LIFE CYCLE COST OF
THE VENTURI OXYGEN STRIPPING™
BALLAST TANK CORROSION PROTECTION SYSTEM
IN CONTAINER SHIPS

By:
NEI Treatment Systems, LLC
3530 Wilshire Blvd., Suite 1465
Los Angeles, CA  90010
USA

www.nei-marine.com

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EXECUTIVE SUMMARY

An increasing percentage of the world’s shipping fleet is of double hull construction. As a result of this design evolution, the traditional methods of maintaining ballast tank structural steel, cathodic protection and coatings, are becoming very costly. This paper presents a life cycle cost benefit analysis of the Venturi Oxygen Stripping™ ballast water treatment system as a new alternative method of ballast tank protection.

The study was conducted using costs and revenues associated with a 5500 TEU container ship using a present-worth cost comparison in US Dollars. The results show that the Venturi Oxygen Stripping™ (VOS) system is a viable economic alternative to coatings alone. Over a 25-year period, the savings in reduced corrosion maintenance costs is shown to be greater than the total lifecycle cost of the VOS system. Therefore, the VOS system reduces the total lifecycle cost of a ship. It is expected that installation of the VOS system on most ship types would result in similar cost savings.
1.0 INTRODUCTION

The passage of the US Oil Pollution Act of 1990 ushered in the era of the double hull tanker. By 2015 virtually all oceangoing tankers will be double hull. In 2006 the International Association of Classification Societies (IACS) finalized Common Structural Rules (CSR) which will require new bulk carriers to be double hull or double sided (IACS 2006). Many container ships are also essentially double hull vessels. In the future, a significant portion of the world’s cargo ships will be of double hull construction.

While double hull construction is designed to decrease the possibility of a catastrophic loss, there are increased structural safety concerns. In double hull vessels the majority of structural steel is located in the ballast tanks. Double hull construction significantly increases the total ballast tank steel surface area. It has been noted that the substantially different structural response of double hull vessel to dynamic loads can accelerate coating breakdown, and create, as described by Contraros, a corrosion “Domino Effect” (Contraros, 2003). To address these concerns, the CSRs include prescriptive corrosion additions to the required thickness of ballast tank plate and structural steel. Corrosion additions are required to account for the perceived inevitability of diminution, and therefore structural strength, of ballast tank steel during a ship’s life.

The cost of building and maintaining double hull ships has increased significantly over single hull design. As the early 1990’s-built double hull tankers reach middle age, ballast tank repair bills are increasing. It is now common for tankers to have ballast tank repair bills exceeding $1,000,000 from a single drydocking. There have been recent cases where ballast tank repair bills have exceeded $5,000,000 (e.g., Top Tankers, 2006).

Traditionally, ballast tank steel has been protected through coating and the use of sacrificial anodes (commonly, blocks of zinc or magnesium). In 2006 the International Maritime Organization (IMO) adopted a new Performance Standard for Protective Coatings (PSPC) that requires shipbuilders to apply ballast tank coatings to last for 15 years (MSC 82, 2006). For all IACS-Classed ships the new PSPC applies to ships built in or after 2007. The PSPC is expected to further increase costs, adding by some estimates, as much 15 percent to the total cost of a ship (Trade Winds, 2006).

In light of the significant changes to ballast tank design over the last 15 years, and consequent increased cost of ballast tank maintenance, is it still cost effective for shipowners to rely solely on corrosion margins, coatings, and anodes to preserve ballast tank structural integrity?

A 2006 report by the International Ship Structures Committee (ISSC) entitled Condition Assessment of Aged Ships (Paik et al, 2006) includes the following passage.

Ship structures while in service are likely to be subject to age related deterioration such as corrosion wastage, fatigue cracking or mechanical damage (e.g., local denting). Maintenance and repair of aged structures is also very costly and complex. It is thus of great importance to develop advanced technologies which can allow for proper management and control of such age related deterioration.
One such technology specifically described in this ISSC report is a ballast water de-oxygenation method called Venturi Oxygen Stripping™ (VOS). In long-term testing the VOS system has been shown to decrease the corrosion of steel by up to 84 percent (Tiku et al, 2006). This result has profound implications for the life-time cost of maintenance and repair of ships’ ballast tanks. The analysis presented herein will show that the VOS system represents a significant cost savings over traditional ballast tank protection measures.

