Shell Side Jet a next-generation solution to revolutionise the treatment of external heat transfer surface fouling

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ABSTRACT

As the market leader in premium cleaning and inspection solutions to all global heavy industrial sectors, Tube Tech International Ltd. was awarded multi-million-dollar Horizon2020 R&D funding (under grant agreement no 805767) to develop an innovative technology, Shell Side Jet™, aimed at addressing the performance issues associated with tube bundle heat exchanger external tube fouling. This paper addresses the fouling problems faced by refineries around the world and how fouling impacts performance, reliability, efficiency, safety and environmental priorities. Launching in February 2020, Shell Side Jet technology is identified as the solution to cleaning surface area that, until now, has been inaccessible and uncleanable, with guaranteed results that offer a fast ROI alongside multiple long-term benefits.

INTRODUCTION

Shell Side Jet from Tube Tech International Ltd. delivers a unique paradigm shift solution to guarantee the complete removal of fouling from the external shell side heat transfer surface (between tubes) of any square pitch exchanger, regardless of fouling, type or severity, without tube damage.

There are many key benefits of the technology to operators. Equipment can be restored to original design cleanliness, enabling more efficient heat transfer with considerable throughput impact, and the potential failure mechanisms associated with corrosion due to fouling build up is minimised resulting in longer asset life and less downtime. Operator safety should always be a priority and many traditional cleaning methods still have significant safety issues such as proximity to water jets. Shell Side Jet mitigates these dangers by being remotely operated and keeping technicians away from safety hazards.

Fouling negatively impacts plant economics, environmental performance and causes safety hazards. Various attempts have been made to quantify the costs of fouling. While there is not yet a comprehensive industry study in the public domain, top line statistics below make for a compelling case to reduce or avoid fouling all together:

- Individual small to medium refineries report losses of $3-4 million per annum due to fouling
- Costs associated with refinery preheat train fouling in four major industrialised countries have been estimated to be in the order of 0.25% of Gross National Product, [1] while the global cost of fouling was estimated at $20 billion in 2016. [2]
- Crude fouling in refinery preheat train (PHT) networks costs 0.25% barrel of oil equivalent (BOE) of all refined crude, or 66 million barrels per year (at $55 per barrel equates to around $3.6 billion in lost revenue). [3]
- 1-5% of the energy consumed by the industrial sector is used to overcome fouling. [4]
- Mitigation of refinery preheat train and fired heater fouling has been estimated to yield fuel savings of up to 15% [5, 6]
- Up to 2.5% of global CO_2 emissions (0.8 Gigatons) are due to fouled heat transfer equipment and account for between 3-10% of an individual refinery's carbon footprint. [1, 7]
- The fouling of and inability to clean preheat train exchangers, especially on the external shell side, can lead to a decline as much as 12°C (54˚F) in furnace inlet temperature. The subsequent need to burn extra fuel therefore results in higher costs and an increase in CO_2 emissions by over 20%. [1]
- Deposit build-up on downstream equipment leads to dangerous increases in pressure and temperatures that cause corrosion, cracks and leaks leading to serious safety hazards and often catastrophic shutdowns. Fatal incidents within chemical plants and refineries have occurred due to inadequately addressed cleaning standards that have led to such fouling and corrosion.

ISBN: 978-0-9984188-1-0; Published online www.heatexchanger-fouling.com

In exploring current practice, this report identifies the need to challenge traditional cleaning methods and the impact their lack of success has on plant profits to global societal issues. The report details the varying fouling characteristics that are inevitable within the heat transfer process, and therefore affect refineries, and their output, worldwide.

MARKETPLACE NEEDS

Heat Exchangers have been over-designed to allow for fouling since their invention. Overdesign can be as much as 30% to 50% [8]. This accepted tolerance has and continues to have drastic global consequences when it comes to increased energy consumption the associated impact of CO2 emissions and ultimately production, asset life and company profit. Tube or bundle replacement is regularly considered when fouling cannot be removed.

A significant number of all fouled shell and tube exchangers in production globally will go back into service in a fouled condition predominantly due to inaccessible external, shell side fouling even after cleaning attempts using the most powerful water blasting rigs. This is because jets and lances have never (until now) been able to slide in between the 6mm tube corridor space.

