Tampereen ammattikorkeakoulu

WESP Service Potential

Julius Korvela

BACHELOR'S THESIS
December 2022

Degree Programme in Mechanical Engineering
Aircraft Engineering

ABSTRACT

Tampereen ammattikorkeakoulu
Tampere University of Applied Sciences
Degree Programme in Mechanical Engineering
Aircraft Engineering

KORVELA, JULIUS:
WESP Service Potential

Bachelor's thesis 24 pages, appendices 6 pages
December 2022

The purpose of this study was to gather information about wet electrostatic precipitator of seagoing vessel for the use of Valmet Marine Services. WESP is a pollutant reducing product that is installed at the end of a flue gas line. At the time there were no Valmet WESP systems in marine use. The focus was on spare parts and maintenance need of WESP equipment. The main tool for information gathering was expert interviews. Information was used to assess the criticality of WESP parts by the means of criticality analysis tool. With the help of analyzed data and formerly known practices from supplied scrubber projects a two-year spare part list was formed.

The key findings were that WESP does not require much maintenance. The most critical parts were found from the emitter system. Interviews supplied relevant knowledge regarding the life-cycle management of the system. Criticality analysis including auxiliary equipment and two-year spare part list are recommended to be used when WESP system is sold and detailed equipment of the project is known.

Further research is recommended for safety perspective and its effects on criticality. The effects of marine environment on faultiness and durability of equipment are unknown which inflicts high uncertainty to true upkeep need.

Key words: wet electrostatic precipitator, criticality analysis, spare parts, maintenance

CONTENTS

1 INTRODUCTION

Interest for pollution reducing solutions is at rise in marine industry. Global regulations for the prevention of air pollution from ships are done by International Maritime Organization. It is expected that regulations will tighten in the future (Arctic Counsel 2021). Valmet Technologies Oy has launched new flue gas cleaning product **wet electrostatic precipitator** (WESP) for seagoing vessels in 2022.

At the starting point of this work there are no sold WESP systems in marine use. Product knowledge regarding WESP is limited in Valmet Marine Services. Goal of this study is to make clear maintenance and spare parts needs of WESP for better system life cycle management. To anticipate future service need it was decided that WESP service potential report needs to be done. Study should address criticality and consumption of spare parts in conclusion. Additionally, the study is meant to gather silent product knowledge for use of service organization.

Primary focus of this work is on precipitator itself and on parts that have something to do with actual cleaning of the flue gas. Case company has substantial experience with most of the subsystems of WESP system. Water treatment and water emission monitoring units of the discharge system are left out of this works scope.

2 VALMET TECHNOLOGIES OY MARINE SERVICES

Valmet provides Marine Services for their Marine Emission control and Marine Automation products. Marine Services improve vessel operation by optimizing performance, operation- and life cycle costs, safety, reliability, and reduced emissions. Valmet stands as a one-stop shop for marine services and adds value to customer by combining Valmet technology process and control system know-how. Valmet Marine Services is formed under Service Business Line in Valmet Technologies Oy.

Valmet Marine Services is located under two business units: PES and PER. Marine service is belonging to recovery and energy services technology unit (RST) in PES business unit. Marine service team of RST technology unit provides inspections, overhauls, maintenance, and training for supplied Valmet equipment. Marine spare parts is belonging to energy spare parts technology unit (ESP) in PER business unit. Marine spare parts team of ESP technology unit offers OEM spare parts for Valmet's own marine products. Products include automation systems and sulfur scrubber systems that reduce SO_X air emissions from flue gas. Newest product to join the line is WESP that removes **particulate matter** (PM) pollutants from flue gas. Valmet's global logistics network enables fast deliveries to every customer location be it port, shipyard, or forwarder warehouse. (Valmet Marine Services 2022)

3 WET ELECTROSTATIC PRECIPITATOR

Theoretical section explores issues that particulate matter causes on the environment and living organism's health. Chapter elucidates theory for questions; What is PM and what are the effects of it? What problem does utilizing WESP technology in marine industry fix?

Secondly this chapter explains how PM collection takes place inside WESP. Design possibilities and notes about different marine configurations are enlightened. Introduction to WESP system hierarchy and function of basic subsystems is also explained briefly.

3.1 Background

PM is a proxy indicator for air pollution. It affects more people than any other pollutant. Majority of PM is made of sulfate, nitrates, ammonia, sodium chloride, **black carbon** (BC), mineral dust, and water. It consists of a complex mixture of solid and liquid particles and compounds of organic and inorganic substances suspended in the air. (WHO 2021)

PM including BC pollutants have negative impact on climate change, environment and living organism's health (WHO 2012, 26; Arctic Council 2021, 23; WHO 2021). Air containing PM emissions absorbs more heat from sunlight because of pigment, thermal conductivity, and other material properties heating the air around them. As a result of winds PM can travel long distances in the air and end up on snowy surfaces or ice. This reduces reflectivity of the surface hence absorbing more energy from sunlight. Especially BC is dangerous for arctic environments and has strong effect on surface reflectivity. (EGCSA 2012, 15–23; Arctic Council 2021, 15) In marine business especially BC emissions are interest of international regulators since BC emissions are relatively high on big combustion engines that burn relatively low-quality fuel (International Chamber of Shipping 2022).

