ENERGY EFFICIENCY TECHNOLOGY SCAN FOR OIL SANDS ACTIVITIES – EXECUTIVE SUMMARY

Minimizing natural gas and electricity consumption is of major importance in order to ensure the economic viability and environmental performance of in situ oil sands production. In this context, COSIA is seeking support in identifying energy efficient technologies relevant for in situ oil sands operations.

The question asked by COSIA is the following: *"What are the most promising technologies among those covered by energy efficiency funding programs and research institutes, able to address specific in situ oil sands energy efficiency challenges in the short and medium term?"*

Heat recovery and heat integration are the main focus of funding programs and research institutes

A total of 74 funding programs and research institutes have been scanned in order to identify publically disclosed technologies, promising for in situ oil sands activities.

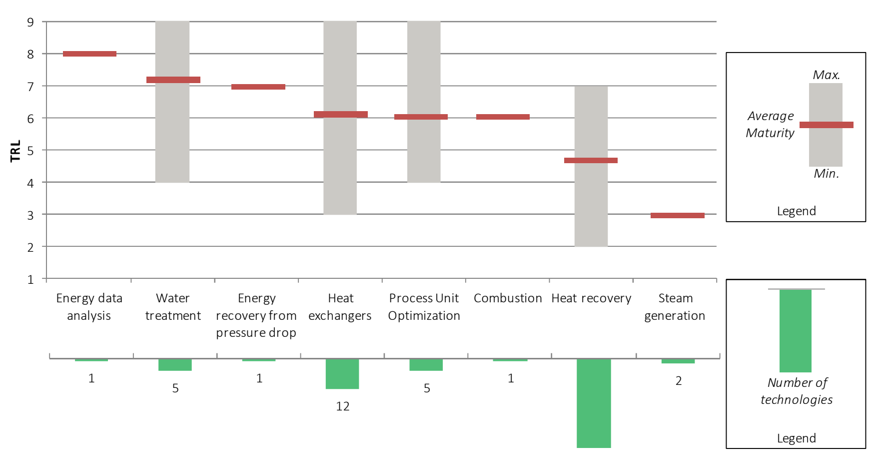
A key learning of the technology scan is that energy efficiency funding programs and research institutes focus on heat recovery, new heat exchangers and heat integration. Indeed, these topics cover approximately 75% of identified technologies potentially suitable for oil sands operations.

Conversely, other technology classes of interest for in situ oil sands operations are relatively sparsely covered by programs (e.g. energy recovery from pressure drop; or energy efficient separation technologies). Similarly, energy efficiency innovation areas such as steam generation or water treatment are hardly covered by these funding programs.

Energy efficiency technologies identified cover a wide TRL range

The maturity of the technologies supported by funding programs and research institutes is variable and ranges from TRL 2 (technology concepts) to TRL 9 (commercial applications), the average TRL being between 5 and 6 (components or prototypes in a simulated environment).

The study focuses on relatively mature technologies (TRL ≥ 7). Nevertheless, technologies with a maturity below TRL 7 and particularly addressing in situ oil sands challenges have also been considered in the technology selection process.



Average TRL, range of TRL, and number of technologies identified for each technology

Seven promising energy efficiency technologies are identified

The technology scan led to the identification of 7 promising technologies. The selection process is mainly a cross between their potential in terms of energy savings, and their relevance regarding in situ oil sands key short and medium term challenges (e.g. corrosion and fouling resistance for heat exchangers, maintenance reduction, Greenhouse Gas (GHG) emissions, and high design capacities).

The selected technologies are classified in 4 categories: new heat exchangers, heat exchanger cleaning technologies, software tools, and combustion diagnostic technologies.

Category	Technology of interest	Key characteristics
New heat exchangers	**Heat recovery with asymmetric plate heat exchangers**	▸ Gas-liquid heat transfers ▸ Heat recovery from gas at high temperatures (500-600°C) for hot water production
	Low temperature polymer heat exchangers	▸ Corrosion resistance ▸ Low temperature heat transfers (typically below 200°C) ▸ Design flexibility
	Vibrating heat exchangers	▸ Fouling prevention ▸ Heat transfer improvement
Heat exchanger cleaning	**In situ off-line and online cleaning**	▸ Turnaround minimization ▸ Heat transfer improvement ▸ Reduction of waste water volume resulting from cleaning
Software tools	**Process heat integration software**	▸ Design and optimization of heat exchanger networks (greenfield and revamp) ▸ Operational optimization of existing heat recovery systems
	Energy data analysis	▸ Identification of key energy efficiency opportunities ▸ Assessment of the potential and actual energy gains of energy efficiency measures ▸ Energy consumption forecasts
Combustion diagnostic	**Advanced laser diagnostics for combustion processes**	▸ Better understanding of the flowing parameter in combustion processes and other gas-phase reactions (e.g. temperature, species concentration such as NOx, SOx, CO, etc.) ▸ GHG emission measurement

The implementation of these technologies can lead to potential energy and cost savings for in situ oil sands operations. Further tracking and investigation of these technologies is consequently recommended.

ENERGY EFFICIENCY TECHNOLOGY SCAN FOR OIL SANDS ACTIVITIES

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Energy efficiency funding program and technology scan for applicability to Oil Sands

Study performed for COSIA.

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Since 2007, ENEA has been advising and supporting leading private sector companies and public authorities around the world on the topic of energy transition sectors and markets. Through dedicated consulting services and pro bono support to NGOs and social entrepreneurs selected for their high potential impact, ENEA is also committed to energy access.

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1 INTRODUCTION

1.1 Context

COSIA

Canada's Oil Sands Innovation Alliance (COSIA) is an alliance of oil sands producers focused on accelerating the pace of improvement in environmental performance in Canada's oil sands production through collaborative action and innovation.

Through COSIA, participating companies capture, develop and share the most innovative approaches and best thinking to improve environmental performance in the oil sands production, focusing on four Environmental Priority Areas (EPAs) – tailings, water, land and greenhouse gases.

To date, COSIA member companies have shared 936 distinct technologies and innovations that cost over $1.33 billion to develop. These numbers are increasing as the alliance matures and expands. Through this sharing of innovation and application of new technologies, members can accelerate the pace of environmental performance improvements.

COSIA takes innovation and environmental performance in the oil sands production to the next level through a continued focus on collaboration.

Energy efficiency in Canada's oil sands

In Situ Oil sands production requires significant amount of steam to be generated and injected, in order to reduce the viscosity of the bitumen (the Steam-to-Oil Ratio (SOR) can vary from 1.5 to 8 depending on the kind of reservoir the in situ bitumen extraction facility is producing from, in addition to the stage that each operating well is in). For in-situ bitumen production, using Steam-Assisted Gravity Drainage (SAGD) technology, steam is commonly produced in Once-Through Steam Generators (OTSG), thereby consuming significant amounts of natural gas. There is also electricity consumption associated with the other types of equipment located at a typical Central Processing Facilities (CPF), as well as the Field Processing Facilities (FPF). In some configurations, steam and electricity are generated using cogeneration techniques.

In a context of low barrel price, minimizing natural gas and electricity consumption is therefore of a major importance in order to ensure the economic viability of oil sands production. COSIA is investigating energy savings opportunities, with additional benefits in terms of GHG emissions reductions.