This study presents a life cycle cost analysis for the use of a VOS ballast water treatment system as a corrosion protection device. Because the CSRs assume a ship design life of 25 years, this study will use 25 years. The interest rate, or cost of money, used is eight percent (8%). The study ship will be a 5500 TEU container ship built in Japan and repaired in China. The life cycle cost analysis will use “present worth method”, and will be presented in several scenarios.

- The first scenario will compare the use of the VOS system as an Alternative Method (MSC 82, 2006) to the new IMO 15-year PSPC.
- The second will calculate a “break-even” steel renewal value, above which the VOS system will be a cost-effective option.
- The third will evaluate the potential financial benefit of longer trading life (more than 25 years) of a vessel fitted with the VOS system.

2.0 BACKGROUND

2.1 Ballast Tank Corrosion

A ship’s ballast tank is one of the most corrosive environments on earth. Where continuously-submerged uncoated steel corrodes at approximately 0.1 to 0.2 millimeters per year (mm/yr) (LaQue, 1975), several factors can make ballast tank corrosion rates significantly higher. Cyclic filling and draining of tanks refreshes available oxygen. Internal ship vibration and wave impact remove built-up oxide layer, exposing steel to additional corrosion. Temperature fluctuations from heating coils (tankers) expand and contract steel, causing coating breakdown. Repair work from denting and/or puncture of cargo tanks into ballast tanks (bulk carriers) creates a galvanic corrosion cell where new steel is joined to old. Oscillating oxygen levels due to biological oxygen demand cycles the anode/cathode reaction, accelerating corrosion.

Importantly, cathodic protection by sacrificial anodes is only effective when the metallic surface is immersed (IACS, 2004), and it requires some time (a day or more) to become effective after the tank as been filled (Parente et al, 1996). When ballast tanks are full, the reported effectiveness of cathodic protection is a maximum of 70 percent (Weber, 1984). Thus, since many ships’ ballast tanks are completely empty when they transport cargo, anodes can only protect ballast tank steel part of the time.
It is difficult and expensive to adequately prepare and coat the complex structures within ballast tanks, especially under the new IMO PSPC. A single hull Very Large Crude Carrier (VLCC) has approximately 40,000 m² of ballast tank surface area. A double hull VLCC has approximately 200,000 m². Now that two coats are required at the newbuilding yard, the total surface area required for coating is increased by a factor of 10. In the future, repair yard re-coating will follow the same PSPC requirements.

Even before a ship is delivered, any location of coating imperfection becomes the sight of a corrosion cell. Coating imperfections such as blistering, cracking, and flaking all lead to failure, and subsequent corrosion of the underlying steel. In addition, it has been shown that a location of coating imperfection, where exposed steel is adjacent to still-protected steel, can act as a sacrificial anode where corrosion is accelerated (Gratsos and Zachariadis, 2006). This is a process commonly described as “rust jacking”. Corrosion not only follows coating failure, corrosion causes coating failure.

A coating is a semi-permeable membrane, and in the long term cannot permanently protect steel from corrosion. Corrosion will eventually initiate even on the surface of coated steel because oxygen and water vapor directly penetrate epoxy coatings (Soares et al, 2005).

Approximately 6,000 commercially-trading cargo ships are more than 35 years old (Faiplay, January 2006). This represents a significant percentage of the world’s commercial fleet. It can be expected that as the percentage of double hull vessels increases, so will the percentage of double hull vessels that are past their design life. Even if the new CSR corrosion additions were specified to avoid any steel renewal for 25 years, the life of many double hull ships at sea will have exceeded the design life of their structures.

Given the changing make-up of the world’s fleet, the evolved understanding of the mechanisms of corrosion, and the shortcomings of existing protective measures, it is worth serious consideration of alternative methods of protecting ballast tank steel.

