NIPES

Advances in Engineering Design Technology

Journal homepage: www.nipesjournals.org.ng

Advances In Engineering Design Technology

Regression Formulas for the Prediction of Optimum Tank Capacities of Gas Carrier Ships from Exiting Ships Data

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ARTICLE INFORMATION

Article history:
Received 13 November 2022
Revised 01 December 2022
Accepted 26 December 2022
Available online 29 Dec. 2022

Keywords:
Gas- tankers, design, Regression, formulas, tank-capacity, dimensions, design.

https://doi.org/10.5281/zenodo.7491631

ABSTRACT

This paper present 18 regression equations for the computation of optimum gas tank capacity for a wide range of gas carrier vessels. This presentation is to ensure that the optimum total gas carrying capacity of a projected or existing gas carrier vessel with known principal dimensions is adequately computed. The method is authenticated by comparing the tank capacities it predicts, with that of 15 randomly selected existing gas carrier ships. The method presented is important to assure that a projected design of this type of ship meet owner's requirement regarding total gas tank capacity, to provide for optimization in ship design and to assist in ship design software development.

1. Introduction

The ship type originating in the early 1930's for the transportation of gaseous cargo products such as Liquefied Natural Gas LNG, LPG, ethane, carbon dioxide, etc are called Gas Carrier ships or gas tanker ships [1]. Normally ship design spiral process start with the owner's requirements stated as cargo capacity (metric tonnes, (m^3) or units), or deadweight(t), ships speed v (kts), endurance (hrs) or range in sea miles as well as other specific requirements such as the trade route, main engine type etc. These owners requirement factors are constant and are the basis for computation of the initial preliminary dimensions of the ship calculated usually by empirical formulas derived from data of similar existing ships [2] [3]. In the design of gas carrier ships the total gas tank capacity in m^3 is usually one of the important inputs. The dimension of the ship estimated at the first design circle stage are length L, Breadth B, Depth D, draft T, main propulsive power P, deadweight Dwt, total tanks capacity for gas cargo Tc, block coefficient C_B and other form coefficients, hydrostatic particulars and other factors calculable by empirical formulas and methods [4] [5].

The second design circle stage begins with the establishment of the predicted main dimension obtained at the first design stage with respect to optimality and conformity with the similar ship parameters and the owner's requirement. Concerning gas carrier ships the optimum deadweight and optimum power with associated ship speed can be calculated from references [6], [7]. The optimum total gas capacity Tc_{opt} can be obtained by the method presented in this paper. When the predicted optimum values deviate significantly from the owner's requirement the predicted dimensions are equally adjusted or recalculated before the next design stages continue in the spiral design circle. These next stages relate to ship body lines geometrical design, hydrostatics, stability, structural design, resistance and powering, sea keeping etc treated in other numerous existing publications.

This work is based on ship principal parameters collected from the internet publications related with details of existing gas carrier ships either advertised on the internet as for sale or otherwise, for 206 existing gas carrier ships. The sources for internet data are published in the author's previous paper [4]. The correlation formula derived from this data, form the resulting governing equations for the method of computation of optimum total tank capacity Tc_{opt} presented below. The variables and range of ship particulars involved in this work are:
Tank Capacity $Tc = 381\ to\ 266000\ m^3$, ship ships length overall $L = 59.37\ \ to\ 345\ m$, ships breadth $B = 10.8\ to\ 53.8\ m$, ships depth $D = 4.5\ to\ 27\ m$, draft of ships $T = 3.81\ to\ 12.2\ m$, block coefficients $CB = 0.52\ to\ 0.95$, ships designed speed $v = 10\ to\ 20\ kts$, main ship power $P = 734\ TO\ 21770\ Kw$, deadweights $Dwt = 963\ to\ 130102\ t$. Other variables involved are factors derived from the above particulars such as B^3, $\frac{Tc}{LBT}$, LB, $LT^{1.5}$, $L/\sqrt{T}$, $\sqrt{BT}$, $\sqrt{B\sqrt{T}}$, $B(\sqrt{T})$, $\sqrt{(BD)}$, $(LBT)CB$, and $\frac{P}{V}$. The ship form factors such as $\frac{L}{B}$, $\frac{B}{D}$, $\frac{L}{T}$, $\frac{B}{T}$, and others were also investigated in the regression analysis but they did not yield good reliable correlation formulas with total tank capacity Tc. Determination of optimum tank capacity at early stage of the gas carrier ships is important due to the fact that the it will lead to optimum ship form of the ship leading to minimized power and fuel consumption of the vessel and maximized transportation efficiency.