1.2 Objectives

The question asked by COSIA is the following: "*What are the most promising technologies among those covered by energy efficiency funding programs, allowing energy efficiency improvements (reduction of natural gas and/or electricity consumption), applicable to SAGD operations, already available on the market or close to, and economically sound?*".

In other words, the study aims to identify relatively mature energy efficient technologies relevant for in situ oil sands operations. The technology identification process is based on the screening at an international level of funding programs and research institutes supporting the development of energy efficient technologies related to the industry. Relatively short term implementation of the technologies is sought by COSIA. The study focuses on technologies at a demonstration stage in an operational environment (TRL ≥ 7[1]).

This study focuses on technologies applicable to a SAGD facility, and not necessarily an oil sands mining facility.

[1] Based on the "Technology Readiness Levels" scale provided by COSIA

2 KEY LEARNINGS

A large number of energy efficiency technologies (62 technologies) potentially relevant for oil sands operations have been identified through the study. The funding program and research institute scan process was consequently relatively fruitful in terms of energy efficient technology identification.

2.1 Funding program and research institute scan

Funding program and research institute scan process

In total, 74 energy efficiency funding programs and research institutes in operation or recently completed have been identified at a global scale. These funding programs and research institutes have been evaluated based on a public literature review (e.g. program descriptions, examples of funded projects) in order to identify those of interest for oil sands activities. This first resulted in a shortlist of 27 programs or research institutes of interest for COSIA.

The shortlisted programs and research institutes were then directly contacted in order to collect a listing of the energy efficiency technologies supported by the programs and institutes. In the end, 10 funding programs and research institutes were able to share public information on the technologies they support.

The funding programs and research institutes identification and data collection process is summarized on Figure 1:

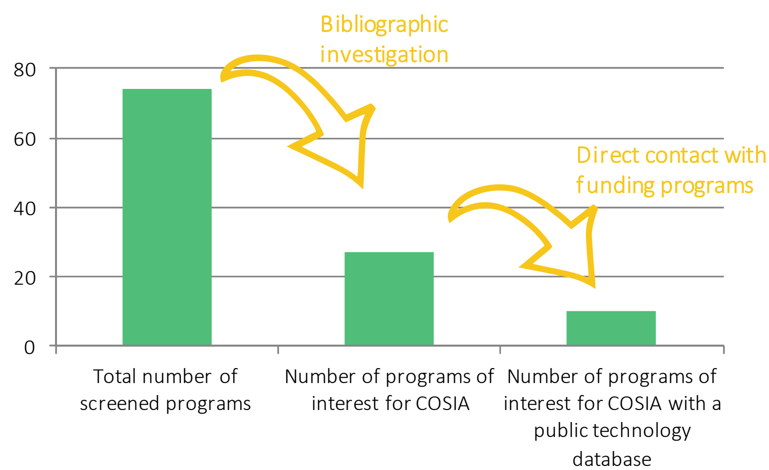


Figure 1 – Funding programs and research institutes identification and data collection process

Mapping of the funding programs and research institutes of interest

Among the 27 funding programs and research institutes identified and of interest for COSIA, the programs and institutes still active in 2016 are mapped on Figure 2. Though non exhaustive, this list can be considered as rather complete with respect to COSIA's expectations. It must be noted that based on COSIA's direction, the study focused on funding programs and research institutes outside Canada, and paid less attention to the United States compared to Europe.

Most relevant funding programs and research institutes are located in Europe, either directly at a European level or at a national level.

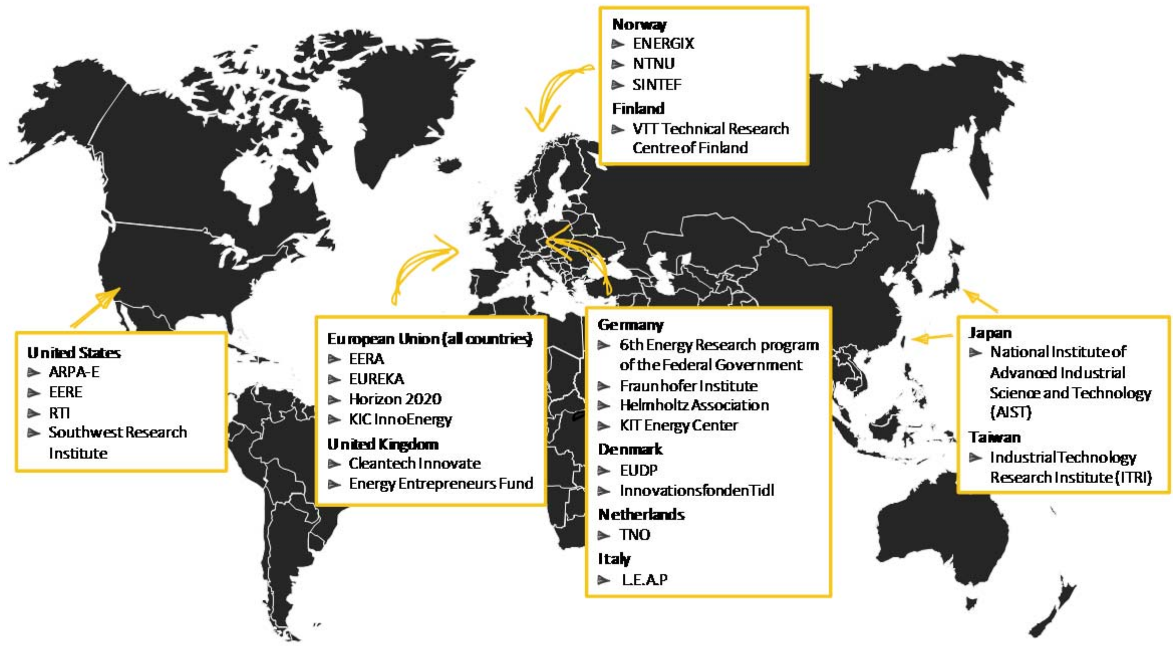


Figure 2 – World map of funding programs and research institutes of interest for COSIA (outside Canada)

2.2 Technology scan

Technologies identification

In total, among the hundreds of technologies listed in the scanned public databases, 62 were identified as of potential interest for oil sands operations (regardless of the TRL). The distribution of the 62 technologies between the different funding programs and research institutes is presented Figure 3. The European funding program H2020 presents the main share of supported technologies (14 technologies), followed by the German government (10 technologies).

