21. Process Safety

COVER PAGE

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Table of Revisions

Section	Description

1. INTRODUCTION 3
2. AIR SOURCE 3
3. AIR COMPRESSOR 4
4. AIR PRECOOLING 5
5. PURIFICATION UNIT 7
6. MAIN HEAT EXCHANGER 11
7. COLD POWER- Turbine/Booster 13
9. DISTILLATION COLUMN 15
10. DECONCENTRATION PURGE 18
11. DECONCENTRATION BY LOX FILTER 19
12. CONTAMINANT ANALYSIS 20
13. OXYGEN PURITY 21
14. DEAD ENDS 21
15. LOW PRESSURE STORAGE TANKS 22
16. GASEOUS OXYGEN PIPING AND COMPRESSORS 24
17. VAPORIZATION BACK UP SYSTEMS 25
18. IMPORTANT ELEMENT FOR SAFETY 26

1. INTRODUCTION

The present section aims to inform the operation teams about main hazards inherent to typical process equipments of an Air Separation Unit, on how such hazards are typically taken into account at design phase and on additional measures that should be taken by the operation team during work or operation to ensure the safe operation of the concerned equipments.

This section does not deal either with usual industrial hazards related to fluids characteristics or the physical parameters such as pressure, temperature or flow, nor with the risks for the operators to work in usual industrial area environment. The section "Personnel Safety" of this operating manual provides information on these subjects.

The mentioned hazards are based on AIR LIQUIDE knowledge at the date of issuance of this operating manual. Therefore the scenarios considered here after are not exhaustive.

It is of utmost importance that the equipment be operated according to descriptions and instructions given in other sections of this operating manual and in the documentation of equipment suppliers. Furthermore, a detailed risk analysis should be undertaken by the operation teams before performing any work or operation on any equipment or part of the facility in order to assess all the risks the intervening people are likely to face during the performance of such a particular work or operation.

2. AIR SOURCE

A major hazard for Air separation unit is the introduction in the equipment, particularly in the distillation column, of an abnormally high amount of contaminants.The introduction of large quantities of hydrocarbons and other contaminants into the plant always represents a risk, regardless of the protection devices implemented in the design and operation.

For this reason, it is necessary to detect when such a condition arises.

The air is supplied to the Air Separation unit through one or several compressor which take the air from the local area. It is therefore essential to maintain a good awareness of the current environment surrounding the plant.

Information to be maintained should include:

- A list of nearby plant complexes liable to release significant quantities of contaminants (for example: ammonia, chlorine, H_2, CO, hydrocarbons, ...) into the air during normal operation, or in the case of mal-operation or accident.
- the distance between these potential sources and the air separation plant air intake, as well as their relative heights
- local atmospheric condition (the instantaneous wind direction and speed should be made available in the control room).

3. AIR COMPRESSOR

3.1 Dust stoppage at the compressor suction

The filtering system at the suction of the feed air compressor is designed according to the existing local situation and particularly the amount and kind of dust present in ambient air.

This filtering system must be kept in good conditions to prevent dust from entering the unit since dust passing through the machine could lead to damages to the wheels of the rotor and to foul the inter-stages coolers and to plug the after coolers drains.

Additional specific filtrations may be required in case of the presence of particular contaminants (Acid vapor, Haze)

The pressure difference measured at this filtering system is a good indication of the fouling condition.

In case modification are performed on this filtering system one should make sure that no gap between the filters and the supporting structure or filter casing creates by pass of the filters.

3.2 Contamination that may occur from the machine

Regardless of the contamination level of the area surrounding the plant:

- no additive should be present in the water used in line rotor cleaning system when such a system is recommended by the machine supplier.
- the absence of leakages form the inter-stage coolers must be periodically checked to order to avoid the contamination of air by treated water which could induce damages (corrosion, deposits) to the rotor and the downstream pipes and equipment.

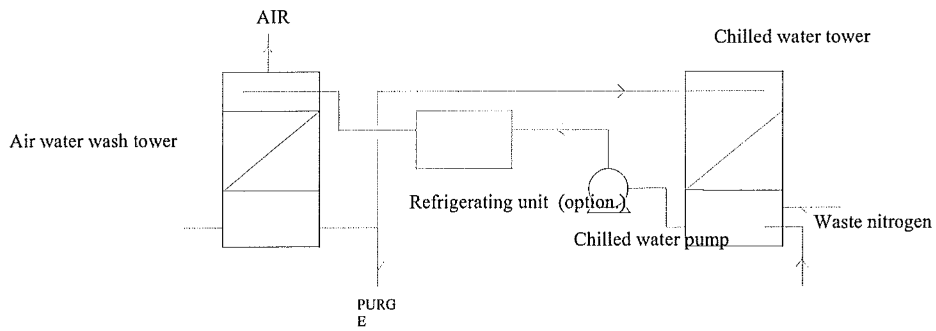
3.3 Removal of condensed water

Checking of the proper operation of the drainers

- To avoid damages to the rotor and bad general operation (surging)
- To avoid sending large amount of liquid water downstream in the process

4. AIR PRECOOLING

4.1 Schematic arrangement



4.2 Air Water wash tower

Air temperature at the outlet of the air/water regarding the contaminants stoppage

Air water towers aim at cooling down the hot air entering the equipment before being sent to the Front End Purification unit. Since this air coming from the air compressor is hot and saturated, it contains a large amount of water. The cooling down of this air removes the main part of this water by condensation.

