# Analytical Design of Isolations for Cryogenic Tankers

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***Abstract*— In this paper it is presented a methodology for the design of the isolations used in the cryogenic tankers. This isolation usually is a combination of vacuum and perlite or vacuum and super-insulation. In this paper it is established a methodology to obtain the temperatures, heat fluxes, etc. using analytical tools, based on the equivalence with an electric circuit.**

**All this aspects are applied to a concrete cryogenic commercial vehicle.**

***Index Terms*— cryogenic, isolation, tanker, design, finite elements**

## I. INTRODUCTION

A main aspect of any type of cryogenic device is the thermic isolation of it content. The case of a cryogenic tanker for liquefied gases is not an exception so it is necessary during the design stages to make a detailed study and analysis of the thermic phenomenon's that take place during the use of the tanker. It is necessary to a thermic analysis to choose and to dimension correctly the isolation used in the zones between both of the two main parts of the tanker to reduce the heat flux, with the resulting heating of the load and so to allow a higher storage time; this aspect involve, that the vehicle has a higher range distance. On the other hand, if the heat losses are reduced, the energy needed in the discharge point to cool the gas is lower and appears an energy benefit.

Nowadays, the thermic analysis that some vehicle designers of the main manufacturing companies make has a low precision and is based on some coarse simplifications of the problem, so the results have low precision.

This paper explains some techniques to make a thermal analysis of these types of vehicles, using analytical and numerical tools.

The main thermal isolation methods used in the cryogenic industry[1,2] are based on the combination of vacuum and superinsulation (based on the Dewar flask) and vacuum with expanded perlite. The use of one or another technic depends on some aspects: economical, manufacturing, gas transported, etc.

Another analyzed aspect is the maximum range time to make the transport, depending on some aspects like the weather, wind, external temperature, filling grade etc.

## II. HEAT TRANSMISSION METHODS

There are three different heat transmission mechanisms: conduction, convection and radiation.

### *A. Conduction*

Conduction is the energy transmission method based on the transmission of the energy between adjacent molecules; it is the heat transmission method of the solids and has not influence in the other states of the material (liquid and gas). The Fourier law (see eq. 1) with the thermal conductivity constant (k) define the conduction transmission method.

$$q"_{cond} = k\Delta T \qquad (1)$$

### *B. Convention*

It is due to the particle movement associated to the variation of it temperature and it density.

This phenomenon depends on the fluid characteristics; if the fluid has a movement related to the tanker, then appear a forced convention and, in the other case a natural convention. Both can be laminar or turbulent, depending on the Reynols number (*Re*)

In this case, the convention appears only in the exterior surface of the exterior main part, and the equation 2, with the thermal convention coefficient ($h_c$), defines it:

$$q"_{conv} = {}^{\Delta T}/_{h_c} \qquad (2)$$

Before the beginning of the calculus of the convention coefficient, the Nusselt number ($Nu_m$) must be introduced; it related the convention flux with the conduction flux in a fluid.

$$Nu_m = \frac{h_c \cdot L_c}{k} \qquad (3)$$

$L_c$ is the characteristic length that for this case is the total length of the vehicle. In this case, the natural convention is quite difficult to obtain using experimental and theatrical tools, but it can be approximated like the natural convention of a horizontal cylinder with a diameter $D$, and so equations 4 and 5 are obtained:

$$Nu_m = \frac{4}{3} \cdot f(Pr) \cdot \left({}^{Gr_D}/_4\right)^{\frac{1}{4}} = \frac{h_c \cdot D}{k} \qquad (4)$$

$$Gr_d = \frac{g \cdot (T_{ext} - T_{env}) \cdot D^3}{v^2 \cdot amb} \qquad (5)$$

where $Pr$ is the Prandtl number and $Gr_d$ the Grashoff number, $g$ the gravity, $T_{amb}$ the environmental temperature and $T_{ext}$ the temperature of the exterior surface. The main problem of these equations is that $Gr_d$ depends on the Text that it is an unknown facto, so it must be estimated initially and using iterative calculus, the real value can be obtained.

Fort he forced convention, the Nusselt number can be

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approximated using equations 6 and 7.

$Nu_m = 0.664 \cdot Re_l^{1/2} \cdot Pr^{1/3}$ if $Re \leq 5*10^5$ (6)

$Nu_m = (0.037 \cdot Re^{0.8} - 872) \cdot Pr^{1/3}$ for other cases (7)

where *Re* is the Reynols number:

$Re = \frac{V_\infty \cdot L}{v}$ (8)

$V_\infty$ is the relative velocity between the tanker and the environment and L the length of the vehicle.

In this particular case, it can be observed that, after the tractor cabin, the flow become into a turbulent one, so the equation 7 is going to be used.

