Circular Asset Management - Conceptual Model and Applications in case studies of Process Industry

HZ University of Applied Sciences – Research groups Asset Management and Data Science

Researchers Padraig Naughton and Albert Repko

June 2023

Article 2 – Results of case study WP 5.1 – Minimization of the release of waste during industrial cleaning (part 1) – methodology to assess environmental impact

ABSTRACT

In the context of the Interreg project Circular Maintenance, the research groups Asset Management (AM) and Datascience (DS) of the HZ University of Applied Sciences (HZ UAS) have conducted research in close cooperation with involved companies into the development of instruments for the effective and efficient implementation of circular maintenance within the process industry. Several products have been delivered. From a theoretical perspective a top-down framework with tools, with a clear line of sight from strategic, tactical to operational level. Known from the Asset Management field, but with a clear translation into steering on sustainability objectives. Measurement models have been drawn up to quantify the KPIs Circularity and CO_2 emission. The theory has been tested in practice in a case study. In that case study minimization of the release of waste during industrial cleaning was considered. The considered problem was that at the start of the research a solid assessment model of industrial cleaning on the basis of the sustainability criterion was not yet available. The overall goal was to minimize the release of waste during industrial cleaning in the process industry. To limit the work and make the research concrete and applied, but still illustrate the approach, the scope is narrowed down to the case of reducing the waste during the cleaning of shell-tube heat exchangers. The research is set out in 3 articles. In this second article the application of the theory of article 1 in this heat exchanger cleaning case study is considered; it describes the development of the methodology to assess the environmental impact of the industrial cleaning process. (Later a third article will be published that presents the results of the follow-up study dealing with a further refined and more advanced decision model.)

Overview of articles

Article 1 – Theoretical Framework, and Research Method

Article 2 – Results of wp 5.1 part 1   ⬅️ Current article

Article 3 - Results of wp 5.1 part 2, Discussion, Conclusions and Recommendations

Context

At present, a multitude of techniques are used in the process industry for cleaning industrial equipment, machines, tools, etc. The performance of these methodologies is still insufficiently controlled and assessed in terms of sustainability. Although it is known that cleaning produces a relatively large amount of waste and requires a significant amount of energy, there is insufficient insight into which of the current cleaning methods and processes is the most sustainable one.

Relevance

This is because steering towards sustainability objectives is still relatively new and needs to be developed. There is a need for a methodology to minimize the release of waste during industrial cleaning. And since this is still relatively new ground, it must be built up step by step from the bottom up. This research is a first step in this regard.

Problem

A solid assessment model of industrial cleaning on the basis of the sustainability criterion is not yet available.

Goal and objectives

The overall goal is to minimize the release of waste during industrial cleaning in the process industry. To limit the work and make the research concrete and applied, but still illustrate the approach, the scope is narrowed down to the case of reducing the waste during the cleaning of shell-tube heat exchangers.

The objectives of the present study are:

- the set-up of a decision-model with which a clear objective assessment can be made between the cleaning methods and processes that are currently used in the process industry on the basis of the sustainability criterion;
- the development of a measurement model with which the environmental impact of this maintenance measure can be determined;
- the actual application (and validation) of these models for the heat tube exchanger cleaning.

Note:

