



Volume 95

2017

p-ISSN: 0209-3324

e-ISSN: 2450-1549

DOI: <https://doi.org/10.20858/sjsutst.2017.95.8>



Journal homepage: <http://sjsutst.polsl.pl>

Article citation information:

Kaup, M., Łozowicka, D., Ślącza, W. A concept of an inland LNG barge designed for operation on the Odra waterway. *Scientific Journal of Silesian University of Technology. Series Transport*. 2017, **95**, 75-87. ISSN: 0209-3324.

DOI: <https://doi.org/10.20858/sjsutst.2017.95.8>.

Magdalena KAUP¹, Dorota ŁOZOWICKA², Wojciech ŚLĄCZKA³

A CONCEPT OF AN INLAND LNG BARGE DESIGNED FOR OPERATION ON THE Odra WATERWAY

Summary. The paper examines the feasibility of transporting liquefied natural gas (LNG) along the Odra waterway. It looks at the existing LNG carriers and presents concepts of inland vessels designed for operation on the Odra waterway.

Examples of inland LNG barges operating on waterways, which involve high inland navigational infrastructure parameters, are presented. Requirements and restrictions of the class III Odra waterway are discussed in the context of the transportation of LNG inland. Possible variants of inland LNG carriers designed for operation on the Odra waterway are examined, with some of their characteristics discussed in view of the restrictions on navigation. Two variants of barges, which meet the requirements of shipping along the Odra waterway, are presented

Keywords: LNG; barge; inland waterways.

¹ West Pomeranian University of Technology Szczecin, Piastów 17 Street, 70-310 Szczecin, Poland.

E-mail: mkaup@zut.edu.pl.

² Maritime University of Szczecin, Waly Chrobrego 1-2 Street, 70 – 500 Szczecin, Poland.

E-mail: d.lozowicka@am.szczecin.pl.

³ Maritime University of Szczecin, Waly Chrobrego 1-2 Street, 70 – 500 Szczecin, Poland.

E-mail: w.slaczka@am.szczecin.pl.

1. INTRODUCTION

Natural gas is widely used in industry and domestic settings. As LNG takes up about 1/600th of the volume of natural gas in a gaseous state, this offers great advantages in terms of transportation.

LNG is transported mainly via gas pipelines and by road, rail and sea. A vast majority (approximately 98%) of total LNG transportation is carried out by sea on huge vessels referred to as gas carriers or methane carriers. In this paper, however, the feasibility of LNG transportation on inland waterways is discussed, especially in the context of the newly built LNG terminal at the Port of Świnoujście. Some solutions available to inland vessels fuelled by LNG, as well as new barge concepts for the transportation of LNG, have already been developed. They are designed for operation on waterways with better navigational infrastructure parameters than those available on the Odra waterway. Vessels of this type have not been operated in Poland so far, due to the small share of inland navigation in cargo handling and the variable parameters of Poland's inland waterways. However, considering its properties, the transportation of LNG on the class III waters of the Odra waterway seems feasible.

This paper examines an inland LNG carrier designed for operation on the Odra waterway, taking into consideration the LNG terminal at the Port of Świnoujście and the possible receivers of gas, as well as the favourable technical and operational parameters of the waterway.

The paper analyses the existing concepts of inland LNG carriers and presents a concept for a vessel, which is designed for operation on class III waterways.

2. ANALYSIS OF THE EXISTING SOLUTIONS FOR INLAND LNG CARRIERS





Inland shipping may be an alternative (to road or rail) means of LNG transportation. LNG transportation is relatively safe. So far, no major disasters or accidents concerning the transportation of LNG by means of inland vessels have been reported. The precondition for the safe transportation of LNG is steady pressure in a vessel's cargo tanks. At temperatures higher than -164°C , LNG changes its state from liquid to gas. In spite of the advanced technologies used in the construction of cargo tanks, it remains impossible to insulate the tank against thermal heat. Boil-off gas (BOG) constitutes, on average, 15% of the daily total tank volume. To prevent an excessive increase in pressure in the tank, BOG must be recovered and utilized. It is often used as fuel to drive the ship; however, being inefficient, this method of BOG utilization is becoming obsolete. BOG is also used for the heating of water, as pressurized water steam drives turbines and propels the ship. Modern ships have advanced LNG BOG recondensers installed [2].

