

DECISION MAKING IN CARGO TANK COATINGS FOR CHEMICAL TANKER COMPANIES

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Abstract: To choose the most effective tank coating is critical issue prior to ship construction for chemical tanker companies. Several criterias according to goals of companies are considered. First application as cost and difficulty, cargo compatibility, cargo tank cleaning, maintenance, durability, freight income and usage life time of cargo tank coating are the criterias to decide the tank coating which is one of epoxy, zinc, stainless steel and MarineLine. In this context, the aim of this study is to decide which tank is most effective as price-performance. According to this aim, the ratings of alternatives for tank coating have been researched and scored among these tank coatings in comparison with their specifications by three tank coating experts. And the importance weights of these criterias to choose a tank coating prior to ship construction have been asked to 15 operation managers of chemical tanker companies that these companies consist eighty percent of whole chemical tanker market in Turkey. 15 decision makers have scored the importance weights of the criterias with linguistic expressions. The ratings of alternatives and the average of importance weights of 7 criterias have been evaluated by fuzzy TOPSIS method. In results of the calculations, coefficients of 4 cargo tank coatings are 0.27 (epoxy), 0.22 (zinc), 0.38 (stainless steel), 0.35 (MarineLine). According to calculated coefficients, stainless steel cargo tank coating is the most effective tank coating when the 7 criterias are considered together. Although the stainless steel cargo tank coating has highest value, the difference between stainless steel and MarineLine is so less in comparison with the other cargo tank coatings. The reason of nuance is the fact that the first application cost of MarineLine cargo tank coating is much less than stainless steel cargo tank coating and MarineLine cargo tank coating is as well as stainless steel in terms of cargo compatibility.

Keywords: tank coating, chemical tanker, stainless steel, MarineLine, fuzzy TOPSIS.

Introduction

A chemical tanker is a type of tanker, which carries liquid cargoes except crude oil and cargoes requiring no significant cooling or pressure tanks. The chemical tankers carry not only chemical products but, commodities such as vegetable oils, molasses, wine, animal fats, solvents and some clean petroleum products and lubricants. Additionally chemical tankers can carry inorganic substances like phosphoric acid, sulphuric acid and caustic soda.

The chemical tanker is a very special type of ship due to the complexity and the particularity of the cargo. Chemical tankers can carry extremely corrosive cargos like sulphuric acid, caustic soda, acetic acid and virgin naphtha. Therefore, much attention is mostly given to the cargo tanks and to their ability to ensure the integrity and the purity of the cargo.

Chemical tanker owners have usually invested large amounts of money on their new building chemical tankers. In general, stainless steel is considered to be the ideal material of construction, being non corrosive and easy to clean. However, first application cost of APC MarineLine is one fourth of the stainless steel cost, so APC MarineLine is decided as a cargo tank coating type by the Turkish chemical tanker companies before constructions of their chemical tankers (Gündoğan, 2017).

Cargo tank coatings can be mainly categorized into four groups:

- Inorganic coating; zinc silicates and ethyl silicate types
- Organic coatings; epoxy and modified epoxy systems
- Advanced polymer coating (MarineLine 784)
- Stainless steel coating

In this context, the ratings of alternatives for tank coating have been researched and scored among these tank coatings in comparison with their specifications by three tank coating experts with respect to following criterias (Table 1). These criterias have sub-criterias and the average of sub-criterias give the rating of related criteria.

Table 1. Tank coating criterias.

<i>C1</i>	<i>C2</i>	<i>C3</i>	<i>C4</i>	<i>C5</i>	<i>C6</i>	<i>C7</i>
First application * C1a; Cost * C1b; Difficulty and duration of application	Cargo compatibility	Cargo tank cleaning * C3a; Cost * C3b; Difficulty and duration of cleaning	Maintenance * C4a; Cost * C4b; Period * C4c; Difficulty	Durability	Freight income	Life time (average)

Then, to determine weights of criterias, 15 decision makers have scored the importance weights of the criterias with linguistic expressions. The ratings of alternatives and the average of importance weights of 7 criterias have been evaluated by fuzzy TOPSIS method.

Cargo tank coatings

During the last 30 years, several types of coating have been used for tank lining service in the sea trades. Being used of some coating materials have stopped and new more reliable and flexible coating materials have been developed. Today's typical coatings (Figure 1) can be categorized as follows:

(a) (b) (c) (d)

Figure 1. Tank coatings; epoxy (a), zinc silicates (b), stainless steel (c), MarineLine (d).



