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# Performance Evolution of Conceptual Designed of Single Panel Cryopump

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## Abstract

Now a day's cryogenic pump available in mega mechanical project such as cryosorption pump available in ITER. This cryopump designed is applied in small scale industries to produce a vacuumed. Cryosorption pump is available in ITER is multi panel cryopump so, convert into single panel and designed it theoretical as well as simulate on ANSYS tool. Then compare of theoretical and simulating result if it is nearer or equal same then it will put in manufacturing. In this paper we had to do theoretical and simulation of one component of single panel cryopump named panel and compare both result and it is mostly same from this result we develop single panel cryopump designed.

**Keyword**: Cryosorption pump, ANSYS, Single Panel Cryopump

## Introduction

### Definition of Cryopump

By international classification a cryopump is defined as a vacuum pump which captures the gas on surfaces cooled to temperatures below 120K. The cryopump is by its physical principle a high vacuum pump. Besides straight forward parameters such as pressure, temperature and gas load the pump performance is very much governed by the complex interaction between gas particles and cooled surface. [9]

Cryopump belongs to the class of entrapment or capture vacuum pumps which retain gas molecules by sorption and /or condensation on its internal surfaces. Thus, the performance of cryopump is governed by the interplay of these two pumping mechanisms.

### Cryopumping Mechanism

1. **Cryosorption:**

Gas particles impinging on a surface of sufficiently low temperature lose so much of their incident kinetic energy that they stay attached to the cold surface by weak intermolecular forces, resulting in significantly higher molecular concentration on the surface than in the gas phase. This phenomenon is called physical adsorption or physiosorption. The equilibrium pressure of adsorbed gas particles is significantly lower than the corresponding saturation pressure for cryocondensation. [4] This is due to the fact that the dispersion forces between the gas molecule and the surface are greater than between the gas molecules themselves in the condensed state. Hence, gas can be retained by adsorption even in a sub saturated state, i.e., at considerably higher temperatures than would be required for condensation. This fact is essential in cryopumping helium, hydrogen, and neon, which are difficult to condense. However, the cryosorption process is quite complex and very much determined by the actual nature of the surface (chemical, mechanical, physical), not only by its temperature, as is the case for cryocondensation. Porous materials with high sorption capacity, such as molecular sieves or activated carbons are most often used as sorbent materials. [5] However, layers of condensed gas frost (Ar, $CO_2$ and $SF_6$) may also be applied. The characteristic of cryosorption is given by the respective sorption isotherm.

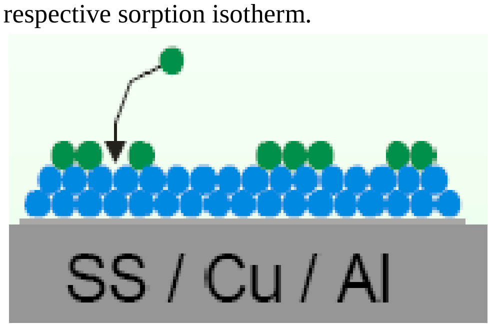


Fig 1 Cryosorption [6]

Due to the physical principle, cryosorption pumping is limited to some monolayer's of gas coverage on the surface. Then the effect of the surface becomes negligible and the resulting pressure starts to increase rapidly.

**2. Cryocondensation**

In this case, the surfaces must be cooled to such a temperature as to keep the corresponding saturation pressure equal to or below the desired vacuum pressure in the chamber. The achievable pressure is determined by the saturation pressure at the temperature chosen for the cold surfaces. This principle is the most elementary of all forms of capture pumping. For many gases, the pressure range of cryopumps is below the triple point pressure of the individual gases to be pumped. Thus, the relevant saturation curve becomes identical with the sublimation curve, i.e., during pumping, the gas particles undergo direct phase transition from the gaseous to the solid phase without any liquid phase. Within this report, as is customary in cryopumping, the term condensation is used for both types of transition out of the gaseous phase, and combines re-sublimation (gaseous - solid) and condensation (gaseous - liquid). During cryocondensation, condensate layers are formed by crystal growth out of the gas phase. This growth process takes place over three stages: Firstly, thermal accommodation of the impinging particle and adsorption on the surface, then, diffusion to the growth site on the crystal lattice, and, thirdly, atomic incorporation. It has been shown that the second step governs the overall condensation velocity. The efficiency of the condensation process is expressed by means of the condensation coefficient ac, defined as the number of condensed particles related to the number of particles incident upon the cryosurface.

