Energy conservation

Benefits from the new generation of
Mass and Heat Transfer Components

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Abstract

With the higher energy cost, shrinking profit margin, refineries worldwide are focusing on improving efficiency of their processes reducing their operating costs.

Energy consumption plays a significant role in the operating cost and particularly in refinery operation, energy occupies a prime cost contribution.

A large amount of energy is required in Refinery operations to sustain the required thermodynamic and/or reaction mechanisms.

The correct design of the fractionation facilities (columns) are one of the key pieces of equipment which can significantly contribute to minimising the operating cost of the refinery.

Distillation columns are typically equipped with specialized internals (trays or packing) to facilitate the separation.

A correct and optimized design of column Mass Transfer Components (MTC) can minimize energy requirements.

The latest developments in high capacity and high performances column internals, such as VGPlus™ trays and MellapakPlus® structured packing, further boost and often provide valuable and cost effective solutions to this challenge.

This paper analyses the major factors affecting the energy balance in operating fractionation columns, evaluates the contribution achievable with the latest technologies and reports case stories where benefits were achieved and validated.
Introduction

Most of the operations in a Refinery unit are finalized in separation columns where a mixture of hydrocarbon components is separated according to their boiling temperature range (cuts) or into specific components.

Main targets in designing separation column are focused to capacity, efficiency and turndown. However, with increasing energy cost, energy consumption is now such an important factor to be taken into account.

The separation processes such as distillation, absorption or stripping are occurring according to the thermodynamic mechanisms and sustained by energy supplied to the column from an external source.

In a refining, the amount of energy required in separation columns may affect the overall energy balance around 40 to 45%.

**Because Energy is a major variable operating cost, the aim of the unit designers and end users is to minimize the overall energy consumption for better revenue and energy savings.**

To correlate and identify the "energy saving" achievable with the latest improved mass transfer technologies, some basic concepts have to be mentioned.

The process

Separation of chemical and hydrocarbon components is performed by continuously contacting the vapour and liquid phases of the processed mixture.

The contact between the two phases is handled in a series of ideal "stages" where the two phases are continuously varying their composition according to the thermodynamic equilibrium.

**Energy** is required to generate the vapour phase and to maintain the correct thermodynamic separation conditions.

The vapour phase is generated by partially or totally vaporizing the feed and/or a portion of the bottom liquid phase (the Reboiler).

The liquid phase can be supplied with the feed and generated by partially condensing the vapour phase (reflux) from the top vapour stream.

To perform the separation according to the required specification, the process is characterized by a calculated number of separation "stages" (NTS).
For a defined feed composition (characterization), desired product qualities and operating conditions, a thermodynamic calculation defines the number of required fractionation theoretical stages (NTS).

**Pressure** is a sensible parameter affecting the distillation mechanism, energy balance and column design.

Operating pressure is selected in function of the physical characteristics of component to be separated (i.e. vapour density) and set by the available cooling temperature to condense the top vapour phase for reflux.

The lower the pressure, the easier the separation.

Medium operating pressure (3 to 5 Bar) is used in separation of hydrocarbon components ranging above four carbons (C4) (Stabilizer, Naphtha splitter).

Higher operating pressures (> 5 Bars) is adopted in separation of lighter hydrocarbon components less than five carbons (C5). In this case pressure is set by the available refrigeration temperature of cooling water, air or cryogenic fluid.

Low operating pressure (< 3 Bar) is allowed by the higher temperature condensation of vapour phase of heavier processed components (Main fractionators).

Lower (vacuum) pressure is required in order to minimize the flashing operating temperature preventing from cracking, reaction-polymerization of thermal unstable components (i.e. Vacuum column).

**Distillation column design fundamentals**

For a quick and reliable design optimization of distillation column, graphical methods developed based on the simulation results are recommended.

"**Sensitivity analysis**"

is the method correlating the required separation performances to the two fundamental parameters as NTS, Reflux ratio (RR) (Fig. 2).

For a specific operating condition, **RR is proportional to the energy supplied to the column** and it can also be even defined in term of heat duty.

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**Fig 2 - Sensitivity analysis for increase**
The optimized design of distillation columns ranges in between minimum RR and minimum NTS (total reflux).

