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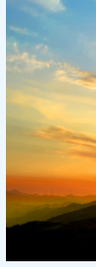


# 2.2 IsoTherming® Hydroprocessing Technology – A Hydroprocessing Revamp Solution for Carbon Footprint Reduction

**Author:** Daniele Noto, Elessent Clean Technologies

Daniele Noto is a Senior Business Development Manager at Elessent Clean Technologies. Daniele is a Chemical Engineer based in Italy. His background includes 20 years of refinery experience having been employed by refineries under ownership of ENI and Lukoil groups. Daniele has served in a variety of roles including technology leadership, operations and planning. He joined Du Pont in 2015 starting as a Senior Technical Service Engineer and became the Global Technical Service Manager for the STRATCO® and Iso Therming® technologies in 2020.
During his technical service tenure he managed numerous startups of both grassroots and revamped units in the Middle East, India and China.
In 2022, under the new company ownership, he moved to his current role of Senior Business Development Manager covering the region of Europe, Middle East, Africa and India for both for the STRATCO® and IsoTherming® technologies.

In the age of energy transition, the value of exploring more efficient and economical processes to produce fuels reducing utilities is becoming much higher.

The IsoTherming® hydroprocessing technology offers a cost-effective solution to revamp existing units to consistently reduce utility consumption and increase the cycle length, in addition to the possibility of increasing the severity and/or capacity of the unit. The Iso Therming® technology is also well suited to provide refiners with a cost-effective option for co-processing renewable feedstocks in the existing hydrotreater units with a relatively small investment compared to the conventional trickle bed technology. The Iso Therming® technology, indeed, is uniquely advantaged to manage the high heat of reaction that comes with processing these renewable components which has proven to be a challenge to those operating hydroprocessing units with the traditional trickle bed technology.

At the same time, the so Therming® hydroprocessing technology is a competitive option for grassroots processing units, with a reduction of 30 to 50% of the capital cost, on top of the proven OPEX reduction.

This article describes the principles of the Iso Therming® hydroprocessing technology and highlights the energy efficiency, versatility, robustness and renewable fuels production capabilities of the process. Two recent revamp case studies will be showcased that demonstrate the benefits, specifically in the areas of energy efficiency and the ability to process difficult feedstocks into Euro VI compliant fuels.

## 1.0 Introduction to the IsoTherming® Hydroprocessing Technology

The Iso Therming® hydroprocessing technology is a commercially proven process that provides refiners worldwide a more economical means to produce today's transportation fuels. Implementing the Iso Therming® technology enables refiners to not only produce high-quality, low-sulfur fuels compliant with local environmental regulations, but also decrease energy consumption and operating costs when

compared with historical trickle bed hydroprocessing technologies. The proven reliability and operational flexibility of the technology also enables refiners to meet business sustainability and social responsibility objectives.

Fig: 1 IsoTherming® Reactor in Commercial Service

The fundamental principle of the IsoTherming® technology is the ability to provide the hydrogen necessary for the chemical reactions using a liquid stream, rather than including a recycle gas system. The liquid reactor feed is saturated with hydrogen, which eliminates the need for a recycle gas compressor and other high pressure equipment, such as high pressure separators, heat exchangers, or high pressure amine absorber. To satisfy hydrogen requirements for the reaction, additional hydrogen can be added by means of reactor effluent recycle toward the inlet and / or inter-bed hydrogen injections. The higher the hydrogen demand of the feed (such as units producing high percentages of crack stock), the more recycle flow is required. Feed types with low hydrogen demand, such as kerosene, may not require an external recycle stream.

Replacing the recycle gas with the recycled liquid also acts as a heat sink for the exothermic reactions, since the heat capacity of the liquid is three times greater than the heat capacity of the gas. Thus, the reactor operates in reduced delta-temperatures and closer to isothermal conditions, which reduces uncontrolled cracking reactions and lowers light ends make.

The catalyst used in the IsoTherming® process is the same that is used in conventional hydrotreaters, and the hydrogenation reactions are also the same at similar operating temperature and pressure.Although the catalyst is the same, the liquid-full environment available with the IsoTherming® technology allows the catalyst to be more preserved and minimizes channeling, hot spots, and undesired reactions. Also, the volumetric flow through the reactor is consistently reduced and consequently the pressure drop is much lower.