The shell side of exchangers has always been notoriously inaccessible and therefore uncleanable whether in a light or heavy fouling process. This makes it just as difficult to quantify financial and environmental losses of such fouling until it is back into service, meaning a wait of about four years before coming offline again to calculate actual losses over four years which will have been substantial.

FOULING CHARACTERISTICS

In order to reduce the furnace load during fractional distillation, crude oil feedstock is heated to around 370 °C before it enters the CDU [9]. This heating process is energy intensive and accounts for as much as 14% of a refinery's total energy consumption. [10]

To improve operational efficiency, feedstock is passed through network of heat exchangers called the preheat train (PHT) in order to recover heat from the distillation column. The PHT must be efficient as it is recovers 60-70% of the heat required for distillation [11].

Fouling hinders the thermal and hydraulic efficiency of the PHT, resulting in operating difficulties, increased economic cost, higher environmental impact and safety hazards arising from cleaning requirements [11]. The impact of fouling has been observed to cause an 8-11°C/year fall in the temperature of PHT outlet crude. [12] One 200,000 bl/day UK refinery reported in 2009 that it bore a cost of £250,000/year for each 1°C loss of preheat. [13]

This decline in temperature is countered by burning additional fuel downstream of the PHT, increasing energy costs and causing an additional release of greenhouse gases. [11] A 2009 estimate put the cost of offsetting the impact of fouling at 186m barrels of oil per year. [14] The impact of fouling on hydraulic efficiency can also lead to higher electricity cost as extra pumping power is required. [11]

Increased hydraulic resistance in the PHT due to fouling can have a significant impact on refinery throughput [15] and may disrupt operations if cleaning does not coincide with scheduled plant shutdown periods, potentially resulting in a need for unplanned maintenance or backup heat exchangers [16].

Fouling in petrochemical plants can arise in the reactors and other process units, process lines, compressors, pumps and heat transfer equipment (See Fig.1). There are thousands of individual pieces of equipment in a refinery or petrochemical plant that can become fouled. At the temperatures involved, cracking of hydrocarbons can lead to free radicals which react to form coke which partially and completely blocks tubes and process lines. Emulsions are also a major nuisance in steam cracking plants. They form because of mixing between lighter hydrocarbons and polymerised material which meet in the quench tower and separator. Emulsions can pass through process lines and transfer from one unit into another causing all kinds of disruption from pressure drop to off-spec product. Other fouling processes include chemical reactions, biological processes, crystallisation, corrosion, particulate build-up (sedimentation), precipitation and metal salt accumulation. Each of the main fouling issues is outlined below.

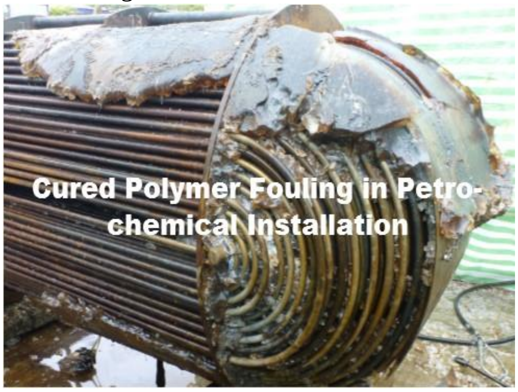
- **Dilution Steam System (DSS).** In an ethylene plant, fouling in the DSS creates many difficulties including increased steam consumption, reduced efficiency, increased wastewater costs, reduced pygas yields and unplanned downtime for cleaning. [17]
- **Transfer Line Exchangers (TLE).** TLEs are usually shell and tube exchangers but other designs including horizontal and vertical tubes or concentric tubes are also possible. Fouling is caused by condensation and coke formation. Corrosion also occurs due to accumulation of boiler feed water (BFW) solids leading to a pH

ISBN: 978-0-9984188-1-0; Published online www.heatexchanger-fouling.com

high enough to get through the protective magnetite layer. [18] Anti-fouling treatments such as amine neutralized sulfonates employed in the furnace coils can protect TLEs to a certain degree but are not sufficient, especially for TLEs located just downstream of the furnace. [19] The failure in respect of the TLEs may be due to premature degradation of the treatments in the ethylene furnace which sees temperatures in the range 1,000° - 1,700°F (about 535 - 930°C).

