Heat Integrated Distillation Columns

(HIDC)

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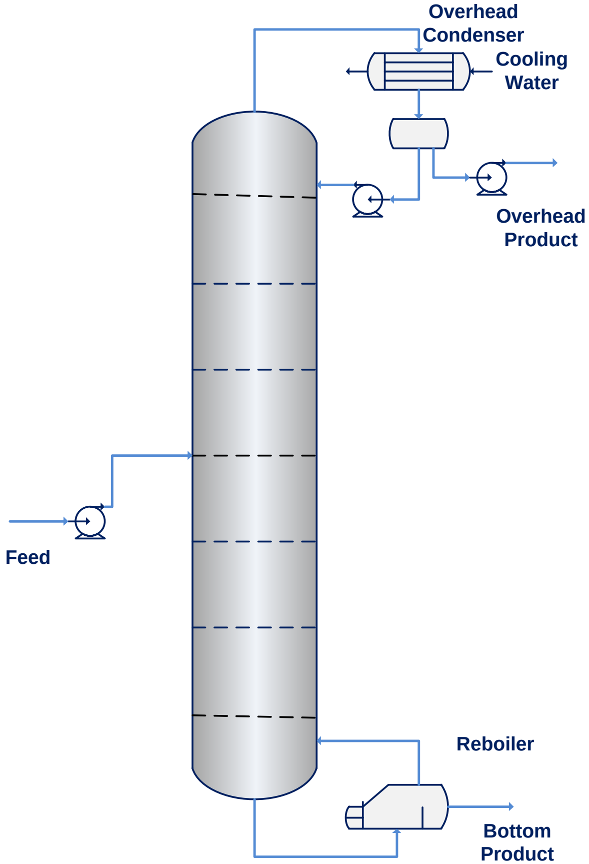
Distillation in the Process Industry

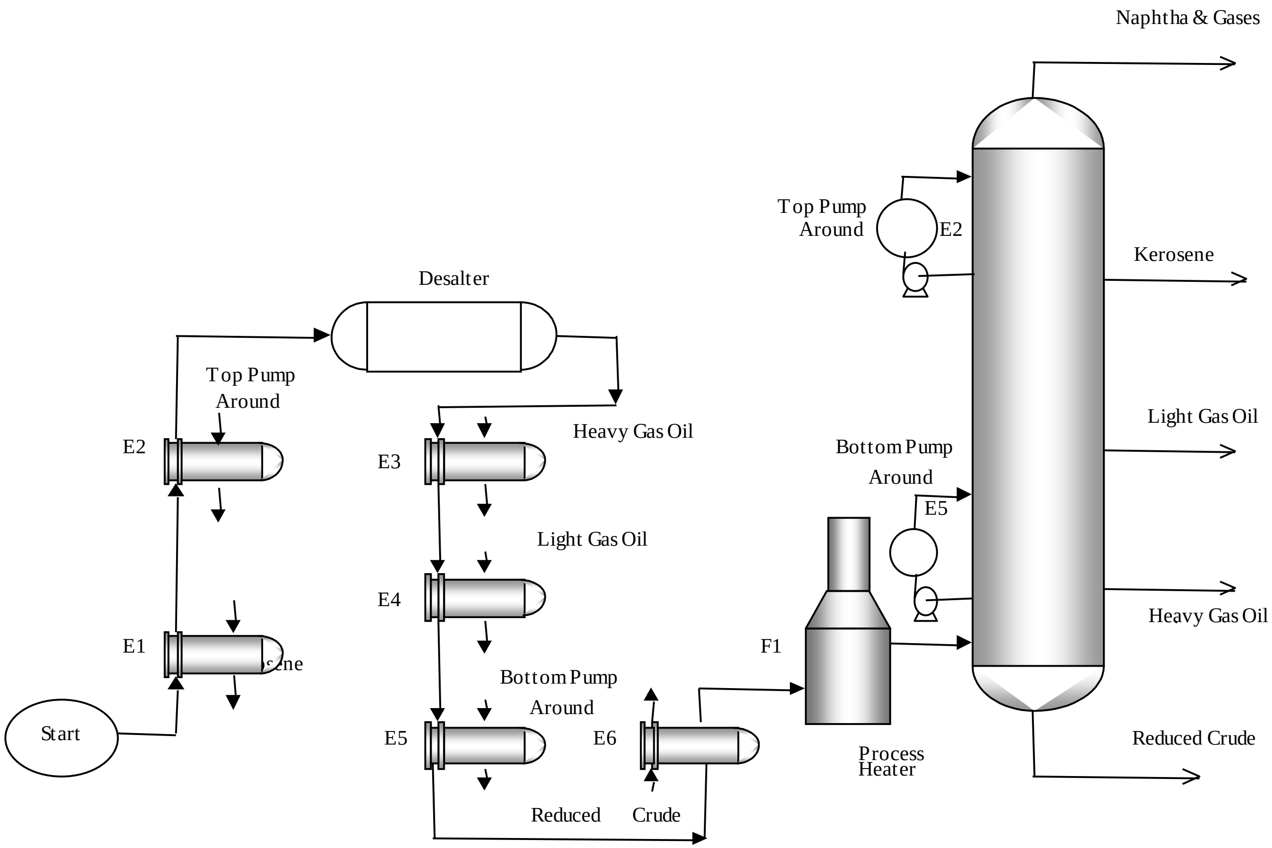
- Separation processes to recover and purify account for over 40% of the Chemical Process Industry (CPI) energy demands
- Distillation is the dominate thermal separation process
- Process industry continues to enhance the energy efficiency of distillation by heat network, improved trays & packings and fouling mitigation, considered low-hanging fruits
- Application of reactive distillation is expected to expand for selective chemical synthesis processes
- Opportunities and challenging for new generation of distillation process for enhanced energy efficiency (i.e. reduced C-footprint) and synthesis of bio-based chemicals and capture & conversion of carbon dioxide to value-added products

