THE ECONOMIC IMPACT OF BETTER HEAT EXCHANGER CLEANING ON AN OIL REFINERY – THEORETICAL, EXPECTED AND ACTUAL RESULTS.

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ABSTRACT

Ultrasonic cleaning of heat exchangers has been in use since at least 2009 [1]. As a cleaning method, it has been shown to provide superior results over traditional hydroblasting techniques, offering better and faster cleaning, with improved safety and a drastic reduction in water use [1,2,3,4]. Despite the apparent benefits, there remains institutional doubt about the actual value that better cleaning can bring to the industry.

Anecdotally, and in at least two publications, [2,5,6] operators have reported apparent improvements in cleaning results of 10-25%, and an improvement in the economic benefits of cleaning of well over US$1M per exchanger cleaned. This paper presents an attempt to validate these reports using real customer data and a Hexxcell Hybrid Digital Twin model of the hot end of a pre-heat train in a 110,000 bbl/day refinery.

We now have data from measured trials conducted in the United States in which operators have provided historical and on-going performance data which allows a detailed comparison of heat exchanger performance pre- and post-cleaning, with both hydroblasting and ultrasonic methods. The results support expectations, showing an improvement in post-cleaning performance of between 0-40%, with an average improvement of about 20%. The data collected thus far suggests a fuel-reduction energy savings value of up to US$700,000, with a concurrent reduction in greenhouse gas emissions of over 6,000 tons, both per exchanger, per year.

We shall present the actual and model results and attempt to translate these results to a refinery and industry scale.

INTRODUCTION

In the 80's and 90's, several authors reported that the fouling of heat exchangers was responsible for losses valued at 0.25% of a modern industrial nations GDP and many estimated the economic impact of fouling to the US refining industry to be in the billion dollars per year [7], a figure that would double at today's energy prices. [8, 9, 10]. Today, there's no scientific debate about the impact or cost that the fouling of heat transfer surfaces imparts to the process industry. In the decade since the introduction of large-scale ultrasonic heat exchanger cleaning, however, we have observed a disconnect between the understanding of the negative impacts of fouling within the scientific and engineering community and the understanding of the value of better cleaning within the maintenance, and operations community, where the services related to cleaning are employed.

One of the key questions which we try to answer here is "what is the economic value of better cleaning?". We will compare four sources of information on the subject, which are directly related to the cleaning of fouled exchangers:

- Anecdotal and published information from operating companies
- The simple "black box" model
- A data-driven estimation using real measured trial data from operating companies
- A detailed modelling exercise using Hexxcell's Digital Twin test bed

In order to do this, we first need to introduce first some definitions:

1. Heat Exchanger Cleaning – for the purposes of our discussion, we are constrained to the ex-situ cleaning of heat exchangers, generally restricted to shell-and-tube (or other removable type) heat exchangers, cleaned using "traditional" hydroblasting methods compared to the ultrasonic cleaning and rinsing.
2. Traditional Hydroblasting – this term shall be used throughout to refer to those techniques which rely only on the transfer of energy from a moving jet of water to the fouling as the mechanism by which that fouling is removed.
3. Better Cleaning – what is meant by better cleaning? Better than what method and how much better? And by what metrics? For our purposes this is defined in the context of the currently accepted level of cleaning performance observed with traditional hydroblasting. We know (and can prove) from experience working with operators that the typical return to service performance of a badly fouled heat exchanger cleaned with traditional hydroblasting varies with the size, design, and fouling level, but is typically less than 90%, ranging from 50-90%.

