ISSN: 1231-4005
e-ISSN: 2354-0133
DOI: 10.5604/01.3001.0012.2516

OPTIMIZATION OF GASSING-UP OPERATION BASED ON COMPARATIVE ANALYSIS OF TWO TWIN ETHYLENE CARRIERS

Agnieszka Wieczorek, Mariusz Giernalczyk

Gdynia Maritime University
Marine Power Plants Department
Morska Street 83, 81-225 Gdynia, Poland
tel.: +48 58 6901307
e-mail: m.giernalczyk@am.wm.gdynia.pl

Abstract

The article consists comparative analysis of the gassing-up operation – purging cargo tanks with cargo vapour, on gas carriers carrying primarily Ethylene – one of the most expensive cargo of all hydrocarbons carrying by the sea. The source of the problem constitutes similar densities of both gases under specific conditions – Ethylene and Nitrogen – a gas that tanks are purged before gassing-up. The analysis is made for considerable optimization of the process. The comparison of gassing-up methods is based on tests and measurements on two particular twin gas carriers. In both cases different methods – parallel and cascade were chosen to do the gassing-up (parallel means to purge tanks separately at the same time, cascade means to purge tanks one after the other) what allows specifying beneficial procedure. What was estimated during voyages were technical parameters measured during gassing-up, time of the process and the most important information – loss of the cargo. Analysis of particular stages of the operation also allows estimate the level of gas mixing in the tank. The basic purpose of this profile, based on Ethylene loss, is selecting alternative for carrying this operation in more efficient way, what constitutes determining the most proper method of gassing-up – parallel or cascade and setting temperatures, pressures, mass flows which minimize vapour of Ethylene vented to the atmosphere.

Keywords: *gassing-up, gas mixing, ethylene, nitrogen*

1. Introduction

The purpose of gassing-up operation – purging with cargo vapour, is to replace the atmosphere in inerted previously cargo tanks with cargo vapour, to prevent a flammable mixture formation.

The crucial principal of the gassing-up operation is based on the densities of inert, and it purges gas difference. To minimize consumption of purge gas it should be passed into the tank through the lower purge line if the cargo vapour has a higher density than the atmosphere in the tank and the higher purge line if the cargo vapour has a lower density than the atmosphere in the tank. There are two methods of the gassing-up operation carrying, parallel and cascade. Parallel method is to gassing-up all tanks separately at the same time; means to pass cargo vapour to each tank simultaneously and vent the inert gas to the atmosphere or return to shore. Contrary to parallel, cascade consists of purge tanks one after the other, means the inert gas from the first tank is directed towards the next tank and vent to the atmosphere or to flare. During the gassing-up, operation stratification of gases should be observed in the tank, so that the cargo vapour could push inert gas out of the tank, acting on the principal of a piston.

In view of imperceptible density difference between Ethylene and Nitrogen at the same temperature, Ethylene is one of the most problematic hydrocarbons in case of carrying gassing-up operation in an effective way. Moreover, Ethylene is the most expensive cargo carrying on gas carriers. These two aspects dispose to deep analysis of purging inerted with Nitrogen cargo tanks with vapour of Ethylene cargo.

Test stands consist of two twin gas carriers – Saturn and Orion with four bilobe tanks with total capacity of 21,600 m^3 each. The inert atmosphere was made by filling tanks with Nitrogen. Basing

on the cargo of Ethylene estimated loss is possible to determine optimal rules for carrying gassing-up operation on this sort of ships.

