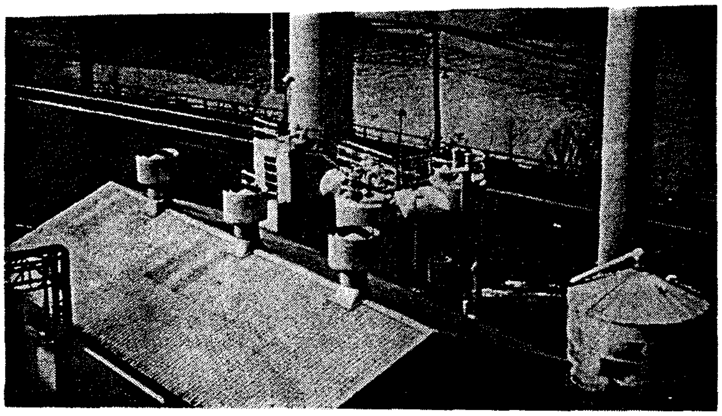

View of a typical unattended oxygen plant with capacity of 48 million cu. ft./month.

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Unattended oxygen plants

Key to safe operation—continuous monitoring of automatic air separation process designed on a fail-to-safe basis.

The unattended plant is defined as one which operates automatically and entirely without operating labor. The building is normally locked to exclude all personnel and the plant is checked weekly or daily depending on the size. The plants have a safety monitoring system which advises a supervisor through a commercial monitoring system if trouble does occur. If the malfunction is serious, a particular piece of equipment or the entire plant will be shut down automatically. Five sizes of unattended plants ranging in capacity from 7 million cu. ft./month to 100 million cu. ft./month have been designed and built. Over thirty of these plants are currently being operated by Linde. The plants are usually located on the customer's property.

The purpose of this article is to present pertinent design features and construction and maintenance practices which have contributed to safe unattended oxygen plant operation. Recognizing the potential hazards associated with gaseous oxygen plants, great emphasis was placed on safety in engineering of these plants. Extensive development work, including two years of pilot plant operation, preceded the installation of the first production unit.

A supervisor is assigned full time to the larger plants and is normally present at the plant 8 hr. a day, 5 days a week. Plants under 40 million cu. ft./month capacity operate completely unattended with weekly service checks which require one man about 6 hr.

Process operation

A low pressure air separation cycle is used in all plants. Refrigeration is supplied by an expansion turbine in the larger size plants and by the addition of liquid oxygen to the column in the small plants. The cycle used in plants of 40 million cu. ft. capacity and larger is shown in Figure 1. Air is compressed to approximately 75 lb./sq. in. gauge pressure and is cooled to liquefaction temperature in one of the regenerators. Dry gaseous oxygen product at atmospheric pressure is withdrawn through regenerator imbedded coils. Waste nitrogen is warmed to ambient temperature in the alternate regenerator. The main cold end air stream and the smaller side bleed air stream from the regenerators are passed through silica gel adsorbers to remove acetylene, heavy or dangerous hydrocarbons, and CO_2. After the gel cleanup, a portion of the cold end air stream is combined with the warmer side bleed air stream to make up the expansion turbine flow. This air is expanded through the turbine and enters the low pressure column. The turbine is a radial inward flow machine loaded with an air blower and operates at 35,000 to 40,000 rev./min. The remaining cold end air is passed to the high pressure column. The rectification equipment consists of the standard high and low pressure column and main condenser. An auxiliary condenser is not used. A liquid phase adsorber is used at the main condenser to remove the trace quantities of acetylene, heavy hydrocarbons, and CO_2 which may have passed through the gas phase gel adsorbers. Liquid oxygen which percolates up through the main condenser during the boiling process is passed through the adsorber and returned to the main condenser liquid sump. The liquid recycles continuously through the gel bed. This adsorber is designed to operate for at least one year without reactivation and has ample safety factor for handling unexpected concentrations of contaminants.

