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To Maintain the Effectiveness of The Nitrogen Gas Plant by Using Electret Filter

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***Abstract*: In manufacturing industries, nitrogen is used for various purposes as the gas is available in very large quantity in our atmosphere. One such application is in the pressure swing adsorption (PSA) nitrogen gas plant. This review summarizes the research work done in maintaining the effectiveness of the nitrogen gas plant by using electret air filter which increases the number of positive ions, thereby reducing the time lag in production of the nitrogen gas. The electret air filters are used for separation of airborne particles from complex air stream mainly by mechanical and electrostatic effects, in which the two effects are assumed independent of each other. The nitrogen production time is reduced thereby reducing the pressure drop time also and increasing the efficiency of the plant. The mechanisms and principles of filtration and modelling of pressure drop by these filters are discussed and analysed in the PSA nitrogen gas plant.**

***Keywords*: Pressure swing adsorption, Nitrogen gas plant, Electret air filter.**

I. INTRODUCTION

NITROGEN GAS PLANT: -

In our earth's atmosphere nitrogen is the only gas which is in abundance and is inert in nature. This inert quality makes the nitrogen gas very useful for us. It is used in various industries to complete their manufacturing of products.

Nitrogen gas (N2) is a colourless, odourless gas which makes up roughly 78% of the earth's atmosphere. It is used in industry as a simple asphyxiant with inerting quality making it useful in many applications ***where oxidation is not desired.***

N2 as an industrial gas is produced (generated) by one of the following means:

- Fractional distillation of liquid air (from companies such as Praxair, Air Liquide, Linde, etc)
- By mechanical means using gaseous air:
  - Polymeric Membrane
  - Pressure Swing Adsorption or PSA

Fractional Distillation (99.999%): Pure gases can be separated from air by first cooling it until it liquefies, then selectively distilling the components at their various boiling temperatures. The process can produce high purity gases but is very energy-intensive.

Polymeric Membrane (90 – 99.9%): Membrane Technology utilizes a permeable fibre which selectively separates the air depending on the speeds of the molecules of the constituents. This process requires a conditioning of the Feed air due to the clearances in the fibre which are the size of a human hair.

Pressure Swing Adsorption (99 – 99.999%): Pressure swing adsorption (PSA) is a technology used to separate some gas species from a mixture of gases under pressure according to the species' molecular characteristics and affinity for an adsorbent material. It operates at near-ambient temperatures and differs significantly from cryogenic distillation techniques of gas separation. Specific adsorptive materials (e.g., zeolites, activated carbon, molecular sieves, etc.) are used as a trap, preferentially adsorbing the target gas species at high pressure.

