Case study of sintered regenerator performance in StirLIN-4 nitrogen liquefier

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Stirling liquefier works on Stirling cycle to produce cooling effect. Sintered Regenerator is a key element of Stirling liquefier which directly affects the liquefier performance. Sintered regenerator is a regenerative heat exchanger where heat from the hot fluid is intermittently stored in a thermal storage medium before it is transferred to the cold fluid. The sintering process bonds together tangent metal surfaces at their points of contact without the addition of any filler metal or bonding agent. It is necessary to maintain regenerator porosity for optimum performance of liquefier. Hence Preliminary study has been carried out to find the properties of SS wire mesh matrix, how it is sintered, problems causing degradation of sintered regenerator performance. The main objective of this paper is to study different methods of maintaining sinter regenerator porosity for optimum performance.

Key words: Stirling Cycle, Liquefier, Sintered Regenerator, Heat Exchanger, Wire mesh

INTRODUCTION

Stirling liquefier works based on Stirling cycle to produce high cooling effect on the cold head of the cooler. Sintered regenerator is heart of Stirling liquefier, performance of sintered regenerator directly affects the liquefier performance [2]. Sintered regenerator (shown in Figure 1) is a regenerative heat exchanger where heat from the hot fluid is intermittently stored in a thermal storage medium before it is transferred to the cold fluid. Sintering may be defined as a thermal process that induces diffusion bonds. The sintering process bonds together tangent metal surfaces at their points of contact without the addition of any filler metal or bonding agent. The system operating on Stirling cycle has highest theoretical efficiency possible for any practical thermodynamic system. A sintered regenerator is used in Stirling cryogenics Netherlands 4 Cylinder Liquid Nitrogen liquefier plant [1]. It is observed that one of the four regenerators is clogged/blocked after about 26,000 working hours of the system, the temperature and pressure of cryocooler cylinder was substantially higher than other cylinders. This was directly affecting the production of Liquid Nitrogen and since the temperature was very high may affect the drive mechanism of the Stirling Nitrogen Liquefier. Keeping this in mind, the study has been carried out on different methods of removing oil and other impurities from the sintered regenerator. This paper is intended to study the solutions for the blockage of sintered regenerator.

REGENERATIVE TYPE HEAT EXCHANGER

A heat exchanger is a device in which the warm fluid gets cooled due to heat exchange with the cold fluid [3]. In most of the cases, the process of heat exchange occurs at a constant pressure. It can either be a regenerative or recuperative type of heat exchanger depending on the kind of heat exchange between the fluids. In a regenerative heat exchanger, a matrix is used as an intermediate heat exchange medium between the warm and cold fluids [4]. The gas flow is periodic in nature alternating between the warm and cold fluids across the matrix. It is important to note that, it is an example of indirect heat transfer. Ideally, the regenerator should be without any pressure drop [2]. Regenerator theory deals with the exchange of thermal energy occurring between the fluid and matrix material.

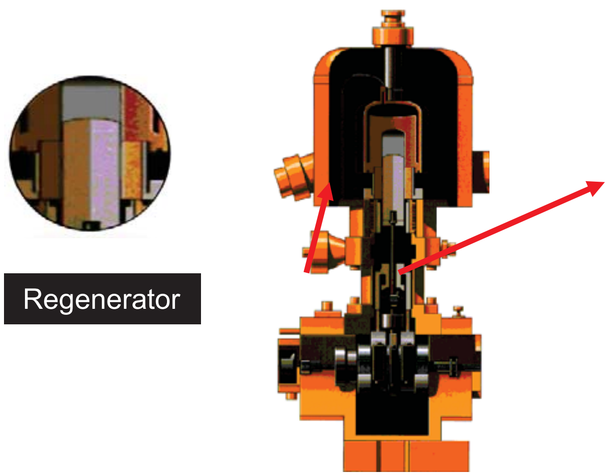


Figure 1: Stirling Cryogenerator

Figure 2: Sintered Regenerator

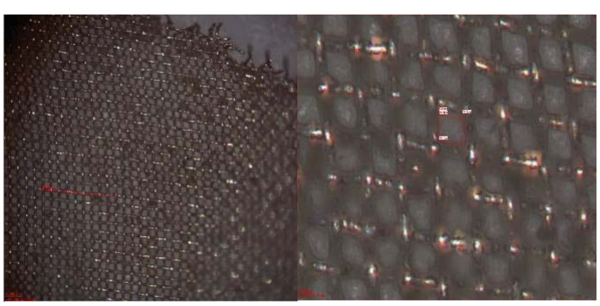


Figure 3: Microscopic view of SS wire mesh

An ideal regenerator should have high volumetric heat capacity of the material. The typical regenerator as shown in Figure 2 is made up of SS wire mesh 230 matrix, wire diameter 0.035mm as seen in the microscope shown in Figure 3. Numerous Mesh layers are compressed with high load and sintered at about 1100°C. Then all the mesh layers stick together to form a sintered regenerator.

