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STRATEGIES TO MAXIMISE PROFITABILITY IN HVO COMPLEXES

Strategies to maximise profitability in HVO complexes

A review of some of the challenges involved in processing hydrotreated vegetable oil and the available solutions to optimise plant profitability

Jay Jeong, Eva Andersson and Bent Sarup
Alfa Laval

Given the ever-increasing focus on reducing Scope 3 CO_2 emissions and closing the gap on carbon neutrality, the interest in biofuels and the pressure to increase their production are higher than ever. Fatty acid methyl esters (FAME) biodiesel has served the industry well for many years as an additive to petroleum-based diesel. However, it has significant limitations with respect to blending ratio, and it cannot be used for jet fuel. These factors restrict its potential to replace fossil fuels.

A more viable solution has emerged in the form of renewable diesel or sustainable aviation fuel (SAF), produced through hydroprocessing of fossil-free feedstock or so-called hydrotreated vegetable oil (HVO) processing. With HVO processing, production capacities of more than 10,000 bbl/day are achievable, and both renewable diesel and SAF can be produced with quality that is equal to or better than that of traditional petroleum-based fuels. Moreover, with an optimally designed pretreatment system, the HVO process can handle a wide variety of feedstocks, ranging from vegetable, animal or even waste fats and oils to second-generation feedstocks, such as pyrolysis or hydro-pyrolysis oils generated from biomass.

Due to these advantages, many existing refineries are now implementing HVO processing, whether through drop-in co-processing of bio-based feedstock in existing diesel hydrotreating units (DHT), by revamping an existing hydroprocessing unit or by integrating a new grassroots HVO processing unit into the existing plant. Additionally, new entrepreneurial companies are entering the fuel market and constructing their own stand-alone HVO complexes.

The investment in an HVO complex is typically higher than that for a traditional FAME plant by at least one order of magnitude. To achieve economies of scale, the complex is commonly designed for a higher capacity. In addition, for a complete stand-alone HVO complex, several process units are required:

- Pretreatment unit (PTU) for bio-based feedstock
- Hydrogen production unit (HPU)
- The HVO process unit itself
- Sulphur recovery unit (SRU), including amine treatment unit (ATU), tail gas treatment unit (TGTU) and sour water stripper (SWS)
- Wastewater treatment unit.

With the exception of a bio-based PTU, these processes are typical in most refineries. However, the feedstock in HVO processes is different, which poses new challenges for the refinery operators. To maximise plant profitability, feedstock flexibility, plant cycle length, and product yield must all be maximised. Meanwhile, the risk of equipment corrosion and fouling must be minimised, along with utility consumption (energy and water). Similarly, waste handling must be optimised.

The following sections will explore some of the challenges in HVO processing, highlighting solutions available to maximise plant profitability.

Feed pretreatment unit

One of the most important success factors for the HVO complex is the feed PTU. Without proper feed pretreatment, the impurities present in bio-based feedstocks can lead to issues such

Impurity	Effect on process/equipment	Pretreatment needed
Phosphorous compounds (phosphatides or phospholipids)	Gum or gum-like material that creates serious fouling issues in process equipment and impacts catalyst activity	Various methods of de-gumming, such as chemical or enzymatic hydration
Free fatty acids (FFA)	Corrosion of process equipment that is not specifically selected for HVO processing (e.g. when existing hydroprocessing unit is revamped)	Neutralisation or steam stripping
Metals, soap residues, chlorides, polyethylene	Shorter catalyst lifetime and/or increased equipment fouling	Different operations, such as washing, bleaching, and filtering

Table 1 Typical impurities in bio-based feedstocks, their effect on process and equipment, and pretreatment processes required for their removal

as equipment fouling and corrosion, as well as to reduced catalyst cycle length and selectivity.

PTU configuration

Depending on whether the HVO plant is a revamped hydroprocessing unit or a new purpose-built process unit, and in order to maximise the feedstock flexibility, the PTU must be tailored with a different set of pretreatment processes. Additionally, the selection of feed pretreatment processes is influenced by environmental legislation, the value and cost of handling the by-products, and the cost and availability of utilities and labour.