### C. *Radiation*

It is an energy transmission phenomenon that occurs because a material has a temperature and emits electromagnetic waves. Like the light the emitted heat can be reflected, refracted and absorbed. In this case there are some different elements that emit radiation: environment, sun, the different parts of the tanker, etc.

The radiation can be defined using the Steffand-Bolzman equation:

$q"_{rad} = \varepsilon \sigma T_{sup}^4$ (9)

where *ε* is the emissivity coefficient and *σ* the Stefan-Boltzmann one(5.67▪108 W/m2 K4).

In this case, the radiation for the exterior part of the tanker can be obtained doing an energy balance (fig. 1)

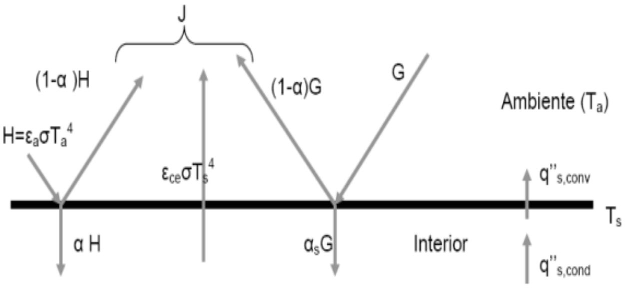

Fig. 1: Energy balance for the exterior part of the tanker

*Incident Radiation*

- Solar incident radiation (*G*): depending of some aspects like the climatology and the geographic situation, vary between 0 and 1000 W/$m^2$
- Environmental radiation (*H*): due to the effect of the environmental gases. The value of the environmental emissivity ($\varepsilon_a$) can be obtained using the Verdal y Fromberg equations:

$\varepsilon_{a,dia} = 0.741 + 0.0063 T_{dp} (ºC)$ (10)

$\varepsilon_{a,noche} = 0.727 + 0.0060 T_{dp} (ºC)$ (11)

where $T_{dp}=T_a+log(H_r)$ , and $T_a$ is the dew temperature and $H_r$ the relative humidity.

*Emitted Radiation*

Is due to the reflected radiation (*J*), where *α* is the absorption coefficient of the exterior part of the tanker and *ε* ≈*α* is the emission coefficient and αs is the solar absorption coefficient of the exterior of the tanker, and depends on the material, color and exterior temperature.

*Absorbed Radiation*

After doing an equation balance, the equation 12 is obtained:

$q"_{rad,abs} = \alpha_{sext} (G + \varepsilon_a \sigma T_a^4) - \varepsilon_{ce} \sigma T_{ce}^4$ (12)

There is an additional consideration about the solar radiation (*G*), that occurs only in a specific zone of the tanker, and so, for the axisymmetric and for the rhetorical case, it must be modified using the equation 13:

$G_{axi-teo} = G \cdot \frac{A_{ext\_pro}}{A_{ext}}$ (13)

## III. THE THERMIC ISOLATION

There are two different isolation configurations:

### A. *Perlite Isolation*

Perlite is the name of a natural silicate that has a 65-75% of $SiO_2$, a 10-20% of AlO and a 2-5% of water. To be used industrially, it must be subjected to a expansion process, where it is heat until 1000ºC; in this process the water evaporates and the internal structure is modified and the perlite increase 20 times it volume, and becoming into expanded perlite.

The main advantages are that it is a natural material, it has not toxic emissions, it is chemically neutral , it a good fire isolation and it is the cheapest industrial isolation. Their thermal properties depend on it density and it grain size. For cryogenic uses the common density is between 128 and 152 Kg/m3. Usually the perlite is used for the tankers is used expanded and combined with the use of vacuum (until 100 Hg mm), so the radiation flux between the interior and the exterior part of the tanker disappears.

The use of vacuum with the perlite implies a decrease of the density and the conductivity. For cryogenic tankers a common value of the density is 4 Kg./m3 and so the conductivity is 22 times lower than the material with a 139 Kg./m3 density.

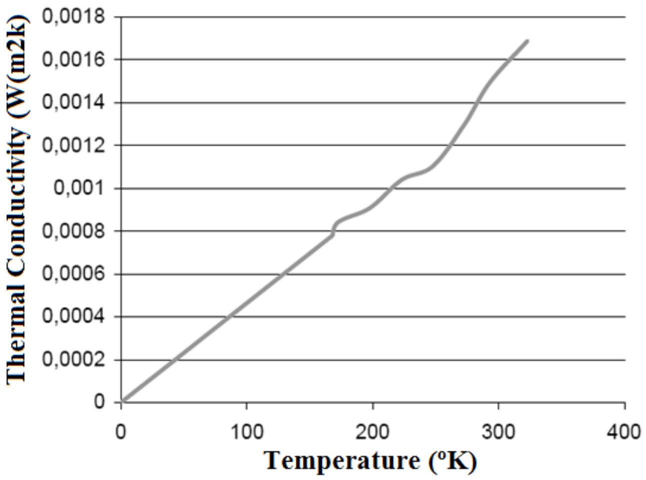

Fig. 2: conductivity for the perlite with a 1m grain size and 4 Kg./m3 density

The main disadvantage of the perlite it is that it usually tends to compact in the inferior zone of the tanker, so the isolation is not uniform.