### 2.2 History of Ballast Tank De-Oxygenation

In 1993 the Hellespont Group of Greece began experimenting with introducing inert gas into ballast tanks to reduce corrosion rates. Ballast tank surfaces were scored (scratched to bare steel) in 250 locations throughout the tanker Hellespont Grand. After 13 months of active trading, a survey was done to assess the condition of the exposed steel. No corrosion was observed in any of the exposed locations. In 2002 Hellespont built four 440,000 dwt Ultra Large Crude Carriers (ULCCs). These ships are the largest double hull tankers in the world, and have more ballast tank surface area than any ships ever built, approximately 300,000 m². Hellespont had them built with ballast tank inerting systems to protect the steel. Based on their many years’ experience with these systems, Hellespont reports “low sulfur inert gas will stop corrosion” (Kennedy, 2004).

In 1996, the US-based naval architecture firm Rosenblatt & Sons published a report entitled *Commercial Ship Design and Fabrication for Corrosion Control*. In it they suggest the use of inert gas in non-cargo tanks to inhibit the progression of corrosion by providing an oxygen-depleted atmosphere (Parente et al, 1996).
In 1997 the Nippon Foundation funded a study by Sumitomo Heavy Industries to develop a ballast water de-oxygenation system to completely replace the use of coatings in ballast tanks. This system was tested aboard a 150,000 deadweight ton (dwt) Capesize bulk carrier for 18 months. The results showed a 90 percent decrease in corrosion rate compared to aerated ballast tanks. (Matsuda et al, 1999)

In 2004 the American Bureau of Shipping (ABS) published its Guide for Inert Gas Systems for Ballast Tanks (ABS, 2004). The stated objective of the ABS Guide is to “prevent the risk of explosion in ballast tanks”, and to “reduce corrosion in ballast tanks”. This Guide provides detailed requirements for the use of inert gas systems for ballast tanks.

Scientific corrosion research has repeatedly confirmed the direct linear relationship between concentration of oxygen and rate of steel corrosion (Melchers, 2003). Oxygen is required to form rust. The engineering challenge has been to develop a de-oxygenation system that is practical for the marine environment, and costs less than the corrosion it’s designed to stop.

NEI Treatment Systems, LLC began development of the VOS system in 2002. The VOS system both removes dissolved oxygen from ballast water as it is drawn into the vessel, and inerts ballast tanks with low oxygen gas as they are emptied. Except for tank entry safety, ballast tanks are permanently maintained in a low-oxygen condition.

The VOS system does not remove 100 percent of oxygen from ballast water or from empty tanks. This could potentially lead to the growth of sulfur-reducing bacteria (SRB), which cause corrosion. Since even 0.03 milligrams per liter (mg/l) of oxygen is toxic to SRBs (Johnson et al, 1997), the VOS system maintains an oxygen concentration above this level to suppress the growth of corrosive bacteria.

Initial bench-scale test results by the US Naval Research Laboratory indicated significant reduction in corrosion. A comprehensive nine-month corrosion study conducted by BMT Fleet Technology in 2006 indicates up to 84 percent lower corrosion with the VOS system compared to untreated, exposed steel (Tiku et al, 2006). The results of this testing are described in detail in this report, and form the basis of this life cycle cost analysis.

2.3 **Description of Venturi Oxygen Stripping™**

The VOS system removes 95 percent of dissolved oxygen from ballast water in under ten seconds. De-oxygenation is accomplished as ballast water is pumped into the vessel by mixing very-low oxygen inert gas with the ballast water through venturi injectors installed in the ballast piping (see photographs below). As ballast is drained, inert gas is introduced into the emptying tanks. This element of the treatment complies with ABS *Guide for Inert Gas Systems for Ballast Tanks*. Please see Figure 1, VOS Process Flow Diagram.
The low-oxygen gas is created by combustion of low-sulfur diesel in a device that is similar to tanker inert gas generators (see above). The size of the venturi injectors and the inert gas generator vary with the capacity of the ship’s ballast pumps. The dimensions of the inert gas generator unit for a 5500 TEU container ship are 3.5 meters x 1.5 meters x 3.0 meters high.