Distillation is perceived as mature technology, which is not TRUE

Conventional Distillation Process



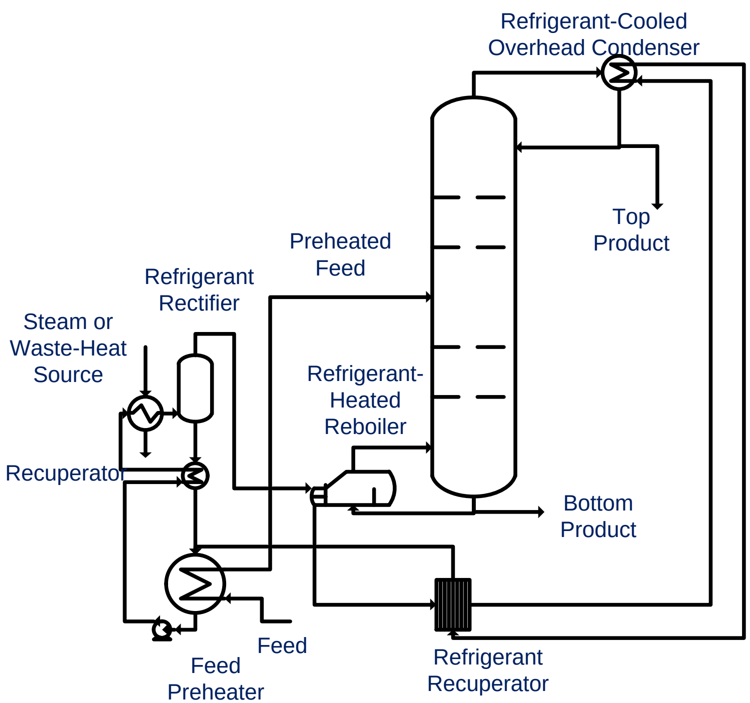
Conventional Column



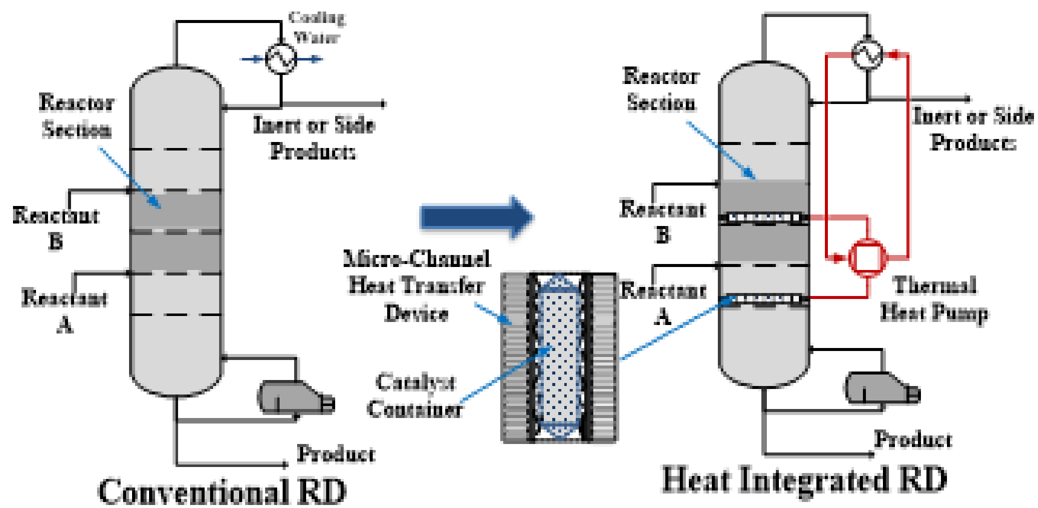
Crude Unit with HX Network

Established distillation process with limited energy efficiency technologies

Heat Integrated Distillation Columns (HIDC)



