2. Equipment operation

2.1. General remarks and Design Limits

This air separation unit is designed for permanent operator attention whose sole responsibility is the supervision of the processes in the air separation unit and its related subsystems. Only skilled and specially trained personnel who are fully aware of all relevant health and safety procedures must be allowed access to the plant. It is assumed that the operators will carry out manual adjustments with due respect to health and safety procedures as outlined in the applicable EIGA and locally relevant regulations.

It should be noted that it is the responsibility of the operator to control the ASU at the individual operating points as well as to shift the ASU from one operating point to another. No provisions have been made for running the plant from outside of the control room. Changes to the logic that is built into the DCS-system of the plant will invalidate all guarantees and warranties.

The operating range of the plant is outlined in the attached stream table. Especially the following maximum limitations for key components must be observed:

Air flow to front-end and cold box (dry)	97,000	Nm^3/h
Molecular sieve inlet temperature	< 15	°C
Gas flow to chill tower	43,000	Nm^3/h
Chilled cooling water flow to DCAC	45	m^3/h

The following chapters deal with the operation of individual pieces of equipment. It should be noted that instructions given by vendors in their own manuals overrule any comments made in this manual. The instructions in manuals of the individual vendors must be adhered to.

2.2. Air compressor (MAC, V11000)

The MAC is controlled by variable inlet guide vanes (IGV) to adjust flow . The discharge pressure of the MAC can be controlled by DCS based PIC11041 which operates the vent valve. In addition, on the discharge line a safety valve is installed. PIC11041 is set in AUTO 4.8 barg during the Startup then increase in normal operation to 5 barg in order to control the MAC with feeding air flow .

Z11031 set pressure = 6 barg

to avoid mechanical damage.

The MAC is set up to control the air flow to the plant via FIC15035.

There are two different trips for the main air compressor:

- Shut down trip
  This trip is protecting the machine against mechanical damage. The trip will immediately stop the motor. The downstream equipment will also be tripped.
- Partial trip “unload”
  This trip is protecting the process: if a unit downstream of the air compressor is shut down via a trip the MAC will be unloaded. This means that the air compressor will blow off with the vent being fully open.

For further information regarding the control and maintenance of the MAC refer to the relevant vendor documentation.

2.2.1. Starting conditions for the MAC

Starting conditions are as follows:

US11000	must be re-set
UH11003_2	Minimum waiting time to be at 0.
EH11001	No electrical default in T80.
US11000_2	Partial trip to be re-set.
E11004	MCC ready
US13000	DCAC trip must be re-set
GL15011	molecular sieve inlet valve closed
GL15021	molecular sieve inlet valve closed
US15018	molecular sieve inlet valve closed
US15028	molecular sieve inlet valve closed
GL11010	inlet guide vanes must be fully closed
GH11074	vent valve fully open
P11854	oil pressure above minimum set-point
EH24163	Oil pump of turbine 1 to be started.
EH24263	Oil pump of turbine 2 to be started.
T11854	oil temperature above minimum set-point
LL11812	oil level above minimum set-point
P11854	oil pressure above minimum set-point
FL80001	cooling water system running
LH11080	Condensates trap 1st stage ok
LH11081	Condensates trap 2nd stage ok
LH11082	Condensates trap 3rd stage ok
H20027	cold box pressurisation valve closed
GL20026	MP-AIR to cold box closed
P16007	BAC inlet valve closed

The MAC is started by switching HS11001 to ON. The operator should slowly increase the opening of the inlet guide vanes to load the compressor. Simultaneously with opening the IGV the vent valve can be closed to increase the discharge pressure.

2.3. Direct contact aftercooler (DCAC, W13001)

The function of the DCAC is to cool down the air from the last stage of the air compressor in order to ensure that the water content of the air reaching the molecular sieve unit is within its design limits. Should the air temperature downstream of the DCAC be allowed to rise above its design limit the MAC partial trip will be activated.

Note that the operating pressure is also affecting the amount of water that the alumina layer of the molecular sieve unit will have to adsorb: The higher the operating pressure the greater the adsorption capacity of the alumina and the lower the water content of the air leaving the DCAC at a given temperature.

To achieve the cooling normal cooling water and pre-cooled cooling water is available. The flow of the normal cooling water FIC13007 is set by the stream table. The flow of chilled cooling water to the DCAC is controlled by FIC13006 and should be adjusted according to the air flow and ambient conditions to ensure that the temperature difference between the chilled cooling water and the temperature of the air leaving the DCAC is kept to a minimum.

The cooling water pumps P13100/200 and the chilled cooling water pumps P14100/200 will have to be switched at least once a week. After switching the strainers should be cleaned and the pump primed so that the stand-by pump is ready for operation.

The DCAC pressure has to exceed the minimum limit before any of the pumps can be switched on. This is to ensure that the cooling water is able to pass into the cooling water return line which is back pressurised.

Note that a low level in the DCAC represents as much a problem as a too high level. If the level is too low there is a danger of air being carried over into the cooling water return line which will upset the cooling water circulation and might lead to a complete trip of the cooling water system. On the other side a too high level in the sump of the DCAC will mean that there is a danger of liquid droplets from the sump being carried over by the air flow which could cause damage to the packing or the support construction. If the high level is reached, the MAC partial trip is activated.