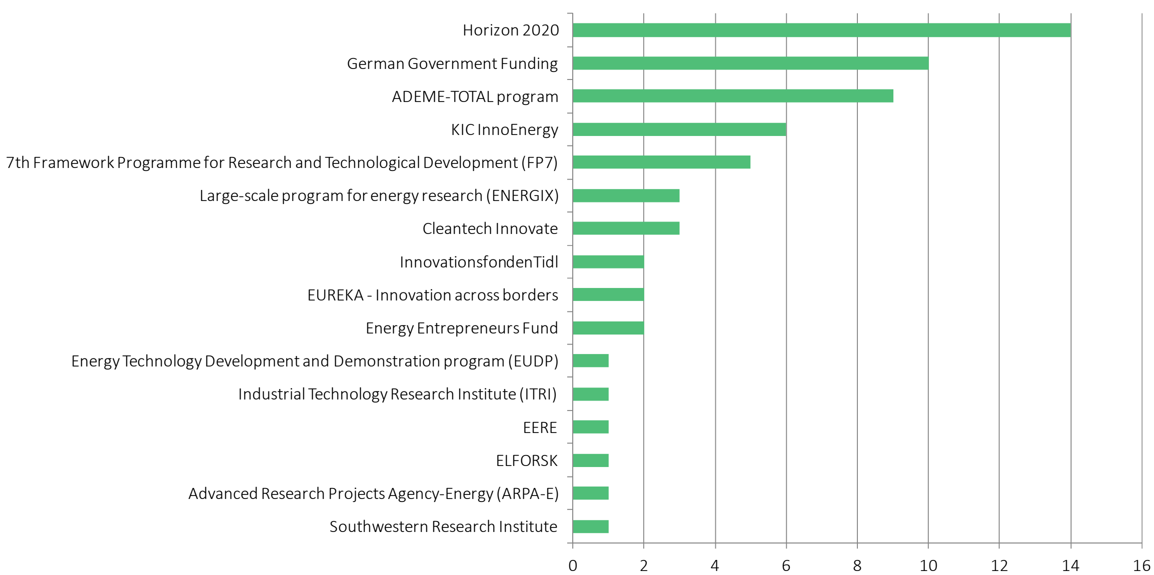


Figure 3 – Number of potentially relevant technologies identified per funding program or research institute

Technologies categorization

The 62 technologies have been categorized in terms of innovation areas. A large majority (75%) of technical solutions supported by funding programs and research institutes concern heat recovery (e.g. power generation based on waste heat recovery with Organic Rankine Cycles) and new heat exchangers (e.g. corrosion resistant heat exchangers, anti-fouling solutions).

The distribution of the 62 technologies between the 8 different innovation areas identified is presented on Figure 4:

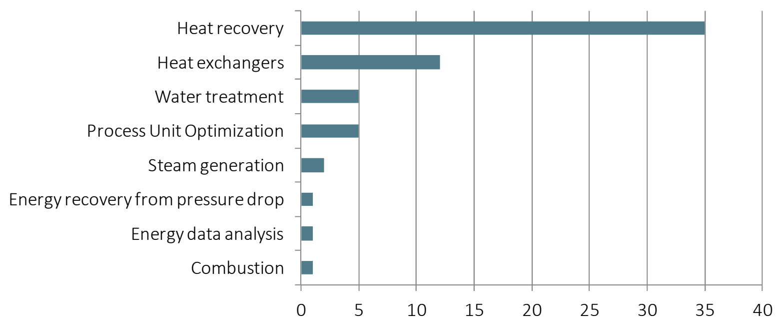


Figure 4 – Categorization of identified energy efficient technologies

Technologies maturity[1]

The maturity of the technologies supported by funding program and research institutes is variable and ranges from TRL 2 (technology concepts) to TRL 9 (commercial applications). The average TRL is between 5 and 6 (components or prototypes in a simulated environment). The average maturity of the technologies supported by programs or institutes is consequently below the minimum maturity initially targeted by the study (TRL ≥ 7). Nevetheless some technologies with a TRL below 7 present a real interest for oil sands operations. Based on COSIA's direction, some of these technologies particularly addressing in situ oil sands challenges have thus been retained for a preliminary analysis.

The average TRL for each technology category (with minimum and maximum TRLs, when available) is presented on Figure 5 (the number of technologies in each category is presented Figure 4):

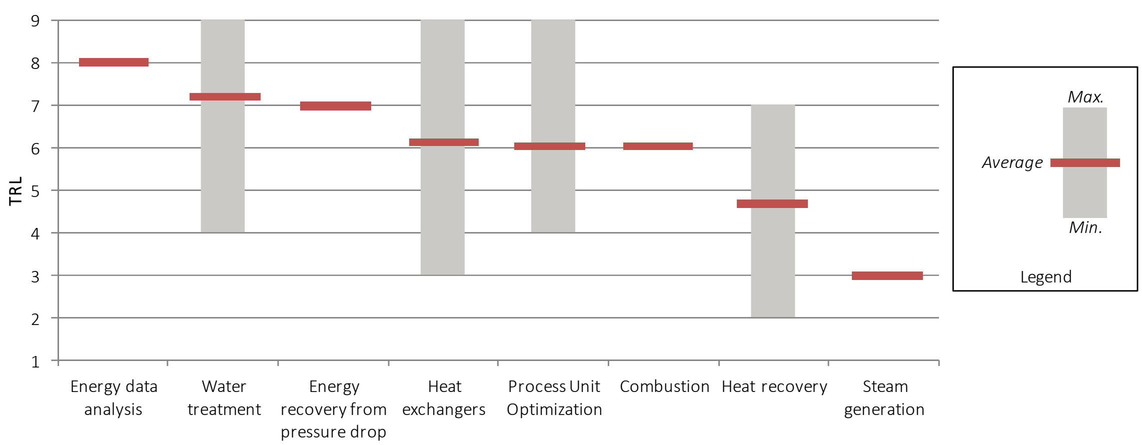


Figure 5 – Average and range of TRL for each technology category

[1] The maturity analysis has been performed on 45 technologies out of 62 (technologies with sufficient public information for a maturity assessment).

2.3 Conclusions

A focus on heat recovery and heat integration

A first key learning of the technology scan is that energy efficiency funding programs focus on heat recovery, new heat exchangers and heat integration generally speaking. Indeed, these topics cover approximately 75% of identified technologies potentially suitable for oil sands operations.

Conversely, other technology classes of interest for oil sands operations are relatively sparsely covered by programs (e.g. energy recovery from pressure drop; or energy efficient separation technologies). Similarly, energy efficiency innovation areas such as steam generation or water treatment are hardly covered by funding programs.

Less information disclosed by research institutes

Research institutes have been included in the scope of the study in order to supplement the technology identification performed firstly through the screening of funding programs. Contrarily to funding programs, it appears that the developments performed by research institutes are more confidential. Little information on energy efficient technologies has consequently been collected through the screening of research institutes. In any case, the limited feedback from research institutes confirms a focus on heat recovery and heat integration.

10 technologies shortlisted

After a preliminary analysis of the 62 identified technologies, COSIA has selected 10 technologies of interest, considering their consistency with COSIA key challenges. The selection process also strove to minimize the possible overlapping with other studies performed in parallel by COSIA.

The relevance of these 10 technologies has mainly been evaluated taking into account their uniqueness compared to oil sands operation key challenges (see Technology fact sheets). Other key characteristics that have been assessed include: potential energy savings, the state of development (TRL), targeted capacities compared to oil sands typical capacities and key development routes (working on oil sands is sometimes not a priority for technology developers).

3 TECHNOLOGY FACT SHEETS

The 10 technologies selected by COSIA have been evaluated based on bibliographic reviews and interviews with technology developers. The objective of the evaluations is to determine if deeper assessment of the technologies as part of future studies is recommended.