Centrifugal air compressors are used in the larger size plants with capacity control maintained by suction throttling. Two-stage reciprocating air compressors are used on the smaller size plants. Capacity of these machines is controlled by clearance pockets and suction valve unloaders. Oxygen gas is compressed to 150 lb./sq. in gauge in a two-stage reciprocating compressor and is delivered to the customer's pipe-line. During periods of low demand, an additional single stage booster compressor is used to further compress a portion of the oxygen for storage. All compressors are electrically driven.

Storage facilities for gaseous and liquid oxygen are usually provided for use during peak demand and to insure a continuous supply during plant shutdown.

The introductory photograph shows an over-all view of a 48 million cu. ft./month installation including the cold box, gas receivers, insulation storage silo, and compressor building. The cold box consists of three interconnected casings. One casing contains the columns, main condenser, and adsorbers, the other two casings contain the regenerators.

A thorough preventive maintenance program is maintained on all compression equipment to insure safe and efficient operation. Cooling water jackets are flushed periodically to remove silt or other obstructions. The valves, connecting rods, and piston rings, etc. are checked periodically to detect any faulty conditions. The petroleum base lubricating oil used in the reciprocating air compressors must meet rigid specifications. The primary requirements are low carbonaceous deposits, low hydrocarbon contamination of the air stream and good lubricating qualities. Special precautions are taken during the erection and operation of the oxygen compressors to insure safe operation. The compressors are normally cleaned at the factory; however, if they are permitted to set idle during extended construction periods, the machines are dismantled to remove any rust and other foreign materials. The oxygen compressors are initially run with air to check for possible hot spots or other malfunctions. The temperature and pressure monitors used to safeguard the compressors are discussed below.

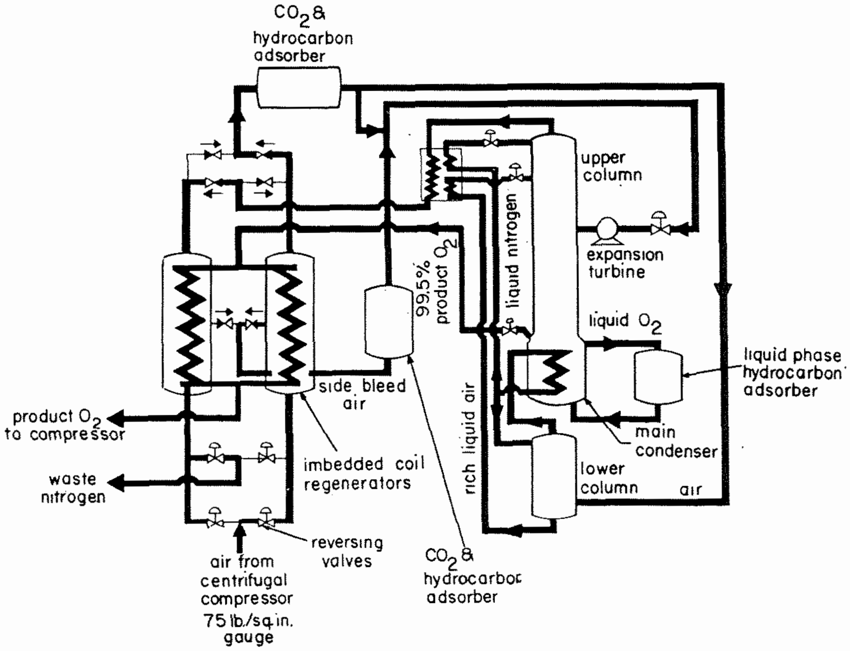

Figure 1. Simple process diagram of an air separation unit for processing 80 million cu. ft./month of oxygen.

Plant instrumentation

Sufficient instrumentation is provided to operate and control the process, and protect equipment in case of malfunction. All of the process controls are basically pneumatic. The monitoring equipment is essentially electrical. The prime consideration in instrument selection was reliability. The simplest instrument which would perform the desired function reliably was chosen.