Stirling Cycle

The Liquid Nitrogen Liquefier uses helium gas as working fluid under high pressure which effects the cooling process in closed cycle. Since nitrogen liquefies at 77K, it is required to use a gas, which does not liquefy at operating temperature of the Cryogenerator. For this reason, helium gas is used as a working gas. The working process of Stirling cycle is shown below (Figure 4 & 5).

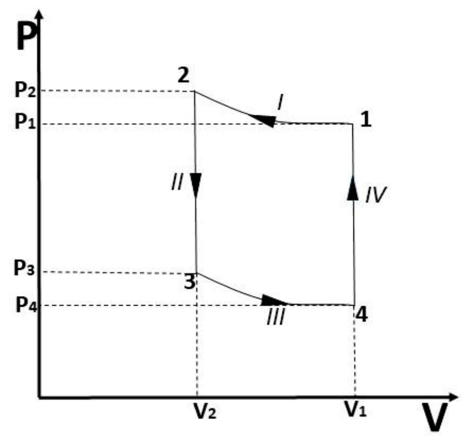


Figure 4: Stirling Cycle PV Diagram

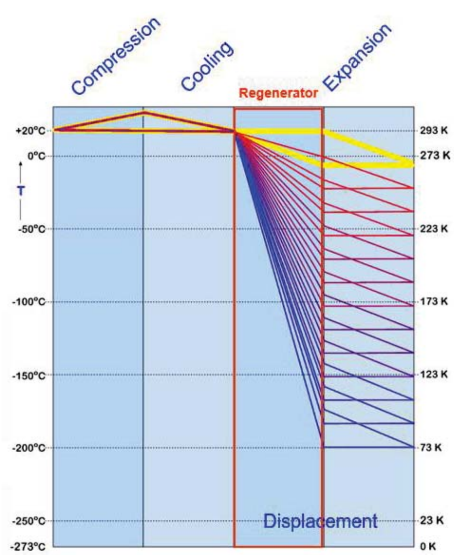
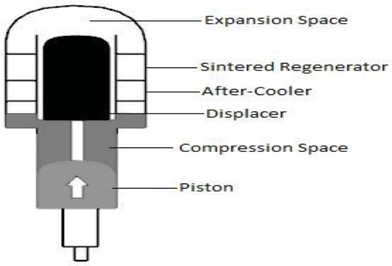


Figure 5: Stirling Cycle

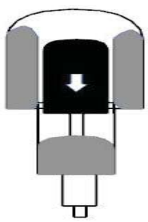
Step 1: Compression

Helium gas is compressed, temperature rises.



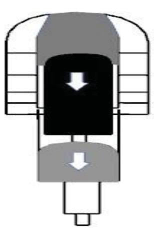
Step 2: Cooling

Compression heat is removed. The helium gas is pre-cooled in the water cooler before expansion starts.



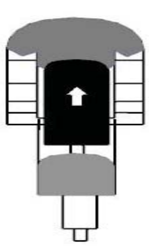
Step 3: Expansion

By expansion, energy is extracted from the gas and thereby the temperature goes down cooling the head and the cold side of the regenerator.



Step 4: Displacement

Gas is displaced back into the compression space. The cold from the helium gas is stored in the regenerator during displacement of the gas back to the state of step 1.



OBSERVATIONS AND TEST SETUP

In a Stirling Nitrogen liquefier during working due to compression of gas at compression space lot of heat is generated. The chilled water is supplied around the after-cooler to maintain the optimum temperature of the Nitrogen Liquefier cylinders. During every working cycle small amount of lubricating oil from the crank case and other worn-out sealing ring material enters into the regenerator (Figure 6). All of it doesn't return to the crankcase. Due to this performance of regenerator decreases. Hence it is required to clean it after specified working hours to remove impurities and oil particles. The practice suggested by manufacturer is to clean it with petroleum ether so that all the oil will dissolve and will be removed. It is also suggested that the difference in weight should be within certain limit. To do this Petroleum Ether 60-80 grade is used to flush the regenerator. In the present system it is observed that one of the 4 cylinders was heating up very much. The temperature noted was about 65°C which is undesirable for plant operation and this temperature is about 12°C more than other three cylinders. After following procedure of regular maintenance of sintered regenerator, the temperature in the cylinder was still rising. It is suspected that Regenerator is blocked more with oil and other impurities and was not clearing even after flushing with Petroleum Ether. To confirm this the suspected regenerator was interchanged with other regenerator in nitrogen liquefier. Still the same temperature conditions persisted and thus confirmed that the sintered regenerator itself has the problem. Since regenerator was not getting cleaned with the regular maintenance, new methods for cleaning have been carried out as explained in the following section.