WESPs (Figure 1) are designed to remove liquids and particulate matter from water vapor saturated gases. Typical operation temperature range is between 50 to 160 °C (Rintanen 2022a). In marine designed vertical WESP temperature range is 30 to 50 °C in practice (Jokiluoma 2022b). They are very efficient at charging and collection of sub-micrometer particles. Commonly emissions below 1mg/Nm^3 have been measured after the WESP.

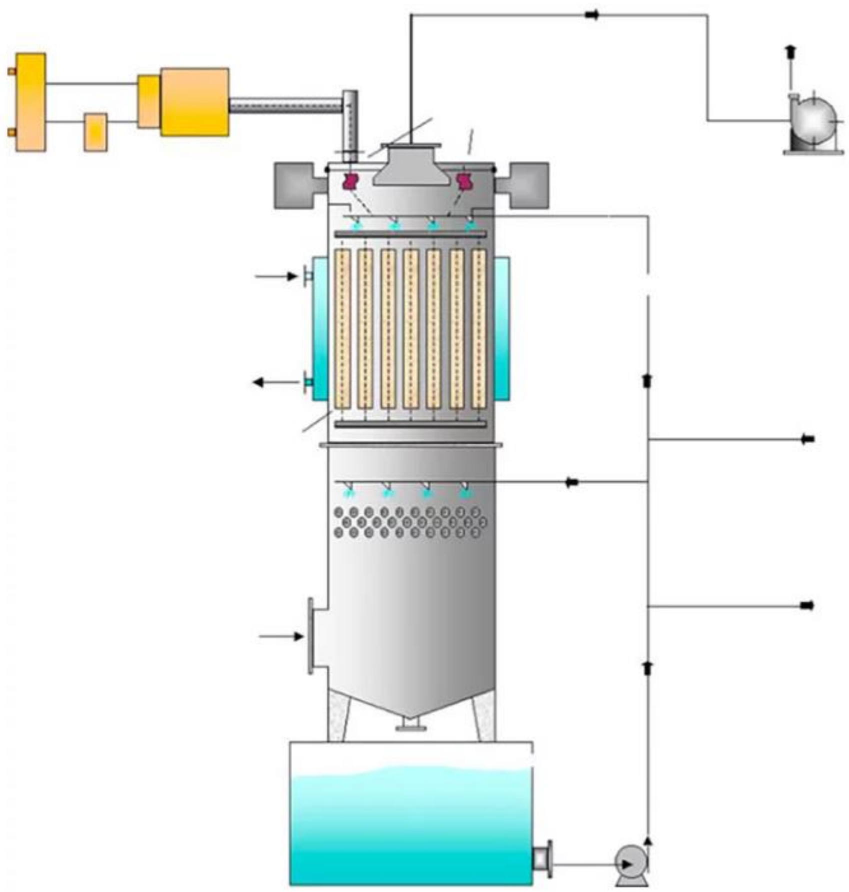

FIGURE 1. Illustrative drawing of WESP (AWS Corporation n.d.)

Visible plume from flue gas line creates clouds. In harbors these plume clouds can drift to inhabited territories effect on enjoyability of the environment. From customer's perspective this visual view might also cause hindrance to the brand. WESP systems capability to collect liquids from flue gas decreases visible plume (Jokiluoma 2022a).

Market for utilizing WESP technology in ships is the result of high interest in environment friendly and pollutant reducing solutions that many companies and their customers value. At the time there are no globally agreed international regulations for PM air emissions for ships as there are for SO_X air emissions (EGCSA 2012, 15–23; Jokiluoma 2022a).

3.2 Collecting PM from flue gas

Electrostatic precipitators (ESP) are a part of flue gas systems installed at the end of a flue gas line. Design and PM removal method of ESP can differ based on customer's demands and wishes. Designs are horizontal and vertical. Word indicates flue gas flow direction inside ESP.

Collection method can be either wet or dry (WESP or ESP). The main principal is the same for all: flue gas from the intake spreads evenly to the collection section where emitters or ionizing rods between collection surfaces emit high frequency high voltage electric field that ionizes flue gas (Figure 2). Plus-ions migrate towards negatively charged emitter and minus-ions migrate to the grounded electrode. On their way through the PM laden flue gas the ions collide and attach with the particles. Grounded collector pipes or collection surfaces attract charged PM to attach as result of law of attraction. Cleaned flue gas continues to outlet.