The temperature of air at the top of the air water tower must therefore not exceed the process design temperature in order to:

- ensure adequate conditions for the adsorption of contaminants in the Front End Purification
- not exceed the amount of water that the allumina is able to adsorb by design.

The proper setting of this temperature is obtained if the following parameters comply with the design conditions:

- flow, temperature and pressure of the air entering the air water tower
- flow and temperature of water streams entering the air water tower
- quality of the water supplied to the column that ensure the cleanliness of the tower packings. The cleanliness of the packing is necessary for ensuring a good heat transfer between water and air, to let the water flow downstream smoothly thus preventing the collection of large amount of water in the column which might result in flooding the downstream circuit. The proper setting of the water treatment system and the adequate setting of the purge is essential to maintain good water quality.

Water level at the sump of the air/water

An improper control of the level at the sump of the air water wash tower could lead to an increase of the level in the water tower which could induce damages to the packing by water hammer effect.

It must be noticed that this level must be taken care of even during the plant stoppage. Water might fill up the tower through a leaking water inlet valve. If it happens that the tower is completely filled with water, then this water may overflow in the downstream pipe and purification unit adsorbants inducing severe damages.

Water supply as a possible source of contaminant ingress into the unit the cold box

Depending on the arrangement of the cooling water system, contaminants such as hydrocarbons, aromatics, alcohol, glycol, amines can be introduced in the cooling water circuit chiefly from cooler leakages. The contaminants contained in the water would be released in air inside the air/water tower by stripping , inducing a serious hazard to the plant. That is why the possible source of polluting the water supplied to the air/water tower must be identified and the quality of the water be carefully checked.

4.3 Chilled Water tower

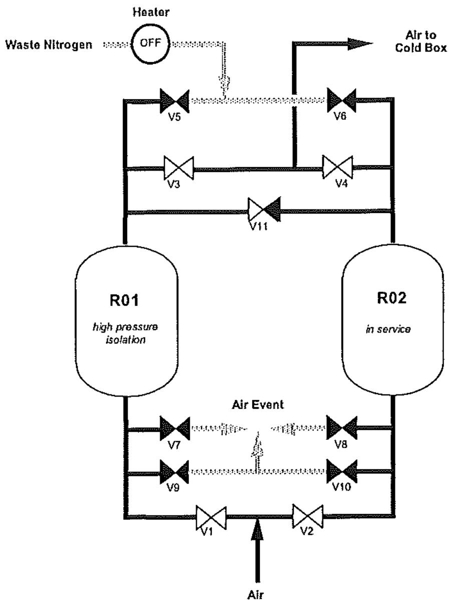
Water supply as a possible source of contaminant ingress into the unit the cold box

Depending on the arrangement of the cooling water system, contaminants such as hydrocarbons, aromatics, alcohol, glycol, amines can be introduced in the cooling water circuit chiefly from cooler leakages. The contaminants contained in the water would be released in air inside the air/water tower by stripping , inducing a serious hazard to the plant. That is why the possible sources of polluting the water supplied to the air/water tower must be identified and the quality of the water be carefully checked.

As for the air water tower, the water supply to the nitrogen –water tower could be polluted with dangerous contaminants due to leakages from equipments cooled down with the water coming from the same circuit. The contaminants possibly contained in the water would be partly sent to the air water tower and from there be stripped in the air feeding the cold box.

5. PURIFICATION UNIT

5.1 Example of arrangement



5.2 Important parameters for Process Safety

5.2.1 CO2 content in the air stream to the cold box

By measuring the CO_2 content at the outlet of the adsorber vessels the proper operation of the front-end purification is verified.

Complete retention of CO_2 at the front-end purification is of vital importance for the unit, for CO_2 having a solubility of only 4.5 ppm in liquid oxygen at -181°C it immediately forms deposits and may clog very rapidly the main exchanger and the vaporizer.

Quality of the adsorption

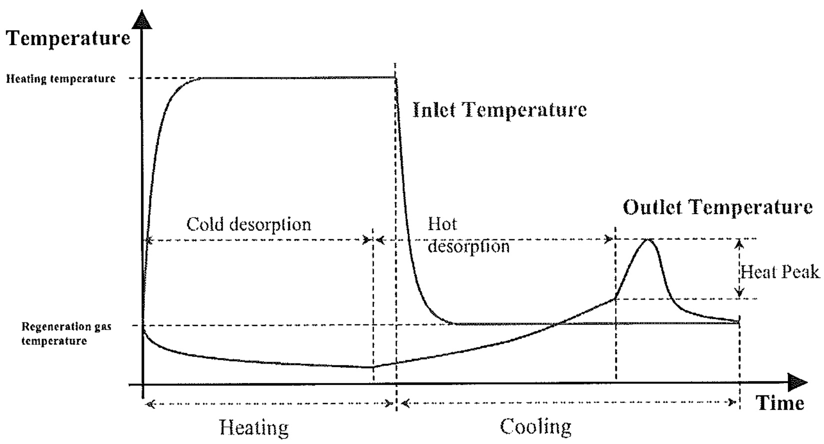
A good adsorption of the contaminants is achieved when the following parameters comply with the design:

- quality of adsorbent beds: alumina and molecular sieve. Only material approved by Air Liquide should be used
- the air flow : the adsorption capacity of the alumina and molecular sieve is based on the maximum design air flow.
- The air pressure: this pressure is normally set by the process control.
- the air inlet temperature: the inlet temperature set the water content in the air entering the purification unit since the water is saturated. The inlet temperature should not exceed the design temperature to prevent exceeding the capacity of the alumina to adsorb water which would result in polluting the molecular sieve with water.
- Duration of the adsorbtion phase

Quality of the reactivation of the adsorbents

A good reactivation of the adsorbents is achieved when the following parameters comply with the design:

- regeneration flow
- heating temperature
- duration of the heating phase



The observance of a “heat peak” (see outlet temperature curve here above) means that the desorption has been properly completed.

