MECHANIKA
CZASOPISMO TECHNICZNE WYDAWNICTWO POLITECHNIKI KRAKOWSKIEJ
TECHNICAL TRANSACTIONS
MECHANICS
2-M/2010
ZESZYT 8
ROK 107
ISSUE 8
YEAR 107

EDWARD LISOWSKI, WOJCIECH CZYŻYCKI, KATARZYNA ŁAZARCZYK*

SIMULATION AND EXPERIMENTAL RESEARCH OF INTERNAL SUPPORTS IN MOBILE CRYOGENIC TANKS

BADANIA SYMULACYJNE I DOŚWIADCZALNE PODPÓR WEWNĘTRZNYCH MOBILNYCH ZBIORNIKÓW KRIOGENICZNYCH

A b s t r a c t

The subject of the presented paper concerns introduction a new generation of cryogenic tanks into production. The tanks were designed as container along with Chemet company. They are assigned for transporting and storing liquefied gases as nitrogen, LNG etc. Construction of a mobile tank requires two walls structure with insulation system between them containing layers of materials, radiation shields and the vacuum. One of the most important matters in design process was to design supports between inner and outer tank. The supports had to fulfill strength requirements as well as high heat transfer resistance. These two requirements are inconsistent as strength considerations lead to such a conclusion that the best materials should be steels. However, due to the very low heat transfer resistance, they cannot be used. A CosmosWorks system was used to carry out simulations of heat transfer with various kinds of insulation. The results of simulations were verified in experimental tests. As an effect, a satisfactory solution was found and introduced into production.

Keywords: cryogenic tank, plastic support, CAD system

S t r e s z c z e n i e

Podjęta w pracy tematyka związana jest z wdrażaniem do produkcji w Chemet Tarnowskie Góry nowej generacji zbiorników kriogenicznych w postaci kontenerów przeznaczonych do transportu i przechowywania skroplonych gazów takich, jak azot, gaz ziemny, itp. Konstrukcja zbiorników tych kontenerów jest dwupłaszczowa z wewnętrznym systemem superizolacji zbudowanej z mat, ekranów promieniowania i próżni. Jednym z ważniejszych zadań przy projektowaniu zbiornika było stworzenie podpór wewnętrznych pomiędzy płaszczami, które są w stanie spełnić wymagania wytrzymałościowe oraz nie przewodzą ciepła. Wymagania te są sprzeczne z sobą. Wiadomo, że ze względów wytrzymałościowych najlepszymi materiałami byłyby stale, natomiast ze względu na przewodzenie ciepła nie mogą być brane pod uwagę. Do poszukiwania rozwiązań zastosowano oprogramowanie CosmosWorks, a uzyskane wyniki weryfikowano w badaniach doświadczalnych. W rezultacie uzyskano zadawalające rozwiązanie, które zostało wdrożone do produkcji.

Słowa kluczowe: zbiorniki kriogeniczne, podpory z tworzyw sztucznych, system CAD

* Prof. Edward Lisowski, PhD. Wojciech Czyżycki, PhD. candidate, Katarzyna Łazarczyk Institute of Applied Informatics, Faculty of Mechanical Engineering, Cracow Uniwersity of Technology.

1. Introduction

Recently, the interest in using liquefied technical gases in the industry is growing. Gases in a liquefied form take up considerably less volume. For example, liquid natural gas takes up about 660 times less volume than in a gaseous form. Other gases behave similarly. This fact has the most important meaning in transport of gases, because a large amount of liquefied gas can be delivered by means of relatively small tanks. Technology of liquefaction is particularly used in transport of natural gas under trade name LNG. There are even several gas fields distant from pipelines, where natural gas is cooled down in order to obtain liquefied form and then is transported using cryogenic tanks [2]. The same situation applies to other technical gases such as nitrogen which is transported and stored in a liquefied form using stationary cryogenic tanks as well. However, the use of mobile cryogenic tanks requires high quality insulation which keeps heat transfer into the tank within limits. Cryogenic tanks are often designed as two-shelled with space between walls filled with insulation material or vacuum. In mobile tanks insulation material must be resistant to vibrations which can appear while transporting, and also meet requirements concerning collisions, fire, etc. Hence, requirements for mobile tanks are considerably higher and before being put into operation tanks must procure acceptance and obtain adequate certificates [2, 4]. Thanks to new materials, obtained recently with the help of nanotechnology, shells of the tank are highly heat-resistant. However, the problem of heat leakage bridges still remains. The bridges appear mainly near to the supports and ferrules. At the Faculty of Mechanical Engineering of Cracow University of Technology for several years are carried out studies on design of cryogenic tanks [5]. The results of work concerning minimization of heat leakage through internal supports of 20-feet mobile container with cryogenic tank are presented in this paper. A tank was designed for transporting liquefied gases with boiling temperature down to minus 196 Celsius degrees and ambient temperature range from minus 20 Celsius degrees to plus 40 Celsius degrees.