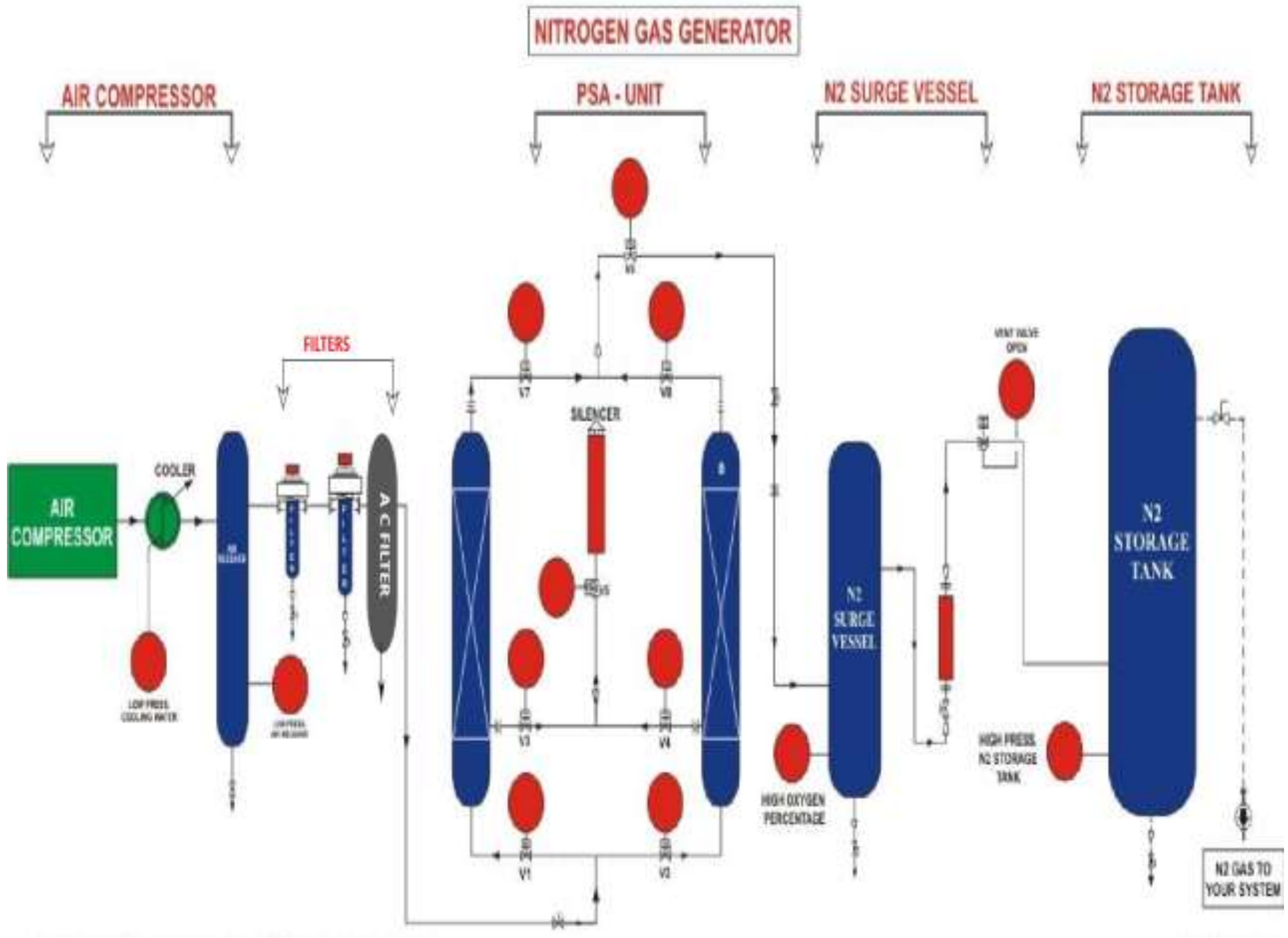


Figure 1: - Block diagram of nitrogen gas plant

ELECTRET AIR FILTER: -

The electret air filters are used for separation of airborne particles from complex air stream. These air filters remove particles from air flow mainly by mechanical and electrostatic effects. The two effects are assumed independent of each other.

There are two ways to combine the electrostatic effect with fabric filtration:

- initially charging the filter fibres with an electret, and continuously charging externally during operation. For initially charged electret filters, the electric charges on electrets dissipate over time so that their efficiency decreases sharply during the operating time.
- The second one is to combine the electrostatic effect with the fibrous filter, including the electret, the ions and external electrostatic field. The electret is a type of fibre containing electrostatic charge.

It is known that when the charged fibres in electret media are clean, the fibre charge can largely enhance the particle removal efficiency. However, as more and more particles deposit on the fibre, the efficiency decreases and reaches a minimum value due to the shielding of the fibre charge.

Reducing fibre diameter is the dominant way of increasing filtration efficiency (Hutten 2007). Theoretical predictions and investigations indicate that, when the fibre diameter is less than 1μm, the filtration efficiency of filter paper can be dramatically improved by the slip-flow effect and the huge specific surface area of ultra-fine fibres (Kosmider and Scott 2002; Ward 2005; Thakur et al. 2013; Otani 2013). Grafe et al. (2001) reported that nanofibers provided significant increases in filtration efficiency with a relatively small reduction in permeability.

