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Review on Development of Ice-Ship Going

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ABSTRACT

In the early stage, sailing by ships at North and Artic Seas should be able to break ice which is commonly called as ice-breakers. Dimensions of the ice breakers were not big enough to be used as a cargo or large carrier. As the demand to merchant ships has been increased, the development technologies on hull form design and propulsion system for ice-going ship have been improved gradually. This paper discussed historical ice going ships, the development of ships in ice such as ice breaker, double acting ship and offshore floating by taken two parameters into account which is hull form design and propulsion system.

KEY WORDS: *Ship in Ice, Double Acting Ship, Podded Propulsion.*

NOMENCLATURE

DAS	Double Acting Ship
NSR	Northern Sea Route

1.0 INTRODUCTION

Developments of oil and gas exploration have been significantly progress that is supported by advanced technology and exploration for new sources oil and gas field. The exploration of oil and gas for open water conditions was moved to the deep sea. A positive growth also occurred in area of the North Pole or the Arctic and beyond. A few things need to be a concern due to the sea ice operational environment in the Artic that will be given a different effect of vessels operating in these environments.

The increasing of shipping activities through, the Northern Sea Route (NSR) and growth of oil and gas activities in Arctic and Sub-Artic regions required suitable design of ice-going ships and planning operations in ice. The characteristic of ice should be noted depends on locations of ice, form of ice level, ice ridges and icebergs. Figure.1 shows the typical geographical regions where the ice actions are of current concern [Gürtner].

Figure 1: Location of ice actions [Gürtner].

2.0 HISTORICAL ICE GOING SHIPS

2.1 Mechanism Failure on Ice

To travelled an Arctic region, the ship must be have capability to break ice and it has existed until now is type of ice breaker. Fore part of the ship has a shape unlikely ordinary ships sailing in open water, where stern angle of ice breaker was acute angle and have a function to break ice. However, dimensions of this ship is inadequate so it does not support if was used as transportation in merchant ship.

In actual practice, merchant ships or any large vessels will be escorted by ice breaker. Ice breaker will be function to make track in advanced position. Furthermore, channel had formed after ice breaker passing will be used by large vessel for sailing. This procedure has still been used on present day even though not economic because be needed additional charge for escorted by ice breaker.

Mechanical properties of ice like flexural strength must be investigated so the ship which was going to pass has enough thrust to crush it. Sodhi (2001) had done small-scale indentation test to prove phenomena breaking at the ice structure interaction by using non-simultaneous formula for brittle crushing and simultaneous formula for ductile crushing. The experiment concluded during low rate ice would be failure ductile but on the high rate brittle. On the other case through medium scale indentation test, Sodhi et al. (1998) had been confirmed same summary in regard to transition fracture properties of ice from ductile to brittle when strain rate increased.

Daley et al. (1998) declared failure on ice would be happened continuum gradually and that was called discrete process from naturally to chaotic. It was concluded after modelled ice as nested hierarchy of discrete. In discrete process, it was formed under plastic deformation. Failure process would start from micro crack and growth up along of grain boundary to macro crack. That had made desegregation at the edge of ice. This model was tested using medium scale indentation. It can be seen in experimental result, there are occurrence creeps on ice following by micro crack at the low velocity and it is dominated flaking by macro crack on the high velocity.

Sawamura et al. (2008) assume ice an infinite at edge and semi-infinite at centre line, homogeneous and floating material on simple hydrodynamic fluid with negligible viscosity. Model was made on finite element software Abaqus in 2D and 3D. Penalty contact algorithm is used to describe frictionless contact in tangential component between fluid and structure. It can be seen from simulation effect of wedge angle at maximum stress and point of hot spot stress. Result shown shape of the broken ice changed from circle to elliptical when angle of wedge increased. Some complex of breaking pattern had been resulted in indentation mode that must be a considered to find out interaction between ship and broken-unbroken ice float. Overall, can be resumed pressure load on ice is function of density and modulus bulk of water.

2.2 Simulation and Experiment on Ice Going Ships

Some researchers have developed and carried out simulation and experiment on ships while operating in ice and open water environment. Stephen, 2004 has report in his paper as follows: Runeberg (1888) has published the first scientific paper on icebreakers with particular reference to the Baltic. Kari (1921) gave some empirical equations for determining the required power, displacement, length, and draught of an icebreaking, Simonson (1936) recognize the importance of the strength of the ice and, referring to some experiments at the University of Illinois. Shimanskii (1938) has employed a semi-empirical method for investigating continuous mode icebreaking resistance. Johnson (1946) described the U.S. Coast Guard's icebreaking vessels and experience in considerable detail. Vinogradov (1946) described some of the Russian experience as well as giving an equation for the downward icebreaking force developed. Kashteljan et al. (1968) are usually credited with the first detailed attempt to analyze level ice resistance by breaking it down into components which are resistance due to breaking the ice, resistance due to forces connected with weight (i.e. submersion of broken ice, turning of broken ice, change of position of icebreaker, and dry friction resistance), resistance due to passage through broken ice and water friction and wavemaking resistance. Virtanen et al., 1975) investigated the effect of draft and found no effect on resistance, within the errors of their experiment. Edwards et al. (1972) conducted an extensive set of full-scale and model-scale tests on a Great Lakes icebreaker, the USCGC Mackinaw. Milano (1973) made a significant advance in the purely theoretical prediction of ship performance in ice. He considered the energy needed for a ship to move through level ice, which varied somewhat with ice thickness.