Heat transfer in cryogenic tank can occur in many different ways. Heat conduction occurs mainly in elements such as supports, fasteners, flanges [1, 3, 6]. Heat conduction appears between two heat sources having different temperatures. In the case of cryogenic tank, temperature difference can reach up to 200 Celsius degrees or even more under particular conditions. Heat conduction is described by Fourier law [1, 6]:

$$q = -\lambda \cdot \mathrm{grad}(T) \tag{1}$$

where:

- q – elementary heat flux [W/m^2],
- λ – heat conductivity [W/(m K)], $\mathrm{grad}(T) = \partial T / \partial n$ (derivative of temperature in direction n – perpendicular to isothermal surface).

Heat conduction through solid bodies goes on as a result of both transmitting lattice vibration energy by energy quantum's known as phonons and free electrons movement [1]:

$$\lambda = \lambda_f + \lambda_e \tag{2}$$

where:

- λ_f – phonon's heat conduction coefficient,
- λ_e – free electron's heat conduction coefficient.

Heat properties of materials often change with a change of temperature. Specific heat and heat conductivity in function of temperature for stainless steel 1.4301 used in tank construction are presented in Fig. 1 and 2.

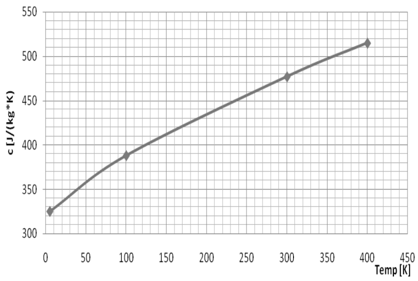

Fig. 1. Specific heat of steel 1.4301

Rys. 1. Ciepło właściwe stali 1.4301

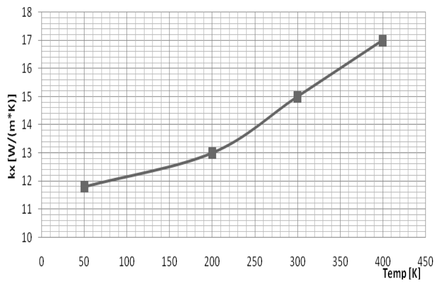

Fig. 2. Heat conductivity of steel 1.4301

Rys. 2. Przewodność cieplna stali 1.4301

2. Object of study

Carrying out research in cryogenic temperature is difficult due to the pressure and influence of low temperature on researchers, sensors and measuring devices. Tasks connected with designing cryogenic tank were realized using an especially built test stand, which allowed the verification of simulation results. Test stand consists of thermo-climatic chamber with ambient temperature controller and tanks equipped with measuring transducers. The scheme of a tank designed for carrying out the tests is shown in Fig. 3. The tank consists of an inner shell 1, outer shell 2, inner shell supports 3, installation for loading and unloading 4 and 6, ferrules for leading conductors from transducers 5 and an eyehole 7. The model allowed temperature value acquisition in selected points, including: temperature of cryogenic liquid, temperature in space between shells and temperature inside supports. The outer tank temperature was also recorded by means of thermo-vision camera.

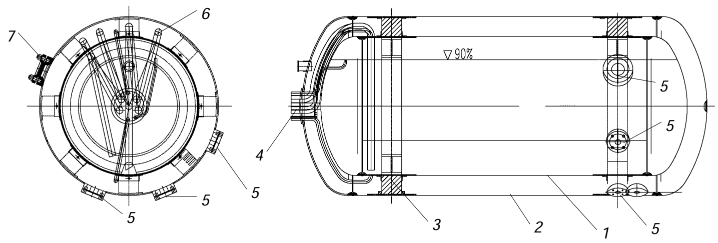

Fig. 3. Schematic diagram of test tank: 1 – inner shell, 2 – outer shell, 3 – support blocks, 4, 6 – installation for loading and unloading, 5 – ferrules for leading conductors from transducers, 7 – eyehole