The selection of a de-gumming process depends on the type and amount of phospholipids in the feedstock. Typically, the oil is treated with acid (phosphoric or citric) for a high conversion of oil-soluble phospholipids into their water-soluble form, which can then be removed efficiently by high-speed centrifugal separators as part of the heavy phase. For difficult-to-remove non-hydratable phospholipids, enzymatic de-gumming can be applied to convert the phospholipids into lysophospholipids (cutting off a fatty acid side chain) and increase their water-solubility. Enzymatic de-gumming is already widely applied as upstream feed pretreatment in FAME biodiesel production units.

Vegetable oil	Phosphorous content, ppm
Coconut and palm oil	<30
Groundnut, sunflower and corn	200-800
Cottonseed, soya and rapeseed	<1,400

Table 2 Typical phosphorous content in various vegetable oils

If the acidity of the oil is high after de-gumming, and if the HVO process equipment is not upgraded to corrosion-resistant materials, neutralisation must be the next step in the PTU. If the free fatty acids (FFA) content is less than 2-3 w/w%, a chemical neutralisation process with caustic soda will be sufficient. However, if the FFA content is above 3-5 w/w%, a physical de-acidification process using steam stripping under vacuum will be required. This type of de-acidification produces a distillate by-product known as 'soap stock', which can be sold to processors who use a soap stock splitting process, in which the acidic oil is liberated through treatment with concentrated sulphuric acid.

For the feedstock to be acceptable for the HVO process, its phosphorous content must typically be less than 3 ppm. With many feedstocks, de-gumming is not enough to reach this level. In such cases, bleaching/adsorption is the next step in the PTU. Various qualities of adsorption clay/earth exist in the market, and there is usually a correlation between price and performance.

For most feedstocks, these three pretreatment steps are sufficient to remove or reduce

Phosphorous compound	Ease of hydration
Phosphatidylcholine (PC) Phosphatidylinositol (PI) PI calcium salt	Acceptable to high
Phosphatidylethanolamine (PE) PE calcium salt Phosphatidic acid (PA) PA calcium salt	Not possible through normal hydration

Table 3 Ease of hydration depending on type of phosphorous compound

impurities to a level acceptable for further HVO processing. However, if used cooking oil (UCO) or tallow is used as the feedstock, another washing step, aimed at removing water-soluble chlorides, must be added upstream of the de-gumming stage. In the case of tallow, a further adsorption step, aimed mainly at removing polyethylene, must be carried out prior to de-gumming.

Figure 1 summarises the many different feed pretreatment steps in one flow chart.

Effluents from the PTU

The de-gumming process produces a significant amount of wastewater that needs to be treated. The main effluents from the PTU are spent adsorption clay (around 0.5-2% of the oil flow, depending on the feedstock and the final quality of the pretreated oil) and wastewater from the different oil washing operations (typically in the range of 5-10% of the oil flow). How the effluents are handled depends on the availability of an outlet for by-products such as spent adsorption clay and soap stock, local site conditions such as spare capacity in an existing wastewater treatment facility, and the specifications for the cleaned wastewater discharge.

Spent adsorption clay contains residual oil of 20-25%. Potential outlets for this by-product include biogas manufacture or burning of the clay to utilise the oil's calorific value, as well as extraction of the residual oil by another company.

If there is no spare capacity in an existing wastewater treatment facility, there is potential to debottleneck or to add another treatment facility. Either can be done using well-known technologies, such as dissolved air flotation (DAF), sequencing batch reactors (SBR), membrane bioreactors (MBR), aerobic digesters, thickeners, presses, decanters and high-speed centrifugal separators.

Impurity	Content before/ after bleaching, ppm
Phosphatides	10 → <3
Soap from de-gumming	5 → 0
Metals	50 → 5
Moisture and volatile matter	0.5 → 0

Table 4 Impurity content before and after bleaching

However, wastewater can also be evaporated, thereby concentrating the waste stream to less than 2 w/w% of the original wastewater stream. Besides minimising the load on the wastewater treatment facility, this recovers more than 98% of process water for reuse in pretreatment processes. A wastewater evaporation plant can be run using low-pressure steam, which can be generated through waste heat recovery from the HVO process itself. This is described in the fractionator optimisation section.