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For the purposes of our investigation, we assume that the difference between cleaning results with ultrasound and traditional hydroblasting will be 20% (improvement). To quantify the improvements provided by better cleaning we define:

a. The maximum theoretical heat duty in clean conditions as Q_c and the actual heat duty calculated with plant data once the heat exchanger is returned into service as Q_a. The ratio between the two (Q_a/Q_c) gives an indication on how effective the cleaning has been performed. The closer the ratio is to one, the better the cleaning has been performed.

b. A cleanliness improvement percentage, *CIP*, as the percentage difference between the ratios Q_a/Q_c for ultrasound and hydro blasting:

$$CIP = \frac{\left(\frac{Q_a}{Q_c}\right)_{Ultrasound} - \left(\frac{Q_a}{Q_c}\right)_{Hydroblasting}}{\left(\frac{Q_a}{Q_c}\right)_{Hydroblasting}} \%$$

ANECDOTAL AND PUBLISHED RESULTS

Over the last decade, many operators have reported that the improvement seen as a result of better cleaning is measured in the millions of dollars, even for a single heat exchanger. This is typically because of five factors:

1. Faster cleaning – in a maintenance shutdown, where the specific focus of the event is to clean an exchanger that is throttling production in some way, the speed of cleaning can play a big role in improving economic value. In these such events, the target bundles are severely fouled, and can take days to weeks to get the best possible result with traditional methods, where the best possible result is still significantly less than 90% of design performance. In these cases, being able to return an exchanger to 100% of design performance within a single shift (<12 hrs) can mean a restart in full production several days faster, which on its own can have a multimillion-dollar impact.
2. Better cleaning result – by getting a problem bundle back to like new levels of performance, the operation of the unit can be improved. We generally don't hear too much about these details, but in one memorable case, we have heard from an operator that by cleaning their bundles regularly back to 100%, he they were able to keep his unit running at optimal levels indefinitely, something he was not able to achieve in the past with traditional cleaning.
3. Longer maintenance intervals – a sometimes overlooked benefit of cleaning to 100% is the potential to extend maintenance intervals. We have one example where an operator was able to double the run time between pit stops on an FCC unit, reducing maintenance costs and improving production throughput at the same time.
4. Less water consumption in cleaning – this benefit is not a direct result of cleaner exchangers, but rather a result of significant reductions in water consumption and wastewater generation during cleaning. The ultrasonic process uses <25% of the water typically consumed on a washpad, and when wrapped in a complete facility with water recycling, will reduce net water consumption by over 95%. We estimate that a medium sized refinery would reduce wastewater generation by over 200,000,000 litres per year. This, for many locations, translates into vary significant savings, indeed we know of several locations where this would directly reduce costs by over US$20,000,000 per year.
5. Lower cleaning cost – the reduced washpad labour effort, faster cleaning and reduced requirement for hydroblasting generally combine to reduce the overall cost of washpad operation for cleaning.

Two operators have published detailed analyses of the economic benefits that better cleaning was able to deliver, focused on the results of a single heat exchanger. In one case, [10] the partial cleaning of ½ of an Alfa Laval Compabloc® OVHD Condenser network (4 out of 8 units in the HEN were cleaned using an ultrasonic method) was shown to save US$4.23M over the subsequent year of operation through improved heat transfer and reduced backpressure (Figure 1). In the figure, the backpressure recorded across the network over time is presented. The green marker represents the recorded back pressure after cleaning 4 of the 8 compabloc units in the HEN. It is evident that cleaning four units reduced back pressure to a similar level as a previous maintenance event where all 8 units were cleaned offsite, and the implication here is that if all 8 were cleaned using the ultrasonic method, the backpressure would likely have been reduced to the same level as the initial (new) performance (on the left axis).

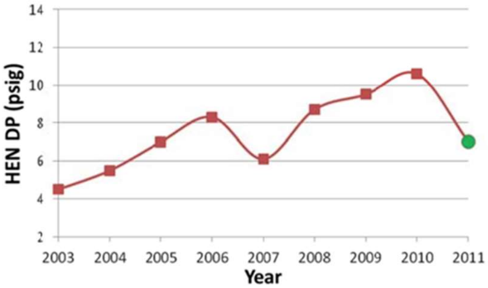

Figure 1. Restoring a welded plate HEN performance using ultrasonic cleaning.

In the second case, the cleaning of a single butadiene production stream bundle was estimated to have saved the company in excess of US$2.3M over the ext 1-year interval, compared to results previously obtained with traditional hydroblasting [11,12]. This type of feedback on the benefits of better cleaning highlighted the need for an improved understanding of the overall value of an approach that would see all heat exchangers currently cleaned using traditional hydroblasting with the ultrasonic method, which brings not only the economic values associated with improved heat transfer performance, but the knock-on benefits of reduced maintenance costs, longer runs times, reduced water consumption, improved safety, and reduced greenhouse gas emissions (a topic of increasing social and economic importance).