- **Gas compressors.** Fouling can occur on the balance drum and discharge lines, diffusers, inlet guide vanes and labyrinths seals between the wheels. The effect is gas leaking, increased polymer and emulsions formation, knock-on fouling in the quench system and the fractionation towers. [20]
- **Quench water and quench oil systems**. Fouling in quench systems is common and is caused by high pour-point material build up. It is especially problematic in gas-based crackers because there may not be a quench oil tower which would otherwise remove coke fines and tars. [21] Additional measures such as fitment of re-distillation units are required. These separate out and route lower pour point hydrocarbon back into the quench tower to moderate the pour point. This adds to the plant CAPEX, OPEX and maintenance requirements.
- **Cracking furnace coils.** Coking is to be expected when hydrocarbon molecules are being smashed up at high temperatures and pressures where free radical reaction mechanisms are operating. It is further promoted by impurities in naphtha feed streams such as sodium, nickel and iron oxide but also forms due to reactions at the tube surface. Heat flux resistance and pressure drop due to coke build up at some point necessitate a decoking exercise. Excessive coking in the furnace coils leads to more frequent need for decoking cycles, increased particulate waste inventory, reduced operating rates, lower product yield, shortened furnace life and higher maintenance costs. [22]
- **Fractionation trains.** Polymer build-up in the de-ethanizer and de-propaniser causes bottlenecks depending on plant configuration and are exacerbated by acetylene feed impurities. This can result in a severe capacity loss due to premature flooding, high tower pressure-drop, abrupt and severe tower bottom level reductions during furnace feed slate switches, separation efficiency reduction such as high concentration of heavy components in the pygas, and difficulties controlling quench oil viscosity.

There are a multitude of mechanisms by which fouling can stop a plant from running smoothly. Keeping fouling under control is a time-consuming and expensive endeavour. Planned shutdowns for each unit varies widely from months to years and this may mean that fouling can build up in certain areas and work arounds are employed to avoid accelerating the maintenance schedule, effectively



patching a problem rather than solving it.

Fig. 1

Source: Tube Tech International Ltd.

ENVIRONMENTAL IMPACT OF FOULING

Inaccessible and immovable fouling creates almost a gigaton (10^9 tons) of carbon dioxide (CO_2) emissions accounting for up to 10% of a refining or petrochemical plant's carbon footprint. Fouled tubes can crack and leak, increasing greenhouse gas (GHG) emissions and creating safety hazards. There is a strong case for highly efficient fouling removal techniques, both from the point of view of financial stakeholders looking for maximum carbon productivity and external bodies including government regulators and consumers pushing for energy efficiency and safety.

Fossil fuels are under more scrutiny than ever before given the evidence that greenhouse gas (GHG) emissions are causing an increase in global air temperatures, subsequent climate change and adverse weather events. Legislation and voluntary measures are continually being developed to tackle

GHG emissions. Over 190 countries have signed up to the Paris Agreement with a view to limiting global warming to 1.5°C above pre-industrialised levels. Each country has pledged to set out a plan of GHG reductions (Intended Nationally Determined Contributions - INDC) to be enacted within the next decade. To date these pledges, if fully enacted, would according to theoretical modelling limit the increase to 2.7°C. If the actual warming reaches 4°C, then catastrophic climate change will be unavoidable. [23,24] Much more effort is required to prevent this irreversible outcome with the burden placed firmly at GHG emitters' doors.