Accidental presence of water in the molecular sieve reduces the CO_2 adsorption capacity of the sieve; In some cases, molecular sieve CO2 adsorption capacity may be recovered by an "exceptional regeneration" at high temperature (over 250°C), performed according a specific procedure.

Exceptional procedure requires stopping the plant for several days.

Particular Hazard during maintenance

One should keep in mind that any maintenance performed inside a vessel filled with any adsorbant, or any operation of replacement of adsorbent may expose the intervening personnel to breath or be in contact with hazardous products that may be naturally desorbed from the adsorbents. Personnel may face to immediate risk of being asphyxiated or intoxicated.

Protection means supplied at design:

- measurement of regeneration flow with alarm and blocking of the heating phase timer in case of low regeneration flow
- measurement of heating temperature with alarm and blocking of the heating phase timer in case of low heating temperature
- no switch to cooling phase before the completion of design heating time through control command system programming

Preventive action to be performed during operation:

- periodical checks of the proper operation of concerned loops (calibration of instruments)
- Frequent check on corresponding trends
- Implementation of adequate operating procedure in case of activation of the step by step operation
- Implementation of work permit procedure and pre-entry permit for any work perform close to or in contact with adsorbent material. The recommendation of the dedicated Material Safety Data Sheets (supplied by the manufacturer) will be taken into account for this purpose.

5.2.2 Temperature of air at the outlet of the FEP

The temperature at the outlet of the front air purification should remain below a maximum temperature (typically 65°C) in order to avoid altering the mechanical properties of the aluminum alloys or producing excessive thermal stress on the main exchanger of the cold box is avoided. That is why one should make sure that the cooling phase of the FEP sequence is completed before the switching of bottles. During normal operation, the programming of the supplied control command system take this condition into account. It may occur that a step by step manual operation of the FEP be required. This is a situation when the risk of mistake is high.

The potential consequences of a too high temperature at the outlet of the FEP are:

- upset of the distillation column due to excessive heat entered into the cold box
- damage to the main exchanger due to excessive mechanical/thermal on welds and structures.

Protection means supplied at design:

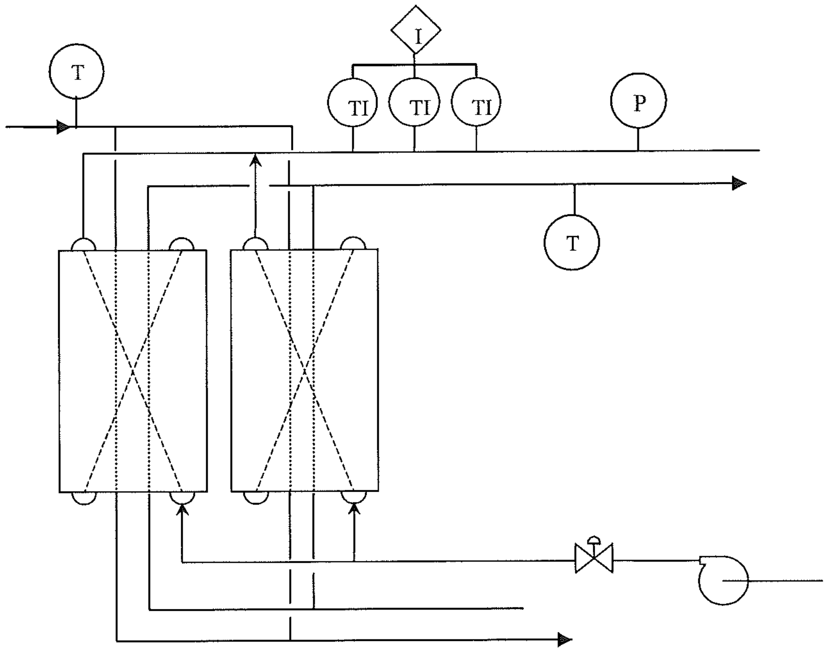
- Temperature measurement with alarm set point and trip set point. To exceed the trip set point leads to automatically shut down the Air Separation Unit

Preventive action to be performed during operation:

- Periodical verification of the proper operation of the loop and the interlock
- Frequent checks of the temperature trend
- Implementation of adequate operating procedure in case of activation of the step by step operation

6. MAIN HEAT EXCHANGER

6.1 Example of arrangement



6.2 Air Inlet temperature

As explain in Purification Unit section, too high air inlet temperature, resulting of an improper operation of the FEP could lead to damage the main exchanger. A temperature measurement is supplied on this line in order to prevent such damages.