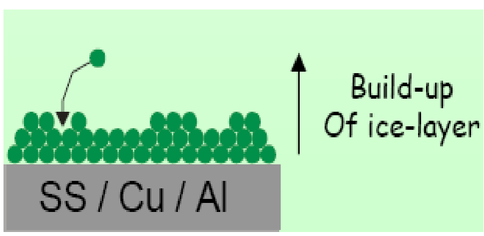


Fig 2 Cryocondensation [6]

Assuming high super saturation, a condensation coefficient of unity is achievable without any problem. In most cases, the cryocondensation growth starts by forming one or a few monolayers and then changes to form islands on top of them. Thus, the cryodeposits obtained during pumping may be quite non-uniform. The growth of condensed layers is not limited in principle. But for regions with increased layer thickness, the surface temperature of the condensate rises, thus leading to higher surface mobility of the pumped particles. This results in a higher risk of spontaneous transpositions and should be avoided in any case.

**3. Cryotrapping**

This is the concurrent pumping of two or more gases by entrainment of gas particles which are not condensable at the prevailing temperatures and pressure conditions. For the purpose of entrainment, a condensing gas is used, so that a mixed condensate is formed. Usually, the small molecules of the gas to be pumped are caught in the open lattice of the cryodeposit of a more abundant species and are quickly buried by subsequent layers. As most of the bonded gas particles are occluded in the condensate layer and only a certain percentage directly interacts with the surface, the achievable equilibrium pressures are even lower than those achievable by cryosorption. [10] The entrapment ratio (i.e., the number of pumped molecules of one species related to the number of deposited molecules of the condensate species) is higher than with pumping by layers of pre-condensed frost (see, for example, pumping of He by condensed Ar). However, the main disadvantage of this technique is the additional gas input into the system which has to be evacuated. This helps during pumping, but has to be coped with during regeneration and, thus, requires larger fore vacuum systems.

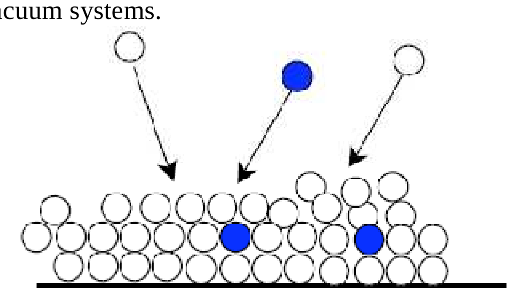

Fig 3 Cryotrapping [7]

**Regeneration of Cryopump**[13]

Cryopumps retain pumped gases as long as their capacity is not exceeded and the arrays are maintained at appropriate temperature. This condition may arise when the cryodeposit condensed at the baffle blocks the louver aperture or when the surface temperature of the panels covered with frozen gas becomes too high due to the temperature gradient through it. However, the cryopump must be regenerated at the latest when the capacity limit has been reached. The capacity is very large for cryocondensation pumps (only limited by the temperature gradient within thick condensate layers) and smaller for cryosorption pumps (limited by full coverage of the active sorption sites, which may be partly clogged). The correct choice of the sorbent is therefore a vital point in cryopump design.

Regeneration is regularly done by heating the cryosurfaces up so that the captured gas deposits are released. As a result, the pressure in the pump increases strongly so that the gas can be pumped away by mechanical for pumps. Before heating, the isolation valve (most appropriate are gate valves which provide full opening) between the pump and system is closed. As the pumping speed starts to decrease before the maximum saturation capacity is reached, a certain safety margin with respect to the maximum operating time must be ensured. After pumping out the release gas, the pump is cooled down again and, thus, the cryopump is ready to be used for the next pumping period. The isolation valve to the vacuum system must remain closed during cool-down, because contaminants resident in the system might be pumped by the second-stage sorbent material, which may result in the plugging of this material.