2. Methodology

The Microsoft Excel software with its regression ad-in was used to obtain numerous regression formulas in this work. The mathematics of the regression analysis can be found in text books [8], [9] to mention a few. The regression analysis was on total tank capacity **Tc** of the respective gas carrier ships as the independent Y-axis variables while the other variables or factor introduced above are the independent X-axis variables. The modeling of the regression analysis are: linear ($Y = m * c$), logarithmic ($Y = m * \ln(x) + c$), exponential ($Y = m * e^{cx}$), power ($Y = m * x^c$), and polynomial ($Y = a_n x^n + a_{n-1} x^{n-1} + \ldots a_2 x^2 + a_1 x + a_0$) functions where :m, c, a and n are constants but n is not greater than 6. The regression formulas thus derived are sorted depending on their correlation factor and deviations in the scatter diagrams also presented.

The method of application of the selected regression formulas are by substitution of the actual or projected dimensional independent variables to get the desired values of predicted values of the total tank capacity pTc from each of the derived regression formulas. The optimum total tank capacity Tc_{OPT} is the mean of the individual formula values of pTc. That is:

$$T_{COPT} = \sum pTc \qquad (1)$$

In other to authenticate the method as well as the formulas, the computed value of Tc_{OPT} for each vessel is compared to the actual value of Tank capacity Tc. this is done for 15 numbers of random samples of existing gas carrier ships and the result of this comparison is also presented.

3.Results and Discussion

The extensive regression analysis carried out on the collection of 206 ships parameters resulted in the scatter diagrams and formulas shown in Appendix 1 (fig 1 to 18) These are a selection of numerous correlation formulas of **Tc** and related variables as the dependent variable. The presented selections are made on the basis that their correlation factor R^2 equal to 0.9 or above. and that deviations are consistently low for each predicted formula for the range of the parameters investigated. The computation of predicted total gas capacity **pTc** using the regression formulas of

Fig1 to Fig.18 is summarized in the Table 1 to Table 6 for a sample of existing gas carrier ships. In these tables the computation for the predicted total gas capacity **pTc** using the regression formulas and their mean value **Tc_{opt}** is shown. This computation was carried out using Microsoft Excel worksheet regression analysis add-in. Each of a total of 15 randomly selected existing gas carrier ships prediction of tank capacity value **pTc** is calculated but only 6 of them are presented in this presentation in Table1 to 6 below in, order to save space. It can be observed that the entire 18 formulas predicted were used to compute **pTc** for vessels of length greater than or equal to 200m (see Table 5 and 6), while a lesser number of formulas are used for the vessels of length less than 200m (see Table 1 to 4). When the block coefficient C_B of the selected vessel is unknown the computation of the value of **pTc** by the formula containing block coefficient can be omitted for that particular vessel as is shown in Table 1 and 4.

The mean value of **pTc (predicted value of gas tank capacity (m^3)** values for a particular ship is the optimum value which is denoted as **Tc_{opt} (optimal gas tank capacity (m^3)** . The **Tc_{opt}** value is compared with the actual value of the total capacity **Tc** of the vessels to authenticate the method. This comparison is shown for the 15 computed vessels in fig.19. Correlation diagram between the **Tc** and **Tc_{opt}** is shown in fig.20 and has a correlation factor of 0.998 which prove that this method can excellently be used in computation of optimum gas tank capacity for gas carrier ships. Fig. 19 clearly show that the predicted optimum values **Tc_{opt}** predicted by the method presented in this work is very close to existing ship **Tc** values. This is further authenticated by the correlation of the two values as presented in fig. 20. Therefore, this method can be used as criteria for the prediction of optimum gas tank capacities for a projected new ship design when the principal dimensions are known. This method can as well be used to compute the optimum gas tank capacity for reconstruction or conversion of existing ship to gas carrier ship.

In Figures 1, 3, 7, 9,10, and 12 have parabolic shape due the fact their correlation is between cubic numbers on one axis and linear number on the other axis. For instance, in between the volume (tank capacity) and the linear (ships length). Figures 2, 6, 11, 16, and 18, resulted in straight line because of the influence of natural logarithm used to factor the values in the one or both axes. Figures 4, 8, 13, 16, 15, and 17 resulted as expected in straight line plots due the fact that the factors on both axes are equal or close to the same power. The Figure 5 and 14 have non-dimensional components on y-axes hence the shape of the scatter plot is linear. The theoretical reason for the shape of these plots can be subject for advanced explanation by future research works.

4.Conclusion

When the principal dimensions of a projected or existing gas carrier ship design is known, it is important to ascertain the optimum total gas tank capacity of the ship to enable satisfaction of the owners requirement and to optimize the principal ship dimensions at the preliminary design stage. Eighteen formulas were carefully sorted based on their correlation factor R^2 of 0.9and above as well as their deviational pattern. These formulas were derived by regression analysis on parameters of 206 gas carrier ships data using Microsoft Excel add-in. These formulas were used to compute the optimum total gas tank capacities of 15 randomly selected existing gas carrier ships. The results were compared with the actual values of tank capacities of the existing ships in order to check the authenticity of the presented method.

The method proved excellently acceptable for usage to compute the optimum total tank capacity for a projected or existing gas carrier ship up to the correlation factor of $R^2 = 0.998$ which is an excellent result. This method is applicable to a wide range of sizes of projected or existing design of gas carrier ships of capacity ranging up to 300000m^3 and length of ship up to 400m. The method can be integrated into computer software for the design and development of gas carrier ships.