- At **minimum RR**, higher NTS are required but **less energy**.
- At **minimum NTS** requires higher RR, corresponding to **higher energy** supply.

**Industrial scale**

On an industrial scale the process is handled in a "**column**" where the mass transfer mechanism is facilitated by specialized internals known as "**trays**" and "**packing**" (mass transfer components **MTC**).

MTC are designed and assembled in the column to maximize and enhance a continuous and effective contact between the vapour and the liquid phases.

**Performances**

As with any type of industrial equipment, trays and packing (**Mass transfer components: MTC**) performances are characterized by an operating "**efficiency**". Efficiency characterizes the deviation of MTC performance from the ideal stage.

"Trays efficiency" defines the % effectiveness to meet the separation of one theoretical stage (TS).

"Packing efficiency" is measured as "Height of Equivalent Theoretical Stage" (HETP) required performing one TS.

For heat transfer, a similar concept should be applied.

**Prorating the calculated NTS with the "efficiency" and/or "HETP" allows the engineers to define the number (or height) of "actual" MTC required to perform the specific separation in the distillation column.**

The lower the efficiency of MTC equipment the more actual trays (or height of packing) are required to perform the separation, and vice versa.

More efficiency, less trays or packing.
Column sizing

For a specific process, the "Internal reflux" is defined by the Reflux Ratio, intermediate feed and vapour condensation (pump around). These factors also define the liquid traffic profile throughout the column. Consequently, the Vapour traffic is thermodynamically defined by the liquid side conditions.

The resulting Vapour and Liquid traffic profiles allow sizing the column cross sectional area based on the MTC hydraulic capacity.

The required NTS and MTC "efficiency" allow us sizing of the distillation column with respect to the Number of stages (or height) of "actual" MTC, and this helps to determine the required column elevation.

In practice, an optimized operating point is selected which balances RR and NTS taking into consideration the cost of column and external facilities (Capital costs) and operating costs. This can be graphically visualized in Fig.3

**Fig 3**

Heat balance optimization is the prime factor setting the column capital and utility cost.
Design of distillation column

The design approach varies depending upon whether the column is new or is revamped.

*New column*

Targets are to minimise investment cost (fix) and annual operating cost.

As the RR increases the capital cost is approaching its minimum (mainly for column height), but the energy cost increases affecting the annual operating cost. The balance between capital cost, (resulting from the column dimensions and equipment) and variable cost (resulting from energy requirements) should identify an optimum corresponding to an optimum energy cost (Fig.3).

For new column, *High Performance Trays (HPT) or Packing allows us to minimize column dimensions and increase operating reliability.*

*Revamp of an existing column*

Typically, the revamping of an existing column requires:

- To increase feed rate: higher hydraulic capacity of MTC and higher heat duty at the re-boiler, condenser and heat removal facilities.
- To increase separation efficiency: higher NTS and higher heat duty at the re-boiler, condenser and heat removal facilities.
- To increase feed rate and separation efficiency: higher hydraulic capacity of MTC, higher NTS and higher heat duty at the re-boiler, condenser and heat removal facilities.

Common for all cases is the increasing of the hydraulic capacity required to handle higher internal Vap/Liq traffic either for the higher feed rate and higher internal reflux.

The target are:
- to reuse the existing vessel,
- to reuse as much the existing column internals and external facilities,
- Minimise the incremental heat consumption.

Together with the hydraulic limitation of existing MTC, most of the time the major limitation approaching the revamp of exiting column is heat duty capacity of external equipments/facilities.
Role of High Performance MTC in column design

As above previously, a new category of MTC has been developed in the past 10 years allowing to better optimisation of column design.

Mainly when approaching the revamp of an existing column, high performances MTC's can significantly help in achieving an optimized and suitable solution in line with energy saving requirements.

