NADA ŠTRUMBERGER, D.Sc.
NATALIJA MALETIĆ, B.Eng.
Fakultet prometnih znanosti
Zagreb, Vukelićeva 4
INES CVEČIĆ, B.Eng.

Traffic Safety and Ecology
Review
U. D. C. 629.5.081.4:504.42
Accepted: Jun. 6, 1999
Approved: Nov. 9, 1999

ASPECTS OF REDUCING POLLUTING IMPACT OF SHIPYARDS ON THE KVARNER BAY

ABSTRACT

Four shipyards are located in the area of the Kvarner Bay, and they normally, at more or less regular intervals perform the cleaning of ship hulls. Due to the lack of necessary financial means, these processes usually mean applying of solid abrasives which, due to their characteristics cause significant environmental pollution.

This paper presents the impact of individual shipyards, with regard to the extent of given service - the treated area in squared metres, on the global pollution of the Kvarner Bay as well as preventive and recovery measures that are feasible on a local level with the aim of reducing pollution.

KEY WORDS

traffic ecology, pollution reduction, sea traffic, Kvarner bay

1. INTRODUCTION

While navigating and in harbour, ships are subjected to various impacts that may damage the ship paint and attack the ship plating: waves, salt, oil, sea organisms, scraping against other ships or against the berth when mooring or leaving. Regarding the aspect of corrosion on steel plating, its corrosive effect and shortening of the ship lifetime, damaging effect of the molecules of the scaled paint and of rust on the sea organisms, and ultimately of the very ugly appearance of the corroded surface covered with the paint remainder or covered with growth of sea organisms, cleaning has to be undertaken - removing the remainder of paint, rust, salt, oil, impurities, and grown organisms, in the shipyard. Abrasives that are used can be divided into dry ones i.e. those in solid state and the wet abrasives - water. Furthermore, the dry abrasives can be divided into two main groups, metal and mineral abrasives:

a) metal abrasives have a longer lifetime, they can take a greater number of impacts with the surface before their diameter is reduced so much that they have to be abandoned. Their advantage is good quality of cleaning and low environmental pollution,
b) mineral abrasives are cheaper than metal ones, but after several impacts with the metal surface they become useless so that they are recommended for single use only.

Another division of solid abrasives can be according to the origin, which means:

a) natural or mineral
b) metal
c) industrial by-products
d) manufactured or synthetic
e) others.

Natural or mineral abrasives can be found in nature, and the most common are silicon or quartz sand and rough sand better known as grit. Metal abrasives are industrially produced, usually steel shot, cut steel wire, and steel filings. Industrial by-products, true to their name, are obtained during production and the most commonly used are: crushed copper slag, crushed iron slag and crushed coal slag. Synthetic abrasives are generated by processes similar to polymerisation and the mostly used one is corundum. As other types of abrasives for other applications there are e.g. dry ice, bone coal, wallnut shells, etc.

The amount of used abrasive depends primarily on the used equipment and the final result desired. The ISO 8501:1988 standard which copied completely the Swedish SIS 055900-1967 standard, is used as the surface preparation standard and abrasive cleaning is thus divided into four levels of finished quality: [1]

Sa 1: light cleaning by abrasive jet. Loose forging scale, corrosion and other contaminants will be removed.

Sa 2: complete abrasive cleaning. Almost all the forging scale, corrosion and other contaminants will be removed. Finally, the surface will be vacuum-cleaned or dusted by compressed pure and dry air or by a clean brush.

Sa $2^1/_2$: very thorough abrasive cleaning. Forging scale, corrosion and other contaminants will be removed completely from the surface, with possible contours on the surface as spots, lines or dots. Finally, the surface is vacuum cleaned or dusted by compressed pure and dry air or by a clean brush.

Sa 3: complete abrasive cleaning to pure metal. Forging scale, corrosion and products and other contaminants are removed completely. Finally, the surface is vacuum cleaned or dusted by compressed pure and dry air or a clean brush.

The analysis of impact of individual shipyards on the global pollution requires data on the type of the used abrasive and its characteristics, the amount of cleaned surface in square metres and the amount of used abrasive. By observation and comparison analysis of the actually quantified data regarding these values, it is possible to single out at the local level the shipyard with the greatest impact on the global pollution of the Kvarner Bay.