2. Methodology of the Saturn and the Orion gassing-up

The gassing-up process on the Saturn was carried with displacement in series. The process is presented in the Fig. 1. One of tanks had already been filled with Ethylene cargo. The vapour produced above the surface of a boiling Ethylene due to evaporation, also called boil-off, was made use to gassing-up process. The operation commenced at 2 a.m., by flashing the minus 50°C boil-off from tank No. 3 to inerted Tank No. 4 with the pressure of about 0.05 bar and the temperature of about 28°C, what was continued until the pressure reached about 0.34 bar. Afterwards, still introducing Ethylene vapour to the Tank No. 4, the valve to the Tank No. 2 was opened. It cannot be said with certainty that stratification was found on the basis of the table presenting measurements showed in the next unit, therefore, it is said that to the next tank was directed a mixture of Nitrogen and Ethylene. After reaching the pressure of 0.16 bars in Tank No. 2, the valve on the pipeline to Tank No. 1 was opened and the mixture started fulfilling Tank No. 1. Hitting 0.06 bar vent to the atmosphere was opened. Ethylene vapour was flowing through all three tanks for 30 hours. Gassing-up completed at 8 a.m. the next day.

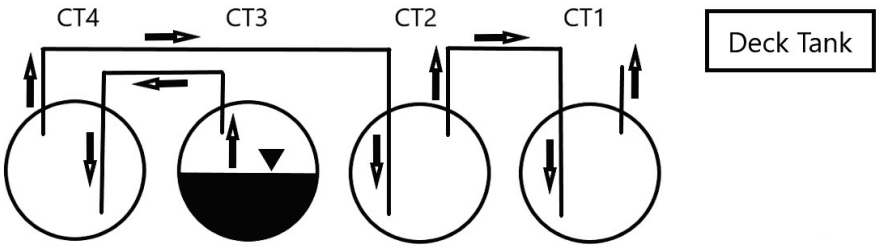

Fig. 1. Gassing-up on the Saturn – displacement in series

Figure 2 shows the way of carrying gassing-up operation on the Orion. The operation was divided into two stages. Stage 1 commenced at 10:30 a.m. one day and completed at 5 a.m. the next day. To begin with, liquid ethylene from shore vaporized in pipelines, vapour of minus 85°C was directed to the Tank No. 4 with a pressure of about 0.05 bars and was filling in to the moment of reaching the tank pressure of about 0.1 bars. At this moment valve on the pipeline to the Tank No. 2 was opened and gassing-up in cascade began. In contrast to the Saturn, after 18.5 hours, the gassing-up operation for Tank No. 4 was completed at the moment of reaching 100% ethylene.

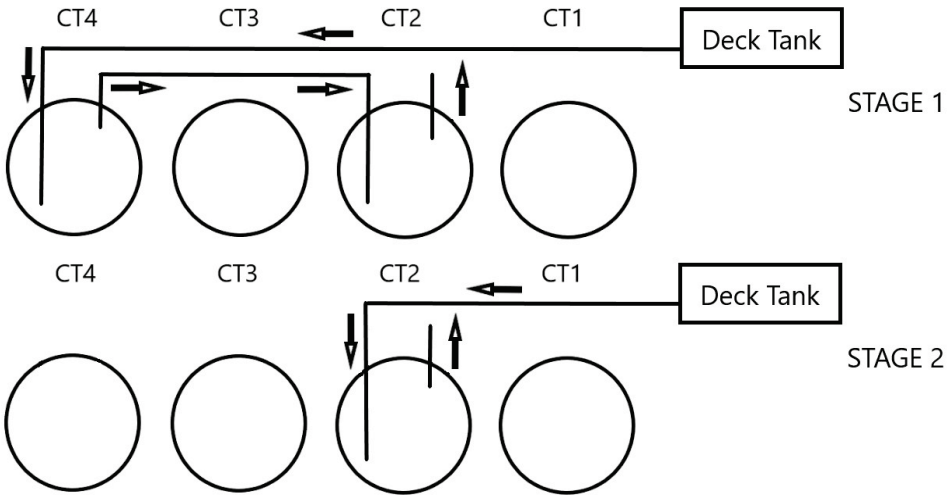

Fig. 2. Diagram of gassing-up on the Orion

At this point stage 2 started. Cold vapour from vaporizer was flashed directly to the Tank No. 2. In case of Tank No. 2 the pressure was kept at two different levels, during cascade gassing-up under 0.06 bars, (then the vent to the atmosphere was opened) and at the moment of parallel purging the pressure grew to the value of 0.13 bars. Parallel operation lasts for another 11 hours.