The performance of the water pumps should be monitored using the setting of the flow control valves as an indicator. If the valves have to increase their opening at constant throughput, this observation is a clear indication that the inlet strainer of the respective pump is in need of a clean.

2.4. Chill tower (W14001)

The chill tower provides refrigeration to the cooling water by humidifying the dry gaseous stream entering above the sump. It also serves as blow-off for the portion of the waste stream that is not needed for the regeneration of the molecular sieves. For this reason care must be taken, to avoid freezing up the chill tower when the cooling water is supplied at low temperatures. For that purpose a warm water injection via TV14010 is foreseen.

Under normal operation cooling water from the main supply is let into the top of the chill tower to make up for the flow of chilled cooling water to the DCAC and for evaporation losses.

2.5. Refrigeration Unit (KA12001)

The main task of the chiller units is to provide chilled cooling water to W13001 at sufficiently low temperature. This is to keep the air temperature at the inlet to the molecular sieve unit within the design limit.

The refrigeration unit controls the chilled cooling water outlet temperature T13026 internally. The operator can adjust the temperature difference over the chiller unit by adjusting the flow F12005 within the specified limits.

2.6. Molecular sieve unit (A15001/2) and regeneration gas heater (W15001)

2.6.1. Summary of the system

The molecular sieve system is designed to adsorb moisture, carbon dioxide and most of the hydrocarbons from the process air stream. It consists of two alternating adsorbers; while one is cleaning the process air the other one is being regenerated with a waste gas mainly consisting of nitrogen from the air separation unit. The beds are changed periodically - the regenerated bed is switched online and the online bed changes to be regenerated.

The molecular sieve unit has been designed to handle an incoming air stream of:

Maximum flow (dry):	97,000	Nm^3/h
at minimum pressure:	5.75	bara
at maximum inlet temperature:	15	°C

The adsorption capacity of the molecular sieve unit is enhanced with decreasing air inlet temperature and increasing air inlet pressure.

Apart from moisture and carbon dioxide the molecular sieve unit will also holds back certain hydrocarbons. The following list describes the strength of adsorption of individual key components:

- water vapour (most strongly adsorbed)
- propylene C_3H_6 (adsorbed)
- acetylene C_2H_2 (adsorbed)
- carbon dioxide (adsorbed)
- nitrous oxide N_2O (partially adsorbed)
- ethylene C_2H_4 (partially adsorbed)
- propane C_3H_8 (partially adsorbed)
- ethane C_2H_6 (only weakly adsorbed)
- methane CH_4 (not adsorbed)

In case of a break through the components will pass the molecular sieve in the above mentioned order i.e. acetylene will start breaking through after carbon dioxide whereas methane is not being adsorbed at all.

Molecular sieve operation is fully automatic. A sequence programmed in the DCS controls the operation of all molecular sieve valves. Additional safety and plausibility checks implemented in the DCS are provided to ensure trouble-free operation. The sequence consists of the following main steps for each bed: The design cycle times for the molecular sieve unit are as follows:

depressurisation	10	minutes
heating	110	minutes
cooling	220	minutes
pressurisation	10	minutes
parallel	25	minutes
adsorption	375	minutes

The valves in the molecular sieve unit (adsorption beds, reactivation heaters and regeneration flow control) are controlled by sequence control logic in the DCS. Their functions are:

tag number	function
UK15018	initial pressure build-up vessel A
UK15028	initial pressure build-up vessel B
UK15011	process air inlet vessel A
UK15021	process air inlet vessel B
UK15016	process air outlet vessel A
UK15026	process air outlet vessel B
UK15013	depressurisation vessel A
UK15023	depressurisation vessel B
UK15012	regeneration gas outlet vessel A
UK15022	regeneration gas outlet vessel B
UK15014	regeneration gas inlet vessel A
UK15024	regeneration gas inlet vessel B
UK15017	pressure build-up
UK15043	electric regeneration gas heater inlet
UK15044	steam regeneration gas heater inlet
UK15045	regeneration gas heater bypass

For a complete cycle 18 steps are needed. Additionally, a start-up and fail-safe step exists. Each step has a predefined set of valve movements and running times associated with it. The switching sequence is shown in the following table.

Step	UK15011	UK15012	UK15013	UK15014	UK15016	UK15017	UK15021	UK15022	UK15023	UK15024	UK15026	UK15018	UK15028	UK15043	UK15044	UK15045	Remark
1	■				■		■				■	■	■				Parallel B
2	■				■							■					Prepare depressurisation B
3	■				■				■			■					Depressurisation B
4	■				■			■	■	■		■					Prepare heating B
5	■				■			■	■	■		■		■	■		Heating B
6	■				■			■	■	■		■				■	Cooling B
7	■				■							■					Prepare pressurisation B
8	■				■	■						■					Pressurisation B
9	■				■	■					■	■					Ready B
10	■				■		■				■	■	■				Parallel A
11							■				■		■				Prepare depressurisation A
12			■				■				■		■				Depressurisation A
13		■	■	■			■				■		■				Prepare heating A
14		■	■	■			■				■		■	■	■		Heating A
15		■	■	■			■				■		■			■	Cooling A
16							■				■		■				Prepare pressurisation A
17						■	■				■		■				Pressurisation A
18					■	■	■				■		■				Ready A

■	Valve open
	Valve closed

It is only possible to step through the sequence in strict chronological order. Individual and independent valve movement is not possible. Manual stepping is under software-lock protection and not available to the operator.