Epoxy (A1)

Epoxy cargo tank coatings contain curing agents in order to cure fast and they are 75-90 % solids by volume. They have limited chemical resistance and their first application consist of two or three layers. First application of epoxy cargo tank coating is so difficult because of that all epoxy coatings need well surface preparation. Also, epoxy coatings do not clink on sharpen surfaces. Corrosion occurs rapidly on these surfaces (*C1b.*, *C2.* and *C5.*) (Gündoğan, 2017).

Epoxy cargo tank coatings are suitable to pick up slight trades of the product carried, especially the chemicals which have only a limited suitability. Alcohols, esters, ketones cause to soften the coating and the coating is more likely to absorb small amounts of cargo. The tank, coated with epoxy coating, should be vented thoroughly before tank cleaning when these types of cargoes are carried (*C2.* and *C3b.*) (Salem, 1996).

Epoxy coatings have compatibility with the carriage of alkalis, glycols, seawater, animal fats and vegetable oils but, they have limited resistance to carriage of aromatics such as benzene and toluene, alcohols which are especially ethanol and methanol. These coatings are also suitable for the carriage of animal and vegetable oils provided the acid value does not exceed 10 (i.e. free fatty acid content of 5%). However, oils or fats with acid value between 10 and 20 acceptable for limited time of carriage. The cargo which is molasses should provide pH above 4 to carriage in epoxy coated cargo tanks, although dilute solutions may become acidic

and attack the epoxy coatings. This problem is remedied by adding an alkali to keep pH in acceptable level (C2.) (Corkhill, 1981).

Epoxy coating is one of the cheapest coating types. Its initial cost is the second cheapest and it requires small amount of time for application (C1a. and C1b.) But it provides lower performance than MarineLine (C5.) (Gündoğan, 2017). It can't resist enough to corrosive liquids even first 3 months from application to tanks, no aggressive cargoes are allowed (C2.).

Zinc silicates (A2)

Zinc silicates are generally applied as one coat which acts as a weak barrier between steel and corrosives. This means that zinc silicates are not resistant to strong acids, bases, alkalis and even seawater which has slow deteriorating effect. Zinc silicates are suitable for carriage of cargoes have pH range of 5.5-10, aromatic hydrocarbons, such as benzene and toluene, alcohols and ketones. Also carriage of vegetable and animal fats are unsuitable since carriage of halogenated compounds are suitable if the tanks' surfaces are free of moisture (C2.) (Gündoğan, 2017).

Although the physical properties (i.e. hardness and abrasion resistance) vary according to the type of silicate used, chemical resistance and cargo compatibility are very similar. These coatings are normally applied as a single coat of 75-125 microns to a blast clean metal surface. They show unequal features because of the quality of surface preparation and blast cleaning for a white metal finish is necessary (C4c.) (Rogers, 1971).

In zinc-coated tanks, cleaning operation is costly and complex work when the cargo to be cleaned is a dyed gasoline, gasoil, or vegetable oil cargo and next cargo is to be methanol or MEG. Only special safe cleaning chemicals made for zinc can be used. It causes to increase the cost of cargo tank cleaning operation (C3a. and C3b.).

Zinc coating is the cheapest cargo tank coating type at first application (C1a.) Besides, it requires less amount of time for its construction than epoxy, MarineLine and stainless steel coatings (C1b.) (Çakmaz, 2017).

Stainless steel (A3)

Stainless steel is the general name given to the whole of chrome high alloyed corrosion resistant steels, and the main alloying element is chromium. Stainless steel coating is generally used for cargo tank coating, steam coils, ladders, supports, pump shell on chemical tankers. Stainless steel is impermeable and generally invisible under oxidizing conditions with a chromium content of 12%. The formation of self-healing and invisible oxide film on the surface serves as a barrier between the metal and the external environment. It provides effectively corrosion resistance (C5.) (Vadakayil, 2010).

Stainless steel coatings provides easy tank cleaning operation. With stainless steel, the cargo would not absorbed inside the coating (C3a.). Typically, washing is firstly carried out with sea water at a certain temperature to remove cargo residues, where possible followed by washing with freshwater to remove chlorides. For some cargoes only fresh water is used (C3a. and C3b.) (Çakıroğlu, 2017).