## Construction of CRYOPUMP

The cryopump consist of cryopanels as pumping surfaces. The pumping surfaces or the cryopanels can be arranged circularly and suspended from the header. Due to the port size limitation, the cryopanels are kept inclined at certain angle. These cryopanels are enclosed by 80K cylindrical shield. The shield can be closed by annular shields on both the sides. Baffles are installed to prevent the cryopanels from the high temperature radiation from the pump inlet. Baffles are also cooled by 80K gaseous helium. The 80K cylindrical shields are enclosed by the pump housing. The cryopanels are covered by activated charcoal sorbent material which is fixed to the metallic substrate of the panels by inorganic cement. Panels are cooled by 4.5K ScHe. The shields and cryopanels are vacuum insulated from the pump housing.

Main components of cryopump are: [1]

1) Outer Shell
2) Cryopanel
3) Radiation Shields
   a) Cylindrical Shield
   b) Front Annulus
   c) Rear Annulus
   d) Front shield
4) Baffles

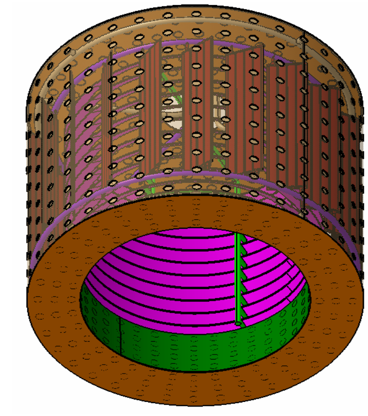

Fig-4 Multi panel Cryopump assembly

**Cryopanel**

S.S.316L material is used for the cryopanel. Each cryopanel is hydro formed. In this case two stainless steel plates are line welded and pressurized fluid is blown between the plates.

Fig- 5 Cryopanel

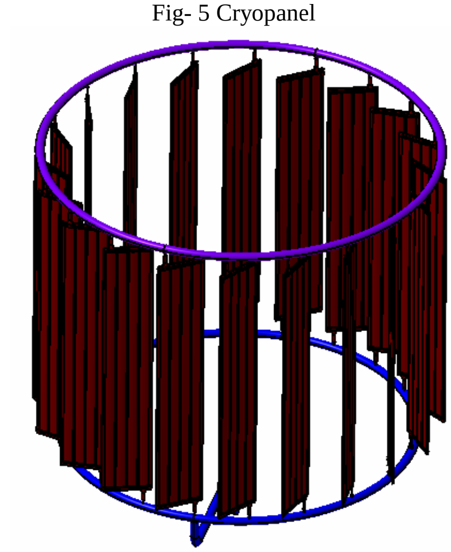

Fig-6 Cryopanel assembly

The cross section of one panel section is 'Eye' shaped. The cryopanels are arranged to form a cylindrical array. Each panel is rectangular shaped and inclined with respect to central horizontal axis. The panels are cooled by forced flow supercritical helium at 4.5K supply from circular manifold. The panels are coated on both sides with the sorbent

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material. The thickness of the sorbent layer, in addition to determining sorption capacity, has a strong influence on the temperature differential between the refrigerant and the panel surface.
High impurities like Argon, Neon, Krypton, will result in high level of sorbent pollution during pump partial regenerations these molecules will be adsorbed at 80K.The solution is to coat the panel on both the side with the sorbent material in order to absorb the impurities on the front side and He on the other side. [8]

## Conceptual Designed And Modeling of Singke Panel CRYOPUMP[3]

Clearance between panel and cylindrical shield = 20 mm
So, diameter of cylindrical shield = 200 + 2(20) = 240 mm
Length of baffle = 155 mm