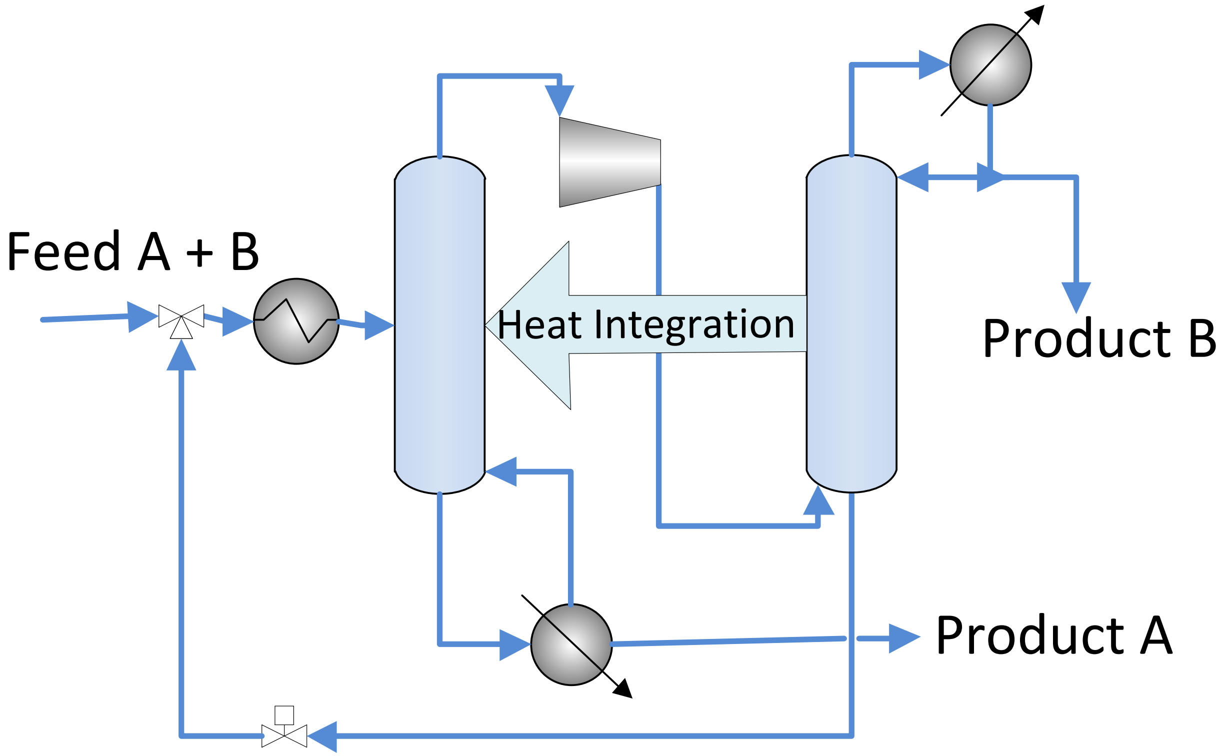
Recovery and Reuse of Latent Heat



Reactive Distillation Equipped with HIDC

Recovery of latent eat and internal heat integration need to be pursued

Thermally Coupled Column



Transferring process heat from rectifier section to stripping section

Thermally Coupled Columns

Potential Applications

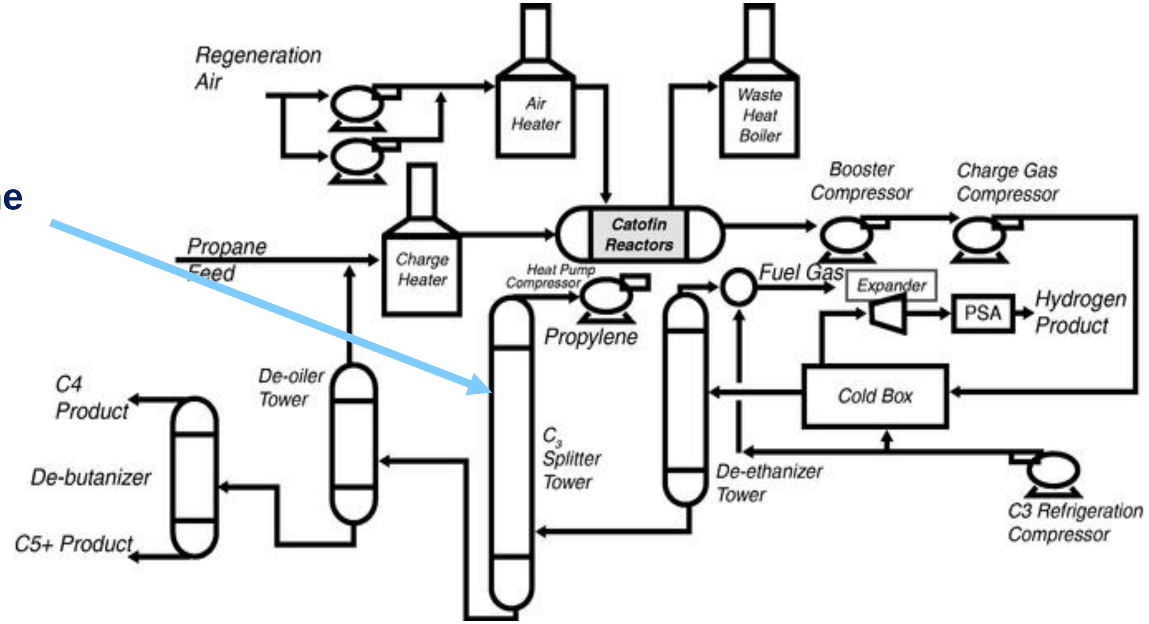
- Close boiling products such as propane/propylene hydrogen peroxide (H_2O_2)/water (H_2O)
- Separation of azeotropic mixtures such as dimethyl carbonate (DMC) and methanol