3. Observations

Despite the insulation of tanks, the high thermal conductivity of steel maintains the temperature of Nitrogen after tanks inerting at an ambient temperature level.

The gassing-up measurements of the ethylene concentration, temperature and pressure for the Saturn and the Orion during the operation of gassing-up are presented in Tab. 1 and Tab. 2 in next two subsections.

Saturn

Tab. 1. Measurement of pressures, temperatures, and HC volume of gassing-up on the Saturn

Cargo Tank		TANK 4													TANK 3											
			HC % VOLUME						TEMPERATURE [°C]							HC % VOLUME						TEMPERATURE [°C]					
		Press	PORT			STBD			PORT			STBD			Press	PORT			STBD			PORT			STBD		
Date	Time	bar(g)	Top	Middle	Bottom	Top	Middle	Bottom	Top	Middle	Bottom	Top	Middle	Bottom	bar(g)	Top	Middle	Bottom	Top	Middle	Bottom	Top	Middle	Bottom	Top	Middle	Bottom
		Commence Gassing-up 13.08/08:30																									
13.08.	08:30	0.06	89	93	**100**	87	87	**100**	27.1	25.2	9.1	26.5	25.7	11.5													
	10:00		94	**100**	**100**	89	**100**	**100**																			
	11:00	0.18	95	**100**	**100**	93	**100**	**100**	27.1	24.3	9.0	27.0	24.8	10.4	0.59							-47.6	-66.3	-95.3	-44,4	-60.0	-95.6
	13:00	0.34	**100**	**100**	**100**	**100**	**100**	**100**	26.9	24.0	5.2	26.8	24.4	5.8	0.58							-49.4	-68.9	-95.4	-45,2	60.7	-95.3
	15:00	0.34	**100**	**100**	**100**	**100**	**100**	**100**	26.3	22.9	3.5	26.2	23.1	4.1	0.55							-50.5	-70.3	-95.6	-45,9	-62.0	-95.6
	18:00	0.33	**100**	**100**	**100**	**100**	**100**	**100**	25,8	21.7	2.3	25.7	21.9	2.7	0.53							-51.9	-71.4	-95.9	-46,6	-63.0	-95.9
	20:00	0.32	**100**	**100**	**100**	**100**	**100**	**100**	25.4	21.2	1.6	25.3	21.3	1.9	0.52							-52.3	-71,9	-96.0	-47,1	-63.3	-96.0
	22:00	0.30	**100**	**100**	**100**	**100**	**100**	**100**	24.6	20.0	0.4	24.5	20.0	0.6	0.50							-53.6	-72.7	-96.3	-48,0	-63.8	-96.3
14.08.	08:00	0.27	**100**	**100**	**100**	**100**	**100**	**100**	21.2	15.8	-1.8	21.0	15.7	-2.1	0.41							-56.8	-74.4	-97.4	-51.1	-63.6	-97.4