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Appendix 1 (Fig.1 to 18)

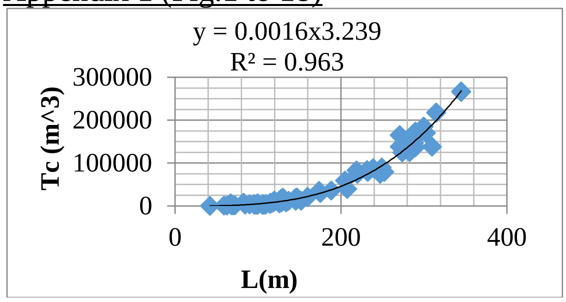


Fig. 1. Regression Between Tc and Length L

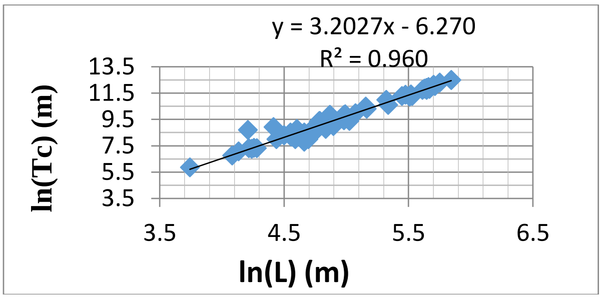


Fig. 2. Regression Between lnTc and Length L

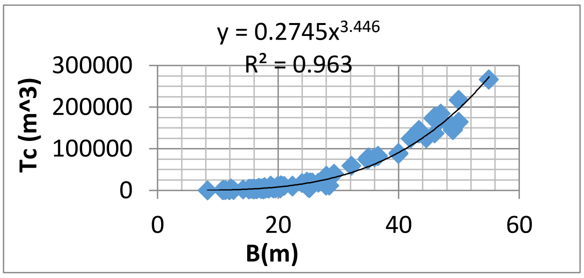


Fig. 3. Regression Between Tc and Breadth B

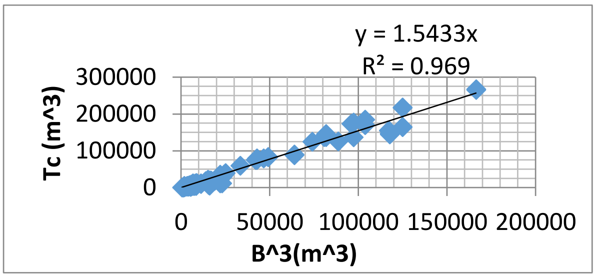


Fig. 4. Regression Between Tc and B^3

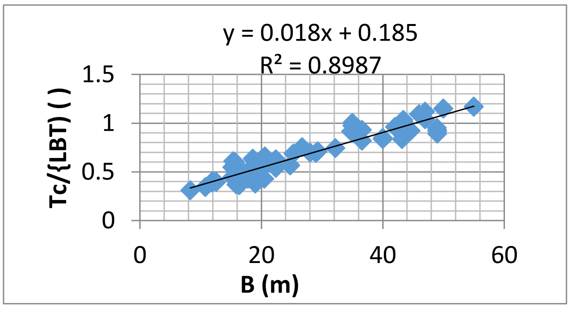


Fig. 5. Regression Between Tc /(LBT) and B

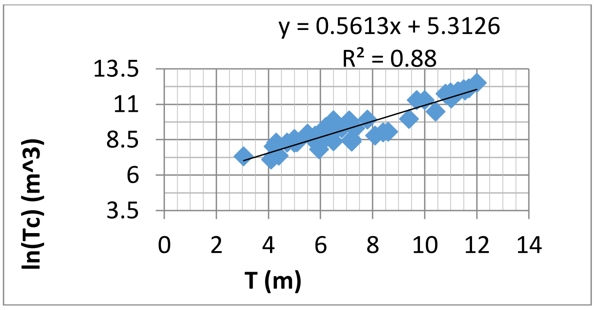


Fig. 6. Regression Between ln(Tc) and DraftT

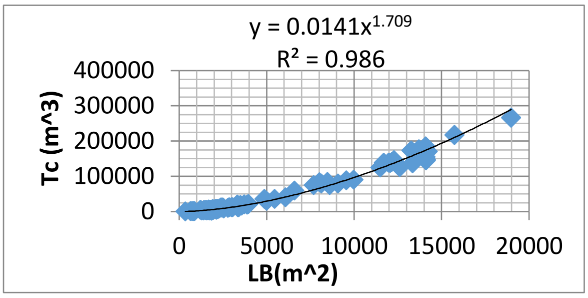


Fig. 7. Regression Between Tc and L*B