### B. *Isolation Using "Super-insulation"*

This isolation method is based on the Dewar balloon. In the cryogenic tankers, it is made a vacuum inside the tanker using a pump, and so, the convection flux is avoided, but nor the radiation one. In the cryogenic tanker, usually there is a material called "multilayer insulation" (MLI) to reduce the radiation. This material is made of some small layers and

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acts like a radiation shield. These layers must be separated between themselves to avoid the conduction, so usually there are some nylon and Polystyrene interior layers. Usually 60 layers per inch multilayer are used[3], but the radiation isolation depends on the thickness of the multilayer and the vacuum grade. Figure 3 shows the equivalent conductivity for this isolation system[3].

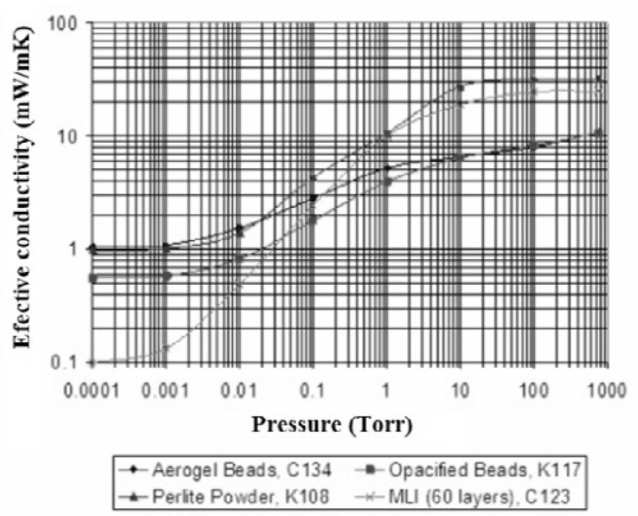


Figure 3: effective conductivity for some isolation

The main disadvantages of the multilayer are because it is difficult to use it for complex geometries, it is sensible to the mechanical compression effects and must be manufactured carefully.

For the application of this isolation system in cryogenic tankers, it is made a composite combination of multilayer (5 mm/layer) an rock wool (20 mm/layer)[4].

This composite configuration is used because the multilayer is quite expensive and with this configuration the final cost is lower

Nowadays there are two different configurations, depending on the zone of the tanker where it is fixed: in the exterior or in the interior part. These configurations imply that exist a free zone between the end of the isolation and to the other part of the tanker and so appears some radiation phenomenon's to take into account. There appear some reflection and absorption effects, like we can see in the figure 4.

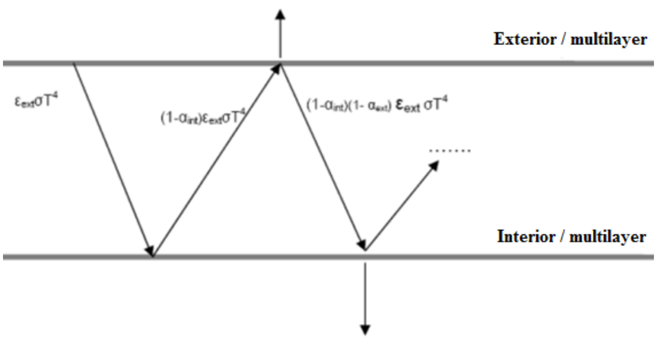


Fig. 4: radiation balance between the multilayer and the corresponding part

Doing an energy balance, the heat flux is obtained.

## IV. THERMAL LOAD CASES

In the thermal analysis of the tanker, depending on the boundaries, there are some different load cases. The boundaries to study are:

- Relative air velocity: it is due to the movement of the vehicle and the movement of the air, and can appear superposed, so then the equivalent velocity is the addiction of both. It has been considered a velocity for the vehicle and for the wind between 0 and 100 Km/h[5]. So they will be studied three different velocities: 0, 100 and 200 Km/h
- Exterior temperature: it has been studied four different temperatures: -10, 0, 20 and 50ºC
- Radiation (G): it has been studied three different solar radiation cases: without sun (0 W/m$^2$), average radiation (500 W/m$^2$) and extreme radiation (1000 - 500 W/m$^2$) [6]