The common feature of all LNG carriers is an on-board discharging system, which includes high-performance discharging pumps. Moreover, all LNG carriers are equipped with ballast systems, which ensure an appropriate draught of the vessel.

A few concepts of inland LNG carriers (barges) have already been developed. Selected examples are presented in Table 1.

The above concepts propose various spatial configurations of a ship's design, with tanks located partly on the main deck or embedded in the vessel's hull.

Table 1. Selected inland LNG carriers (barges)
own work based on [5], [8], [12]

Type of vessel	Example
<p>The concept of an LNG barge; LOA=90m; total tank capacity=2,250m³; designed for operation on inland waters in the Netherlands.</p>	 <p>[9]</p>
<p>The concept of an LNG barge for operation along the US coast; contains four type C tanks (pressure tanks), each with a capacity of 750 m³.</p>	 <p>[3]</p>
<p>The concept of a barge with LNG tanks above the deck; it can carry other types of cargo.</p>	 <p>[2]</p>
<p>The concept of a barge with tanks located partly below the deck; the solution ensures a lower height overall of the vessel.</p>	 <p>[2]</p>

3. RESTRICIONS AND REQUIREMENTS IMPOSED BY THE CLASS OF WATERWAY

Properties, along with technical and operational parameters, of inland vessels are conditioned by the restrictions of inland waterways and the operational requirements in certain areas. In compliance with the Regulation of the Council of Ministers of 7 May 2002 [11],

the classification of inland waterways in Poland effectively includes five classes: Ia, Ib, II and III for regional waterways; and IV, Va and Vb for international waterways.

The total length of Poland's inland waterways amounts to merely 3,655 km, although only 5.9% (214 km) are class IV and V waterways. Other inland waterway networks comprise regional class I, II and III waterways [7]. Transportation is mainly carried out at a local level on sections of class III waterways. Fig. 1 presents the restrictions related to inland waterways, which determine the parameters of inland vessels.

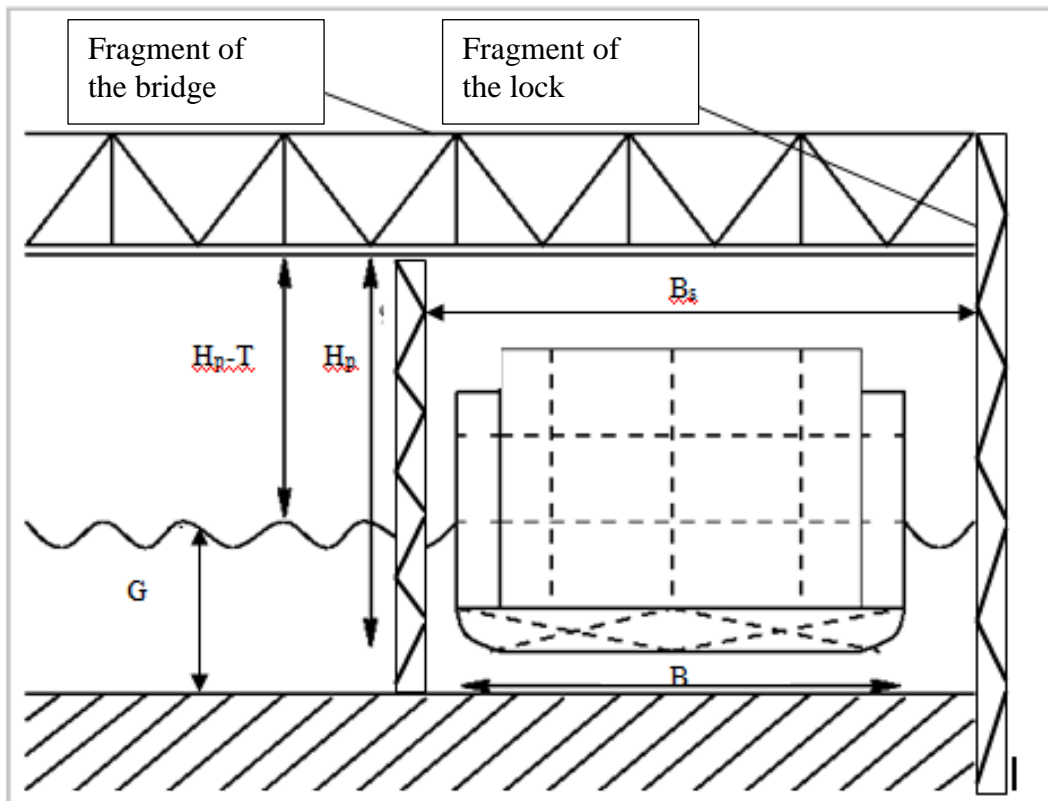


Fig. 1. Inland waterway restrictions [9]

where:

H – depth of the waterway [m]

A_p – height of the vessel above the waterline [m]

T – the vessel's draught [m]

B – the vessel's breadth [m]

B_s – the breadth of the hydraulic structures [m]

AH – the vertical clearance

Ad – the distance between the span and the top of inland vessel

The Odra waterway is Poland's best developed waterway of the highest class. It is divided into the following sections: the Gliwice Canal (*Kanał Gliwicki*), the Upper Odra Canalized Branch (*Odra Górna Skanalizowana*), the Middle Odra (*Odra Środkowa*), and the Lower Odra (*Odra Dolna*). Table 2 includes a list of principal standards and parameters of the four sections.

Table 2. Principal standards and parameters of the Odra waterway [6]

Name of section	Section length [km]	Max. LOA [m]	Max. width [m]	Draught [m]	Clearance below bridges [m]	Class	Note
Odra (Szczecin-Widuchowa)	37.50	82.0	11.45	2.50	5.17	IV	Lower Odra
Odra (Widuchowa-mouth of the River Warta)	86.50	82.0	11.45	1.80	4.54	IV	Lower Odra
Odra (mouth of the River Warta-mouth of the River Nysa Łużycka)	75.20	82.0	11.45	1.40	4.47	III	Middle Odra
Odra (mouth of the River Nysa Łużycka-Brzeg Dolny)	259.80	70.0	9.00	1.20	3.72	II	Middle Odra
Odra (Brzeg Dolny - Koźle)	187.00	70.0	9.00	1.60	3.72	III	Upper Odra Canalized Branch
Gliwice Canal	41.20	70.0	11.40	1.70	4.04	III	Gliwice Canal

In view of LNG transportation along the Odra waterway, vessel parameters must meet the requirements set for class III, assuming an upgrade of certain sections of class II waterways.

According to the classification, vessels approved for operation on class III waterways have the following parameters [11]:

1) For self-propelled ships and barges:

$$L_{\max}=67-70 \text{ m}, B_{\max}=8.2-9 \text{ m}, T_{\max}=1.6-2 \text{ m} \quad (1)$$

2) For sets of pushed barges:

$$L_{\max}=118-132 \text{ m}, B_{\max}=8.2-9 \text{ m}, T_{\max}=1.6-2 \text{ m} \quad (2)$$

where the minimum bridge clearance under high navigable water conditions is 4.0 m.

4. ANALYSIS OF PERMISSIBLE VARIANTS OF LNG TRANSPORTATION

LNG tanks may be divided into the following groups, according to where the tanks sit:

1. Independent tanks located on the main deck of a barge or platform
 - stationary horizontal cryogenic tanks
 - cryogenic container tanks
2. Independent tanks located partially below deck
 - stationary horizontal cryogenic tanks
 - cryogenic container tanks
 - self-supporting prismatic (SPB) tanks
 - MOSS tanks (spherical)
3. Hull tanks (integrated into the structure of the hull)
 - membrane tanks

Considering various tank designs and sitting arrangements, three concepts of LNG carriers can be distinguished, namely:

- a platform with tanks positioned on the main deck
- a barge with tanks integrated into the hull or partly embedded in the hull
- a pushed set, consisting of a pusher boat and barges

Platforms can carry horizontal cryogenic tanks or cryogenic container tanks. Cryogenic tanks can be positioned in several rows across the platform, with a single tank or multiple tanks in a row. A platform is relatively light and has a relatively small draught. However, tanks located on the main deck increase its height overall, which, taking into consideration numerous bridges and other hydraulic structures on waterways, can significantly restrict the shipping area. Nevertheless, apart from LNG, platforms can carry other cargo, including oversized and containerized cargo. Fig. 2 presents examples of a horizontal cryogenic tank and a cryogenic container tank, along with their parameters.