Punitive measures in the form of carbon taxation, fines and loss of investment all await industries who do not react to remedy the situation. Activist investors are demanding better economic, environmental and safety performance from businesses engaged in the production and use of fossil fuels. Recently several high-profile investors have pulled out of these assets altogether. Companies active in the fossil fuels supply chain must carry out process intensification and improvements to meet the expectations of their stakeholders and to avoid penalties. Addressing fouling in the most cost-effective and efficient manner possible has never been more of a priority. [14]

FINANCIAL LOSSES DUE TO FOULING

The effects of fouling on ethylene plants cash cost of production and capital cost is typically considered in five key areas:

1. Maintenance costs – increased costs due to planned and unplanned maintenance due to fouling
2. Energy costs – fouling increases energy costs due to reduced heat transfer efficiency
3. Yield – fouling affects conversion of feedstock in the steam cracker
4. Annual operating rate – unplanned downtime leading to falling behind on production plan operating target set by market conditions
5. Total CAPEX (total fixed investment) – equipment overdesign to account for fouling

Each of these directly impacts the cash cost of production. The most significant issues are those which impact the energy requirements of the plant e.g. utility costs and the total plant output i.e. loss of yield or operating rate. [25]

TRADITIONAL CLEANING METHODS

The cleaning process, as with traditional cleaning methods, requires the tube bundle to be removed from the shell to enable cleaning. Typical current methods involve High Pressure Water Jets (HPWJ) delivering 1,000 bar via a remote indexing jib, but this technique fails to remove all fouling from exchanger tubes and generally leaves up to 60% of fouling behind in the entrapped area between the bundle tubes as traditional water jetting equipment cannot penetrate deep between the 6mm space between tube rows.

Over 80% of water volume used by current water blasting techniques bounces off the first tube row. The remaining 20% of water barely makes it through the other side and the impact pressure will have reduced exponentially. Cleaning efficiency is further reduced as the water jet direction passes across the external tube surface at a tangent effectively trying to skim deposits off the surface rather than blasting perpendicular to the tube surface – not forgetting the distance of the jet head standing off from the bundle itself.

The effectiveness of a high-pressure jet decreases as the distance from the nozzle to the surface being cleaned increases. For this reason, when using a conventional large diameter lance, only the visibly accessible outer tubes near to the outside of the tube bundle can be cleaned efficiently.

Chemical cleaning on the other hand, aside from the detrimental environmental aspect, cannot go through blockages or remove hydrocarbon fouling. It can also erode and etch the metal surface and is dependent on getting the concentration mix right, and the circulation time and sheer force required of 2m per second.

SHELL SIDE JET

Shell Side Jet is designed to clean the external surfaces of the tubes within a shell and tube bundle heat exchanger. To do this, the tube bundle needs to be removed from the shell so that access can be gained to the external, surfaces of the tubes.

The semi-automated technology is a super-stressed metallic array of tubes formed from different materials as narrow as 3-5 mm diameter which allows it to clean between the tube rows on both a Koch twisted tube bundle as well as your standard square pitched, shell and tube floating head exchanger.

With Shell Side Jet, the lance comprises two or more rotary hollow lances having an outer diameter sufficiently small to fit between the tubes of the bundle and arranged with their axis in the same plane. By providing a lance with two or more hollow lances, the technology enables the lance to slide in between tube rows and deliver the necessary volume and water pressure within close proximity to the fouling for effective and rapid cleaning. To suit most applications, it is preferred for the pipes to have an outer diameter of no more than 6mm.

Pressure from 1000 to 4000 bar (15,000 to 60,000 psi) is used with perpendicular contact to within 1mm of the fouled tube surface, at every point within the centre of the bundle where required, regardless of exchanger diameter. For the first time, it guarantees to remove all fouling including the hardest concrete, hydrocarbon scale and cured polymer back to bare metal if required (See Fig.2).

Commercial benefits:

- Shell Side Jet will deliver guaranteed standards of fouling removal
- Shell Side Jet will dramatically reduce CO2 emissions and energy usage by cleaning back to design thermal efficiencies
- Shell Side Jet can use as little as 10 litres (ca. 2 gallons per minute) compared to 90 gallons per minute using current technology. Especially useful in water-short areas such as the Middle East.
- Shell Side Jet, as a result, extends run times and can avoid shutting down an entire plant
- Shell Side Jet guarantees to remove more fouling than any other water jetting system
- Shell Side Jet guarantees to remove any type of fouling regardless of volume, process or severity compared to traditional water jetting
- Shell Side Jet is efficient in cleaning the external tube surfaces of any tube bundle where line of sight exists whether square or triangular pitch e.g. this includes but not limited to fouled HRSGs, WHRUs, Furnace Tubes, Boilers, and Condensers.
- Shell Side Jet can access tube spaces as little as 4mm including Koch Twisted Tube Exchangers
- Shell Side Jet is completely remote, ensuring operator safety
- Shell Side Jet delivers real-time angle correction during clean
- Shell Side Jet cleans near 100% in the same time it takes current jetting to clean 5-50% of the bundle
- Multiple Shell Side Jet systems can be used simultaneously to reduce downtime even further