Listed below is a preliminary and practical procedure to identify the feasibility requires:
- Identify how much spare heat duty capacity is available with the existing facilities (heater, re-boiler, condenser, heat exchangers).
- Apply the additional heat duty extra capacity to the process simulation of the column and create the new vap/liq profile at which the separation performances are met. This requires preliminarily evaluate the NTS.
- Apply the resulting vap/liq loads to design the tray geometry and define the minimum tray spacing of selected HPMTC that can be used in the existing column.
- Number of suitable HPMTC, and corresponding efficiency define the achievable NTS.
- Achievable NTS is than applied to the thermodynamic calculation to define the heat duty.
- When NTS and max available duty are matching with the operating curve in the sensitivity analysis graph, the feasibility is confirmed.

All above is visualized with a specific sensitivity study (Fig 4)
Benefits of HPMTC

For new column use of HPMTC allows the designer to:

- Minimize column dimensions
- Obtain a large turndown
- Minimize the investment cost of the column

For column revamps use of HPMTC allows the designer to:

- Increase hydraulic capacity in the existing column vessel,
- Increase separation efficiency (more NTS)
- Minimize the heat duty requirement
- Maximize the use the existing heat facilities
- Minimize the capital investment cost

Sulzer state of art HPMTC

Sulzer Chemtech is constantly dedicated to improving its mass transfer technologies with new products able to satisfy the stringent market requirements.

Sulzer Chemtech has developed and tested the highest performance MTC (tray and packing) performance technologies available in the market today.

With the new VGPlus tray, Shell tray and internals technology and MellapakPlus structured packing Sulzer can provide the highest performances achievable minimizing capital cost and energy requirements.

The new generation of MTC allows for optimizing column designs for revamping existing columns as well as new column design.

Additional hydraulic capacity and better vap/liq phase distribution of new generation on Sulzer MTC allow significant design improvements reflecting in reduced overall investment and operating costs.

The new generation of **high performance trays (HPT)**, compared with conventional tray, achieves:

- Up to > 50 % more hydraulic capacity.
- Up to 10% higher efficiency per tray and
- More than 20% overall column efficiency (more trays at lower tray spacing)

New generation of **high capacity packing** compared with conventional packing provides:

- Up to 40 % more hydraulic capacity for same specific surface area.
- Higher capacity allows upgrading column section with higher surface area packing for a higher available efficiency (NTSM)

Increased hydraulic capacity allows increasing the vapour/liquid traffic either for higher feed rate capacity or separation efficiency (higher RR).
Moreover higher capacity allows designing for reduced tray spacing for more NTS installed either for more separation efficiency or less RR.

All above mentioned techniques systematically affecting the overall energy balance

More about packing technology

While for medium-high pressure columns the high performance tray (HPT) technology gives considerable advantages in term of performances and reliability, for low pressure operating column Packing is the generally the most suitable solution.

In specific sections of low pressure columns such as a Main Fractionators, packing has significant benefits to meet higher performances either in capacity and efficiency. However, the use of packing in moderate pressure columns should be carefully evaluated as an alternative to trays based on the column section function (pump around or fractionation) and required performances. Each design should be on a case by case asis and based on the required achievements (pressure drop, capacity, heat transfer, number of fractionation stages, space limitations).

In main fractionator packing can be used to provide better hydraulically and heat transfer characteristics to de-bottleneck column sections (such as pump arounds) or improve specific fractionation sections up to a defined maximum NTS.

In specific, for main fractionator (MF) such as an FCC, using packing (as opposed to trays) can significantly reduce the pressure drop across the column which will de-bottleneck the air blower and wet gas compressor.

Where packing has significantly advantage is in Vacuum columns and any application where pressure drop has a significant impact on column performances.

In Vacuum columns the reduced pressure drop internals allows us to higher capacity, improve product recovery and a significant reduction of the heat duty requirement. This also affects the operating reliability due the lower operating temperature. Moreover, significant benefits are achieved in qualities of FCC and Hydrocracker feed or base lube cuts.
Evaluation of energy saving

Typically, the first approach of any column design is focused on capacity and separation performances. Nevertheless, the final optimization of column design is focused in minimizing the energy requirement.

Column design parameters and operating variables are affecting the energy balance according to the following graph (see Fig 5).

As energy proportionally increases with the feed rate and RR, NTS and hydraulic capacity reduce helping to mitigate energy requirement.