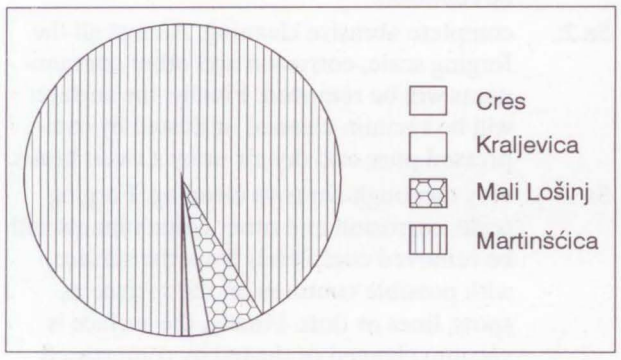
2. QUANTIFICATION OF THE IMPACT OF INDIVIDUAL SHIPYARDS ON GLOBAL POLLUTION

For successful determining of the impact and its analysis in searching for both preventive and restoration measures to reduce pollution the relevant data should be available. This means that it should be first determined which of the considered shipyards use a certain type of abrasives and in which amounts, i.e. how many square meters of steel plating are treated annually.

Table 2.1. presents the data about the surface treated by certain abrasives for the four considered shipyards in Martinšćica, Kraljevica, Cres and Mali Lošinj in 1997.[2]

Table 2.1.

Used abrasive / Shipyard	Grit	Water
Martinšćica	63 000 m^2	1 100 m^2
Kraljevica	4 400 m^2	–
Cres	1 200 m^2	–
Mali Lošinj	9 000 m^2	–



Graph 2.1

It is evident that the Viktor Lenac shipyard in Martinšćica generates the greatest amount of services annually. The selection of abrasives whose usage is the most acceptable considered economically and ecologically includes also considerations about their technical and exploitation characteristics. In forming Table 2.2. the values of abrasive consumption and operating speed have been taken with the minimal deviation as mean values of those variously damaged surfaces cleaned with cleaning standard Sa $2^1/_2$ and exceptionally in using garnet with standard Sa 3. Although the amount of used abrasive can deviate even up to +30% in cleaning extremely dirty and corroded sheets, for the success of the presented comparative analysis, deviations did not have to be taken into consideration. The price of waste disposal usually represents the contracted price of removal per tonne and depends on the type of transport, used means of transport, distance travelled, and the possibility of usage at the removal destination (recycling, filling up in construction industry, and refuse disposal). The costs of equipment and labour are given approximately taking into consideration the spent energy per equipment operating hour and the average salary of the shipyard worker with 178 working hours monthly.

Table 2.2. Characteristics of certain types of solid abrasives

	Coal Slag	Grit	Garnet
Abrasive	50 kg	50 kg	50 kg
Size	0,25-1,45 mm	01-2,0 mm	0,2-0,6 mm
Hardness (MOH)	6,7	6,4	8
Specific weight	2	2	4
Cleaning standard	Sa $2^1/_2$	Sa $2^1/_2$	Sa 3
Treated surface	1,27 m^2	0,73 m^2	2,75 m^2
Required time	5 min	2,5 min	9 min
Operating pressure	8 bars	8 bars	8 bars
Generation of dust	high	very high	low
Profile	52 microns	38 microns	65 microns
Operating speed	15 m^2/h	17,5 m^2/h	18,33 m^2/h
Abrasive consumption	600 kg/h	1 200 kg/h	333 kg/h
Price of abrasive	2 200 kn/t	870 kn/t	4 000 kn/t
Price of disposal	165 kn/t	95 kn/t	95 kn/t
Equipment and labour cost	70 kn/h	70 kn/h	70 kn/h

The cause of greatest pollution is considered to be the use of grit. Apart from generating great amounts of dust, grit is characterised by the ecologically unfriendly chemical composition. Approximately 85% of

grit is composed of iron, silicon and aluminium oxides. Silicon oxide known as quartz sand has a mechanical and poisonous effect on the lungs and the whole organism, causing silicosis and other side-infections. In case of longer exposure and greater concentrations, the iron causes muscle contractions and aluminium has an adverse effect on lungs and liver. Coal slag does not contain dangerous nor poisonous compounds and its usage is acceptable. Although of mineral origin, garnet does not contain silicon compounds nor heavy metals, the chloride percentage is very low and it is very effective in cleaning - it cleans fast and thoroughly.