So there are thirty-six different load cases for each isolation configuration; there are two extreme load cases:

- Maximum energy profit: with a 200 Km/h relative air velocity, G=1000 W/m2K and a 50ºC exterior temperature
- Minimum energy profit: with a 0 Km/h relative air velocity, G=0 W/m2K and a -10ºC exterior temperature

## V. ANALYTICAL CALCULUS OF THE ISOLATION

The thermal analytical calculus is governed by the next differential equation:

$$\nabla \cdot (k\nabla T) + \dot{q} = \rho c \frac{\partial T}{\partial t} \qquad (14)$$

If the stationary state is analyzed, and there is not heat generation inside the tanker, so the equation become into this one:

$$\nabla^2 T = 0 \qquad (15)$$

This equation has analytical solutions for simple geometries[7]: cylinders, spheres, shells, … but not for this particular case, so it cannot be solved exactly.

Due to this fact, an approximated analytical calculus must be made, and the tanker must be considered like two cylinders, one inside the other, and four spherical caps.

In this calculus, it has been taken into account the isolation and the steel of the different joint zones.

### A. *Analytical Calculus with Perlite*

In this case the tanker can be approximated with this equivalent circuit:

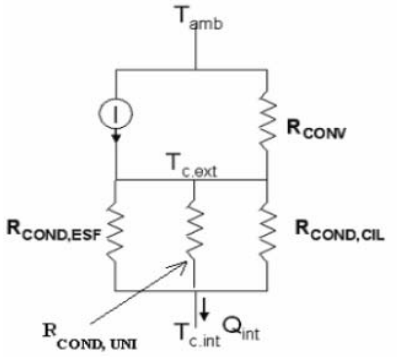


Fig. 5: equivalent circuit for the perlite isolation configuration

After the definition of the equivalent circuit, the different variables involved must be obtained:

- I: is the power due to the radiation emissions. It can be obtained using this equation:

$$I = A_{ext} \cdot q"_{rad,abs} = (2\pi r_{ext} l_{cil} + 4\pi r_{ext}^2) q"_{rad,abs} \qquad (16)$$

$q"_{rad,abs}$ in the equation 13

- $R_{conv}$, is the thermal resistance due to the air convention, and their equation is:

$$R_{conv} = \frac{1}{h_{conv} A_{ext}} \qquad (17)$$

$h_{conv}$ is obtained using 4, 6 and 7 equations.

- $R_{cond,esp}$: is the thermal resistance due to the conduction in the spherical zones and is defined in the next equation:

$$R_{cond,esp} = \frac{{}^{1}/_{r_{int}} - {}^{1}/_{r_{ext}}}{4\pi k_{perlite}} \qquad (18)$$

$k_{perlita}$ depends on the temperature, so for this case the conductivity will be used at the average temperature: $(T_{amb}+T_{int})/2$

- $R_{cond,cil}$: is the thermal resistance for the cylindrical zone and it is obtained using this equation:

$$R_{cond,cil} = \frac{ln\left({}^{r_{ext}}/_{int}\right)}{2\pi k_{perlita} l_{cilindro}} \qquad (19)$$

- $R_{cond,uni}$: is the thermal resistance in the support zones, and it can be approximated with this equation:

$$\frac{1}{R_{cond,uni}} = \sum_{i=1}^{n} \frac{A_{trans,i} k_{asteelcero}}{l_i} \qquad (20)$$

In this case the supports are simplified as sheets with a longitude l and an average transversal area.

$k_{steel}$[4] will be obtained like $k_{perlite}$

Now, the thermal circuit can be solved for the perlite in each load case. There is a problem because the radiation depends on the temperature of the exterior part of the tanker (equation 12), and so there is a 4th order equation. It has been used MATLAB to solve the equations system using the Newton method.