The technology evaluations are presented in fact sheets organized in 6 sections:

- General description
  - Presentation of the company or the university that develops the technology
  - Description of the general principles of the technology
- State of development
  - Evaluation of the maturity of the technology (depending on the targeted application when relevant)
  - Presentation of references and track records
  - Presentation of targeted markets and key development routes
- Technical performance
  - Evaluation of the efficiency or the potential energy savings related to the technology
  - Description of the operating conditions (e.g. pressure and temperature)
  - Evaluation of the robustness of the technology (e.g. corrosion resistance)
- Economic performance
  - CAPEX and OPEX estimates
  - Indication of typical payback times
- Relevance in oil sands context
  - Evaluation of the retrofitability to existing facilities
  - Assessment of the suitability to oil sands capacities
  - Evaluation of the technology's relevance in oil sands' aggressive environments

It must be noted that the fact sheets are based on public information only. Some technology characteristics are consequently not available.

AARHUS UNIVERSITY – Antifouling solutions

General description

Aarhus University is currently developing antifouling coatings for heat exchangers as part of a research project funded by the Danish National Advanced Technology Foundation and several industries. The project started in 2014 and is expected to end in 2017.

In the short term, the antifouling solutions targets plate heat exchangers for fresh water installations.

State of development

TRL 3

Aarhus university is currently performing analytical studies. The antifouling solutions are consequently at a research level and no prototype has been built yet.

Current developments include the formulation of coating solutions, and the evaluation of their physical characteristics. Next steps include the evaluation of the coating thickness impacts on heat transfer characteristics.

Current research focuses on organic based coatings that minimize bio-fouling and scaling on the cold side of heat exchangers (on the hot side, the fouling is not expected to be a big issue). The evaluation of other coating materials (e.g. inorganic materials) would require the development a dedicated research program. It must be noted that very few studies have been performed on the application of coatings to heat exchangers.

Technical performance

Due to the use of polymers, the maximum temperature for antifouling solutions being developed is currently 120°C. For operating conditions with high temperatures, other types of coating (likely inorganic coatings) would need to be developed.

Short term applications target water installations with low pH variation and low level of impurities. The antifouling solutions being developed are consequently not compatible with high concentrations of impurities such as salts, metals or silica.

Anticipated solutions involve less than 1 µm-thick coatings that ensure suitable heat transfer characteristics. But these types of coating would not be compatible with high temperatures and high levels of impurities.

In order to cope with high levels of impurities, the coating thickness would have to be increased. Nevertheless, this would impact the heat transfer characteristics of the heat exchanger. A proper modeling needs to be performed to assess the actual impact of the coating thickness on heat transfer characteristics.

Economic performance

Considering the development stage of the technology, no information on economic characteristics is currently available.

Cost estimates would require the involvement of coating and heat exchanger manufacturers (e.g. Alfa Laval, see Appendix)

Relevance in Oil Sands Context

Coatings can be applied as part of retrofit projects provided that the heat exchanger is full cleaned. No particular limitations in terms of capacities are expected.

The coating capability to cope with aggressive environments (high temperature gaps, etc.) needs to be assessed.

Current developments are not compatible with Oil Sands operating conditions.

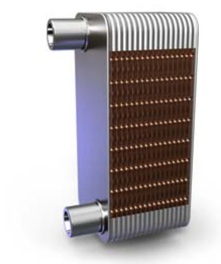
AIREC – Asymmetric plate heat exchangers

General description

Airec is a company based in Sweden, specialized in the development and manufacture of plate heat exchangers for applications where traditional plate heat exchangers do not entirely meet targeted application's needs.

More specifically, Airec is particularly focused on highly asymmetric gas-liquid heat transfer applications and heat exchangers designed to cope with high gas temperatures (e.g. exhaust gases at 500-600°C).

Standard targeted applications are typically heat recovery systems from exhaust gases that aim to produce of hot water.



Airec's Cross 30 heat exchanger

Source: Airec

State of development

TRL 9 for current applications
TRL 8 for COSIA's applications

The heat exchangers designed and produced by Airec are at a commercial stage for small and medium scale applications. The technology is particularly established for Combined Heating and Power applications: typically heat recovery from genset exhaust gases that aims to produce hot water. Airec has more than 50% market share in Germany on CHP applications.

The capacities usually targeted by Airec (0.01-1 GJ/h) are smaller than heat transfers involved in oil sands operations (10-100 GJ/h). The applicability of current technologies will consequently depend on the heat recovery targeted. As an illustration, a 1 MW / 3.6 GJ/h would require 12 Cross 30 units in parallel, which is at the upper limit of usual Airec's applications.

Airec focuses its developments on applications where the company's technologies are expected to be more efficient than state-of-the-art applications. Airec performs both the design and the manufacturing of plate heat exchangers but is not a turnkey supplier: an EPC / integrator company is required for the construction of heat exchangers' casing / housing, as well as the installation and start-up of the overall unit.

Technical performance

Airec is focused on gas-to-liquid heat transfers with highly asymmetrical flows. Airec's designs can handle configurations with volume flows 100-10 000 times greater on one side than the other, while traditional plate heat exchangers generally handles asymmetry up to 1:10.

Airec's technologies can be used for the preheating of a boiler feed water or the heat recovery from low pressure steam (~1 bar). Airec's designs mainly target the production of hot water (or other low temperature heating mediums) and are consequently not suitable for the generation of steam. In order to maximize the heat recovery, Airec's technologies are also designed to enable a high condensing performance (condensation of the water vapor in the exhaust gas), provided that the inlet temperature of the heating medium system is low enough (typically between 45 and 55°C).

Airec heat exchangers can handle pressures up to 10-50 bar, typical pressures being around 4-6 bar on the liquid side, and atmospheric pressure on the gas side. In addition, Airec technologies are suitable to handle high gas temperatures (e.g. exhaust gas at 500-600°C).

Considering that applications mainly target the production of hot water for heating medium systems, clean water is expected to be used. Corrosion is thus not expected to be an issue on the liquid side. On the gas side, corrosion can be an issue depending on the gas composition (e.g. sulfur content of the exhaust gas). The heat exchanger material consequently needs to be selected accordingly. As an illustration, Airec's Cross 30 heat exchanger is made in stainless steel 316L, with copper or nickel as brazing material depending on the corrosion resistance targeted.

Economic performance

Airec has performed a preliminary budget assessment for a 3.6 GJ/h (i.e. 1 MW) heat recovery unit from a gas boiler exhaust. A relatively corrosive exhaust has been assumed, leading to the selection of Nickel as a brazing material. The related CAPEX for the overall system (12 Cross 30 units and casing included) is approximately 53 k€.

Assuming a exhaust gas at 220°C, a production of hot water at ca. 55°C, a thermal efficiency of ca. 62% and a fuel cost of 0.02 €/kWh, the payback time would be less than a year.

Generally speaking, payback times of less than 2 years are expected (from 1/3 to 1/2 of shell and tube exchanger typical payback times).

Relevance in Oil Sands Context

Airec's plate heat exchangers are much more compact than common shell and tube heat exchangers (10% of a shell and tube heat exchanger for a similar heat duty). Airec heat exchangers are consequently suitable for retrofit applications.

As part of oil sands operations, Airec's technologies can be relevant for OTSG gas exhaust heat recovery, or LP steam (~1bar) heat recovery. Airec being more focused on low and medium scale applications, the suitability of its system to typical oil sands heat duties (10-100 GJ/h) needs to be further assessed.