HVO processing

The HVO process is, in fact, a series of processes. First, hydrotreatment (HDT) removes oxygen and splits the triglycerides into three chains of hydrocarbons. Next, the paraffins are converted into a mixture of hydrocarbons with the right cold flow properties, either through isomerisation for maximal diesel yield or mild hydrocracking (HCK) for maximal SAF yield. By-products from these reactions, such as propane, CO_2, and sour water, are removed in a stripper, while the final liquid products are separated in a downstream fractionation section. **Figure 1** shows all HVO processes in a simplified flow chart.

The following sections focus on the

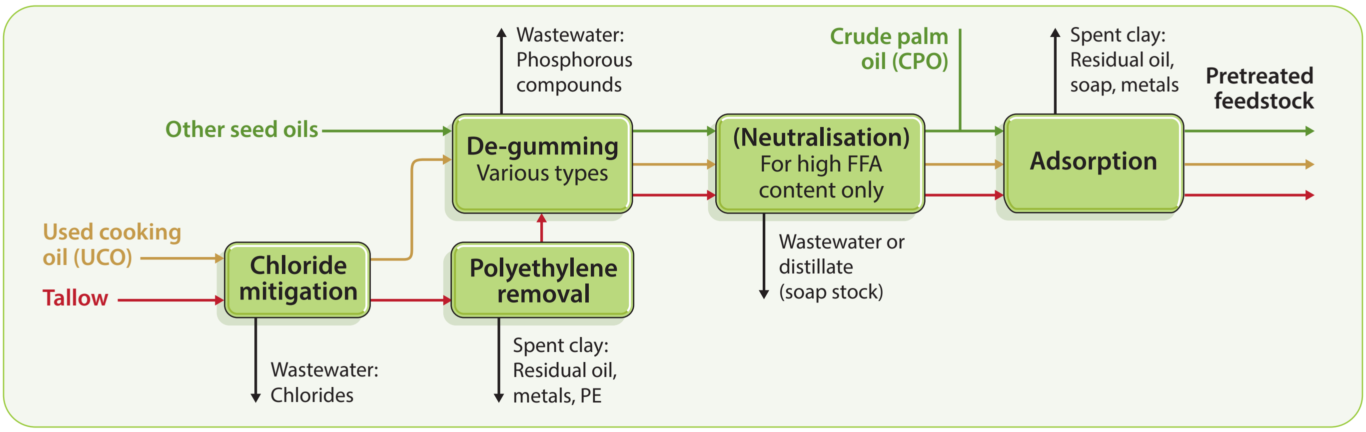

Figure 1 A flow chart summarising the many different feed pretreatment processes

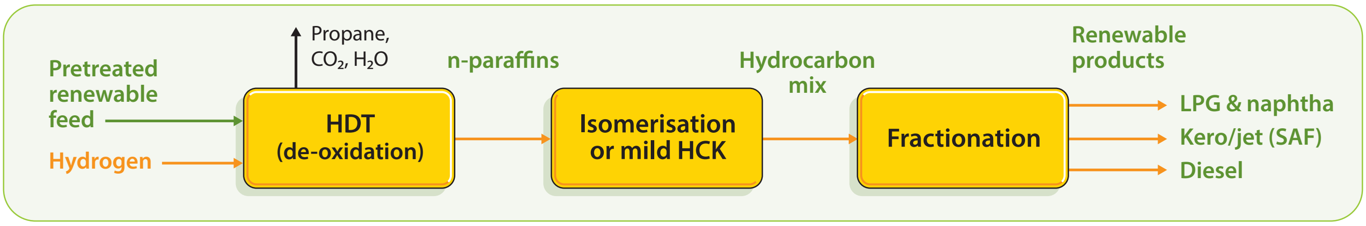

Figure 2 A simplified flow chart summarising the various HVO processes

fractionation process and the potential to optimise the fractionator for maximal performance. Most fractionator designs are based on old rules of thumb that limit energy efficiency and product recovery while increasing project Capex. Instead, the fractionator can be optimised with high-efficiency heat exchanger solutions that have been on the market since the early 1990s. Such optimisations can drastically improve efficiency in this part of the HVO process.

Fractionator optimisation: feed/bottoms interchanger

The first heat exchanger position to consider is the feed/bottoms interchanger. In this position, the aim is to maximise energy recovery from the fractionator bottom stream for use in preheating the feed. Doing so will maximise both the final product cooling and the feed heating, which will reduce the load on both the final product cooler and the fractionator reboiler.

