

Research Article

Discharging Part of LNG Liquid Cargo Handling Simulator

Zhen-Zhou Yang, Xian-Ku Zhang and Jing-Hua Cao

Laboratory of Marine Simulation and Control, Dalian Maritime University, Dalian Liaoning Province, 116026, China

Abstract: With the development of the national economy, it is important to develop LNG (Liquefied Natural Gas) liquid cargo handling simulator. In this paper, the discharging part of Liquid Cargo Handling Simulator of LNG Carriers is developed by Visual Basic. The system includes 5 major forms and 3 mathematical models such as cargo pump model, the pressure and temperature model of the LNG vapour in the cargo tank and the liquid level model. The system can complete the unloading task. The system has become a preliminary model of LNG liquid cargo handlings simulator training.

Keywords: LNG Ship, liquid cargo handling, simulator, unloading operation

INTRODUCTION

According to the latest report of the world energy, with the booming of the world economy, the request of energy is rapidly growing, and the request of natural gas is increasing even faster (BP Statistical Review of World Energy, 2012). Meanwhile China had put forward clearly that it would import much more LNG around the world. So China will need lots of LNG carriers and the crew of LNG carriers (SIGTTO, 2008).

While the LNG carriers as the high technology, high challenge and high value-added, have a very high demand for the crews. It is an urgent to train the crew for the LNG carriers (Zhiyong, 2012). In order to meet the requirement, Dalian Maritime University imports the Liquid cargo Handling Simulator of LNG Carriers from Kongsberg of Norway in 2009, and decides to digest and absorb it. At last, liquid cargo handling simulator can be developed with proprietary intellectual property rights (Guoqing *et al.*, 2012). The discharging simulation as one of the constituent part of Liquid Cargo Handling Simulator is also very important.

On the other hand the development of Liquid Cargo Handling Simulator meets the requirement of STCW (Maritime Safety Administration of the People's Republic of China, 2010).

Regulation I/12 of STCW Code, use of simulation.

The performance standards and other provisions set forth in section A-I/12 and such other requirements as are prescribed in part A of the STCW code for any certificate concerned shall be complied with in respect of:

- All mandatory simulator-based training
- Any assessment of competency required by part A

of the STCW Code which is carried out by means of a simulator; and

- Any demonstration, by means of a simulator, of continued proficiency required by part A of the STCW Code.

The discharge part of the simulator is an indispensable part of Liquid Cargo Handling Simulator, which meets with the mandatory requirement of the Convention. This paper aims at introducing the simulation of unloading operation of the LNG carriers.

INTERFACES DESIGN

The system is designed with Visual Basic, and it consist of 5 major forms and auxiliary forms which are used for logging in, managing system time, speeding up and calling models.

It is Cargo Tank in Fig. 1, Deck Line in Fig. 2, Manifolds in Fig. 3 Ship/Shore Connection in Fig. 4, and Shore Tank in Fig. 5.

The entire interface is referred to the Liquid Cargo Handling Simulator of Kongsberg of Norway (Steffen Harstad Jensen, 2008).

MODELING

Pressure and temperature model of LNG vapour :

When it begins to unload the LNG, the pressure of cargo tank would decrease. In order to maintain the pressure of cargo tank in the right range, it is necessary to supply LNG vapour to ship from the shore station. So it is imperative to build the pressure and temperature model of LNG vapour in the cargo tank.

Corresponding Author: Zhen-Zhou Yang, Laboratory of Marine Simulation and Control, Dalian Maritime University, Dalian Liaoning Province, 116026, China, Tel.: 13591357507

This work is licensed under a Creative Commons Attribution 4.0 International License (URL: <http://creativecommons.org/licenses/by/4.0/>).