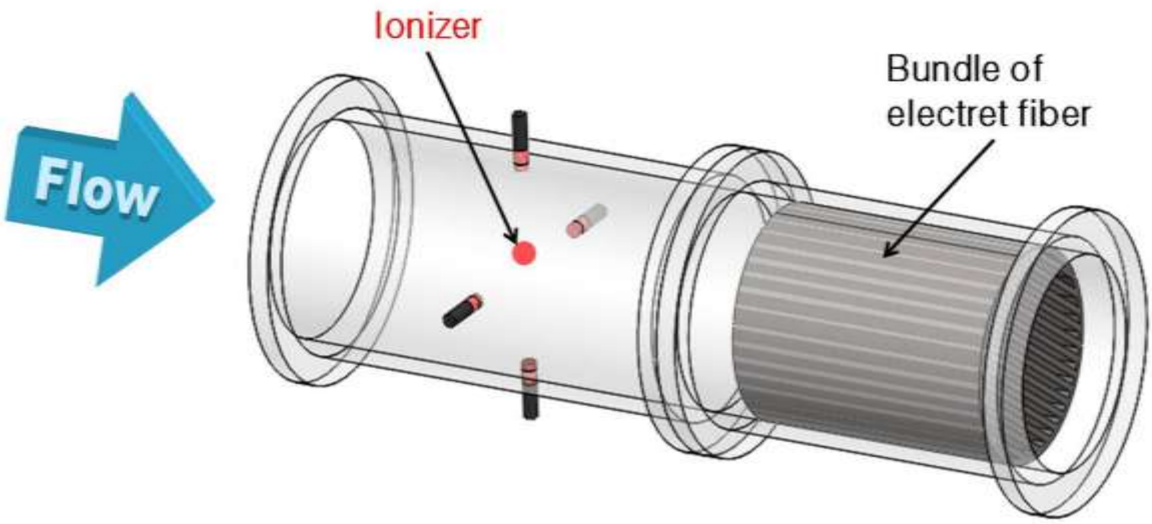


Figure 2: - Electret air filter

II. METHODOLOGY

PSA Principle: -
This Process consists of 2 beds filled with carbon Molecular Sieves (CMS). When Prefiltered compressed air is passed thought one CMS bed, Nitrogen comes out as the product gas. The waste gas (oxygen, carbon dioxide, etc) is discharged back into atmosphere. Upon saturated of the CMS bed, the process switches nitrogen regeneration to other bed, while allowing the saturated bed to undergo regeneration by depressurization to atmospheric pressure. This ensures continuous supply of Nitrogen to your System.

Process: -
In PSA air is passed under pressure through a vessel containing an adsorbent bed of CMS that attracts OXYGEN more strongly than it does Nitrogen, part or all of the OXYGEN will stay in the bed, and the gas coming out of the vessel will be enriched in Nitrogen. When the bed reaches the end of its capacity to adsorb OXYGEN, it can be regenerated by reducing the pressure, thereby releasing the adsorbed OXYGEN. It is then ready for another cycle of producing Nitrogen enriched air.
P S A (Pressure Swing Adsorption) is an advanced air separation technology. It remains an irreplaceable standing on site gas supply field. Under adsorption balance condition, for any adsorbent, when adsorbs one sort of gas, the higher the air pressure is, the more quantity it can adsorb, vice versa. As mentioned above, when the air pressure is high, the carbon molecular sieve will adsorbs lots of oxygen, carbon dioxide and water. When the pressure is reduced to the atmospheric pressure, the adsorbing capacity of the carbon molecular sieve to oxygen, carbon dioxide and water will be small. The PSA equipment is composed of A and B two adsorption towers, which have installed the special carbon molecule sieve, and control system. When the cleaned compressed air enters tower A entrance and flows tc carbon molecular sieve, O2, CO2 and H2O were adsorbed by the carbon molecular sieve, while the nitrogen products flow out from the top of the adsorption tower. The condensed moisture shall be drained out of the air receiver through the drain valve. After a period of time, the carbon molecular sieve adsorption in tower A is saturated. This time, tower A will automatically stop adsorbing, the compressed air flows into tower B to carry out the oxygen adsorption and nitrogen production and then carry out the regeneration to the molecular sieve in tower A. The so-called regeneration is the process of discharging the gas of the adsorption tower to atmosphere to make the pressure reduced to the atmospheric pressure quickly, and then make the oxygen, carbon dioxide, and H2O adsorbed by the molecular sieve desorbed from the molecular sieve.

CAUSES OF FAILURE:-
Due to the increase in negative ions in the normal filter the efficiency gets minimised resulting in the frequent pressure drop.

III. EXPERIMENTAL SETUP

The major components are a pair of adsorbers, surge tanks, switching valves, intelligent PLC, gas analyser and other instruments.