The amount of energy that can be recovered is limited by the heat exchanger technology selected. When conventional shell-and-tube technology is selected, maximising the energy recovery requires a series of several large heat exchangers. This is often too costly or practically infeasible to install in the plant.

The alternative is to use a high-efficiency welded plate heat exchanger (WPHE). This technology enables a tight temperature approach down to 3°C, which can be achieved in a single heat exchanger with a minimal flooded weight and plot space requirement. Thus, it becomes economically favourable and practically feasible to maximise energy recovery.

Often, at least 25% more energy can be recovered with a WPHE. This reduces the reboiler duty by an equivalent amount and may even eliminate the need for an air cooler upstream of the final trim cooler, as outlined in **Figure 3**.

Fractionator optimisation: overhead condenser

Minimising the column operating pressure is another opportunity to maximise the energy efficiency of the fractionator. Often, this can also improve separation efficiency in regard to fractions with similar or even overlapping boiling

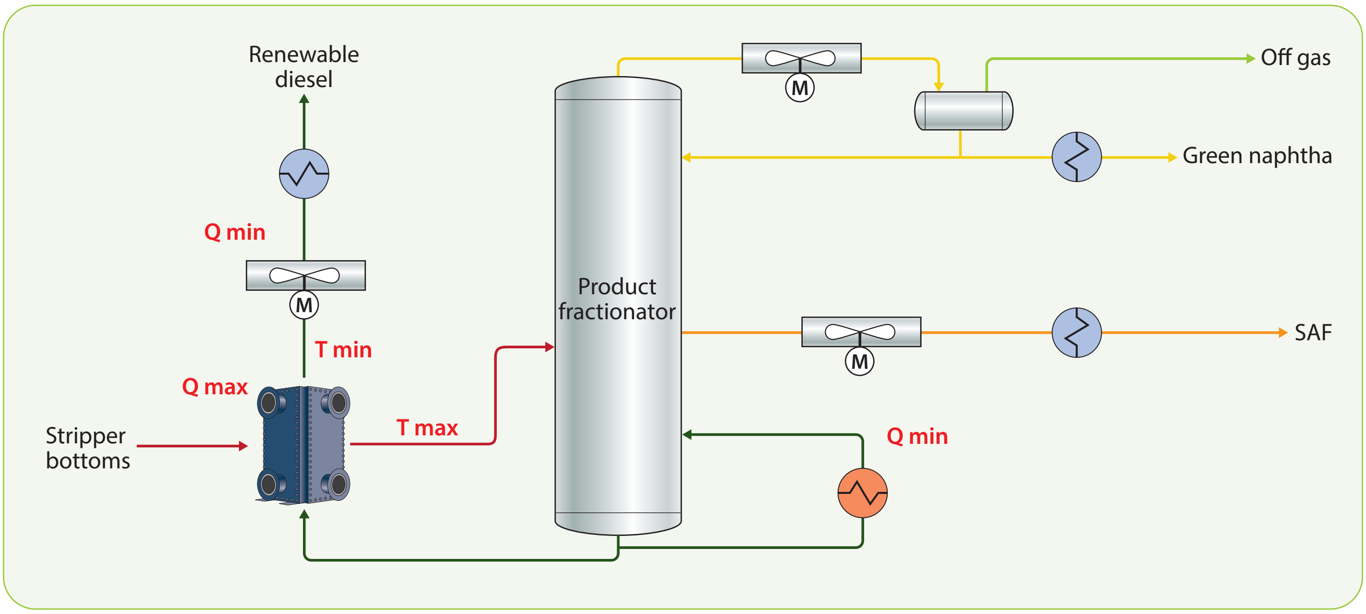

Figure 3 Improved product fractionator design using a WPHE to maximise energy recovery in the feed/bottoms interchanger

ranges, such as naphtha and SAF, thus making it possible to maximise the yield of the most high-value product.

Because the pressure in the column is decided by the overhead vapour condenser, optimal condenser design and technology are key parameters in minimising the column pressure.

When conventional shell-and-tube or air heat exchangers are used as overhead vapour condensers, a higher temperature approach to the supply temperature of the cooling media is required. Hence, a higher pressure in the column is needed to achieve a certain liquid yield at the condenser outlet.