- Reactive distillation equipped with PerVaporization (PerVap) membrane separation
- Synthesis of bio-based specialty chemicals

Thermally coupled distillation can play key role in process intensification

Separation of Propane/Propylene

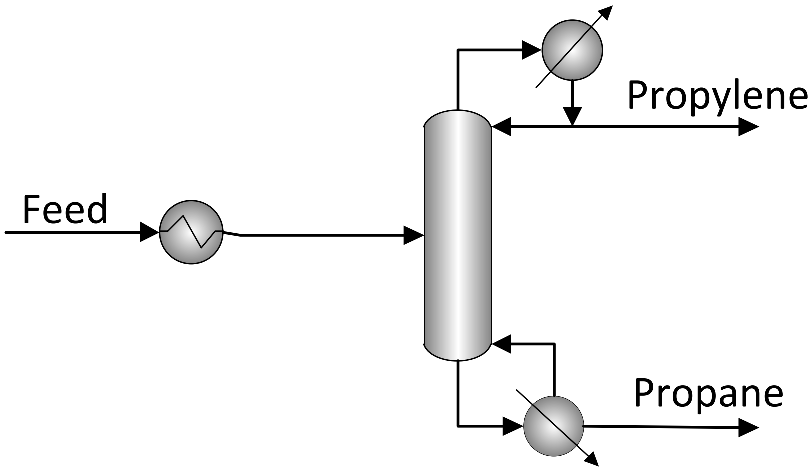
- Major petroleum chemical – propylene to polypropylene to consumer products
- Propylene is produced by de-hydrogenation of propane
- Boiling points – Propane -47.6 C Propylene -53.7 C at 1 atm.