Rys. 3. Schemat ideowy zbiornika testowego: 1 –zbiornik wewnętrzny, 2 – zbiornik zewnętrzny, 3 – klocki, 4, 6 – instalacja załadowcza i wyładowcza, 5 – króćce do wyprowadzenia przewodów od przetworników, 7 – wziernik

3. Thermal studies of supports in CosmosWorks system

Research on the construction of inner supports was carried out using commercial system CosmosWorks. Minimization of heat leakage requires using material for supports which on one hand is characterized by adequate strength properties, and on the other hand, has as low heat conduction coefficient as possible. These requirements are inconsistent as usually materials with good strength properties are also characterized by high heat conduction. Heat conduction of steel is ten times larger than this of Polycarbonate, Teflon, Tarnamid (Polyamide) [7], etc. For example, Tarnamid B, according to manufacturer's information, has heat conduction coefficient equal to 0,28 W/(m·K), while its specific heat is 1,7 J/(g·K). Hence the mentioned materials were chosen for simulation tests.

3.1. Assumptions for simulations

Heat leakage through supports was computed on the basis of created model of tank section. Dimensions of the section were assumed as multiple of inner shell support dimensions, which is presented in Fig. 4. Particular elements of the model are as follows: 1 – support of inner shell, 2 – inner tank shell, 3 – outer tank shell, 4 – cryogenic liquid, 5 - outer environment.

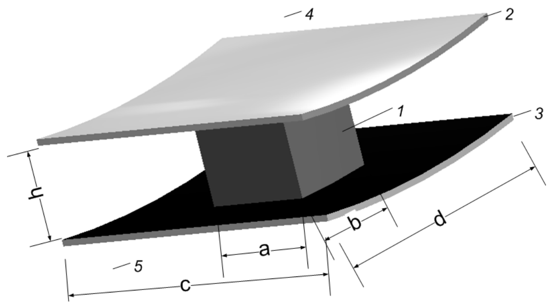

Fig. 4. Schematic diagram of tank section used in simulation tests: 1 – support of inner shell, 2 – inner shell, 3 – outer shell, 4 – cryogenic liquid, 5 - environment

Rys. 4. Schemat ideowy wycinka zbiornika użyty do badań symulacyjnych: 1 – klocek, 2 – zbiornik wewnętrzny, 3 – zbiornik zewnętrzny, 4 – ciecz kriogeniczna, 5 – otoczenie

The following assumptions were formulated for simulations: model is in thermal equilibrium, equilibrium state is obtained after 24 hours, inner surface of inner tank has the constant temperature equal to the temperature of stored liquid gas, outer surface of outer tank exchanges heat with the environment by convection, convective heat transfer coefficient is known, support exchanges heat only with shells of tanks. Heat exchange with thermal insulation and radiation were omitted because of its low influence. The model meshed with solid elements was created for FEM calculations. Generated mesh is presented in Fig. 5.

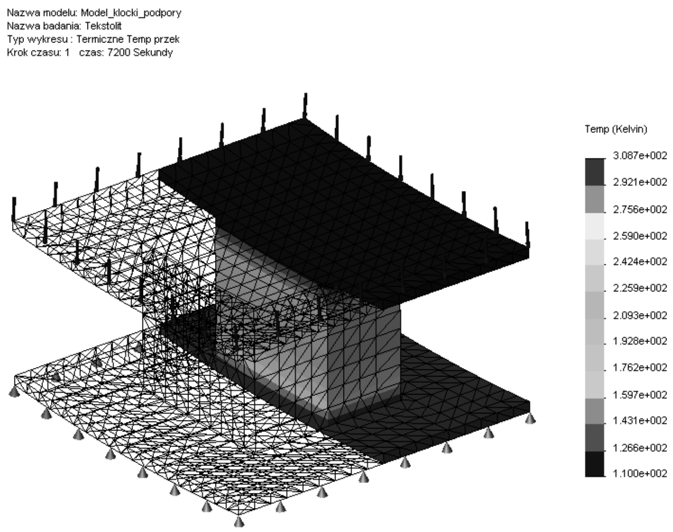

Fig. 5. FEM mesh with cross-section through centre of the support

Rys. 5. Widok siatki MES modelu z przekrojem przez środek podpory

Values of physical and material parameters assumed for simulations:

1.	Initial temperature of inner surface of inner tank:	110 K
2.	Initial temperature of outer surface of outer tank:	323 K
3.	Environment temperature:	323 K
4.	Type of convection:	natural
5.	Thermal material properties of inner tank surface:	function of temperature
6.	Thermal material properties of outer tank surface:	constant
7.	Thermal material properties of support:	constant
8.	Dimensions: a, h	100 mm x 100 mm
9.	Dimensions: c, d	200 mm x 200 mm
10.	Materials of support:	Polyamide, Tarnamid B, Tarnamid B casted, Tekstolit, PTFE Tarflen, Polycarbonate

3.2. Results of simulations

Results of simulations: temperature distribution and resultant heat transfer for Polyamide is shown in Fig. 6–9.