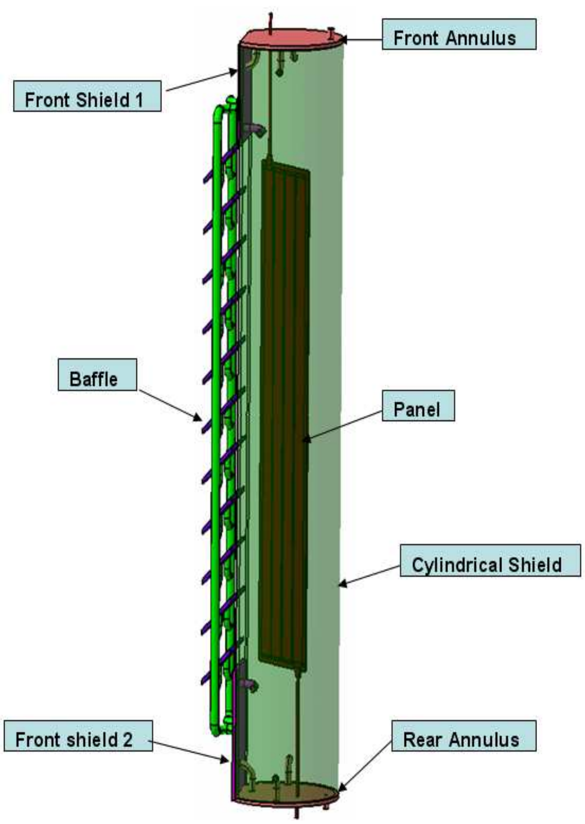


Fig-7 Single panel Cryopump assembly

It is made from two hydro formed rectangular plate joined by welding.
Material - SS316L.1000mm x 200mm.
Plate thickness= 1.5mm.
Spot welded portions are shown by circles of 12mm diameter.
Line welding is shown by 2 mm lines. Seam welding of 10mm is shown at the periphery

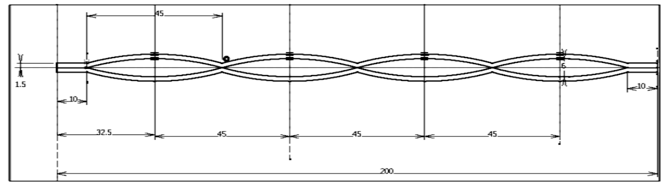

Fig 8 Dimensions of cross–section A-A of Cryopanel

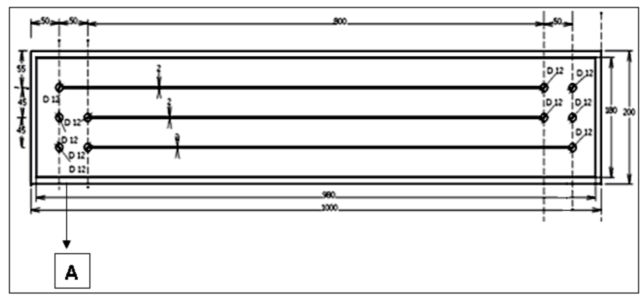


Fig 9 Dimension of Cryopanel

## Theoretical Calculation For heat Transfer And Pressure Drop

**Steady State Heat Load Calculations for Cryopanel**

**(1) Heat load due to gas throughput ($Q_p$) [10]**

**For DT**

M = 78.7 mole/hour (ITER data)
ΔH for DT at 100K to 4.5K = 3600 J/mole
Heat load due to pumping of gas throughput

$$Q_{p1} = 78.7 \times 3600 \times \frac{1}{3600 x 20} = 3.935 \text{ W}$$

***For Helium***

M = 0.86 mole/hour
ΔH for Heat 100K to 4.5K =2500 J/mole
Heat load due to pumping of gas throughput

$$Q_{p2} = 0.86 \times 2500 \times \frac{1}{3600 \text{x} 20} = 0.0298 \text{ W}$$

Total residual gas heat load $Q_p = Q_{p1} + Q_{p2}$
= 3.935 + 0.0298

= 3.964 W
~ 4 W

**(2) Heat load due to radiation ($Q_r$)**

***Heat load due to radiation $Q_{r1}$ from shields***

Warm surface temperature $T_2$ = 80K
Warm surface emissivity $e_2$ = 1

Cold surface temperature $T_1 = 4.5K$
Cold surface emissivity $e_1 = 1$
Cold surface area $A_1 = 0.4\ m^2$

$$Q_{r1} = \frac{\sigma A_1\left(T_2^{\ 4} - T_1^{\ 4}\right)}{\frac{1}{e_1} + \frac{1}{e_2} - 1} = 0.928\ \text{W} \sim 1\ \text{W}$$