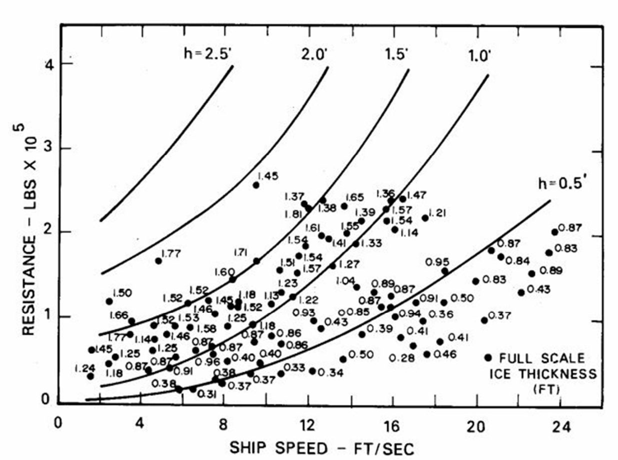


Figure 2: Full-scale tests of ship resistance versus speed for USCGC Mackinaw as a function of ice thickness (Milano, 1973).

Kitagawa et al., (1982, 1983, 1986) investigated the effect of parallel mid-body length, and beam, on an Arctic tanker model.

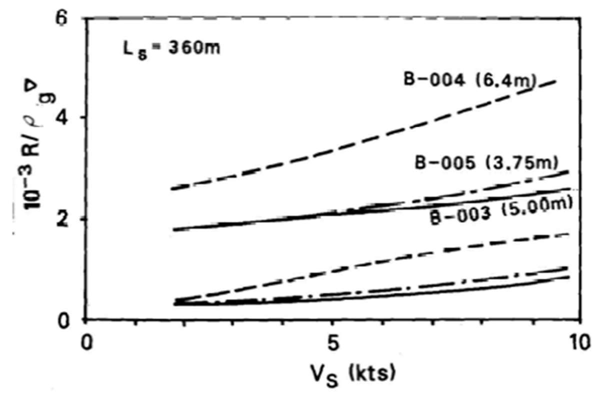


Figure 3: Resistance per unit displacement for three Arctic tanker models of different lengths as shown, scaled-up to a ship of length 360 m (Kitagawa et al., 1982).

Vance (1980) and Vance et al. (1981) conducted full-scale tests of the 140 ft (43 m) Great Lakes icebreaker, Katmai Bay. He analysed his results somewhat differently from other workers, plotting Propulsive Coefficient (PC) against velocity.

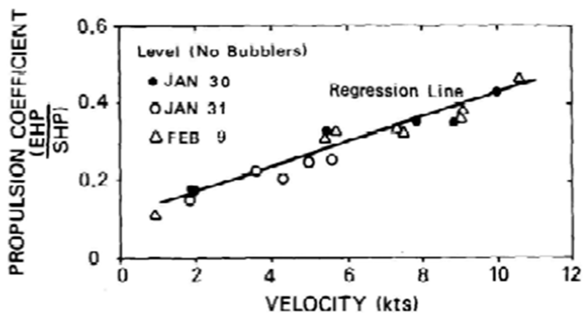


Figure 4: PC versus velocity for Katmai Bay in level ice with no bubblers operating. Clearwater value, not shown, was 0.565 (Vance, 1980).

Lindqvist (1989) had done test on full scale using different ship at the Baltic Sea to verify effect of some parameters such as dimension of ship, hull shape, ice thickness, flexural strength of ice and friction working load when ship interacted on ice. It can be known from experiment that ice crush due to bending load after vertical force applied during ship moving forward. From underwater observation revealed not merely crushing and bending, submersion ice at the below of hull generated large friction load as a resistance on ship.

Soininen (1998) combined simulation and experimental to define relation between thrust, torque and another aspect of propeller of ship performance. These methods can observe ice spall and extrusion phenomena at propeller blade. Suppression of propeller blade can make crack in contact area when interact in ice these followed by flaking. It was difficult to ensure pressure distribution at blade but not for simulation. Conduct some modified at geometric shape, simulation could predict pressure distribution and bending moment at blade as function of angle of attack.