As it comes from the results, despite temperature of cryogenic liquid is minus 163 Celsius degrees, the temperature of outer side of outer tank remains close to environment temperature. Also the obtained values of heat transfer are relatively low, which proves that designed supports are characterized by good heat resistance.

Cumulative comparison of obtained temperature for supports made of various materials on outer surface of outer tank below the support is shown in Fig. 10. As it comes from the figure, the best material is Polycarbonate. However, other materials also allowed for obtaining satisfactory results.

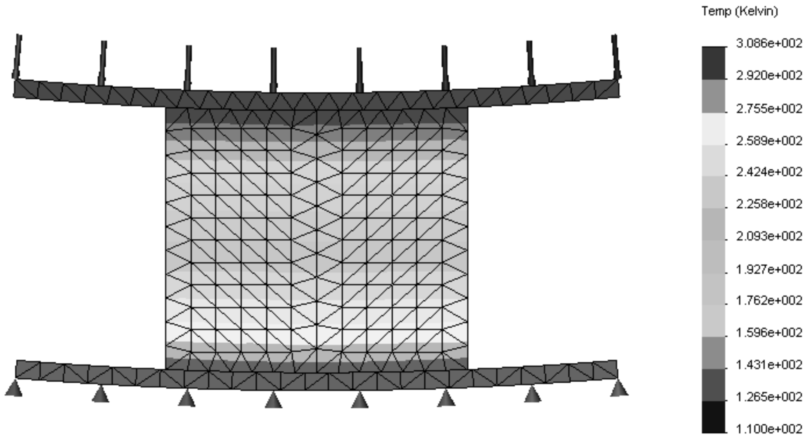

Fig. 6. Distribution of temperature through centre of support

Rys. 6. Rozkład temperatur w przekroju przez środek podpory

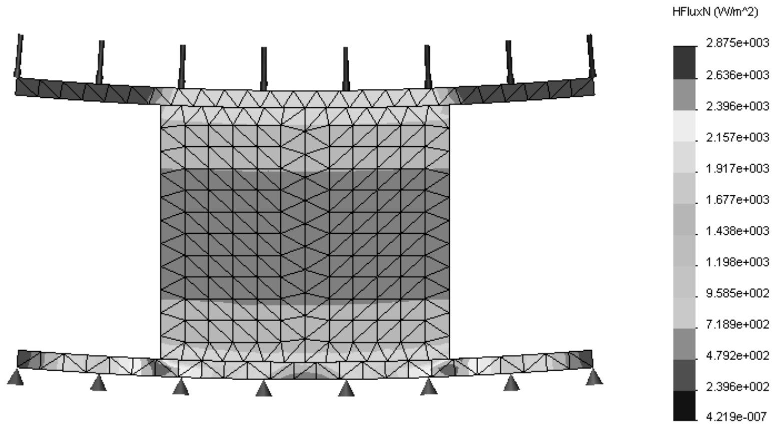

Fig. 7. Distribution of resultant heat flux in cross-section through center of the support

Rys. 7. Rozkład wypadkowego strumienia cieplnego w przekroju przez środek podpory

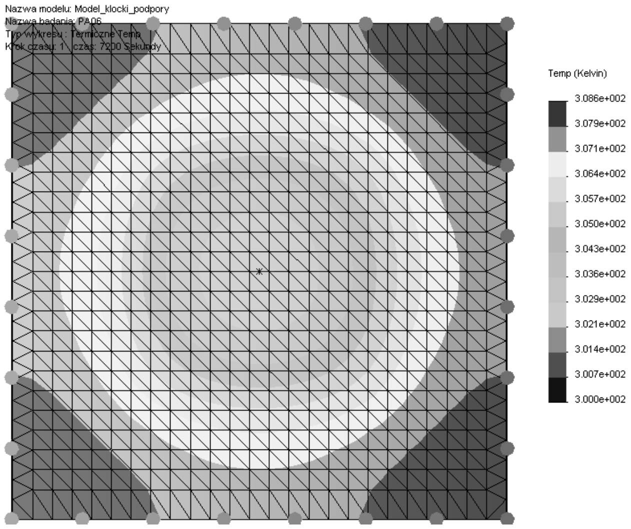

Fig. 8. Temperature distribution on the outer surface of outer tank, below the support [Celsius]