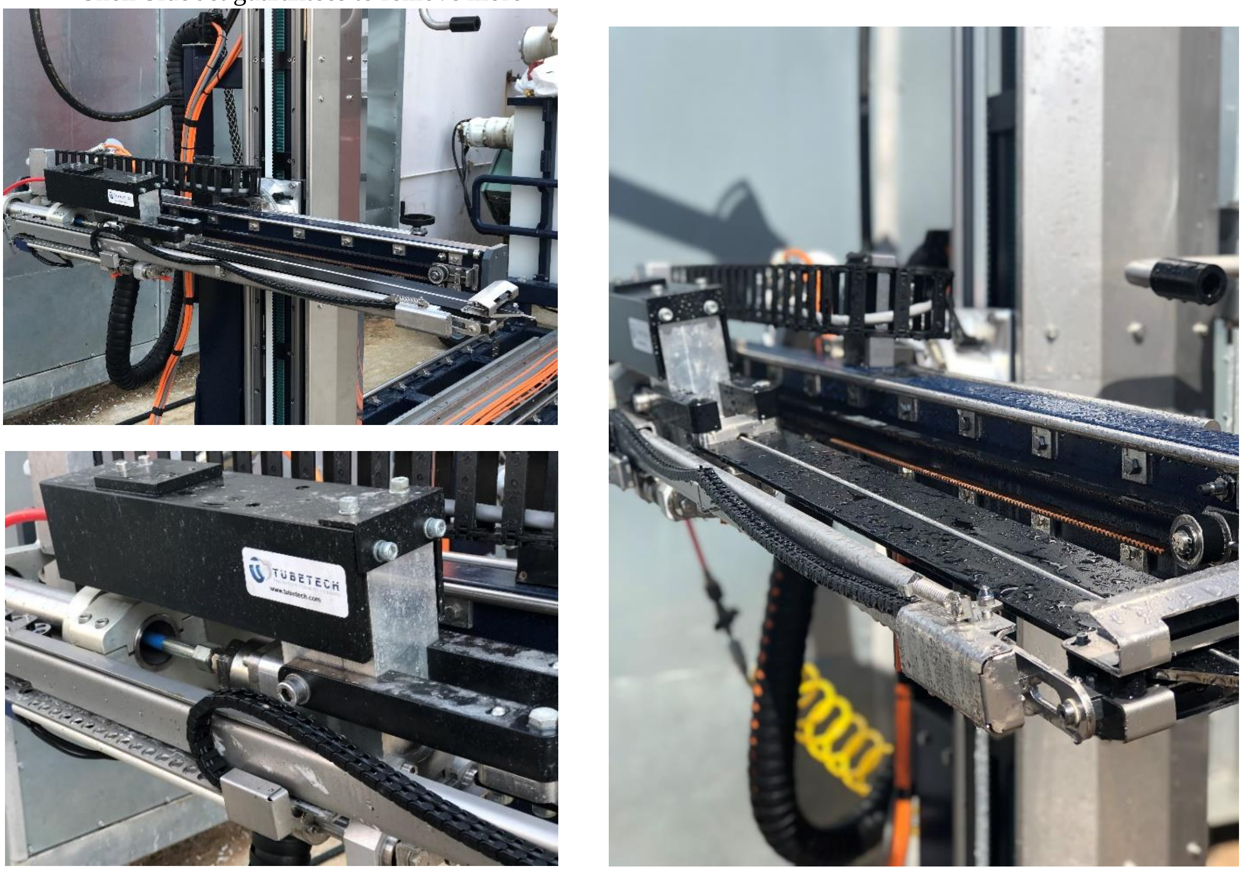


Fig. 2 Shell Side Jet – coming to market in 2020

ISBN: 978-0-9984188-1-0; Published online www.heatexchanger-fouling.com

Source: Tube Tech International Ltd (TTIL)