Juurma *et al*. (2001) had reported full scale experiment result on double acting ship SUMITOMO which had first been built while running ahead in open water and astern in ice condition. Ice breaking capability of ship was shown in Figure 11 in graph form which described velocity of ship related to ice thickness.

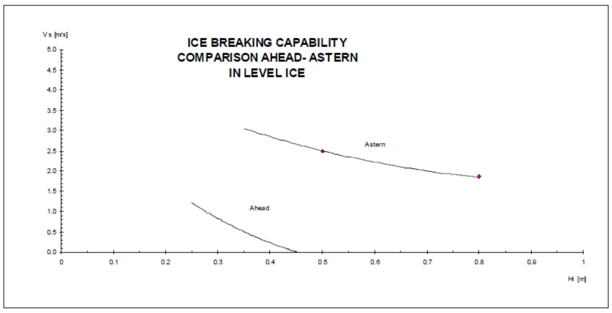


Figure 11: Ice breaking capability of DAT (Juurma *et al*. 2001).

Juurmaa *et al.* (2002) made a model by scaling referred to Aframax, a tanker vessel with specification: 16 MW of power system, 106000 DWT of weight and using azimuth for propulsion system. Model was running ahead in open water test and astern on consolidated, unconsolidated, rubble field and ridge ice condition and made some modification on bow shape and stern part. Model test confirmed to fulfill 1A super class vessel on Finnish-Swedish Ice Rules for operated in channel ice and result test was verified using CFD simulation program.

Wilkman and Juurmaa (2002) have tried to apply three concepts basis design and have been compared with functional approach every of typical constant value for geological, typical variable value for weather and ice, and typical changing value for environment. Design concept was applied in ice breaker and independent tanker where operated at Pechora Sea–Murmansk–Rotterdam company with Russian Maritime Register regulation. Result indicated when conventional vessel got assistance by icebreaker there to be needed 11% surcharge compared independent vessel.

Chen and Lee (2003) had been investigated through simulation using Chimera concept on RANS. Some propeller configuration was observed when ship moving ahead at open water, back of and crash-astern. This method chose to find flow pattern at propeller whilst distribution load at propeller was determined using MPUF3A software. Azimuth system propulsion which was used series-60 with coefficient hull (Cb) 0.6 became review on this study. Prediction result for thrust and torque of this program apparently was quite accurate and accordance to experimental data. It also concluded that container vessel can be operated astern without stuck on ice harsh environment.

Wilkman *et al*. (2003) made another experiment test in full scale on double acting tanker Tempera and Mastera where traveling from Porvoo-Primorsk and return Porvoo. Figure 12 shows speed of vessel related to ice thickness. It confirmed tankers can take easy to reach speed 3 m/s – 4 m/s for traveling on 0.6 m - 0.8 m ice thickness.

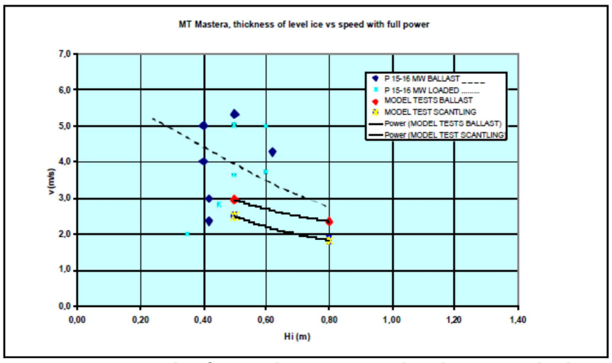


Figure 12: Speed of vessel Mastera related to ice thickness (Wilkman *et al*. 2003)

Jaswar (2005) had reported result after making modification of stern shape and stern angle while compare with existing hull of DAT Tempera. Analysis was done focus on ice resistance and hull form for operated in open water and ice condition. The result showed modification stern shape and hull form has given lower ice resistance when sailing in unfrozen, frozen channels for full load and ballast situation.

Wilkman *et al.* (2005) reported result from experiment on full scale of ice breaking tanker MT Uikku while sailing astern using continuous speed. The vessel operated at Bay of Bothnia, Northern Baltic seas in condition 10m thickness ice rubble. It was concluded ice resistance had reduced 14% comparing if vessel was running ahead at the same condition, as depicted in Figure 13.

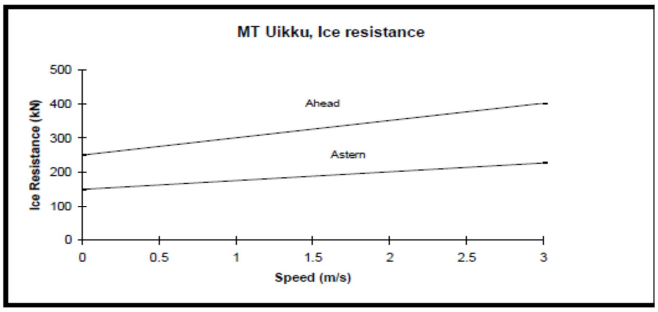


Figure 13: Ice resistance on ice breaking tanker MT Uikku (Wilkman *et al*. 2005)

Matsuzawa et al (2006) were made ice in setup experiment, his concluded that load in the aft-ship region increases with increasing lateral force of the pods while using twin podded propulsion.