As with traditional tanker inert gas generators, the gas is passed through a vertical cooling water section prior to introduction into ballast tanks or ballast water. The gas sulfur concentration is reduced to parts per billion range, far below a level that creates a sulfuric acid corrosion concern. In natural water within pH range from 4 to 10 there is no effect on corrosion rates of shipbuilding steel (LaQue, 1975). Therefore, acid attack is not an issue with the VOS system.

The VOS system also enables ships to comply with the IMO Ballast Water Management Convention of 2004. The system has been shown in independent laboratory, pilot-scale, and shipboard testing to consistently meet the IMO D-2 ballast water discharge performance standards (Tamburri et al, 2006).

The VOS system has been installed on two actively trading ships. One system operates at a ballast flow rate of 500 m³/hr, and the other at 1,000 m³/hr. The same low-oxygen conditions created in the laboratory testing are induced by the full-scale shipboard equipment.

### 3.0 VOS CORROSION TESTING

In 2006 BMT Fleet Technology, Ltd. conducted a nine-month study of the effect of the VOS system on the corrosion rate of steel. The study included a comparison between untreated steel (to simulate current ballast tank corrosion conditions) to VOS-treated steel. The test included four steel exposure conditions: buried, submerged, cycling, and humid. The buried condition simulated the potential sediment build-up in ballast tanks. The submerged condition simulated the condition of full ballast tanks. The cycling condition simulated the “splash zone” at the top of full ballast tanks. The humid condition simulated an empty ballast tank.
The experimental data revealed that overall corrosion rates were low under de-oxygenation conditions as compared to control conditions. Comparison of experimental data after 30 days exposure indicated that under de-oxygenated conditions the corrosion rates were reduced by 40 percent in the splash zone environment, 48 percent in the submerged condition, 78 percent in the humid environment and 14 percent in the buried condition. After 270 days the corrosion rates were lower by 38 percent in the splash zone environment, 84 percent in the humid environment and 20 percent in the buried condition.

The humid condition showed the greatest reduction in corrosion. And the photos clearly show a difference in treatment even for those coupons that seem to show similar numerical corrosion rates. See Figures 3.5 (a) and (b) below.

![Figure 3.5(a): Corroded Plates after 270 Days Exposure under Splash Zone Environment](image)

Although, for example, the numerical test results indicate difference of 38 percent in the Splash Zone, there is clearly a difference in the corrosion pattern between treated and untreated. The BMT testing did not simulate ship vibration or wave impact. Under shipboard conditions it is expected that the corroded steel on the untreated coupon (Tank 2) would flake off, and the newly exposed bare steel would begin to corrode.

It is difficult to simulate shipboard conditions in a laboratory setting. As indicated in the Executive Summary of their report, therefore, the BMT numerical test results used in this life cycle cost analysis should be considered conservative. Actual shipboard corrosion conditions are expected to be closer to those shown by previous studies (i.e., Hellespont, Sumitomo Heavy Industries, etc.)
The untreated submerged condition tests showed an average corrosion rate of 0.24 mm/yr for control conditions. This is consistent with published estimates (LaQue, 1975). As expected, it is the empty ballast tank condition that exhibited the highest corrosion rate for untreated coupons. The corrosion rate of untreated coupons in the humid condition was as high as 1.19 mm/yr, and stabilized at approximately 0.55 mm/yr by 270 days.

### 4.0 LIFE CYCLE COST ANALYSIS

The study VOS system is for a 5500 TEU Container Ship. The approximate total ballast tank surface area is 30,000 m². Class rules for corrosion margins differ for containerships, so this study will use the CSR corrosion margins for bulk carriers. It is expected that corrosion allowances for container ships will not exceed that of bulk carriers.

The ballast pumps for this vessel are 2 x 1,000 m³/hr, though only one is used at a time. The vessel is on transpacific liner trade with four port calls on a 36-day round trip, making 10 trips per year. It is assumed the vessel takes on 2,000 m³ of ballast at three ports and discharges all 6,000 m³ ballast at the bunkering port. Therefore the total annual volume ballast treatment is 60,000 m³. Total running time of the VOS system is 120 hours. A vessel on longer voyages would have fewer port calls, fewer ballast operations, lower annual VOS operating cost, and lower VOS life cycle cost, and *vis versa*.