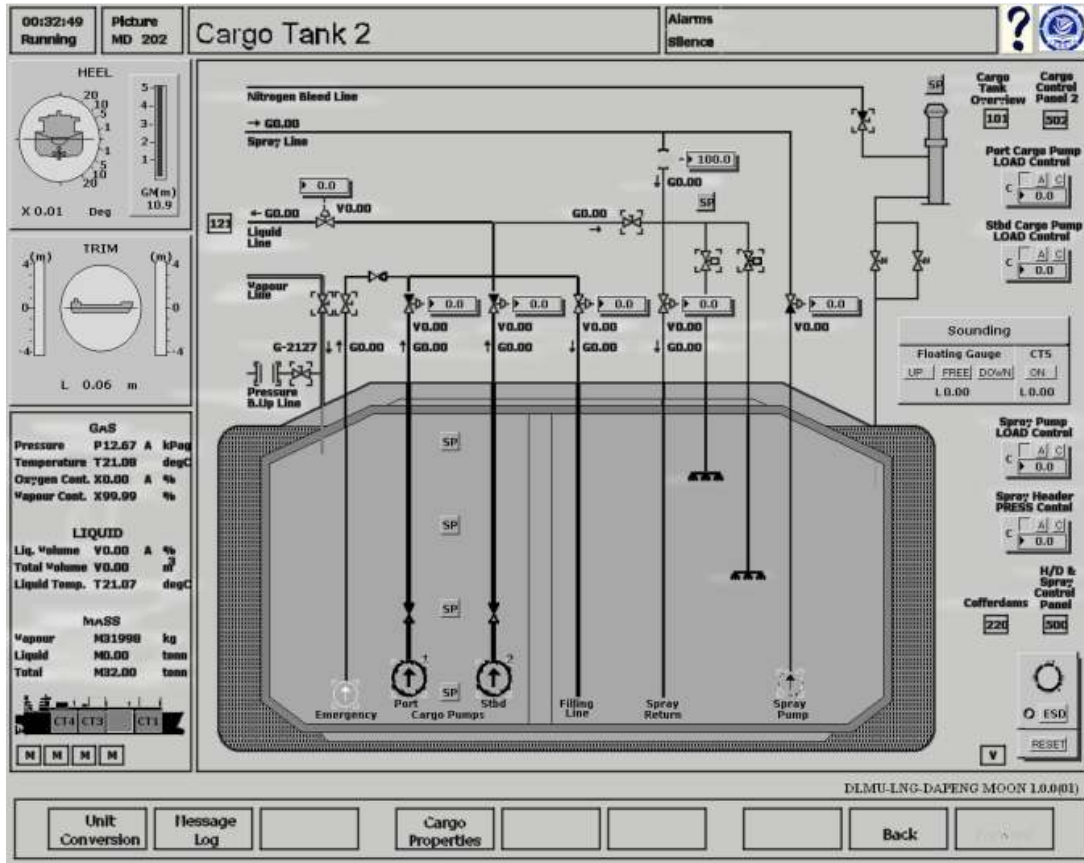


Fig. 1: Cargo tank

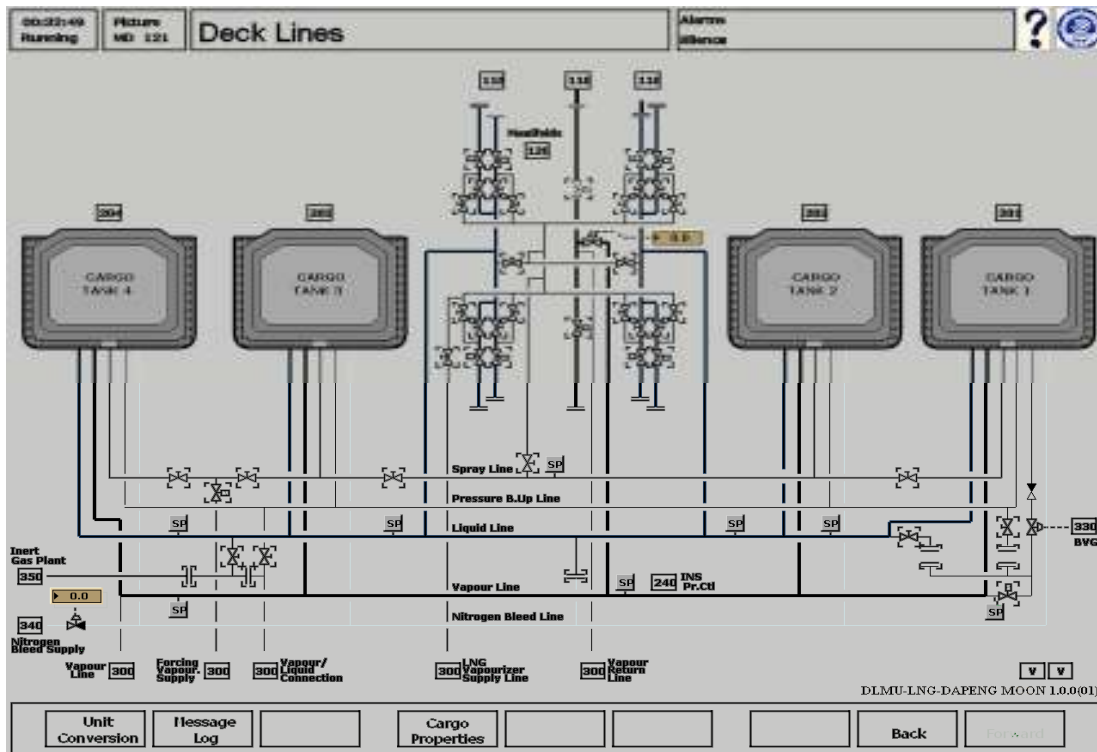


Fig. 2: Deck line

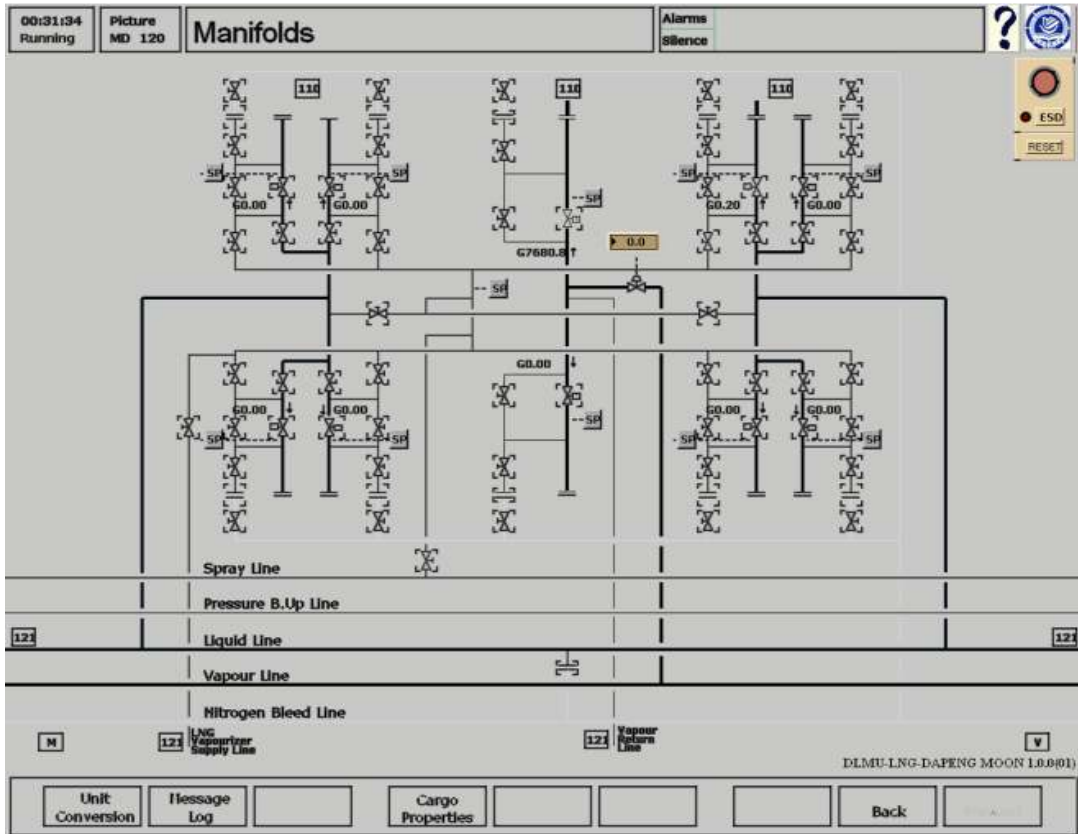


Fig. 3: Manifolds

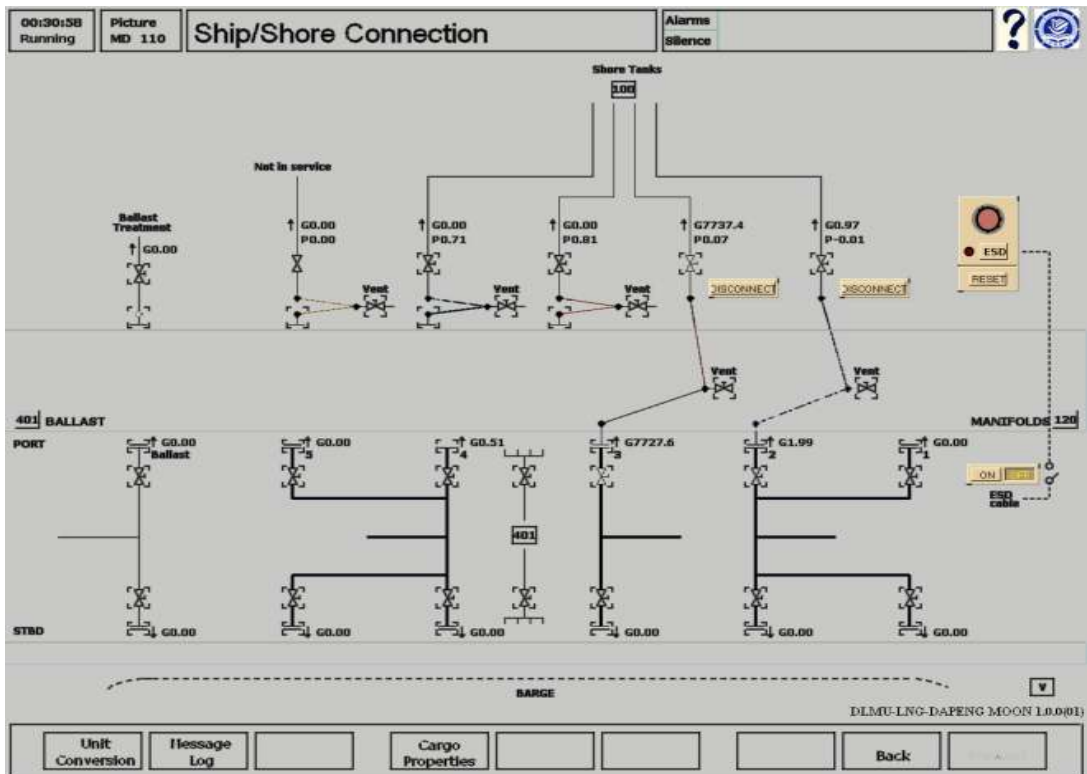


Fig. 4: Ship/shore connection

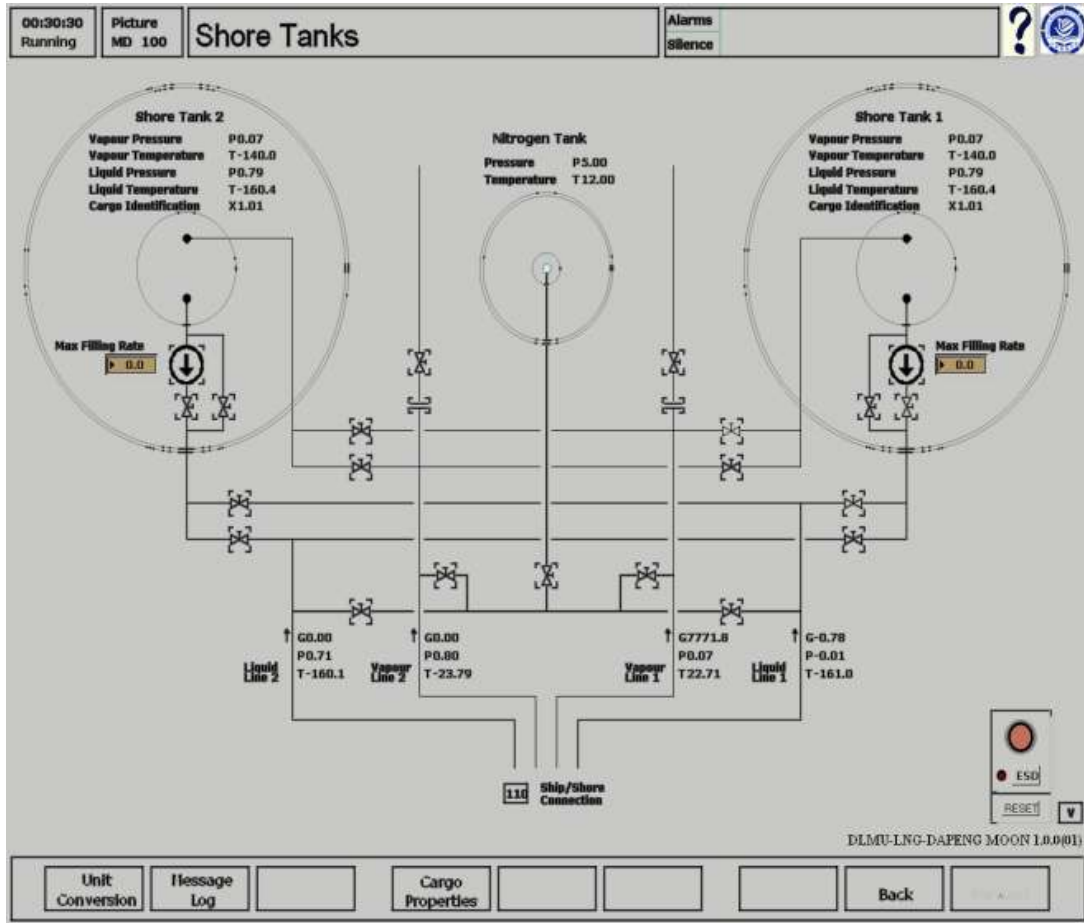