Lee (2006) had developed simulation through finite element using vortex-lattice method to find out performance of ship traveling on ice. Finish Swedish Ice Class Rule (FSICR) has published regulation as hint to be followed by ship which sailing at Baltic seas such as strengthened of hull and running in 5 knots. Those concept was verified through ship model scale referred to merchant vessel Aframax. Simulation model concluded, thickness of propeller blade must be added 12% to protect from cavitation failure and recommendation from experiment mentioned thrusting power of ship must be increased 32% while those were load of ice resistance 1800 kN.

Hänninen *et al.* (2007) had derived ice working load and relation between thrust, torque of propeller when ship structure-ice interaction because there were no Mathematics model reliable to predict ice load on pod propulsion system conjunction with model scale and full scale. Experimental data was collected using strain gauge on container vessel MV Norilskiy Niclkel while running with Azipod system. The ship classified into double acting type with power 13 MW operated route from Murmansk to Dudinka and designed to meet requirement of LU7 Russian Register for Arctic ice.

Islam *et al.* (2007) had published article concerning to numerical prediction and experimental result while investigation effect of hub taper angle, pod-strut configuration, azimuth statics condition, pod-strut interaction, gap pressure and pod-strut geometric on performance of pod propulsion system. Experiment had been done on puller and pusher propeller configuration in open water situation. Observation focused on pod diameter, pod length, pod taper length, strut distance and effect of hub propeller angle. Coefficient thrust and torque can be reached higher if propeller was function in puller.

Pivano *et al.* (2007) had been created some scheme to estimate thrust and torque especially if propeller being operated in extreme environment. Experimental study base on nonlinear was approach to get closed extreme situation on the ocean. This was done because difficult to make propeller and ship model on dynamic situation and having trouble to measure behaviour of environment. From this concept can be understood where on nonlinear approach thrust and torque have a piecewise relation in linear part.

In the medium scale test Moslet (2008) observe ice-structure interaction with pulling ice floe and hit a fixed cylindrical structure. Other researchers like Wang et al (2008) using commercial code DYTRAN in finite element analysis to investigate non-linear collision model on LNG ship and crushable ice. Taylor et al (2010) develop a normalized curve method to find a local pressure in hull as a structure in ice behavior. He also develops another method by collaborate research with Li et al (2010) use up-crossing rate method.

Lubbad and Løset (2011) had developed complex system on simulator to describe breaking length of ice and speed of ice floe against conical structure where chosen physx graphics to display result of structure-ice interaction. Real time criterion was completed using elastic foundation for floes and analytic solution for maximum ice stress conducted in numerical modelling, Comsol Multyphysics. Ice was modelled as semi-infinite resting plate subjected by gravitational, buoyancy, damping and contact force. After interaction some crack in ice would initiate and propagate until reach failure criteria beyond flexural strength of ice. The broken pieces of ice were called cusps or wedges.

Choi et al. (2012) had reported some working load on ice after using impact testing method and verified result using equation issued by DNV and IACS Polar class rule. These article described variant of buttock angle 20°, 25°, 30°, and 40° and investigated effect of ship speed against failure of ice. It can be concluded load on ice increasing linearly as increase of impact velocity. Below 3 m/s ice would start failure in flaking formation, upper that speed ice fractured in brittle mode and maximum load had taking on 40° of buttock angle. At the end, this article proposed new formula to define contact area and ice load on ice structure interaction.

Tan *et al.* (2013) had proposed new semi-empirical model through numerical method using completed coding in Fortran programming language to describe concept superposition in varying load when ship made indentation on ice. Ice breaking is a continuous process. Some breaking pattern would be formed when bow contact with ice followed by chaotic event crushing dominantly and bending that unpredictable event. Then result verified with full scale performance data on icebreaker Tor Viking II while operated in Baltic Sea and implemented pressure-area relation to investigate effect of local contact on ship-ice interaction.

Zhou *et al.* (2013) had summarized working load wile ship sailing on ice, some force was used to push ice sheet moving horizontal, to slip block ice down of hull or bow, to lift up ice on sloping or breaking ice. After making experiment model in towing tank can be confirmed that ice would be broken in crushing and bending. Large piece could become rubble, some part slid away, rotate then hit hull and another piece going down submerged sliding underneath of hull. Zhou *et al.* (2013) also did simulation while assuming ice broken slide away but experimental result exhibited ice cusp rotate then against hull at shoulder area and mid hull that can be effect on performance of ship.