| Temperatura Ambiente (ºC) | Radiación Solar Incidente (W/m$^2$) | Velocidad del Viento (km/h) | $T_{cext}$ (ºC) | I (W) | $Q_{abs}$ (W |
|---|---|---|---|---|---|
| -10 | 0 | 0 | -13,16 | -1699,46 | 283,43 |
| -10 | 0 | 100 | -10,32 | -2149,20 | 287,90 |
| -10 | 0 | 200 | -10,81 | -2070,48 | 287,13 |
| -10 | 500 | 0 | -5,98 | 2819,65 | 294,74 |
| -10 | 500 | 100 | -9,60 | 3419,15 | 289,04 |
| -10 | 500 | 200 | -9,77 | 3446,71 | 288,77 |
| -10 | 1000 | 0 | 1,06 | 7266,10 | 305,84 |
| -10 | 1000 | 100 | -8,88 | 8986,54 | 290,17 |
| -10 | 1000 | 200 | -9,36 | 9064,86 | 289,42 |
| 0 | 0 | 0 | -3,54 | -1927,84 | 298,59 |
| 0 | 0 | 100 | -0,36 | -2490,19 | 303,60 |
| 0 | 0 | 200 | -0,21 | -2517,20 | 303,84 |
| 0 | 500 | 0 | 3,46 | 2492,49 | 309,62 |
| 0 | 500 | 100 | 0,35 | 3066,25 | 304,72 |
| 0 | 500 | 200 | 0,20 | 3093,44 | 304,48 |
| 0 | 1000 | 0 | 10,35 | 6835,27 | 320,48 |
| 0 | 1000 | 100 | 1,00 | 8632,65 | 305,74 |
| 0 | 1000 | 200 | 0,61 | 8703,74 | 305,13 |
| 20 | 0 | 0 | 15,61 | -2431,89 | 328,77 |
| 20 | 0 | 100 | 19,53 | -3285,49 | 334,95 |
| 20 | 0 | 200 | 19,73 | -3330,00 | 335,26 |
| 20 | 500 | 0 | 22,28 | 1779,24 | 339,28 |
| 20 | 500 | 100 | 20,24 | 2240,82 | 336,07 |
| 20 | 500 | 200 | 20,14 | 2263,20 | 335,91 |
| 20 | 1000 | 0 | 28,84 | 5913,48 | 349,62 |
| 20 | 1000 | 100 | 20,95 | 7765,97 | 337,19 |
| 20 | 1000 | 200 | 20,55 | 7856,01 | 336,55 |
| 50 | 0 | 0 | 44,15 | -3303,32 | 373,75 |
| 50 | 0 | 100 | 49,33 | -4807,02 | 381,91 |
| 50 | 0 | 200 | 49,62 | -4893,08 | 382,37 |
| 50 | 500 | 0 | 50,13 | 638,90 | 383,17 |
| 50 | 500 | 100 | 50,03 | 668,85 | 383,02 |
| 50 | 500 | 200 | 50,02 | 671,84 | 383,00 |
| 50 | 1000 | 0 | 56,39 | 4392,90 | 393,04 |
| 50 | 1000 | 100 | 50,73 | 6143,35 | 384,12 |
| 50 | 1000 | 200 | 50,43 | 6233,61 | 383,65 |

Fig. 5: analytical results obtained for the perlite

### *B. Calculus of the Super-insulation Isolation*

There has been analyzed the two different isolation configurations that use super-insulation:

*Calculus of the Isolation Using Super-insulation in the Exterior.*

This is the configuration the super-insulation is located between the parts of the tanker and joined only to the exterior part. It can be approximate with this equivalent circuit:

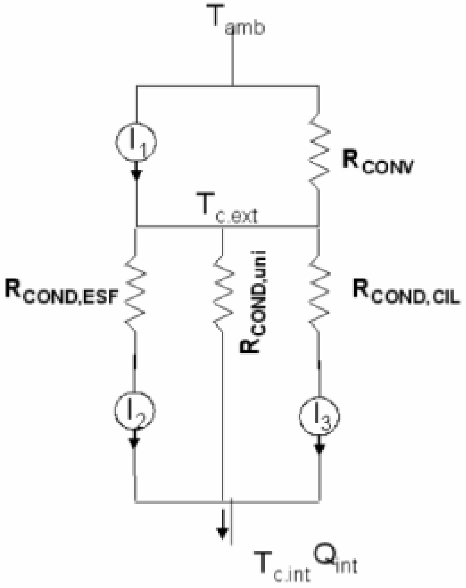


Fig. 6: Equivalent circuit for the vacuum and super-insulation with it joined to the exterior part of the tanker

After establishing the equivalent circuit, the diverse variables involved must be defined. Some of them where defined for the perlite equivalent circuit.

- $I_1$: is the thermal power due to the diverse radiation emissions, and can be obtained using equation 18.

- $R_{cond,esp}$: is the thermal resistance due to the conduction in the diverse spherical and it is the addition of the resistance of the resistance of each layer (see figure 11 and eq. 23 and 24).