As the hydraulic capacity and separation efficiency help to reduce energy requirements, HPMTC compared to conventional, designer can adopt them for:

- new columns: to better optimize the balance among the process parameters to minimize the column capital cost,
- revamping of existing column: all variable are involved in the evaluation.

Case by case review of the revamp targets (capacity, product quality, others.) has to be conducted with the existing available parameters such as column dimensions, heat equipment capacity and available energy, actual efficiency, hydraulic capacity, mechanical constraints, turndown and whatever else can be a limitation/constraint. Therefore, the final evaluation of the benefits on the energy balance is a function of the optimization of all the above parameters.
The evaluation of the advantages only on energy balance and specifically their economics is complex and it is function of different variables. However, as quick rules of thumb, different design situation and specifically for **existing column revamping** are here mentioned and cases by case the potential contribution in duties defined.

**Case 1:** Increase capacity – Same separation performances required

- Higher vapour and liquid loads are limiting the existing MTC capacity
- Higher amount of heat is fed to the column.
- Higher duty is required from feed preheating, Reboiler and condenser.

**Advantages**

- HP MTC allow designer to hydraulically de-bottlenecking the column.
- When more trays can be installed (at lower tray spacing), more NTS become available to proportionally reduce the RR, therefore the energy supply.
- Required additional duty capacity of reboiler and condenser can be addressed within the existing maximum capacity of equipments; therefore no major external modifications are required.

**Within an increase of 10 to 20% capacity, existing reboiler and condenser could be suitable (capital cost saving) and a corresponding energy saving (for more NTS installed) is estimated between 5 to 10 %.**

**Case 2:** Increase fractionation – Same feed rate

Separation efficiency can be increased by increasing RR and/or NTS.

- At same NTS, higher amount of heat is required from re-boiler and condenser to increase RR.
- Higher hydraulic capacity to handle higher vapour and liquid loads.

**Advantages**

- One by one existing tray replacement with HPMTC increases hydraulic capacity up to 40% to handle more RR.
- Increased RR within existing reboiler and condenser capacity can increase separation efficiency up to an equivalent of 30% more NTS.
- Estimation of energy saving up to 10%.

- Replacement for more actual trays installed at lower tray spacing and more hydraulic capacity (for higher RR) can add up to 30% more NTS equivalent.
- More NTS allows designer to proportionally reduce the RR, therefore the energy supply within existing reboiler and condenser capacity.
- Estimation of energy saving up to 15%.
Within 20 to 30% increase in NTS, column could be revamped (capital cost saving) and corresponding energy saving is estimated between 10 to 20%.

Case 3: Increase capacity and increase fractionation

A combination of the two above conditions is to be analyzed and optimized.

Energy saving can estimated between 5 to 15% depending on the level of performances

Case studies

To better identify the benefit achievable on the energy balance with the HPMTC, some case study of revamped column are reported here for trays and packing.

All the revamping case studies here reported have been approached by transferring the relevant process simulation results to a specific sensitivity analysis. Graphical analysis of NTS and energy balance function of the required separation performance allowed identifying the optimum achievement within or at he minimum heat duty requirements. The resulting vapour and liquid loads were hydraulically checked for the new HPMTC design to define the best the suitability in the existing column diameter.

Final evaluation of achieved energy saving was conducted by comparing all the involved variables and cost factors. It has to be mentioned that the energy saving evaluation should be case by case according to the specific conditions of unit and refinery energy balance and costs.
**Case study 1**  Column: De-isoButanizer column in Alkylation unit

**Scope of revamp**
- Increase the capacity: from 36.5 to 45.5 t/h;
- Increase Iso-Butane Recovery > 94 %wt;
- Reduce N-Butane in the Top Stream < 3% wt.
- Minimized investment cost

**Original configuration**
- Column diameter 2964 mm
- 56 conventional 2 pass trays
- Max performance achievable at maximum capacity about 45 NTS.

**Constraints**
- Max duty from Re-boiler: 13.5 MMKcal/h;
- Condenser duty;
- Other service equipments
- No welding in column.

**Process study**
Process simulations for
- increased capacity: 45.5 Tons/h
- distillate product quality: < 3% N-C4 in distillate
- re-boiler duty fixed at 13.5 MMKcal/h
defined Vapour / Liquid loads and about 50 NTS required.