No particular issues are expected regarding the applicability to the Oil Sands environment (the technologies are qualified for aggressive environments in Sweden.

ENERGIENCY – Energy data analysis

General description

Energiency is a French company founded in 2013 specialized in the application of data sciences to the energy performance of industries.

Energiency has developed machine learning algorithms that performed "big data" analyses on industrial processes' operational data. Energiency enables the monitoring, diagnostic and management of the energy performance of industrial sites.

Screenshot of Energiency software tool

Source: Energiency

State of development

TRL 8

Energiency has completed its pilot phase and is now at a commercial development stage. After a first experience in the food industry, Energiency is currently operating its solutions in approximately 20 sites in various sectors, including the automobile, chemicals and paper industries.

Energiency has no reference in oil and gas companies, but oil and gas is a development route currently considered by Energiency. Generally speaking, Energiency is particularly in contact with utilities and energy companies for the application of its software tools.

Some features are currently in development, and should be available this year (e.g. identification of key parameters and their weight on energy performances, simulation of the implementation of energy efficiency solutions and their expected energy gains).

Energiency's geographic development is focused on Europe. Nevertheless, Energiency also considers developments outside Europe on an opportunistic approach (e.g. developments in the fertilizer industry in Brazil).

Technical performance

Energiency's solution is an Energy Management System fully compatible with the ISO 50 001 certification process. Energiency data analysis tool can be used for multiple purposes.

Energiency can be used build a large number of energy KPIs. Most relevant KPIs can be monitored and the Energiency can identify and point out drifts or heterogeneities on these KPIs (e.g. drifts on the specific energy consumption, energy consumption gaps compared to the predictions…). The different parameters impacting the KPIs and their weight on the energy performed can be identified by the software tool (feature to be issued this summer). Energy efficiency opportunities aiming to align the performances with the best historical performances observed can consequently be identified.

The software tool can be used to predict or forecast energy consumption profiles. This feature can be used by an industrial site to provide its energy distribution company with a consumption forecast (e.g. hourly electrical consumption). In some specific contracts, accurate energy consumption predictions can be rewarded by the energy distribution company. This feature is currently used by an industrial site that saves ca. 0.5% on its 40 M€ electricity annual bill.

This energy consumption prediction feature can be used to quantify the actual energy gains of an energy efficiency measure. Indeed, Energiency can reconstruct a virtual baseline after the implementation of the energy efficiency measure. In addition, the software tool can also anticipate the effects of an energy efficiency measure on different operational parameters, and the energy savings that can be expected (feature to be issued end of 2016).

Finally, the software tool can also be used to optimize energy utilities. This feature is currently used by a chemical industrial platform (80 M€ energy consumption) for its energy mix optimization and the minimization of thermal deaeration.

Economic performance

Energiency's business model is based on a monthly SaaS subscription. The subscription cost mainly depends on the targeted site's architecture and the total data flow to be analyzed.

Energiency targets payback periods below 1 year. Generally speaking, the subscription cost represents maximum 1 to 2% of the total energy bill.

Relevance in Oil Sands Context

Energiency's solution requires the availability of a data flow. A minimum metering and monitoring of the targeted site is consequently required.

In general, approximately 20 meters appropriately located on a whole facility are sufficient to provide enough data to the software tool, the actual number of meters depending on the complexity of the site to be analyzed. The data analysis' relevance highly depends on the quality of the data flow. A suitable selection of the data to be metered is consequently important, and the reliability of the collected data needs to be well monitored.

Apart from the availability of an appropriate data flow, no particular constraints are expected regarding the implementation of Energiency's solution.

GRENOBLE UJF – Vibrating heat exchangers

General description

The Joseph Fourier University located in Grenoble (Grenoble UJF) studies the applications of ultrasound to industrial processes for the enhancement of both heat and materials transfers.

In this context, as part of the ADEME-TOTAL funding program, Grenoble UJF has studied the application of ultrasound to heat exchangers (vibrating heat exchangers).

The main objectives of vibrating heat exchangers are:

- Fouling mitigation
- Heat transfer enhancements, to a lesser extent

Foreseen applications concern both shell and tube and plate heat exchangers.

State of development

TRL 3

Vibrating heat exchangers are at a very early stage of development. UJF has built a lab-scale prototype working on non-industrial fluids for proof-of-concept.

Initially, Grenoble UJF's research program on vibrating heat exchangers was launched to study the potential heat transfer improvement induced by the use of ultrasound. Then, fouling mitigation was rapidly identified as a potentially better application for ultrasound, considering that first outcomes on heat transfer improvements were relatively mitigated.

Grenoble UJF has initiated some discussions with the food industry in France on the application of vibrating heat exchangers for fouling mitigation. The research program was nevertheless stopped at the proof-of-concept stage since it was initially supposed to be focused on heat transfer enhancement.

No funding is thus currently available for the research program: the development of vibrating heat exchangers within Grenoble UJF is consequently on standby.

Technical performance

The heat transfer improvement induced by vibrating is relatively moderate (up to 10-15% improvement on Grenoble UJF's lab-scale prototype with non-industrial fluids). It must be noted that no energy balance that considers the energy required to produce ultrasound is currently available.

Regarding fouling mitigation, preliminary tests have been performed by Grenoble UJF on limescale. First results show that the technology prevents the formation of limescale and maintains the heat transfer characteristics of clean heat exchangers. On the other hand, the technology's potential for cleaning is relatively limited.

The heat transfer improvement and the fouling mitigation are based on liquid cavitation. In addition, the ultrasound waves being generated by an external ultrasound emitter, the transmission of ultrasound waves requires the presence of liquid in the heat exchangers. The technology is consequently applicable to liquid-liquid and gas-liquid heat exchangers only.

Economic performance

No actual economics have been performed as part of Grenoble UJF's research program.

Nevetheless, OPEX reductions can be expected thanks to this technology, based on fouling mitigation (reduction of turnaround duration) and heat transfer improvement.

Relevance in Oil Sands Context

The technology is theoretically suitable for retrofit applications on existing heat exchangers. Indeed, Grenoble UJF has performed tests on existing heat exchangers. Nevertheless; better improvements can be expected with purpose-built heat exchangers (new designs can take into account resonance, and be adapted to improve vibrations).

No particular issues are anticipated regarding the suitability of the technology in aggressive environments.

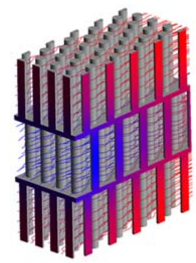
HIFLUX – Compact high temperature heat exchangers

General description

Hiflux Limited is a company based in London, founded in 2000 by aerospace engineers (including engineers from Rolls Royce).

Hiflux is currently focusing on the development of compact high temperature gas-gas heat exchangers (up to 800°C) for heat recovery on small gas turbines / micro CHP systems.

Generally speaking, targeted marketed are applications where high temperature, robust or compact heat exchangers are required.


Heat Flow in Pin Array

Source: Hiflux Ltd

State of development

TRL 9 for current applications
TRL 6 for COSIA's applications

Hiflux technology has currently two early commercial applications and has passed 10 000 hrs in field trials with conclusive operational feedback (micro CHP heat exchangers).