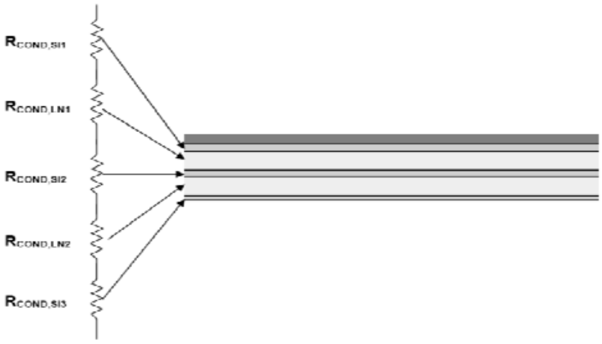


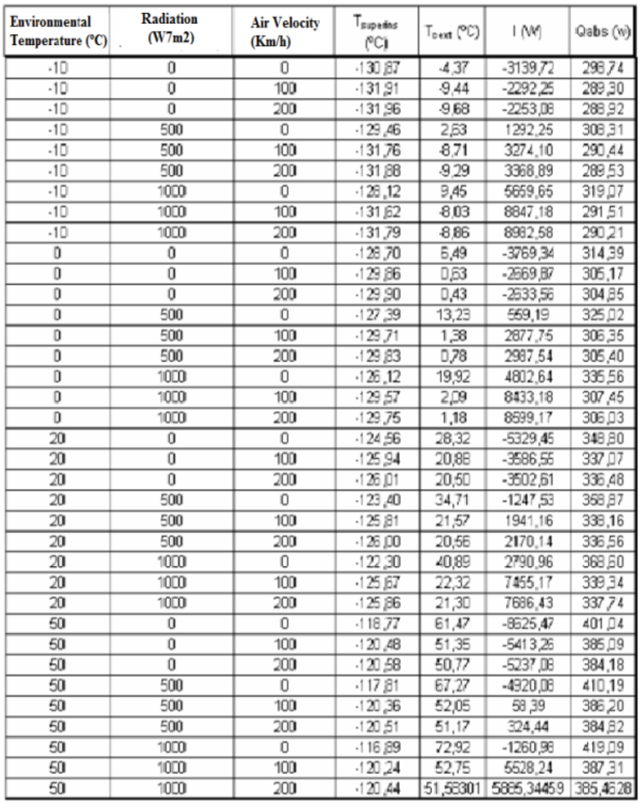
Fig. 7: equivalent conduction for the multilayer and the rock wool

$$R_{cond,esf} = \sum_{SI=1}^{3} R_{cond,esf,i} + \sum_{Lana=1}^{2} R_{cond,esf,wool} \qquad (21)$$

$$R_{cond,esf,mat} = \frac{{}^{1}/_{r_{int,mat}} - {}^{1}/_{r_{ext,mat}}}{4\pi k_{mat}} \qquad (22)$$

- $K_{mat}$ is the conductivity for each material
- $R_{cond,cil}$: is the thermal resistance due to the conduction in the diverse cylindrical zone
- $I_2$ e $I_3$: are the heat fluxes due to the radiation inside the tanker, for the spherical and for the cylindrical zone.

Now, the equivalent circuit can be solved, like in the perlite case.



| Environmental Temperature (°C) | Radiation (W7m2) | Air Velocity (Km/h) | $T_{superins}$ (°C) | $T_{c.ext}$ (°C) | I (W) | Qabs (w) |
|---|---|---|---|---|---|---|
| -10 | 0 | 0 | -130,87 | -4,37 | -3139,72 | 298,74 |
| -10 | 0 | 100 | -131,91 | -9,44 | -2292,25 | 289,30 |
| -10 | 0 | 200 | -131,96 | -9,68 | -2253,08 | 288,92 |
| -10 | 500 | 0 | -129,46 | 2,63 | 1292,25 | 308,31 |
| -10 | 500 | 100 | -131,76 | -8,71 | 3274,10 | 290,44 |
| -10 | 500 | 200 | -131,88 | -9,29 | 3368,89 | 289,53 |
| -10 | 1000 | 0 | -128,12 | 9,45 | 5659,65 | 319,07 |
| -10 | 1000 | 100 | -131,62 | -8,03 | 8847,18 | 291,51 |
| -10 | 1000 | 200 | -131,79 | -8,86 | 8982,58 | 290,21 |
| 0 | 0 | 0 | -128,70 | 6,49 | -3769,34 | 314,39 |
| 0 | 0 | 100 | -129,86 | 0,63 | -2669,87 | 305,17 |
| 0 | 0 | 200 | -129,90 | 0,43 | -2633,56 | 304,85 |
| 0 | 500 | 0 | -127,39 | 13,23 | 569,19 | 325,02 |
| 0 | 500 | 100 | -129,71 | 1,38 | 2877,75 | 306,35 |
| 0 | 500 | 200 | -129,83 | 0,78 | 2987,54 | 305,40 |
| 0 | 1000 | 0 | -126,12 | 19,92 | 4802,64 | 335,56 |
| 0 | 1000 | 100 | -129,57 | 2,09 | 8433,18 | 307,45 |
| 0 | 1000 | 200 | -129,75 | 1,18 | 8599,17 | 306,03 |
| 20 | 0 | 0 | -124,56 | 28,32 | -5329,45 | 348,80 |
| 20 | 0 | 100 | -125,94 | 20,88 | -3586,55 | 337,07 |
| 20 | 0 | 200 | -126,01 | 20,50 | -3502,61 | 336,48 |
| 20 | 500 | 0 | -123,40 | 34,71 | -1247,53 | 358,87 |
| 20 | 500 | 100 | -125,81 | 21,57 | 1941,16 | 338,16 |
| 20 | 500 | 200 | -126,00 | 20,56 | 2170,14 | 336,56 |
| 20 | 1000 | 0 | -122,30 | 40,89 | 2790,96 | 368,60 |
| 20 | 1000 | 100 | -125,67 | 22,32 | 7455,17 | 339,34 |
| 20 | 1000 | 200 | -125,86 | 21,30 | 7686,43 | 337,74 |
| 50 | 0 | 0 | -118,77 | 61,47 | -8625,47 | 401,04 |
| 50 | 0 | 100 | -120,48 | 51,35 | -5413,26 | 385,09 |
| 50 | 0 | 200 | -120,58 | 50,77 | -5237,08 | 384,18 |
| 50 | 500 | 0 | -117,81 | 67,27 | -4920,08 | 410,19 |
| 50 | 500 | 100 | -120,36 | 52,05 | 58,39 | 386,20 |
| 50 | 500 | 200 | -120,51 | 51,17 | 324,44 | 384,82 |
| 50 | 1000 | 0 | -116,89 | 72,92 | -1260,98 | 419,09 |
| 50 | 1000 | 100 | -120,24 | 52,75 | 5528,24 | 387,31 |
| 50 | 1000 | 200 | -120,44 | 51,58301 | 5865,34459 | 385,4628 |