MEASURING PERFORMANCE

With a mission to deliver and evidence unrivalled fouling removal levels, TTIL's extensive R&D programme has focused on how to both prove and measure results prior to, during and after clean. Alongside detailed digital reports, results can be determined by the client weighing the bundle before and after cleaning to ascertain the level of fouling removed. Other information provided in the report includes the distance of baffle plates, location of damaged or broken tubes, volume of fouling, photos of before, during and after the clean, and an intuitive heat map.

CONCLUSION

Fouling within manufacturing plants places considerable burden on performance. Loss of production wipes millions of dollars in revenue from the bottom-line, creating supply shortages, safety hazards and exacerbating a plant's negative environmental and CO2 footprint. With ever-increasing pressure on energy and chemical producing sectors to become more green, efficient fouling mitigation and removal methods are increasing in importance. Investors are more environmentally conscious than ever before and are switching their funds from businesses involved in the production and use of fossil fuels to those with more sustainable activities. [14]

A world-first innovation, Shell Side Jet technology guarantees to remove all fouling, reaching the previously inaccessible and uncleanable external shell side of heat exchangers. Shell Side Jet will significantly raise the standard of clean that contributes to overall plant performance and output, as well as the increasingly scrutinised environmental impact of global oil and gas industry operations.

Shell Side jet will improve safety and increase fuel efficiency to substantially reduce CO2 emissions and water usage within industry.

The project has been funded as part of Horizon 2020 SME Instrument Programme, the biggest European Union research and innovation programme to date under grant agreement no 805767.

REFERENCES

[1] "Heat Exchanger Fouling"; ESDU Case Study; IHS Markit; https://www.esdu.com/productdemos/online/pet/downloads/Heat%20Exchanger%20Fouling%20Case%20Study.pdf

[2] Jackowski, et al.; "Industrial Perspective on Fouling Research - Fouling Mitigation through Modifications of Heat Transfer Surfaces"; Proceedings of International Conference on Heat Exchanger Fouling and Cleaning (2017). http://www.heatexchanger-fouling.com/papers/papers2017/16_Jackowski_Industrial%20Perspective%20on%20Fouling%20Research.pdf

[3] Pugh, S. and Ishiyama, E.; "Managing fouling in refinery networks"; IHS Energy; (2015); July http://www.digitalrefining.com/article/1001191,Managing_fouling_in_refinery_networks.html

[4] Garrett-Price, B.A. et al "Fouling of Heat Exchangers – Characteristics, Costs, Prevention, Control and Removal. Noyes Publications, Park Ridge, New Jersey (1985).

[5] US Department of Energy (DoE); "Energy Bandwidth for Petroleum Refining Processes"; US Office of Energy Efficiency and Renewable Energy Industrial Technologies Program (2006). https://www.energy.gov/sites/prod/files/2013/11/f4/bandwidth.pdf

[6] Coletti, F. and Macchietto, S.; "A Dynamic, Distributed Model of Shell-and-Tube Heat Exchangers Undergoing Crude Oil Fouling"; Industrial & Engineering Chemistry Research 50, 8 (2011).

[7] Soto, E.; "Heat exchanger fouling: the big picture and case study"; Altum Technologies (2017); 30 October; (www.altumtechnologies.com/heat-exchanger-fouling-case-study/) Last Accessed May 2018

[8] Coletti, F. and Hewitt, G.; "Crude oil fouling"; Gulf Professional Publishing (2015). https://www.sciencedirect.com/topics/engineering/heat-exchanger-design

[9] Ishiyama, E.M. et al.; "Effect of Scheduling Cleaning of Crude Preheat Train Exchangers on the Operating Conditions of Fired Heaters"; Proceedings of International Conference on Heat Exchanger Fouling and Cleaning (2015). http://www.heatexchanger-fouling.com/papers/papers2015/61_Ishiyama_Fired%20heater_F.pdf

[10] Erdener Akınç, H. et al.; "Fouling monitoring in crude oil preheat trains, Proceedings of International Conference on Heat Exchanger Fouling and Cleaning" (2013). http://www.heatexchanger-fouling.com/papers/papers2013/03_Becer_PHT_F.pdf

[11] Diaz-Bejarano, E. et al.; "A new dynamic model of crude oil fouling deposits and its application to the simulation of fouling-cleaning cycle"; Process Systems Engineering (2015).