Cargo Tank		TANK 2													TANK 1											
			HC % VOLUME						TEMPERATURE [°C]							HC % VOLUME						TEMPERATURE [°C]					
		Press	PORT			STBD			PORT			STBD			Press	PORT			STBD			PORT			STBD		
Date	Time	bar(g)	Top	Middle	Bottom	Top	Middle	Bottom	Top	Middle	Bottom	Top	Middle	Bottom	bar(g)	Top	Middle	Bottom	Top	Middle	Bottom	Top	Middle	Bottom	Top	Middle	Bottom
		Cascade From CT4 p/s																									
13.08.	08:30	0.03	8	11	21	8	12	22	28.1	26.6	26.0	28.3	26.4	26.1		0	0	0	0	0	0						
	10:00		21	21	29	28	27	39								0	0	3	0	0	5						
	11:00	0.14	31	30	41	37.0	37.0	47.0	28.5	27.4	27.3	28.6	27.7	27.1	0.06	4	4	5	4.0	4.0	7.0	29.0	27.5	27.4	28.9	27.4	27.1
	13:00	0.16	64	65	68	61	60	65	28.5	27.3	27.7	28.6	27.1	27.6	0.06	28	30	32	27	30	32	28.6	27.5	27.5	28.4	27.3	27.3
	15:00	0.16	76	75	78	74	72	76	28.6	27.6	28.0	28.7	27.4	28.0	0.06	48	49	52	49	49	52	28.6	27.7	27.9	28.5	27.6	27.7
	18:00	0.16	86	84	87	84	83	86	28.7	27.7	28.1	28.8	27.5	28.1	0.06	65	65	68	67	67	68	28.7	27.9	28.0	28.6	27.7	27.8
	20:00	0.16	90	90	91	90	90	91	28,6	27.7	28.0	28.8	27.5	28.1	0.06	76	76	78	76	76	78	28.7	27.9	28.1	28.6	27.8	27.8
	22:00	0.14	94	95	95	94	94	95	28,5	27.7	27.9	28.7	27.5	27.9	0.06	84	84	86	86	86	86	28.6	27.9	28.1	28.5	27.8	27.9
14.08.	08:00	0.14	**100**	**100**	**100**	**100**	**100**	**100**	28.3	27.9	28.0	28.5	27.6	28.0	0.07	98	98	98	97	97	97	28.5	28.4	28.5	28.5	28.3	28.3

- mass flow during gassing-up was about 0.42 kg/s,
- ethylene vapour at the moment of commence of gassing-up was at the temperature of minus 50°C,
- lower pressure in every subsequent tank starting with 0.034 bar of gauge pressure in Tank No. 4, 0.16 bar in Tank No. 2 and 0.06 bar in Tank No. 1,
- no sub-zero temperatures during the whole gassing-up process in cargo tanks were measured,
- only in Tank No. 4 HC concentration difference were measured between the levels – on bottom higher HC concentration than on top and in the middle; in the other two tanks HC concentration the same at all three levels in time,
- temperature difference measured only in Tank No. 4 on bottom; in Tank No. 2 and Tank No. 1 ambient temperature measured (the temperature of Nitrogen after tanks inerting),
- Tank No. 4 purged with Ethylene vapour after 12 hours,
- ethylene vapour noticed in Tank No. 2 halfway through gassing-up Tank No. 4, in Tank No. 1 after 100% HC concentration reached in Tank No. 4,
- towards the end Tank No. 2 purging with Ethylene vapour, similar value of HC concentration to tank No. 1.

Orion

– mass flow during gassing-up was about 0.25 kg/s,
– Ethylene vapour at the moment of commence of gassing-up was at the temperature of minus 85°C,
– Tank No. 4 overpressure maintained at about 0.1 bar, lower pressure in Tank No. 2 about 0.05 bar (during Tank No. 4 gassing-up) and growth to about 0.1 bar (after completing Tank No. 4 gassing-up).

Tab. 2. Measurement of pressures, temperatures and HC volume of gassing-up on the Orion