Protection supplied at design (same than at section 5):

- Temperature measurement with alarm set point and trip set point.
- Interlock to trip the plant if the trip set point is exceeded

Preventive action to be performed during operation

- Periodical verification of the proper operation of the corresponding loop and interlock
- Frequent checks of the temperature trend

6.3 Temperature at warm end

If the heat exchange in the main exchangers is not properly balanced, which may arise during particular transient phases or improper operation, the temperature difference between entering and outgoing fluids increases. The temperature of outgoing fluids happen to reach, in such a specific circumstances, may reach temperature below 0°C. Depending on which material they are made of, the concerned pipes may be embrittled and broken due to the combined effect of low temperature and pressure.

Such an event would induce a serious hazard for people who may be present in the surrounding of the break, due to splinters casting and fluid release, and of course would make the plant unavailable for several days or weeks.

Protection means supplied at design:

- Temperature measurement with 1 to 3 (depending on the concerned fluid characteristics) sensors, with a low alarm and a trip set points. Any temperature lower than the trip set point leads to automatically shut down the Air Separation Unit. The interlock is active either permanently or during transient phases depending on the fluid characteristics

Preventive action to be performed during operation:

- Periodical verification of the proper operation of the loop and the interlock
- Frequent checks of the temperature trends
- Compliance with operating conditions specified at design
- Compliance with the start up procedure of this operating manual

6.4 Pressures of outgoing fluids

The main heat exchanger is designed for both a maximum working pressure and a maximum fluid velocity. Therefore, one should take care of keeping the pressure of fluids at design values.

The fluid maximum velocity criteria particularly applies to gaseous oxygen

– Very high oxygen velocity could lead to combustion of passage walls by particle impact ignition. Therefore, the operating pressure of gaseous oxygen streams in the main exchanger must not be lowered significantly below design value.

Protection means supplied at design:

- Pressure measurement with low pressure alarm set point

Preventive action to be performed during operation:

- Periodical verification of the proper operation of the corresponding loops
- Frequent checks of the pressure trends
- Compliance with operating conditions specified at design

6.5 Liquid oxygen vaporization in the main exchanger: link with pressure and risk of contaminant deposit

Regardless of the prevention measures taken to limit the concentration of contaminants in the Liquid oxygen of the main vaporizer, there is always a certain amount of contaminant in the liquid oxygen sent in main exchanger to be vaporized.

If the liquid oxygen vaporization takes place at a too low pressure, deposits of contaminants in the corresponding passages of the exchanger may occur, thus creating a risk of inflammation.

Therefore in no case the vaporization pressure should be set below the design value.

Protection means supplied at design:

- Pressure measurement with low pressure alarm set point

Preventive action to be performed during operation:

- Periodical verification of the proper operation of the corresponding loops
- Frequent checks of the pressure trend
- Compliance with operating conditions specified at design

7. COLD POWER- TURBINE/BOOSTER

7.1 Moisture downstream the booster cooler

Any moisture resulting from a leakage at the booster cooler and entering a cryogenic exchanger, would lead to plug rapidly the concerned passage of the exchanger.

The incident is detected by the increase of pressure loss on the air line. As a consequence, the concerned exchanger must be defrosted as well as the downstream cold equipments.

It may happen that the exchanger be damaged (passages rupture) as a result of excessive thermal stress on passages, (typically due to mal distribution induced by plugging).

Another risk is the formation of ice blocks in the exchanger breaking fins or plates.

Protection means supplied at design:

- Moisture measurement at the outlet of booster cooler with alarm

Preventive action to be performed during operation:

- Periodical verification of the proper operation of the corresponding loop and calibration of the moisture analyzer
- Frequent checks of the corresponding trend if existing
- Verification of the absence of water by manual opening of the existing drain valve when the equipment is without air pressure (plant stopped and cooling water system in operation).

8. COLD POWER- LIQUID ASSIST

8.1 Fast cooling down of the plant from warm state

The use of the liquid assist system for cooling down a plant induce a risk of equipment damage, the main vaporizer is particularly as sensitive part regarding this matter, due to excessive thermal stresses (cold liquid at –196°C versus warm parts at ambient temperature)

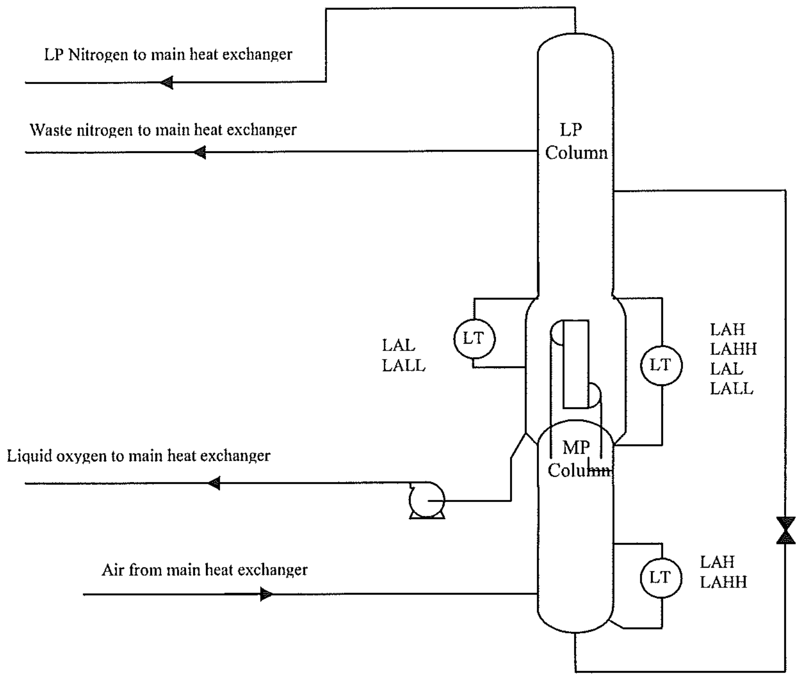
As a rule, using the liquid assist when the cold box is warm is not recommended.

