Engineering and Technology
2017; 4(2): 9-15
http://www.aascit.org/journal/et
ISSN: 2381-1072 (Print); ISSN: 2381-1080 (Online)

American Association for Science and Technology

Operational Up-Gradation of Stirlin-8 Liquid Nitrogen Plant

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Citation
K. V. Srinivasan, A. Manimaran, M. Arulprakasajothi. Operational Up-Gradation of Stirlin-8 Liquid Nitrogen Plant. *Engineering and Technology*. Vol. 4, No. 2, 2017, pp. 9-15.

Keywords
Upgradation,
Maintenance,
Automation

Received: March 10, 2017
Accepted: March 30, 2017
Published: June 7, 2017

Abstract
Low temperature facility (LTF) at Tata Institute of Fundamental Research (TIFR), Mumbai operating Stirling Cryogenics make, Model: STIRLIN-8 liquid nitrogen plant since 2010. For the operational and maintenance conveniences of this plant, we have incorporated many additional features to the plant monitoring system with an objective to enhance the Mean Time Before Maintenance (MTBM) considerably. Our up-gradation system, which is successfully implemented at LTF, ensured the plant maintenance to be carried out based on the need rather than the operational hours as specified by the manufacturer. The work includes the special focus on the optimization of critical components like regenerator of Stirling cryocooler. This paper will present the in depth details about the methodology utilized for achieving the above objective effectively.

1. Introduction

Low temperature facility (LTF) of Tata Institute of Fundamental Research, (TIFR) Mumbai, India, is one of the largest facilities in India under the R&D sector and has been operating and maintaining cryogenic plant for about five decades.

The liquid nitrogen is produced with the Stirling Cryogenics, Netherlands make STIRLIN-8 operating since October 2010 [1]. The plant liquefaction capacity is about 110 liter per hour at an operating pressure of 2 barg and with a provision of increasing up to 4 barg, if required.

The various users of the institute consume just above 3,50,000 liters of liquid nitrogen annually. The photograph of the liquid nitrogen plant installed at LTF is given as Figure 1 and the year wise liquid nitrogen consumption at TIFR as Figure 2.

***Figure 1.** STIRLIN-8 Liquid nitrogen plant at LTF.*

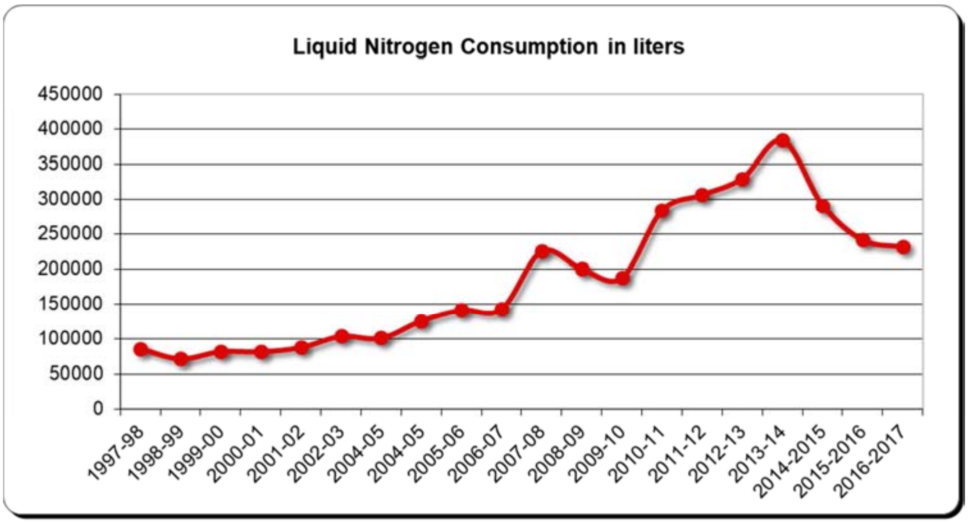

Figure 2. *Liquid nitrogen consumption chart.*

2. Necessity of Plant Upgradation

Unlike other cryogenic plants, maintenance of Stirling cycle based plant are highly manpower intensive in maintenance. To be specific, the maintenance of the cryogenerator part needs special skill, special tools and experience, in the current era of plug & play mode of operation. Many components of the plant preventive maintenance is based on some standard operating conditions with the scheduled maintenance time interval as prescribed by the manufacturer. However, these are much different from the actual site conditions. This is more so for the liquid nitrogen plants, wherein the raw material is the atmospheric air. The quality of air is highly depends on the atmospheric temperature and the seasonal humidity variation.