THE “BLACK BOX” IMPACT MODEL

In 2019, on the heels of feedback from trials with operators about the value seen in cleaning individual exchangers, we proposed a simple approach to extrapolate these results from single unit to refinery-scale. The goal was to create a very simple “black box” impact model (BBIM) which could estimate the net value to a refinery of switching all traditional hydroblasting cleaning done on a washpad to the ultrasonic method. To do so, we consider the entire refinery as a “black box” or single process, with two inputs – raw material and energy – and two outputs – products and energy. This is represented in Figure 2. In the absence of heat exchangers, all of the energy input into the system is retained in the products, however in practice, heat exchangers are employed to recover heat energy and reuse it to reduce the required net heat input.

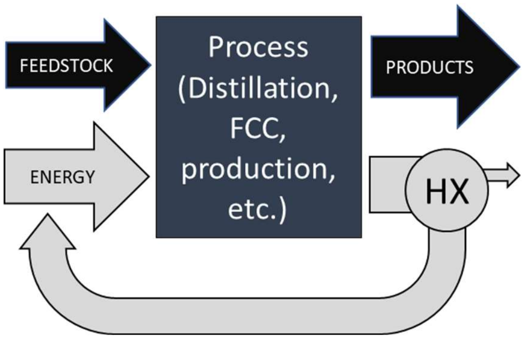

Figure 2. The Black Box Model Concept

The BBIM attempts to calculate the economic benefits of ultrasonic cleaning to a refinery in US Dollars, based on specific plant input parameters, commodity prices, and an improvement in cleaning performance. The BBIM provides a tool that gives an estimate of the savings possible by switching from hydroblasting on a washpad to ultrasonic cleaning in an on-site facility.

This model uses a very simplified treatment of refining and chemical production by approximating the entire plant as a single process, based on the above conceptual model. In the refinery model there are inputs for the refining capacity (bbl/day). These numbers are used to calculate the approximate Energy Total (flux) in the plant (this is the total energy required or released by the input processes). The model treats endothermic (require heat) and exothermic (produce heat) processes the same. The logic behind this assumption is that both types of processes require heat to be captured and moved somewhere else by heat exchangers, and it is this overall heat flux that can be improved with cleaner heat exchangers.

The calculation for refining is simple in concept. The economic impact calculated is primarily the sum of the following components:

1. Direct energy savings associated with cleaner heat exchangers. The formula used here is very simple: the total amount of energy required is determined by multiplying the energy required for the process per unit (E_p) by the total yearly production throughput (ϕ) and by the cost of energy. This is then simply multiplied by cleanliness improvement percentage, CIP.

   $$\Delta E = E_p \times CIP \times \phi$$

   This approach relies on several assumptions:

   a. The performance of heat exchangers can be directly, and linearly linked to overall energy consumption.
   b. The exchangers removed for cleaning are largely responsible for the energy efficiency of the whole process. While it is difficult to estimate how this assumption affects the quality of the estimates, it is not unreasonable to assume that exchangers are designed to be removable precisely because they are expected to foul significantly and thus are likely to need regular cleaning in order to maintain performance.

2. Savings during the turnarounds in cleaning activities. Ultrasonic cleaning, overall, is generally less than half the cost of traditional washpad cleaning of heat exchangers and parts. We capture this savings by assuming an average heat exchanger washpad cleaning cost of US$30K (based on client washpad analysis, the actual cost varies between US$ 30-80K per exchanger), and applied a US$15K savings per exchanger, based on a model estimate of the number of heat exchangers cleaned annually.

3. The “savings” associated with increased production. These are not “savings” per se, but rather an economic improvement resulting from improved performance, longer maintenance

intervals, reduced lost profit opportunities, etc. not captured in either of the two classes above. We initially tried to calculate this based on time savings, but feedback from operators and engineers led to us simplifying this calculation, simply making this value 5X the energy savings. This factor is based on feedback from several operators and consulting engineers, that this net "production" benefit was at least five times the associated energy savings. This approach has proven to be less contentious and yielded a more moderate result than our initial approach.