Malfunctions in the molecular sieve unit itself or malfunctions of other units (e.g. compressor trip) cause a molecular sieve trip. In this case, the sequencer is tripped to the actual frozen step/status, with the current step number retained. After resetting the trip and switching on the sequence again, the molecular sieve sequence starts from the last state before being tripped.

⚠ **Avoid switching off the molecular sieve sequence during heating of a bed. Switching on the sequence again, the step starts with the total waiting time remaining so that the regeneration time for the bed increases significantly. If the molecular sieve sequence is tripped during heating of a bed and the step "heating" has to be repeated in its full length, the operator has to observe the carbon dioxide concentration after the molecular sieve station carefully to prevent CO_2 and hydrocarbons from entering the cold box.**

2.6.2. Automatic/manual Operation

The sequence can be operated in either

Automatic mode The sequence switches to the next step automatically after a fixed time and all other switching conditions have been fulfilled or

Manual mode The operator supervisor switches the molecular sieve sequence step by step using the software protected step advance buttons.

Both methods of operation are constrained and subject to process interlock checks. The sequence is set and/or stopped by either an interlock failure or by operators interface.

2.6.3. Checks carried out during the sequence

Process Checks

Internal process checks are carried out to make sure that all necessary conditions to switch to the next step are fulfilled. Thus, not only the time criteria determine the switch to the next sequence step but also special process conditions. If the check is not satisfied the current step (but not the timer) is held.

⚠ **The Operator cannot advance the sequence until the process check is satisfied.**

In automatic mode, for example, the sequencer will not move to the heating position until the pressure in the bed is less than the limit value. Once this requirement is satisfied the sequence is allowed to step on when the timer has reached zero. In automatic mode the process check alarm will only initiate an alarm if the process check is still not satisfied at the end of the step. In this case the sequencer will hold in automatic until the check is satisfied. Step on will then be automatic.

Interlock Checks

Each process check performed as above also forms an interlock check. There are two categories of interlock checks: process interlock and valve interlock checks.

Comparable to the process checks, failure of either of the two interlock checks will cause the sequencer to alarm and hold. In contrast to the process checks, however, an interlock failure forces the sequence into manual mode at the end of a step.

Process Interlocks

The sequencer checks at the beginning of a step whether all process conditions are fulfilled. Furthermore, it will check at the end of the step whether all conditions are satisfied. If any deviation is discovered, the sequence alarms and holds on the existing step. This provides a degree of protection against faulty instrumentation.

Valve Interlock Checks

The sequencer continuously compares each controller output. If after reaching the new process conditions, the check fails then an alarm specific to that valve is activated. The sequence holds at that step.

Action on Interlock failure

Once an interlock check has failed the sequence stops and the operator must perform the following actions:

Investigate all the possible causes for the interlock failure.

(b) Decide whether the sequence can be allowed to continue.

(c) Once the interlock failure has been reset, continue the sequence by switching back to automatic.

2.6.4. Sequencer Start-up

A plant trip will hold the timer and set the sequencer to default trip position, i.e. all valves with the exception of the air inlet valves and initial pressurisation valves will remain in their position. The four valves mentioned are closed. The valves will remain in default even if the step-on command is issued, until all the trips associated with the plant shut-down are cleared. Stepping-on will only effect valve movements if all interlocks are satisfied. No valve can be moved if the valve interlocks are not fulfilled.

Once the external trips have been reset, use the following procedure to restart the sequences.

- Reset molecular sieve trip
- This action will simultaneously lock the air inlets closed and reset all the remaining valves to the current step position. The release of the air inlet valves is only possible if the differential pressure across the inlet valves is below the limit value.
- If the molecular sieve trip is reset, one of the small bypass valves opens automatically to pressurise the bed currently in operation. Bed pressures should be monitored and must be equalised within the limit value of the inlet pressure in order to remove the differential pressure checking constraint.
- With all molecular sieve alarms cleared (with the exception of the "Sequencer in STOP POSITION") the regeneration with air can be started if required.
- The sieves are now online in STOP POSITION and can be switched to automatic mode.

2.6.5. Carbon Dioxide Breakthrough

In case of a carbon dioxide breakthrough freezing/blocking of the main heat exchanger or other cold box equipment occurs. Carefully check the CO2 analysis at the molecular sieve outlet.

Indications for a breakthrough are

- high pressure drop in cold box heat exchangers
- high differential pressure in HP column

and might be caused by

- high air inlet temperature to molecular sieve unit
- low air pressure to molecular sieve unit
- low regeneration gas flow rate
- low regeneration gas temperature

⚠ **Check temperature-time-trends of molecular sieve adsorption and regeneration cycle several times per day! The molecular sieve shall be deemed sufficiently regenerated if the heat peak that is observed during the cooling phase of the bed is exceeding 100°C. Before pressurisation may commence the bed must be cooled down to temperatures below the set limit.**

2.6.6. Front End Regeneration

Before admitting air to the cold box at least one bed has to be prepared for operation, i.e. fully regenerated. Hence it might be necessary to carry out a regeneration of the molecular sieve with air.