Additionally, the manufacturer provided process monitoring parameters such as pressure, temperature, flow, valves & switches are highly inadequate and does not provide the progressive online monitoring but giving a mere OK or NOT OK status [2].

3. Objectives of Upgradation

The major objective of the up-gradations are to identify the area for operational convenience and carry out suitable modification so as to simplify the plant maintenance in terms of tools & labor; enhance the Mean Time Before Maintenance (MTBM) significantly; carry out the equipment maintenance based on the need rather than by simple operating hours as prescribed in the operation manual.

Our expected results with the full implementation will ensure that the plant maintenance interval be enhanced by a factor of 30%, simplify the plant maintenance by a factor of 35%, reduction in the plant maintenance time by a factor of 20%.

As a case study, a typical Stirling Cryogenics make Model: STIRLIN-4 liquid nitrogen plant was considered for the up-gradation study and feasibility check even though plant in LTF is STIRLIN-8 model, which is just a two STIRLIN-4 plants in parallel [3] [4]. Typical flow diagram of a Stirling Cryogenics make STIRLIN-4 plant is illustrated as Figure 3.

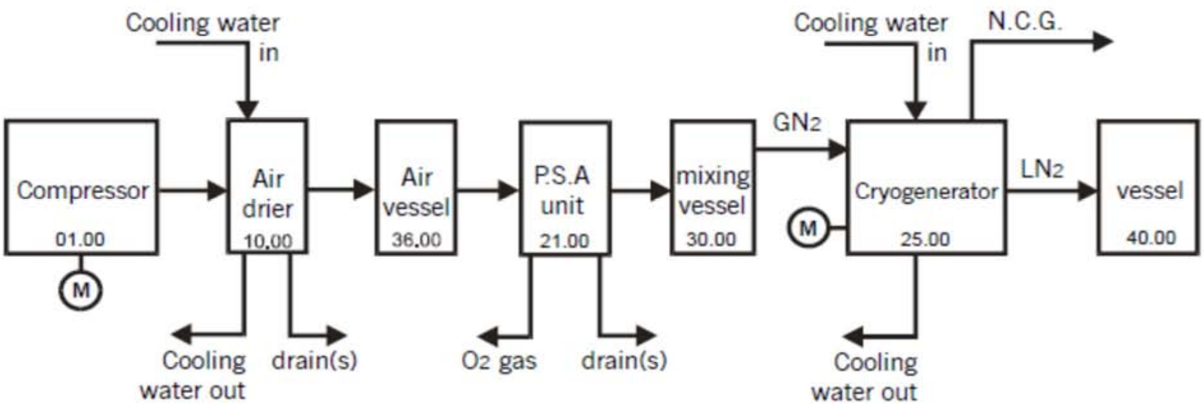

Figure 3. *Flow diagram of a STIRLIN-4 model nitrogen plant.*

The following areas were considered for the up-gradation, which will enable to achieve the proposed objectives.

a. Provision of air cooler prior to drier unit

The compressed air with an outlet pressure of about 9.5 bar(g) is stored in the air storage vessel. The temperature of the high pressure air will be always higher than the ambient temperature, as the standard air compressors are of air-cooled one. Similarly the relative humidity (RH) percentage level of the atmospheric air is highly variable, more so for the plant operating in places like Mumbai where the RH may cross even 90% RH during peak monsoon periods.

The bulk water content of the compressed air needs to be removed using the cyclonic filtration process. The compressed air is guided over the swirl vanes causing a cyclonic motion within the housing, causing liquid aerosols and particles flow down the filter housing and are drained out of the filter housing at a periodic intervals. Further water content is separated using pre-filter assembly fitted with either fibrous or cellulose based filter cartridges. Additionally, the air is allowed to pass through the desiccant chamber (beds of activated alumina), to remove the left out traces of moisture from the pre-filters. The filtration and moisture separation by these filters are directly depends on the air temperature.