Wherever possible this cost analysis will use the most conservative numbers available. For example, when evaluating the running cost of the VOS system, a high fuel cost is used. When evaluating the off-hire time during drydocking, a low time-charter rate is used. Please see Appendix A for Study Assumptions.
4.1 Steel Corrosion

The corrosion protection effect of sacrificial anodes is known (70 percent). The BMT testing did not include coupons with anodes attached. Therefore observed corrosion rate for full ballast tank condition will be reduced by a factor of 70 percent for both treated and untreated results. Also, it is unclear what effect cathodic protection would have in the Splash Zone in the shipboard environment. Therefore, despite a 38 percent lower corrosion rate for the VOS-treated steel in the Splash Zone condition, this result will not be incorporated into the cost analysis.

Irrespective of the duration of voyages, the study vessel would the majority of the year with most ballast tanks empty. The corrosion rate analysis will incorporate Humid Condition test results to the empty ballast tank condition, and Submerged Condition results multiplied by a cathodic protection factor of 70 percent for ballast-filled condition. To use the most conservative analysis, it will be assumed that the vessel’s ballast tanks will spend 50 percent of the time in ballast.

As stated previously, this study will conservatively assume the same corrosion rate using the VOS system when ballast tanks are full. This is a very conservative method, and will produce results that can be confidently used to make financial decisions. The following presents the corrosion data for this analysis:

<table>
<thead>
<tr>
<th>Tank Identification</th>
<th>Condition</th>
<th>Corrosion Rate at 270 days</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tank 1 – VOS Treatment</td>
<td>Submerged</td>
<td>0.24 mm/yr</td>
</tr>
<tr>
<td></td>
<td>Humid</td>
<td>0.09 mm/yr</td>
</tr>
<tr>
<td>Tank 2 – Control</td>
<td>Submerged</td>
<td>0.24 mm/yr</td>
</tr>
<tr>
<td></td>
<td>Humid</td>
<td>0.55 mm/yr</td>
</tr>
</tbody>
</table>

To determine the expected corrosion rate for both submerged results (0.24 mm/yr), the observed rate is multiplied by a cathodic protection factor, 0.3 (1 – 0.7).

\[
0.24 \text{ mm/yr} \times 0.3 = 0.07 \text{ mm/yr}
\]

As described above, the study vessel is expected to spend half the year with cargo and half the year in ballast. Thus, the following formula incorporates the humid condition results to calculate expected annual corrosion rates (CR) for treated and untreated condition:

\[
CR_{\text{untreated}} = (0.07 \text{ mm/yr} \times 0.5 \text{ yr}) + (0.55 \text{ mm/yr} \times 0.5 \text{ yr}) = 0.31 \text{ mm/yr}
\]

And

\[
CR_{\text{VOS-treated}} = (0.07 \text{ mm/yr} \times 0.5 \text{ yr}) + (0.09 \text{ mm/yr} \times 0.5 \text{ yr}) = 0.075 \text{ mm/yr}
\]
As shown in Table 2, when these corrosion rates are used to calculate the expected time to exceed the CSR corrosion allowance, the results indicate that within the 25-year design life steel renewal is not expected when using the Venturi Oxygen Stripping™ system. In fact the minimum indicated time to exceed the corrosion margin using the VOS system is 32 years. The calculations show most structures will not exceed the corrosion margin until 40 years. The maximum expected time to required steel renewal for the ballast tank compartments of a CSR-compliant Panamax bulk carrier is conservatively estimated to be 53 years.

4.2 Sacrificial Anode Diminution

Significantly reducing the oxygen level in ballast tanks significantly reduces the oxidation of steel. The same outcome occurs for sacrificial anodes. This cost analysis will also account for the decreased consumption of sacrificial anodes in ballast tanks.