The Viktor Lenac shipyard has the equipment for high-pressure water cleaning. The insufficient width of the dock often prevents the usage of this method and thus solid abrasives are used. Water cleaning offers many advantages: the price of the abrasive is significantly lower than the price of other abrasives, environmental pollution is almost completely eliminated, the price of waste disposal is minimal and the level of noise is reduced. Considering over a long term and with the aim of protecting the environment, water cleaning is justified although the ratio of capital costs of the dry cleaning system and the wet cleaning system can amount to 1:10.[3] Table 2.3. presents the characteristics of the existing high-pressure washing system.

Table 2.3.

Abrasive	amount	Cleaning standard	Treated surface	
water	92 litre	Sa $2^1/_2$	0,32 m^2	
Required time	Operating pressure	Operating speed	Consumption of abrasive	Cost of abrasive
3,84 min	2 000 bars	5 m^2/h	1 140 l/h	8 kn/m^3

From the ecological aspect the usage of solid particles compared to liquid particles is considered to be the worst solution since it generates great amounts of dust, reduces insulation, affects the vegetation (the process of photosynthesis) and physical presence on the leaves (not edible). Abrasives contain poisonous elements, and their disposal is more complex, more demanding and requires greater financial means, skilled personnel and locations favourable and big enough for disposal. If solid particles cannot be substituted by liquid ones, an abrasive can be selected that allows recycling and re-usage, reducing thus the costs of abrasive purchase and its disposal. Recycling of the at first sight most expensive abrasive - garnet - is economically justified. After the first use, garnet is collected, weighed and reused. With every usage about 10% of the mass is lost, and the size of particles is reduced so that after four uses the particles lose the necessary abrasive power and have to be disposed of. New particles are then used for further cleaning. Data on every single recycling procedure are presented in Table 2.4.

3. COST - IMPORTANT FACTOR IN SELECTING ABRASIVES

Lacking the financial means to purchase less polluting cleaning systems and other protective means, the only thing that can influence the shipyard to use ecologically friendly abrasives is the economic cost-effectiveness. Therefore, the total cost of abrasive procedure needs to be calculated, and this may be presented by the following formula [4]

$$\text{total cost} = \frac{A*(B+C)+D+E}{Y} + F \quad (\text{p.u.} / m^2) \qquad (1)$$

where

A – consumption of abrasive (kg/h)
B – cost of abrasive (p.u./t)
C – cost of storage (p.u./t)
D – cost of equipment and labour (p.u./h)

Table 2.4.

	USE I	USE II	USE III	USE IV
Abrasive	50 kg	45 kg	40 kg	36 kg
Cleaning standard	Sa $2^1/_2$ to 3	Sa $2^1/_2$	Sa 3	Sa $2^1/_2$
Treated surface	2,75 m^2	2,00 m^2	1,70 m^2	1,7 m^2
Required time	9 min	7 min	6,5 min	6,5 min
Operating speed	18,35 m^2/h	17,14 m^2/h	13,84 m^2/h	13,84 m^2/h
Consumption of abrasive	333 kg/h	385 kg/h	369 kg/h	332 kg/h
Price of abrasive	4 000 kn/t	0 recycled	0 recycled	0 recycled
Price of disposal	95 kn/t	95 kn/t	95 kn/t	95 kn/t
Cost of equipment and labour	70 kn/h	70 kn/h	70 kn/h	70 kn/h
Cost of recycling	150 kn/h	150 kn/h	150 kn/h	150 kn/h

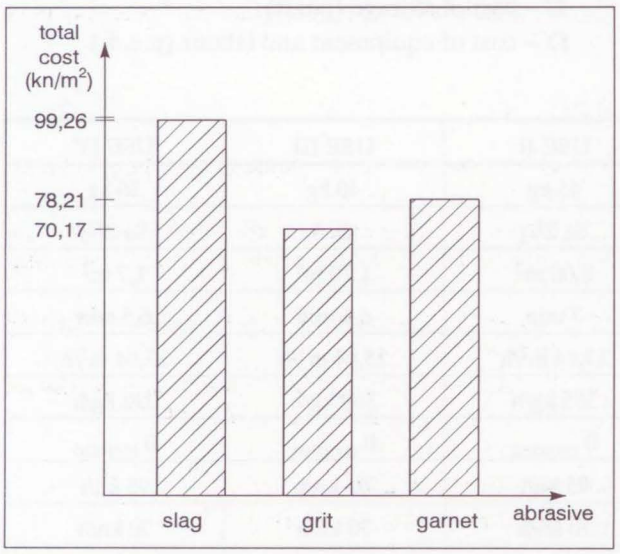
E – cost of recycling (p.u./h)
F – cost of reducing and controlling environmental pollution (p.u.)
Ψ – productivity (m^2/h).