To do the air regeneration the main air compressor has to be started and the DCAC, chill tower and refrigeration unit brought into operation. After resetting the molecular sieve trip the air regeneration can be switched on.

If one bed is regenerated completely and has been switched into service, air may be fed to the cold equipment. The automatic sequence will continue to change the vessels in the adsorption/regeneration cycle. As soon as the waste gas flow from the air separation unit is established, the air regeneration can be switched off and control transferred to the waste nitrogen stream.

2.6.7. Long time shutdown of Front End Purification

As the sequence stops after shutdown of FEP, if the sequence is in heating or cooling step , the bottle in regeneration will stay opened to atmosphere. In order to avoid saturation of alumina and molecular sieve with wet air during a longtime shutdown, the FEP must be isolated. When the FEP is tripped and the MAC is stopped, an isolation button appears on screen. By switching this button ON, operators can close from the DCS (sequence is bypassed) the outlet regeneration valves UK15012, UK15013, UK15022 and UK15023 depending of which bottle is in regeneration.

Before restarting the plant, this isolation of the FEP must be released. Operators can switch this button OFF. The bypass of the sequence is released and the valves go in their normal position according the sequence. Note that if there is pressure in the bottle, operators have to depressurize the bottle before to release the isolation button (using bypass valves of automatic drains V15085 or V15088). Anyway, in there is a difference of pressure on both side of the 24" valves, the depressurization valves UK15013/UK15023 will open. The regeneration valves UK15012/UK15022 will open only when the pressure will be low in the bottle.

2.7. Booster air compressor (BAC, V16000)

The BAC is controlled by variable inlet guide vanes (IGV) to adjust the pressure. The discharge pressure of the BAC is also controlled by the surge protection which operates the recycle valve. In addition, on the discharge line a safety valve is installed:

Z16074 set pressure = 63 barg

to avoid mechanical damage.

There are two different trips for the booster air compressor:

- Shut down trip
  This trip is protecting the machine against mechanical damage. The trip will immediately stop the motor. The downstream equipment will also be tripped.
- Partial trip "unload"
  This trip is protecting the process: if a unit downstream of the air compressor is shut down via a trip the BAC will be unloaded. This means that the air compressor will operate at full recycle.

For further information regarding the control and maintenance of the BAC refer to the relevant vendor documentation.

2.7.1. Starting conditions for the BAC

Starting conditions are as follows:

US16000	must be re-set
UH16003_2	Minimum waiting time must be 0
EH16001	Motor OFF
US16000_2	Partial trip must be re-set
EH16004	No electrical fault
US15000	molecular sieve trip must be re-set
GL16010	inlet guide vanes must be fully closed
H16073	outlet valve closed
GH16074	Anit-surge valve fully open
PL16854	oil pressure above minimum set-point
TL16854	oil temperature above minimum set-point
LL16812	oil level above minimum set-point
F80001	cooling water system running
GL16073	Gate valve BAC must be closed
G16071	Blow-out valve must be closed
P16007	BAC pressurised above minimum pressure and PK16007 100% open
G16010	inlet guide vanes must be fully closed
G16074	recycle valve fully open
G16071	vent valve closed
L16812	oil level above minimum set-point
T16854	oil temperature above minimum set-point
P16855	oil pressure above minimum set-point
E16001	main drive ready
E16004	MCC ready
F80001	cooling water system running
PL16751	sufficient seal gas pressure
P15035	pressure ex molecular sieve above minimum
T20008	HP-Air (Joule Thompson) valve closed

The BAC is started by switching HS16001 to ON. The operator should slowly increase the opening of the inlet guide vanes to load the compressor. Simultaneously with opening the IGV the recycle valve can be closed to increase the discharge pressure.

2.8. Expansion turbine (ET24101 and ET24201)

The expander consists of an expansion turbine which drives the connected generator. The function of the expansion turbine is to provide the refrigeration requirement of the process, which is set by:

- the heat leak into the cold box
- heat input through the process pumps
- the temperature difference at the warm end of the main heat exchanger
- the liquid production

High pressure air from the BAC is cooled in the main heat exchanger, taken off at an intermediate point and expanded in the expansion turbine to a pressure level of about the operating pressure of the high pressure column.

The turbine is designed to handle no liquid portion in the exhaust stream. If the inlet temperature of the turbine is allowed to fall too low a portion of the air stream will liquefy. If such condition occurs extreme caution must be taken because if the liquid content of the exhaust stream becomes too high, liquid will start to accumulate at the discharge of the turbine an eventually flood the turbine thus destroying the unit.

Several interlocks have been implemented in the control system to protect the turbine.