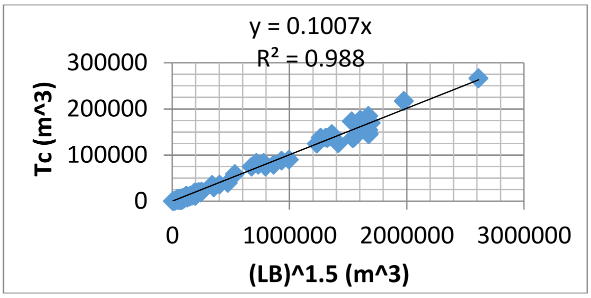
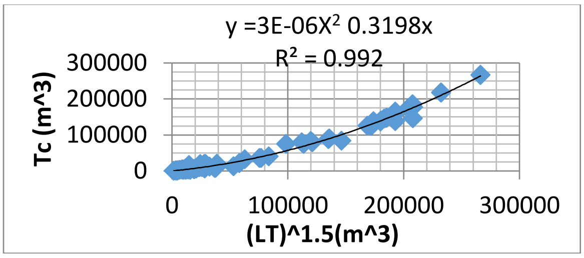


Fig. 8. Regression Between Tc and (LB)^1.5



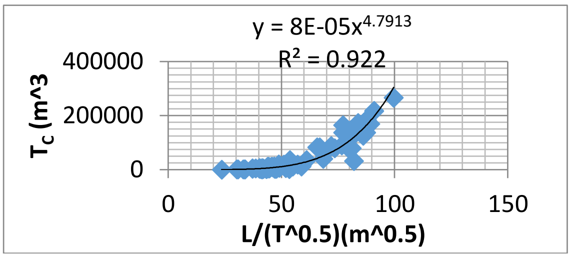
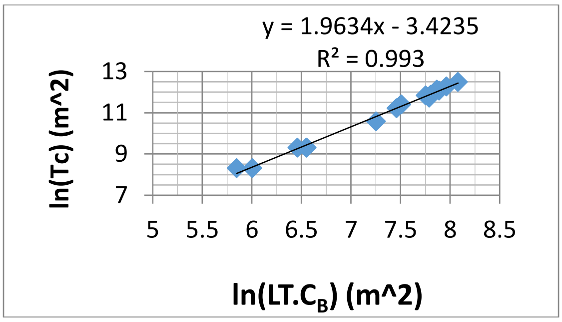


Fig. 9. Regression Between Tc and (L*T)^1.5. Fig. 10.. Regression Between Tc and L/(T^0.5)



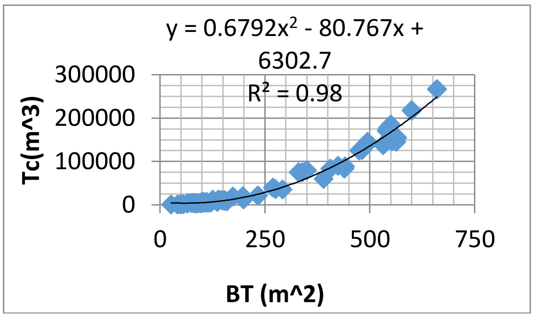
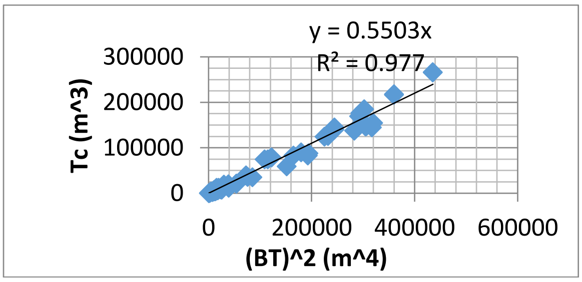


Fig. 11. Regression Between ln(Tc) and ln(L*T*C_B) Fig.12. Regression Between Tc and B*T



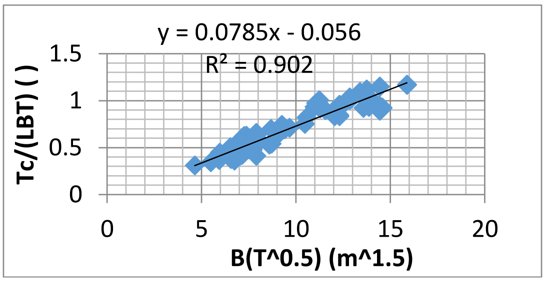
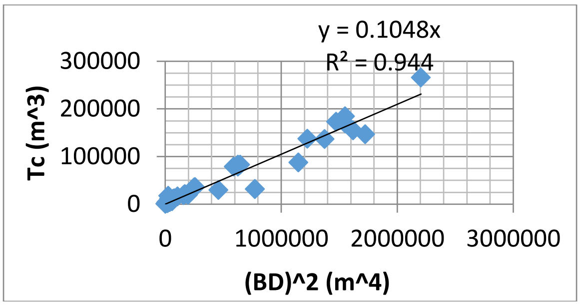


Fig. 13. Regression Between Tc and BT)^2 Fig.14.. Regression Between Tc/(LBT)BreadthB(T^0.5)