Fig. 8: analytical results for isolation with the super-insulation in the exterior part of the tanker

### *Calculus of the Isolation Using Super-insulation in the Interior*

This is the configuration the super-insulation is located between the parts of the tanker and joined only to the interior part. It can be approximate with this equivalent circuit

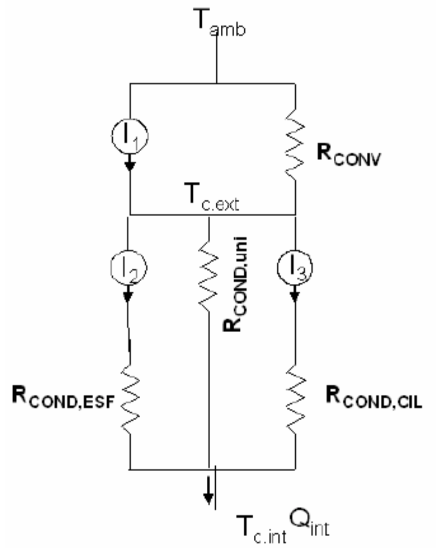
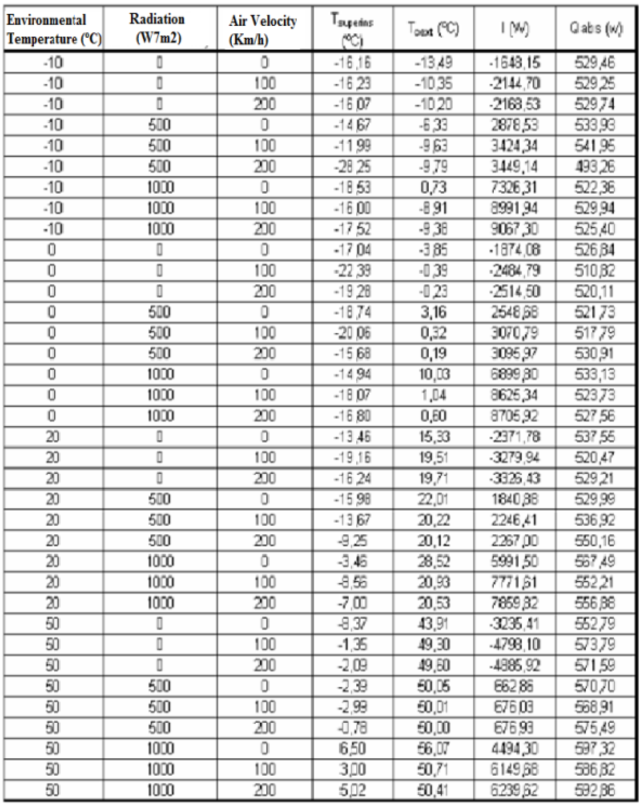


Fig. 9: Equivalent circuit for the vacuum and super-insulation with it joined to the interior part of the tanker

The different equations are similar to the obtained for the perlite and for the other super-insulation configuration; only $I_2$ and $I_3$ change and the $k_{mat}$ value. Now, the equivalent circuit can be solved, like in the other configurations.