Rys. 8. Rozkład temperatur na powierzchni zewn. zbiornika zewn. pod podporą [°C]

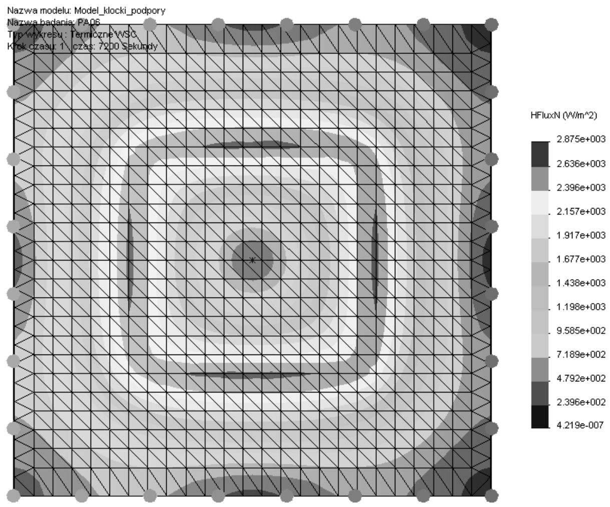

Fig. 9. Distribution of resultant heat flux on the outer surface of outer tank

Rys. 9. Rozkład wypadkowego strumienia cieplnego na powierzchni zewnętrznej zbiornika zewnętrznego pod podporą

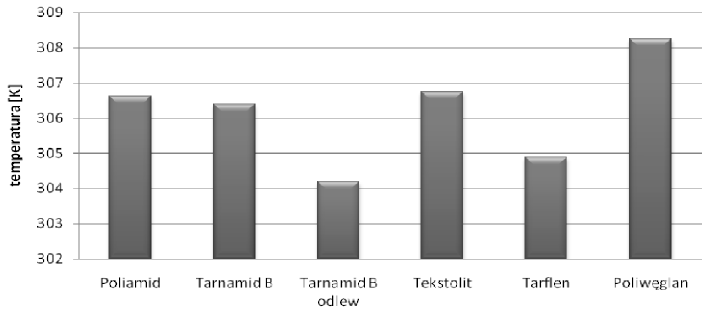

Fig. 10. Average temperatures on the outer surface of outer tank, below the support

Rys. 10. Średnie temperatury na zewnętrznej powierzchni zbiornika zewnętrznego pod podporą

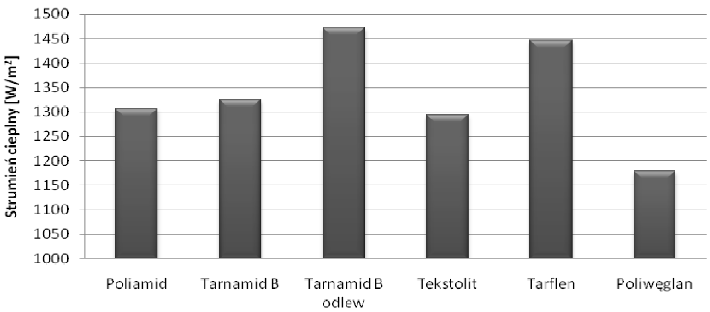

Fig. 11. Heat transfers on the outer surface of outer tank

Rys. 11. Strumienie cieplne na zewnętrznej powierzchni zbiornika zewnętrznego

If we consider values of heat transfer, the most advantageous is Polycarbonate, while the worst results were obtained for Tarnamid B casted. Summarizing results of temperature distribution and heat transfer, it can be said that the best material for the support is Polycarbonate: temperature of outer surface of outer tank is equal to 308,24 K and heat transfer 1170,6 W/(m^2·K).

4. Experimental research

Experimental tests with complete tank container with necessary measuring transducers were carried out in thermo-climatic chamber. Temperature in selected points was recorded using signals from transducers and thermo-vision camera. The scheme of transducers installation inside the support is shown in Fig. 12.