As described in the previous Theoretical Framework as outlined in article 1 to fully achieve the above goal additional works will be needed, for instance corresponding sustainability performance requirements still need to be defined in order to be able to assess the performance of the cleaning works. This is further discussed in the recommendations.
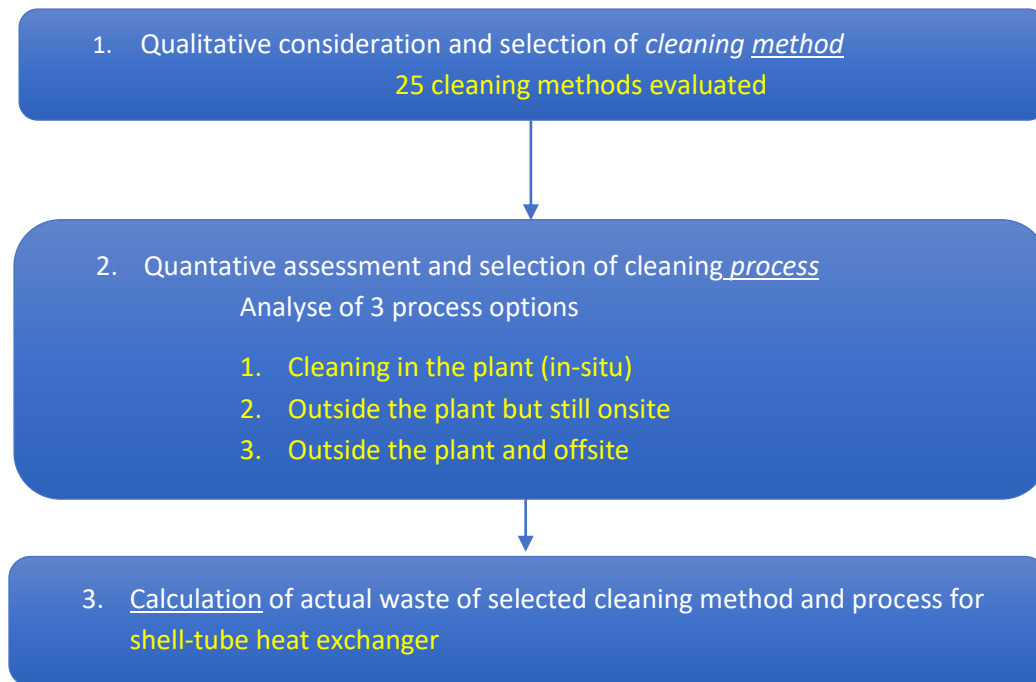
Research questions (of this case study):

As mentioned, this research is multi-part, therefore two research questions:

- *What does the decision model look like for effectively selecting the best cleaning method and process of the heat tube exchanger, based on the applicable sustainability criteria and operational aspects of the cleaning works?*

- *How should the environmental footprint of the cleaning activities be determined, and what does its quantification look like in concrete terms?*

Summary of the Approach:

The approach has been divided into three main steps based on the previous objectives:

Table 1 - Flow chart research works of wp 5.1

1. Qualitative consideration and selection of *cleaning method*
   25 cleaning methods evaluated

2. Quantative assessment and selection of cleaning *process*
   Analyse of 3 process options
   1. Cleaning in the plant (in-situ)
   2. Outside the plant but still onsite
   3. Outside the plant and offsite

3. Calculation of actual waste of selected cleaning method and process for shell-tube heat exchanger

As illustrated, step 2 is based on the cleaning method chosen from step 1. Where step 1 only focusses on the cleaning method itself, step 2 zooms out and determines the environmental impact of the total cleaning process. In this consideration a trade-off is made between cleaning in the plant (in-situ), outside the plant but still onsite or offsite (= on external location outside site).

Method

What are the research steps more in detail? How is the best cleaning method determined for the heat exchanger in detail?

1. Qualitative consideration and selection of cleaning method

Given the content of the cleaning process, the sustainability aspect has been considered by looking at water usage, energy consumption, and chemical usage. Similar to the risk priority number (RPN) as used in FMECA applications, an equivalent '"RPN number" is defined with which the environmental impact of the previous three factors has been taken into account. It is simply defined as:

RPN = Water usage (1-10) × Energy usage (1-10) × Chemical usage (1-10)

The rating 1-10 (ranging from negligible "1", to extremely high "10") is determined qualitatively. Based on this RPN score, the cleaning methods are ordered, with the one with lowest RPN obviously being the most environmental friendly. Furthermore in addition a qualitative assessment has been made to what degree the water that is being used for cleaning is being recycled (0-100%) and to what degree the residue can be re-used (0-100%). Obviously the latter should be included in the former RPN scores to get a fair comparison.

2. Quantitative assessment and selection of cleaning process

As said to be complete, all parts/ aspects of the cleaning procedure should be considered.