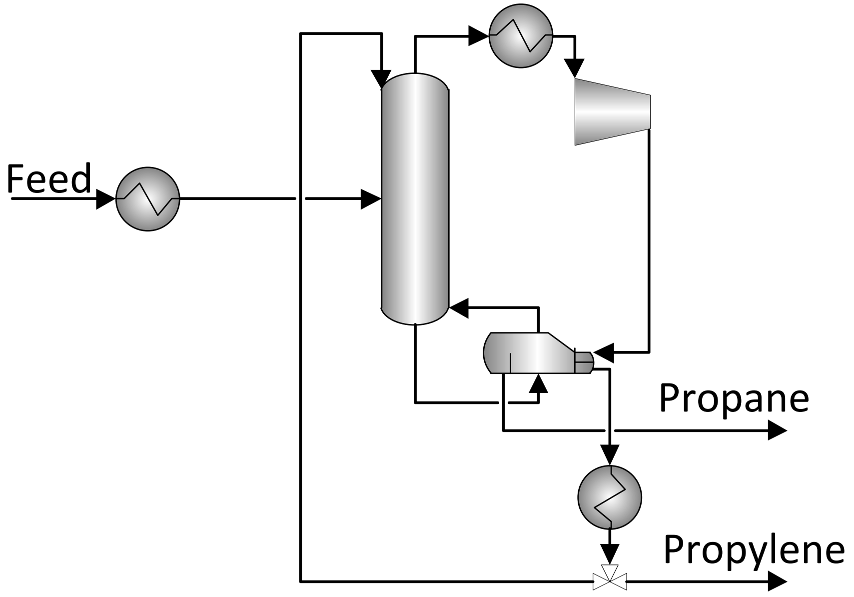
Propane/Propylene Column



Propylene is one of the large commodity chemicals

Separation of Propane/Propylene



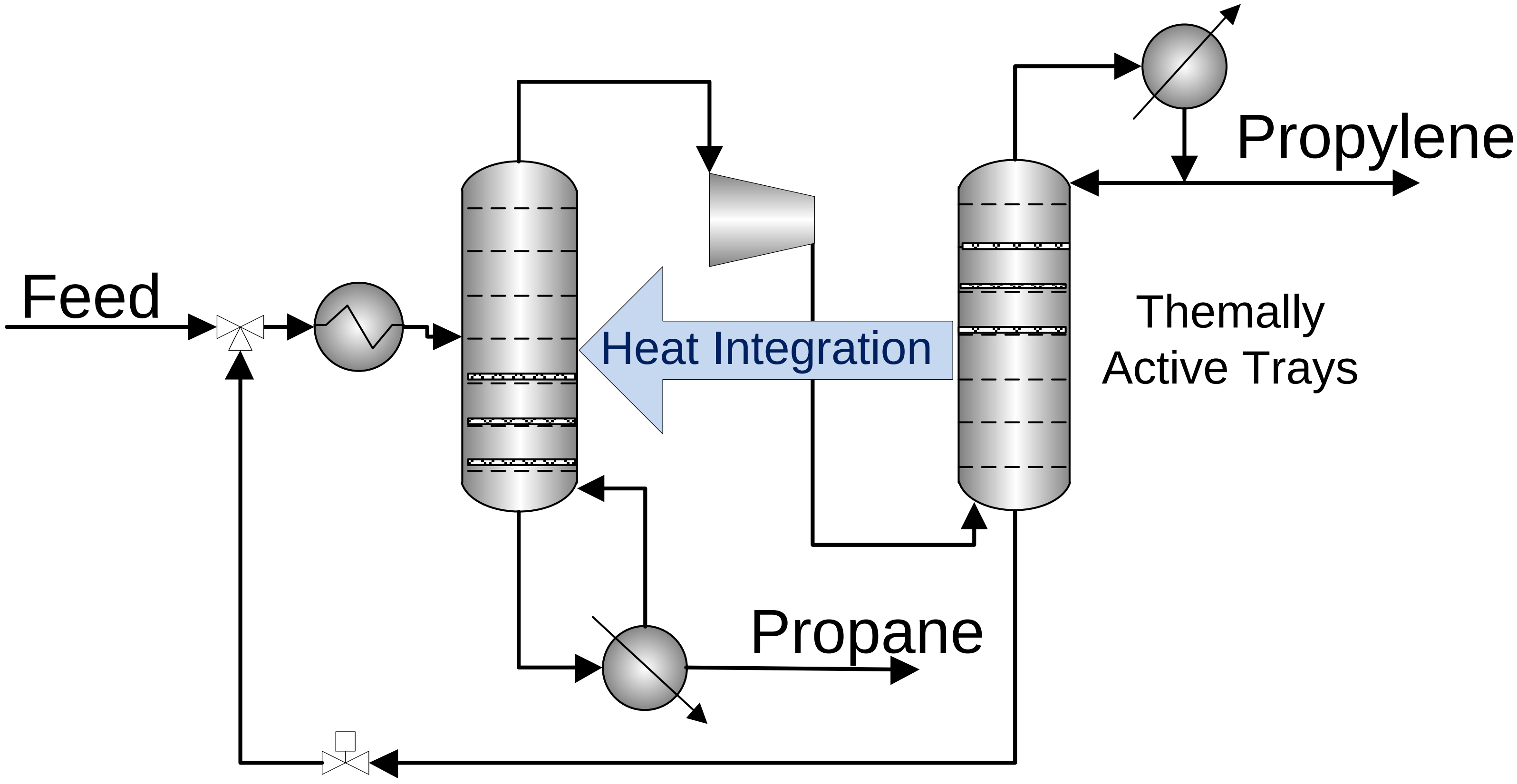


Conventional Distillation Process

Vapor Recompression (VCR) Heat Pump

VCR being Installed as retrofit with existing columns

Separation of Propane/Propylene



Thermally Coupled Distillation Columns

Need to develop thermally active trays & packings

Separation of Propane/Propylene

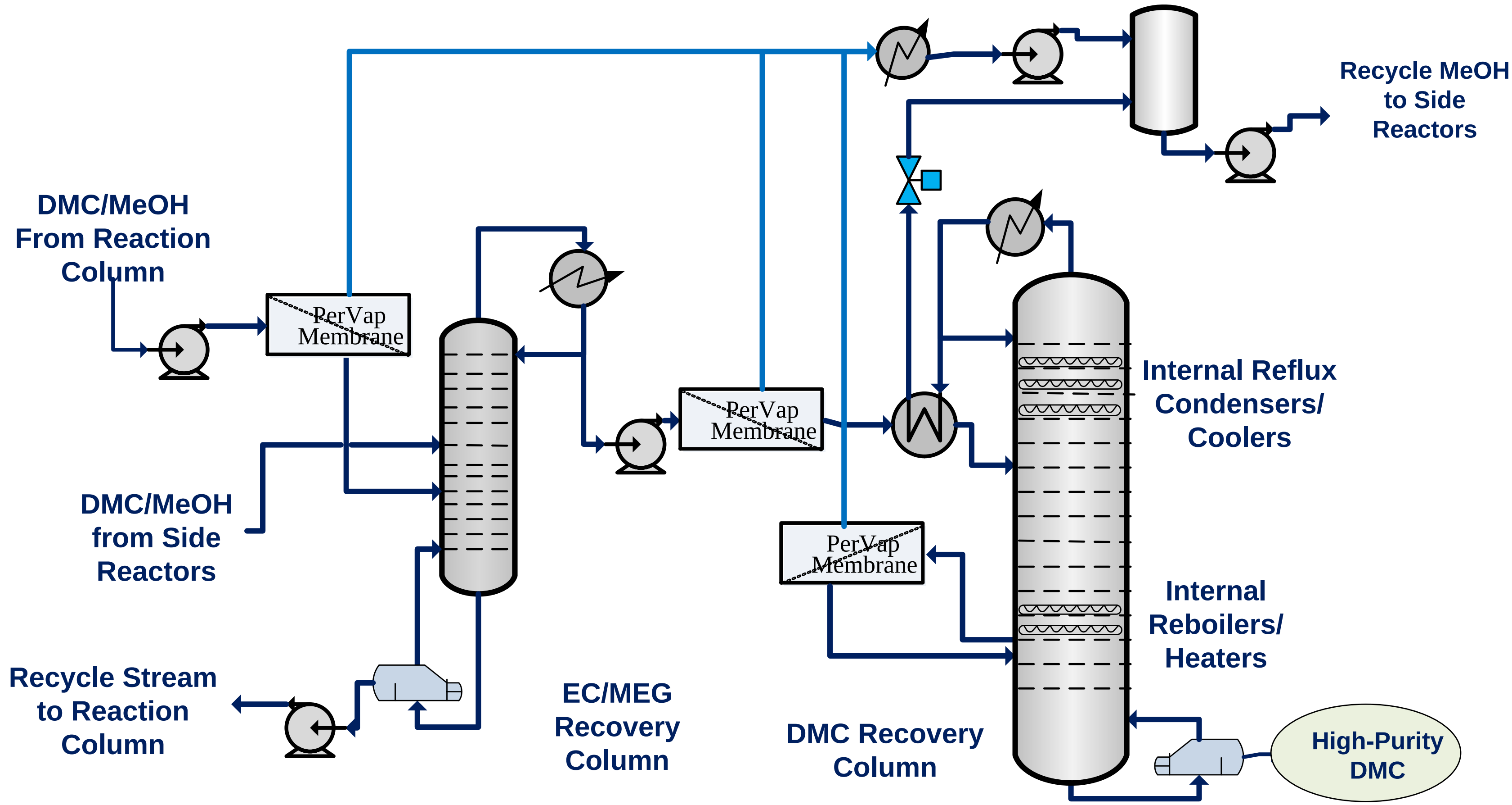
- ASPEN Plus process simulation performed for the three separation processes
- Feed rate 21 tonnes/hr
- Composition – Propane 0.8 mass fraction
- Pressure for conventional distillation 18 bars

Separation of Propane/Propylene

		Conventional	Heat Pump	HIDiC
Utilities	**Units**	**18 bar**	**18/30 bar**	**15/18 bar**
Steam	tonnes/hr	35	2	5
Relative	%	100%	6%	15%
Cooling Water	tonnes/hr	1726	293	203
Relative	%	100%	17%	12%
Electric	kW	0	2822	1068
Product Purity				
Propane	wt%	97.5%	94.3%	95.0%
Propylene	wt%	98.5%	99.3%	97.3%
CO_2 Emission				
kg /hr		5452	2170	1341
kg CO_2/kg Feed		0.26	0.10	0.06