Stainless steel, which is the most resistant for heavy chemicals and it is the most expensive tank coating type (C1a. and C2.). The performance of a stainless steel coated cargo tank drops off dramatically when exposed to halogen salts, especially chlorides that penetrate the passivation and allow corrosive attack (C2. and C5.). But if the passivation maintained correctly, stainless steel tank coating is the most durable type for corrosion (C5. and C7.) (Gündoğan, 2017).

The chemical tanker which have stainless steel coated cargo tanks, have more freight income than the other cargo tank coating types even carrying same cargoes. Also obviously seen that the cargoes which can carried in only stainless steel coated cargo tanks, are more valuable cargoes than others (C6.) (Aydın, 2017).

Stainless steel cargo tank coating has less maintenance period than the other cargo tank coating types, if the required passivation is done. So the maintenance cost of stainless steel cargo tank coating is not much as others. General maintenance is required in only 5 years shipyard period (C4a., C4b. and C4c.) (Soykan, 2017).

APC MarineLine 784 (A4)

Advanced Polymer Coatings offers the unique MarineLine coating to the chemical tankers market in respect to carrying most of IBC- approved cargoes. MarineLine 784 provides high functionality by formulated with a polymer designed and engineered with 28 functional groups per molecule. When heat cured, MarineLine 784 coating forms 3-dimensional, screen-like structures with up to 784 cross-links which its maximum performance. This far surpasses Phenolic Epoxies which only deliver 2 functional groups with only 4 cross-links as showed in Figure. 2.

More densely cross-linked molecular structure provides; higher chemical resistance, higher temperature resistance, higher reactivity at lower temperature, more resistance to absorption, greater toughness, faster tank cleaning relative to epoxy and zinc cargo tank coatings. MarineLine 784 is resistance to; thermal Shock (-40 C to +200 C), flex stressing, wear and abrasion, product absorption, impact (C2., C5. and C3b.) (APC, 2002).

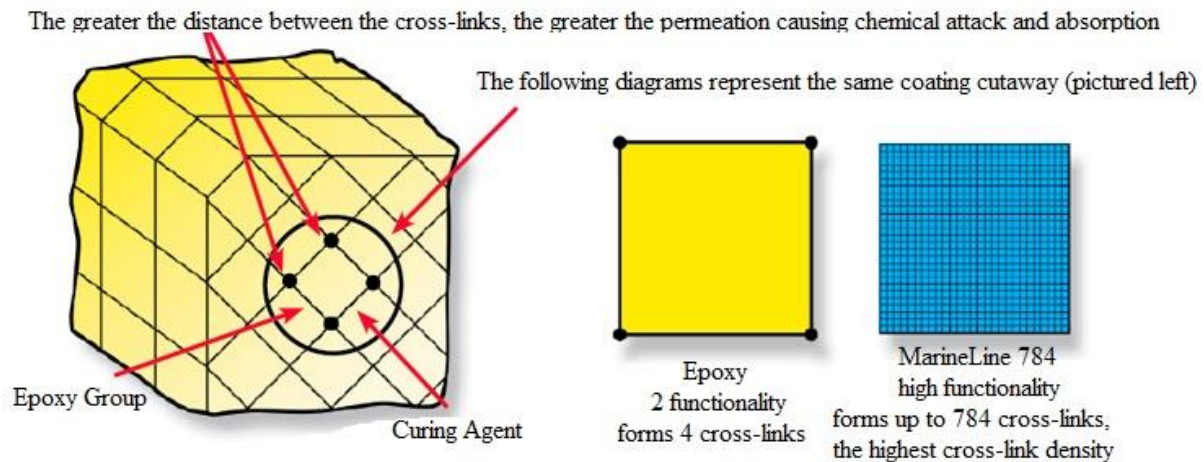


Figure. 2. Cutaway of Epoxy and MarineLine 784 coatings (APC, 2002).

MarineLine is much cheaper than stainless steel and more expensive than zinc silicate and epoxy coatings. Its initial cost is about 1/4 of stainless steel initial costs (*C1a.*). If the all costs are considered, the cost comparison makes MarineLine the best option. More time is required during first application than epoxy and zinc coatings but less than stainless steel (*C1b.*) (Erzurumlu, 2017).