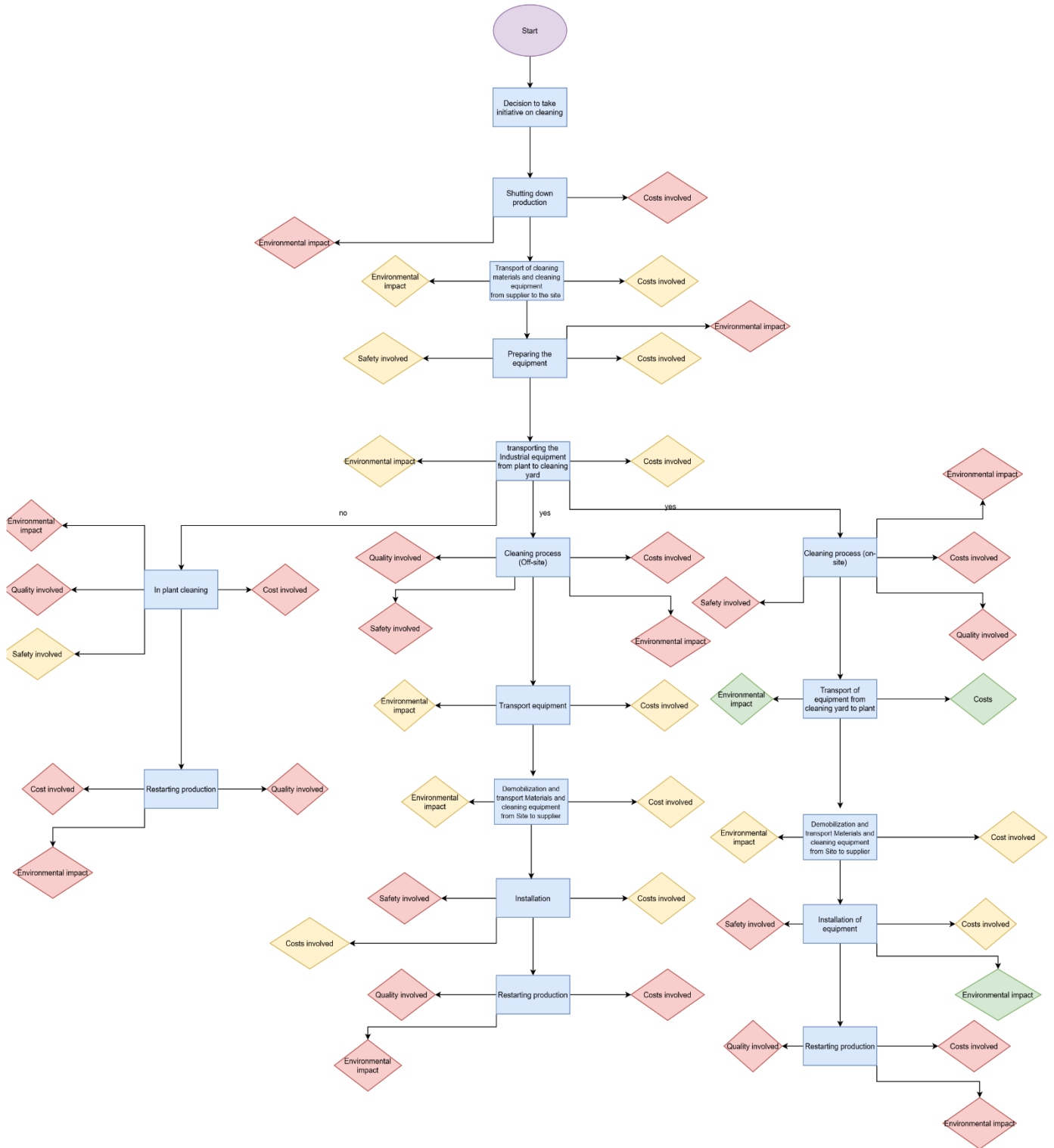The process can be visualized in a flow chart as show in figure 1.
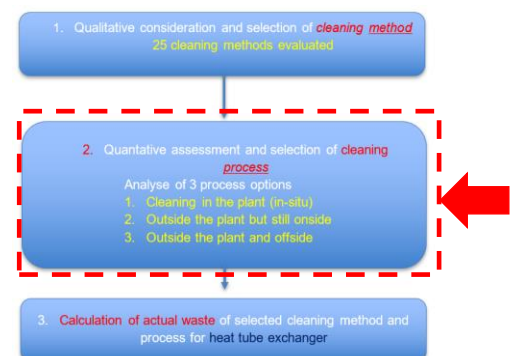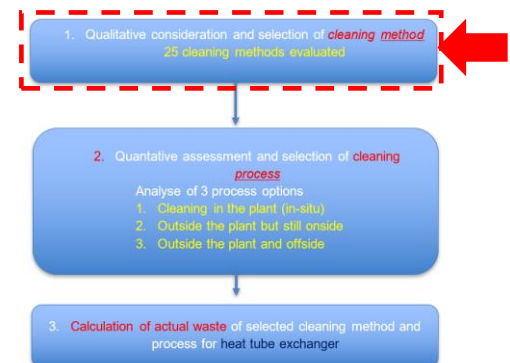
Fig. 1 Process decomposition: Flow chart of total process of 3 alternative methods of industrial cleaning, in-plant, on site, and off site.