2.8.1. Starting conditions for the turbines

Starting conditions are as follows (e.g. unit ET24101):

F24101	must be in manual mode and Y<1%
GL24105	inlet guide vanes must be fully closed
LL24160	there must be no low level alarm for the oil reservoir
HS24106	deriming mode must not be OFF
HS24163 (delay 30 min)	Turbine is ready to start for at least 30 minutes prior to start of turbine
P24144	seal gas to turbine above minimum set-point
PH21002	HP column pressurisation successfully finished
PH24101	turbine inlet pressure must be above minimum set-point
P24102 – P21002 – PD21003	pressure difference from turbine discharge to HP column must be below minimum: manual discharge valve must be open
PDL24141	DP seal gas not low
H24105	Nozzle ring (guide vane) must be closed
PL24169	oil pressure to turbine within normal limits
H16073	HP AIR valve at BAC outlet fully open
TL24120	bearing temperature above minimum
H20026	Cold box Air inlet valve fully open
GL24101 (delay 5min)	Quick shut-off valve closed
TH24169	oil temperature to bearing must be higher than minimum set-point
XH24124	no vibration on shaft
US24100	must be re-set

The turbine is started by switching HS24101/201 to ON. This action will open the quick shut-off valve UK24101/201 – now the operator has a defined period of time to bring the turbine rotational speed to values over the minimum limit by manually opening the inlet guide vanes via FIC24101/201. Once this is achieved the operator should slowly increase the opening of the inlet guide vanes to bring the turbine to its operating speed. Care must be taken not to over-speed the turbine as this could damage either turbine or the generator. Once operational speed is achieved the generator will automatically switch on and start to break the turbine. The operator must be ready to increase the guide vane opening to avoid a drop in turbine speed and a "motor" operation of the generator. Turbine will trip if power generation is less than 5 kw for 30s after start-up

Under no circumstance should the operator try to switch on the generator manually. If the generator is switched on at the wrong speed the turbine and the gearbox could be destroyed.

2.8.2. Defrosting the turbines

If the plant has been shut down for a prolonged period of time it is advised to defrost the turbine prior to start-up. The defrosting procedure is as follows:

- close the manual inlet and outlet valves and allow the trapped gas to flow to atmosphere – the pressure at the either side of the turbine must be below the maximum limit before defrosting may commence.
- make sure that the following criteria are met before activating the defrost:

GL24101 (delay 5 min)	Quick shut-off valve is closed
HS24163 (delay 30 min)	Expander ready for minimum 30 min
HA24100	No emergency shut-down button
SH24124	Speed not high
PLL24168	Seal gas pressure not very low
PLL24168	Oil pressure not very low
PH24102	Outlet pressure not high
PH24107	Inlet pressure not high
GL24101	Quick shut-off valve is closed
GL24105	Nozzle ring (guide vane) is closed

  - the turbine must be connected to the generator to avoid spinning
  - defrost outlet is open

Pushing the defrost switch will open the quick shut off valve. Afterwards the turbine nozzles can be opened slightly. The operator must be careful to open the defrost air inlet very slowly to avoid spinning the turbine. If too high a speed is detected, the quick shut-off valve will close immediately. The operator must then close the defrost air inlet immediately.

2.9. Air Separation – Cold Box

2.9.1. Main Heat Exchanger W20010/20/30/40

In the main heat exchanger HE20000 heat is transferred from the incoming warm streams, medium pressure air (AIR) and high pressure air (HP AIR), to the exiting cold streams, high pressure gaseous oxygen (HP GOX), high pressure gaseous nitrogen (HP GAN) , low pressure gaseous nitrogen (LP GAN) and the low pressure impure nitrogen stream (WN2). Thus the AIR is being cooled into the vicinity of its dew point, whereas the cold products of the column system are heated up to about ambient temperature. A portion of the HP AIR stream is taken at an intermediate temperature and fed to the expansion turbines where it is expanded to the operating pressure of the high pressure column. This way cold is produced in the turbine which is needed to cover:

- insulation losses
- heat ingress through the process pumps
- liquid production (LIN, LOX and LAR)
- refrigeration lost due to the fact that streams exiting the main exchanger are colder than air streams entering the exchanger.

The majority of the high pressure air stream however is used to vaporise the HP oxygen and HP nitrogen which enter the main heat exchanger as liquids having been pumped to the desired product pressure upstream of the exchanger. Please note that the pressure of the HP AIR stream must be high enough to render the HP AIR warmer than the streams being vaporised.

⚠ **If the pressure or the flow of the HP AIR stream are allowed to drop too far not enough heat is available to vaporise the liquids entering the exchanger with the result that the temperature of the products leaving the exchanger will drop quickly and eventually cause the temperature traps to trip the cold box!**

The portion of the HP AIR that is not used in the turbine to provide refrigeration will be cooled to values of about 100 K and afterwards flashed in the Joule-Thompson valve (JT-valve) TV20008 to the operating pressure of the high pressure column.

The smaller the temperature difference between the cold and hot streams on the warm end of the main exchanger is kept the lower the refrigeration losses of the plant will be and the less HP AIR is required to provide refrigeration for the plant in the turbine.

Brazed plate-fin type heat exchangers fabricated out of aluminium are used within the cold box because they allow more than two streams to take part in heat exchange simultaneously while combining excellent heat transfer performance with small block dimensions and weight. Those plate-fin exchangers consist of several layers of stacked plates with fins that are kept at the specified distance by means of spacer bars. This way passages are created through which the fluids may flow. The main advantage of this concept is that in addition to excellent heat transfer performance and low pressure drops a great number of different heat duties and streams can be combined into a single block.