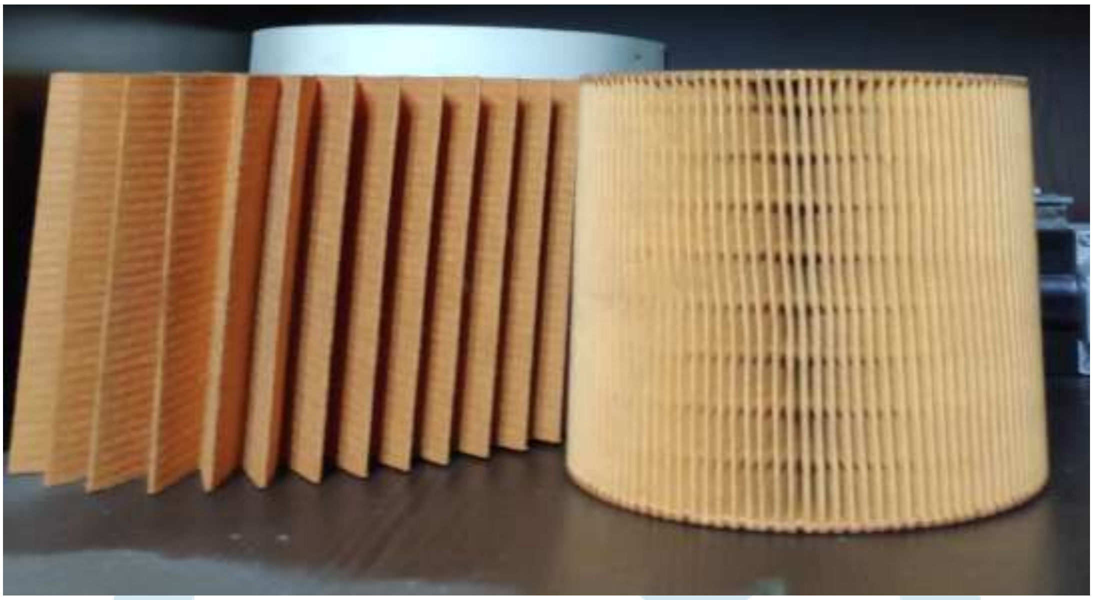


Figure 3: - Electret filter

Figure 4: - Air suction vent & compressor

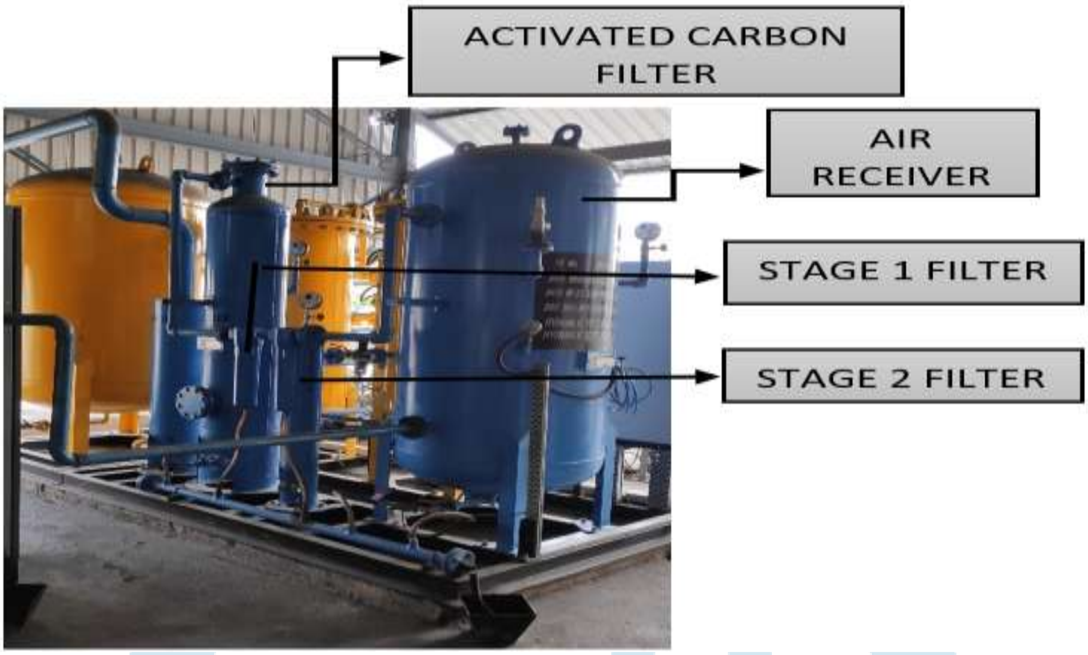


Figure 5: - Filters & Air receivers

Figure 6: - PSA Nitrogen gas plant

IV. EXPERIMENTS

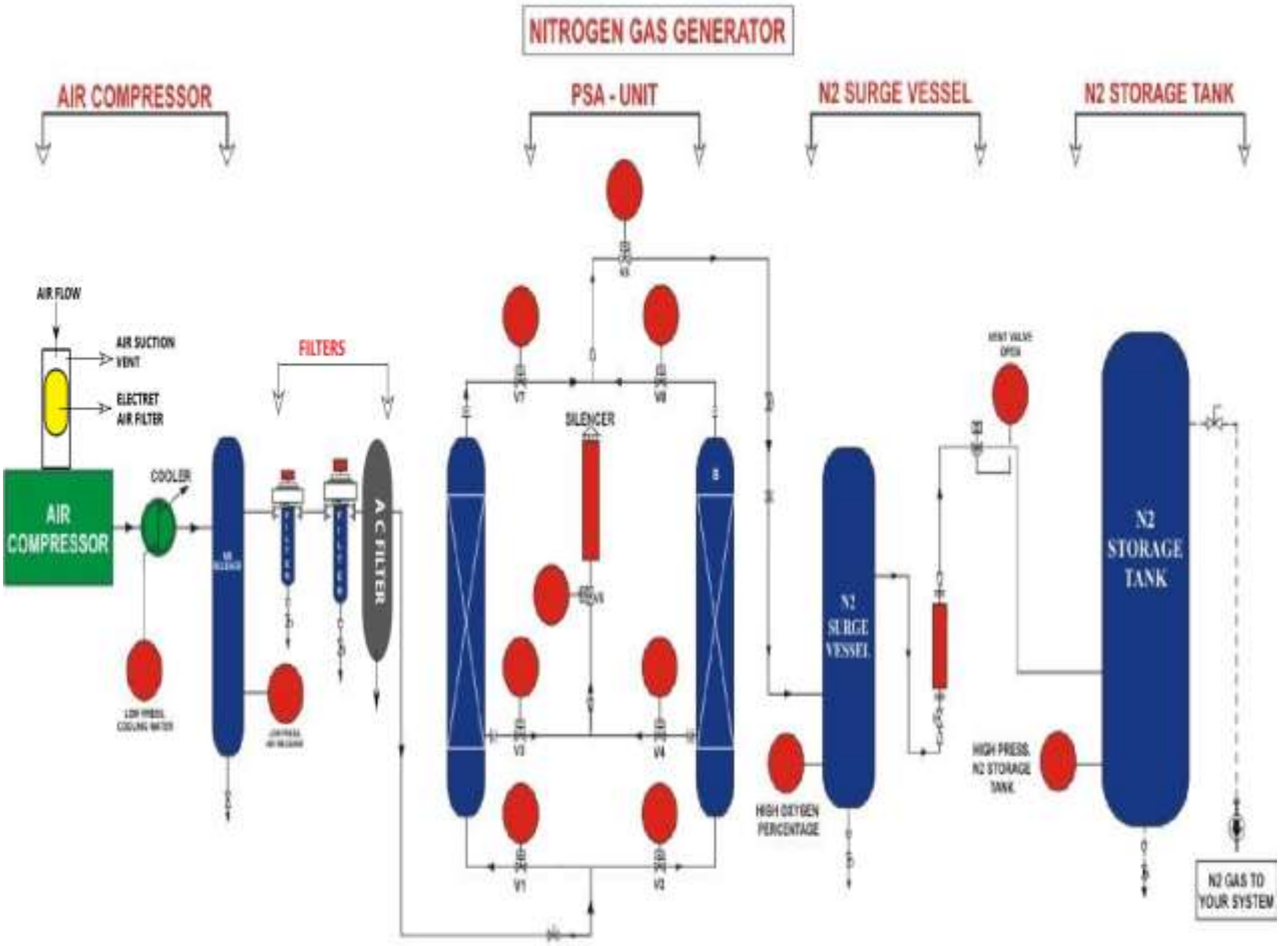


Figure 7: - Block diagram of nitrogen gas plant with electret air filter setup

1. **AIR COMPRESSOR WITH ELECTRET AIR FILTER AND REFRIGERATED DRYER:**
In this setup the air flows in suction vent of the air compressor through the electret air filter. The electret filter acts as the initial filter where airborne foreign particles are removed by the mechanical fibrous filter and increases the number of positive ions by ionising them with the help of electrostatic effect. The positive ions work as the neutraliser by reacting with the negative ions and increases the nitrogen content in the airflow to the compressor. The air compressor is a screw type lubricated air compressor and is air cooled where the air is compressed up to 8.5 kg/cm²g and the temperature of the air varies from 15°C – 20°C. The compressed air is further cooled to ambient temperature in a shell and tube type heat exchanger. The hot, humid air delivered from the compressor is cooled by the dryer in the two stages down to a pressure dew point of +5°C. In the first stage, the compressed air is initially cooled by heat exchanger with the cold air exiting from the dryer. In the second stage, the condensed and contaminated water droplets formed by the refrigeration process is separated by the highly efficient separating system which is connected in series. After this, the compressed air is reheated in the air-to-air heat exchanger and finally, the purified air leaves the dryer in warm and dry state.