Besides environmental impact, the total cleaning process can of couse also be assessed by looking in addition to all relevant RAMSHEEP (key) performance indicators, or more stripped down to essentials like safety, costs, and quality as shown in the above figure. However, as this present report primarily focusses on sustainaiblity, the latter will not be discussed in detail here.

The choice between an *in plant*, *on site* or *off site* cleaning process is determined by the asset owner together with the cleaning company, looking at feasibility, costs, time and relative complexity of the cleaning process versus the operation of the asset.

3. Calculation of actual waste of selected cleaning method and process for shell-tube heat exchanger

Quantification of environmental impact:

The following parameters will be considered during quantification:

1- Energy usage: estimates are made of the energy used at each step of the work process. Based on the energy use, a CO_2 equivalent can be calculated. This may be electrical energy, diesel fuel etc.

2- Water usage: For most of the mechanical methods in use in cleaning shell-tube heat exchangers, water is a very frequently used, in the form of high-pressure cleaning. Water usage is a significant element in the environmental impact factor. The water used can be collected, but is normally polluted and treatment is needed to recover clean water. leading to a higher carbon footprint.

3- Chemical usage: Chemical cleaning method are some of the most effective cleaning methods that are in place in the cleaning industry. However, if the chemical cleaning residue is not handled properly, or the chemical cleaning itself is not handled properly, then the environment impact could be high. For this reason, chemical cleaning is a strong element when it comes to quantifying the environmental impact and circularity factor. On the other hand chemical cleaning can be very efficient and effective, resulting in a lower overall environmental effect.

4- Fuel: This is considered under energy usage, but it is worth mentioning that apart from the fact that some cleaning methods require fuel for them to function, some of the other parts of the total process require fuel, such as transport. The burning of fuel, depending on which fuel, could cause various concerns for the environmental impact and pollution by leading to the release of gases such as carbon monoxide, carbon dioxide and nitrogen oxides. It is an essential part when providing the cleaning service and needs to be carefully considered when quantifying the environmental impact and circularity factor.

5- Recycling waste water: Water usage is in itself an important aspect, as mentioned above. However, special attention should be paid to treatment and recycling of the water. Reuse of the water will contribute to circularity, but the process of recycling is also a result of the cleaning action and needs to be included in assessments. This is a strong element for the circularity part of the total factor.
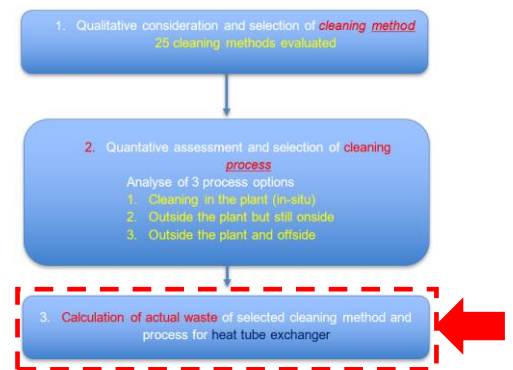
6- [Residue disposal](#): Once the recycling process has taken place the residue must be taken care of properly. Since 99% of the residue cannot be put to use, the residue is then disposed of. the effects of disposal are, for instance incineration, also need to be considered.

7- [Incineration](#) As mentioned before the final product of the cleaning process is a final residue. However, re-using the residue is not always an option at times which would lead us to destroying the final waste which could be done through burning it. This of course affects the environmental impact factor due to the fuel levels used and potential emissions.

Results

- *What are the results, what is the preferred cleaning method and why?*

1. Qualitative consideration and selection of cleaning method
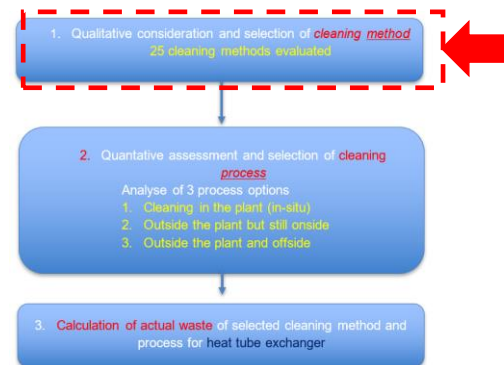
An extensive study of a total of 25 cleaning methods has been carried out, see figure below.

This has been done for a wide range of equipment, besides heat exchangers, including the cleaning of tanks/ vessels, boilers/ furnaces, piping, cooling towers and others. The total matrix covering all this equipment is enclosed in *appendix I*. The figure below only shows the decision matrix regarding the cleaning of [the shell and tube heat exchanger](#); to limit the scope of the works this is the only equipment whose cleaning has been further studied in the following quantitative assessment of the cleaning process in step 2.