Preventive action to be performed during operation:

- Procedure for using the liquid assist must be closely followed

9. DISTILLATION COLUMN

9.1 Schematic arrangement



9.2 Level in the sump of the medium pressure column

The level in the sump of the medium pressure column must be sufficient in order to prevent disturbing the liquid flow sent to the downstream equipments (Low pressure column or Argon column) and must no be too high to avoid any risk to damage the distillation packing of the column. These potential damages may be caused by the bursts of liquid pushed by the gaseous air stream.

The plant must not be started up or must be shut down if the level is too high.

Protection means supplied at design:

- Level measurement with a low level alarm set point, a high level alarm set point and a very high trip set point.

Preventive action to be performed during operation:

- Periodical verification of the proper operation of the corresponding loop and interlock and calibration of the level transmitter

9.3 Level in the bath type vaporizer

The concentration of solid or liquid impurities in rich liquid or liquid oxygen baths may induce very serious explosions.

Maintaining the core completely and permanently submerged will ensure a proper recirculation of the liquid and therefore that the hydrocarbon concentration in the bath is homogenous, and avoids local concentrations which may exceed the solubility and / or explosivity limits.

When the liquid level of the bath is below a specific level, the liquid vaporizes completely as it flows up the passages. This phenomenon is called "dry vaporization". In this case, the contaminants likely present in air stay in the passages instead of being removed at the upper part of the exchanger and locally concentrate in the passages. In such case, deposits of solid hydrocarbons may build up in the passages which is, depending on the contaminants characteristics, a dangerous situation.

<u>Protection means supplied at design:</u>

- Overall measurement with a low level set point giving an alarm is the level decrease down 90% of the core submergence, and a very low level set point which automatically trips the plant is the level decreases down 80% of the vaporizer core after a 60mn period.
- Operating level measurement with a set point ensuring the full submergence of the core, a low level set point giving an alarm is the level decrease down 90% of the core submergence, and a very low level set point which automatically trips the plant is the level decreases down 80% of the vaporizer core after a 60mn period.
- A level gauge located slightly above the top of the vaporizer core for the verification of the proper calibration of the level transmitters

<u>Preventive action to be performed during operation:</u>

- Periodical verification of the proper operation of the corresponding loop and interlock and calibration of the level transmitters.
- Periodical verification of the proper calibration of the level transmitters by performing the gauge test
- Frequent verification of the proper operation of the level transmitter by comparison between the indications of the two transmitters

9.4 High level in the bath type vaporizer

A too high level in a bath type vaporizer may result in damages to the equipment installed above or downstream.

Protection means supplied at design:

- Overall measurement with an alarm high level set point and a trip set point which activates the automatic plant shut down if exceeded.

Preventive action to be performed during operation:

- Periodical verification of the proper operation of the corresponding loop and interlock and calibration of the level transmitters.
- Periodical verification of the proper calibration of the level transmitters by performing the gauge test

9.5 Management of hydrocarbon hazard during transient phases

9.5.1 Shutdown phase

When the unit is shut down, the gaseous flows discontinue. The liquid contained in the trays or packings drain to the low points of the column, making the vaporizer level increase significantly.

Cold standby - Short duration (less than 48 hours)

Control of the liquid level at the vaporizer:

If a liquid nitrogen assist system exists, the vaporizer level and the levels of the capacities in which a liquid rich in oxygen is stored, must be maintained at normal values. It is important to monitor the temperatures at the warm end of the main exchanger, in order to ensure that they do not fall below the low temperature limit.

If that operation is not possible and the level decreases until attaining an 80 % immersion of the core, drain all liquids of the unit.

Cold standby - Long duration (more than 48 hours)

If shutdown is scheduled to exceed 48 hours, it is recommended to drain all liquids

Cold start up (presence of liquid in the unit)

with liquid nitrogen assist system

During start-up, keep the liquid level of the vaporizer at normal operating level with the aid of the liquid nitrogen assist system.

without possibility of liquid nitrogen assist system

It is probable that the liquid level decreases to a very low value, until the vaporizer is deactivated.

The time during which the unit is run with a very low level should be limited by:

- using the full refrigerating capacity available
- feeding the unit with only the appropriate quantity of air required to keep up the pressures.

Before the normal operating level (complete immersion of the vaporizer) is reached the oxygen purity should be as low as possible, in order to limit the hazards during the start-up phase. For this purpose, the gaseous oxygen outlet, if existing, must be widely opened, while the openings of the gaseous and liquid nitrogen outlet valves must be reduced at maximum.

From units with internal compression (LOX vaporized under pressure), the oxygen is extracted by starting the pumps. In terms of "frigories", that purge is compensated by the corresponding liquefied air.

Monitor the impurities, if an adequate analyser is available.

Warm startup (without liquid in the unit)

The precautions to be taken during warm startup are the same as for cold startup, since concentration of dangerous materials is only possible when the first liquids appear. These liquids vaporize partially under the effect of the progressive cool down of the unit or when the vaporizer starts operating.