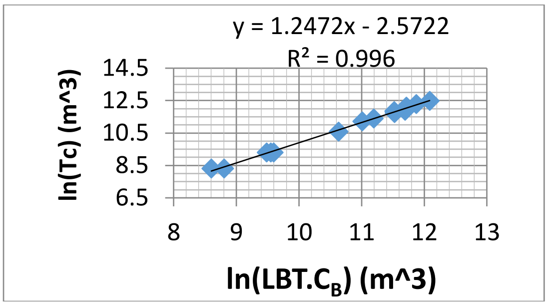
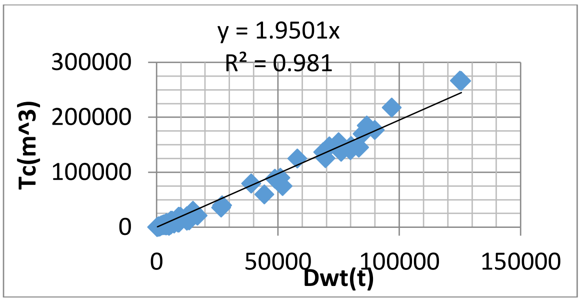


Fig. 15. Regression Between Tc and (B*D)^2

Fig. 16. Regression Between ln(Tc) andln(LBT*C_B)



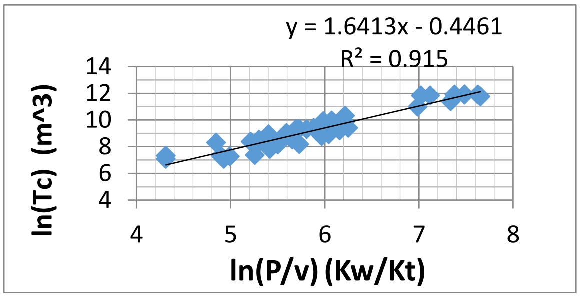


Fig. 17. Regression Between Tc and Dwt

Fig. 18. Regression Between ln(Tc) and ln(P/v)

Table 1. EXCEL Computaion for Prediction of Total Capacity pTc based on the above presented regression analysis formulas for Gas Carrier Ship "GASCHEM DANUBEGAS".

Vessel Name/ IMO No GASCHEM DANUBEGAS / IMO 9176125		**L** 98.53	**B** 15.2	**D** 10	**T** 6.2	**C_B**
		Tc 4365	**P** 2640	**v** 14.5	**Dwt** 4000	
Eq. No.	**Formula**	**y**	**x**	**x1**	**y1**	**pTc**
1	y = 0.001x^3.239	Tc	L	98.53	2865.288	4584.461
2	y = 3.2027x - 6.2701	ln(Tc)	ln(L)	4.590361	8.4314494	4589.147
3	y = 0.2745x^3.4461	Tc	B	15.2	3245.58911	3245.589
4	y = 1.5433x	Tc	B^3	3511.808	5419.77329	5419.773
5	y = 0.018x +0.185	Tc/(LBT)	B	15.2	0.4586	4258.315
7	y = 0.0141x^1.7095	Tc	LB	1497.656	3780.8204	3780.820
9	y = 3E-06X^2 + 0.319X	Tc	(LT)^1.5	15098.72442	5500.40753	5500.408
10	y = 8E-05x^4.7813	Tc	L/√T	39.57060024	3472.22437	3472.224
12	y = 0.6075x^2 - 30.058x	Tc	BT	94.24	4532.16506	4532.165
13	y =0 .5503x	Tc	(BT)^2	8881.1776	4887.31203	4887.312
14	y = 0.0785x - 0.056	Tc/(LBT)	B/√T	6.1044669	0.4232007	3929.616
18	y = 1.6413x - 0.4461	ln(Tc)	ln(P/v)	5.204385547	8.095858	3280.851
					MEAN **pTc** =**Tc_{opt}** =	**4290.06**

Table 2. EXCEL Computation for Prediction of Total Capacity pTc based on the above presented regression analysis formulas for Gas Carrier Ship "GASCHEM SHINANO".