Process controls are provided to perform the functions normally carried out by the operators. Typical controls on the cold box components are liquid levels, regenerator side bleed air flow, expansion turbine flow, turbine temperature, product purity, and regenerator reversal. In the larger plants it is necessary to automatically switch and reactivate the side bleed gel adsorbers. Instrumentation is also provided to control the capacity of the air compressor, liquid oxygen storage utilization, gaseous oxygen storage and the oxygen compression system. The instruments are conventional pneumatic recorder-controllers.

The cleanliness and reliability of instrument air supply is important. In these plants the air for operation of instruments and valves is taken from the process stream at a point where it is oil-free, and has a dew point of −150°F. With this ideal supply, problems arising from instrument air supply are negligible.

Monitoring system

Process monitors, the key to an unattended plant, are provided for items which would normally be observed by the operator. The monitoring system is separate and independent from the process control system. In applying monitors to critical variables which are controlled, it was assumed that a controller with alarm contacts cannot monitor its own control and a separate instrument for this purpose was provided. A typical example of this is the liquid level monitor on the oxygen side of the main condenser. Primary sensing elements for pressure switches are bellows or diaphragms. Elements for temperature switches used for ambient or higher temperatures are normally based on the expansion of a liquid in a closed system. Resistance thermometers are used in the low temperature process.

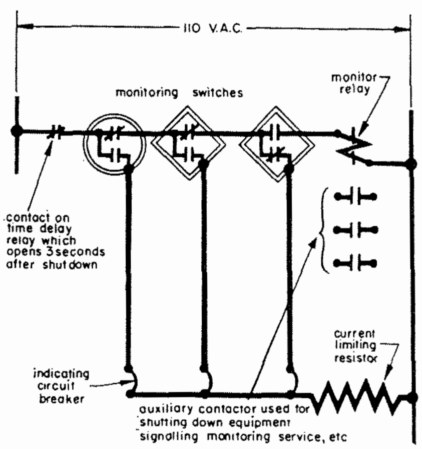

Figure 2. Typical safety monitor circuit used for safe operation of unattended oxygen plant.

The primary variables that are monitored in the cold box portion of the cycle are high and low liquid level in the main condenser, product purity, regenerator or reversing heat exchanger reversal, and bursting disk temperatures. Several monitors are required on the side bleed adsorber reactivation system. Items monitored on the expansion turbine include oil pressure and temperature, bearing temperature, high and low speed, and high and low discharge temperature. Items that are normally monitored on the compression equipment are common cooling water pressure, oil pressure, interstage and discharge temperatures, high and low discharge pressure and bearing temperatures on compressors, motors and gear boxes. The standard overload protection is provided on all electric motors. On the larger plants monitors are provided for as many as 80 items.

A simple monitor circuit is shown in Figure 2. Each of the monitor switches has a normally open and normally closed contact. When a switch actuates, these contacts simultaneously reverse. The normally closed contacts are defined as those which are closed during normal, safe plant operation and are all wired in a series-type circuit to the coil of the monitor relay to provide an energized circuit of the "fail-to-safe" design.

The normally open contacts on each of the monitor switches are wired to a separate indicating circuit breaker. In case of a malfunction, the series circuit opens causing the monitor relay to drop out. At the same time the normally open contact on the monitor switch closes, causing the indicating breaker to actuate. Power is disrupted by the time delay relay after a few seconds delay to prevent other breakers from actuating due to secondary abnormal condition caused by the shutdown. When the monitor relay drops out it opens the compressor motor start-stop circuit to affect the compressor shutdown. Additional contacts on the monitor relay open the circuit to the commercial monitoring service causing a signal to be transmitted and lights a pilot light to indicate which equipment has been shut down.

All indicating circuit breakers in the monitor circuit are mounted in a panel to provide visual indications of actuation. This panel contains 76 breakers or annunciators and is used on an 80 million cu.ft. per month plant. To explain the operation of the panel, suppose the plant had been shut down due to high discharge temperature on an oxygen compressor. Upon arrival at the plant, the supervisor would find indicator No. 856 actuated and the base load oxygen compressor circuit pilot light glowing bright. The difficulty is therefore clearly indicated. Upon restarting the plant, it is necessary to by-pass certain of the monitors until the plant is running normally. The by-pass pilot light glows brightly when a by-pass is actuated and if the supervisor does not acknowledge an audible alarm every twenty minutes by pressing the by-pass reset, the by-pass will be automatically nullified. This prevents the plant from being improperly monitored if the supervisor should become careless.