The technology is currently focused on small scale developments (tens of MJ/h heat duties) for gas-gas heat transfers. Hiflux has little experience to date on gas-liquid or liquid-liquid applications. Higher capacities are not priority targets in the short term, mainly because of limited available manpower resources. Hiflux actually focuses its efforts on small gas turbine / micro CHP applications.

Nevertheless, Hiflux is interested in other applications of its technology, including larger industrial heat exchangers. The time-to-capacity for large scale developments (above several GJ/h) is estimated at 3 years minimum by Hiflux; the time-to-market will depend on the application details.

Current key development routes are:

- Manufacturing productivity increase
- Cost reduction

Other development plans include:

- Scalability (in terms of capacity)
- High pressure applications

Regarding other market potentials, Hiflux expects possible applications for the cooling of solids (e.g. power electronics cooling and battery thermal management). Hiflux currently targets the European market, but is nevertheless interested in working with other potential customers, including the USA and Canada.

Technical performance

In Hiflux technology, the heat transfer is based on a modular array of pins laser-welded to plates. This system ensures a relatively efficient heat transfer while being more compact than more conventional shell & tube heat exchangers: For gas-gas applications, for a given heat transfer duty, Hiflux technology is expected to be approximately two times smaller than a conventional shell & tube system.

The temperature effectiveness typically targeted for gas-gas applications is around 85-90%.

Hiflux technology currently uses a nickel based alloy, suitable for high temperatures (up to 800°C) and highly resistant to corrosion compared to conventional steel. The system currently works at a relatively low pressure (up to 10 bar at 800°C). Higher pressures can be reached at lower temperatures.

Fouling can be challenging because of the pin plates arrangement. For gas-gas CHP applications, the technology is designed for 40,000 operating hours.

Economic performance

Heat exchangers' costs highly depend on the choice of materials. Ni-alloys are more expensive than conventional steel. The compactness of Hiflux technology leads to less material requirements, but this does not currently compensate the price gap between steel and nickel based alloys. It must be noted that depending on the application (e.g. operating temperatures lower than 800°C), steel can be selected and the technology cost can consequently be reduced.

Hiflux currently presents a small production capacity, leading to relatively high manufacturing costs (no economy of scale for the time being) compared to conventional heat exchangers. Production capacity increase and cost reduction are current Hiflux's key efforts.

Relevance in Oil Sands Context

Hiflux technology is relevant for retrofit applications. Indeed, the technology is compact, and designed and manufactured in-house. The technology shape can consequently be adapted to be easily integrated in an existing process. The only issue regarding retrofitability is that the technology is currently designed for small capacities. Larger applications would require multiple arrays or grids of current small scale stacks.

Due to selected materials, Hiflux technology can work in aggressive environments and wide temperature ranges (in addition to high temperature, cryogenic applications have been discussed), and is consequently suitable in the oil sands environment.

LUND UNIVERSITY – Advanced laser diagnostics for combustion processes

General description

The Combustion Physics Division of Lund University in Sweden conducts research and education within the areas of laser-based combustion diagnostics and chemical modeling of combustion phenomena. The division aims to improve knowledge on combustion processes, with the long-term aim of using this knowledge in order to make the processes more efficient, decreasing the emissions of green-house gases like CO_2 and other pollutants like unburned hydrocarbons, NOx and soot.

The Combustion Physics division notably develops non intrusive laser diagnostics for measurements of key parameters such as species concentrations and temperature in combustion processes.

State of development

TRL 6-8 depending on the targeted application

Historical developments of advanced laser diagnostics in Lund University are focused on combustion applications (due to numerous grants on this field). The division has some references with industries in the energy sector (e.g. Vattenfall, E.On, Siemens, VOLVO, SCANIA). The maturity of the technology depends on the targeted applications. The application of advanced laser to steam boilers is currently at a research stage.

Key developments include 2-dimension to 3-dimension temporal measurements.

The Lund University division is also currently developing activities in areas other than combustion, including:

- Plasmas (the knowledge on plasma characterization is currently relatively limited)
- Biomass gasification (e.g. bio-particles identification during the gasification process)
- Catalysis (e.g. understanding of the reactions that are taking place near catalyzers)

Generally speaking, current development areas concern diagnostic techniques for chemical reactions in gas phase. For industrial applications, the development areas performed by the division are generally selected jointly with the related industries.

Technical performance

Advanced laser technologies developed by Lund University are specialized in multi-dimensional (2D and 3D) direct and non intrusive diagnostics of combustion processes. Typical measured parameters include the combustion temperature, gas velocities and the concentration of minor species (e.g. CO, NOx, SOx). It must be noted that the detection by advanced laser technologies of large molecules is relatively complex: the technologies are more suitable for small molecules.

Laser diagnostics enable to improve the understanding of combustion processes. Industrial applications generally aims to solve pre-indentified issues related to combustion. As an illustration, the division has worked with Siemens on the reduction on the NOx emissions and the improvement of the combustion stability of their gas turbines.

Similarly, Lund university has worked with Volvo on the reduction of vibration and noise of internal combustion engines for automotive applications.

Economic performance

The combustion physics division essentially works on the technology development and does not perform economic assessment.

Relevance in Oil Sands Context

Advanced laser diagnostics are non intrusive and can be applied for retrofit applications. No particular regarding an application of the technology to oil sands is foreseen.

POLITECNICO DI TORINO – Low temperature polymer nanocomposites heat exchangers

General description

The Polytechnic University of Turin (Polito) has led several research projects on the application of polymer nanocomposites to heat exchangers. One of the main projects, the Thermonano project, was funded as part of the European funding program FP7 from 2009 to 2012.

The main objective of heat exchangers based on polymer nanocomposites is to achieve a high corrosion resistance while ensuring a better heat conductivity than pure plastic heat exchangers.

The technology targets both shell and tube and plate heat exchangers for low temperature applications (up to 250°C).

Liquid-liquid applications mainly and gas-liquid to a lesser extent are targeted.

State of development

TRL 5

The Thermonano project led to the construction of a lab-scale prototype of the technology. There still are some research projects on polymer nanocomposites heat exchangers performed in Polito (low temperature heat recovery applications mainly). However, the development of the technology is mainly carried out by other companies and institutes involved in the Thermonano project (the companies and institutes involved are: Tu Bergakademie Freiberg, Ustav Polymerov - Slovenska Akademia Vied, Commissariat A L Energie Atomique Et Aux Energies Alternatives, Starom Grup S.R.L., Nanocyl SA, A.S.T.R.A. Refrigeranti S.P.A., Simona AG, Sgl Carbon Gmbh, Onni-Stamp SRL).

The Thermonano project mainly led to the nanoCOOL project which focuses on the application of thermally conductive polymer nano-composites to air conditioning (HVAC systems).

It must be noted that generally speaking, Polito is in charge of the research on materials. Other considerations (e.g. heat exchanger sizing or arrangement) are covered by other partners.

Technical performance

The technology is relevant for low temperature applications (generally up to 250°C, depending on the selected polymer).

The main purpose of the nano compounds is to improve the thermal conductivity of pure polymers. Indeed, pure polymers generally lead to 0.2 to 0.5 W/(m.K) thermal conductivity, while composites can lead to 2 to 5 W/(m/K) (state-of-the-art results from the Thermonano project).