*Table 2 Qualitative assessment and selection of **cleaning method***

	1- Tube Darting & Scraping	2- 3D- Nozzle	3- Rotating Hose Devices	4- Water Jetting (UHP)	5- Automated Indexer	6- Pigging/Smart Pigging	7- Ultrasonic Fouling Prevention (depends size)	8- Abrasive Blasting	9- Drilling (Rodding)	10- Hydrokinetic Cleaning	11- Manway Cannon	12- Remotely Operated Vehicles	13- Acidizing	14- Degreasing	15- Decontamination	16- Ultrasonic Bath	17- Laser Cleaning	18- Pyrolysis	19- CO2 Blasting	20- Liquid Nitrogen Jetting (Fouling must be dried)	21- Washing/Flushing with Low Pressure Water	22- Sodium Bi-carbonate Blasting	23- Brushing Dry	24- Brushing Wet	25- Vacuum, blowing, suction techniques
Heat Exchangers																									
Shell and Tube																									
- Bundle	9	O	70	48	8	O	30	3	40	18	O	O	27	27	9	30	O	10	O	O	O	O	O	5	21	O
- Shell	O	60	70	48	O	O	30	O	O	O	O	O	27	27	9	30	10	10	O	O	O	O	O	O	O
- Heads & Channels	O	60	O	48	O	O	30	O	O	O	O	O	27	27	9	30	10	10	O	O	O	O	O	O	5

The numbers in the figure are the RPN numbers of the cleaning method, obviously the ones with smallest value are the preferable methods from a sustainability perspective. For instance Abrasive Blasting scores best and is therefore preferred. The final decision on the choice of method is, however, dependent on many other factors. So the experts will need to weigh up what is possible. This assessment gives input to allow the environmental aspects to be included in the decision.

Additional background information:

The **straight-tube heat exchanger**:   *The selected equipment whose cleaning has been studied as*
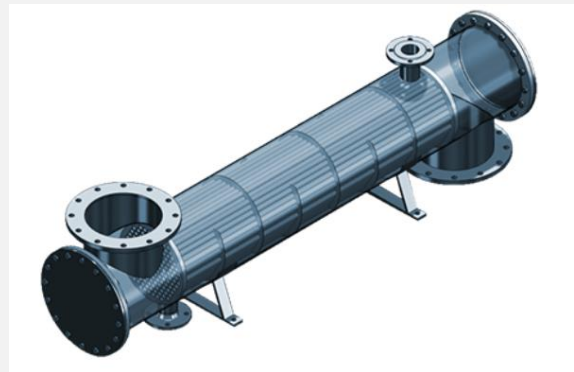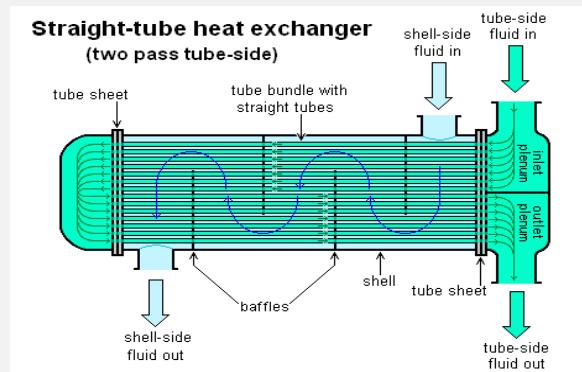
case study.

Fig. 2 Straight-tube heat exchanger

Brief description of equipment:

The straight tube heat exchanger is a version of the tube bundle heat exchanger. It can be found wherever viscous or contaminated media is used or where a fast heat transfer without pressure loss is necessary.

For straight tube heat exchangers, very thin single tubes are guided straight through a large pipe. They can be operated according to the parallel flow principle or counterflow principle. The straight tube heat exchanger only generates a **very low pressure loss** during operation. It is available in an upright (vertical) or horizontal design.

Brief description of cleaning method:

Straight tube heat exchangers can be quickly and easily cleaned without complete disassembly. If the front heads at both ends are removed, grease and other deposits can be easily removed using brushes or high pressure cleaners.