Fig. 5: Shore tank

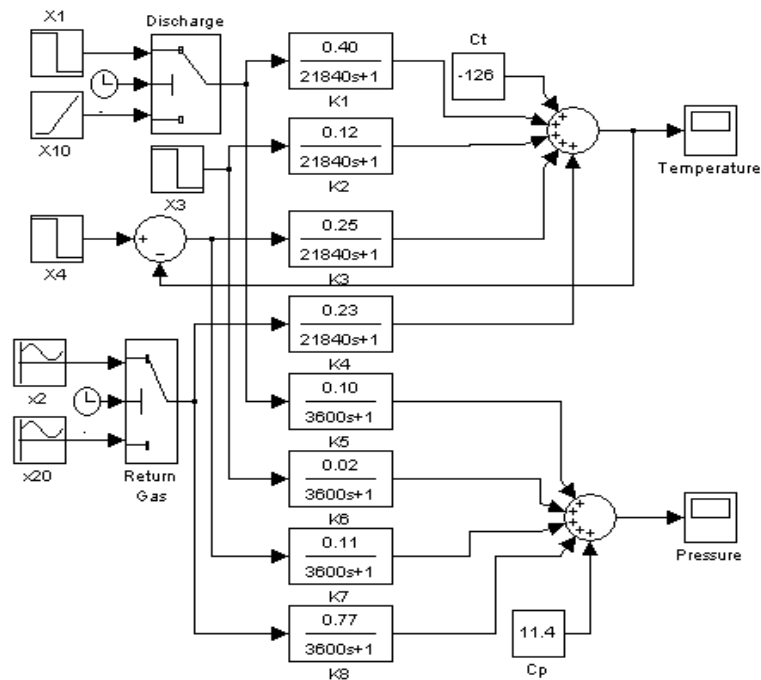


Fig. 6: The block diagram of the temperature and pressure of LNG vapour

In this study the responding model (Xianku *et al.*, 2008) was built. In the model, there are four inputs and two outputs. The four inputs are x_1 for the discharge rate, x_2 for the gas-return speed, x_3 for the temperature of return-gas, x_4 for the temperature of liquid cargo in the cargo tank. And the two outputs are y_T for the temperature of LNG vapour, y_P for the pressure of LNG vapour in the cargo tank. The model is built according to one of the unloading process.