Xian Tan (2014) from Norwegian University of Science and Technology had made in numerical and scale model to represent ice breaking tanker MT Uikku, another parameters shown in

Table 7. In fact since 1993 Azipod propeller unit in pushing type has begun to replace conventional rudder propeller which was used from 1977. From experiment could be known on 18 mm ice thickness ship was moving in 0.59 m/s whereas in 29 mm ice thickness maximum speed would reach 0.33 m/s.

Table 7: Ship parameter in Full and Scale Model of MT Uikku (Xian Tan, 2014)

Parameter	Notation	Dimension	Full Scale Value	Model Scale Value
Length overall	LOA	m	164.4	5.21
Length between perpendiculars	L_{pp}	m	150	4.75
Breath, moulded	B	m	22.2	0.7
Draught, icebreaking	D	m	9.5	0.3
Propulsion power	P_D	W	11.4×10^6	64.55
Propeller diameter	D_P	m	5.6	0.18

Islam *et al*. (2015) have chosen RANS method to find distribution flow while propeller operated in some configuration such as puller, pusher or bollard pull. That would be happened when port, a long platform of offshore or area around escorted ship needed to be clean. Characteristic interaction between rotating part (propeller) and fixed part (strut/pod) investigated through CFD program. Left Hand Propeller (LHP) with taper angle -15° was function puller whilst Right Hand Propeller (RHP) with taper angle +15° as a pusher. These article concluded performance thrust on puller propeller type higher than pusher but on the other side intensity velocity on pusher propeller type higher than puller. It can be known from turbulence region closed to the pod area.

2.0 HULL DESIGN OF ICE-GOING SHIPS

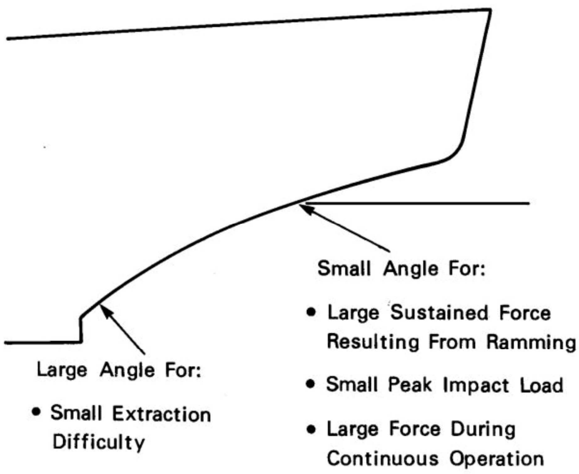
Design of ice-going ships requires considering the performance, adequate hull and strength of machinery and good functioning of the ship in ice condition and open water condition. Concept of double acting ship has started developed since 1990 by Kvaerner Masa-Yards Artic Technology Centre which known as Aker Arctic Technology Inc., a Finnish company. The idea to build ice breaking merchant ship appeared to eliminate ice breaker as assistance when merchant ship sailing in ice conditions (Krzysztof, 2014). Double acting ship was designed to run ahead in open water and astern in ice conditions. Bow form of the ship was modified without bulbous that can give better characteristics in open water than conventional vessels (Juurma, 2012). The structure of double acting ship has been improved by increasing the strength of structure to ensure the hull structure can withstand with ice resistance while break the ice.

2.1 Stem Hull Design of Ice-Going Ships

The stem hull design of double acting ship differs from common ships. The common ships have a bulbous bow at the head of ship a shown in Figure.2 The main function of bulbous bow is to reduce the drag force that it was an effect of wave making resistance while ship moving ahead in open water. Therefore, the resistance of ship will reduce that can make increasing speed and improve stability of a ship.

Figure 2: Bulbous bow for common tanker

When the double acting ship moves astern, then bulbous bow would bring in drag force and increasingly more resistance. In the other side, on double acting ship, the bulbous bow has been removed and new design on bow form namely Ice Breaking Bow. 1970, White identified the parameters of a bow which was desirable for improvement of continuous icebreaking, ramming and extraction ability by decreasing spread angle complement (i.e. a blunter bow), decreasing the coefficient of friction and increasing thrust. He proposed a bow form, shown in as shown in Figure 3 incorporating to above parameters. This hull form was used on the Manhattan for its voyage in the Arctic.



