring, and controlling data. The word SCADA is an abbreviation for (Supervisory Control and Data Acquisition). A SCADA system consists of a set of software and hardware components, which in turn allow commercial and industrial institutions and organizations to perform several tasks, such as:

- Controlling and managing production and industrial processes locally or internationally.
- Monitoring, collecting, and processing data.
- Directly interacting with devices, sensors, pumps, and valves using computer operating systems.
- Recording and saving events in dedicated files.

Accordingly, the SCADA system is considered one of the most important systems for industrial establishments and institutions, in addition to its importance in maintaining workflow efficiency and speed in data processing, which allows for sound and healthy decision-making [22].

In this research, the xArrow program was used to represent the SCADA interface, which is a graphical interface representing the oxygen generation station, through which the working status of all components is monitored and an alarm is given in the event of a malfunction, Note the figure(7) showing the SCADA interface on the program.

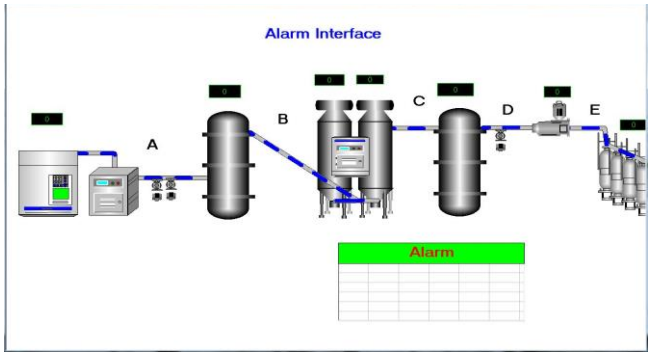


Fig. 7. Simulink model for a cascade dissolved oxygen control system

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C. pressure sensors

It is a device that converts pressure into a small electrical signal that is sent and displayed on measuring devices, or on a computer screen. These pressure sensors are also called pressure transmitters. The measured pressure is expressed as an electrical current ranging in value from 4 to 20 mA, or as an electrical voltage ranging in value from 0 to 5 volts, depending on the actual pressure value. It is expressed using different units of measurement, the most famous of which are (Pascal) and (Bar), and also (PSI).

Figure (8) shows the digital pressure sensor located in the control laboratory that was used.



Fig. 8. pressure sensors

The digital pressure sensor provides a direct pressure reading via an LCD screen in megapascals and gives an analog signal between v(0-5) to the analog input of the PLC. It is also equipped with a mounting base for easy installation in the workstation.

Pressure sensors on network pipeline distribution systems must be installed in a well-ventilated and accessible location [23].

III. SYSTEM TESTS

Three tests were conducted on the SCADA interface to verify its effectiveness and response time to alarms.

• First test:

This test monitors the pressure rise in the medical air tank or the occurrence of a leak on line A by observing the difference in pressure between the compressor reading and the pressure sensor reading in the medical air tank.

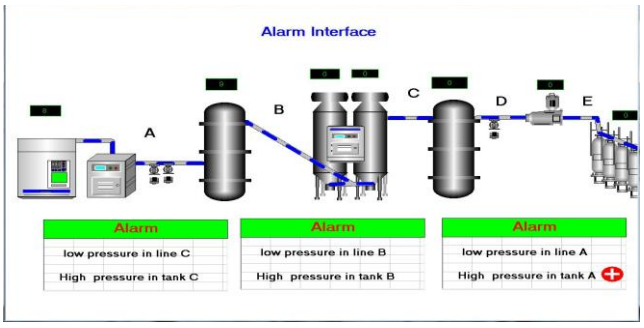


Fig. 9. First test

Figure (9) shows that the pressure in the medical air tank has increased above the design value of 8 BAR.

• Second test:

If the pressure in one of the granule tanks exceeds 5 BAR, the zeolite granules will break down. Therefore, in this test, the pressure within the granule tanks is monitored and the appropriate alarm is given. The pressure on line B is also monitored in order to detect leakage.