Operative effectiveness of these pre-filters are better, only if the air temperature is in the rage of 15 to 22°C. Since the ambient condition are hardly sees these effective operating temperature, it is highly essential that the compressed air temperature be brought down (i.e., before entering the drier unit) for the effective filtration process. This is possible only by providing the chilled water-cooled heat exchanger (pre-cooler) to reduce the compressed air temperature.

It can be seen from the plant P&ID, a water-cooled gas cooler is provided to cool the nitrogen gas before entering the cryogenerator. The benefit of reducing the nitrogen gas temperature at the entry of cryogenerator, from the room temperature to a lower temperature by the gas cooler is extremely negligible compared to the nitrogen liquefaction temperature. Since the refrigeration capacity of the cryogenerator is huge and time to liquefy the nitrogen gas by the cryogenerator irrespective of nitrogen gas entry temperature is the same or even unnoticeable.

This clearly indicates that the use of gas cooler prior to the cryo-generator does not give any technical advantage to the liquefaction process. Hence, it is proposed that this gas cooler be utilized for the cooling of compressed air before the drier unit, which assures the better and enhanced moisture separation.

b. Strengthening of Process Monitoring

Strengthening the plant parameters monitoring by incorporating additional instrumentation to the existing plant logic control enable to achieve the "true" online plant process monitoring and also to develop graphical plant process visualization, so as to monitor or control the plant remotely. To assist this, existing process monitoring system needs augmentation to monitor the critical plant process parameters such as temperature, pressure, moisture, oxygen etc.

The following are the list of additional parameters monitoring sensors incorporated in the plant for achieving the objective of the plant up gradations.

1. Provision of temperature sensor to monitor the temperature of the compressed air at the air drier inlet. The continuous monitoring enables to have a check on the water-cooled gas cooler condition, filtration healthiness and its effectiveness.
2. Provision of temperature sensors at the inlet and or at outlet of chilled water line of the cryogenerator. This assures the chiller performance and the effective cooling of cryogenerator heads.
3. Provision of pressure sensors at the chilled water line of the inlet/exit of the cryogenerator to keep a watch on the effective cylinder head cooling of cryogenerator.
4. Provision of suitable hygrometer to measure the moisture content of the compressed air after the air drier unit, which will indicate the healthiness of the air drier unit.
5. Provision of suitable hygrometer at the exit of the nitrogen gas separator unit which will indicate the effectiveness of the unit. This is highly essential as the nitrogen separator unit is maintenance free and any deterioration of this will affect the plant performance adversely. Additionally this can also be a standby support for the moisture measurement of air drier unit.
6. Provision of suitable oxygen sensor at the exit of the nitrogen gas separator unit which will indicate the purity of the nitrogen gas.

To monitor the plant performance, these transmitters/sensors were added at the appropriate location and wired back to the plant process control logic system. The list of parameters and the sensor details are attached as Table 1.

Table 1. *List of parameters and sensor used.*

Sl. No	Transmitter / Sensor	Unit range	Make	Signal Type
1	Pressure	0 – 40 bar	Wika	4 – 20 mA
2	Temperature	0 99°C	PT-100	4 – 20 mA
3	Hygrometer	0-9999 ppm	Michell Cermet	4– 20 mA
4	Oxygen	0– 25 %	Ntron	4 – 20 mA

c. Additional Modifications to STIRLIN8

With the above plant process monitoring tool, we have also carried out few additional modification to the STIRLIN-8 plant at TIFR for the operational convenience and the plant efficiency enhancement.

1. Replacement of mechanical hour meter of the cryogenerator with the digital hour meter in its relocated position from the cryogenerator to the main control panel.
2. Nosie from the PSA dumping process are quite high and highly inconvenient for the operating personnel, more so as these dumping operations happens in a cycle of every 3 minute. Hence the dump valve silencer of air drier decant chamber PSA and also from the Nitrogen gas separation PSA system were moved out of the operational area. This relocation of dump valve

silencers resulted substantial noise reduction of the operational area.