At the beginning, the temperature of LNG vapour is -126.45°C , the pressure is 11.4kPa (G); at the end, the temperature is -158.74°C , the pressure is 12.8kPa (G). And the whole process is lasting about 18 hours (CLSICO, 2008). So the formula of transfer function is as follows:

$$\begin{bmatrix} y_T \\ y_P \end{bmatrix} = \begin{bmatrix} \frac{K_1}{T_1s+1} & \frac{K_2}{T_2s+1} & \frac{K_3}{T_3s+1} & \frac{K_4}{T_4s+1} \\ \frac{K_5}{T_5s+1} & \frac{K_6}{T_6s+1} & \frac{K_7}{T_7s+1} & \frac{K_8}{T_8s+1} \end{bmatrix} \begin{bmatrix} x_1 \\ x_2 \\ x_3 \\ x_4 \end{bmatrix} + \begin{bmatrix} C_T \\ C_P \end{bmatrix} \quad (1)$$

In the formula (1) $K_1 + K_2 + K_3 + K_4 = 1$, $K_5 + K_6 + K_7 + K_8 = 1$; in the system the temperature would decrease as the proceeding of unloading, until completing. So here takes $T_1 = T_2 = T_3 = T_4 = T_T$, the value is about one thirds of the unloading time; while the pressure is different, it shakes during the unloading process. The accommodation time is relative short, here takes it as 3 hours, so $T_5 + T_6 + T_7 + T_8 = T_P$; C_T ; and C_P is the initial value, in order to make the desperation and pressure reach the expectation effect. And the formula of transfer function comes as follows:

$$\begin{bmatrix} y_{T_0} \\ y_{P_0} \end{bmatrix} = \begin{bmatrix} y_T - C_T \\ y_P - C_P \end{bmatrix} = \begin{bmatrix} \frac{K_1}{T_1s+1} & \frac{K_2}{T_2s+1} & \frac{K_3}{T_3s+1} & \frac{K_4}{T_4s+1} \\ \frac{K_5}{T_5s+1} & \frac{K_6}{T_6s+1} & \frac{K_7}{T_7s+1} & \frac{K_8}{T_8s+1} \end{bmatrix} \begin{bmatrix} x_1 \\ x_2 \\ x_3 \\ x_4 \end{bmatrix} \quad (2)$$

In order to make sure the model is correct, the Simulink boxes of MATLAB are used for simulation. In Fig. 6, the simulation block diagram is as follows:

The result of the simulation is shown as follows:

According to the result of simulation, the temperature shown in Fig. 7 is decreased during the discharge period, and at last it is close to the temperature of return-gas. While the pressure shown in Fig. 8 is falling down quickly with relative less return-gas at the beginning, it will back to the normal level (between 8 to 10 kPa) with the flow of return-gas increased.

The liquid level model: The shape of cargo tank of Dapeng Sun is octagon, which is the top and bottom side relative narrow and the middle is relative wide, which is shown in Fig. 9.

The included angle of each adjacent edge is 135° . Suppose the height of top and bottom to the middle is h_1 and h_2 , the height of middle is h_0 ; the wide of top is

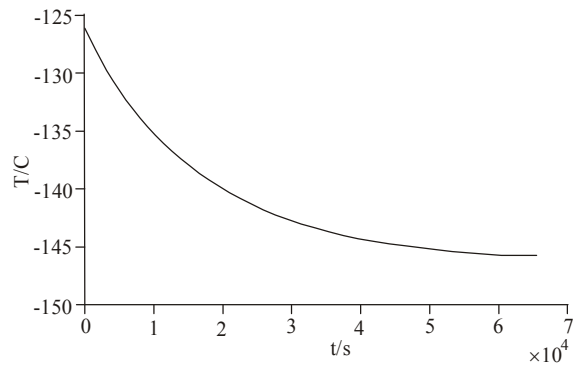


Fig. 7: The temperature variation curve of LNG vapour in cargo tank

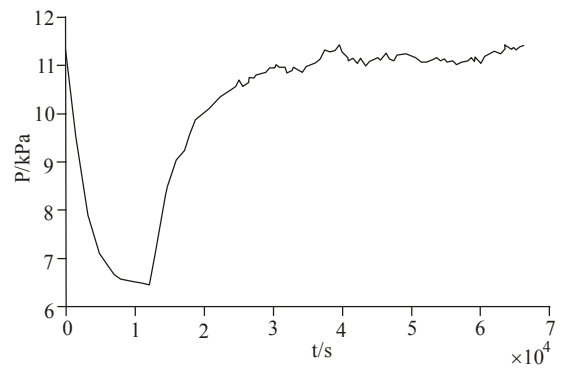


Fig. 8: The pressure variation curve of LNG vapour in cargo tank

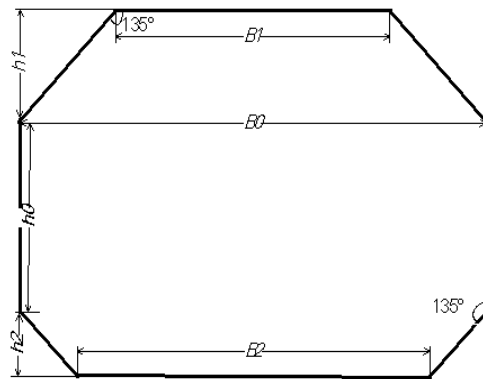


Fig. 9: The shape of cargo tank

B_1 , the wide of bottom is B_2 , the wide of middle is B_0 ; h is the total height of cargo tank, L is the length of cargo tank. The particular of each cargo tank is shown Table 1.