2.9.2. Subcooler W23001

The main task of the subcooler is to cool the LIN product and reflux to the low pressure column, the sump product of the high pressure column (CLOX) and the liquid air to the low pressure column (LAIR). By cooling the liquid streams that are either withdrawn as a product or used as reflux two things are achieved:

- The amount of vapour that is generated when flashing the streams to the operating pressure of the tanks and the low pressure column respectively is minimised. This means that more liquid ends up being stored in the tanks and that the low pressure column is operating much more efficiently because there is more reflux and less gas intake as without the subcooler.
- Furthermore the cold gaseous product of the low pressure column is heated up so that the performance of the main heat exchanger is optimised.

2.9.3. Main Condenser W21001

The main condenser is fabricated out of aluminium as a plate fin exchanger and located in the sump of the low pressure column. The main task of this exchanger is to condense the pure gaseous nitrogen at the top of the high pressure column to provide the reflux which is required to maintain rectification in that column. Due to the elevated pressure in the high pressure column the condensing nitrogen is warmer than the liquid oxygen in the sump of the low pressure column. Thus the heat generated by condensing the nitrogen is used to vaporise liquid oxygen in the sump of the low pressure column so as to provide an upwards flowing gas stream for the rectification in that column.

The submergence of the block in the liquid bath of the low pressure column is of crucial importance for the operation of the condenser, because it affects the temperature difference between oxygen and nitrogen as well as the ratio of liquid to vapour exiting the condenser block. The smaller the submergence of the block is kept the lower the sub-cooling that has to be overcome when the liquid oxygen enters the exchanger which in turn means that the lower the submergence is kept the lower the operating pressure of the high pressure column becomes. Thus from a point of view of power consumption a low submergence is preferable. However, the higher the submergence the more liquid is circulated for a given amount of vaporised LOX and thus the lower the chance of hazardous local dry boiling.

⚠ **Safety considerations render it necessary to maintain the submergence at a level of 100% or above to avoid accumulation of hydrocarbons to dangerous levels as described in chapter 3 of this manual. Please refer to chapter "Level Transmitters" for a detailed sketch of the required submergence.**

The operating pressure of the low pressure column is set mainly by the pressure which is required to allow enough regeneration gas to pass the molecular sieve unit during regeneration. A pressure setting has to be found that will allow the required regeneration flow to pass the molecular sieve unit during the entire duration of the regeneration. Depending on the temperature difference over the main condenser the temperature at which the gaseous nitrogen is condensing will be set and thus the corresponding condensing pressure will be forced upon the high pressure column. As the main air compressor is working against the pressure derived from the high pressure column a lower operating pressure in the low pressure column will invariably lower the head pressure of the main air compressor.

2.9.4. High Pressure Column K21001

In order to separate components by rectification intense mixing of a liquid and a gaseous (vapour) stream is required, so that energy and diffusion transport of individual components can take place. During normal operation it is possible to assign a ratio between the flows of the uprising vapour and the down-coming liquid for every section in the distillation columns of the ASU. It is this ratio that the operator can adjust to influence the thermodynamic equilibrium for each stage: Changing the amount of liquid that is flowing down a certain section of the column – i.e. by adjusting a column feed – will change on every stage of that column the composition of the vapour stream as well as the composition of the liquid stream.

Here is an example to illustrate the above outlined theoretical approach. Let us assume that during constant operation, i.e. when the plant is settled and running smoothly, more liquid nitrogen (LIN) is withdrawn from the high pressure column. After a short while the purity of the LIN will decrease i.e. the oxygen content of the LIN stream will increase because less liquid is directed back into the high pressure column. But if the high pressure column is given less liquid to flow down the column a smaller amount of oxygen can be taken up by that liquid stream. Less oxygen will therefore leave with the liquid product taken off the sump and more will force its way up the column. Thus the oxygen profile is shifting upwards. Let us now consider what will happen in the low pressure column. An increase in the reflux provided by the LIN from the high pressure column means there is more liquid to take up the oxygen. However the liquid is entering the top with a higher oxygen content which moves the equilibrium towards higher oxygen contents for the nitrogen stream. Thus the operator should aim at increasing the LIN off-take from the high pressure column until he observes either the oxygen purity in the low pressure column or the purity of the nitrogen product at the top of the high pressure column is starting to decrease.

It should be noted that high pressure column needs to be optimised and smoothly run before any other part of the ASU can be optimised.

2.9.5. Low Pressure Column K22001

In the low pressure column the oxygen is separated from the two other components, nitrogen and argon. Furthermore argon is concentrated in lower section so that it can be purified downstream in the crude argon column to yield a crude argon product. Liquid oxygen is vaporised in the sump of the low pressure column to form a stream of uprising gaseous oxygen. The heat of vaporisation is provided by the gaseous nitrogen product from the top of the HP column which condenses and is partly fed back to the HP column to provide reflux. The pure liquid nitrogen (LIN) withdrawn from the HPC stream is sub-cooled and then flashed into the low pressure column to provide reflux. The sump product from the HP column is also sub-cooled and fed to the LP column via the crude argon condenser. Furthermore liquid air from the air separator and a liquid stream of argon enriched oxygen is fed to the low pressure column to facilitate the rectification. At the top of the column a gaseous nitrogen product stream and from the bottom of the column a liquid oxygen product is withdrawn.