2. **AIR RECEIVER:**
After the drainage of the moisture, the cold compressed air is taken to an air receiver to feed to the downstream system and acts as a temporary storage of air for air cyclic consumption in the system. This air receiver is equipped with pressure gauge, safety valve and manual drain valve. The cold compressed air is taken to an impingement baffle type air receiver. The moisture laden air hits the baffle plate, moves downwards thereby draining the moisture by gravity and then moves up with a relatively low velocity.

3. **FILTERS: -**
Three stage oil filters are used in the series for removing of oil, dust and water particle in compressed air inlet.

    a. **SECOND STAGE FILTER: -**
    This is a filter in compressed air line with borosilicate fibre type. This is required to restrict the flow of carried over dust and physical water droplets that might have come in the compressed air supply. Filtration level is 1micron. In this filter lot of moisture gets condensed, therefore manual drain valve are provided at the bottom of the filter.

b. **THIRD STAGE FILTER: -**
The second stage filter is important to make the compressed air supply absolutely free from foreign particle and tiny water droplets. For this purpose, borosilicate fibre element is used in fine filter to clean the air up to 0.01micron level. There is a manual draining valve at the bottom to check for any oil or water accumulation in the unit.

c. **ACTIVATED CARBON FILTER: -**
After third stage filtration unit, there is activated carbon filter which is filled with activated carbon to adsorb oil content in vapour form. These are the towers filled with special grade of activated carbon desiccant to adsorb oil present in the incoming compressed air. At the bottom of the tower, mild steel performed plate with 10mm diameter holes at 20°pitch and 1mm thick stainless-steel perforated sheet is welded to hold the activated carbon bed. Above the sheet the ceramic balls are filled and activated carbon is charged on it.

4. PSA UNIT: -
The dry compressed air is then taken to a twin tower PSA unit consisting of carbon molecular sieves (CMS). Two vessels are filled with special grade alumina and CMS to adsorb moisture, oxygen and carbon di-oxide present in the air. It is important to maintain the tightness of the beds with coconut fibre mats to avoid any sort of dusting or fluidization of the carbon molecular sieves. Each tower has an air inlet valves (V1 & V2) at the bottom, gas outlet valves (V7 & V8) at top and exhaust outlet valves (V3 & V4) at the bottom. Besides these, a valve V6 is for pressure equalisation at the top and a valve V5 after exhaust valves V3 & V4 at the bottom. The air inlet line from air receiver has one globe valve V9 to control the flow of air so that the pressure in the adsorbing towers goes to 10 kg/cm^2g. Separation of nitrogen from air is based on selective absorption of oxygen particles in carbon molecular sieves at high pressure. The carbon molecular sieves is the adsorbent that has infinite number of small pores, the diameter of these small pores are in the same range as those of the molecules of oxygen. The oxygen molecules having smaller diameter than nitrogen molecular enters into these pores at pressures higher than 4 kg/cm^2g. During regeneration, the tower is depressurised to atmosphere to vent off the adsorbed oxygen. This process is continued in both the towers one after the other and the production of the nitrogen is carried out. The two towers work simultaneously producing the required quantity of the nitrogen.

5. NITROGEN SURGE VESSEL: -
Nitrogen from PSA module will have varying purity depending upon the pressure in the absorber during the one-minute cycle time. This vessel gives nitrogen as a product at constant pressure with constant average gas purity. One pressure gauge and one manual drain valve are fitted with vessel.

6. NITROGEN ROTAMETER: -
This is an acrylic type rotameter fitted at the outlet of the surge vessel. This constantly indicates the amount of nitrogen fed to the purification system.

7. BACK PRESSURE CONTROLLER: -
The back-pressure controller is installed after the rotameter to maintain a minimum pressure of 5.5kg/cm^2g in the surge vessel. When the inlet pressure increases to the maximum spring setting, the outlet port of valve will open and in case this pressure goes down, the controller will close the outlet port.