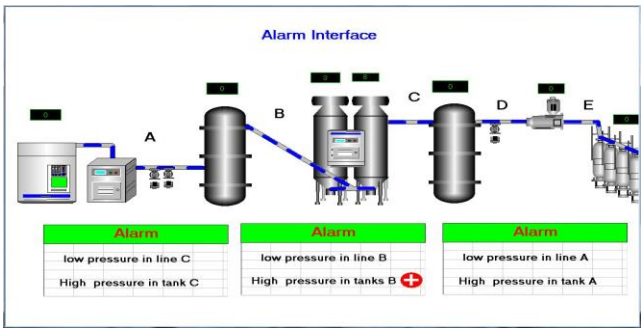


Fig. 10. Second test

In Figure (10), we note the presence of a high pressure in one of the granule tanks, reaching 8 BAR, which is dangerous and can cause the zeolite granules to break down.

• Third test:

In this test, a cut was made in the transmission line between the compressor and the compressed air tank, and we observed an alarm occurring on the SCADA interface. We note in Figure (11) that the compressor reading is 8 BAR while the medical air tank reading is 5 BAR.

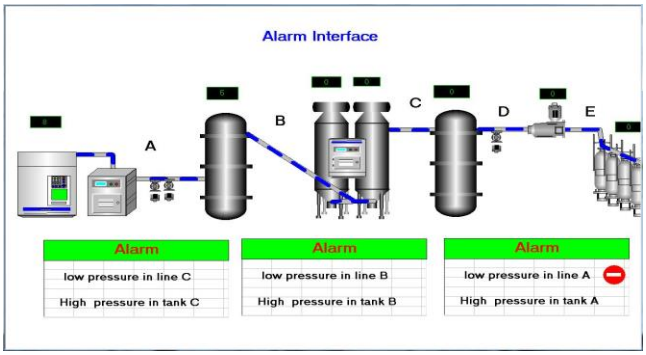


Fig. 11. Third test

DISCUSSION OF RESULTS

The oxygen gas pressure monitoring system at the oxygen generation plant has been automated, in addition to identifying and immediately addressing any leaks that may occur, as well as maintaining safety through alarm systems.

Initially, the experiments and tests that were carried out showed the system's ability to monitor pressure values with high accuracy at various stages of system operation, which contributes to ensuring network stability and distribution efficiency. The system was able to issue immediate warnings when an abnormal change in pressure values occurred, thus providing sufficient time to carry out the required maintenance or improvements. This feature is extremely important to ensure

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the safety and security of the station, as early warnings contribute to preventing potential accidents and reducing risks.

The system is also capable of issuing alerts in the event of a gas leak and pinpointing its location, enabling immediate repairs or continuous monitoring of the affected area. Furthermore, the ability to issue leak alerts allows technicians to intervene as quickly as possible, thus preventing potential damage and minimizing oxygen loss, thereby enhancing system efficiency and reducing maintenance costs.

Therefore, the developed system represents a significant step towards improving network monitoring in oxygen generation plants.

CONCLUSIONS AND RECOMMENDATIONS

- The system contributes to improving the level of safety and security in oxygen generation plants through early detection of gas leaks, or low or high pressure, thus enabling the staff to take quick action to avoid danger to patients.
- The research showed that an effective system can be designed to monitor oxygen gas at various stages of the station using available components at appropriate costs.
- Identifying the location of the leak reduces maintenance costs.
- The designed system can be circulated to all parts of the oxygen gas generation and distribution station to monitor pressures within permissible limits, detect leaks, determine their location, and then issue appropriate warnings for rapid intervention in critical cases.

FOR FUTURE WORK, WE RECOMMEND USING ARTIFICIAL INTELLIGENCE OR MACHINE LEARNING ALGORITHMS TO INCREASE THE ACCURACY OF LEAK LOCATION.

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