Not included in the BBIM is the potential impact of cleaning of some parts, such as fragile filters and metal column packings that are currently disposed of because they cannot be effectively cleaned with hydroblasting. Also, a plant's water consumption and wastewater generation at the washpad would essentially be eliminated with an onsite facility and this is not factored into the savings total.

REFINERY BBIM: ESTIMATING THE SAVINGS IN A REFINERY

To estimate the potential savings that could be realized by a refinery using ultrasonic cleaning, the following method, data and assumptions are used:

1. The average energy required to refine a barrel of crude oil to all its ultimate products (through the processes of atmospheric and vacuum distillation, hydrotreating, hydrocracking, fluid catalytic cracking, alkylation, coking/visbreaking, reforming and isomerization), used in the model, is 300kBTU/barrel. This value is based on a number of sources, ranging from theoretical to actual measurements which yielded a range of values from 4.6 (theoretical) – 500 kBTU barrel (actual) [10,11,12]. In our BBIM we use a conservative value of 300kBTU per barrel, thus rejecting >40% of the required energy as unaffected by heat exchanger performance (not collected by recovery, for example).
2. The potential value of these savings is calculated by assuming an average energy cost for heating and cooling derived from a mixture of sources: 10% electricity, 70% natural gas and 20% oil fuels (at market prices).
3. We assume that the impact of cleaner heat exchangers is applicable to the overall energy efficiency and cost of the process.
4. We assign a return to service performance improvement over traditional hydroblasting of 20%.

Based on the above method, data and assumptions, the BBIM predicts an economic improvement for refining as outlined in Table 1.

Table 1. Black Box Impact Model estimates of savings in a refinery that switches all washpad traditional hydroblasting cleaning to ultrasonic cleaning.

Economic impact of ultrasonic cleaning per barrel refined (through all processes in $US)			
Energy	Maintenance	Production	Net
$0.28	$0.04	$1.39	$1.70

The BBIM predicts an average energy savings per heat exchanger cleaned yearly of US$117k. The BBIM further makes the assumption that all fouling service exchangers can be cleaned at once in estimating total value, whereas in reality, the total value could not be achieved for several years – i.e. long enough for all fouling service bundles to have gone through the cleaning process. It is likely however, that most of the value could be obtained faster simply because it is the bad actor heat exchangers that get cleaned first and most frequently, and that's where the bulk of the value likely lies.

DATA-DRIVEN ESTIMATION WITH OPERATOR MEASUREMENTS

Since 2020, we have engaged several operators in measured trials, in which they provide historical, pre- and post-cleaning heat exchanger performance data which we then use to calculate the economic impact that better cleaning provides.

The operator provides performance data including inlet-outlet temperatures, flow rates, process fluid properties and exchanger design for a period of time covering the last cleaning interval(s) and subsequent to ultrasonic cleaning and restart.

The data is used along with HTRI's Xist® (9.0) Software to rate the heat exchanger performance and estimate the economic value of the improvement. A total of 19 exchangers (or exchanger series pairs) were evaluated, from 7 different refineries. Of these, two were found to be operating under conditions in which the fouling level was not limiting performance, 4 had insufficient data to make the comparison, and 2 remain outstanding (we are waiting for data), leaving a total of 10 systems for which the improvement could be estimated. The heat exchangers thus used in the evaluation were all 6,096mm (20 ft) in length, with tube counts from 566 to 1982. Not surprisingly, most of these bundles were part of a crude pre-heat train, with two being part of an FCC unit. Results of this modelling exercise are shown in Table 2.