8. HIGH PRESSURE NITROGEN GAS STORAGE TANK: - Nitrogen storage tank is fitted for the storage of nitrogen gas and to remove the variations in the flow of the gas. Pressure indicator is provided over the storage tank to check up non-uniform consumption pattern of the nitrogen gas.

V. OBSERVATIONS

OBSERVATION TABLE - 1

TIME (MIN)	PRESSURE (BAR)
4:15AM	19.69
4:23AM	16.69
4:54AM	18.32
5:03AM	15.32
5:34AM	17.05

Table 1: - Observations before changing the setup

The readings in the table 1 are observed before changing the setup of the nitrogen gas plant at different time intervals (in min) and the pressure (in bar). The initial pressure is 19.69 bar that is maintained at the beginning of the nitrogen plant and keeps on decreasing as per the usage in the plant.

OBSERVATION TABLE - 2

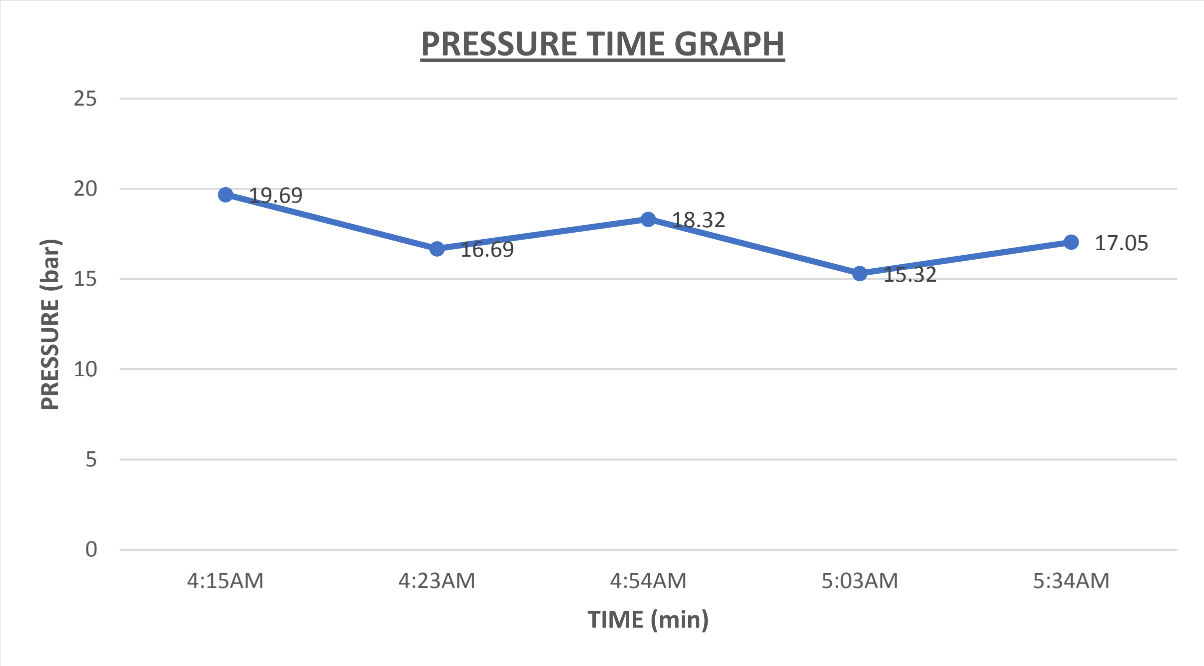
TIME (MIN)	PRESSURE (BAR)
5:15PM	19.69
5:23PM	16.57
5:43PM	18.72
5:51PM	15.63
6:11PM	17.71

Table 2: - Observations after changing the setup

In table 2 the readings are observed after the addition of the electret filter which are taken at various time (in mins) and at pressure (in bar). The initial pressure is maintained to 19.69 bar which is the maximum pressure for the safety of the tank.