2. Qualitative assessment and selection of total cleaning process

Qualitative assessment of location as input for selection of _in plant (=in situ)_, _on site_ or _off site_ based cleaning process:
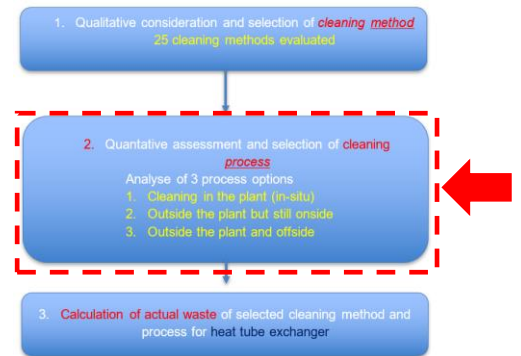
Table 3 Qualitative assessment of location as input for selection of cleaning process

| Criteria	In-situ	On-site	Off-site	Weight	Total In-situ	Total On-site	Total Off-site
Frequency of current usage	5	5	1	5	25	25	20
Cleaning method possibility	3	5	5	3	9	15	15
Complexity of process	2	5	5	5	10	25	25
Total					**44**	**65**	**60**

Motivation of scorings:

- Frequency of current usage: In-situ and on-situ cleaning is both applied in 40% of cases in practice (5pts), off site only 20% (1 pt)
- Cleaning method possibility: applicability of in-situ cleaning is limited compared to other two (3 pts vs 5 pts);
- Complexity of process: in-situ cleaning involves a rather complicated process compared to the other two (2 pts vs 5 pts).

Based on this comparison the on-site process option appears to be marginally favorable in terms of applicability. The final decision is normally based on the asset owner and cleaning company experience, keep in mind all factors surrounding the asset.

3. Calculation of actual waste of selected cleaning method and process for heat tube exchanger

In summary:

- Equipment that is cleaned:
  straight-tube heat exchanger
- Selected cleaning method:
  Water Jetting (UHP) – this is most commonly used for this application
- Selected cleaning Process: On-site
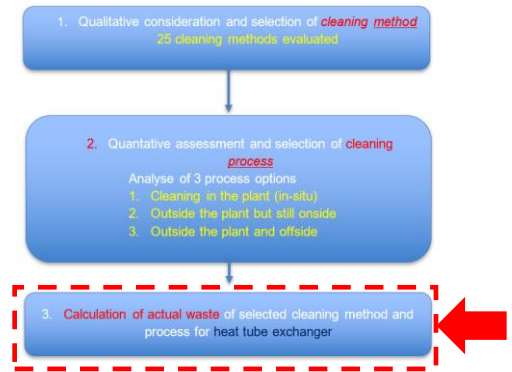
The process steps with the quantified used water (re-used, recycled is negative), nitrogen gas, C02 emission in kgs/ footprint:

Table 4 Calculation of actual waste of selected cleaning method and process for shell-tube heat exchanger

Process step	Elements involved (Environmental impact)	Usage	Incineration weight (Tons)	Time required (In hours)	Production period	Distance travelled (In kilometers)	Units required	Sub-totals	Carbon foorprint (kg CO2)	Totals CO2 kg	Total nitrogen gas Nm3 (Normal meter cube)	Chemical environmental hazard	Totals Water Litres
									2,62				
1- Decision to take initiative on cleaning	X	X	X	X	X	X	X	X					
2- Shutting down production	Water usage	400.000	X	X	X	X		400.000					
	Nitrogen gas	600.000	X	X	X	X		600.000					
3- Preparing the equipment	Fuel for cranes L/h diesel	40	X	0,5	X	X	1	20	52,4				
	Fuel for forklifts L/hr diesel	30	X	0,5	X	X	1	15	39,3				
	Environmental footprint									91,7	600.000		400.000
4- Transport of cleaning materials and cleaning equipment from supplier to the site (mobilization):	Fuel km/L diesel per truck	3,6	X	X	X	18,7	1	5,19	13,61				
	Environmental footprint									13,61			
5- Transporting the equipment from plant to cleaning site (Horizontal transport)	Fuel for trucks	3,6	X	X	X	3	1	0,83	2,18				
	Environmental footprint									2,18			
6- On-site cleaning process	Pump Energy usage	350	X	1	X	X	1	261					
	Pump Fuel	0,47	X	6,00	X	X	1	736,01	1928,34				
	Water usage	130	X	6,00	X	X	1	46800					
	Chemical usage	0	X	0	X	X	X	0					
	recycling of water	30420	X	X	X	X	-1	-30420					
	Incineration	659	X	1	X	X	X	659	1726,58				
	Electrical generation (during incineration)	500	1	1	X	X	-1	-500	-116				
	Environmental footprint									3538,92		0,00	16380
7- Demobilization and transport Materials and cleaning equipment from cleaning Site to Cleaning company	Fuel	3,6	X	X	X	18,7	1	5,19	13,61				
	Environmental footprint									13,61			
8- Transporting the equipment from cleaning site to plant (Horizontal transport)	fuel	3,6	X	X	X	3	1	0,83	2,18				
	environmental footprint									2,18			
9- Installation	Fuel for cranes L/h diesel	40	X	0,5	X	X	1	20	52,4				
	Fuel for forklifts L/hr diesel	30	X	0,5	X	X	1	15	39,3				
	Environmental footprint									91,7			
10- Restarting production	Water usage	200.000	X	X	X	X	1	200.000					
	Fuel usage	200	X	20	X	X	1	4000	10480				
	Nitrogen gas	100.000	X	X	X	X	1	100.000					
	Environmental footprint									10480	100.000		200.000
Total										14233,90	600000,00	0,00	416380,00