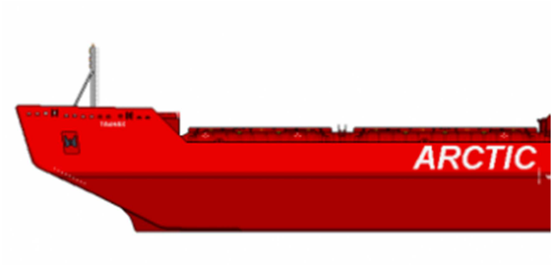


Figure 3: Ice Breaking Bow of double acting ship (Stephen, 2004)

2.1 Stern Hull Design of Ice-Going Ships

The stern hull of double acting ship is also important parts to be designed for double acting tanker. Basically, stern hull geometry has been designed with an edge and certain angle to ensure that can break the ice while moving astern and reduced ice resistance. Stern hull also designed with consideration less effect of resistance while moving ahead in open water. Figure 4.3 shows stern hull design of the ship Vasily Dinkov (AAT, 2007). The figure describes design hanger which still existing commonly used to hang a pod. Adding angle at the hanger pod with the intent to reduce ice resistance working and give a better performance when DAT going to breaking ice in the astern mode without it hanger pod would contribute to making additional resistance when ship-ice interaction.

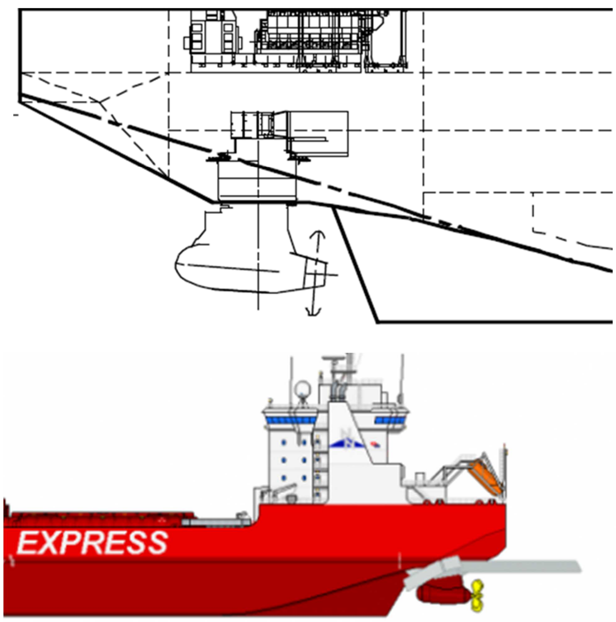


Figure 4: Stern hull design of Vasily Dinkov tanker (AAT, 2007).

2.3 Development Hull Design of Ice-Going Ships

In 1993, the vessel MT Uikku has been delivered owned by Neste and Kvaerner Masa-Yards (NEMARC) where operated by Artic Shipping services, at Murmansk route in the Northern Sea, (Wilkman *et al*. 2005). This vessel has been converted for better performance in manoeuvring. Figure.5 illustrated the MT Uikku tanker. Below in Table.1 shows main dimensions of MT Uikku (AAT, 2007);

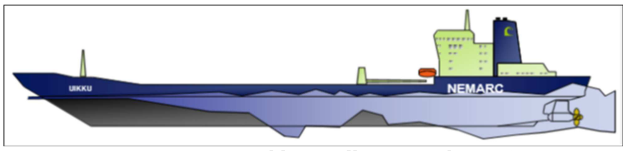


Figure 5: MT Uikku (Wilkman *et al*. 2005)

Table 1: Main Dimension of MT Uikku

Length	164.5 m
Draught	9.5 m
Breadth	22.2 m
Power	11.4 MW

In 2001, first development of DAT was launched as name Sumitomo DAT. The design was based on Kvaerner Masa-Yards Arctic Technology (KMY) with assisted by Sumitomo Heavy Industries, (Juurma *et al.*, 2012). The stern shape was designed to breaking ice at Baltic Sea. The stern was fitted with Azipod using one propeller with a diameter blade 7.6 m. Figure.6 shows the stern shape of model scale for testing. Below in Table.2 shows main dimensions of Sumitomo Double Acting Ship.

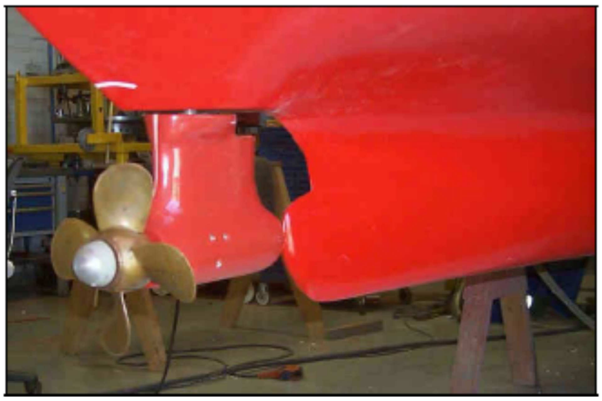


Figure 6: Stern design for model scale of Sumitomo DAT (Juurma *et al.*, 2012).

Table 2: Main Dimension of Sumitomo DAT

DWT	106000 dwt
Length	243 m
Breadth	44 m
Draught	14.5 m
Power	16 MW

In 2002 and 2003, others Double Acting Ships, MT Mastera and Tempera have been built. The tankers use Azipod in a propulsion system containing a pod capable rotating 360° with maximum power 16 MW. Figure.7 shows the side view of MT Tempera. Below in Table.3 shows main dimensions of tanker Tempera (Wilkman *et al.*, 2005).