Table 2. Results from measured trial where clients provided data that allowed for a calculation of the expected benefit of better cleaning on an annual basis for the exchangers cleaned

Customer	Service	Shell Side	Tube Side	Hydroblasting (Qa/Qc)	Ultrasonic (Qa/Qc)	CIP (%)	Energy Savings (kUSD/yr)	CO2 Reduction (tons/yr)
A	CPHT	Vac Resid	Crude	86%	97%	14%	$41.50	
A	FCC Slurry	BFW	FCC Slurry	78%	91%	17%	$473.00	6403
A	CPHT	HGO	Crude	62%	100%	61%	$269.00	5350
A	CPHT	Vac Resid	Crude	75%	100%	33%	$123.00	2178
A	CPHT	HGO	Crude	91%	100%	10%	$64.00	1131
A	CPHT	HGO	Crude	78%	93%	19%	$39.90	704
B	CPHT	Vac Resid	Crude	80%	100%	25%	$226.40	2178
A	CPHT	Vac Resid	Crude	80%	93%	16%	$326.80	4218
C	L/R DEA	Lean Amine	Rich	90%	100%	11%	$184.00	1833
A	CPHT	ABPA	Crude	92%	98%	6%	$144.00	1912
D	CVDU	Flashed Crude	Vac Resid	86%	100%	14%	$679.00	6465
			Average	**82%**	**97%**	**21%**	**$233.69**	**3237**

Several assumptions were made in the modelling exercise to attempt to improve the results by accounting for non-ideal conditions:

1. Decay Factor = 0.75 - this factor is used to account for the fact that these typically fouling service bundles will foul over time, thus the immediate incremental improvement will diminish with time.
2. Network Factor = 0.9 – this factor attempts to account for integration impacts of other exchangers in the train "absorbing" this exchangers improvement.
3. Furnace Efficiency = 0.9 – this factor accounts for imperfect furnace delivery of heat to the process fluid.

CO_2 reduction is estimated using the US-EPA "Greenhouse Gas Equivalencies Calculator" and the calculated reduction in heat requirement.

The performance improvement is expressed as the CIP (defined above). The post-ultrasonic cleaning Qa/Qc was determined using data obtained within the first week after start-up and compared to the Qa/Qc determined similarly (i.e. also determined immediately after startup post-hydroblasting cleaning).

Over the 10 evaluations, the CIP ranged from 61% to 4%, with an average CIP, weighted on the surface area, an improvement of 21%. This supports well the assumption of an average 20% improvement made in the BBIM and confirms the anecdotal evidence that traditional hydroblasting is returning these fouling service bundles back to service operations at 80% of the expected performance level. In most cases, ultrasonic cleaning was able to return the trial bundles to (or indistinguishable) from 100% (in all cases >90%).

It is difficult to extend the results of these measured trial to refinery scale. If we consider only the crude preheat bundles analyzed, the average improvement in heat duty seen is 22%, with an average yearly energy savings estimate of US$ 212K. The CIP value is consistent with the assumptions made in the BBIM, and the average savings per exchanger is of the same order of magnitude as the BMIM prediction, with the BBIM prediction expectedly lower due to the fact that the underlying improvement estimate of 20% is slightly lower and that the savings are averaged over a larger number of exchangers.

The only conclusion we can draw at this point is that the data from the measured trials is in qualitative agreement with the assumptions made in the BBIM. What we need is a way to model an entire refinery to estimate the impact of better cleaning.

THE HEXXCELL DIGITAL TWIN MODEL

In order to attempt to address the limitations of the measure trial analysis in extending results to a refinery level, Clean As New contacted Hexxcell with the idea of using an existing Digital Twin within their Hexxcell Studio™ platform to attempt to model and predict the value of better cleaning. Hexxcell was contracted to independently provide an analysis based on input parameters similar to those used in the BBIM and observed in the measured trial results.

Hexxcell Studio™ is a digital platform for advanced monitoring, predictive analytics and prescriptive maintenance of industrial thermal systems. It is powered by Hexxcell's Hybrid Digital Twin technology which integrates Artificial Intelligence with rigorous physics-based models and deep domain knowledge. The Hexxcell Hybrid Digital Twin (HDT) models:

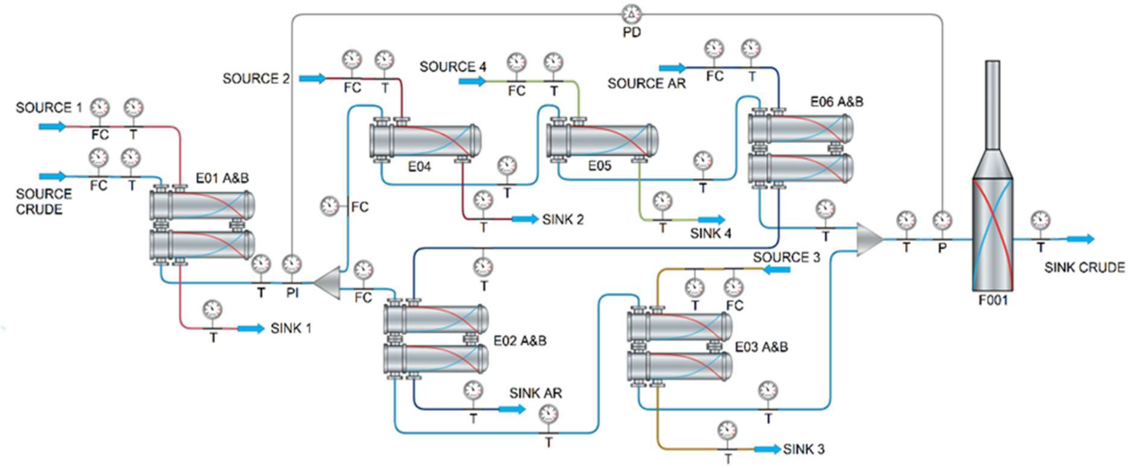

Figure 3 – The Hexxcell Hybrid Digital Twin test bed used to evaluate the benefits of a CIP=19%.

- Account for the thermal impact of fouling but also for the hydraulic one (*i.e.* increased pressure drops) and possible reduction of throughput associated with fouling growth in the heat exchangers [13].
- Using a moving boundary approach, capture the growth of the fouling layer over time and the corresponding reduction in cross–sectional flow area [13] .
- Include the effects of fouling in the shell-side, including growth on the tube outer surfaces and occlusion of geometrical clearances [14].
- Account for the detailed configuration of the heat exchanger (e.g. number of tube–side passes, tube diameter and length, baffle spacing, pitch arrangement, etc.).
- Calculate from the plant data the current state of each individual heat exchanger in the network
- Assess the impact of specific cleaning actions based on:
  - Current state of the units
  - Interaction between heat exchangers while a cleaning is performed
  - Furnace efficiency
  - Economic trade-offs, including:
    - Production savings
    - Fuel consumption and related costs
    - CO2 emissions
    - Duration and efficiency of a cleaning action
- Optimize flow split during operations to minimize the impact of fouling while maximizing furnace inlet temperature
- Generate an optimal cleaning schedule based on the above

The results presented here have been generated from Hexxcell's Hybrid Digital Twin refinery test bed. This is a standardized case study for the hot end of a pre-heat train in a 110,000 bbl/day refinery depicted in Figure 3. The network includes six heat exchangers (two single shells and four double shells). The spirit of the study was to obtain an independent evaluation of the benefits that better cleaning provides to refineries. Therefore, to maintain objectivity, Hexxcell worked with Clean As New to make sure the cases examined were relevant but Hexxcell had the ultimate say on the values of the parameters to be used. With respect to the specific case study presented here, it should be noted that:

1. The digital twin was built for a well-run, efficient, European refinery. The models have been trained on the refinery data over a four-year period. Some of the parameters and configurations have been modified to protect confidentiality without affecting the conclusions.
2. The model has been validated with plant data and is able to predict the Coil Inlet Temperature within ±1.5% over an extended period of time.
3. Costs model and CO_2 calculations used here are the same applied in the plants monitored with Hexxcell Studio™ hence extensively validated with refinery practice.
4. The throughput is limited by the furnace maximum firing limit at 304 MMBTU/h.
5. The model assumed that traditional hydroblasting is 90% effective on the tube side and 70% effective on the shell side, and that ultrasonic cleaning delivers 100% cleaning efficacy on both the tube and shell-side. Overall, the CIP considered for ultrasonic cleaning was 19%. The analysis presented here is not meant to

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validate these values but rather establish what is the realistic impact on the economics and CO_2 emission of a typical refinery if these improvements can indeed be achieved with ultrasound cleaning.