The most important element of the total cost is productivity (Ψ) which depends on the material, operating method and used equipment. The size, form and especially the abrasive grain mass determine the efficiency of abrasion on steel, but the type of surface steel and its configuration need to be taken into consideration, too. The costs of reduction and control of environmental pollution are expenditures for various protective systems, first of all of the air in the form of protective curtains and cabins, for personnel training, for monthly, quarterly, or annual analyses of the shipyard impact on the quality of air and various studies on the possibilities of introducing the ecologically friendlier abrasive procedures. These expenditures are not necessary for the cleaning procedure itself, and their presence and amount are not regulated by rules, but they rather depend only on good will and ecological awareness of the shipyard and they are proportional to its economic power.

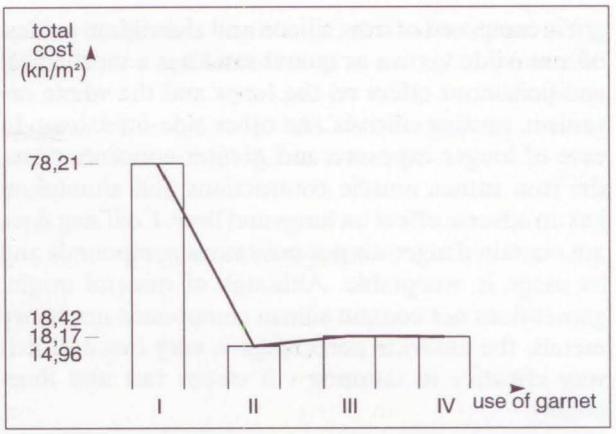
Using formula (1) the cleaning cost per square metre of using certain abrasives can be calculated, based on the tables 2.2. and 2.4.

The results are presented in graphs 3.1. and 3.2.

The cost analysis illustrates that, in spite of the fact that the price of garnet is almost double the price of coal slag (4000 kn/t to 2000 kn/t), the use of garnet provides a saving of 21.21% of the total actual cleaning cost per square metre. The total garnet cleaning cost is only by 8 kn/m^2 higher than the total grit cleaning cost, although the purchase price for garnet is 3 130 kn higher than the purchase price of grit. By comparing the obtained values it may be concluded that, apart from ecological, using garnet also offers



Graph 3.1 - Total costs of cleaning



Graph 3.2 - Total costs in multiple use of garnet

great economical justification. In multiple use the cleaning cost amounts to 32.44 kn/m^2.

4. POLLUTION REDUCTION MEASURES

Proper location of a shipyard may greatly reduce the polluting effect, first of all from the aspect of distance from a settlement and subjection to wind, but in the majority of shipyards this factor cannot be influenced since shipyards have been at the existing locations for a long time already. As an alternative, preventive measures are taken into consideration, in accordance with the selected abrasive, location, weather conditions and economic power, as well as recovery measures within the area in case of pollution.

4.1. Preventive Measures for Reducing Pollution

Preventive measures can be divided into three groups:
- developing regulations and their strict implementation in cleaning
- use of protective curtains i.e. closed space from the existing dry cleaning
- proper selection of abrasives whose usage causes minimal pollution.

Basic ideas regarding protective curtains which can completely or partly prevent impurities to spread in the atmosphere are the following:
- setting of curtains along the whole length of the ship and dock that would prevent dust and impurities from spreading, in combination or without the water curtain at the bow and stern of the ship at dock,
- cabin design allowing recuperation of a part of abrasives and impurities.

Efficiency of such curtains can reach up to 50%, whereas their great disadvantage is their short lifetime.

In accordance with the presented analysis, the use of metal instead of mineral abrasives is economically justified, i.e. when using mineral abrasives, they have to be regularly recycled. In selecting abrasives, it is necessary to calculate the actual total cost of the abrasive procedure.