3. The existing capacitance level controlled auto drain valves connected to the air receiver tank drain and the air drier filters were replaced with the timer based solenoid control valves. Thus frequent malfunctioning of capacitor level sensor and choking of auto drain valves by sediments clogging are avoided.
4. Reuse of large quantity of pure, dry nitrogen boil-off gas from the external liquid nitrogen storage vessel and from the large users like LINAC which are earlier being left out to atmosphere. Boil off gas from these locations are now re-routed with the laid piping and are exposed at the air compressor suction. This resulted substantial saving in the filtration system life, purity of air and also the compressor life.
5. Structurally combining the individual loose components like control panel, pre-filter and air drier assemblies as a single unit, resulted in space saving, self-supportive and safe structure.
6. Cleaning of regenerators using ultrasonic bath and petroleum ether which resulted in fast and better cleaning

Few of the above mentioned modifications are carried out on the STIRLIN8 plant at TIFR are shown as Figure 4, 5 & 6.

Figure 4. *Modification of the STIRLIN8 plant.*

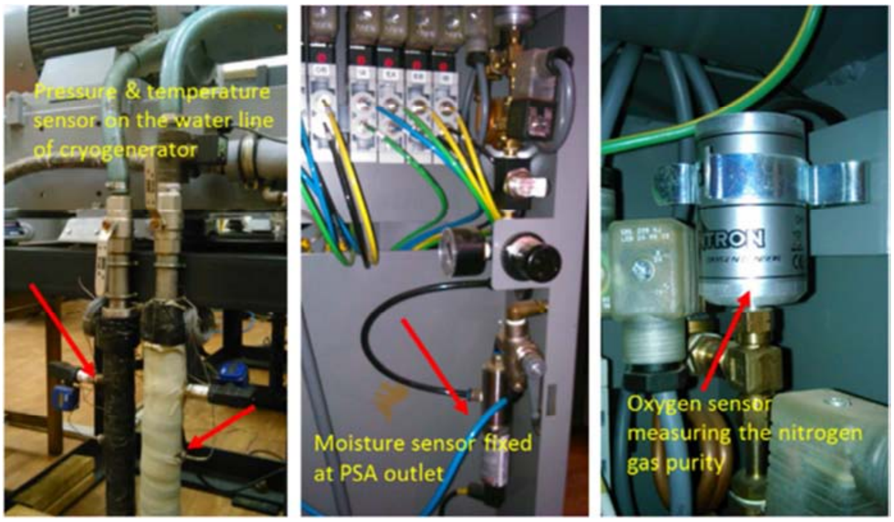

Figure 5. *Modification of the STIRLIN8 plant.*

Figure 6. *Modification of the STIRLIN8 plant.*

Our plant control system uses Siemens make, Programmable Logic Controller (PLC) [5]. The communication between the PLC and the desktop PC is through the profibus cable. The process visualization is developed through the Siemens WinCC software. The report generation, alarms by email & SMS are integrated with the help of Sytech XL reporter software [6] [7]. The architecture of the plant automation is schematically described as Figure 7.