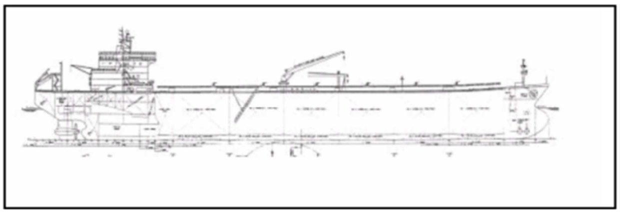


Figure 7: Side view of double acting tanker Tempera (Wilkman *et al.*, 2005).

Table 3: Main Dimension of Tempera

Length	230 m
Breadth	44 m
Draught	15.3 m
Power	16 MW

In 2005, Samsung Heavy industries had developed 70000 dwt Artic Shuttle Tanker namely as MT Vasily Dinkov and MT Kapitan Grotskiy. This vessel used double Azipod in 10 MW for each. Figure.8 shows the general arrangement for the vessel (AAT, 2007). Below in Table.4 shows main dimensions of MT Vasily Dinkov.

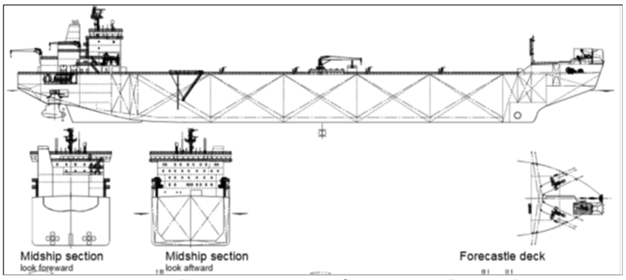


Figure 8: General arrangement of MT Vasily Dinkov (AAT, 2007).

Table 4: Main Dimension of MT Vasily Dinkov.

Length overal	258 m
Length b.p	234.7 m
Length w.l	245 m
Breadth, moulded	34 m
Design draught, moulded	14 m
Deadweight	70000 dwt

In 2010, OAO Admiralty Shipyards has been manufactured MT Mikhail Ulyanov and MT Kiril Lavrov. The vessel entirely designed by Aker Artic Technology to shuttle oil from Prirazlomnoye oil field in Pechora Sea to Floating Storage and Offloading (FSO) unit moored off Murmansk. ABB Marine provides proper solution for propulsion system in the shape of twin Azipods. The azimuthing thrusters enable the ships to penetrate cross ridged ice when running astern with continuous slow speed. Figure.9 shows the picture of MT Mikhail Ulyanov. Below in Table.5 shows main dimensions of MT Mikhail Ulyanov, (AAT, 2010).

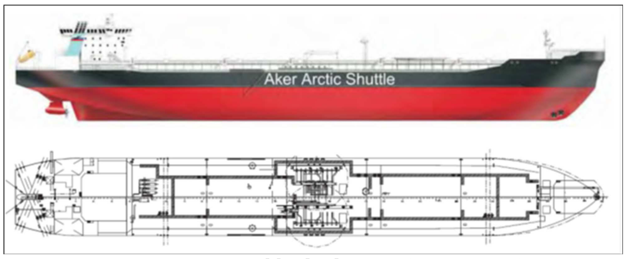


Figure 9: MT Mikhail Ulyanov (AAT, 2010)

Table 5: Main Dimension of MT Mikhail Ulyanov.

Length over all	257 m
Length between perp.	236 m
breadth	31 m
depth	20 m
draught summer load line	14 m
draught ballast open water	8.93 m
deadweight	70000 dwt
trials speed	16 knots

3.0 PROPULSION SYSTEM OF ICE-GOING SHIPS

Jones (2004) reported propulsion system of ships on ice have been great changing with applied podded propeller until evolving using azimuth thruster. Since 1990 some changing happened in ship propulsion systems, which previously was using diesel engines into electric propulsion system. These systems provides several advantages such as reduced fuel consumption, more friendly in environment because low emissions, increasing in manoeuvrability due to nothing load from transmission system because electric motor had eliminated reduction gear from old methods. Transformation in propulsion system encourage the emergence of new vessels with double acting ability to sail on traveling route from Kara Sea and Arctic in Russia to ports in Europe which always almost covered by ice.

The Podded propulsion system used on ships is combination of both propulsion and steering systems. The system consists of a propeller which is driven by an electrical motor and the propeller is turned by the rudder which is connected to the system. The motor is placed inside the sealed pod and is connected to the propeller. It should be noted that the sealing of the pod should be perfect otherwise it can damage the whole motor and make the ship handicap from maneuvering. The motor used for this system is variable frequency electric motor. Using variable frequency, the rotational speed of the propeller can be controlled i.e. the speed can be increased or decreased. The whole podded propulsion system is situated outside the hull in the aft of the ship. The podded can turn in all the directions i.e. 360 degrees with the help of a rudder, and thus provides a thrust in any direction which is not possible in the conventional system. The propeller in the pod system is moved by the rudder which is placed in the steering flat, also the power module for the system.