MarineLine cargo tank coating provides easy tank cleaning between cargoes. MarineLine creates a protective barrier that is easily cleaned, eliminating long ventilation times and putting the ship back into service faster this means more number of voyage then slower ones. MarineLine coating has a much smoother surface than stainless steel and this superior ‘slip’ promotes significant savings in fuel, energy, time and in cleaning chemicals used, all of which have a positive impact on the environment (*C3a.* and *C3b.*) (Karagöz, 2012).

Periodic surveys of the tank and regular maintenance are needed to ensure a long service life (*C4b.*). The tanks coated with MarineLine do not require any passivation to deliver a long service. Key points of maintenance for MarineLine are to only carry approved chemicals, clean properly the tanks, and touch up any areas as needed with the MarineMend coating repair kit (*C4c.*) (Balta, 2017).

However, MarineLine tank coating has a much lower freight rate compared to stainless steel in chemical tanker market because of the fact that the cargo owners want their cargos carry in stainless steel tanks rather than MarineLine (*C6.*).

Methodology

The ratings of alternatives have been scored between them according to literature and 3 tank coating experts. There are the references about criterias in “Cargo tank coatings” section and they refer to ratings of alternatives. To model the tank coatings’ ratings, fuzzy numbers have

been used rather than crisp numbered data for real approach on tank coatings. Therefore, the fuzzy TOPSIS methodology has been adopted to solve multi-criteria decision making problem on the issue. Wang and Elhag's (2006) linguistic expression (Table 2) has been used for ratings of the tank coatings.

Table 2. Linguistic variables and fuzzy ratings of the alternative (Wang and Elhag, 2006).

Linguistic expression	Fuzzy numbers
Very Poor (VP)	(0, 0, 1)
Poor (P)	(0, 1, 3)
Medium Poor (MP)	(1, 3, 5)
Fair (F)	(3, 5, 7)
Medium Good (MG)	(5, 7, 9)
Good (G)	(7, 9, 10)
Very Good (VG)	(9, 10, 10)

Same linguistic expression has been adopted for the importance weights of these criterias with very high (VH), high (H), medium high (MH), medium (M), medium low (ML), low (L) and very low (VL) terms. 15 decision makers have scored the importance weights of the criterias with these linguistic expressions.

Results

In fuzzy TOPSIS, the decision makers may use linguistic variables or fuzzy numbers to evaluate the ratings of alternatives with respect to criterias. In assumption of a decision group has K people, the ratings of alternatives belong to each criterion can be calculated as (Chen, 2000);

$$\tilde{x}_{ij} = \frac{1}{K} [\tilde{x}_{ij}^1(+) \tilde{x}_{ij}^2(+) \dots (+) \tilde{x}_{ij}^K] \quad (1)$$

where \tilde{x}_{ij}^K is the rating of the K^{th} decision maker for i^{th} alternative with respect to j^{th} criterion. With respect to equation, decision matrix has been obtained (Table 3).

Table 3. The fuzzy decision matrix for four alternatives.

	<i>C1</i>	<i>C2</i>	<i>C3</i>	<i>C4</i>	<i>C5</i>	<i>C6</i>	<i>C7</i>
<i>A1</i>	(6, 7.5, 8.5)	(3, 5, 7)	(1.5, 3, 5)	(2.3, 4.3, 6.3)	(0, 1, 3)	(3, 5, 7)	(0, 1, 3)
<i>A2</i>	(7, 8.5, 9.5)	(0, 0, 1)	(1, 3, 5)	(2.3, 4.3, 6.3)	(1, 3, 5)	(0, 0, 1)	(1, 3, 5)
<i>A3</i>	(0, 0.5, 2)	(9, 10, 10)	(9, 10, 10)	(7.7, 9.3, 10)	(7, 9, 10)	(9, 10, 10)	(9, 10, 10)
<i>A4</i>	(3, 5, 7)	(7, 9, 10)	(6, 8, 9.5)	(1.7, 3, 5)	(5, 7, 9)	(5, 7, 9)	(5, 7, 9)

Then, fuzzy decision matrix has been normalized by following formula (Chen, 2000) and results are shown in Table 5.

$$\tilde{r}_{ij} = \frac{x_{ij}}{x_{j^*}} \quad (2)$$

where x_{j^*} is the highest value of that criteria. To determine the weights of each criteria, 15 decision makers have scored the importance weights of the criterias with these linguistic expressions (Table 4). Then, the average of these scores as the weights of each criteria has been stated in Table 4.