6. Ultrasound cleaning is assumed to take one day less than hydroblasting to return the heat exchanger(s) to service.
7. The model did not include the potential effect of a slower decay of the heat exchanger performance due to a cleaner exchanger being reinstalled. While there are some anecdotical reports on this, there were not enough data to establish this behaviour. Examination of this impact may be done in the future if better data demonstrating this effect becomes available.

Subject to these assumptions, two scenarios are presented below:

- Scenario 1: The cleaning of two heat exchangers, no furnace limit applied.
- Scenario 2: The cleaning of all exchangers in a turnaround, furnace limit applied.

Hexxcell HDT, Scenario 1: Individual Cleaning Comparison

In the first scenario, the model was run for two individual cleanings. This, for example, could represent maintenance cleanings of preheat exchangers. In this Scenario, to provide a conservative estimate of the benefits, only fuel related savings (*i.e.* no production losses) are included by imposing a very large furnace limit so that it is never hit within the time horizon of the simulations (1 year).

Table 3. The Hexxcell HDT results for cleaning heat exchangers E01AB and E06AB cleaned independently.

Parameter - HX E01A&B	Units	Results HX E01AB / E06AB Hydroblasting Cleaning	Ultrasonic Cleaning	Delta
Initial fouling layer – Tube side	inches	0.017 / 0.62	0.017 / 0.062	
Initial fouling layer – Shell side	inches	0.010 / 0.052	0.010 / 0.052	
Fouling resistance – Tube side	$ft^2 \cdot h \cdot °F/BTU$	0.017 / 0.062	0.017 / 0.062	
Fouling resistance – Shell side	ft2·h·°F/BTU	0.007 / 0.036	0.007 / 0.036	
Q/Qc before cleaning		0.40 / 0.32	0.40 / 0.32	
Q/Qc after cleaning		0.81 / 0.77	1.00 / 1.00	0.19 / 0.23
HEX duty gain after cleaning	MMBTU/h	32.0 / 22.0	45.0 / 33.0	13.0 / 11.0
Furnace gain after cleaning	MMBTU/h	22.0 / 16.0	33.0 / 25.0	11.0 / 9.0
Total CO_2 emissions	kton	151 / 155	150 / 153	-1.0 / -2.0
Total fuel cost	kUSD	10,366 / 10,616	10,300 / 10,504	-66.0 / -112.0
Total CO_2 cost	kUSD	830 / 850	825 / 841	-5.0 / -9.0

The two exchangers selected for cleaning were E01AB and E06AB, at each end of the pre-heat train. A comparison of the pre-heat train performance was then developed by allowing the model to run for a one-year period as if each exchanger was cleaned with traditional hydroblasting or with ultrasonic cleaning.

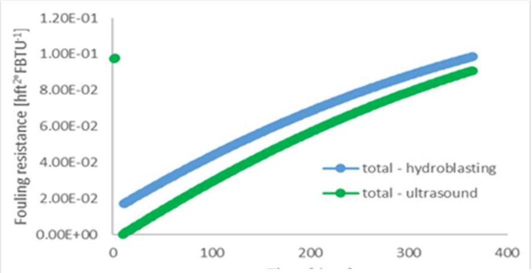

Figure 4 – Typical heat exchanger fouling resistance predicted by Hybrid Digital Twin in Hexxcell Studio™ for the two cleaning results on Exchanger E06AB.

Figure 4 shows the effect of a CIP=19% on the initial fouling resistance and its evolution over time. A summary of the model results for the two heat exchangers *is* given in Table 3. The fouling growth model used in each case is the same, *i.e.,* there was no attempt made to modify the fouling growth *behaviour; however,* in the case of hydroblasting, the fouling resistance curve "starts" at a point where the exchanger is already fouled. The difference in saving*s* for ultrasound cleaning is estimated *at* US$66k for the upstream unit and US$ 112k for the one closer to the furnace.