***(3) Heat load due to radiation $Q_{r2}$ from Baffles***

Warm surface temperature $T_2 = 450K$
Warm surface emissivity $e_2 = 1$
Cold surface temperature $T_1 = 80K$
Cold surface emissivity $e_1 = 1$
Warm surface area A2 = 0.1193 $m^2$
Transmission coefficient of photons through baffle (assumed) E = 0.01

$$Q_{r2} = \frac{\sigma_2 x\left(T_2^{\ 4} \quad T_1^{\ 4}\right)E}{\frac{1}{e_1} + \frac{1}{e_2} \quad 1} = 23.227\ \text{W/m}^2$$

Radiation Heat load transmitted through baffle = $Q_{r2}$ x $A_2$
= 23.227 x 0.1193= 2.77 W
Total radiation heat load at 80K $Q_r = Q_{r1} + Q_{r2}$

= 1 + 2.77= 3.77 W
~ 4 W

***(4) Heat load due to residual gas conduction ($Q_g$)***

Gas = $H_2$
Specific gas constant of $H_2$, R = 4157 J/kg K
Pressure, P = $10^{-3}$ mbar = 0.1 Pa
Warm surface temperature $T_2 = 80K$
Cold surface temperature T1 = 4.5K
Accommodation coefficient of warm surface at 80K, $a_2 = 0.53$ (Appendix-C, table C-1)
Accommodation coefficient of cold surface at 4.5K, $a_1 = 1$ (Appendix-C, table C-1)
Cold surface area of cryopanel A1 = 0.4 $m^2$

Accommodation factor $$\frac{1}{F_a} = \frac{1}{a_1} + \frac{A_1}{A_2}\left(\frac{1}{a_2} - 1\right)$$
$$= \frac{1}{1} + \frac{1}{1}\left(\frac{1}{0.53} - 1\right)$$
$$F_a = 0.53$$

$$G = \frac{\gamma+1}{\gamma-1}\left(\frac{g_c R}{8\pi T}\right)^{1/2} F_a$$

$$G = \frac{1.4+1}{1.4-1}\left(\frac{1\times 4157}{8\times 3.14\times 300}\right)^{1/2} \times 0.53$$

G = 2.3618 m/s K
Heat load due to residual gas,

$$\frac{Q_g}{A_1} = G\times P\times\left(T_2 - T_1\right)$$
$$= 2.3618\times 0.1\times(80 - 4.5)$$
$$= 17.831\ \frac{W}{m^2}$$

Heat load due to residual gas $Q_g$ = 17.831 x 0.4

= 7.132 W

Total heat load, Q = $Q_p + Q_r + Q_g$
= 4+4+7.132 = 15.132 W

**(5) Heat load due to solid conduction ($Q_s$)**

$Q_s$ = 3.0264 Watt (Assuming 0.2 times total heat load)
Now, Total heat load = 15.132 + 3.0264
= 18.158 W
By taking 20% safety margin, net heat load = 21.789 W
~ 25 W

**(6) Mass Flow Rate of ScHe at 4.5K Temperature difference across the Panel[10]**

The temperature difference results from the heat flux through the panel and various thermal resistances offered to the flux.
Heat flux through Panel material.
q = Q/A
= 25/0.4
= 62.5 W/$m^2$
Δ T Sc He/panel wall: $\Delta T_1$
Average heat transfer coefficient: h = 500 $m^2$ K
$\Delta T_1$ = q/h
= 62.5/500
= 0.125 K
Δ T through stainless steel wall: $\Delta T_2$
$\Delta T_2$ = q.e/K
e = 1.5 mm,
K ( SS@5K) = 0.35 W/mK,
$\Delta T_2 = 62.5 \text{ x} 1.5\text{x}10^{-3} / 0.35 = 0.267$ K
Δ T through sorbent coating: $\Delta T_3$
e = 1 mm
Ks = 0.13 W/m K [2]
$\Delta T_3 = 62.5 \text{ x} 1.0\text{x}10^{-3} / 0.13 = 0.48$ K
Δ T through sorbent /frost interface: $\Delta T_4$
R = $2\text{x}10^{-4}$ $m^2$ K/W [17]
$\Delta T_4$ = R. q
= 2 x $10^{-4}$ x 62.5
= 0.0125 K