Conclusions

The aim of the research is multi-layered. First of all, developing <u>a decision model</u> with which a clear objective assessment can be made between the cleaning methods/ processes that are currently used in the process industry for heat exchangers on the basis of the sustainability criterion. Secondly, the development of <u>a measurement model</u> with which the environmental impact of this maintenance measure can be determined. This concerns the quantification of CO_2 emissions, Nitrogen gas consumption, and total water consumption. As a case, the footprint of the most commonly used variant is worked out/ calculated.

The decision and measurement model has been developed on the basis of the indicated three-step plan. The application in the case study indicates the best cleaning methods with respect to shell-tube heat exchangers. The most commonly used cleaning process for bundles has been evaluated, based on on-site cleaning. Furthermore the corresponding KPIs CO_2 emissions, Nitrogen gas consumption, and total water consumption of the cleaning have been quantified.

Discussion and recommendations

This applied bottom-up research is actually an exploratory study into how the process industry can sustainably regulate and control maintenance in general and the cleaning of equipment in particular. The step-by-step plan and the methodology set out should therefore be regarded as a first step towards a more refined and further developed methodology. Below are a further analysis and recommendations with regard to the step-by-step plan of the research itself, including recommendations related to the development of tools to be able to zoom out from operational to tactical and strategic level (and vice versa) and as such to obtain a clear line of sight how to manage the maintenance works effectively from a sustainability perspective (as also outlined in chapter 2).

Step 1 Selection of cleaning method:

- In the analysis, equal weight was assigned to the 3 parameters (water usage, energy usage, chemical usage). The question is whether this matches the relative criticality of each, or otherwise stated: What does the company find acceptable in terms of consumption, is prioritization needed (link with company value matrix)?
- The heat exchangers has been split up in 3 parts (bundle, shell, heads and channels): how large is the relative contribution of each? Again, should weighting factors be used to refine this, is it reasonable to assume that all three contribute equally?
- Selection is still done qualitatively and then various methods quantified, is earlier quantified selection possible in future ?

Step 2 Selection of cleaning location:

- Frequency of current usage is used as selection parameter. Although this provides insight which process is preferred in the daily practice of the process industry, most ideal this should be further translated into more concrete decision parameters, arguably best when related to the sustainability KPIs of the cleaning process;
- Selection is still done qualitatively, is a quantified selection possible in future? Evaluation of a large number of options and variants would enable direct comparisons on a quantitative basis.