Cargo tank		Tank 4													Tank 3	Tank 2												Tank 1
		press bar(g)	HC % VOLUME						TEMPERATURE[°C]							press bar(g)	HC % VOLUME						TEMPERATURE[°C]						
			PORT			STBD			PORT			STBD					PORT			STBD			PORT			STBD			
Date	Time		Top	Middle	Bottom	Top	Middle	Bottom	Top	Middle	Bottom	Top	Middle	Bottom			Top	Middle	Bottom	Top	Middle	Bottom	Top	Middle	Bottom	Top	Middle	Bottom	
		Commence Gassing-up 21.02 10:00														Cascade From CT4 p/s												
21.02.	10:30	0.10	0	0	14	0	0	10	24.3	23.7	19.1	24.7	23.2	19.0		0.03	0	0	0	0	0	0	23.9	23.0	22.0	23.5	18.8	18.8	
	12:00	0.08	12	26	57	15	29	67	24.0	23.3	7.0	24.0	22.5	6.8		0.03	0	0	0	0	0	0	24.0	23.1	22.1	23.5	19.1	18.9	
	13:00	0.10	25	37	93	24	37	88	24.0	22.9	-0.9	24.1	22.0	0.1		0.04	0	0	7	0	0	8.0	24.3	24.2	24.1	24.3	20.1	19.2	
	14:00	0.12	32	46	100	32	45	97	23.7	22.1	-10.8	23.7	21.3	-7.1		0.05	0	0	13	0	0	15	25.1	24.8	24.6	24.6	20.8	20.5	
	15:00	0.10	42	51	100	41	50	100	23.3	21.0	-16.1	23.4	20.0	-12.0		0.04	0	0	19	0	0	21	25.0	24.6	24.3	24.6	21.0	20.6	
	16:00	0,09	51	63	100	50	52	100	22.8	20.1	-25.9	22.9	19.2	-19.6		0.04	0	0	23	0	0	25	25.1	24.8	24.8	24.7	20.8	21.2	
	17:00	0.10	62	70	100	62	68	100	22.4	19.5	-34.6	22.5	18.7	-26.3		0.05	0	0	30	0	0	30	25.2	24.8	24.7	24.8	20.9	21.2	
	18:00	0.11	68	72	100	69	71	100	22.0	18.8	-42.4	22.1	17.7	-35.9		0.05	0	22	35	0	21	34	25.1	24.8	24.5	24.8	20.9	21.1	
	19:00	0.09	70	75	100	70	74	100	21.4	18.1	-47.8	21.4	16.5	-44.0		0.04	0	25	40	0	24	40	25.1	24.7	24.3	24.8	20.7	20.9	
	20:00	0.09	72	77	100	72	77	100	21.0	18.0	-53.5	20.8	15.7	-50.1		0.04	26	38	52	25	36	53	25.1	24.8	24.3	24.7	20.8	20.9	
	21:00	0.10	75	80	100	75	80	100	20.4	16.7	-58.1	20.2	14.9	-56.2		0.05	33	42	60	35	42	62	25.1	24.9	24.3	24.9	21.0	20.9	
	22:00	0.11	80	84	100	78	83	100	19.9	15.7	-65.3	19.5	14.3	-61.2		0.05	39	47	62	40	48	64	25.2	25.0	24.3	24.9	21.1	20.8	
	23:00	0.12	83	86	100	82	86	100	19.2	14.7	-72.1	18.9	13.4	-66.0		0.06	44	50	63	45	51	65	25.1	25.1	24.3	24.9	21.2	20.8	
22.02.	00:00	0.11	85	88	100	86	90	100	18.8	14.0	-72.6	18.5	12.2	-70.6		0.06	46	55	66	47	53	67	25.0	24.8	24.1	24.7	20.9	20.7	
	01:00	0.12	91	95	100	90	96	100	18.1	13.2	-72.8	17.7	10.9	-75.7		0.06	48	59	71	49	57	73	24.9	24.8	24.1	24.6	20.9	20.7	
	02:00	0.11	96	98	100	95	100	100	17.4	11.8	-79.4	17.0	10.0	-79.3		0.06	49	60	77	50	59	78	24.8	24.7	24.0	24.5	20.8	20.6	
	03:00	0.11	97	100	100	99	100	100	17.0	10.3	-83.5	16.4	9.2	-85.6		0.06	51	64	81	50	60	80	24.8	24.7	23.9	24.5	20.8	20.5	
	04:00	0.11	98	100	100	99	100	100	16.5	9.5	-83.5	15.8	8.3	-85.6		0.06	52	65	83	51	62	83	24.8	24.7	16.1	24.5	20.8	15.6	
	05:00	0.11	99	100	100	99	100	100	15.2	8.7	-83.5	15.0	7.1	-85.6		0.06	53	67	89	52	65	88	24.8	24.8	11.2	24.4	20.7	10.8	
	06:00															0.06	56	70	94	56	70	95	24.8	24.8	2.1	24.4	20.7	3.4	
	07:00															0.05	69	73	100	68	73	100	24.8	24.8	-6.9	24.4	20.7	-5.3	
	08:00															0.07	71	76	100	71	76	100	24.8	24.7	-11.2	24.4	20.7	-10.1	
	09:00															0.08	74	79	100	73	78	100	24.8	24.7	-18.4	24.4	20.7	-17.5	
	10:00															0.09	76	81	100	76	81	100	24.7	24.1	-25.6	24.2	20.5	-24.8	
	11:00															0.11	79	85	100	79	86	100	24.2	22.9	-30.1	23.9	18.9	-30.0	
	12:00															0.11	84	90	100	85	91	100	23.8	21.9	-33.6	23.3	18.0	-35.5	
	13:00															0.11	90	94	100	90	96	100	23.3	21.1	-37.3	22.9	17.2	-38.0	
	14:00															0.12	94	99	100	94	99	100	23.0	20.7	-40.6	22.5	16.7	-42.6	
	15:00															0.13	98	100	100	98	100	100	22.7	20.3	-44.6	21.4	15.8	-46.6	
	16:00																												