Vessel Name/ IMO No GASCHEM SHINANO/ IMO 9269271		**L** 114.91	**B** 16.8	**D** 11.825	**T** 6.64	**C_B** 0.74
		Tc 6500	**P** 4400	**v** 16	**Dwt** 7413	
Eq. No.	**Formula**	**Y**	**x**	**x1**	**Y1**	**Tcp**
1	y = 0.001x^3.239	Tc	L	114.91	4715.188	7544.301
2	y = 3.2027x - 6.2701	ln(Tc)	ln(L)	4.7441492	8.9239867	7509.970
3	y = 0.2745x^3.4461	Tc	B	16.8	4582.2699	4582.270
4	y = 1.5433x	Tc	B^3	4741.632	7317.7607	7317.761
5	y = 0.018x +0.185	Tc/(LBT)	B	16.8	0.4874	6247.708
7	y = 0.0141x^1.7095	Tc	LB	1930.488	5835.3516	5835.352
9	y = 3E-06X^2 + 0.319X	Tc	(LT)^1.5	21076.0323	8055.8517	8055.852
11	y = 1.9634x - 3.4235	ln(Tc)	ln(LT.C_B)	6.33615608	9.0169088	8241.263
12	y = 0.6792x^2 - 80.767x	Tc	BT	111.552	6359.6676	6359.668
13	y =0 .5503x	Tc	(BT)^2	12443.8487	6847.8499	6847.850
14	y = 0.0785x - 0.056	Tc/(LBT)	B/√T	6.51966441	0.4557936	5842.563
16	y = 1.2472x - 2.5722	ln(Tc)	ln(LBT.C_B)	9.15753497	8.8490776	6967.959
18	y = 1.6413x - 0.4461	ln(Tc)	ln(P/v)	5.6167711	8.7727064	6455.620
					MEAN **pTc** = **Tc_{opt}** =	**6711.18**

Table 3 EXCEL Computaion for Prediction of Total Capacity pTc based on the above presented regression analysis formulas for Gas Carrier Ship "KESWICK".

Vessel Name/ IMO No KESWICK/ IMO 9267950		**L** 119.95	**B** 20	**D** 10	**T** 7.365	**C_B** 0.798
		Tc 11028.8	**P** 5970	**v** 15.9	**Dwt** 8692	
Eq. No.	**Formula**	**Y**	**x**	**x1**	**Y1**	**Tcp**
1	y = 0.001x^3.239	Tc	L	119.95	5418.534	8669.654
2	y = 3.2027x - 6.2701	ln(Tc)	ln(L)	4.787074989	9.061465068	8616.7656
3	y = 0.2745x^3.4461	Tc	B	20	8356.449959	8356.4500
4	y = 1.5433x	Tc	B^3	8000	12346.4	12346.4
5	y = 0.018x +0.185	Tc/(LBT)	B	20	0.545	9629.4061
7	y = 0.0141x^1.7095	Tc	LB	2399	8460.203733	8460.2037
9	y = 3E-06X^2 + 0.319X	Tc	(LT)^1.5	26257.87069	10444.68807	10444.6881
10	y = 8E-05x^4.7813	Tc	L/√T	44.19914585	5892.60535	5892.60535
11	y = 1.9634x - 3.4235	ln(Tc)	ln(LT.C_B)	6.558167358	9.45280579	12743.8718
12	y = 0.6792x^2 - 80.767x	Tc	BT	147.3	11115.97525	11115.9752
13	y =0 .5503x	Tc	(BT)^2	21697.29	11940.01869	11940.0187
14	y = 0.0785x - 0.056	Tc/(LBT)	B/√T	7.369594974	0.522513205	9232.0951
16	y = 1.2472x - 2.5722	ln(Tc)	ln(LBT.C_B)	9.553899631	9.34342362	11423.4509
18	y = 1.6413x - 0.4461	ln(Tc)	ln(P/v)	5.928183097	9.283826917	10762.5406
					MEAN **pTc** = **Tc_{opt}** =	**9973.87**

Table 4 EXCEL Computaion for Prediction of Total Capacity pTc based on the above presented regression analysis formulas for Gas Carrier Ship “ID: 11806 HORIZON SHIP BROKERS”.

Vessel Name/ IMO No ID 11806		**L** 125.8	**B** 22.7	**D** 13.1	**T** 6.77	**C_R**
		Tc 14174	**P** 6000	**v** 15	**Dwt** 9098.9	
Eq No.	**Formula**	**Y**	**x**	**x1**	**Y1**	**pTc**
1	y = 0.001x^3.239	Tc	L	125.8	6322.163	10115.46
2	y = 3.2027x - 6.2701	ln(Tc)	ln(L)	4.8346933	9.213972374	10036.386
3	y = 0.2745x^3.4461	Tc	B	22.7	12928.34864	12928.349
4	y = 1.5433x	Tc	B^3	11697.083	18052.10819	18052.108
5	y = 0.018x +0.185	Tc/(LBT)	B	22.7	0.5936	11475.961
7	y = 0.0141x^1.7095	Tc	LB	2855.66	11395.91947	11395.920
8	y = 0.1007x	Tc	(LB)^1.5	152601.832	15367.00448	15367.005
9	y = 3E-06X^2 + 0.319X	Tc	(LT)^1.5	24854.4390	9781.795448	9781.7954
12	y = 0.6792x^2 - 80.767x	Tc	BT	153.679	12104.11811	12104.118
13	y =0 .5503x	Tc	(BT)^2	23617.23504	12996.56444	12996.564
14	y = 0.0785x - 0.056	Tc/(LBT)	B/√T	8.72431872	0.628859019	12157.617
18	y = 1.6413x - 0.4461	ln(Tc)	ln(P/v)	5.99146455	9.387690761	11940.494
					MEAN **pTc** = **Tc_{opt}** =	**12107.83**

Table 5 EXCEL Computaion for Prediction of Total Capacity pTc based on the above presented regression analysis formulas for Gas Carrier Ship “GAS CAPRICON”.