Hexxcell HDT, Scenario 2: Turnaround Comparison

The second scenario considered was a complete turnaround where all exchangers are cleaned during a unit shutdown. In this case, all units were considered fouled as in the case for Scenario 1. Some results are shown in Figure 5 and summarized in Table 4. As in the previous Scenario, the exchangers were cleaned on day 3 from the start of the simulations and returned to service depending on the type of cleaning used.

However, in Scenario 2, we included a throughput limitation by introducing a furnace limit. The furnace limit used in this case was the actual 304MMBTUh^{-1} imposed on the real crude unit with which the model was trained. As the fouling resistance increases, the furnace duty increases until it hits the limit on day 172 for the hydroblasting cleaning, and on day 201 for the ultrasonic cleaning. After this point, in both cases the production begins to drop.

The Hexxcell HDT predicts an energy savings difference for a CIP=19% of US$ 186K over the 1-year period following the T/A event. When the production losses are accounted for a total annual value of US$ 590K is estimated.

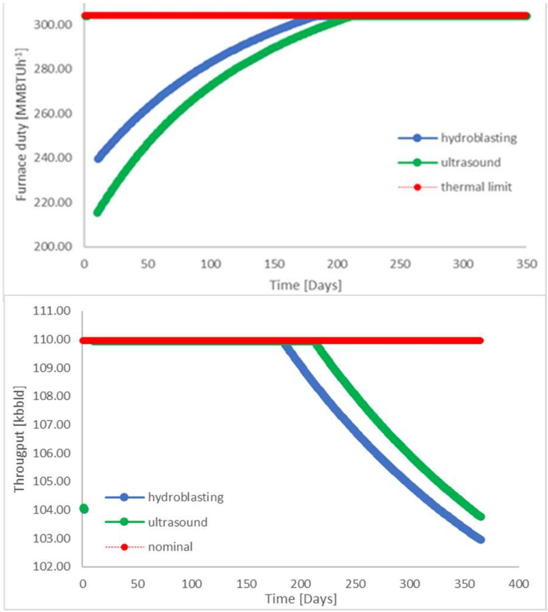

Figure 5 – Hexxcell HDT Model results for Scenario 2

Table 4 – Hexxcell HDT Model results for T/A cleaning of all 6 heat exchangers

Parameter	Units	Hydroblasting Cleaning	Ultrasonic Cleaning	Savings
Days to thermal limit after cleaning	Days	172	201	29
Total CO_2 emissions	kton/yr	144.1	141.4	2.7
Total production loss	kbbl/yr	742	546	196
Total production loss cost	kUSD/yr	1,480	1,090	390
Total fuel cost	kUSD/yr	9,898	9,712	186
Total CO_2 cost	kUSD/yr	792	778	14
Total cost	kUSD/yr	12,170	11,580	590

CONCLUSIONS

The three different approaches to estimating the value of better cleaning share several important characteristics:

1. All three methods clearly demonstrate that there is a large value that can be captured by cleaning heat exchangers back to design performance and that the tacitly accepted limitations of hydroblasting-only cleaning philosophy can cost the industry significantly.
2. All three methods show that speed of cleaning can have a significant impact on economic return. In the case of maintenance cleaning especially, the Hexxcell HDT has shown (and we know from experience with operators) that the reduction in lost profit can be larger than the energy savings.
3. Particularly evident in the data-driven evaluation with operator measurements and the Hexxcell HDT results is that cleaning leads to minimize energy consumption, greenhouse gas emissions and reduce total operating costs.
4. All three modelling approaches return similar energy savings values when single, problem heat exchangers are cleaned better. These results align well with operator reported results.

The Hexxcell HDT model results also clearly show the risk in estimating plant-wide savings by extrapolating from single heat exchanger results. The built-in assumptions of the BBIM may or may not be applicable, as the HDT model shows that thermo-hydraulic network interactions, current state of the equipment, furnace limit etc. play an important role in the extrapolation of the results from a single heat exchanger to an entire network.

What these results teach us is that to optimize economic performance, optimized maintenance planning is essential. The better, faster and less expensive cleaning offered by the ultrasonic method provides an opportunity to re-think maintenance, and tools like the Hexxcell HDT can play a key-role in that optimization.

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