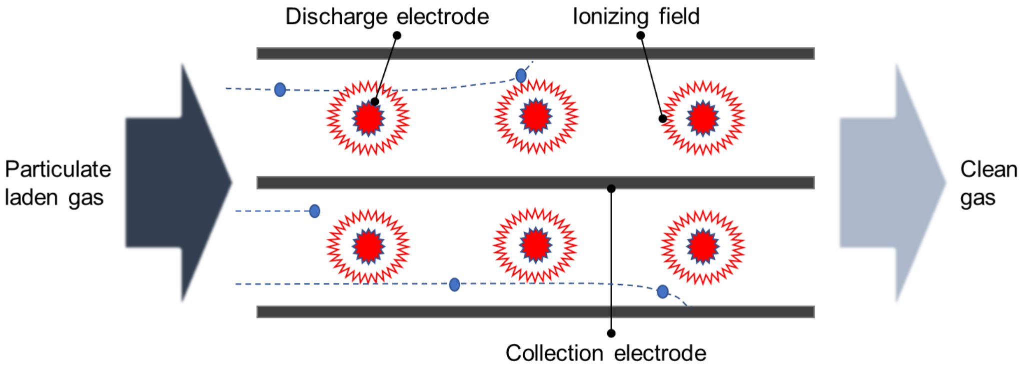

FIGURE 2. Collection of particles (modified from Dayley & Holbert 2003)

To remove matter from the collection surfaces system uses periodically either rapping hammers that inflict mechanical vibration to the surfaces (ESP) or water from washing nozzles to wash surfaces clean (WESP). Operation of WESP minimizes re-entrainment since the particles become captured in a film of liquid at the collection surface and are drained by gravity into the precipitator bottom (Rintanen 2022a).

WESP is installed at the topmost sections of the exhaust piping (Photo 1). Space in flue gas line of a ship is always limited. Tight fit is a challenge and vessels can have different flue gas handling systems in their towers. For example, space is very limited for WESP if scrubber is installed in the tower.

PHOTO 1. Top section in vessel exhaust gas tower (Valmet Oyj 2022)

3.3 System and subsystems

System hierarchies can be shown in many ways. They can describe system with processes or by equipment. By process different equipment in WESP system can be sorted to four subsystems which are

- emitter system
- feed water system
- flue gas control system
- discharge water system (Figure 3).

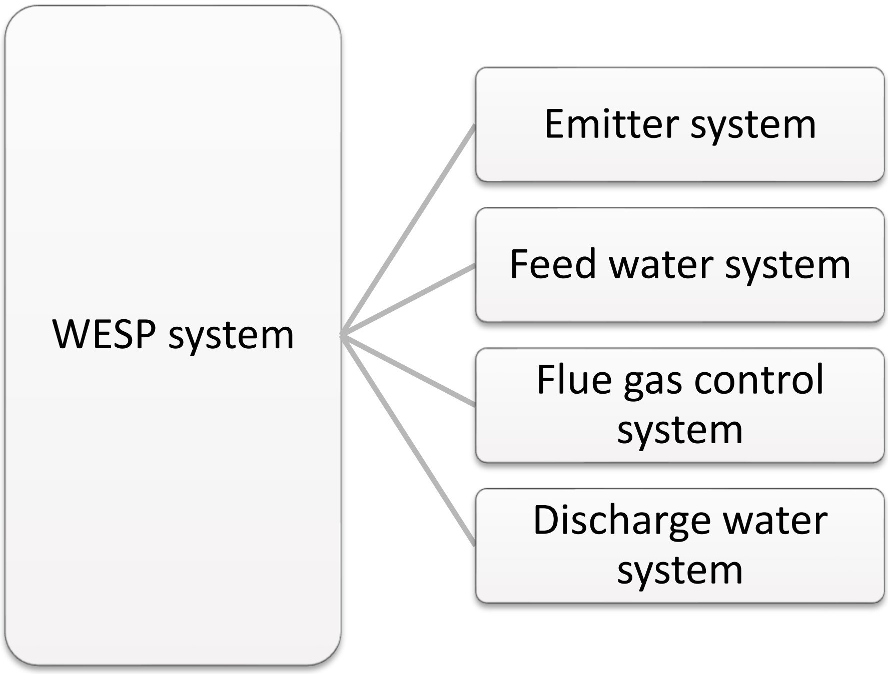

FIGURE 3. System hierarchy

Content of subsystems can vary from case to case because of different ship design. Most invariable subsystems are emitter system and flue gas control system. Possible flue gas scrubber before WESP has major influence on configuration. Examples are given in following passages.