The technology is particularly relevant when high corrosion resistance is required. Other advantages include design flexibility. Complex shapes can indeed be achieved thanks to tailored polymer processing techniques (molding or extrusion).

Compared to metal based heat exchangers, polymer nanocomposites heat exchangers present a lower compactness due to a lower thermal conductivity. In addition, in case of solids presence (e.g. silica particles) in the fluids involved in the heat transfer, additional coating shall be necessary to tackle abrasion issues.

Economic performance

No public information on costs can be disclosed from the Thermonano project. Nevertheless, according to public information available from the nanoCOOL project, 50% cost reduction compared to highly alloyed steels can be achieved through polymer nanocomposites.

Relevance in Oil Sands Context

Due to its relatively low compactness compared to alloy-based heat exchangers, the technology may not be suitable for retrofit applications.

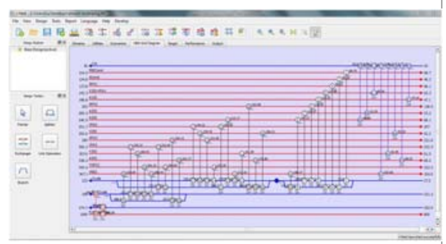
Maximum capacities for polymer nanocomposites heat exchangers are not assessed by Polito (focus on materials).

PROCESS INTEGRATION LIMITED – i-Heat™

General description

Process Integration Limited (PIL) is a UK-based company that develops and provides process improvement software tools mainly focused on the oil and gas, petrochemical and chemical industries.

In particular, PIL has developed i-Heat™, a software tool that aims to design, analyze, simulate and optimize heat recovery systems. i-Heat™ provides a platform for designing and optimizing heat exchanger networks from conceptual design to detailed engineering. The software tool can be used for new designs (greenfield applications) and for operational optimization and retrofit applications of existing networks. i-Heat™ can consequently be used to design new heat exchanger networks, evaluate existing processes and identify cost-effective performance improvement opportunities.



i-Heat™ software (screenshot)

Source: PIL

State of development

TRL 9

i-Heat™ is a commercial software tool used by PIL and its clients for 6 years. It has provided improved designs in more than 10 projects in the Oil and Gas industry. For the time being, PIL has no specific reference on Oil Sands processes. Previous projects have generally focused on retrofit for crude distillation units and delayed coker units. The applications of the tool are not limited to the Oil and Gas industry.

PIL mainly focused on the European market, but i-Heat™ has already been deployed in Europe, Asia and America. PIL is interested in working with other potential customers, including the Canadian market.

Technical performance

When performing a new design (greenfield), i-Heat™ synthesizes an optimal heat exchanger network considering the trade-offs between operational and capital costs. Practical constraints are considered when designing the network.

For retrofit applications, the software tool identifies the network bottlenecks and proposes structural changes to overcome those bottlenecks and improve energy recovery while considering design constraints (e.g. maximum area to be added).

Finally, operational optimization of an existing process can be performed by i-Heat™, by adjusting the degrees of freedoms in the process (e.g. stream-split flows, heat exchanger duties, etc) while taking into account the network constraints (e.g. area available).

It must be noted that the software tool works in open loop. Closed loop control of the operating conditions can be developed if required.

Operational optimization through i-Heat™ generally leads to 3-5% energy savings for crude oil distillation units. Higher energy savings can be achieved for retrofit applications.

The software tool also enables the development of antifouling strategies that aim to optimize heat exchangers cleaning sequences. It must be noted that no actual fouling simulation is performed by the tool: fouling factors are inputs to the tool.

Economic performance

The software tool is provided to customers under license agreement. The length of the agreement can be discussed with discounts provided for longer contract periods.

The payback period depends on the complexity of the solution and the client's budget. In previous retrofit studies, PIL has synthesized improvement solutions with payback periods of less than three (3) years for delayed coker units and crude distillation units.

No further details on economical aspects are currently available (see Appendix).

Relevance in Oil Sands Context

The software tool can be used to improve the design of new heat exchanger networks or revamp existing ones. It can also be used to optimize operational conditions of existing heat exchanger system.

No particular integration issues, including prerequisites in terms of existing monitoring and control systems, are expected regarding the use of i-Heat™ tool in the Oil Sands industry.

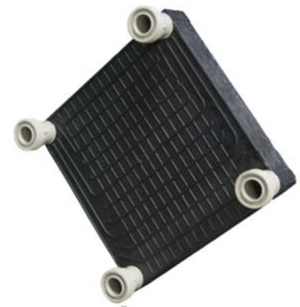
TMW – TET Plastic heat exchanger

General description

TMW is a French company founded in 2000 specialized in water technologies, more specifically water treatment technologies based on evapo-concentration processes.

As part of its water treatment technologies, TMW has developed liquid-liquid and gas-liquid plastic plate heat exchangers to cope with the aggressive compounds contained in the treated effluents.

In this context, considering the particular characteristics of plastic heat exchangers, TMW has started to develop a specific plastic heat exchanger product (the TET heat exchanger) that targets new small scale applications (that differ from TMW's initial in-house water treatment technologies).



TET Plastic Heat Exchanger

Source: TMW

State of development

TRL 9 for current applications
TRL 6 for COSIA's applications

TMW's TET heat exchangers are at a commercial stage for applications targeting capacities similar to its water treatment technologies. Consequently, targeted process flows currently range from 1 to 100 m^3 per day.

Current priority markets consequently involve small scale heat exchangers. As an illustration, potential applications are currently discussed within hospitals, municipal pools, water distribution companies…

Heat transfers currently involved in Oil Sands operation (10-100 GJ/h) would be relatively unrealistic for TMW's technology: it would imply hundreds to thousands arrays of current TET modules.

The upscaling of the TET technology is not a priority for TMW in the short term. In order to address large scale markets, TMW would require a partnership with a key player in the heat exchanger manufacturing industry that may be interested in including TET technology in its existing offer.

Designing and building a large scale TET heat exchanger would require 24 to 36 months (which is the duration required to invest in an appropriate tooling, and perform all the necessary thermo-mechanical qualifications required).

Technical performance

TET heat exchangers are based on thermoplastic materials produced by injection molding. The technology is consequently particularly suitable for corrosive environments.

Fouling issues are expected to be similar to more common plate heat exchangers.

Maximum temperatures for the thermoplastic materials currently used by TMW are around 140°C. Specific thermoplastic material shall consequently be selected to cope with higher temperatures. For instance, PVDF can be selected for process streams up to 175°C. It must be noted that the selection of a new thermoplastic material would require a development phase of 6 to 9 months to quality the new material.

Thermoplastic materials have a lower thermal conductivity than more usual materials used for heat exchangers: (0.5 to 4 W/(m.K) for thermoplastics, compared to 16 W/(m.K) for stainless steel and 19 W/(m.K) for titanium). TET heat exchangers are consequently much less compact than metal-based heat exchangers. For instance, for a same application, the volume of a TET heat exchanger is approximately 3 to 4 times higher than the volume of a titanium heat exchanger. Reachable heat transfer coefficients are between 330 and

1170 W/(m^2.K).

Economic performance

TET heat exchangers aim to compete with stainless steel and titanium heat exchangers usually used in corrosive environments.