The rule of thumb for assuring proper cathodic protection of coated steel is 5 milli-Amps per square meter (mA/m²) (Amtec Consultants, 1998). This generally translates to approximately 1 kilogram of zinc anode per 7 square meters of ballast tank surface. Using current proper ballast tank protection measures, zinc anodes are expected to be replaced every five years. In fact zinc anodes are sized to last approximately five years.

This analysis will use 22 kilogram zinc anodes distributed to enable protection of 7 m²/kilo. Since our 5500 TEU containership has approximately 30,000 m² of ballast tank surface area, this ship requires 195 anodes throughout the tanks.

The results of testing corrosion rate of steel found up to 84 percent lower corrosion. For the purposes of evaluating the reduced cost of sacrificial anodes, a reduced zinc diminution rate of 75 percent will be assumed. Therefore, zinc anodes will be replaced at 20 years only, versus every five years for unprotected tanks.

The following case examples evaluate the cost implications of this result.

5.0 CASE STUDIES

Case 1 – PSPC vs. VOS

This case evaluates the difference between the cost to protect ballast tanks of a 5500 TEU containership using the new Performance Standard for Protective Coatings versus the traditional coating methods and the VOS ballast water treatment system.

In this case, no steel renewal cost is used for either steel protective measure. Ideally with the new PSPC there would be complete protection from the coating for the first 15 years. This case assumes that 15 percent of the coating will be repaired at the 3rd Special Survey, 12 years after delivery to assure that the vessel can trade for the rest of its 25 year design life with no additional coating repair or steel renewal.
With the VOS system corrosion test results indicating the locations of coating imperfection would be protected for at least the entire 25 year design life, no steel renewal is required. The life cycle cost of the VOS system is as shown in Appendix C.

Present Value of 25 Years of VOS Ownership = $776,951

Imabari Zosen reports that the cost to comply with the new PSPC for Panamax bulk carrier ballast tanks will be between ¥300,000,000 and ¥500,000,000. The minimum value of the expected total cost range, in US Dollars, is $2,530,000. It is reported that the PSPC cost is three times higher than the previous cost (previous cost = $844,000). The minimum additional cost at the newbuilding yard for a 15-year coating for a Panamax bulker is $1,686,000.

A Panamax bulk carrier has approximately 40 percent more ballast tank surface area than a 5500 TEU containership. Therefore the expected additional cost for the study containership is $1,012,000. Assuming 15 percent of the 30,000 m² of ballast tank surface is recoated at the 3rd Special Survey, the following calculates the present worth of the total life-time PSPC coating cost:

\[
PSPC = 1,012,000 + (0.15)30,000 \times \left( \frac{65}{m^2} \right) (P/F,8\%,12 = 0.40) = $1,129,000
\]

Calculating the lifetime cost savings on anode replacement will be from eliminating the cost at the 5, 10, and 15 year drydocking and adjusting for present worth:

Newbuild Anode Cost = 195 anodes x $100/anode = $19,500

\[
= 19,500 [(P/F,8\%,5 = 0.68) + (P/F,8\%,10 = 0.46) + (P/F,8\%,20 = 0.21)]
\]

= $26,325

And

\[
($1,129,000 + $26,325) - $776,951 = $378,374
\]

The present worth of the cost savings using the VOS system compared to PSPC coatings and anodes for the 25-year ship’s life is almost $400,000. This is a 33 percent cost savings. Alternatively, this can be considered a 49 percent return on investment in the VOS system.

Case 2 – Break-Even Steel Renewal Cost

This case assumes no difference in coating cost between the two options, but rather evaluates the total steel renewal cost at the 3rd Special Survey that makes investment in the VOS system a “break-even” proposition. Recalling that the predicted time to required steel renewal for a vessel with the VOS system varies between 32 and 53 years, it is not expected that any steel renewal would be required for a vessel running a VOS system.
The cost comparison will be between the present worth ownership cost of 12 years of VOS system ownership, and present worth of the steel renewal cost for a Panamax bulk carrier at the 3rd Special Survey drydocking 12 years after delivery.

From Appendix C, the cost for 12 years of VOS ownership is $550,672.