Horizontal cryogenic tank		Cryogenic container tank	
Outer diameter of the outer tank [mm]	2,300	Length overall [mm]	20' - 6,058 30' - 9,125 40' - 12,192
Outer diameter of the inner tank [mm]	2,500	Height overall [mm]	2,591
Nominal water volume [L]	25,000	Width overall [mm]	2438
Total height [mm]	6,790	Water capacity [L]	20' - 19,000 30' - 30,500 40' - 41,000
LNG net weight [kg]* at a 90% filling rate	10,575	Maximum weight of cargo [kg]	20' - 10,000 30' - 14,300 40' - 19,500

Fig. 2. Parameters of a horizontal cryogenic tank and a cryogenic container tank [3]

Ballasting of the platform is required to reduce the height of the vessel above the waterline when operated without cargo.

Another concept involves a barge with tanks integrated into the hull or partly embedded in the hull. With the centre of gravity positioned lower and a reduced height overall, this seems a useful concept in view of the restrictions concerning the height of the vessel above the waterline and the depth of the River Odra. Three options for installing the tanks may be considered:

- 1. A barge with independent tanks (not integrated into the hull)
 - a) Cryogenic tanks (as in the variant discussed above) located inside the hull
 - b) SPB-type tanks (self-supporting, prismatic shape, IMO type B tanks), MOSS (the Norwegian company Moss Maritime’s Spherical IMO type B LNG tanks) etc.
- 2. A barge with membrane tanks, where the membrane comes into direct contact with the insulation supported on the ship’s structure

Fig. 3 presents various types of LNG tanks.