According to Table 1, the liquid level model can be built as the formula (3).

$$\begin{cases} V_{LNG} = V_{LNG_0} + \int_0^t Q dt \\ h = f_{non}(V_{LNG}) \end{cases} \quad (3)$$

Table 1: Particular of cargo tank of dapeng sun. (Unit: m) (CLSICO, 2008)

Tank No.	h	L	B ₁	B ₂	B ₀
No.1	26.40	35.63	16.80	21.40	27.50
No.2	26.47	46.60	23.75	29.40	35.50
No.3	26.47	46.60	23.75	29.40	35.50
No.4	26.47	43.79	23.75	29.40	35.50

Tank No.	h ₁	h ₂	h ₀	Volume (m ³)
No.1	5.35	3.05	18.00	24516.112
No.2	5.88	3.05	17.55	41747.396
No.3	5.88	3.05	17.55	41747.396
No.4	5.88	3.05	17.55	39260.010

Table 2: Particular of main cargo pump

Liquid Cargo	LNG(Density:469Kg/m ³)
Capacity	Rated at 1,500m ³ /h
Head	140mth
Power required	363kW(rated)
Efficiency	88.45%
Motor Speed	1,800rpm

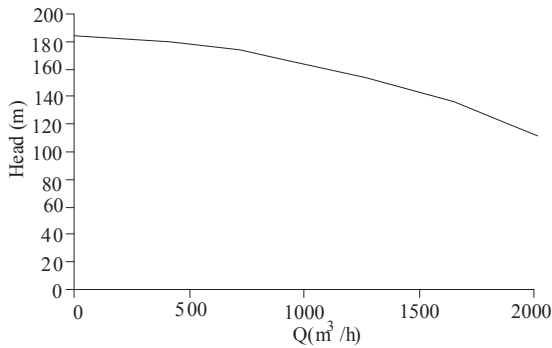


Fig. 10: The cargo pump const speed characteristic curve

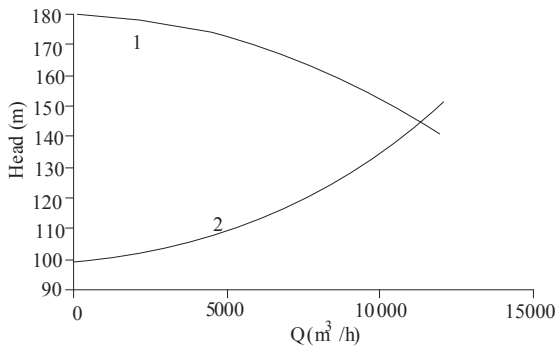


Fig. 11: H-Q characteristic curve of 8 cargo pump in parallel

In the formula, Q represents the discharge flow in unit time; V_{LNG_0} represents volume before discharge, V_{LNG_1} represents volume after discharge.

The cargo pump model: The cargo pump of Dapeng Sun is designed by Ebara International Corporation, its type is 12EC-24, fixed vertical. (CLSICO, 2008).

Table 2 is the particular of cargo pump in Dapeng Sun ship. In Fig. 10, the cargo pump const speed characteristic curve is shown.

According to the constitution mechanism, the formula of cargo pump const speed characteristic curve

is a quadratic polynomial (Qian, 2008). So when building the model of cargo pump, the fitting of a polynomial can be introduced. The formula can be expressed as follows:

$$H = a_1 Q^2 + a_2 Q + a_3 \quad (4)$$

In the formula, Q is the flow of cargo pump, H is the head of cargo pump. The coefficient of the formula is $a_1 = -1.6308 \times 10^{-5}$, $a_2 = -1.7001 \times 10^{-5}$, $a_3 = -179.243$.

In order to make the cargo pump work well, the pipeline characteristic curve should also be built. According to the actual operation condition point analysis of the cargo pump, the formula of pipeline characteristic can be obtained (Changzhen, 2008).

$$H_{\text{pipe}} = 100 + 0.0000225 Q^2 \quad (5)$$

In the formula (5), H_{pipe} represents the resistance of the pipeline.

While there are 8 cargo pumps in the LNG carriers, when they work together, the head of the cargo pump and the resistance of pipeline will be changed, as shown in Fig. 11.