Next, translate off-hire time to unit steel renewal cost. Since the expected daily production rate of steel renewal is 7 tons/day (from Table 1), and the daily charter rate is $20,000 per day (Table 1) the following formula is used:

\[
\left( \frac{\$20,000}{\text{day}} \right) \left( \frac{1\text{ day offhire}}{7\text{ tons steel}} \right) = \frac{\$2,900}{\text{ton steel}}
\]

The daily lost revenue (opportunity cost) to a shipowner from off-hire time exceeds the unit cost of steel repair, $2,500/ton.

Simply using these two factors, assigning \( x = \) tons, yields the following formula:

\[
\$2,500x + \$2,900x = $550,672
\]

\[
x = 102 \text{ tons}
\]

The Venturi Oxygen Stripping™ system is an attractive economic alternative to steel renewal and repair for a Panamax bulk carrier that may have more than 102 tons of steel repair. The amount of steel renewal where the VOS system would provide a 15 percent return on investment is:

\[
102 \times 1.15 = 117 \text{ tons}
\]

Please note, this includes any additional structural steel at “hot spots” that might be required to make up for lost structural strength due to corrosion.

This case does not account for additional coating cost. That would be additional, and make the VOS system a more attractive economic alternative.

Case 3 – Extended Trading Life Past 25 Years

When using the VOS system aboard a CSR-built Panamax bulk carrier, as Table 2 shows, steel renewal would not be required for 32 years at the earliest. Case 3 evaluates the cost benefit of continuing to trade a vessel from 25 to 30 years.

The marginal cost to operate a Panamax-sized VOS system for five additional years is a simple multiple of the annual operating cost discounted over five years:
$10,300 (P/A, 8%, 5=3.99) = $41,097

If the ship earns a 15 percent gross profit (excluding VOS running cost) on $20,000 per day for five years the approximate income is:

$20,000(0.15) x 365 (P/A, 8%, 5=3.99) = $4,370,000

The present worth of these two amounts is:

$41,097 (P/F, 8%, 25=0.15) = $6,165

$4,370,000 (P/F, 8%, 25=0.15) = $655,000

A shipowner does not have to wait 25 years to enjoy the financial benefit from a ship expected to have an extended trading life. Although some ships are sold “as-is”, many ship sale transactions include ballast tank surveys, which take into account the condition of the ship. The purchase price in an efficient market between informed parties would account for expected future cost and revenue. Ships in good shape sell for more than ships in poor shape.

Please note, based on this analysis, it would not be a good economic decision to scrap the subject vessel after 30 years. If the ballast tanks are in good condition at 30 years, there is no reason why such a ship cannot trade for another 10 or even 20 years before the economics become unattractive.

6.0 CONCLUSION

Independent testing of the VOS system indicates that steel corrosion progresses so slowly that a ship would reach the end of its 25-year design life before any ballast tank steel renewal would be required. In Case 1, using these results to evaluate the VOS system as an augment to traditional coating methods indicates the cost savings is 33 percent versus the new Performance Standard for Protective Coatings. In Case 2, it is shown that the total cost of a VOS system is equivalent to replacing 102 tons of steel at a 3rd Special Survey drydocking, and represents a 15 percent cost savings versus 117 tons of steel renewal. Finally, in Case 3 a significant benefit is seen by increased trading life as a result of superior condition of a ship with ballast tanks protected by the VOS system.
REFERENCES

IACS. January 2006. “Common Structural Rules for Bulk Carriers”. Annex 1


Top Tanker Management, Inc. 2006. “Special Survey No: 3 – M/T Priceless”.

MSC.82. 2006. “Performance Standard for Protective Coatings for Dedicated Seawater Ballast Tanks in All Types of Ships and Double-Side Skin Spaces of Bulk Carriers”. Industrial Maritime Organization.


Tiku, Sanjay et al. 2006. “To Investigate the Effects of Using De-Oxygenation as a Ballast Water Treatment System”. BMT Fleet Technology Ltd. 5943C.FR.