Total ΔT across the panel surface
$\Delta T_s = 0.125 + 0.267 + 0.48 + 0.0125 = 0.88$ K
Let us take $\Delta T_s = 0.9$ K

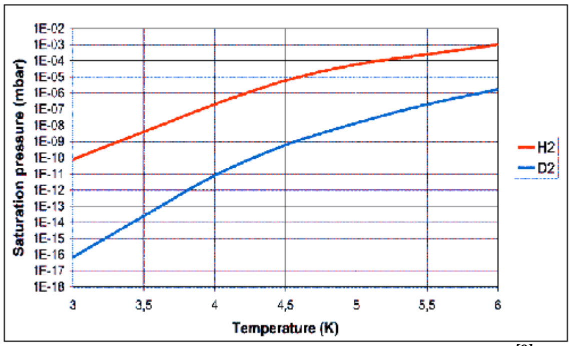

Fig 10 Sublimation Pressure curves of $H_2$ and $D_2$ [9]

From the curve it is clear that there is a window of 4.5 K (@ 4.5 K Saturated vapour pressure of Hydrogen is $10^{-5}$ mbar & Deuterium $10^{-9}$ mbar) and 5 K ((@ 5 K Hydrogen SVP of Hydrogen is $10^{-4}$ mbar and deuterium $10^{-8}$ mbar). Rise in pressure above $10^{-5}$ mbar is not acceptable as the conduction loses will increase drastically. If inlet temperature of SCHe is taken as 4.5 K then $T_s$ max = 4.5 + 0.9 = 5.4 K which will give a higher saturated vapour pressure. Thus we cannot allow a temperature rise of more than 0.2 K
So that $\Delta T_s \sim 4.7$ K.
Temperature difference between inlet and outlet of Cryopanel should not be more than 0.2K.
Q = m Cp (To – Ti)

25 = m x 4130 (4.7 – 4.5)

m = 0.03 kg/s

By considering safety factor of 2, mass flow rate of liquid helium, m = 0.06 kg/s

$m = \rho \times A_f \times V$

0.06 = 128.77 x 0.000182 xV

V = 2.56 m/s

**Pressure Drop Calculation for Cryopanel[12]**

Helium inlet temperature $T_\infty$ = 4.5K

Helium outlet temperature $T_{out}$ = 4.7 K

Surface temperature $T_s$ = 5.05K (assumed)

Mean film temperature $T_m = \frac{4.5+5.05}{2} = 4.775$K

Bulk temperature $T_b = \frac{T_\infty + T_{out}}{2} = \frac{4.5+4.7}{2} = 4.6$ K

**(1)Fluid Properties Based on Mean Film Temperature 4.775K[11]**
Specific heat Cp = 4884 J/kg K
Viscosity μ =3.506 x $10^{-6}$ Pa s
Density of helium = 128.77 Kg/$m^3$

**(2)Area of panel:**

Area of sector = $\left(\frac{\angle AOB}{360^\circ}\right) \times \pi \times r^2$

$= \left(\frac{31.413}{360^\circ}\right) \times 3.14 \times 0.080344^2$

= 0.001769 $m^2$

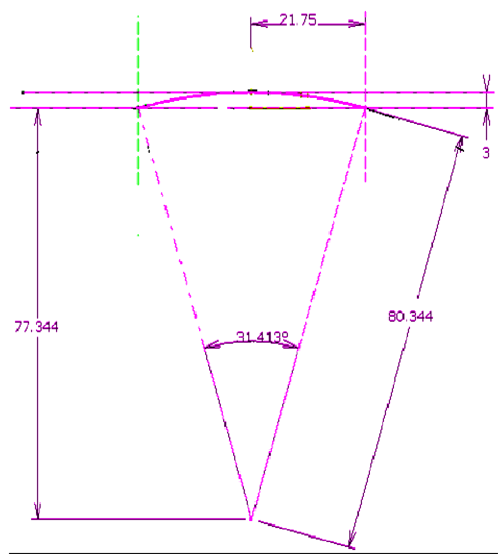


Fig.11 Dimension of one channel of panel

Area of triangle = 1/2 x base x altitude

= 1/2 x 0.0435 x 0.077344

= 0.001682 $m^2$

Free flow area $A_f$ = 2 x (0.001769 - 0.001682)