3.3.1 Emitter system

Emitter system has a transformer/high-voltage rectifier (T/R) that creates high voltage electrical field in collection section of WESP. In current design of marine WESP there is one electrical field. One rectifier creates one field. Multiple fields are possible if there is more than one rectifier. Emitter frame connects rectifier to ionizing rods or emitters. If sparking emerges between ionizing rod (discharge electrode) and grounded collection surface (collection electrode) (Figure 2), rectifier decreases voltage output automatically. Best PM collection performance is right before sparking emerges. For this reason, emitter system is programmed to creep as close as possible to the critical sparking voltage. (Jokiluoma 2022b; Rintanen 2022a) Grounded collection surfaces are regarded as a passive structural part of WESP. Typically made from stainless steel they are formed by a bundle of pipes or a honeycomb passage for flue gas to flow through. Ionizing rods are placed in the center of each pipe or passage (Photo 2).

PHOTO 2. (Valmet Internal n.d.)

The emitter frame is supported by ceramic insulators to avoid short circuit via supports. Insulators must be intact and kept dry. Scavenge air fans provide insulators with warm purge air to keep insulators dry. Dielectric properties of insulator change unfavorably if moisture occurs in ceramic insulator making smaller voltage cause short circuiting.

3.3.2 Feed water system

Centre of the feed water system are wash water pumps that supply WESP with feed water. On/off valves allow or deny flow to washing or quench nozzles inside WESP. System can be run with sea water, fresh water, or recirculated water depending on configuration (Jokiluoma 2022b). Illustrative pictures of two different configurations can be seen in appendix 6.

Quench might be needed before collection section to decrease temperature and to increase humidity of flue gas. Alkali additive system can be added if feed water is recirculated back into the quench process. Added alkaline chemical keeps pH of recirculated water in check. Increase of alkaline neutralizes acidic sulfur oxides more efficiently. Quench stages are not needed if WESP is installed after flue gas scrubber since media is already water vapor saturated. (Jokiluoma 2022b)

3.3.3 Flue gas control system

Flue gas control system allow or deny flue gas flow through the WESP. Intake consists of dampers and field instruments. The dampers are actuated by actuators. They can also be switched from one position to other manually. Sealing air fans provide dampers with sealing air to keep them closed tight. Field instruments enable process control and surveillance.

In some cases, exhaust gas fan might be needed to ensure sufficient flow velocity if pressure drop is too high without it in the system. Deplume air fan can also be added to the system. Deplume air fan blows warm dry air to WESP outlet to decrease visible plume even more.

3.3.4 Discharge water system

Discharge valves allow flow of solution of water and cleaned pollutants to water/process tank from precipitator bottom. Dirty wash water is pumped back into the process or to water treatment system. Discharge water system can be joined to the existing water treatment system on vessel, for example when there is a scrubber onboard. In such a case the configuration is relatively simple.

Water treatment system and water emission monitoring units are one of the most maintenance needy equipment in WESP system. Wash water monitoring and discharge quality criteria is set in EGCS 2015 guidelines. Monitoring must be continuous which sets certain demands on upkeep. Water treatment system filters dirty wash effluent to form sludge and cleaned effluent. Filters are washed or replaced by manufacturer’s guidance to meet the criteria for cleaned effluent. PAH, turbidity, and pH measurements must be done before wastewater can be discharged to sea or stored in discharge effluent tank.

4 CRITICALITY OF SPARE PARTS

Acquiring information on critical parts of the equipment is paramount for preparation of faults and useability management of an equipment. Relevant knowledge leads to preventative action to address the risk that some factors produce (Popov, Lyon & Hollcroft 2016, 53).

In this chapter basic theory behind criticality analysis is explained. Finally, an example method is introduced to assess criticality with help of risk judging and weight factors.

4.1 Theory

Criticality is a character that is used to describe the size of the risk. In industrial surround an equipment or part is critical when risk related to the object is not acceptable. (Järviö, J. 2000, 2) Risk analysis is used to find such objects. It is a part of risk management which purpose is to identify risks and prevent damage. It determines the parts, characteristics, likelihood, and consequences of risks. Typical evaluated risk characteristics are:

- production loss
- safety effect
- environmental effect
- quality costs
- repair costs.

Evaluated risk can be anything that has value to the user or owner of the object in hand. (PSK 6800 2008, 4) Values are typically weighed so that different characteristics can have more, or less effect on total criticality (Appendix 1). In pollution reducing environmental solutions production loss can be seen as unused time when system should be running for the sake of environmental values. If down time causes monetary losses to the user – in example mandatory usage of more expensive fuel for the sake of system failure – preferred way would be to count production loss in currency.

In need spare parts availability is critical in reducing downtimes. Hence cost-effective inventory management that maintains high service level for critical spare parts is essential for maintenance efficiency. (Iravani & Seyed 2021, 15.11.5.) Risk analysis or criticality analysis can be used when developing maintenance plan or at procurement phase to determine characteristics, acceptance criteria, storing, and needed quality for critical equipment (PSK 6800 2008, 5).