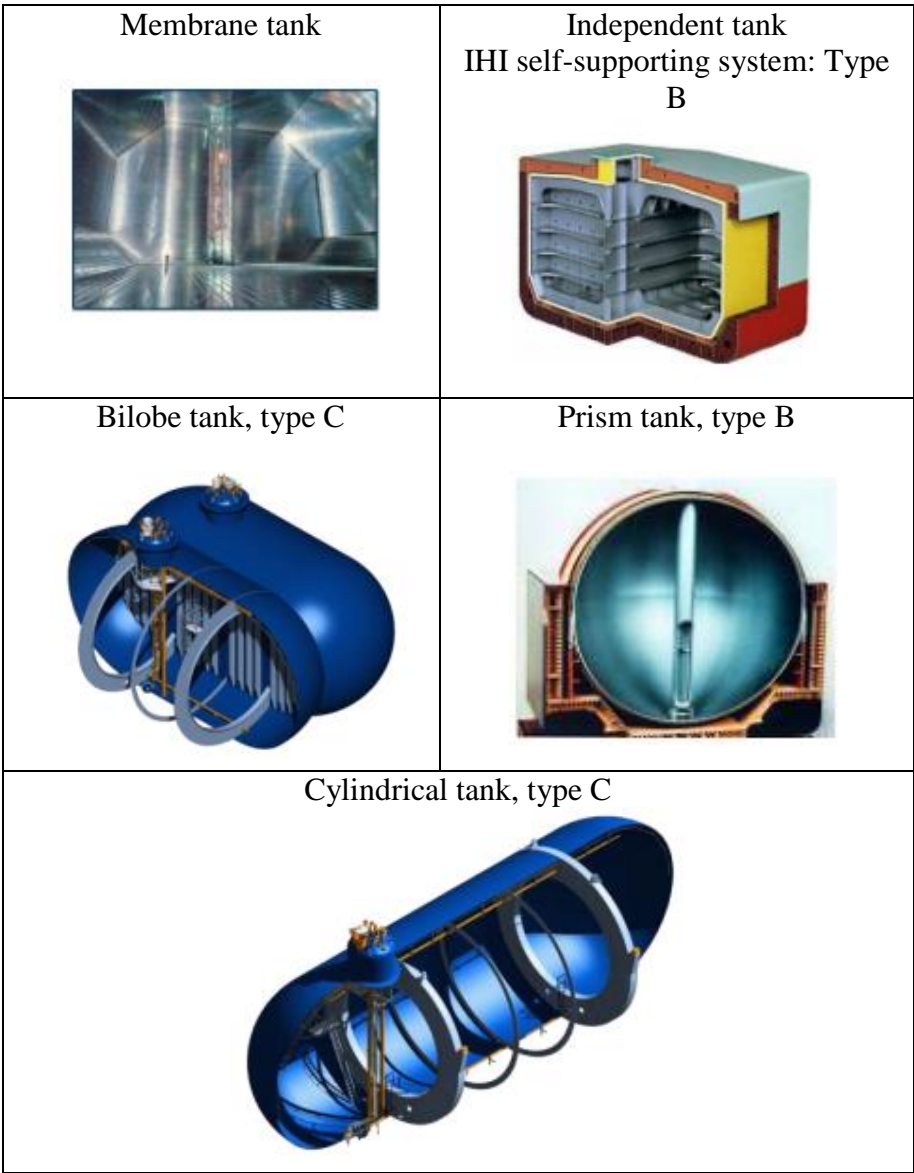


Fig. 3. Examples of LNG tanks [10]

While there is a concept involving a pushed set of barges, difficulties may arise when sailing along bends in waterways, given that, due to its rigidity, the set requires a wider traffic lane. The economic advantage of this solution is a significant cargo carrying capacity without increasing the ship's draught.

5. CONCEPT FOR AN INLAND LNG CARRIER DESIGNED FOR OPERATION ON THE CLASS III Odra WATERWAY

An analysis of the concept of an inland LNG tanker must be carried out according to a predetermined sequence of steps. Fig. 4 presents an algorithm for the determination of parameters of inland LNG carriers. The algorithm comprises the following steps:

Step 1: Definition of the general dimensions of the inland LNG carrier on the basis of an analysis of the demand for LNG along the Odra waterway.

Step 2: Analysis of the types of tanks and a hull structure, which meets the requirements of the waterway in terms of operational safety.

Step 3: Estimation of the vessel's tonnage and volume of gas carried on board, for one vessel, considering the vessel's cargo carrying capacity.

Step 4: Selection of the vessel propulsion system, taking into consideration environmental requirements and operational efficiency.

Step 5: Definition of the vessel's basic dimensions, taking into consideration transportation and operational requirements.

Step 6: Analysis of the operational risk, taking into consideration navigability of the waterway and the existing hydraulic structures.

Step 7: Economic analysis of the proposed solutions for an inland LNG carrier.

Step 8: Development of an initial design of an inland LNG carrier (barge).

In the determination of parameters of inland LNG carriers, a number of restrictions must be taken into consideration, with the concept verified against various criteria. The most important restrictions are those imposed by class III of the waterway. The vessel's horizontal dimensions strictly depend on the dimensions of hydraulic structures, as well as the radiuses of the bends and width of the waterway. Moreover, the ship's length overall is restricted by the strength standards, while its draught is restricted by the type of waterway and its hydraulic infrastructure.

Various models of operation of the proposed vessels can be adopted, depending on the number and location of potential receivers of LNG. Vessels may be operated on (direct and indirect) transport corridors or for the local distribution of LNG. Appropriate infrastructure must be developed in the ports of call.

Efficiency criteria, such as transportation efficiency (S_p) and transportation time (T_p), as well as economic criteria, such as the return on investment (PBP), transportation time (KT) and operational profit (Z), must be considered.

As a result of an analysis, two variants of LNG carriers have been developed, both equipped with independent tanks positioned partly below the deck. In the first variant, six cylindrical tanks are proposed (Fig. 5, Fig. 6 and Fig. 9). The other variant provides for three bilobe tanks, each in the shape of two merged cylindrical tanks (Fig. 7, Fig. 8 and Fig. 9). Table 3 presents selected tank parameters and the main dimensions of the two proposed variants of inland LNG carriers.