= 0.0001746 $m^2$

Length of Arc of the segment = $r \times \theta$

$= 0.080344 \times \frac{31413 \times \pi}{180}$

= 0.044 m

Wetted perimeter $P_w$ = 0.044 x2 = 0.088 m

**(3) Hydraulic diameter**

$D_h = \frac{4A_f}{P_w} = \frac{4 \times 0.0001746}{0.088}$

$D_h = 7.936 \times 10^{-3}$ m

**(4) Reynolds's Number:**

$Re = \frac{\rho x V x D_h}{\mu} = \frac{128.77x2.66x0.007936}{3.506x10^{\ 6}}$

$R_e$ = 777845.7

**(5) Friction Factor:**

$f = (1.58 \ln Re - 3.28)^{-2}$

$= (1.58 \ln 777845.7 - 3.28)^{-2}$

$= 3.035 \times 10^{-3}$

**(6) Head loss due to friction:**

$hf = \frac{4xfxlxv^2}{2xgxD_h}$

$= \frac{4x3.035x10^{-3}x0.98x(2.66)^2}{2x9.81x0.007936}$

= 0.5406

**(7) Pressure drop due to friction**

$\Delta Phf = hfx\rho xg$

= 0.5406 x 128.77 x9.81

= 682.9 Pa

**(8) Surface temperature of panel**

Heat flux, $q = \frac{Q}{A}$

$= \frac{25}{2x0.98x0.2}$

= 63.77 W/m$^2$

$q = \frac{KdT}{dx}$

$63.77 = \frac{0.35x(T_{outside} - 4.5)}{0.0015}$

$T_{outside}$ = 4.773 K

## Simulation On ANSYS

**Load and boundary conditions**

Inlet temperature = 4.5 K

Inlet velocity = 2.66 m/s

Heat flux on outer surface = 63.77 W/m$^2$

Velocity on outer surface = 0 m/sPressure at outlet = 0 Pa

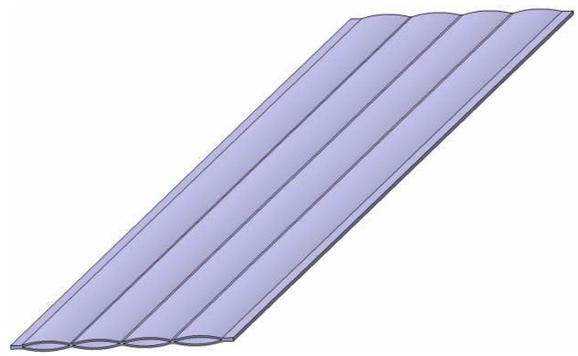

Fig 12 Model of Cryopanel

Fig 13 Cross section of Cryopanel

**Meshing of Cryopanel**

Element type – Fluid 142

No. of elements = 196480

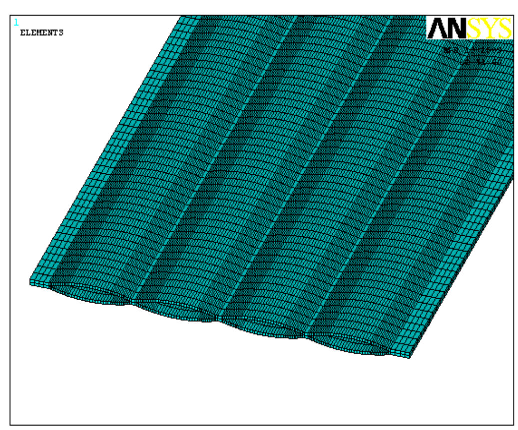