When a WPHE is used as an overhead condenser, it is possible to operate with only a 3°C temperature approach to the cooling media. As a result, the same liquid yield can be achieved at the condenser outlet at a much lower operating pressure. Moreover, thanks to the multiple short, parallel channels in the WPHE design, the condenser pressure drop can be reduced compared to conventional heat exchangers. Together, these factors minimise the necessary column operating pressure.

Depending on the supply temperature of the cooling media, the operating pressure in the column can sometimes be reduced by 2 bar or more when using a WPHE. This reduces the fractionator reboiler duty and increases the difference between the naphtha and SAF boiling temperatures (see **Figure 4**).

Fractionator optimisation: condenser and run-down coolers

Several process streams, including overhead vapour and run-down streams, are usually cooled utilising either cooling water or air, as recovering low-grade energy from these streams is difficult and expensive with conventional shell-and-tube heat exchangers. Such coolers require a large amount of either cooling water or electrical power, which puts high demands on the utility system of the HVO complex. In this way, the coolers increase both the project investment and the plant operating cost.

With WPHEs, it is possible to maximise the recovery of low-grade energy, using it to generate both low-pressure steam and hot water. The steam can then be used to evaporate the wastewater (as described in the effluents from the PTU section) or to produce electricity by means of Organic Rankine Cycle (ORC) systems. The hot water can be used as boiler feed water or for tank or plant heating, and it can even be supplied to district heating networks. Recovering otherwise wasted heat in this way turns process cooling from a cost generator into a profit generator (see **Figure 5**).

Fractionator optimisation: final product and vapour trim coolers and condensers

The final optimisation step within the scope of this article is to minimise the fractionator's cooling water requirement in all final product and vapour trim coolers and condensers.

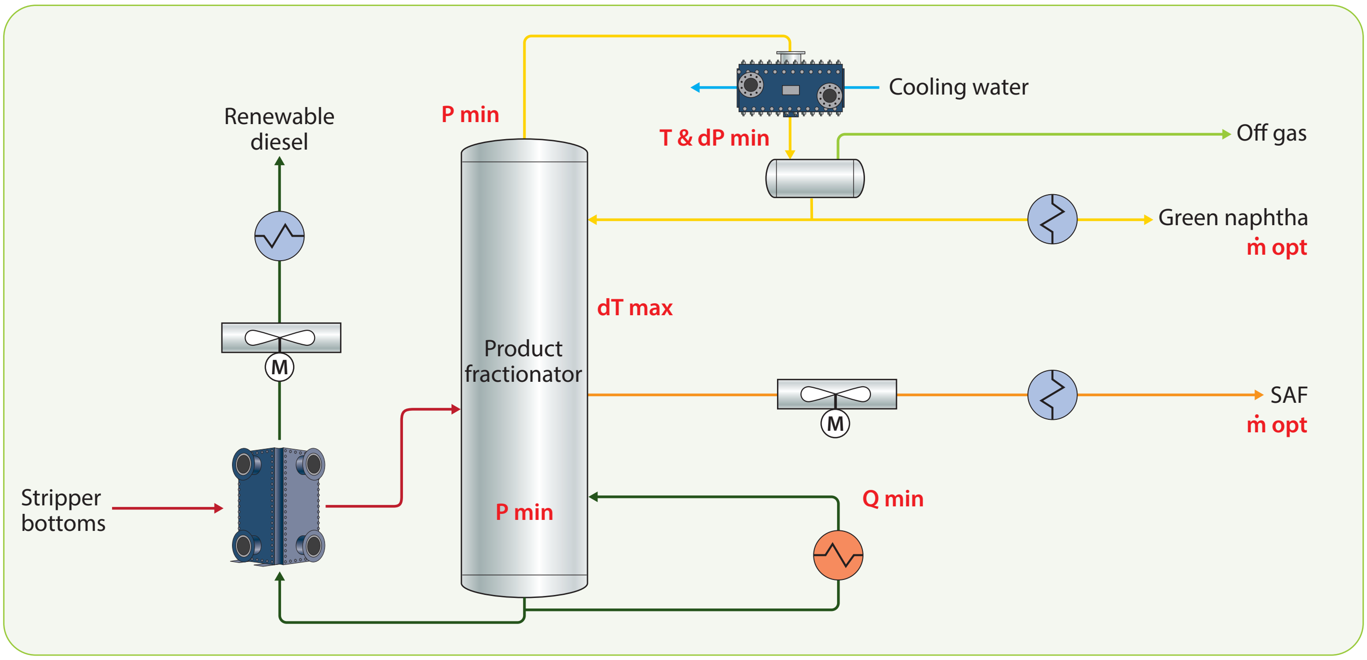

Figure 4 Improved product fractionator design using a WPHE to minimise column pressure