In the Fig. 11, the first curve is the cargo pump characteristic curve, and the second curve is the pipeline characteristic curve. The value of the curves will follow as the formula (6).

$$H_z = a_1 \left(\frac{Q_z}{8}\right)^2 + a_2 \frac{Q_z}{8} + a_3 \quad (6)$$

$$H_{\text{pipe}} = 100 + 0.000000351 Q^2$$

In the formula (6) the value of a_1, a_2, a_3 is the same as formula (4).

DESIGN OF THE PROGRAM

The program flow chart: The program is designed and developed with Visual Basic. First, the unloading process of LNG carrier should be well understood, then the flow chart of program should be drawn (Yong, 2011).

In Fig. 12, the program flow chart is drawn, which is useful to project and programme (Steffen Harstad Jensen, 2008; CLSICO, 2008).

In order to make the programming more clearly, more flow charts need to be drawn at the same time, which is the process of cargo tank unloading, cargo tank pressure controlling and cargo tank liquid level monitoring.

In Fig. 13, the calling procedure of multi-model of cargo tank is shown, which can ensure the program work better.

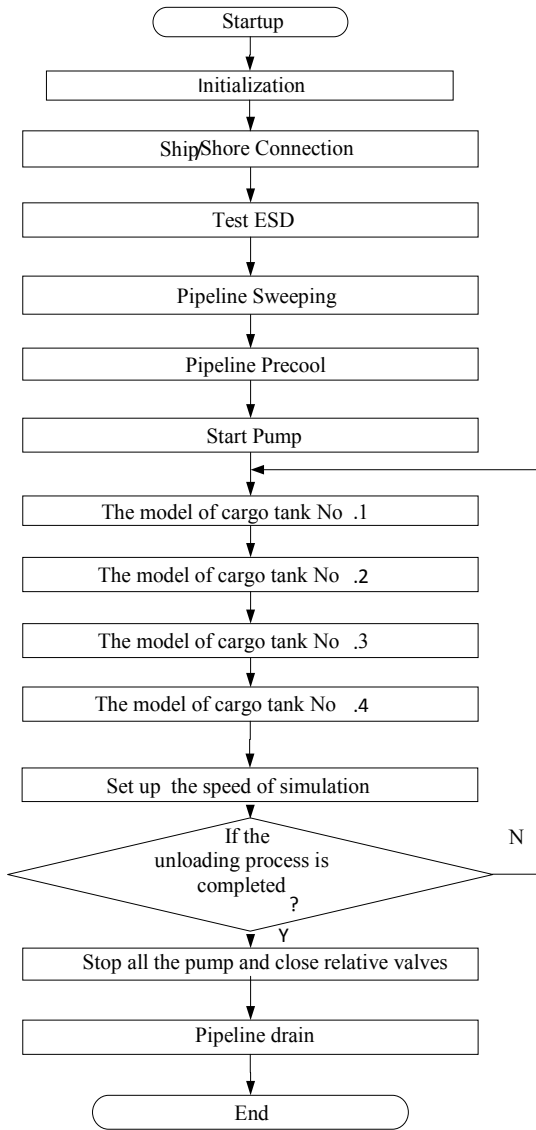


Fig. 12: Diagram flow chart of the unloading operation of LNG carrier

The working principle of cargo tank pressure control system is shown in Fig. 14. In the process of unloading, the pressure of cargo tank should maintain between 8 to 10 kPa, and when the pressure is less than 6.5kPa, the ship must inform the shore station to increase the rate of return gas which means calling gas- return model 2 in Fig. 14 (Steffen Harstad Jensen, 2008; CLSICO, 2008).

Figure 15 shows how the program monitors the cargo tank level. During the process of unloading, the crew must pay attention to the liquid level. According to the different liquid level, the trainer should take appropriate measures. If the trainers don't take the right measures, the system will sound alarm shown as in Fig. 15.

In order to make the program perfect, several other operations will be needed, such as the process of