– during gassing-up operation sub-zero temperatures measured only on bottom of the tank,
– temperature difference measured between the middle and top of tanks,
– slight temperature drop from the very beginning to the end of gassing-up at all three levels,
– 100% HC concentration on bottom measured after 4 hours,
– on top and in the middle approximate values of HC concentration measured in time,
– Tank purged with ethylene vapour after 18.5 hours.

Tank No. 2:

– for the first four hours ethylene noticed only on the bottom during gassing-up,
– before disconnecting vapour line from Tank No. 4, ambient temperature measured in the tank,
– sub-zero temperature measured right after introducing directly to the tank ethylene of minus 85°C,
– minor temperature drop in the middle and on top of the tank measured even after vapour from Tank No. 4 was disconnected,
– gradual pressure growth measured in the tank.

4. Cargo loss

During gassing-up cargo tanks on the Saturn, Ethylene loss (vented to the atmosphere or to shore) constitutes 25 tonnes and 5 tonnes during cooling the cargo. The amount was measured for all three tanks.

On the Orion Ethylene, loss constitutes 14.5 tonnes during gassing-up two cargo tanks and 3 tonnes during cooling the cargo.

In both considered cases, it is impossible to determine the amount of Ethylene loss for one particular cargo tank.

The comparison of a basic data of gassing-up on the Saturn and on the Orion is presented in Tab. 3.

Tab. 3. Data sheet of gassing-up on the Saturn and on the Orion

	SATURN	ORION
Temperature of Ethylene (^{0}C)	-50	-85
Approximate value of pressure in tanks (barg)	• CT4 – 0.34 • CT2 – 0.16 • CT1 – 0.06	• CT4 – 0.10 • CT2 – 0.05-0.11
Mass flow (kg/s)	0.42	0.25
Time of the operation (hrs)	• First tank – 12 • All tanks – 30	• First tank – 18.5 • All tanks – 29.5
Loss of Ethylene (t)	• Gassing-up – 25 • Cooling – 5	• Gassing-up – 14.5 • Cooling – 3

5. Conclusions and suggestions

To begin with, it is important to emphasize that Portable Gas Detector used on ships (Riken Keiki GX-8000) is not a precise device. Indicate accuracy is less than 5%. What means that measured 100% HC concentration in tank, in fact may constitutes only 95% of Ethylene, remaining 5% is Nitrogen.