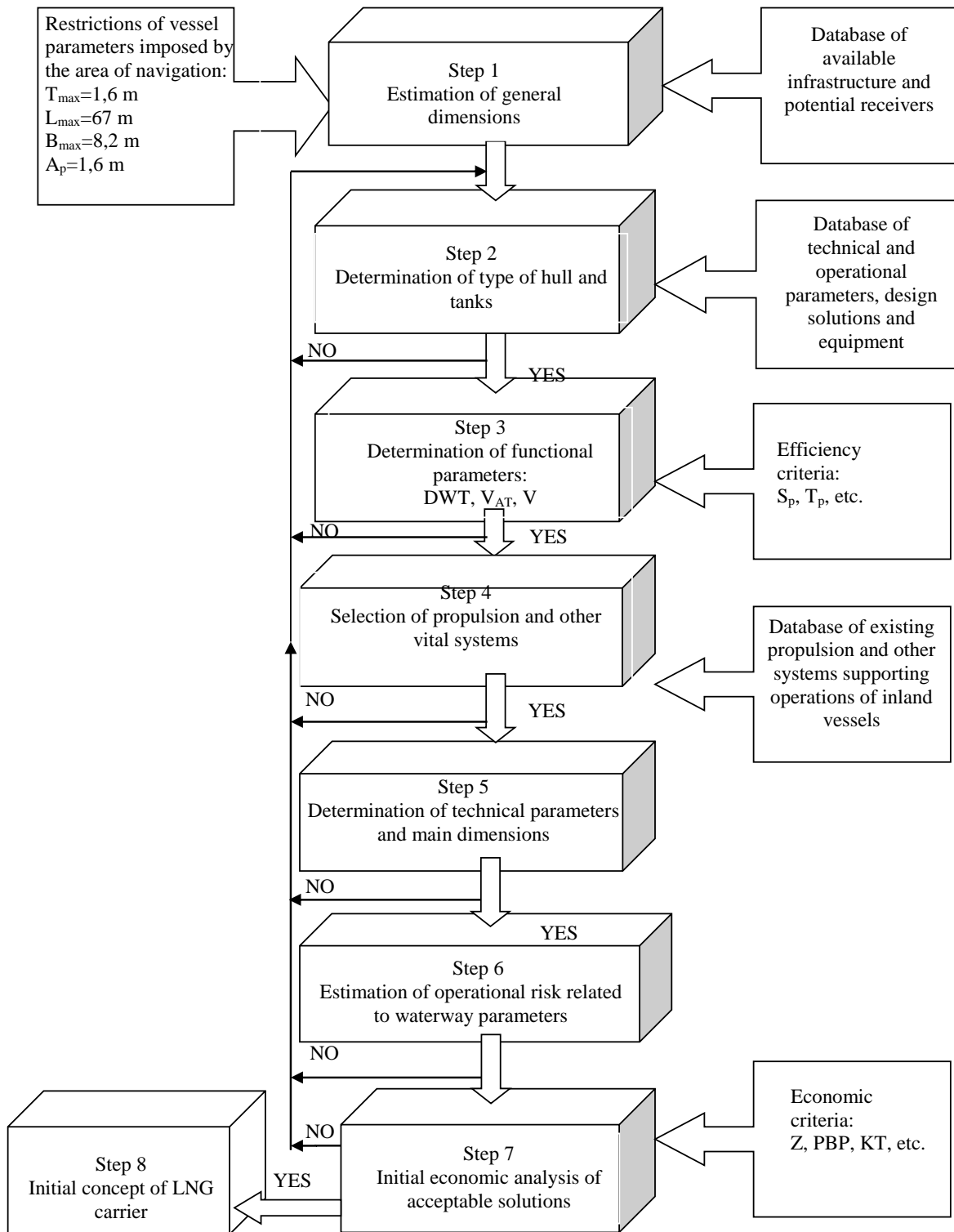


Fig. 4. An algorithm for the determination of inland LNG carrier parameters (own work)

Table 3. Selected parameters of the proposed concepts of inland barges (own work)

Dimensions and parameters	Variant 1	Variant 2
Length overall [m], L_c	67	67
Breadth overall [m], B	7.6	8.2
Draught [m], T	1.6	1.6
Height overall [m], H_s	3.6	4.6
Number of tanks, NOT	6	3
Cross-sectional area of the tank [m ²], D_t	6.1	20.9
Quantity of cargo per one linear metre of the tank [t/m]	2.5	8.8
Single tank volume [m ³], V_T	103.7	355.3
Overall volume of all tanks [m ³], VAT	622.2	1065.9
Deadweight tonnage [t], DWT	263	450