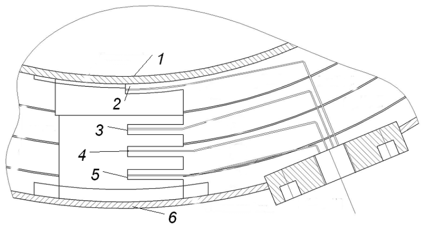

Fig. 12. Scheme of temperature transducers installation inside the support: 1 – inner shell, 2, 3, 4, 5 – temperature transducers, 6 – outer shell

Rys. 12. Schemat instalacji przetworników temperatury w przekroju podpory: 1 – zbiornik wewnętrzny, 2, 3, 4, 5 – przetworniki temperatury, 6 – zbiornik zewnętrzny

Tests were carried out using condensed nitrogen as a cryogenic liquid. The time courses of temperature obtained for environment temperature plus 40 Celsius degrees and temperature of liquid minus 190 Celsius degrees are presented in Fig. 14. Points from 1 to 6 indicate temperature inside the support in accordance with Fig. 12. As it comes from Fig. 14, despite of extremly low liquid temperature, the outer surface of outer tank temperature is similar to the ambient temperature. A distinction between the ambient temperature and outer surface temperature is about 2,5 degrees. This fact has been prooved by thermo-vision camera. Example picture of temperature distribution from the camera is shown in Fig. 13.

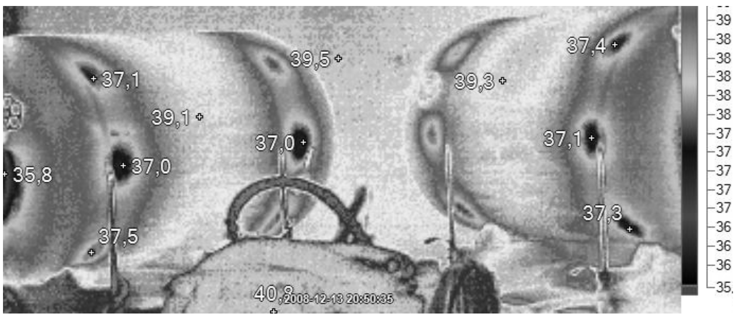

Fig. 13. Temperature on the outer surface of outer tank [Celsius]

Rys. 13. Temperatura na zewnętrznej powierzchni zbiornika [°C]

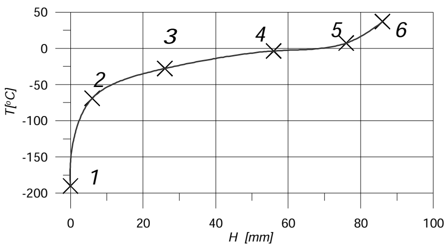

Fig. 14. Course of temperature in cross-section through the support

Rys. 14. Zmiana temperatury w przekroju zbiornika przez podporę

4. Conclusions

Research of the cryogenic tank consisted of simulations in CosmosWorks as well as experimental tests carried out using both test pieces and real tank in thermo-climatic chamber. Obtained results proved, that internal supports which are in contact with cryogenic tank should be made of plastics characterized by low thermal conductivity. Elaborated method allowed for determination of the heat flux through supports for ambient temperatures range from minus 20 to plus 40 Celsius degrees. The results were used for creating technical documentation and building prototype of tank container (Fig. 15). Container has been introduced into production, passed Lloyd's certification and has been authorized for using in road, rail and sea means of transport.

Fig. 15. 20-feet container for transporting cryogenic liquids introduced into production in Chemet company

Rys. 15. 20 stopowy kontener cysterna do przewozu płynów kriogenicznych wdrożony do produkcji w przedsiębiorstwie Chemet

References

[1] C h o r o w s k i M., *Kriogenika. Podstawy i zastosowania*, IPPU Masta, Gdańsk 2007.

[2] E d e s k u t y F.J., S t e w a r t W.F., *Safety in the handling of cryogenic fluids*, Plenum Press, New York 1996.

[3] W e i s e d II J.G., *Handbook of cryogenic engineering*, Taylor & Francis, USA, 1998.

[4] L e b u r n P., *Safety with inert cryogens – engineering approach*, LHC Technical Seminar, CERN, 1998.

[5] L i s o w s k i E., F i l o G., C z y ż y c k i W., *Computer Aided Design in Mechanical Engineering*, ch. 4: *Transport of Liquid Natural Gas by mobile tank container*, Bergen 2009.

[6] T a l e r J., D u d a P., *Rozwiązywanie prostych i odwrotnych zagadnień przewodzenia ciepła*, WNT, Warszawa 2003.

[7] Materiały informacyjne Zakładów Azotowych w Tarnowie-Mościcach S.A., 2008.