Figure 7. *Architecture of plant automation.*

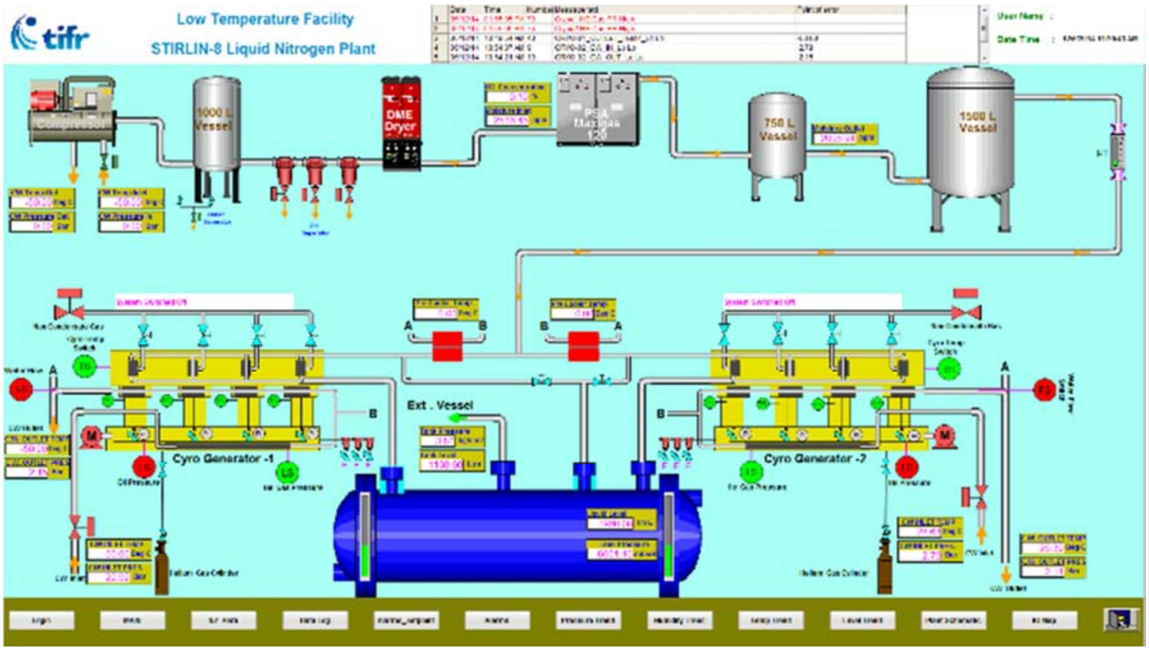

Figure 8. Screenshot of the plant process visualization.

We have indigenously developed a graphical process visualization screen, with suitable navigation tools in the process screen enabling the remote monitoring and remote diagnostic along with the online data acquisition, online reporting, intimation of triggered alarms via Email and SMS. The screenshot of the indigenously developed graphical plant process visualization is attached as Figure 8.

4. Present Status

With the successful implementation of various modifications to the plant, the results are quite encouraging and interesting.

a. Our current implemented modifications ensured that the plant maintenance be carried out based on the need rather than the scheduled maintenance hours prescribed by the manufacturer. We have successfully used the filter cartridges of drier units 870 hours more than the scheduled replacement hours.
b. Purity of nitrogen ensured with the deployed online O_2 monitor.
c. Leak tightness of the charged helium gas ensured with the helium sensor more precisely.
d. Better & faster cleaning of regenerators ensured with ultra-sonic bath cleaning.
e. Substantial reduction in noise of the plant by taking out the dump gas silencer from the operational area.

5. Planned Upgradation in Future

We are currently working on further improvements in the Stirling cycle liquid nitrogen plant in order to achieve the required objectives, as it is evident from the positive results seen from the implemented modifications.

1. Theoretical analysis and process optimization of Regenerator:

The above works involves the Theoretical study of regenerator geometry and its effect on refrigeration [8]; Optimization of regenerator using Numerical modeling and simulation study for various geometry and material. The work is also indent to develop the regenerator (based on the above analysis) using additive manufacturing [9][10]. The work methodology is depicted as Figure 9 and optimization of possible process parameters are listed as Figure 10.

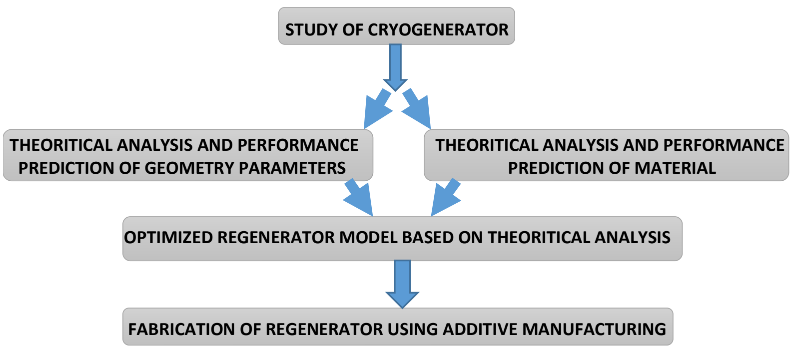

Figure 9. Methodology on Regenerator Optimization.