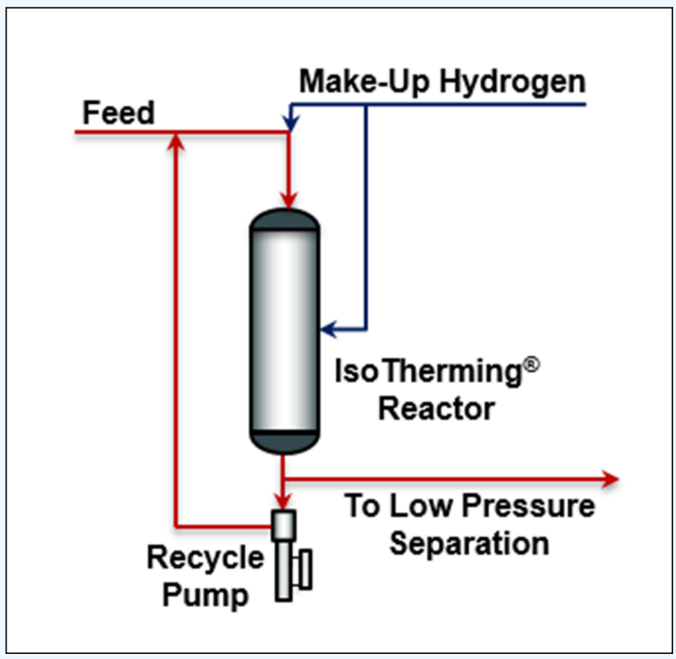
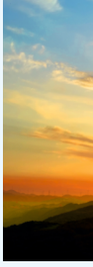



Fig: 2 IsoTherming® Reaction Zone

The type of hydroprocessing application, the product quality and chemical hydrogen requirements dictate optimal reactor design considerations, such as number of catalyst beds and recycle ratio. In the case of revamping, Elessent Clean Technologies uses the existing reactors, nozzles, operating and design parameters. Taking into account the design basis and the goals of the refinery, a revamp study is developed, minimizing modifications to the existing reactors and keeping the same number



of reactor beds by optimizing the recycle ratio and number of extra internal hydrogen injections. In most cases, the replacement of the internals and the installation of the recycle pump are the only modifications needed for a revamp to Iso Therming® technology.

The Iso Therming® reactor design is robust and has been commercially proven to successfully provide over 160% percent of design chemical hydrogen consumption while processing fluctuating feedstocks. This flexibility allows refiners the ability to process a wide variety of feeds to maximize refinery profits.

The Iso Therming® technology currently has 30 licenses comprised of 25 grassroots units and 5 revamp units, 16 of which are currently in operation. The remaining units are either in the design or construction phase.

## 2.0 Benefits of the IsoTherming® Hydroprocessing Technology

The IsoTherming® hydroprocessing technology has several benefits when compared to the conventional trickle bed technology. The list below details some of the most important benefits:

(1) **Capital Cost and Plot Space Savings.** The recycle pump is much cheaper than a recycle compressor and the high pressure zone in the IsoTherming® technology is much more compact because of the reduction in high pressure separators, high pressure heat exchangers, high pressure piping and high pressure amine scrubber. The savings in capital costs are in the range from 30 to 50%.

(2) **Reduced utility consumption-fuel gas in particular.** When converting a conventional hydrotreater to Iso Therming® technology, it is possible to achieve utilities savings up to 60%, with each application having its own unique savings case. Electrical power, cooling water, and steam demand are all reduced, but the most valuable benefit is the reduction of fuel gas. The lack of recycle hydrogen gas passing through the heater and absence of vaporization, together with the benefit of direct heat transfer of the recycled effluent, can reduce the fuel gas demand by up to 70%. In addition to the utility savings, this results in a direct reduction of $CO_2$emissions.

(3) **Reduction in $CO_2$ Emissions.** The significant reduction in utilities consumption leads to a significant reduction in $CO_2$ emissions. The reduction of fuel gas alone leads to a $CO_2$ reduction of approximately 1-3 metric tons/year for every MTPD of feed processed in the Iso Therming® technology.

(4) **Ability To Process More Challenging, Highly Exothermic Feeds.** Replacing the recycle gas with the recycled liquid creates a heat sink for the exothermic reactions. Thus, the reactor operates in a reduced temperature rise environment and closer to isothermal conditions, which, moreover, reduces uncontrolled cracking reactions and allows for the inclusion ofmore exothermic feedstocks in the throughput, like highly aromatic, olefinic and/or renewable feeds.

(5) **Increased catalyst performance and cycle length.** Catalyst used in the Iso Therming® technology is similar to that used in conventional hydro treaters, but in a liquid-full environment and in reduced temperature ranges, the catalyst deactivation is slower, and the catalyst cycle is usually longer. In several cases, catalyst cycle length has been doubled.