VI. RESULT

BEFORE: -

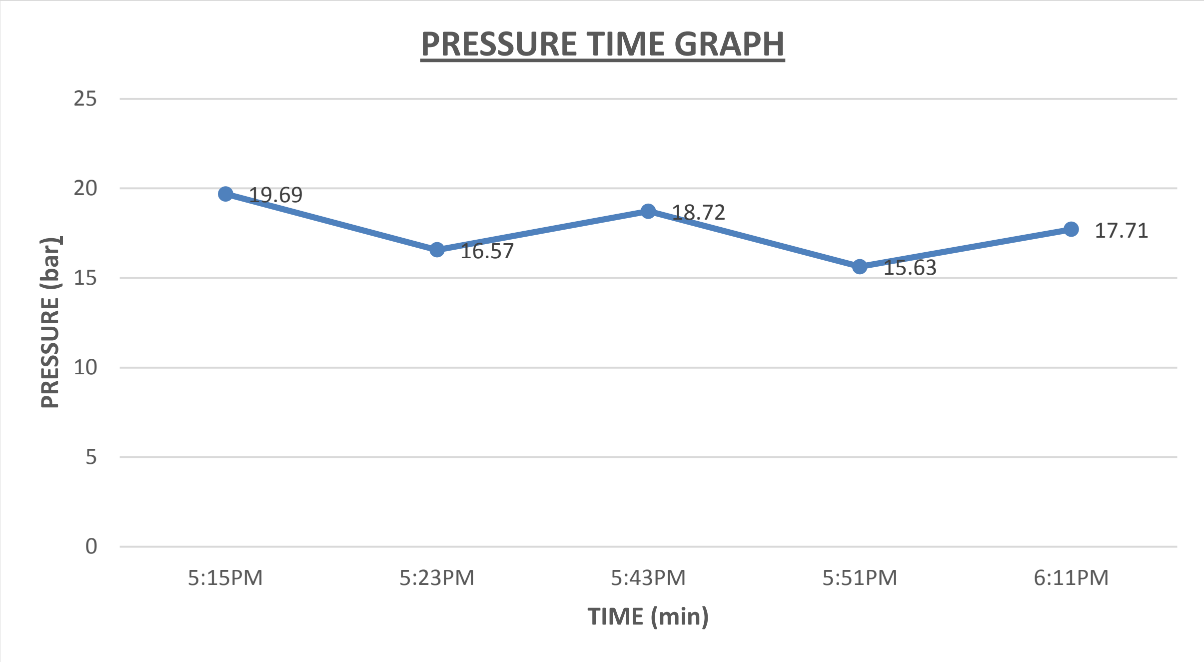


Graph 1: - Before changing the setup

The graph 1 shows the reading from the observations of the pressure-time table of before the addition of the electret filter which is in bar and in minutes. The pressure of nitrogen gas at 04:15 hrs is 19.69 bar which is the initial pressure of the plant, then the nitrogen is used at 04:23 hrs and the pressure is dropped to 16.69 bar which is approximately 3 bar that is used in 8 mins from 04:15 hrs-04:23 hrs. From 04:23 hrs- 04:54 hrs i.e. 31 mins, the generation of the nitrogen takes place and goes till 18.32 bar which develops the pressure of approximately 2 bar. Then the nitrogen gas is used and the pressure is recorded to 15.32 bar at 05:03 hrs again reducing the pressure of about 3 bar. Again, the pressure of the nitrogen gas is generated from 05:03 hrs - 05:34 hrs developing the pressure of 2 bar which is recorded to 17.05 bar.

USAGE: - 8 min (Time) = 3 bar (Pressure)
GENERATION OF N2 GAS: - 31 min (Time) = 2 bar approx. (Pressure)

AFTER: -



Graph 2: - After changing the setup

The pressure-time graph 2 shows the readings of the observation after the addition of the electret filter in the suction vent of the compressor. In this graph the initial pressure is 19.69 bar at 05:15 pm and then the nitrogen gas pressure is used for operation of about 3bar which is dropped to 16.57 bar at 05:23 pm which is 8 min from 05:15 pm-05:23 pm. Then the generation of nitrogen gas takes place from 05:23 pm - 05:43 pm i.e. 20 mins and the pressure is recorded to 18.72 bar which is approximately 2 bar of pressure generation. Again, the nitrogen is used for operation leading to the consumption of nitrogen and reducing the pressure of 3 bar from 18.72 bar - 15.63 bar in about 05:43 pm to 05:51 pm i.e. 8 mins. Again, the production of the nitrogen takes place to 17.71 bar in 20 mins at 06:11 pm.

USAGE: - 8 min (Time) = 3 bar (Pressure)
GENERATION OF N2 GAS: - 20 min (Time) = 2 bar approx. (Pressure)

VII. CONCLUSION

From our theoretical and experimental results, the following conclusions were drawn:

1. Ionizers were operated by applying a few kilovolts to a bundle of carbon fibers which increases the collection efficiency of a filter without affecting the pressure drop.
2. After certain changes 15 days of checks, maintenance and replacements has been achieved which was 7 days earlier.

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