## ASSUMPTIONS

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<thead>
<tr>
<th>Cost Item</th>
<th>Price</th>
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<td>Steel Renewal</td>
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<td>2006 COSCO Nantong Shipyard</td>
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<tr>
<td>Steel Production</td>
<td>7 tons/day</td>
<td>Gratsos and Zachariadis, 2006</td>
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<tr>
<td>Coating Repair</td>
<td>$65/m²</td>
<td>Japan Marine Paint (est. for PSPC)</td>
</tr>
<tr>
<td>22 Kilo Anode</td>
<td>$100 ea</td>
<td>Samgong Co, Ltd. (zinc anode manufacturer)</td>
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<td>Charter Rate</td>
<td>$20,000/day</td>
<td>Baltic Dry Index, 2.5-Year Low (Jan 2005 – April 2007)</td>
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<td>Yen/Dollar Conversion</td>
<td>$1/¥118.6</td>
<td>FXTrade (OANDA.com)</td>
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APPENDIX B

FINANCIAL CALCULATIONS
**FINANCIAL CALCULATIONS**

**INTEREST RATE AND FACTOR CALCULATIONS**

\( i \) = interest rate (8 percent throughout analysis)

\( n \) = years

<table>
<thead>
<tr>
<th>Factor Name</th>
<th>Converts</th>
<th>Symbol</th>
<th>Formula</th>
</tr>
</thead>
<tbody>
<tr>
<td>Single payment present worth</td>
<td>Future to Present</td>
<td>( (P/F, i%, n) )</td>
<td>((1+i)^n)</td>
</tr>
<tr>
<td>Capital recovery</td>
<td>Present to Annual</td>
<td>( (A/P, i%, n) )</td>
<td>( \frac{i(1+i)^n}{(1+i)^n-1} )</td>
</tr>
<tr>
<td>Uniform series present worth</td>
<td>Annual to Present</td>
<td>( (P/A, i%, n) )</td>
<td>( \frac{(1+i)^n-1}{i(1+i)^n} )</td>
</tr>
</tbody>
</table>
APPENDIX C

VOS LIFECYCLE COST
**VOS LIFECYCLE OWNERSHIP COST**

Newbuilding Shipyard – Imabari Zosen, Japan  
Study Vessel - 5500 TEU Containership

VOS System Purchase Price = $389,000  
Installation Cost = $150,000  
Total Initial Cost = $539,000

**Annual Operating Cost:**

\[
\text{Annual Fuel Cost} = 120 \text{ hours} \times \left( \frac{1,250 \text{ m}^3 \text{ gas}}{\text{hr}} \right) \times \left( \frac{1 \text{ liter fuel}}{10 \text{ m}^3 \text{ gas}} \right) \times \left( \frac{1 \text{ ton}}{1,000 \text{ liter}} \right) \times \left( \frac{620}{\text{ton}} \right) = $9,300
\]

Annual Maintenance Cost = $1,000  
Total Annual Cost = $10,300

**Periodic Maintenance Costs:**

Every 5 Years – Replace Various Sensors, Gaskets, Worn Parts = $10,000  
Every 10 Years – IGG Overhaul = $35,000  
Replace Venturi Injectors = $40,000  
$75,000

**Present Value of Lifetime Cost of Ownership (25 Years):**

Initial Cost + Annual Operating Cost + Periodic Maintenance Cost

\[
\begin{align*}
&$539,000 + $10,300(P/A, 8\%, 25 = 10.67) + $10,000(P/F, 8\%, 5 = 0.68) + $85,000(P/F, 8\%, 10 = 0.46) + $10,000(P/F, 8\%, 15 = 0.32) + $85,000(P/F, 8\%, 20 = 0.21) = \\
&$539,000 + $109,901 + $6,800 + $39,000 + $3,200 + $17,850 = $776,951
\end{align*}
\]

**Present Value of Annual Cost (25 Years):**

$776,951(A/P, 8\%, 25 = 0.094) = $73,033 per year

**Present Value of 12 Years of VOS Ownership:**

$73,033(P/A, 8\%, 12 = 7.54) = $550,672

**Present Value of 15 Years of VOS Ownership:**

$73,033(P/A, 8\%, 15 = 9.71) = $709,150