(6) **Lower total hydrogen consumption.** The chemical hydrogen consumption of Iso Therming® technology is similar to conventional hydrotreaters, since the hydrotreating reactions are the same. But the total hydrogen consumption of the unit




is usually lower due to the lower quantity of hydrogen loss and lower off-gas production.

**(7) Higher yield.**
The lower temperature rise of the Iso Therming® technology reduces cracking and coking reactions, and wild naphtha yield is reduced at the same feed and operating conditions.

## 3.0 Renewables Processing

The global market demand for bio fuels continues to increase as mandates and renewable fuel credits are being implemented globally. Whether mandated or not, renewable fuel production is likely on the mind of all refiners. The Iso Therming® technology is well suited to assist refiners in their production of renewable distillate range products. The liquid full technology is uniquely positioned to handle the high hydrogen consumption and temperature rise that are associated with processing lipid-based feedstocks – whether in conjunction with a petroleum derived feedstock or in a stand-alone unit. In addition, the Iso Therming® technology unlocks the ability to co-process without concern of trickle bed's recycle gas compressor limitations. The capital cost savings, energy efficiency and sustained catalyst life highlighted in the below case studies will also be apparent in a renewable processing application.

## 4.0 Case Studies

The following case studies will detail how the IsoTherming® technology has proven its value in two refineries through revamps of their existing hydroprocessing units.

### Case Study #1

The first case study detailed is for Refinery A, located in Western Europe. Refinery A has an existing trickle bed diesel hydrotreater that lacks a recycle gas compressor. This unit currently produces ultra-low sulfur diesel with poor cycle length. Even at reduced throughput rates, current cycle length ranges from 12-14 months. Evaluation by catalyst suppliers has concluded that a catalyst upgrade by itself could not achieve the desired product and operating targets due to unit constraints. Therefore, Refinery A chose to evaluate the option of a unit revamp for their low-pressure diesel hydrotreater.

Refinery A extensively studied the revamp solution with the current trickle bed technology and compared to a revamp solution offered by Elessent Clean Technologies with the Iso Therming® technology. The trickle bed revamp was considerably more expensive with less benefit than what could be achieved with the Iso Therming® technology. A full conversion of the unit to liquid phase with the Iso Therming® technology will provide the customer not only extended cycle length, but a return to nameplate capacity and the ability to process cracked feedstock. A summary of the key benefits can be seen in Table 1.

| Parameter | Current | IsoTherming® Revamp |
|---|---|---|
| Capacity | 149 $Sm^3/hr$ | 205 $Sm^3/hr$ (↑ 38%) |
| % Cracked Feedstock | 0% | 8.1% |
| Feed Density @ 20C, $kg/m^3$ | 860 | 909 (+ 49 points) |
| LHSV $hr^{-1}$ | 0.34 | 0.78 |
| Cycle Length | 12-14 months | 36 months (↑ 3x) |
| Recycle Hydrogen | Once thru | Recycle Pump |

Table-1 Refinery A – Current Operation vs IsoTherming® Revamp




Feedback from Refinery A indicated that the proposed trickle bed revamp solution was much more capital cost intensive and included a much longer list of new equipment including a new recycle gas compressor (and associated high pressure auxiliary equipment such as amine absorber and heat exchangers). Even with a new recycle gas compressor the trickle bed technology was unable to offer the same extension in cycle length at the nameplate capacity as the Iso Therming® technology, and additional catalyst volume or reduced feedstock rates were required to meet a similar cycle length.

Not only is this revamp solution with the IsoTherming® technology a low capital cost endeavor, but it has additional operating efficiency benefits for Refinery A. The feedstock under review has a very high hydrogen consumption and thus a high heat release. Due to the extremely energy efficient nature of the Iso Therming® technology coupled with this high heat release, the feed fired heater is only required to operate at minimum operation rates outside of start-up conditions. Even at this minimum rate, there is surplus heat after pre-heating the feed. Therefore, a cost/benefit analysis was conducted, and it was deemed economical to utilize the excess heat of reaction to produce medium pressure steam in the unit. Table 2 quantifies the energy savings expected post-revamp with the Iso Therming® technology compared to current trickle bed operation:

| Parameter | Current Trickle Bed | IsoTherming® |
|---|---|---|
| Normal Operating Charge Heater Duty, MMkcal/hr | 4.936 | 1.780 |
| % Savings | - | 64% |
| Fuel Gas, kg/hr | 414 | 149 |
| Fuel Gas Value, $/yr[1] | $ (1,233,224) | $ (444,711) |
| Steam Produced, kg/hr | 0 | 10,281 |
| Steam Value, $/yr[2] | $ | $ 891,035 |
| Annual Net Value of Utility Consumption / Production | $ (1,233,224) | $446,324 |

Table-2 Refinery A – Utility Comparison Current Operation vs. IsoTherming® Revamp

[1] Based on a Fuel Gas Value $/MMkcal of 29.7 USD
[2] Based on Steam Value $/1000 kg of $10.3 USD





Based on the assumed cost values of fuel gas and steam, the revamp saves Refinery A $1.7 MM USD ($51 USD / barrel of feedstock) annually in high pressure utilities alone. Additional savings are also expected from low pressure utilities.