10. DECONCENTRATION PURGE

The method for mandatory deconcentration of impurities believed to be present in air and that are not completely removed by front-end purification is a continuous LOX purge. This purge is achieved by withdrawing liquid oxygen out of the system.

The LOX purge is the only mean that provide a full efficiency to deconcentrate the contaminants whatever they are.

The plant must not be operated without this purge.

Protection means supplied at design:

- Measurement of the purge with a low flow alarm an a low flow trip function. The plant is automatically shut down is the purge has been detected below the very low flow limit during a certain period of time.

Preventive action to be performed during operation:

- Periodical verification of the proper operation of the corresponding loop and interlock and calibration of the flow transmitters.
- Follow up of the contaminant analyzer (when foreseen at design) in order to verify the efficiency of the deconcentration purge.

11. DECONCENTRATION BY LOX FILTER

The LOX filter ensures the deconcentration of the LOX bath. As a rule it recycles a LOX flow rate corresponding to at least 10% of the air flow rate. The LOX filter does not replace the mandatory LOX purge but acts as its complement to deconcentrate contaminants. The installation of a LOX filter is decided when the environmental conditions together with the process of the plant does not ensure a satisfactory deconcentration of the contaminants.

The LOX filter and accessories such as valves should be kept in good operating conditions. One should take the opportunity of the periodical plant stoppage and defrosting to perform the inspection of the LOX filter system.

The LOX filter itself, its isolation and by-pass valves must be kept in good condition. The insulations valves should work on their full range from 100% to 0% opening. The stem and seat should be in such conditions that when the valves are closed, there is not liquid oxygen passing through.

The internal parts of the filter should be inspected as well. The adsorber should be clear of powder and the grid in good condition, with no crack nor blockage. No lack of adsorbant should be noticed. By taking a sampling of the adsorbant, one should make sure that the pebbles are not reduced to powder nor broken.

It is important that the specified period for operation of the adsorber vessel should not be exceeded, and also that when reactivating the adsorber the required outlet temperature should be achieved

Protection means supplied at design:

- Measurement of the LOX flow rate through the filter.
- Measurement of the outlet temperature of reactivation gas

Preventive action to be performed during operation:

- Frequent verification that the operation (duration of the adsorption, quality of the reactivation) complies with the design conditions.
- Periodical inspection of LOX filter internal part and isolation and by pass valves.

LOX filter operation during plant stand by

The inlet and outlet valves of the LOX filter that was in operation during the shutdown phase, must be kept open, as long as liquid drain is not necessary.

If cold box liquids are drained (case of stand-by longer than 48 hours), the filter should be isolated, liquid purged fn the filter and the reactivation of the filter should be undertaken.

12. CONTAMINANT ANALYSIS

12.1 Analysis during normal operation

Depending on the environmental condition and the type of process used, analysis of the contaminants contents must be required. Thresholds are defined for each contaminants.

Preventive action to be performed during operation:

Action to be taken in situations between 1st Step threshold and 2nd Step threshold

When a 1st Step threshold is exceeded, an alarm is activated. At that signal, corrective measures must be taken, to avoid exceeding the 2nd Step threshold.

Diagnosis :

Confirm the validity of the analysis - Inquire about atmospheric conditions and their forecast evolution - Determine the possible cause of pollution. Examples:

-acetylene cylinder close to the air intake

-discharge of pollutants (ethane, ethylene, propane, etc...) of a nearby facility

-nearby road paving

-trucks with engines running parking close to the air compressor suction

-generator set exhaust

If possible, eliminate the cause

Verify proper operation of the deconcentration equipment and the complete immersion of the vaporizer

Corrective measures may be taken simultaneously and immediately after activation of an alarm

- switching of the filters, if applicable
- quick draining of liquid oxygen
- if necessary, increase as much as possible the turbine flow rate or use the LIN assist system if provided, so as to maintain the level of the vaporizer.

Actions to be taken if 2nd Step thresholds are exceeded

Exceeding a 2nd Step thresholds means that something highly abnormal is occurring. **Immediate attention is required.** The plant will have to be shutdown if the situation cannot be corrected.

If the situation cannot be corrected the unit should be shut down, all liquids inside the columns should be drained and complete defrosting of the unit should be undertaken

Note: For N_2O, NO, NOx and CO_2, operation above the 2nd Step threshold may be allowed for very short period.

Permanent or frequent operation above those thresholds is not acceptable. In such cases the plant should be shutdown and defrosted.

12.2 Analysis during cold stand by – Short duration (less than 48 hours)

During standby, the cryogenic liquid begins to evaporate slowly, due to heat leaks from various sources. The longer the duration of the standby, the more hydrocarbons concentrate in the liquid.

For this reason it is important to continue monitoring the analyses of hydrocarbons (if analyzers are included in the design) in liquid oxygen. If an alarm threshold 2nd Step, as defined in volume B of this operating manual, is reached, all liquids must be drained and the unit defrosted.

13. OXYGEN PURITY

It is assumed that a very high purity of oxygen is an aggravating factor in the propagation of the combustion of aluminum. Therefore, due to the possible presence of hydrocarbons in the liquid oxygen of the vaporizer, the oxygen purity of this liquid oxygen is taken into account in the design. During operation, the maximum allowable oxygen content must not be exceeded.