To comply with the new operating conditions and performances two alternatives were available:
- Replace existing 56 trays with 81 high capacity Multi-down-comers trays.
- Replace one by one the existing 56 trays with High performance trays able to perform a minimum of 50 NTS.

Due to the no-welding constrain, the second alternative was preferred.

**Feasibility**
- The existing 56 conventional trays were replaced one by one with 56 HPT Sulzer VGPlus and no welding were required in the column.
- New tray geometry was fit to the existing tower attachments with special TA adaptors.
- Modifications of column internals were done well within the shut-down time frame.
- New re-boiler, condenser and pumps were also modified to satisfy the new rates.

**Achievement and comment**
The column was able to achieve and exceeding the design requirements
A simulation of the operating test run performances shows the following results:
- N-C4 in the top distillate < 3 % wt;
- Estimated NTS @ 52
- Tray efficiency @ 93 %
- Operating tray flooding up to 87 %.
- Good operating stability.

Because of the limited feed availability during test run, the extra available tray hydraulic capacity was occupied operating at higher RR. At this condition the column performed for < 1.0% N-C4 content in top distillate, 93% efficiency at 89% FF.

Typically tray efficiency is increasing with % flood and it then lower after a certain value. At this breaking point the efficiency decrease and performances is substantially reduced.

The proper hydraulic evaluation identifying the optimum liquid and vapour loads at which the installed trays achieve their maximum efficiency is the basis to achieve the maximum tray performance.

**Energy benefit evaluation**

From the increased fractionation prospect, a sensitivity analysis of the new operation can be visualized as follows:

- Increased feed rate requires that the first portion of the total 13.5 MMKcal/h duty to accommodate the new operating conditions.
- Second portion, fully integrated with the first, requires the correct RR to achieve the distillate specification.
- According to the sensitivity graph, a gain in energy is from the higher NTS allowing higher fractionation performances at 13.5 MMKcal/h total duty.
- Similar performances at original NTS (45) should have required more duty.

**From the overall energy balance, saving was estimated around 12%.**
**Case study 2**  De-Butanizer Revamp

**Scope of revamp**

- Increase Capacity: 25%
- Improve Gasoline RVP: from 8 to 7.1 psi
- Decrease C5’s in LPG: from 0.5 to 0.4% Vol

**Original configuration**

36 two pass conventional valve trays

**Constraints of Revamp**

- Existing trays limited in hydraulic capacity.
- Condenser Duty: 8.5 MMKcal/h maximum
- Reboiler Duty: 11.4 MMKcal/h maximum
- Vessel: Minimum welding to tower wall
- Installation Schedule: 12 working days

**Process study**

- Process Study: Simulations, Check of Re-boiler, Condenser Duty, Reflux Pump
- Process Guarantees: Capacity, RVP Gasoline, LPG quality

**Tower Internals Modification**

- One by one replacement with High Performance VGPlus Trays
- Trays, Liquid Distributors
- Tower Attachment Adaptors were used to minimize welding.

**Unit Performances**

- Capacity: over 210 ton/h (vs design: 204 ton/h)
- RVP of Gasoline: 7 – 7.5 psi depending on market requirements
- C5 plus in LPG: less than 0.4% Vol
- Tray Efficiency: over 85%

**Estimated energy saving: about 13 %**.

Estimated on:
- increased capacity to handle higher RR and
- 10% increase trays efficiency.
Case study 3: De-Bottlenecking a C3 Splitter in Ethylene Plant

Scope of Revamp

- Increase Capacity: from 29.5 to 35 t/h, i.e. 18 %wt
- Products Quality: C3=Polymer-grade>99.5%mol
  C3= in Propane < 5%wt

Original configuration

- Two columns in series equipped with 248 conventional trays

Constraints

- Reuse Existing Major Equipment: Columns, Top Condenser,
  Side Re-boiler - Bottom Re-boiler, Pumps
- Column Stress Relieved: No direct welding to tower shell.
- Installation time frame: 22 days plant turnaround

Process study

Sensitivity analysis provided the optimum operating point balanced between the:
- max achievable NTS and
- max RR from achievable reboiler duty.
- All loads handle with new HPMTC.