This revamp solution is not only attractive from a capital and operating cost standpoint, but it lowers the carbon footprint of the refinery due to the reduction in combustion of fuel gas from the fired heater. Based on the normal operating duties shown in the above table, the reduction of 5,520 tons of $CO_2$ emissions per year is equivalent to the removal of over 1,200 light passenger vehicles annually (based on heat content of propane of 139 MMBtu and 4.6 metric tonnes $CO_2$ emissions / year from a single light passenger vehicle). Support for the revamp of Refinery A's diesel hydrotreater unit with the IsoTherming® technology continues in anticipation of a 2025 start-up date.

**Case Study #2**

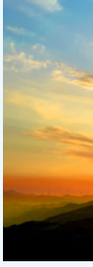
The second case study is for Refinery B, located in Eastern Europe. Refinery B has an existing trickle bed diesel hydrotreater with an approximate capacity of 229 Sm3/hr (35,000) bpsd. The refinery is investigating options to reach their decarbonization targets and optimizing operating expenses while maintaining their current capacity. Elessent Clean Technologies worked closely with Refinery B to evaluate multiple revamp scenarios geared toward their decarbonization and sustainable operating objectives. A comparison of the final revamp conditions compared to current operation is presented in Table 3.

| Parameter | Current | IsoTherming® Revamp |
|---|---|---|
| Diesel Yield, wt% | 96.7 | 98.5 |
| Additional Diesel Value, $/yr[1] | - | $ 701,527 |
| Fuel Gas. Gcal/hr | 10.0 | 6.4 |
| Fuel Gas Savings, $/yr[2] | - | $ 1,128,325 |
| $CO_2$Emissions, tons/year | 21,003 | 13,442 |
| $CO_2$Tax Savings, $/yr[3] | - | $39,338 |
| Annual Net Value of Diesel Yield / Fuel Gas, $/yr | - | $ 1,869,190 |

Table-3 Refinery B –Current Operation vs IsoTherming® Revamp

[1]Based on a diesel value $/t of 558 USD and off gas value $/t of 426 USD.
[2] Based on 11.1 Gcal/t heating value for fuel gas and fuel gas value $/t of426 USD.
[3]Based on 2.58 ton $CO_2$/ton fuel gas ($CO_2$, $SO_2$, $NO_x$) and tax of fuel gas $/t of 150.50 USD.



Based on the assumed values of diesel and fuel gas, the revamp saves Refinery B $1.9 MM USD ($53 USD / barrel of feedstock) annually from increased diesel yield, fuel gas savings and tax savings from reduced carbon footprint of the unit.

In addition to a reduction in operating expenses and carbon footprint, the revamp cost and effort from trickle-bed to the Iso Therming® technology was proven to be minimal. It was confirmed that the heat exchangers and air coolers supporting the existing trickle bed unit can be utilized with the Iso Therming® technology, with the only new equipment required being the reactor recycle pump and proprietary Iso Therming® Reactor internals. Due to the low capital expenditure required for conversion to the Iso Therming® technology, the calculated payback for the effort is only 3 years given the value provided with increased diesel yield, reduced fuel gas consumption and $CO_2$ tax savings. Support for the revamp of Refinery B's diesel hydrotreater unit with the Iso Therming® technology is ongoing as we anticipate a revamp from trickle bed in the near future.

## 5.0 Conclusion

Elessent Clean Technologies continuously optimizes the liquid-full Iso Therming® reactor design and unit configuration to improve energy efficiency and reduce the carbon footprint for refiners. Elessent is also actively identifying and evaluating opportunities for the Iso Therming® technology for existing hydrotreaters with the objective of increasing the severity and / or the capacity, looking for the most sustainable and cost-effective solution.

Elessent licenses the Iso Therming® technology and offers products and services that support its customers throughout the life of the unit. With licensed and operating commercial units worldwide, the Iso Therming® technology is changing the way refiners look at hydroprocessing. This commercially proven technology can provide customers with an attractive option for meeting current and future demand for cleaner fuels at the lowest capital and operating cost while providing the most sustainable hydroprocessing option on the market.