In the lower part of the low pressure column argon is accumulating. At the point of optimum concentration the so called side-arm-gas is withdrawn to the crude argon column from which a stream of oxygen rich liquid is returned. To maximise the argon recovery from the plant a high argon concentration in the side-arm-gas is favourable. However, the higher the argon concentration becomes the more nitrogen will be part of the side-arm-gas. The nitrogen content to the crude argon column must be maintained below a level of a few vppm of nitrogen to ensure trouble free operation of the crude argon condenser.

In the upper part of the low pressure column the oxygen composition of the uprising vapour is gradually depleted to the required GAN purity. The oxygen content of the waste gas can be measured and is a measure for the oxygen recovery.

It was already mentioned above that the low pressure column is not fitted with trays but rather with structured packing. Both trays and structured packing allow for intimate liquid vapour contact but the mechanism to provide this contact differ. On trays the uprising vapour is made to pass through a liquid column. To pass this liquid inventory on the tray the gas has to overcome a pressure drop which is at least as high as the static height of the liquid on the tray. With structured packing the liquid is dispersed and is flowing down numerous small passages. Contact is made on the phase surface only.

This has some further implications:

- A packed column is holding much less liquid then a comparable tray column. This means that a packed column responds much quicker to changes in the operating conditions because less liquid inventory translates to less inertia.
- The pressure drop of the structured packing is much lower than that of the equivalent number of trays, because there is no static height of clear liquid inventory through which the vapour has to pass.

When the air flow to the plant remains constant, the oxygen profile along the low pressure column may be adjusted by controlling the total oxygen off-take from the plant. Therefore the operator should aim at maintaining constant liquid levels in the columns and use the gaseous oxygen production to control the oxygen purity in the sump of the low pressure column and the oxygen purity at the off-take of the side-arm-gas to the crude argon column. The cold production of the plant will be regulated by controlling the amount of HP AIR to the turbine.

The main criterion for the operation of the low pressure column is the concentration of oxygen in the side-arm-gas to the crude argon column. To increase the oxygen content one can decrease the amount of liquid or gaseous oxygen off-take provided enough argon is taken as product.

Note that the amount of liquid nitrogen product which is withdrawn from the high pressure column as liquid product to tank has a profound influence on the argon production: the more nitrogen is withdrawn from the high pressure column the less liquid reflux is available to the low pressure column. This means that the operator has to decrease the amount of side-arm-gas to the crude argon column and increase the level of oxygen in the side-arm-gas.

2.9.6. Liquid pumps P61100/200, P71100/200 and P40100

For each duty, LOX and LIN internal compression (IC) two 100% liquid pumps are provided. One pump is in operation while the other one is in cold stand-by. The operating pump must be swapped with the stand-by pump on a regular basis.

Special care must be taken when cooling down the pumps. The pumps must be at cryogenic temperature for at least fifteen minutes before starting. Furthermore the operator might open the venting valves around the pumps to facilitate cool-down.

With respect to trouble-free production the seal gas system of the pumps must be checked on a regular basis in order to ensure that proper purging and sealing is ensured. Please refer also to the vendor documentation for further information on the pumps.

When starting the pumps make sure that the suction valve and the recycle valve are fully open. Having started the pump wait for about 5 to 10 seconds before gently but steady closing the recycle valve. Bring the pressure manually to the desired level by adjusting the recycle valve. Special care must be taken when starting the LIN or LOX pumps when both pumps have been down. If too much liquid is passed too quickly the main heat exchanger might fracture due to thermal stresses. Therefore limit the opening of the GOX and GAN valves at the warm end of the exchanger and ensure that the LIN and LOX passages at the main exchanger have been cooled down properly before starting the pump. Monitor the temperature profiles at the exchanger and shut the pump down immediately if the temperature differences on the warm or cold end of the main exchanger widen to more than 30 K.

2.9.7. Crude Argon Columns K40001/40002

Like the LP column the crude argon columns are equipped with structured packing. In the crude argon columns the argon is separated from oxygen. The side-arm-gas from the low pressure column is fed to the bottom of the crude argon column. The gaseous crude argon with the required oxygen content is condensed in the crude argon condenser and partly fed to the pure argon column for further separation. The main amount serves as reflux of the crude argon columns. This reflux is taken from the bottom and pumped to the low pressure column.

2.9.8. Pure Argon Column K43001

The pure argon column is fed by crude argon withdrawn from the crude argon column. This crude argon contains some nitrogen. In the pure argon column the separation of argon and nitrogen takes place. It is equipped with a reboiler at the bottom and a condenser at the top.

The reboiler is fed with nitrogen from the high pressure column which is liquefied. On the other side argon is vaporised and serves as upstream gas in the column. At the top of the column a condenser produces the reflux liquid. It is cooled by liquid from the bottom reboiler. Surplus liquid is send to the low pressure column, whereas additional liquid is withdrawn from the high pressure column.

At the top of the column the nitrogen separated from the crude argon is vented to atmosphere, at the bottom pure liquid argon can be fed to the storage tank or to the dump vaporiser.

The controller PDIC43021 controls the load of the pure argon column. More flow through the reboiler causes a higher column load and a better separation. In case of increasing nitrogen content in the pure argon product the column load should be increased.

Prior to start pure argon column, check that the manual bypass valve V40018 is close.