Vessel Name/ IMO No GAS CAPRICON/ IMO:		**L** 230	**B** 36.64	**D** 20.8	**T** 10.79	**C_R**
		Tc 78934	**P** 12360	**v** 16.7	**Dwt** 49999	
EQ.	**Formula**	**Y**	**x**	**x1**	**Y1**	**pTc**
1	y = 0.0016x^3.239	Tc	L	230	71409.57421	71409.57
2	y = 3.2027x - 6.2701	ln(Tc)	ln(L)	5.438079309	11.1464366	69316.386
3	y = 0.2745x^3.4461	Tc	B	36.64	67311.50124	67311.501
4	y = 1.5433x	Tc	B^3	49188.81894	75913.10428	75913.104
5	y = 0.018x +0.185	Tc/(LBT)	B	36.64	0.84452	76791.771
6	y = 0.5613x + 5.3126	ln(Tc)	T	10.79	11.369027	86597.567
7	y = 0.0141x^1.7095	Tc	LB	8427.2	72472.74577	72472.746
8	y = 0.1007x	Tc	(LB)^1.5	773615.124	77903.04299	77903.043
9	y = 3E-06X^2 + 0.319X	Tc	(LT)^1.5	123630.0147	85291.11634	85291.116
10	y = 8E-05x^4.7813	Tc	L/√T	70.01919504	53165.09235	53165.092
12	y = 0.6792x^2 - 80.767x	Tc	BT	395.3456	80773.53863	80773.539
13	y =0 .5503x	Tc	(BT)^2	156298.1434	86010.86833	86010.868
14	y = 0.0785x - 0.056	Tc/(LBT)	B/√T	11.1543622	0.819617433	74527.394
15	y = 0.1048x	Tc	(BD)^2	580814.7005	60869.38062	60869.381
17	y = 1.9501x	Tc	Dwt	49999	97503.0499	97503.050
18	y = 1.6413x - 0.4461	ln(Tc)	ln(P/v)	6.606812012	10.39766055	32782.842
					MEAN **pTc** = **Tc_{opt}** =	**73039.93**

Table 6 EXCEL Computaion for Prediction of Total Capacity pTc based on the above presented regression analysis formulas for Gas Carrier Ship "Q-MAX, MOZAH".

Vessel Name/ IMO No		L	B	D	T	C_B
Q-MAX MOZAH/ IMO:		345	53.8	27	12.2	
		Tc	**P**	**v**	**Dwt**	
		266000	21770	19	130102	
Eq. No.	**Formula**	**Y**	**x**	**x1**	**Y1**	**Tcp**
1	y = 0.0016x^3.239	Tc	L	345	265531.4895	265531.490
2	y = 3.2027x - 6.2701	ln(Tc)	ln(L)	5.84354442	12.4450197	253982.261
3	y = 0.2745x^3.4461	Tc	B	53.8	252924.6449	252924.645
4	y = 1.5433x	Tc	B^3	155720.872	240324.0218	240324.022
5	y = 0.018x +0.185	Tc/(LBT)	B	53.8	1.1534	261180.740
6	y = 0.5613x + 5.3126	ln(Tc)	T	12.2	12.16046	191082.395
7	y = 0.0141x^1.7095	Tc	LB	18561	279507.3006	279507.301
8	y = 0.1007x	Tc	(LB)^1.5	2528727.643	254642.8737	254642.874
9	y = 3E-06X^2 + 0.319X	Tc	(LT)^1.5	273066.4779	310804.1104	310804.110
10	y = 8E-05x^4.7813	Tc	L/√T	98.77321267	275459.8439	275459.844
12	y = 0.6792x^2 - 80.767x	Tc	BT	656.36	223633.5492	223633.549
13	y =0 .5503x	Tc	(BT)^2	430808.4496	237073.8898	237073.890
14	y = 0.0785x - 0.056	Tc/(LBT)	B/√T	15.40289519	1.153127273	261118.9828
15	y = 0.1048x	Tc	(BD)^2	2110046.76	221132.9004	221132.9004
17	y = 1.9501x	Tc	Dwt	130102	253711.9102	253711.9102
18	y = 1.6413x - 0.4461	ln(Tc)	ln(P/v)	7.043849175	11.11496965	67169.1706
					MEAN **pTc** = **Tcopt** =	**240580.005**

Table 7 Comparison of PREDICTED TOTAL CAPACITY Tcoptand the actual volume of gas transportable by different sizes of Gas Carrier Ships.