Table 4. The importance weights of the criterias

	D1	D2	D3	D4	D5	D6	D7	D8	D9	D10	D11	D12	D13	D14	D15
C1	VH	VH	VH	VH	M	VH	VH	VH	ML	VH	H	VH	VH	VH	VH
C2	M	M	H	ML	ML	H	H	M	VH	MH	VH	MH	H	VL	ML
C3	L	L	VL	MH	MH	MH	VL	H	L	M	MH	ML	MH	MH	M
C4	MH	MH	MH	L	H	ML	MH	MH	M	H	M	M	M	H	MH
C5	ML	ML	L	H	L	M	L	L	H	L	L	L	ML	ML	VL
C6	H	H	M	M	VH	L	M	ML	VL	ML	VL	H	L	L	L
C7	VL	VL	ML	VL	VL	VL	ML	VL	MH	VL	ML	VL	VL	M	H

The results of formula 2 and the average of importance weights, which are shown in Table 4, has been stated in Table 5.

Table 5. The fuzzy normalized decision matrix and the weights of the criterias

	C1	C2	C3	C4	C5	C6	C7
A1	(0.63, 0.79, 0.89)	(0.3, 0.5, 0.7)	(0.15, 0.3, 0.5)	(0.23, 0.43, 0.63)	(0, 0.1, 0.3)	(0.3, 0.5, 0.7)	(0, 0.1, 0.3)
A2	(0.74, 0.89, 1)	(0, 0, 0.1)	(0.1, 0.3, 0.5)	(0.23, 0.43, 0.63)	(0.1, 0.3, 0.5)	(0, 0, 0.1)	(0.1, 0.3, 0.5)
A3	(0, 0.05, 0.21)	(0.9, 1, 1)	(0.9, 1, 1)	(0.77, 0.93, 1)	(0.7, 0.9, 1)	(0.9, 1, 1)	(0.9, 1, 1)
A4	(0.32, 0.53, 0.74)	(0.7, 0.9, 1)	(0.6, 0.8, 0.95)	(0.17, 0.3, 0.5)	(0.5, 0.7, 0.9)	(0.5, 0.7, 0.9)	(0.5, 0.7, 0.9)
Weight	(0.79, 0.91, 0.95)	(0.45, 0.63, 0.77)	(0.29, 0.45, 0.63)	(0.43, 0.62, 0.8)	(0.14, 0.28, 0.46)	(0.27, 0.41, 0.57)	(0.12, 0.2, 0.33)

Considering the importance weights of each criterion, the weighted normalized fuzzy decision matrix has been constructed by following formula (Chen, 2000). The results of multiplication have been stated in Table 6.

$$\tilde{V} = [\tilde{v}_{ij}]_{m \times n}, i = 1, 2, \dots, m, j = 1, 2, \dots, n, \text{ where } \tilde{v}_{ij} = \tilde{r}_{ij}(\cdot) \tilde{w}_j. \quad (3)$$

Table 6. The fuzzy weighted normalized decision matrix

	C1	C2	C3	C4	C5	C6	C7
A1	(0.5, 0.72, 0.85)	(0.14, 0.32, 0.54)	(0.04, 0.14, 0.32)	(0.1, 0.27, 0.5)	(0, 0.03, 0.14)	(0.08, 0.21, 0.4)	(0, 0.02, 0.1)
A2	(0.58, 0.81, 0.95)	(0, 0, 0.08)	(0.03, 0.14, 0.32)	(0.1, 0.27, 0.5)	(0.01, 0.08, 0.23)	(0, 0, 0.06)	(0.01, 0.06, 0.17)
A3	(0, 0.04, 0.2)	(0.4, 0.63, 0.77)	(0.26, 0.45, 0.63)	(0.33, 0.58, 0.8)	(0.1, 0.25, 0.46)	(0.24, 0.41, 0.57)	(0.11, 0.2, 0.33)
A4	(0.25, 0.48, 0.7)	(0.32, 0.57, 0.77)	(0.17, 0.36, 0.6)	(0.07, 0.19, 0.4)	(0.07, 0.2, 0.41)	(0.14, 0.29, 0.51)	(0.06, 0.14, 0.3)

According to weighted normalized fuzzy decision matrix, it has been known that \tilde{v}_{ij} values are normalized in the range of interval [0, 1]. Then, the fuzzy positive ideal solution (FPIS, A^*) and the fuzzy negative ideal solution (FNIS, A^-) has been calculated as (Chen, 2000)

$$d_i^* = \sum_{j=1}^n d(\tilde{v}_{ij}, \tilde{v}_j^*), i = 1, 2, \dots, m, d_i^- = \sum_{j=1}^n d(\tilde{v}_{ij}, \tilde{v}_j^-), i = 1, 2, \dots, m. \quad (4)$$

where $\tilde{v}_j^* = (1, 1, 1)$, $\tilde{v}_j^- = (0, 0, 0)$, $j = 1, 2, \dots, n$ and where $d(\cdot, \cdot)$ is the distance measurement between two fuzzy numbers. The results of equations have been stated in Table 7.