Protection means supplied at design:

- Oxygen purity analysis with high purity alarm (if process used allows to reach high oxygen purity).

Preventive action to be performed during operation:

- Periodical verification of the proper operation of the corresponding loop and calibration of the analyzer.
- Compliance with the design operating conditions.

14. DEAD ENDS

If dead ended line happens to be fed with oxygen enriched liquid (rich liquid, liquid oxygen) a partial vaporization of this liquid takes place permanently due to the heat entrance.. This vaporisation leads to:

An increase of the oxygen content of the liquid

An increase of the concentration of the contaminants contained in the liquid filling the line

If the phenomenon is allowed to go on for extended periods of time, this may lead to spontaneous ignition of the contaminants, inducing damages to surrounding equipment.

When it is located outside the cold box, the freezing of the dead end is a clear indication that liquid is possibly getting into it and that potential hazard exists. When the freezing is observed, and as already explained, a leak must be suspected first and corrected. If there is no leak, the presence of the cold point must be investigated.

Protection means supplied at design:

- for defrosting inlet and outlet, the connection on the line is made at the upper part of the pipe section and the initial routing of the defrosting line follows an upward slope aimed at creating a gas plug preventing liquid to enter the line.
- Automatic drain or operating instructions to drain liquid from the liquid oxygen pumps left in cold stand-by (on line with suction valves opened)

Preventive action to be performed during operation:

- observation of dead ends, and detection of possible freezing of dead ends , should be included to the operating procedures.
- Compliance with operating instruction related to the periodical drain of dead end of LOX pumps in stand-by.

15. LOW PRESSURE STORAGE TANKS

The major hazard that is considered is a liquid spillage and its associated oxygen-enriched (or oxygen-deficient) cloud resulting from the vaporization of a fraction of the liquid. The extent of a spillage depends on the breached size; a liquid outlet line rupture is less critical than a large rupture of the inner tank located at the shell bottom.

The identified main causes of the inner tank rupture are the following:

overpressure due to the flash of the warmer liquid entering into the inner tank which exceeds the vent and safety relief valves capacity.

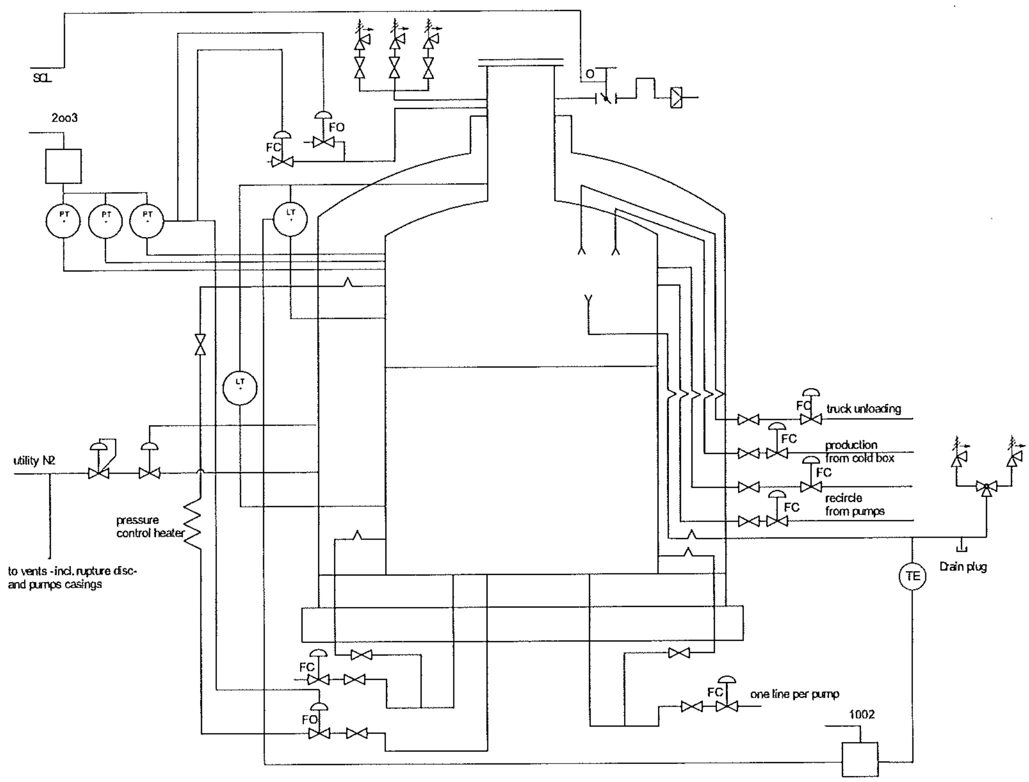
Overpressure due to overfilling

Vacuum

Liquid line rupture may result of various causes, typically external aggression (chock with a truck…)

An other hazard to be taken care of is the rupture of the outer shell due to overpressure in the tank annular space that can generate a local atmospheric pollution with perlite. Gaseous nitrogen is injected into the annular space to keep it free of moisture. A permanent nitrogen flow ensures that the pressure in the annular space is kept at the nominal value.