4.2. Recovery Measures for Reducing Pollution

Situations when preventive measures fail or have not been even undertaken, result in polluting the environment - air, sea, improperly disposed waste material, as well as endangering the health of the workers, and of the whole neighbouring population. Recovery measures in such cases serve to prevent further pollution of the environment. In case that a great amount of polluted substance is generated in the form of floating particles, the cleaning must be immediately discontinued and the waste material safely disposed of. If it is not properly disposed of, it should be removed to a specially prepared place together with the ground surface which was beneath it, taking special care of ground porosity so as to avoid contaminating fresh water. Very often the waste material is used for filling in the landfills which may present great danger in case of fire, especially at times of high summer temperatures, since burning of ship paint generates poisonous gases.

Unfortunately, there are moments when recovery measures have a very low or no impact on the undesired pollution, e.g. when the abrasive substance together with the removed impurities end up in the sea, either by accident or on purpose, thus deposit on the sea bed and cause extinction of the flora and fauna, benthos and change the biotop. In accordance with reduced efficiency of recovery measures compared to preventive measures, it is more important to carry out the preventive ones, and to try and make the recovery measures superfluous.

5. CONCLUSION

Abrasive cleaning of ship plating as one of the basic shipyard activities, evidently causes environmental pollution. According to the amount of the treated surface and the used abrasive, shipyards are a link in the chain that requires our attention and action both at the county and government level, in order to protect the environment. In favourable weather conditions (low air dampness and no wind) the polluting effects of the considered shipyards in Martinšćica, Kraljevica, Cres and Mali Lošinj were present in the local region. Since the abrasive procedure is contracted in advance, and the weather conditions cannot be influenced, the pollution very often acquires a global character.

Taking into consideration the poor economic power and insufficient knowledge about using the substitute abrasives, the general opinion at the shipyards prevails that it is impossible to introduce more environmentally friendly cleaning systems. Apart from increasing the shipyard productivity and reducing the total cost of cleaning, thus increasing the profit, the right selection of abrasives which are environmentally acceptable and whose characteristics allow recycling can also reduce i.e. eliminate the polluting effects.

SAŽETAK

ASPEKTI SMANJENJA UTJECAJA BRODOGRADILIŠTA NA ONEČIŠĆENJE KVARNERSKOG ZALJEVA

Na području Kvarnerskog zaljeva locirana su četiri brodogradilišta u kojima se redovito, u pravilnim ili nepravilnim vremenskim razmacima provodi proces čišćenja trupa brodova. U pomanjkanju financijskih sredstava pri tom se najčešće koriste kruti abrazivi koji zbog svojih karakteristika uzrokuju znatno onečišćenje okoliša.

U ovom radu predstavljen je utjecaj pojedinih brodogradilišta, u skladu s količinom proizvedene usluge - obrađene površine u kvadratnim metrima, na globalno zagađenje Kvarnerskog zaljeva te preventivne i sanacijske mjere koje je na lokalnoj razini moguće provesti da bi se onečišćenje smanjilo.

REFERENCES:

1. ISO 8501-1:1988, SIS SS 055900, Wezäta, Göteborg, 1989., Sweden, ed. 3. p.5-6
2. The table has been formed on the basis of verbal data obtained at shipyards and rounded off for clearness and in such a way that the rounding off does not influence the final results of analysis
3. Shipyard Mali Lošinj
4. **Hansik, I. D.**: *Economics of Abrasive Selection for Shipyard Use*, Protective Coatings Europe, Vol.3, May 1998, p.25

LITERATURE:

[1] *Coating and Inspection Manual*, Jotun Paints, Sandefjord, Norway, 1997.

[2] **Hansik, I. D.**: *Economics of Abrasive Selection for Shipyard Use*, Protective Coatings Europe, Vol.3., May 1998.

[3] *ISO 8501-1:1988, SIS SS 055900*, Wezäta, Göteborg, 1989, Sweden, Edition 3,

[4] **Pariera, J.**: *Which Abrasive Sand, Slag or Garnet*, Protective Coatings Europe, Vol.3., May 1998

[5] www.westerngarnet.com

[6] www.gma.garnet.de/

[7] www.isrv.com/abrasive/blast.htm