Table 7. The distance measurement

	A^*	A^-
$A1$	5.29	2.00
$A2$	5.62	1.64
$A3$	4.53	2.78
$A4$	4.80	2.58

A closeness coefficient is defined to determine the ranking order of all alternatives once the d_i^* and d_i^- of each alternative A_i ($i = 1, 2, \dots, m$) has been calculated (Chen, 2000). The closeness coefficient of each alternative is calculated as,

$$CC_i = d_i^- / (d_i^- + d_i^*), i = 1, 2, \dots, m. \quad (5)$$

The highest CC_i is the best one from among a set of feasible alternatives (Chen, 2000). According to equation, closeness coefficients of 4 tank coating alternatives have been calculated and stated below,

$$CC_1 = 0.27, CC_2 = 0.23, CC_3 = 0.38, CC_4 = 0.35.$$

It can be seen that stainless steel is the best alternative for tank coating type and the MarineLine is the second alternative. On the other hand, it is clear that there is no obvious difference between these two tank coating types.

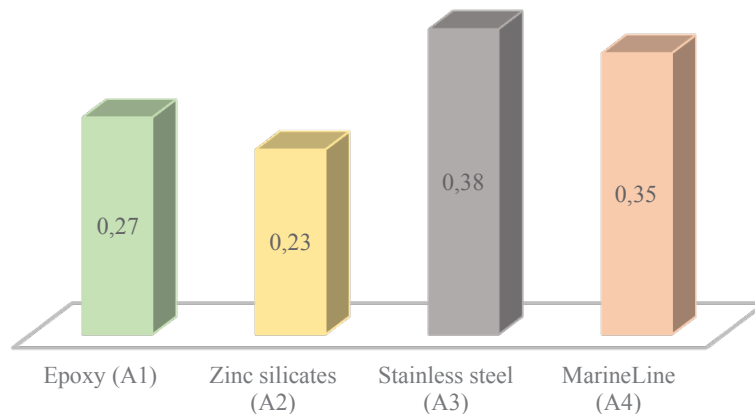


Figure. 3. Closeness coefficients of 4 tank coating alternatives.

Conclusion

To decide which tank coating can be most effective, several criterias according to goals of companies should be considered for chemical tankers. Generally four type tank coatings have been used for carriage of chemical substances in tankers. They are epoxy, zinc silicates, stainless steel and MarineLine. And chemical tanker companies have considered the performances of ships, freight income of carriage or maintenance costs etc. to choose one of them.

In this study, 7 main criterias and their sub-criterias have been determined and 4 tank coatings have been researched within these criterias. 3 tank coating experts evaluated the criterias for each tank coating with the information from literature and scored them with linguistic expressions of Fuzzy decision making method. Besides, 15 operation managers of chemical tanker companies that these companies consist eighty percent of whole chemical tanker market in Turkey, scored the importance weights of the criterias with similar linguistic expressions. With fuzzy ratings of these linguistic expressions, decision matrix was constructed and 4 tank was evaluated in fuzzy TOPSIS method to choose best alternative of tank coatings.

According to results of decision matrix, stainless steel cargo tank coating is the most effective tank coating when the 7 criterias are considered together. Although the stainless steel cargo tank coating has highest value, the difference between stainless steel and MarineLine is so less in comparison with the other cargo tank coatings. The reason of nuance is the fact that the first application cost of MarineLine cargo tank coating is much less than stainless steel cargo tank coating and MarineLine cargo tank coating is as well as stainless steel in terms of cargo compatibility. Indeed, MarineLine tank coating has been used in 93% of chemical tankers in Turkish chemical market. While stainless steel has been best one in decision, MarineLine has been decided for many years by Turkish chemical tanker companies due to mentioned nuance above. Consequently, stainless steel is what companies dream about, MarineLine is what they get by taking the risks of being in limited world chemical market.

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