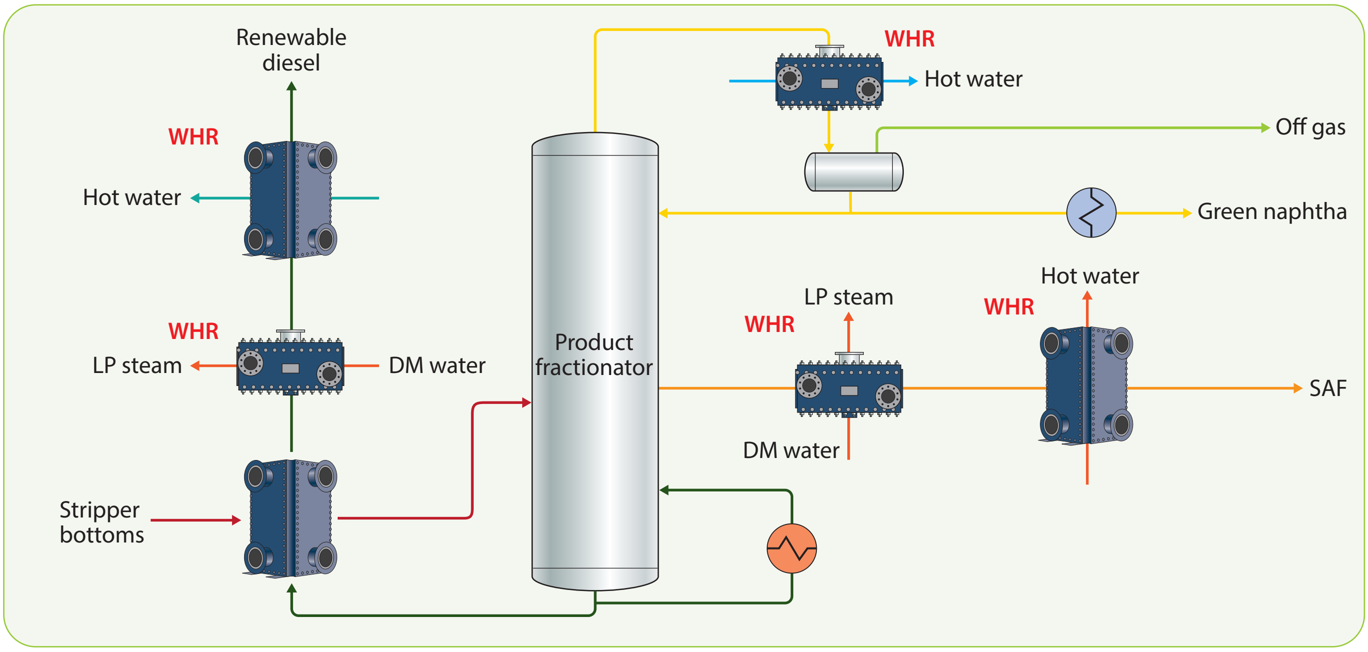

Figure 5 Improved product fractionator design using WPHEs to maximise waste heat recovery (WHR)

Conventional water-cooled shell-and-tube heat exchangers are designed to avoid a temperature cross so that the cooling water return temperature is the same as or lower than the outlet product or vapour/condensate temperature. As a result, the difference between the cooling water supply and return temperatures is sometimes less than 10°C. This means a large amount of cooling water needs to circulate between the HVO complex and the cooling water plant.

When WPHEs are first used to maximise the WHR from process streams, the remaining cooling duty is minimised. In addition, for the final trim cooling or condensing duty, the cooling water return temperature can be maximised in a single heat exchanger with a minimal flooded weight and plot space requirement, thereby reducing the amount of cooling water in circulation by up to 50% (see **Figure 6**). This will reduce the piping and pump cost of a new cooling water system (or minimise load on an existing system), as well as the energy consumption of the circulation pump.