4.2 Criticality analysis tool

In this passage criticality analysis tool (CA-tool) is introduced. Intent of CA-tool is to help go through chosen objective's all spare parts systematically and efficiently transfigure expert's knowledge into easily interpreted form (Rinkinen 2017, 22). For most industrial equipment basic risk characteristics used in criticality analysis are production, environment, and safety. This passage is based on master's thesis ''Development and Implementation of Criticality Analysis Tool for Spare Parts of Fluidized Bed Boiler'' by Rinkinen Pyry. For more detailed background information about CA-tool see mentioned master's thesis.

CA-tool is first filled with objects that are put under criticality review. User estimates greatness of risk characteristic in hand for every object (Table 1; Table 2; Table 3). CA-tool turns selection into numeric value. Numeric values will be calculated together to generate the risk priority number RPN_X (Equation 1).

$$RPN_X = RPN_P \text{ v } RPN_E \text{ v } RPN_S \tag{1}$$

TABLE 1. Production stop risk R_p scale and effect options (Rinkinen 2017, 24)

Risk description	**Consequences on production (R_p)**	**Numeric value**
Extreme risk	Production stop more than a week	R_{p5}
High risk	Production stop less than a week	R_{p4}
Moderate risk	Production stop less than three days	R_{p3}
Low risk	Reduced production	R_{p2}
Minimum risk	No effect to production	R_{p1}

TABLE 2. Environmental risk R_e scale and effect options (Rinkinen 2017, 25)

Risk description	Consequences on environment (R_e)	Numeric value
Extreme risk	Serious off-site environmental impact	R_{e5}
High risk	Significant off-site environmental impact	R_{e4}
Moderate risk	Some local environmental impact	R_{e3}
Low risk	Minor environmental impact	R_{e2}
Minimum risk	No environmental impact	R_{e1}

TABLE 3. Safety risk R_s scale and consequence options (Rinkinen 2017, 26)

Risk description	Consequences on production (R_s)	Numeric value
Extreme risk	Fatality	R_{s5}
High risk	Serious injury or illness with permanent disablement	R_{s4}
Moderate risk	Significant injury or illness with sick leave	R_{s3}
Low risk	Medical treatment	R_{s2}
Minimum risk	Minor injury	R_{s1}

Severe consequences do not always mean high criticality. As in a case where probability for risk to come true is minimal. Criticality is a product of greatness and probability of the risk (PSK 6800 2008, 2). For each risk probability must be assessed according (Table 4).

TABLE 4. Options of probability for production loss, environmental effect, and safety consequences (Rinkinen 2017, 23)

Probability description	Probability options (P_n)	Numeric value
Very likely	once per year	P_{n5}
Likely	once per 1–2 years	P_{n4}
Possible	once per 2–5 years	P_{n3}
Unlikely	once per 5–10 years	P_{n2}
Very unlikely	once per 20 years	P_{n1}

For each characteristic risk priority number RPN_X is counted (Equation 2; Equation 3; Equation 4).

$$RPN_P = R_p P_p \tag{2}$$

$$RPN_E = R_e P_e \tag{3}$$

$$RPN_S = R_s P_s \tag{4}$$

In addition to risk priority numbers CA-tool uses fuel factor *F*, location factor *L* and delivery factor *D* to calculate final criticality score. Fuel factor is meant to take the effect of variety of used fuel into account. Location factor takes the effect of geographic location of the site into account. It effects every parts criticality score as a constant. Different location factor options can be seen in table 5.

TABLE 5. Location factor options

Location factor description	**Numeric value**
Long distance, hard to deliver (> 4 weeks)	L_4
Long distance, easy to deliver (> 3 weeks)	L_3
Short distance, hard to deliver (> 3 day)	L_2
Short distance, easy to deliver (< 3 day)	L_1

Delivery factor is formed by lead time from manufacturer to case company warehouse. Longer lead time results to higher criticality score. For object under review total criticality score *C* is demonstrated in equation (5). (Rinkinen 2017, 32–46)

$$C = \sum RPN_n + F + L + D = RPN_P + RPN_E + RPN_S + F + L + D \tag{5}$$

5 EMPIRICAL PART

The target of this work is to clarify service and spare parts need for a new marine pollutant reducing product WESP. With gotten results warehouse management of case company and onboard stock management of the end user ship regarding WESP parts is expected to be easier.

First in this chapter starting point and progression of the study is looked over. Different used tools and project limits are addressed. Due to business sensitive information detailed final product cannot be shown.

5.1 Starting point and plan

Work needed to address spare parts criticality and consumption as well as to know how maintenance requiring WESP equipment is. Case company has WESP experts working on-land projects and design team had some knowledge regarding marine configurations so gathering information and WESP training took place. Main tool for information gathering was expert interviews. Interview schedule can be seen in appendix 2.

Relevant for case company was to know spare parts and service need for WESP equipment. Criticality analysis was deemed necessary to get clear idea of spare part consumption and system downtime risks if spare parts were not available onboard – or in other words – if they should be onboard. Auxiliary systems in WESP are similar with scrubber system. In addition, two-year spare parts list utilizing criticality analysis and scrubber know-how was required.