Chemical analysis

Instrumentation is not provided for continuous analysis of the main condenser liquid for dangerous contaminants. An Ilosvay acetylene test and total hydrocarbon analysis is run by the plant supervisor on a weekly basis. Visual inspection of a liquid sample is made daily when the supervisor is present. As stated earlier, the gel adsorber at the main condenser is designed with ample safety factor based on the removal of CO_2 and dangerous contaminants. The small trace quantities of acetylene, heavy hydrocarbons and CO_2 which may pass through the regenerator and the gas phase gel adsorbers are easily adsorbed in the main condenser gel adsorber.

A positive acetylene test has never been indicated in the 80 operating years of experience on the unattended plants. The total hydrocarbon concentration of the condenser liquid will fluctuate only slightly depending on the quantity of methane and ethane entering the plant. Since acetylene, heavier hydrocarbons and CO_2 will preferentially displace the light, highly soluble hydrocarbons in the adsorbers, the total hydrocarbon concentration is entirely the lighter fractions, namely methane and ethane. Laboratory analyses of main condenser liquid samples have shown that methane and ethane are the only hydrocarbons present in the liquid. The adsorbers therefore provide a basic inherent safety feature because of their selective adsorption of acetylene and the heavy or less soluble hydrocarbons. The concentration of methane and ethane would have to exceed 4% before reaching their lower limit of flammability and cause a potential hazard.

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The CO_2 concentration in the main condenser liquid will normally be appreciably less than 1 ppm. Since acetylene and the heavy hydrocarbons will preferentially displace CO_2 in the adsorbers, the CO_2 would exceed its solubility limit in the liquid and form a cloudy solution before reaching a dangerous concentration of heavy or less soluble hydrocarbons in the condenser liquid. However, this condition has never occurred in any of the plants.

All plants are thawed on a yearly schedule.

In conclusion, the important features that contribute to safe unattended plant operation are:

1. Use of a simple low pressure process cycle.
2. Maximum use of silica gel to remove dangerous contaminants such as acetylene from the process streams and not just control them to a supposedly safe level.
3. A complete thaw of the plant annually.
4. The design of all process equipment monitor devices on a fail-to-safe basis.
5. Thorough cleaning of all equipment to remove any foreign materials and the selection of safe materials.
6. A thorough preventative maintenance program to keep all mechanical equipment, process equipment, and instrumentation in top operating condition.

Discussion

COCHRANE—Sun Oil: Does part of your safety procedure include blowing down any liquid from your reboiler, either continuously or intermittently?

ANDERSEN—Linde: We do not rely at all on drainage. In fact we have never drained this type of plant. We rely entirely upon the silica gel to remove the contaminants. The silica gel adsorber in the main condenser is actually required to remove only a very small quantity of the impurities. Most of them are removed in the gas phase adsorbers.

WALTON—Atlantic: Is there any duplication of your instrumentation for emergency shut down? The reason I ask this is that there are occasions where we have instrument failures which are completely unpredictable. How can you be confident that when you have a failure (a mechanical failure, a bearing failure, or something like that) your instrument is going to truly detect it; that it won't, at that unfortunate time, give a false signal, or no signal at all? The second part of the question is do you have temperature-monitoring on compressor packing?

ANDERSEN—Linde: In answer to the first question, in all cases we apply the monitors on a fail-to-safe basis so that if the monitor, or instrument itself, should fail, it will cause a shut down. The greatest portion of the shut downs are actually caused by the malfunction of a monitor rather than malfunction of the equipment. This results in greater safety, although certainly, a few more shut downs. In regard to the second question, we do not monitor the packing temperature on any of the compressors. #