The podded propulsion system is a type of electric propulsion system which consists of three main components as shown in Figure.10:

1. Supply Transformer

The power produced from the generators is as high as 6600

KV, which is stepped down to the necessary voltage by the supply transformer required and is provided to the motor placed in the pod.

2. Propulsion motor

Propulsion motor is used to drive or to produce thrust. The system needs some method for rotating the propeller and this is done with the help of electric motor.

3. Frequency Controller/converter

This is used to change the frequency of the supplied power so that the rotating speed of the motor can be controlled depending on the requirement.

3.1 Advantages of Podded Propulsion System

1) Greater maneuverability as the propeller can be turned in all directions (360^0). This enables better stop distance during crash maneuvering than that provided by the conventional system.
2) In case of ships having large breadth, two or more podded propulsions which are independent of each other can be used. This provides subtle maneuvering.
3) It saves a lot of space in the engine room as there is no engine, propeller, shafting and other arrangements. The saved space can thus be used for storing more cargo.
4) The system can be placed below the ship's height thus providing more efficiency than the conventional system.
5) Use of side thruster is eliminated as the pods can be used for providing the side thrust.
6) Low noise and vibrations than the conventional system.
7) Low fuel and lube oil consumption.
8) Environment friendly as emissions are extremely low.

3.2 Disadvantages of Podded Propulsion System

1) Podded propulsion system requires massive initial cost.
2) A large number of diesel generators are required for producing power.
3) There is a limitation to the power produced by the motor. As of now the maximum power available is 21 MW.
4) Cannot be installed in large ships with heavy cargo which need a lot of power and large motors.

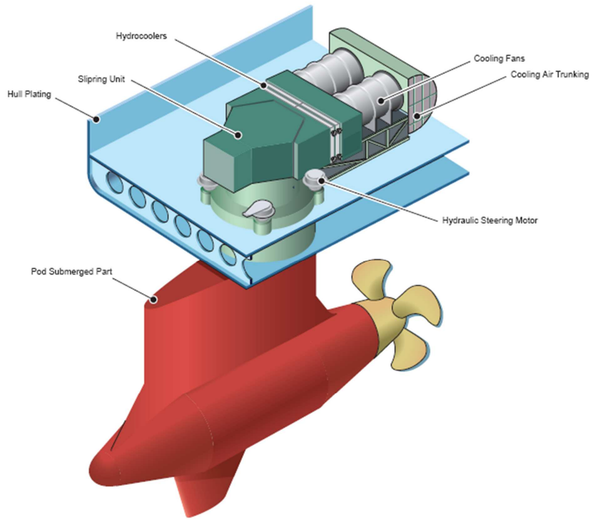


Figure 10: Layout of podded propulsion system

3.3 Development of Podded Propulsion System

The vessels where operated in Arctic have begun to use with consideration it can reduce cost while eliminate existence of ice breaker such done by Tempera, that is tanker which can travel on double acting. Table 6 shows the list of the vessel including name, year of delivered, units of Azipod used and the power of Azipod. Refer to the table, it shows that for single unit Azipod, the maximum power is 16.0 MW that used by Double Acting Ship Tempera and Mastera, otherwise for using double Azipod can produce maximum power 20 MW.

Table 6: List of double acting tanker (DAT) power by podded propulsion system

No	Delivered Year	Vessel Name	Ice Class	Builder	Azipod Rating (MW)	Units	Total Power (MW)
1	1993	Uikku	1A Super	Masa-Yards	11.4	1	11.4
2	1994	Lunni	1A Super	Masa-Yards	11.4	1	11.4
3	2002	Tempera	1A Super	Sumitomo Heavy Inds. Ltd	16.0	1	16.0
4	2003	Mastera	1A Super	Sumitomo Heavy Inds. Ltd	16.0	1	16.0
5	2008	Vasily Dinkov	LU6	Samsung Heavy inds.	10.0	2	20.0
6	2008	Kapitan Grotskiy	LU6	Samsung Heavy inds.	10.0	2	20.0

7	2009	Shturman Albanov	LU6	Samsung Heavy inds.	10.0	2	20.0
8	2010	Mikhail Ulyanov	LU6	Admiralty Shipyard	8.8	2	17.0
9	2010	Kiril Lavrov	LU6	Admiralty Shipyard	8.8	2	17.0

5.0 CONCLUSION

In conclusion, this paper discussed historical ice going ships, the development of ships in ice such as ice breaker, double acting ship and offshore floating by taken two parameters into account which is hull form design and propulsion system.

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