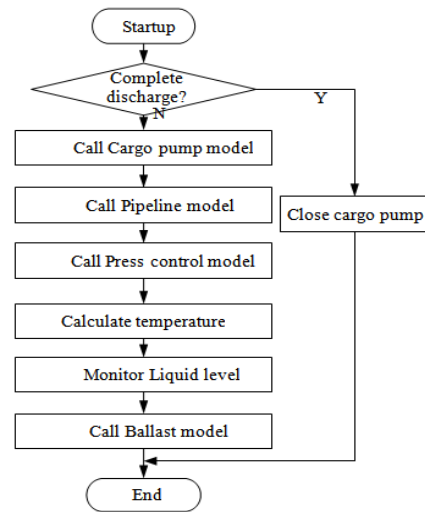


Fig. 13: Flow chart of cargo tank unloading

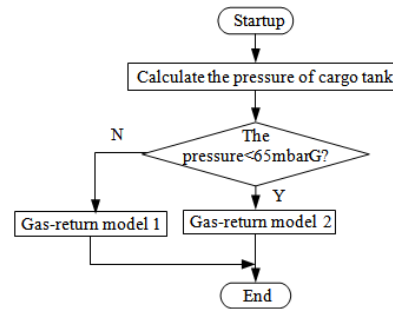


Fig. 14: Flow chart of cargo tank pressure control system

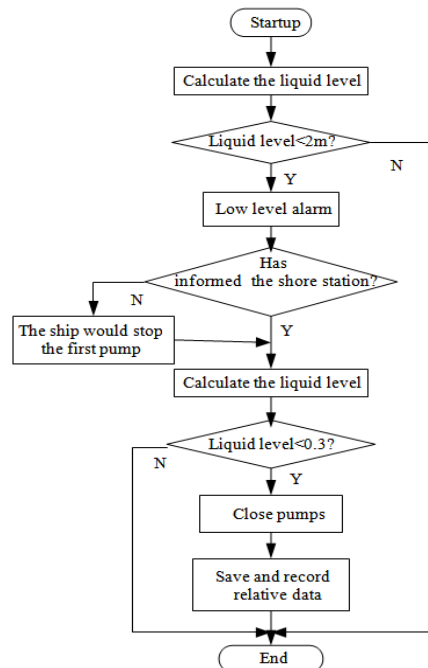


Fig. 15: Flow chart of cargo tank liquid level monitor system

pipeline pre-cool and the cargo pump start-up. Due to the limit of space, they will not be shown in this study.

The detail of program: In order to make the program more artistic and practical, the designer has done plenty of work.

In the program, there are at least 4 modules that are the system time management module which is used to keep the time synchronization, the cargo tank module which is used for calling the models of cargo tank, the pipeline module which is used for calling and managing the model of pipeline, and some other modules which can help make the interface more artistic. There are 10 custom components used in the program, which is in favor of programming and can make the interface more user-friendly.

RESULTS

In this study, the LNG liquid cargo operation simulator is introduced. The interface is designed as Fig. 1-5, and the program is developed in according with the several flow diagrams from Fig. 12-15, and the three models is added. At last, the discharge simulation as an integral part of the simulator is realize, which can complete the LNG discharge task and work well. The program can help the trainers be familiar with the process of LNG discharging.

CONCLUSION

According to the introduce of discharge simulation on the interface design, models building and programming realization, this paper can help realize the liquid cargo handling simulator of LNG carriers. Combining with the evaluation system of that (Hongqian, 2012), the Liquid Cargo Handling Simulator of LNG Carriers will be achieved in the future.

While there are still some problems which must be solved in the later study, such as replace the responding models with the mechanism models. Beside the unloading part, there are some other simulation modules need to be developed. They are the loading, insulation space inerting, CT(Cargo tank) drying, CT inerting, CT gassing up, CT cooling-down, laden voyage, ballast voyage, stripping, CT warm-up, CT inerting, CT aeration (Junquan, 2003; Guanfang, 2007; Jianjun, 2008).

ACKNOWLEDGMENT

The author thanks the anonymous reviewers for their valuable remarks and comments. This work is

supported by National Science Fund of China (Grant No. 10BGL028), National Natural Science Fund of China (Grant No.50979009), the Programme of Introducing Talents of Discipline to Universities (Grant No. B08046), and the Fundamental Research Funds for the Central Universities (Grant No. 2011QN093).

REFERENCES

- BP Statistical Review of World Energy, 2012.
- Changzhen, W., 2008. Analysis for Cargo Handling Pipeline of LNG Carrier. Shanghai Jiao Tong University, Shanghai.
- CLSICO, 2008. Dapeng Moon Cargo Operating Manual.
- Guanfang, Z., 2007. Simulation Study of Liquid Cargo Handling System of LNG Carriers. Dalian Maritime University, Dalian.
- Guoqing, Z., Z. Xianku and J. Yicheng, 2012. Overview of liquid cargo handling simulator of LNG carriers. *Navigat. China*, 35(1): 41-46.
- Hongqian, H, 2012. The Evaluation System of LNG Liquid Cargo Operations Simulator Training. Dalian Maritime University, Dalian.
- Jianjun, Y., 2008. Simulation Study on the Main Liquefied Cargo System of LNG Carrier. Dalian Maritime University, Dalian.
- Junquan, H., 2013. Simulation Study on the Liquid Cargo System of LNG Carriers. Dalian Maritime University, Dalian.
- Maritime Safety Administration of the People's Republic of China, 2010. The Manila Amendments to the International Convention on Standards of Training: Certification and Watch keeping for Seafarers, 1978. Dalian Maritime University, Dalian.
- Qian, F., 2008. Marine Auxiliary. 3rd Edn., Dalian Maritime University, Dalian.
- SIGTTO, 2008. LNG Shipping Knowledge: Underpinning Knowledge to the SIGTTO 2005 Standards. Seamanship International, Livingston, ISBN: 1905331193.
- Steffen Harstad Jensen, 2008. Neptune CHS LNG-M User Manual.
- Xianku, Z., J. Yicheng and Y. Yong, 2008. Simulation of ballast water system in the navigation simulator for semi-submersible heavy lift vessels. *Navigat. China*, 31(3): 230-235.
- Yong, Q., 2011. Submerging and Surfacing Simulation and Computer-aided Control System of a Semi-Submersible Vessel. Dalian Maritime University, Dalian.
- Zhiyong, L., 2012. The Risk Assessment and Consequences Forecasting Study of LNG Carriers and Dock. Dalian Maritime University, Dalian.