Summary and conclusions

HVO processing has clearly made its way into

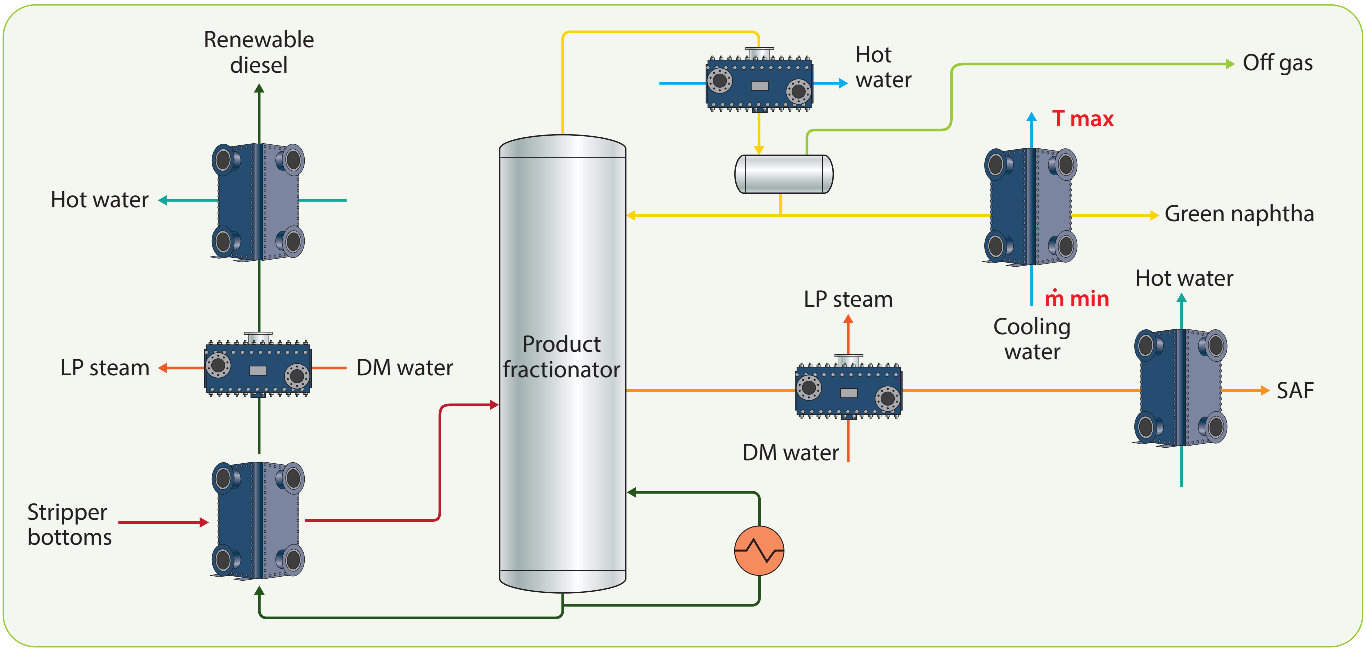

Figure 6 Improved product fractionator design using WPHEs to minimise cooling water requirement