Emission monitoring unit and water treatment unit of the discharge water system were limited out of this thesis work since case company has already clear picture on service and spare part need for those systems. Lastly the results should be reviewed before handout.

5.2 Execution

Expert interviews

Expert interviews took place throughout execution period. Case company WESP training and internal material review also took place. Main frame for WESP topic interviews was the same. Following titles were addressed:

- equipment criticality
- spare parts criticality
- spare parts consumption
- process clarification (by expertise)
- mandatory equipment clarification (by expertise)
- comparability with on-land WESP

Each interviewee was also questioned uniquely regarding their expertise to get a clearer picture on possible effects of marine environment and on auxiliary systems configurations and criticality to aid making of two-year spare part list. Interview schedule can be seen in appendix 2.

Criticality analysis tool

Criticality analysis was made using CA-tool from previously made master's thesis work in 2017. Tool is made using computer application Microsoft Excel. Spare parts for WESP were received from pilot case WESP supplier. Intent was to go through systematically all the spare parts of WESP and to transfigure expert's knowledge into criticality score. For each spare part risks were estimated (Chapter 4.2) and different factors like fuel, location and delivery factors were used. A table with final criticality score for each part (Table 6) to display criticality distribution was formed as an output. Parts were sorted in three criticality levels by score.

TABLE 6. Encrypted table of output window

Row ID	Item code	Equipment	Item description	Criticality score	Criticality level	Qty	Unit
1		**Equipment 1**					
2	-		Part 1	[redacted]	III	-	pcs
3	-		Part 2	[redacted]	III	-	pcs
4	-		Part 3	[redacted]	II	-	set
5	-		Part 4	[redacted]	II	-	pcs

6	-		Part 5		[redacted]		II	-	pcs
7		**Equipment 2**					0		
8	-		Part 6		[redacted]		II	-	pcs
9	-		Part 7		[redacted]		II	-	pcs
10		**Equipment 3**					0		
11	-		Part 8		[redacted]		II	-	pcs
12	-		Part 9		[redacted]		II	-	pcs
13	-		Part 10		[redacted]		II	-	pcs
14	-		Part 11		[redacted]		II	-	pcs
15	-		Part 12		[redacted]		II	-	pcs
16	-		Part 13		[redacted]		II	-	pcs
17	-		Part 14		[redacted]		II	-	pcs

Two-year spare parts list

List is created to taken example of when WESP system is sold, and all detailed equipment information is known. List was formed using two different tools – CA-tool and scrubber method – and with expert interviews in mind. If criticality level (Figure 4) was ≥ 2 the part was going on the two-year spare part list. Objects that scored to level three should have more than 50% coverage of the installed quantity on the list. For level two objects less than 50% coverage was suffice. Criticality level one means object is not going on two-year spare part list. Final quantity per object was determined separately but rules above were followed.

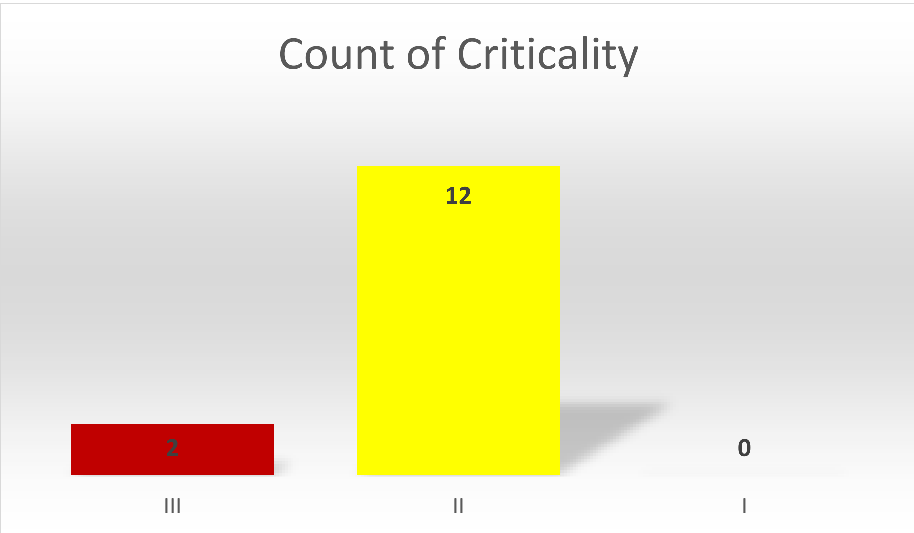

FIGURE 4. Count of criticality

Auxiliary systems have a lot in common with marine WESP and scrubber systems. It was seen efficient and reasonable to use scrubber method (Appendix 3) with WESP auxiliary systems. Two-year spare parts list can be found in appendix 4.