15.1 Example of arrangement



Protection means supplied at design:

- A rupture disc against overpressure located at the top of the tank .
- A set of pressure safety valves against overpressure and vacuum located at the top of the tank. A mechanical interlock system ensures that at least 100% of the required capacity through the set is kept in any circumstance.
- A set of vent valves controlled by the pressure inside the inner tank
- Pressure control loops to ensure the control of the pressure in the inner tank, to activate an alarm in case of too low pressure and to isolated the inner tank in case of very high pressure
- A dedicated control loop to prevent the overfilling by detecting a level at the top of the inner tank and temperature measurement on the line to the overfilling safety valve to detect the presence of liquid.
- A pressure safety valve to release the liquid potentially resulting of an inner tank overfilling
- A safety valve to protect the tank inter space from an over/under pressure.
- A pressure control system to set the proper pressure in the tank inter space

Preventive action to be performed during operation:

- Periodical maintenance of pressure safety devices
- Periodical verification of the proper operation of the corresponding loop and interlocks and calibration of the flow transmitters.
- Frequent verification of the proper operation of the purge gas of the inter space (flow and pressure).

16. GASEOUS OXYGEN PIPING AND COMPRESSORS

Many engineering materials which are considered "non flammable" may burn fiercely in oxygen enriched atmosphere. Even metallic material used for the manufacture of equipment such as piping, vessel or machines can burn in presence of oxygen-enriched gas. Therefore, specific design rules apply for gaseous oxygen piping and stringent operating procedure must be set in order to maintain an adequate safety level of the gaseous oxygen systems.

A fire resulting of the presence of oxygen enriched general lead to burning the material containing the fluid such as piping or vessel . An oxygen fire is always accompanied by violent projections of incandescent splinters of molten metal. Serious consequences with regards to casualties and damages to the facility can result of such an incident.

Metallic and non metallic materials used in over oxygen enriched atmosphere are selected for design pressure and flow. It is therefore recommended to keep the operating condition in the oxygen lines, vessels and equipment at the design values.

Furthermore oil, grease, hydrocarbons, cloth, wood, paint, and dust among others can react violently with oxygen. Therefore any maintenance on an oxygen system should be performed with taking a particular care to avoid any pollution of the equipments with any contaminant. The cleanliness of any oxygen system should be systematically and exhaustively checked before assembly and start up.

Protection means supplied at design:

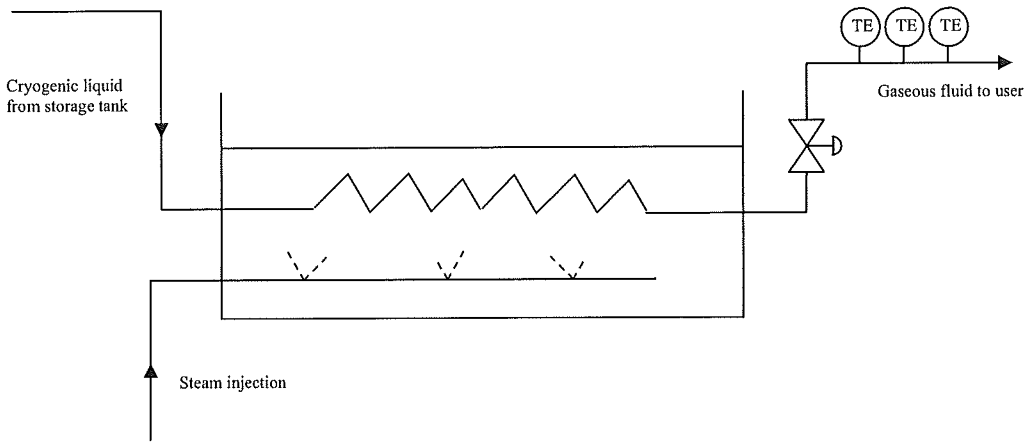
- Choice of architecture and material according to design operating conditions: oxygen content, pressure and flow
- Selection of materials and equipments compliant for oxygen use in the design conditions
- Installation of protective barriers

Preventive action to be performed during operation:

- Ensure that cleanliness of all parts in contact with oxygen is ensured after maintenance
- Ensure that any material or equipment replaced during the plant lifetime is compliant for oxygen used in the design condition
- Operating procedure to be worked out to make sure that during start up of oxygen systems, the pressurization of oxygen lines is performed at slow speed to limit the increase of temperature due to adiabatic compression.
- Access inside protective barriers during to be forbidden during the operation of the system

17. VAPORIZATION BACK UP SYSTEMS

Schematic arrangement



Black up systems installed to provide a high reliability of gaseous products supply ensure the vaporization of the cryogenic liquid by a heat exchange with hot water. Since the some piping and equipment cannot withstand cold temperatures, the verification that the completed vaporization of the liquid and that the heating of the gas up to ambient temperature are performed is essential.

That is why the temperature of process fluid at the outlet of the vaporization pool is performed by three temperature sensors. A 2 out of three interlock ensure that the automatic on off valve located at the pool outlet will close in case a low temperature is detected.

Protection means supplied at design:

- Temperature probes with a two out of three interlocks to close the automatic valve at the outlet of the vaporization pool.

Preventive action to be performed during operation:

- Periodical verification of the proper operation of the corresponding loop and interlock .

18. IMPORTANT ELEMENT FOR SAFETY

Changes of the operating conditions can induce an upset of the plant or parts of the plant. In particular circumstances, the upset might lead to reach hazardous situations with potentially serious consequences for personnel safety.

The prevention of such events in ensured by the " Important Element for Safety". The list of these elements is included to the volume B of this operating manual.

Since these element are essential for the general safety of the plant, a special care should be dedicated to the periodical verification of their proper operation.