Significant reduction of CO_2 emissions for thermally coupled columns

Separation of Azeotropic Mixture of Dimethyl Carbonate and Methanol



Separation of Azeotropic Mixture of Dimethyl Carbonate and Methanol

	Baseline	HI & PerVap
DMC Column Feed		
Feed Rate, kg/hr	22,355	22,355
DMC, %wt	35.0%	35.0%
Feed PerVap		
Retendent DMC %wt	NA	40.0%
Permeate MeOH %wt	NA	99.4%
Overhead Stream		
OH Rate, kg/hr	16,040	12,827
DMC, %wt	9.7%	7.3%
DMC Flow Rate, kg/hr	1,563	931
Bottom Product		
Product Rate, kg/hr	6,313	6,933
DMC, %wt	99.9%	99.8%

Separation of Azeotropic Mixture of Dimethyl Carbonate and Methanol

	Baseline	HI & PerVap
Reboiler		
Heat Duty, kW	6,460	5,860
Temperature, C	223.1	223.1
Internal Reboilers, kW	NA	200
Overhead Condenser		
Heat Duty, kW	4,850	3,960
Temperature, C	167.3	167.1
Internal Reflux Condensers	NA	600
PerVap Heat Duty, kW*	NA	600
Temperature, C	NA	106

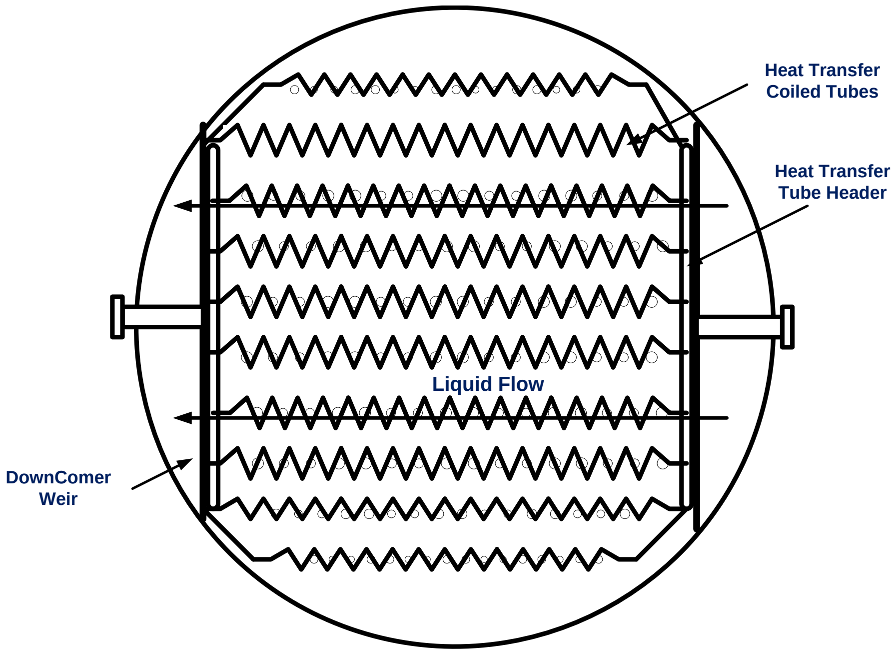
* PerVap modules heat integrated with reflux condensers

Thermally Active Trays and Packings

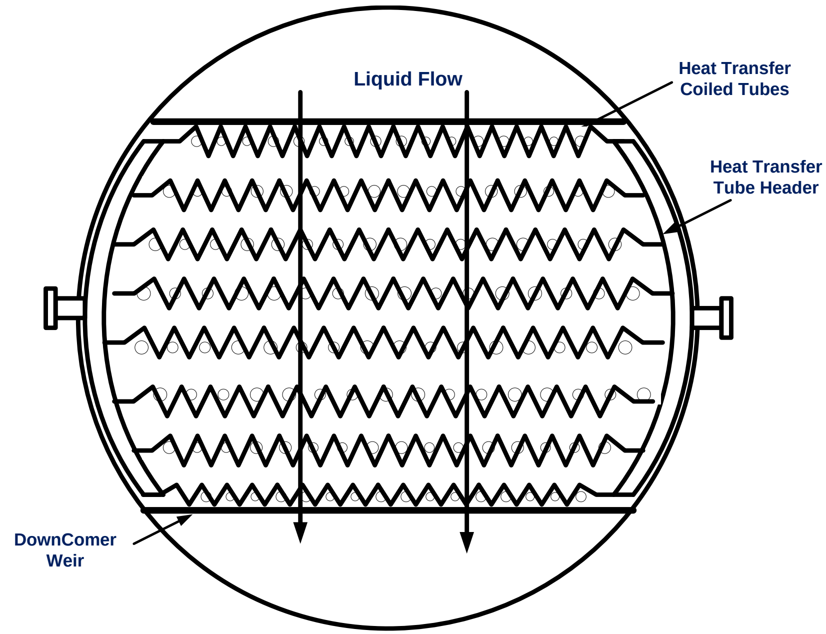
Design Criteria and Technology Opportunities