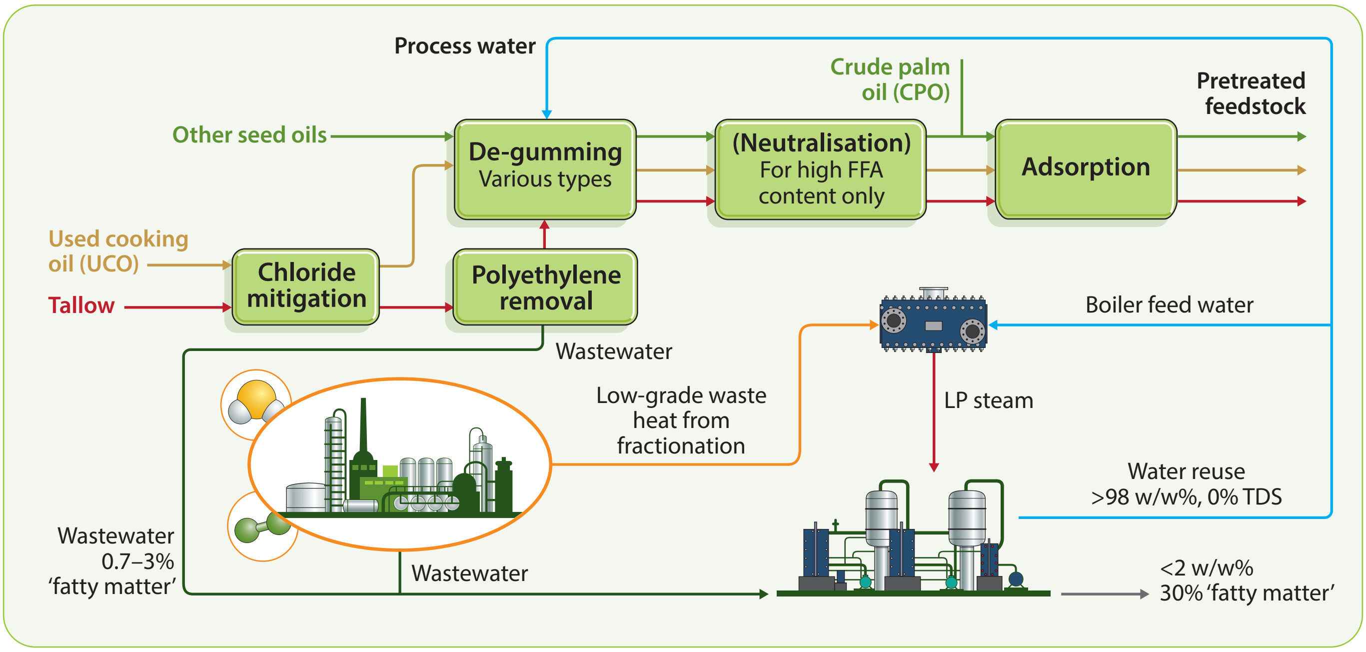

Figure 7 Using a holistic design approach to maximise energy efficiency while minimising the process water consumption and environmental footprint of the HVO complex

petroleum refineries, where many facilities are already on-stream or under construction. The quest for the future is to maximise the use of wastes and non-edible oils as renewable feedstocks and to design the pretreatment facilities for maximum flexibility to handle such feedstocks. At the same time, there is increased focus on saving energy, reducing emissions and molecule management. Optimising the product fractionator for maximal performance – using high-efficiency WPHEs whose capabilities exceed those of conventional heat exchangers – is fully in line with these goals.

Alfa Laval can be instrumental in both regards. The company, which has been designing fat and oil treatment plants for more than 50 years, has delivered more than 1,000 plants to the food and biofuel markets and is also the leading supplier of pretreatment plants for HVO processing. It has also supplied close to 3,000 WPHEs (Compabloc) for different refinery processes since the mid-1990s.

When the fractionation section is optimised using WPHEs as feed/bottoms interchangers, overhead vapour condensers, steam generators and product coolers, it is possible to:

- Increase energy efficiency
- Increase the recovery of high-value molecules
- Maximise waste heat recovery
- Minimise the cooling water requirement
- Reduce the cost of investment in expensive process equipment such as reboilers, air coolers, piping, and pumps.

It is even more important, however, to take a holistic approach to the investment in a new HVO complex. The pretreatment, wastewater, and HVO processes should be considered together rather than optimised independently:

- Waste heat from the HVO processes can be utilised to generate low-pressure steam
- The generated steam can be used to evaporate the wastewater from all processes
- Evaporation of the wastewater will minimise the final waste stream to be treated, making it possible to recycle and reuse more than 98% of the process water in the pretreatment plant.

Such interconnections are an opportunity well worth evaluating, as they can maximise the profitability of the HVO complex (see **Figure 7**). Alfa Laval can help select the best pretreatment scheme for HVO feedstock. It has expertise in designing wastewater evaporation systems and its WPHEs can boost HVO processing profitability.

Jay Jeong
jay.jeong@alfalaval.com

Eva Andersson
evae.andersson@alfalaval.com

Bent Sarup
bent.sarup@alfalaval.com