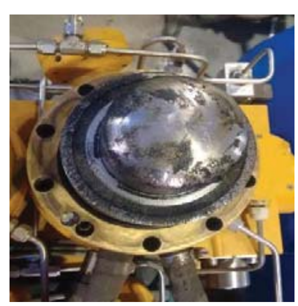


Figure 6: Stirling Cycle

Method 1: It is the normal method of regular maintenance. Flushing of regenerator by petroleum ether with high air pressure. Repeated this process three to four times and then warmed in hot air oven at about 50°C about an hour.

Method 2: This involves after flushing petroleum ether and high air pressure. Regenerator is immersed in ultrasonic petroleum ether bath as shown in Figure 7. for about two hours then warmed in hot air oven at about 50°C about an hour.

Figure 7: Regenerator Ultrasonic bath

Method 3: Flushing regenerator with petroleum ether and air pressure. Then an arrangement made to put it into defroster which is high pressure hot air blower about six hours continuously as shown in Figure 8. The schematic drawing is shown in Figure 9.

Figure 8: Regenerator flush with High pressure hot air blower

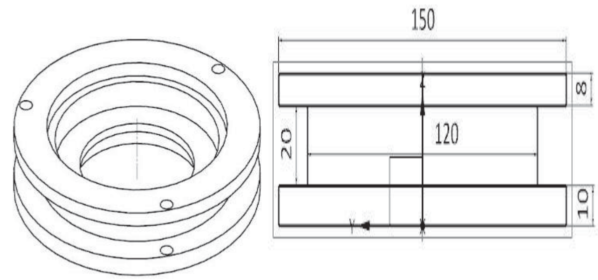


Figure 9: Schematic drawing of aluminium holding arrangement for regenerator for flushing with high pressure hot air

Method 4: Removed blackened SS wire mesh three to four layers which were loosened from top and bottom side of the sintered regenerator is shown in Figure 10. Then flushing regenerator with petroleum Ether 60-80 grade with high pressure nitrogen gas at about 5 bar in both normal as well as in reverse flow directions. This was repeated 10 times, the arrangement shown in Figure 11.

Figure 10: Loosened SS wire mesh

Figure 11: Regenerator flush with high pressure Nitrogen and petroleum Ether

RESULTS

After every method of maintenance, the system has been run for enough time to observe the temperature and pressure distribution over the Nitrogen liquefier cylinders. The Figure 12 shows temperature distribution before and after cleaning sintered regenerator by method

4. The method 4 is observed to be showing a significant drop in temperature and pressure and the increase in performance of regenerator is observed through increase in the production of liquid nitrogen. The cleaned regenerator was put in the system and plant was operated again. The difference in temperatures before and after the cleaning is shown in Figure 4. The difference for the regenerator 4 (clogged regenerator) is found to be as high as 17 °C.

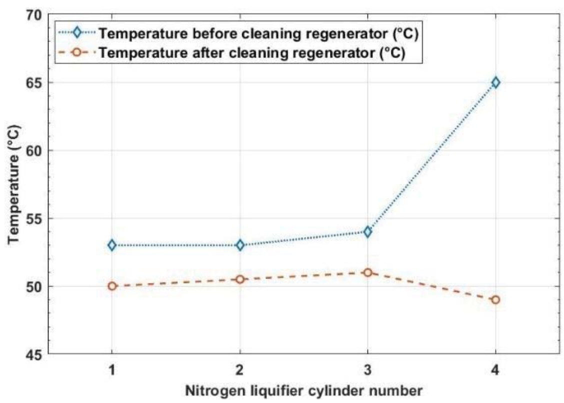


Figure 12: Temperature distribution across cylinders

The nitrogen flow meter on the plant also showed improvement in the flow rate from 40% to 60% before and after the cleaning. Indicating the usefulness of the methodology

Hence method 4 is found to be a better method to clean the regenerator to remove oil and other impurities.

Present status

After using method four the system has been running for 1200 hours while the temperature and Pressure distribution over the cylinder is normal as well as the performance of regenerator is increased

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