| Environmental Temperature (°C) | Radiation (W7m2) | Air Velocity (Km/h) | $T_{superins}$ (°C) | $T_{c.ext}$ (°C) | I (W) | Qabs (w) |
|---|---|---|---|---|---|---|
| -10 | 0 | 0 | -16,16 | -13,49 | -1648,15 | 529,46 |
| -10 | 0 | 100 | -16,23 | -10,35 | -2144,70 | 529,25 |
| -10 | 0 | 200 | -16,07 | -10,20 | -2168,53 | 529,74 |
| -10 | 500 | 0 | -14,67 | -6,33 | 2878,53 | 533,93 |
| -10 | 500 | 100 | -11,99 | -9,63 | 3424,34 | 541,95 |
| -10 | 500 | 200 | -28,25 | -9,79 | 3449,14 | 493,26 |
| -10 | 1000 | 0 | -18,53 | 0,73 | 7326,31 | 522,36 |
| -10 | 1000 | 100 | -16,00 | -8,91 | 8991,94 | 529,94 |
| -10 | 1000 | 200 | -17,52 | -9,38 | 9067,30 | 525,40 |
| 0 | 0 | 0 | -17,04 | -3,85 | -1874,08 | 526,84 |
| 0 | 0 | 100 | -22,39 | -0,39 | -2484,79 | 510,82 |
| 0 | 0 | 200 | -19,28 | -0,23 | -2514,50 | 520,11 |
| 0 | 500 | 0 | -18,74 | 3,16 | 2548,68 | 521,73 |
| 0 | 500 | 100 | -20,06 | 0,32 | 3070,79 | 517,79 |
| 0 | 500 | 200 | -15,68 | 0,19 | 3095,97 | 530,91 |
| 0 | 1000 | 0 | -14,94 | 10,03 | 6899,80 | 533,13 |
| 0 | 1000 | 100 | -18,07 | 1,04 | 8625,34 | 523,73 |
| 0 | 1000 | 200 | -16,80 | 0,60 | 8705,92 | 527,56 |
| 20 | 0 | 0 | -13,46 | 15,33 | -2371,78 | 537,55 |
| 20 | 0 | 100 | -19,16 | 19,51 | -3279,94 | 520,47 |
| 20 | 0 | 200 | -16,24 | 19,71 | -3326,43 | 529,21 |
| 20 | 500 | 0 | -15,98 | 22,01 | 1840,88 | 529,99 |
| 20 | 500 | 100 | -13,67 | 20,22 | 2246,41 | 536,92 |
| 20 | 500 | 200 | -9,25 | 20,12 | 2267,00 | 550,16 |
| 20 | 1000 | 0 | -3,46 | 28,52 | 5991,50 | 567,49 |
| 20 | 1000 | 100 | -8,56 | 20,93 | 7771,61 | 552,21 |
| 20 | 1000 | 200 | -7,00 | 20,53 | 7869,82 | 556,88 |
| 50 | 0 | 0 | -8,37 | 43,91 | -3235,41 | 552,79 |
| 50 | 0 | 100 | -1,35 | 49,30 | -4798,10 | 573,79 |
| 50 | 0 | 200 | -2,09 | 49,60 | -4885,92 | 571,59 |
| 50 | 500 | 0 | -2,39 | 60,05 | 662,86 | 570,70 |
| 50 | 500 | 100 | -2,99 | 60,01 | 676,03 | 568,91 |
| 50 | 500 | 200 | -0,78 | 60,00 | 676,93 | 575,49 |
| 50 | 1000 | 0 | 6,50 | 56,07 | 4494,30 | 597,32 |
| 50 | 1000 | 100 | 3,00 | 50,71 | 6149,68 | 586,82 |
| 50 | 1000 | 200 | 5,02 | 50,41 | 6239,62 | 592,86 |

Fig. 9: analytical results for isolation with the super-insulation in the interior part of the tanker

## VI. CONCLUSIONS

After analyzing the obtained results, it can be observed that the best configuration is the configuration with perlite, although the configuration with superinsulation in the exterior part has too a good behavior. Analyzing both in deep, it can be concluded that the perlite configuration has a 2.2% average better isolation capabilities and a 6.65% maximum better. About the configuration with superinsulation in the interior part, it can be observed that it is a 65.8% average worse and an 85.7% maximum worse. This behavior is due, because analyzing equations 14 and 15, the radiation depends on the temperature. Then the configuration with the isolation in the exterior has a lower temperature tan with the isolation in the interior (in this case the temperature is similar to the environmental temperature). In the equations 14 and 15 the exterior temperature will govern the equations and the interior temperature (between the radiation parts) is insignificant.

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