Conclusions of gassing-up on the Saturn and on the Orion are following:

– first tank gassing-up may be considered as parallel, appearance of sub-zero temperatures on the bottom of the tank suggests Nitrogen and Ethylene stratification,
– no temperature difference noticed in tanks during cascade gassing-up, an ambient temperature remained in tanks (ambient temperature means the temperature of Nitrogen after tanks inerting),
– similar values of HC concentration and temperatures on bottom, in the middle and on top of the tank suggest total mixing of Ethylene and Nitrogen,
– as presents Tab. 1 (section 3.1), vapour from tank with cold liquid cargo used to gassing-up, heats up in pipeline from about minus 50°C to 10°C what totally prevents any stratification.
– vaporizing liquid Ethylene from shore or deck tank makes it more difficult to accurate control of a mass flow,
– liquid Ethylene does not vaporize fully in pipeline, gassing-up this way demands a very slow rate of Ethylene so that the liquid at temperature of about minus 103°C does not make any tank construction destruction,
– according to the Saturn and the Orion, lower value of a mass flow enable gas stratification a better way,
– the average amount of Ethylene loss per one tank on the Saturn and on the Orion is approximate.

Suggestions:

– using a vaporizer would enable more precise a mass flow control,
– precise assessment of Nitrogen concentration in gas mixture would allow carrying gassing-up operation in more efficient way,
– parallel gassing-up would be optimal way to do the gassing-up operation than displacement in series,
– it should be determined a maximum value of a mass flow which enable stratification,
– since lower pressure let using less vapour, the lowest value of pressure in tank, which enables stratification, should be determined.
– ethylene vapour should be as cold as possible,
– higher temperature of Nitrogen may decrease the amount of cargo loss.

References

[1] Włodarski, J. K., (ed.), *Bezpieczeństwo Transportu Gazów Skroplonych Na Zbiornikowcach, Poradnik dla oficerów statków morskich*, Studium Doskonalenia Kadr S.C. Wyższej Szkoły Morskiej, Gdynia 1993.
[2] McGuire and White, *Liquefied Gas Handling Principles On Ships and in Terminals*, Witherby&Co Ltd, London 2000.
[3] Nanowski, D., *Analiza Wydajności Chłodniczej Kaskadowego Obiegu Skraplania Etylenu i Stanu Izolacji Zbiorników Ładunkowych Podczas Transportu Ładunku na Gazowcu LPG o Pojemności 22500 m^3*, Zeszyty Naukowe Politechniki Rzeszowskiej 290, Mechanika, RUTM, T. XXXI, Z. 86 (2/14), pp. 225-230, 2044.
[4] *Ship owner's data,* London 2017.
[5] *Ship owner's data,* London 2018.
[6] *Ship owner's documentation,* London 2015.
[7] Mieczyński, M., *Istota symetrii termodynamiki klasycznej i współczesnej*, Oficyna Wydawnicza Politechniki Wrocławskiej, Wroclaw 2003.
[8] Nanowski, D., *The Influence Of Incondensible Gases On The Refrigeration Capacity Of The Reliquefaction Plant During Ethylene Carriage By Sea*, Journal of KONES Powertrain and Transport, No. 3, pp. 359-364, 2016.
[9] Serwiński, M., *Zasady inżynierii chemicznej i procesowej*, Wydawnictwo Naukowo-Techniczne, Warszawa 1982.
[10] Wieczorek, A., *The problem of insufficiently optimal gassing-up operation carrying after tanks inerting with reference to ethylene carriers*, Scientific Journal of Gdynia Maritime University, No. 100, pp. 179-186, Gdynia 2017.

Manuscript received 18 October 2017; approved for printing 9 March 2018