Maintenance need

Expert interviews results were that WESP does not require much maintenance. Closer inspections are usually done by customer or interest for them is raised by customer (Engels 2022). Good to check items are

- part 2
- connections from frame supports to emitter frame
- part 7
- emitter frame connections to ionizing rods
- condition of collection section surfaces.

Suggested action after inspections is usually cleaning of ceramic insulator chamber and changing part 2 and part 7 (Table 6) (Engels 2022). There are no wear parts inside WESP (Rintanen 2022b; Engels 2022). Periodic consumption of spare parts is limited outside precipitator.

Review

Used parameters and factors in CA-tool for each part was reviewed when work was deemed near completion. At this point very small changes were made and total count of criticality (Figure 4) did not change for the parts in hand. Two-year spare part list was also reviewed. Due to possible different configurations notes were added to the list to ease necessity determining. One part was deleted completely but none were added.

6 DISCUSSION

In this thesis expert interviews played a substantial role. They provided ''silent knowledge'' from outside of boundaries of service organization. Data is not comparable with other sources. Repeatability of analysis from data is not possible due to highly empirical and qualitative aspects of this study. Information is also under prejudice of interviewer and interviewee. Interviewer's prejudice might have effects on choosing interviewees and deciding what questions are worth asking. Because there is no empirical experience on marine WESPs, the prejudice of each interviewee might have effect on their answers and thoughts. For example, effects of marine environment on wear. Regardless of these faults, qualitative prospect of the study was deemed more important than gathering of quantitative and repeatable data.

The results of the criticality analysis are not absolute. Analysis always illustrates completer's interpretation of the case and data. Data is also impacted by the tool or software maker's interpretation through used parameters. Criticality analysis tool that was used is made for boilers. This was not seen problematic since focus was on production loss or down time avoidance. Completed criticality analysis resembles best guess of the suppliers that would be involved in the project at the time of this works execution. Location factor was chosen based on most promising clientele: cruise ships. Cruise ships are generally frequently visiting ports at big cities where shipping is relatively fast from warehouse of case company. Fuel factor was used if part under review were in direct contact with flue gas. Effects of location and fuel factor were low on total criticality of the parts.

WESP spare parts need evaluation for two-year spare part list was done using results of criticality analysis. Spare parts of auxiliary equipment were added after scrubber method which is used with newly supplied scrubber projects. Basis to assess spare part need was either criticality, wear, or harshness of marine environment – like strong vibration – that has seen to have negative effect on some equipment (Friman 2022; Rintanen 2022; Salmi 2022). In addition, the list takes usual maintenance instructions or suggestions of equipment manufacturer into account. Content of final product is not absolute due to variables between different capital projects (ships). Different configurations and possible design details cause irregularities. Two-year spare part list should be used as a reference to ease making of final list that is relevant for final design of sold WESP system.

At the time when new WESP system is sold to customer, new criticality analysis is encouraged to be done when detailed scope is known. Auxiliary equipment or subsystems that were left out of scope of criticality analysis is recommended to include in. Valmet warehousing is recommended for criticality level three objects.

This work focused on productivity and avoidance of down time when the interviews were done. A survey regarding personnel’s wellbeing and safety when maintaining or operating near WESP is seen as a possibly useful subject. Especially safety point of view with high voltage emitter system should be taken into consideration.

LÄHTEET

Arctic Council. 2021. Expert Group on Black Carbon and Methane - 3rd Summary of Progress and Recommendations. Read on 20.10.2022. https://oaarchive.arctic-council.org/handle/11374/2610

AWS Corporation. n.d. Wet Electrostatic Precipitator. Website. Read on 5.11.2022. https://www.awscorp.it/en/products/air-pollution-control-systems/16-aerosol-spray-and-mist-separation/37-wet-electrostatic-precipitators-wesp

Dayley, M. & Holbert, K. 2003. Electrical Precipitators for Power Plants. Arizona State University. Accessed 1.12.2022

EGCSA. 2012. A practical guide to exhaust gas cleaning systems for the maritime industry. Handbook. Sustainable Maritime Solutions. Accessed 30.11.2022

Engels, T. 2022. Interview 4.10.2022. Tampere.

Friman, E. 2022. Specialist, Electrification & Automation, P&E Energy ES ESP Technology. Interview 4.10.2022. Tampere.

International Chamber of Shipping. 2022. Black Carbon: the next frontier. Webpage. Read on 20.10.2022. https://www.ics-shipping.org/current-issue/black-carbon-the-next-frontier/

Iravani & Seyed, M. R. 2021. Operations Engineering and Management: Concepts, Analytics, and Principles for Improvement. 1st ed. New York: McGraw Hill. Accessed 20.10.2022. https://www.accessengineeringlibrary.com/content/book/9781260461831

Jokiluoma J. 2022a. Product Manager, P&E Energy ES Technology. ESP Training for Marine Team. Lecture 10.2.2022. Microsoft Teams. Tampere.