For a similar applications (i.e. similar heat transfer duties), TET heat exchangers' investment costs are comparable to stainless steel heat exchangers, and lower than titanium heat exchangers. The payback of TET technology mainly relies on a longer lifespan (due to a better resistance to corrosion) compared to usual heat exchangers.

Relevance in Oil Sands Context

Due to a low compactness, TET heat exchangers are generally not relevant for retrofit applications, the required footprint being several times higher than metal-based heat exchangers. The technology shall consequently be considered for greenfield applications.

Current capacities (1-100 m^3/day) are much lower than typical capacities involved in Oil Sands operations. Larger applications would require multiple arrays TET modules.

TET heat exchangers being designed for aggressive environments, no particular issues are expected regarding the suitability to the Oil Sands environment.

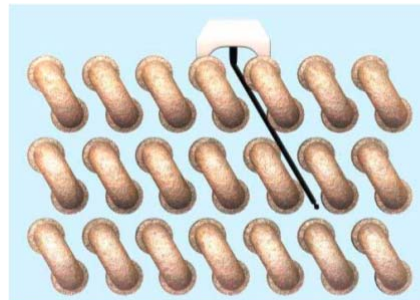
TUBE TECH – In situ off-line and online cleaning

General description

Tube Tech international is a UK-based company with 32 year experience in fired and unfired static heat transfer equipment cleaning and inspection services.

Tube Tech has developed off-line and online (during production) in-situ cleaning technologies that minimizes equipment downtime, improves standard of cleanliness, safety and reduces waste whilst ensuring a deep clean or fouling mitigation of heat transfer assets compared to all other traditional cleaning methods.

Targeted equipment includes ethylene and refinery fired heaters, shell and tube heat exchangers, pipelines, slug catchers, chemical reactors, and pipelines in Up and Downstream sectors (including LNG plants), Power, and Chemical process sectors.



Tube tech robotic in-situ cleaning

Source: Tube Tech

State of development

TRL 9 for in-situ off-line cleaning
TRL 6 for on-line cleaning

Tube tech has developed approximately 60 cleaning technologies over 32 years and carried out over 20 R&D projects. Approximately 80% of the technologies, mostly in-situ off-line cleaning technologies, are ready for deployment. Nevertheless, developed technologies are currently used as part of specific service contracts but not yet commercialized as off-the-shelf technologies. A key development route for Tube Tech is currently the commercialization of its developed technologies.

On-line (i.e. live during full production) technologies are currently at an early stage of development compared to in-situ but off-line technologies. The concept has been proven at a lab-scale at Stuttgart University (proof-of-concept performed as part of a FP7 research program). The time-to-market for on-line technologies is expected to be around 1 year provided that Tube Tech receives sufficient funding to mobilize a full team for final developments. Tube Tech works closely with Shell Global Solutions on the development of advanced mechanical off and on-line cleaning technologies.

Other developments currently include early stage research on the cleaning of plate heat exchangers (discussions are being carried out with Alfa Laval Packinox).

Technical performance

Tube Tech's cleaning technologies include a simultaneous inspection and deep clean (polishing) of heat exchanger tubes enabling IRIS integrity inspection standard to be achieved "first time every time" thereby avoiding critical path, CAPEX replacement and other highly costly situations. Common blasting methods include water, dry ice, abrasives and harsh language which generally only cleans 5% to 50% maximum of the fouled heat transfer areas whereas Tube Tech technologies achieves near 100% cleanliness every time regardless of fouling severity. Tube Tech consequently enables to retrieve heat transfer performances guaranteed close to as new design performance. As an illustration, preliminary assessments have been performed with an Oil & Gas company operating in Nigeria and USA. Several global refineries and petrochemical groups' heat exchanger performance are currently limited to 45%. Tube Tech expects to increase this efficiency to at least 65%.

On-line technologies can also be used to clean and/or maintain optimum performance of the heat transfer assets. The cleaning sequence needs to be set up to limit fouling to an acceptable level.

Operations are unaffected as the in-situ; off-line cleaning technologies are performed during shutdowns. Regarding on-line cleaning technologies, no particular issues are expected. As an illustration, targeted applications in refineries include: shell and tube heat exchangers (up to 320°C), fired heater (up to 650-700°C / 1000°C) and air cooled condensers (up to 250°C).

No erosion or corrosion issues are expected on components during online cleaning technologies. Indeed, online cleaning technologies have been developed to cope with aggressive and corrosive fluids.

The applications of Tube Tech's cleaning technologies include liquid-liquid; gas-gas and gas-liquid heat transfer units and remove all fouling characteristics regardless of environments.

Economic performance

Tube Tech's business model is based on added value creation by including measuring, monitoring and recording of performance before and after cleaning for its clients compared to traditional "just cleaning" service. Tube Tech's service benefits include:

- The reduction of shutdown durations (Tube Tech's in-situ technologies avoid dismantling, pulling or lifting out assets, reducing cleaning durations by up to 80% depending on the application. Similarly, on-line cleaning technologies theoretically substantially reduce and avoid maintenance)
- An increased safety standard by introducing remote and robotic manipulators to avoid manual and vessel entry intervention
- Higher standards of cleanliness improve energy efficiency (Tube Tech's technologies are able to ensure a deep cleaning (back to bare metal) of assets compared to common every day methods, and consequently improve heat transfer coefficiencies, run length, asset life, opex and life cycle costs.
- The reduction or complete avoidance of secondary waste e.g. nuclear, water and other chemicals compared to traditional high volume water blasting)

These benefits lead to potentially important OPEX, CAPEX and Environmental reductions.

Regarding service costs, daily rates for traditional high pressure water jetting contract are estimated around 1000-3 000 €/day. Tube Tech rates are around 5 000-20 000 €/day with previous confirmed savings of 4x to 40x on investment – always previously quantified with clients before justifying Tube Tech's unique technology engagement.

Similarly, daily rates for manual or semi-automated exchanger bundle blasting are around 1000-5000 €/day. Traditional Bundle blasting generally removes only 5% to a maximum of 50% fouling from between tubes. Tube Tech guarantee to achieve a near 100% cleaning standard every time within the same duration at a 10 000 €/day rate. Potential savings related the improved efficiency is estimated around 100 000 € per exchanger (based on case studies with Valero).

Should clients have a project requiring unique intervention to remove fouling in a previously unproven manner TT will provide a 3D animation, AUTO CAD and scale size mock up replicas with remote party video presentation for client approval prior to mobilization. These are all approved by 3rd parties such as Shell Global Solutions prior to mobilization.

Relevance in Oil Sands Context

Generally speaking, retrofit possibilities have to be studied on a case-by-case basis, especially for on-line technologies that may require some equipment modifications to ensure compatibility with the proposed cleaning system. For shell and tube heat exchangers, when the retrofit is feasible, a modification of the header is generally required with an increase of the front header length by ca. 50 cm.

Regarding targeted capacities, no particular limit is expected.

No specific issues are expected regarding the suitability of Tube Tech's technologies to the Oil Sands environment (the dwell time of cleaning systems is relatively low, which minimizes the impact to the environment and risk).

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