Fig 14 Meshing of structure

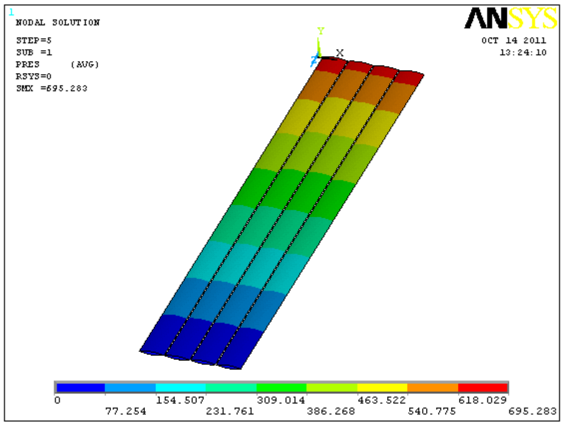


Fig 15 Pressure drop distribution

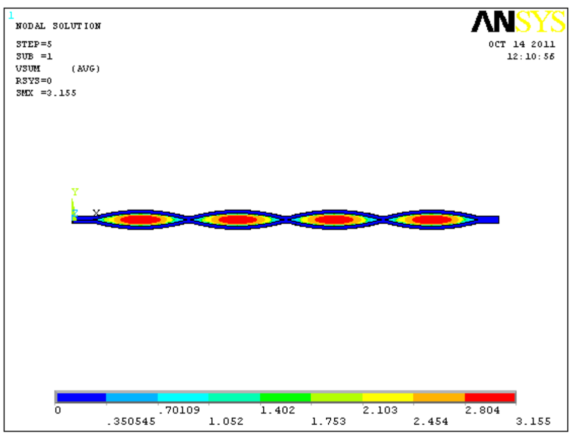


Fig 16 Velocity distribution

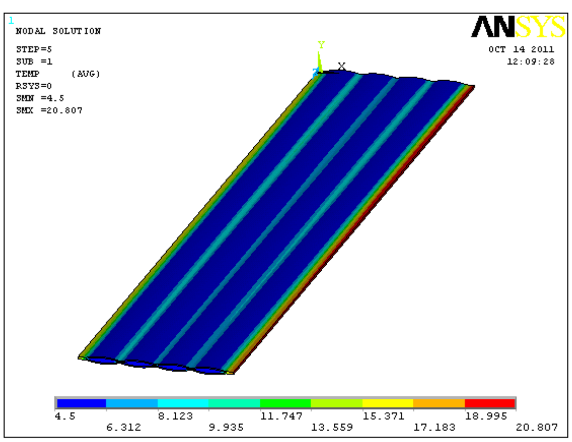


Fig 17 Temperature distribution

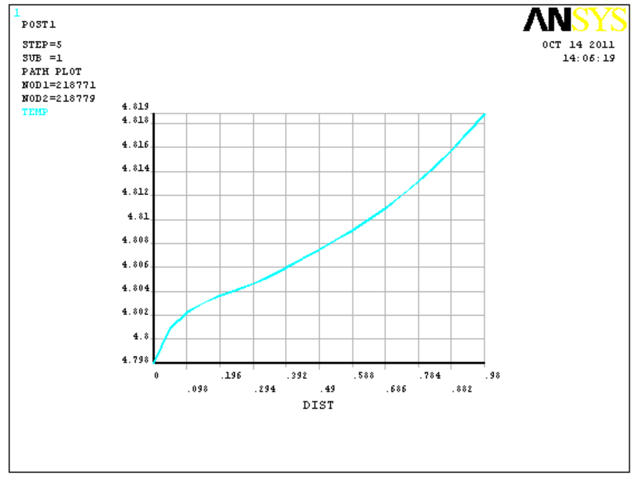


Fig 18 Temperature plot on graph

## Results Comparison

| Sr. No | Parameters | Theoretical | ANSYS |
|---|---|---|---|
| 1 | Pressure (N/m$^2$) | 682.9 | 695.283 |
| 2 | Velocity (m/s) | 2.66 | 3.155 |
| 3 | Final surface temp. (K) | 4.773 | 4.808 |

## Conclusion

We can conclude by above comparison that Conceptual design of single panel cryosorption cryopump is done successfully. For given conceptual design of single panel cryopump, heat load and pressure drop calculations are done and also Simulation and theoretical results for cryopanel are in good agreement.

## Future Scope

- Modifications in considering different phase of fluid as like liquid helium and gaseous helium respectively studied for minimum heat losses.
- Modifications in the cross sections of cryopanels and shields can be made and can be studied for minimum pressure drop.
- Experiment on whole single panel pump can be performed for checking various parameters like Pumping probability due to geometric arrangement of baffles and panel, sticking coefficient, max. Saturation capacity of charcoal, pumping time required, etc.

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