Optimization of REGENERATOR of Reversed Stirling cycle based cryo-refrigerator				
Sl. No	Property / Condition	Parameters	Possible parameters for alteration	Proposed Methodology
1	Physical condition	Length, diameter, height	No change	No change
2	Initial Boundary conditions	Temperature, Pressure, mass flow	Pressure, mass flow	Theoretical analysis
3	Material	Brass/copper mesh, SS304 porous/micro-porous material, Nano fiber, Nano coated material, Nano coated alloys, composite material	possible combination of SS304 porous/micro-porous material, Nano fiber, Nano coated material, Nano coated alloys, composite material	Theoretical analysis
4	Types of regenerator	Mesh type, Porous, fibrous, micro porous, etched foil	Porous and fibrous material	Theoretical analysis and optimization

Figure 10. *Parameters for Regenerator Optimization.*

2. Replacement of existing electro-mechanical oil pressure switch with pressure transducer.
3. Up gradation of existing starting valve with solenoid valve by a simple solenoid valve assembly. With the above oil pressure transducer, the staring valve can be replaced by a simple solenoid valve, which will be triggered from the PLC after checking the required oil pressure and the suitable time delay. Thus the complicated maintenance of the starting valves may be eliminated, as this valve operation is required only one cycle in its each start/ stop of the plant.
4. Optimization of air temperature for efficient filtration at various environmental condition like ambient temperature and Humidity level are being currently being studied.
5. Replacement of existing, complicated, multi-spacer ring filter element of the oil filter assembly with a simple sintered filter.
6. Replacement of existing complicated replenishment valve with a simple solenoid valve. The incorporated pressure transducer measuring the helium gas pressure at the working space, the adequate supply of helium gas to the working space from the buffer space can be achieved by a solenoid valve. However, we need more understanding of the pulsating helium gas pressure at the working space, to achieve practical objective.
7. Conversion existing temperature switches with the Pt-100 temperature transmitter on all the cylinder head which will ensure the online monitoring/control of each cylinder head for timely action and diagnostics.
8. The charging of working fluid helium gas (with the typical gas purity of 99.995%) shall be passed through the helium gas purifier panel so as to remove the traces of moisture getting into the cryogenerator and enhance the life of regenerator getting clogged.
9. Replacement of existing rubber hose pipe of chilled water line connected to the cryogenerator cylinder head with the swivel cammozzi type quick connection fitting.

Acknowledgements

My acknowledgements to all my colleagues at LTF, TIFR & for their support & cooperation. My acknowledgments to Prof. P L Paulose, Chairman LTFC for his continued guidance and support.

References

[1] Technical note on Stirling cycle by M/s Stirling Cryogenics,Netherlands.Ref:https://www.stirlingcryogenics.com/files/__documents/3/StirlingCycle.pdf

[2] K V Srinivasan, paper titled “Operational Up-Gradation of Stirlin-8 Liquid Nitrogen Plant” presented at 25th National Symposium on Cryogenics, University of Hyderabad, Hyderabad, December, 2014

[3] User Manual Stirlin-8 [document #60 9276 03] Stirling Cryogenics

[4] Service Manual SPC-4 [Document # 60 9221 10] Stirling Cryogenics

[5] K V Srinivasan, Data logging, Graphical Process Visualization of Cryogenic Plant Parameters through PLC. Publication Indian Journal of Cryogenics IJC Vol: 37-2012. Indian Journal of Cryogenics Year: 2012, Volume: 37, Page: 174- 179. Print ISSN: 0379-0479.

[6] K V Srinivasan, Operation of cryogenic facility in e-way at Tata Institute of Fundamental Research, Mumbai, INDIA. Publication Journal of Physics: Conference Series (Ref: http://iopscience.iop.org/1742-6596/400/5/052008/).

[7] K V Srinivasan et all, “LIQUID NITROGEN DISTRIBUTION FOR PELLETRON LINAC FACILITY, MUMBAI” Journal of Cryogenics IJC Vol: 39-2014. http://dx.doi.org/10.5958/2349-2120.2014.00808.5

[8] Analysis of Regenerator for Reversed Stirling Cycle Which Various Geometry, Vikram Patel et al, IJESRT [Patel, 2 (10): October, 2013] ISSN: 2277-96.

[9] "Analysis of Porous Regenerator material of Stirling cryocooler using numerical techniques" – Poster presented by R. D. Pokale, K V Srinivasan et al., at 26th National Symposium on Cryogenics (NSCS-26), Kolkatta, India, February, 2017. Ref: http://indico.vecc.gov.in/indico/getFile.py/access?contribId=35&sessionId=14&resId=0&materialId=0&confId=44

[10] K V Srinivasan, A Manimaran, et al., paper on "Study on Stirling Cryocooler" presented in NAFEMS International Conference on Engineering Modelling, Analysis Simulation and 3D Printing – NAFEMS-3D, August 2016.