2.10. Nitrogen compressors (NIC, V70000, V77000)

Two nitrogen compressors are installed in parallel. The NIC is controlled by variable inlet guide vanes (IGV) to adjust the discharge pressure. The discharge pressure of the NIC is also controlled by the surge protection which operates the recycle valve. The discharge is also equipped with a vent valve to release pressure and to purge the compressor.

There are two different trips for the nitrogen compressors:

- Shut down trip
  This trip is protecting the machine against mechanical damage. The trip will immediately stop the motor. The downstream equipment will also be tripped.
- Partial trip "unload"
  This trip is protecting the process: if a unit upstream or downstream of the compressor is shut down via a trip the NIC will be unloaded. This means that the compressor will blow off for a defined duration.

For further information regarding the control and maintenance of the NIC refer to the relevant vendor documentation.

2.10.1. Starting conditions for the NIC

Starting conditions are as follows:

US70000	must be re-set
EL70001_2	Minimum waiting time must be 0
E70001	main drive ready
US70000_2	Partial trip must be re-set
GH70004	MCC ready
T70854	oil temperature above minimum set-point
P70854	oil pressure above minimum set-point
F80001	cooling water system running
HV70035	vent valve is closed
HK70036	discharge valve is closed
FL20005	LP GAN production higher than minimum level
H70001_2	Charge GAN N2 compressor 1
F20005	LP GAN valve to N2 compressor open higher 99%
G70010	inlet guide vanes must be fully closed
G70074	recycle valve fully open

The NIC is started by switching HS70001 to ON. The operator should slowly increase the opening of the inlet guide vanes to load the compressor. Simultaneously with opening the IGV the recycle valve can be closed to increase the discharge pressure. Prior to starting the customer supply the compressor has to be purged by opening the vent valve.

2.11. Cooling Water System

The cooling water system serves to supply the plant with water to remove heat from the process, mainly from the compressors. The cold water is supplied to the individual users from where it returns to the customer.

2.12. Instrument Gas and Cold Box Purge

Instrument gas is taken off the molecular sieve unit or supplied from the existing system which may contain nitrogen. Therefore all instrument gas lines must be treated from a health and safety point of view as nitrogen containing.

The cold box purge is supplied by the waste nitrogen stream or is taken off the N2 purge and seal gas header. Purging the cold box with nitrogen is essential to avoid liquid build-up within the cold box insulation. A positive nitrogen pressure inside the cold box must be ensured at any time.

2.13. Liquid Gas Conversion

The plant provides the option to cover a gaseous oxygen demand above the nominal capacity by injection of liquid oxygen into the ASU process. The liquefaction energy of the injected LOX will be recovered by additional liquid nitrogen production.

On the other hand the ASU can operate at gaseous oxygen turn down. In this case liquid oxygen is withdrawn from the ASU and fed to the storage tank. The required refrigeration is partially made up by injecting liquid nitrogen.

The production range in the liquid gas conversion mode is set by the operating range of the compressors, the cold box operating limits and the turbine refrigeration power.

The injection of liquid can also be used to supplement the turbine at high cold production requirements for example during start-up. It is also possible to use the injected liquid to replace some turbine refrigeration.

2.14. Liquid Disposal Vaporiser

The dump vaporiser serves to dispose cryogenic liquids from the cold box. These are fed into the vertical vaporiser pipe which is fed with steam from the bottom.

The disposal of cryogenic liquids is required before defrosting the cold box. In case of bad product purity, either LIN or LOX or LAR, the stream is also sent to the disposal vaporiser.

Before starting to feed cryogenic fluids to the vaporiser the steam flow must be started. The temperature measurement at the vaporiser outlet ensures that the vaporiser is not being overloaded.

2.15. Vents

Vents are installed to dispose gases from the plant to atmosphere. The vents are equipped with silencers to reduce the noise level of the high velocity releases. The vents are designed to provide a safe release of the gases to atmosphere.

The plant is equipped with several vents for the disposal of the following streams:

- air ex main air compressor, booster air compressor
- oxygen ex cold box
- nitrogen ex cold box, molecular sieve adsorber, product compressors

2.16. Analysis Instruments

The following analysis instruments / locations are provided for the plant:

TAG No.	Measurement
QE 15038	ppm CO_2
QE 15043	ppm H_2O
QE 16055	ppm H_2O
QE 20001	ppm O_2
QE 20005	ppm O_2
QE 20011	% O_2
QE 20012	ppm N_2
QE 20029	% O_2
QE 21004	% O_2
QE 22011	ppm C_nH_m
QE 23013	ppm O_2
QE 23016	% O_2
QE 40011	% O_2
QE 40012	ppm O_2
QE 43033	ppm O_2
QE 43034	ppm C_nH_m
QE 64051	% O_2
QE 74090	ppm O_2

Please consult the vendor documentation for information on handling, calibration periods and maintenance of the analyser equipment.

2.17. Liquid Storage Tanks / Back-up

Storage is provided for each liquid product. To minimise evaporation losses from storage the tanks are insulted either with perlite or by vacuum.

2.17.1. LAR Storage

For storing liquid argon vacuum insulated tanks are provided. A pump is installed to transfer the liquid from the low pressure to the high pressure storage. The liquid from the HP tank is sent to the vaporisers for gaseous argon product supply.

A separate pump is used for road tanker filling.