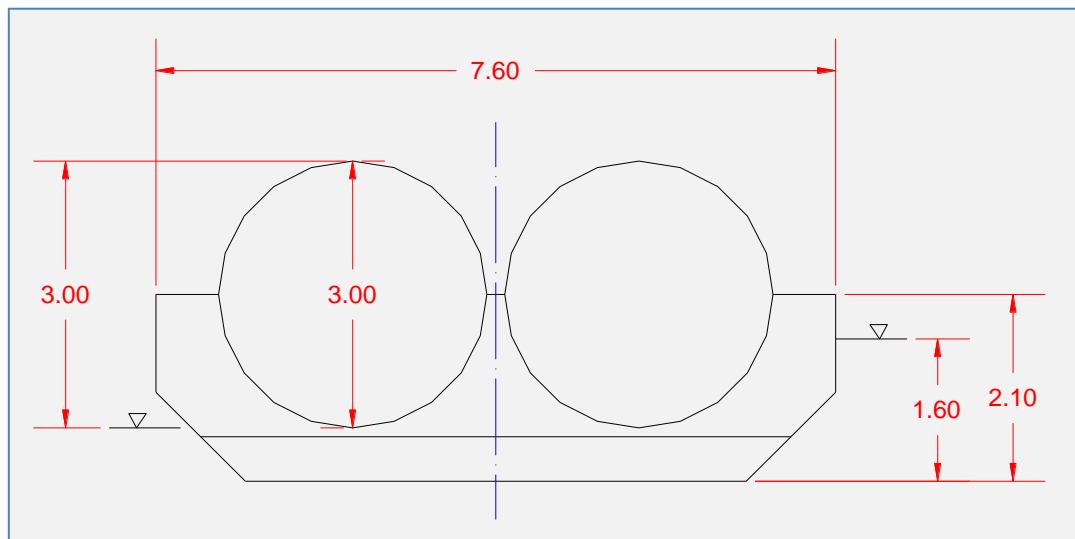


Fig. 5. Variant 1, spatial arrangement: cross section (own work)

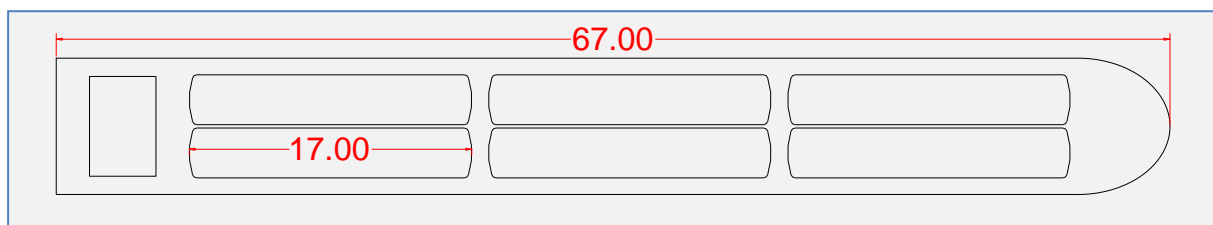


Fig. 6. Variant 1, spatial arrangement: view over the main deck (own work)

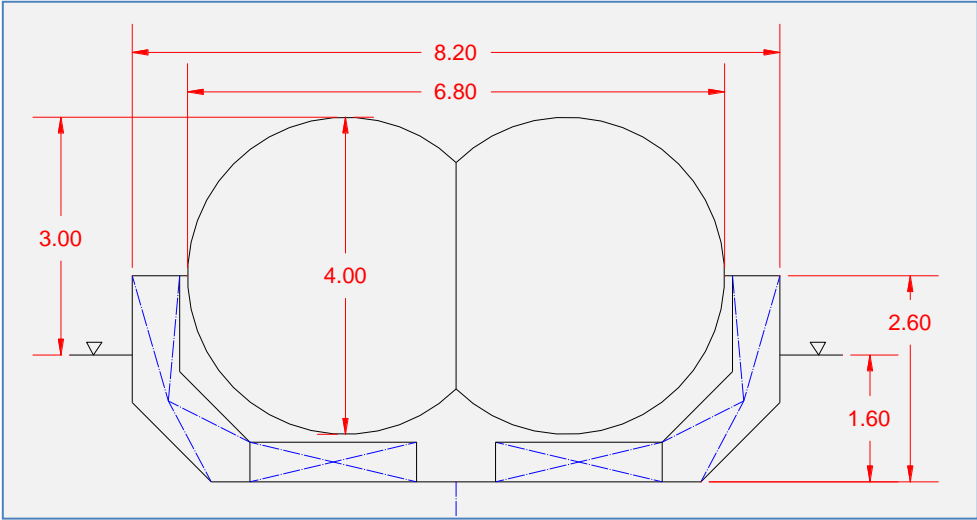


Fig. 7. Variant 2, spatial arrangement: cross section (own work)