Jokiluoma J. 2022b. Product Manager, P&E Energy ES Technology. Interview 5.7.2022. Tampere.

Järviö, J. 2000. Luotettavuuskeskeinen kunnossapito. 1st edition. Helsinki: Kunnossapitoyhdistys ry.

Leimeister M. & Kolios A. 2018. A review of reliability-based methods for risk analysis and their application in the offshore wind industry. Renewable and Sustainable Energy Reviews. Volume 91. Pages 1065-1076. Accessed 20.11.2022. https://doi.org/10.1016/j.rser.2018.04.004

Popov, G., Lyon, B. K. & Hollcroft, B. 2016. Risk assessment: a practical guide to assessing operational risks. E-book. New Jersey: John Wiley & Sons, Incorporated. Accessed 20.11.2022 https://ebookcentral.proquest.com/lib/tampere/detail.action?docID=4538959

PSK 6800. 2008. Criticality Classification of Equipment in Industry. PSK Standards Association. Read on 20.10.2022 https://psk-standardisointi.fi/wp-content/uploads/psk6800_liitteineen.pdf

Rinkinen, P. 2017. Development and implementation of criticality analysis tool for spare parts of fluidized bed boiler. Faculty of Engineering Sciences. Tampere University of Technology. Master's Thesis. Read on 25.9.2022. https://urn.fi/URN:NBN:fi:tty-201704201327

Rintanen, J. 2022a. RTD Manager, P&E Energy ES Technology. ESP Training for Marine Team. Lecture 1.2.2022. Microsoft Teams. Tampere.

Rintanen, J. 2022b. RTD Manager, P&E Energy ES Technology. Interview 1.9.2022. Tampere.

Salmi, J. 2022. Project Engineer, Spare Parts, Marine and Operations Development. Interview 1.11.2022. Tampere.

Valmet Internal. n.d.

Valmet Marine Services. 2022. Website. Read on 24.9.2022. https://www.valmet.com/more-industries/marine/marine-services/

Valmet Oyj. 2022. Website. Read on 24.11.2022. https://www.valmet.com/media/articles/marine/valmet-wesp-chosen-as-2022-seatrade-maritime-award-finalist/

WHO. 2012. Health effects of black carbon. Janssen, N. A. H., Gerlofs-Nijland, M. E., Lanki T., Salonen, R. O., Cassee, F., Hoek, G., Fischer, P., Brunekreef, B. & Krzyzanowski, M. Report. World Health Organization. Regional Office for Europe. Read on 22.10.2022 https://apps.who.int/iris/handle/10665/352615

WHO. 2021. Ambient (outdoor) air pollution. Fact sheet. Read on 22.10.2022. https://www.who.int/news-room/fact-sheets/detail/ambient-(outdoor)-air-quality-and-health

APPENDIXES

Appendix 1. PSK6800 Appendix 1, example of risk analysis

Unit
Object of classification
Prepared by
Version
Date

Criticality limit 400
Weighting factor of production loss Wp 100

Identifier of object	Name of object	Time between failures (1…8)	Safety risks (0…16)	Environ-mental risks (0…16)	Production loss (0…4)	Quality costs (0…4)	Repair costs (0…4)	Criticality index	Criticality sub-indexes				
		Weighting W -->	30	20	100	30	20	K	Ks	Ke	Kp	Kq	Kr
								0	0	0	0	0	0
								0	0	0	0	0	0
								0	0	0	0	0	0
								0	0	0	0	0	0
								0	0	0	0	0	0
								0	0	0	0	0	0
								0	0	0	0	0	0
								0	0	0	0	0	0
								0	0	0	0	0	0
								0	0	0	0	0	0
								0	0	0	0	0	0
								0	0	0	0	0	0
								0	0	0	0	0	0
								0	0	0	0	0	0
								0	0	0	0	0	0
								0	0	0	0	0	0
								0	0	0	0	0	0
								0	0	0	0	0	0
								0	0	0	0	0	0

Appendix 2. Interview schedule

Name	**Expertice / Title**	**Date**	**Topic**
J. Jokiluoma	P&E Energy ES Technology / Product Manager	5.7.2022	WESP
J. Rintanen	P&E Energy ES Technology / RTD manager	1.9.2022	WESP
E. Friman	Electrification & Automation / Specialist	4.10.2022	WESP, Electrics
T. Engels	Pilot case WESP supplier representative	24.10.2022	WESP
J. Salmi	Spare Parts, Marine and Operations Development / Project engineer	1.11.2022	Auxiliary systems
J. Jokiluoma	P&E Energy ES Technology / Product Manager	9.11.2022	Review

Appendix 3. Scrubber method

Appendix 4. Two-year spare part list

Appendix 5. Output list of CA-tool

Appendix 6. Different configurations of WESP