- Minimum impacts on vapor and liquid flows that may cause flooding
- High heat-transfer performance heat transfer to minimize size
- Configuration that can be integrated with trays and packings
- Effective integration with catalysts holding containers
- Heat transfer media can be liquid or phase-change media based on heat capacity requirements
- Potentially used of heat pipe with micro-channel flow passages
- Micro-channel device that can be manufactured by 3-D printing

Thermally Active Trays and Packings

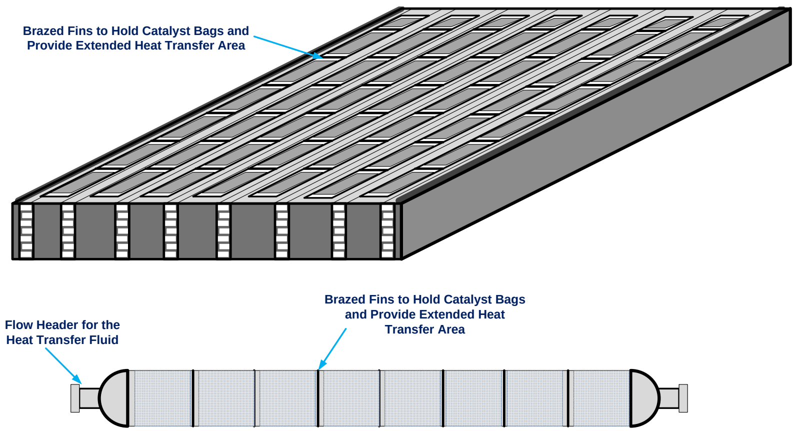


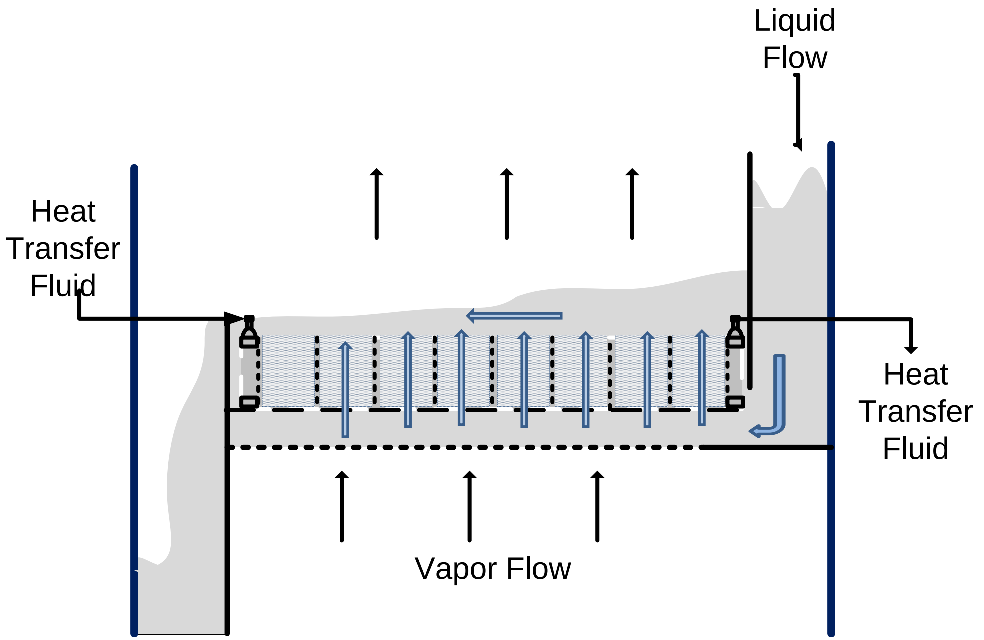
Parallel Flow Configuration



Cross Flow Configuration

Thermally Active Trays and Packings





Micro-Channel Brazed Unit

Compact HX Configuration

Conclusions and Path Forward

- Thermally-coupled distillation columns enhances energy efficiency and potentially increased capacity
- Heat pipes can be integrated into divided-wall columns for an effective thermal management
- Development of heat-transfer devices for thermally-active distillation trays and packings