[12] Chambon, A. et al.; "Fouling in the Crude Oil Distillation Pre-Heat Train: Comparison of Experimental Data with Model Results"; Proceedings of International Conference on Heat Exchanger Fouling and Cleaning (2015). http://www.heatexchanger-fouling.com/papers/papers2015/10_Chambon_F.pdf

[13] Macchietto, S. et al.; "Fouling in Crude Oil Preheat Trains: A Systematic Solution to an Old Problem"; Proceedings of International Conference on Heat Exchanger Fouling and Cleaning (2009). http://www.heatexchanger-fouling.com/papers/papers2009/1_Macchietto_CROF_F.pdf

[14] Müller-Steinhagen, H. et al.; "Heat Exchanger Fouling: Environmental Impacts"; Heat Transfer Engineering, 30,10-11 (2009).

[15] Yeap, B.L. et al; "Mitigation of Crude Oil Refinery Heat Exchanger Fouling Through Retrofits Based on Thermo-Hydraulic Fouling Models"; Chemical Engineering Research and Design, 82, 1 (2004).

[16] Bott, T.R.; "Fouling of heat exchangers"; Elsevier Science (1995).

[17] Ethylene Processing – Dilution Steam System, Pall Corp (1997) http://www.pall.de/pdfs/Fuels-and-Chemicals/HCP-24.pdf

[18] Robinson J.O.; "Avoiding waterside corrosion problems in ethylene plant steam systems"; Suez; Water Technologies & Solutions Technical Paper (2014); Pages 1-8 https://www.suezwatertechnologies.com/kcpguest/documents/Technical%20Papers_Cust/Americas/English/TP1201EN.pdf

[19] Kisalus, J.C, "Method for reducing fouling in ethylene cracking furnaces" European Patent EP0391620B1; (1989); April 3 to Nalco Company LLC https://patents.google.com/patent/EP0391620B1

[20] Snider, S.; "Ethylene Plant Cracker Gas Compressor Fouling"; AICHE Spring National Meeting, EPC Conference, Houston, Texas; (2006); April 23-26 www.kemco.or.kr/up_load/blog/CGC_Fouling_Check.pdf

[21] "Effective, Economical Emulsion and Fouling Control for Ethylene Plants"; Dork Ketal; https://www.dorfketal.com/component/attachments/download/72.

[22] Brayden, M; Wines, T.H. and Del Guidice, K.; "Improve Steam Cracking Furnace Productivity and Emissions Control through Filtration and Coalescence"; Pall Corp Fuel and Chemicals, Scientific & Technical Report GD8138; (2006); Pages 1-9 https://chemicals-polymers.pall.com/content/dam/pall/chemicals-polymers/literature-library/non-gated/GDS138.pdf

[23] "What is the Paris Agreement on climate change? Everything you need to know"; The Telegraph; (2018), February 1 https://www.telegraph.co.uk/business/0/paris-agreement-climate-change-everything-need-know/

[24] Scott, M.; "$1.6 Trillion of Investments at Risk If Fossil Fuel Firms Fail to Heed Climate Targets" Forbes, (2018) 8 March https://www.forbes.com/sites/mikescott/2018/03/08/1-6-trillion-of-investments-at-risk-if-fossil-fuel-firms-fail-to-heed-climate-targets/

[25] Lynch, M. for Tube Tech International Ltd.; "A Techno-Economic Overview of Fouling in Steam Crackers and Available Solutions"; White paper; February 2019 https://www.tubetech.com/wp-content/uploads/2019/02/White-Paper-1-TubeTech-3.pdf

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