Step 3 Quantification of water usage, nitrogen gas and CO_2 emission

- Absolute quantities have been determined, but what else does this mean? There is still no frame of reference with regard to it. In other words, performance requirements and targets with regard to sustainability must be determined. For this tools like the circularity ladder, the CO_2 performance ladder can be used. As illustrated and discussed in the previous theoretical frame work, in this way the constantly ongoing circular "sustainable maintenance" process of Plan-Do-Check-Act is closed, see figures below:
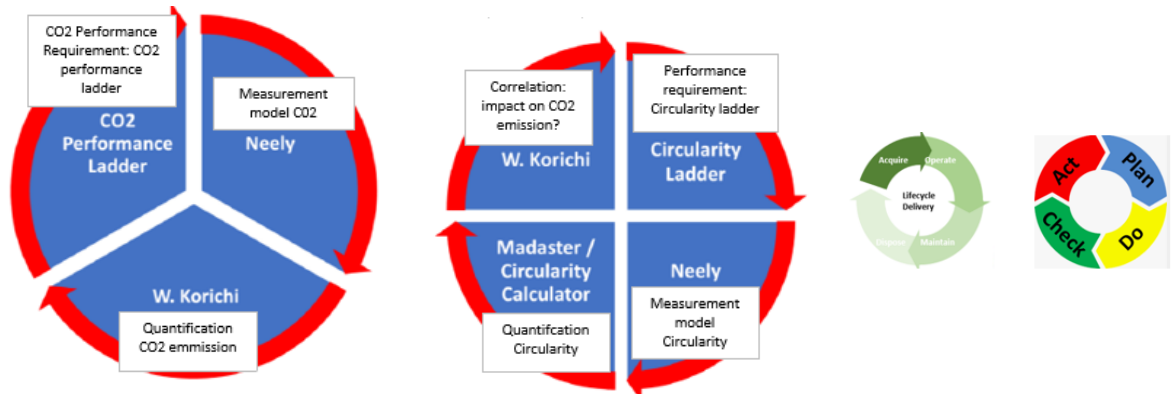

Fig. 4 Circular process performing "sustainable maintenance", based on KPIs CO_2 performance and Circularity the middle figure takes also into account a possible correlation between circularity and CO_2 emission. On the right side in addition the continuous character of these repeating processes is illustrated with the lifecycle delivery and the Plan-Do-Check-Act circles)

The present study has mainly focused on waste: besides CO_2 emission, also water usage, emission of nitrogen gas. When talking about circularity, water usage might be a useful KPI in case that the water is (partly) reused. How to translate all these parameters into a limited number of corresponding core values can be further studied;

- In addition, also necessary for a failure analysis: does the system comply now, or are measures needed to reduce the emissions? And suppose that the corresponding performance requirements have been defined and that the current emissions exceed these bench mark values, how critical is that? In other words: what are the corresponding risk acceptance levels of the sustainability core values to be defined in the company value matrix?

- When making a more in-depth comparison of maintenance measures based on KPIs such as CO_2 emissions: see fig. 11 in theoretical framework of article 1. For a fair comparison and in order to obtain a total overview, similar to LCC analysis of costs, for instance the CO_2 emissions over time can be evaluated. As also emphasized in the latter article, it is important to be complete, so not only look at the CO_2 emission of the maintenance measure itself over time, but also the CO_2 emissions of the total installation (of which the shell-tube heat exchanger, in this case, is part of). The latter also means developing models that estimate "CO_2 condition" of the total installation over time, in accordance with the commonly used P-f curves for the determination of the minimal inspection interval of maintenance works (of an aging ((sub) component of) an asset).

References (all articles)

1. Roes, Van der Male (2019) *Eindrapport Project Circulaire Verdienmodellen in de procesindustrie en maintenance sector*. KicMPi

2. M. Nagelhout, R. Schoenmaker (2020), *Measurement Model Circular Maintenance*, Research Group HZ Asset Management.

3. IAM (Institute of Asset Management) (2015). *Asset Management – An antonomy Version 3*. Bristol.

4. IAM, Robert Davis (no date), *an Introduction to Asset Management*. EA Technology Ltd

5. Smith, Thomas W (2014). *The impact of ISO 55000. The New Asset Management Handbook*. Reliability Web

6. Schoenmaker (2011). *De ingeslagen weg*. Delft: Next Generation Infrastructures Foundation.

7. Dunn, S. (1999), Maintenance Outsourcing – Critical Issues. Taken from www.plant-maintenance.com [accessed: 16-02-2021]

8. Murthy, D.NP. & K.A.H. Kobbacy (2008). *Complex system maintenance handbook.* London: Springer.

9. PBL Netherlands Environmental Assessment Agency. Circular Economy: Measuring Innovation in the Product Chain. 2017. Available from: https:// www.pbl.nl/en/publications/circulareconomy-measuring-innovation-inproduct-chains [Accessed: 2021-04-02]

10. A. Neely, H. R. (1997). Designing performance measures: a structured approach. Cambridge: University of Cambridge.

11. Rau-Oberhuber, F. H. (2019, September 26). Calculation, and evaluation of circularity indicators for the built environment using the case studies of UMAR, and Madaster. Retrieved from sciencedirect.com: https://www.sciencedirect.com/science/article/pii/S0959652619333529

12. (n.d.). Retrieved from circularitycalculator.com: http://www.circularitycalculator.com/#us

13. W. Korichi (2021), Decision model for industrial cleaning. HZ

14. https://www.kizeo-forms.com/en/ - Mobile Forms Application