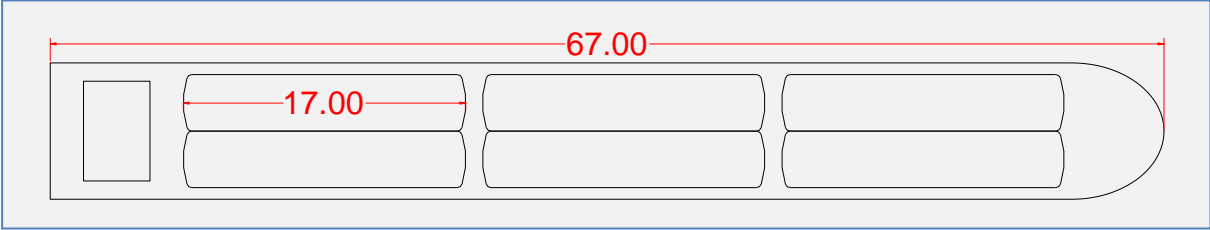


Fig. 8. Variant 2, spatial arrangement: view over the main deck (own work)

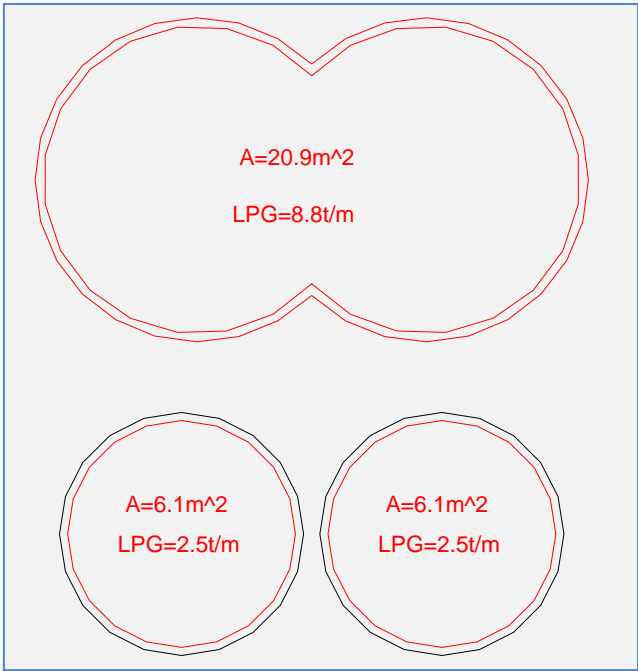


Fig. 9. Variants 1 and 2: cross section of tanks (own work)

The concepts presented above have been developed without taking into consideration all the local restrictions prevalent on the Odra waterway. Implementation of the proposed LNG carriers requires upgrading selected sections of the Odra waterway. Considering the current developments in the transport industry in Poland and the growth trend in inland shipping, it is highly probable that the bottlenecks on Poland's inland waterways will be eliminated in the near future, while the effective operation of the proposed inland vessels on the Odra waterway will become feasible.

6. CONCLUSIONS

Technical alterations to the natural features of inland waterways (construction of artificial canals, dredging etc.) represent the underlying condition for the development of inland shipping. However, the amount of investment required is the main impediment. Therefore, in some cases, rather than change the parameters of the existing infrastructure, it is easier to adjust the parameters of vessels in line with the existing environment.

The classification of inland waterways prioritizes shipping on class IV waterways. However, certain types of cargo can be transported on waterways with lower infrastructure parameters, which is a positive observation from both functional and economic points of view.

The hydraulic infrastructure on class III waterways imposes certain technical solutions at the stage of designing LNG carrying vessels. The restrictions primarily pertain to the main dimensions of vessels and their speed, and result from the interdependence between the waterway and the inland vessel.

Considering the availability of the LNG terminal at the Port of Świnoujście, access to the Odra waterway, as well as the location of potential receivers of natural gas, the concept of LNG transportation on inland LNG carriers along class III waterways is not unreasonable. The operational capability of inland vessels depends primarily on the duration of the shipping season, as well as permissible transit depths and their duration.

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Received 11.01.2017; accepted in revised form 23.04.2017



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