Feasibility from process study

Option a) 1 for 1 Tray Replacement
- Minimum cost for tower internals and site work activities
- Reboiler and Condenser duties 16% higher than original design
- Maximum energy cost

Option b) 5 for 4 Trays Replacement
- Maximum cost for tower internals and site work activities
- Reboiler and Condenser duties within spare capacity of original design
- Minimum energy cost

Revamped solution

- 248 conventional trays replaced with 316 HiFi Trays,
- New trays installed with self supported TA for no welding.

Revamp Results

- Capacity higher than design
- Propylene recovery @ 99%wt
- Pay-back less than 1 year

Estimated energy saving about 12 % (Based on increase NTS and capacity)
**Case study 4:** Crude Atmospheric column revamp for increase:

**Scope of Revamp**

- Feed rate capacity increase by 10%
- Fractionation stages from 25 to 33
- Minimum modification to Heater, heat exchanger, overhead condenser.

**Original configuration**

- Diameter 7315 mm
- Three fractionation sections equipped with two 12 + 5 + 10 conventional trays,
- Two PA sections equipped with 5 + 3 four pass trays
- Bottom Stripping equipped with 5 four pass trays

**Constraints**

- Minimum external equipment modification

**Process and feasibility study**

Process study at the new operating performances confirmed internals loads, NTS and energy balance.

Mechanical study confirmed the feasibility at reduced TS.
- Three fract. section equipped with 16 + 12 + 10 HPT
- Two PA section equipped with Structured packing Mellapak.
- Bottom Stripping section equipped with 5 new HPT
- Minor modifications were required to heater, top condenser, heat exchanger train.

**Revamp Results**

- Capacity higher than design
- Product fractionation better than expected
- Pay-back less than 1 year

**Estimated energy saving about 14%** (Based on increase NTS)
Case study 5  
Revamp of Vacuum column from conventional packing to MellapakPlus

Scope of Revamp

- Replacement and design updating
- Reduce pressure drop for:
  - reduce flash zone temperature
  - increase yield recovery
  - increase MVGO quality
  - increase LVGO fractionation

Original configuration

- Diameter 7300 mm
- Two PA equipped with packing
- Wash section equipped with packing
- LVGO fractionation sections with packing
- Operating flash zone temperature
- Pressure drop: 32 mbar

Constraints

- Column with packing operating 15 years

Process and feasibility study

Process study for less pressure drop and more NTS
In LVGO section confirmed new loads and qualities.

- Wash section packing replaces with MellapakPlus and
  New configuration.
- HVGO PA sections replaced with two PA section equipped with MellapakPlus
- LVGO fractionation section equipped with higher efficiency MellapakPlus.
- Bottom Stripping section equipped with 5 new HPT
- Minor modifications were required to heater, top condenser, heat exchanger train.

Revamp Results

At same feed rate and yield recovery
- Pressure drop was reduced to 29 mbar
- Flash zone temperature reduced by 6 °C
- HVGO contaminants reduced by 20%
- LVGO Pour point reduced by 9 °C

Estimated energy saving about 16 %
(Based on reduced pressure drop and increase NTS)
Conclusion

With the higher energy cost, shrinking profit margin refineries worldwide are focusing on improving efficiency of their processes.

The higher hydraulic capacity, enhanced efficiency and feature of HPMTC allow designers minimizing both capital and variable costs either for new columns and mainly the revamping of existing.

HPMTC enhancements systematically reflect on the thermodynamic mechanisms of the separation process and involved energy.

The 50% more capacity of HPMTC compared with conventional MTC, allows to redesign existing distillation columns for higher feed rate and up to 20% additional separation efficiency.

Higher capacity allows a higher RR for a further enhancement of separation within the existing reboiler duty limit.

Higher NTS allows to reduce RR for a given separation performance and consequently less energy requirement.

As fundamental parameter of the thermodynamic process, energy plays a substantial role in the variable operating cost.

The Sulzer technology, strongly supported by new generation of high performance as VGPlus and Shell trays, and structured packing MellapakPlus significantly contributes in optimizing new and revamped column design addressing the energy saving issues.
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