s/n	Ship Name/IMO: Number	Loa	B	D	T	Tc	Tcopt
1	SHUHO/ imo: 9634878	59.37	10.8		3.861	855.4	1007.78
2	SENRYU MARU/IMO: 9309564	62.15	11		4.1	1176	1250.64
3	CORAL MONACTIC/IMO: 9373735	95.2	15.5	8	6.5	3937	4274.82
4	GAS PATRA 2/IMO: 9132821	94.99	16.24	6.8	4.2	3439	3759.12
5	GASCHEM DANUBEGAS/IMO:9176125	98.53	15.2	10	6.2	4345	4290.06
6	PLUMERIA CORAL/IMO: 9747065	99.98	17.2	7.8	6.1	5015.2	5299
7	GASCHEM SHINANO/IMO: 9269271	114.91	16.8	11.825	6.64	6500	6711.18
8	KESWICK/IMO: 9267950	119.95	20	10	7.365	11029	9973.87
9	GASCHEM ATLANTIC/IMO: 9371660	129	17.8	11.9	8.6	8516	9919.98
10	ID: 11806 HORIZON SHIPBROKERS	125.8	22.7	13.1	6.77	14174	12107.83
11	ELLINGTON/IMO: 9744922	159.99	24.8	16.7	9.4	21220	23029.02
12	GAS CAPRICON/IMO: 9255701	230	36.64	20.8	10.79	78934	73039.94
13	ID: 10374 HORIZON SHIPBROKERS	277	43	26	12	138000	129627.22
14	LNG ENUGU/IMO: 9266994	285.48	43.44	26	12.37	142988	143345.46
15	Q-MAX/IMO: 9337755	345	53.8	27	12.2	266000	240580.01

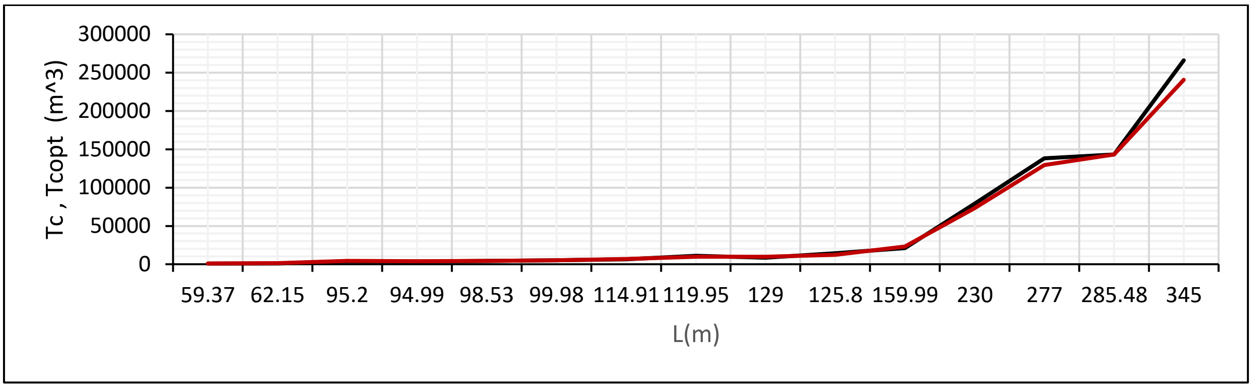


Fig. 19 comparison plot for Tc against Tcoptfor 15 existing gas carrier ships with respect to ships length L.

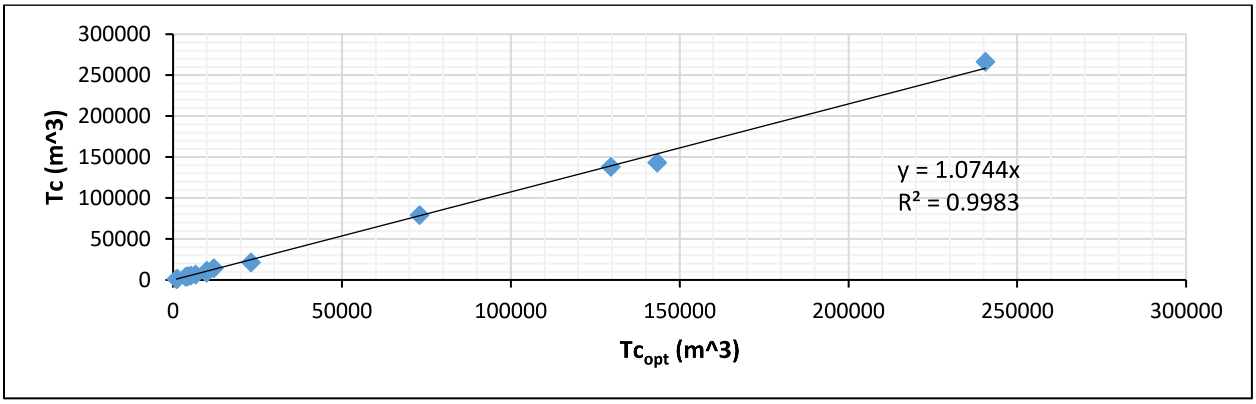


Fig. 20. Regression analysis relationship between Tc and Tcopt.