Abstract

Propylene is one of the most important raw materials for the production of other organic chemicals. It was produced almost exclusively as a by-product in ethylene plants (steam crackers) and refinery operations (primarily fluid catalytic cracking) until about ten years ago. The supply landscape has changed dramatically over the last decade as propylene output from these traditional sources has slowed, due largely to developments in shale gas and the associated impact on relative feedstock pricing. The resulting imbalance in propylene supply/demand has led to an increasing reliance on other, on-purpose technologies for manufacturing propylene.

Propane dehydrogenation (PDH) is one on-purpose technology that has gained much traction in the marketplace. Dozens of new PDH installations have been announced worldwide, and many are already under construction. The single feed/single product feature is one of the most attractive aspects of propane dehydrogenation, but despite the simple chemistry, industrial implementation is complicated by equilibrium constraints, side reactions, and coke formation.

PEP previously evaluated the three leading commercial PDH technologies, but the focus of this report is on alternative/emerging technologies that have not yet been commercialized for propane dehydrogenation. A general review of the technical field is provided along with detailed economic evaluations for the following processes:

- Dow Fluidized Catalytic Dehydrogenation (FCDh)
- Linde/BASF PDH
- Snamprogetti/ Yarsintez Fluidized Bed Dehydrogenation (FBD-3)

The analysis and technoeconomic results that follow are based on a design capacity of 550,000 metric tons (1.2 billion pounds) per year of polymer-grade propylene. Alternative investment and production cost estimates are also provided for plant capacities that are half and double the base case. While the capital and production cost results herein are presented on a US Gulf Coast basis, the accompanying iPEP Navigator Excel-based data module (available with the electronic version of this report) allows for viewing results for other major regions along with conversion between English and metric units.
Contents

1 Introduction 8
2 Summary 9
   Industry aspects 9
   Technical aspects 9
   Dow FCDh 11
   Linde/BASF PDH 11
   Snamprogetti/Yarsintez FBD-3 12
   Economic aspects 12
3 Industry status 14
   Propane 14
   Supply 14
   Demand 16
   Trade 18
   Propylene 19
   Supply 19
   Demand 20
   Trade 21
   Strategic issues 22
   PDH investment 29
4 Technology review 32
   Chemistry 32
   Thermodynamics 34
   Catalysts 35
   licensors 36
   UOP Oleflex™ 36
   CB&I/Lummus CATOFIN® 38
   ThyssenKrupp/Uhde STAR® 40
   Dow FCDh 41
   Catalyst 42
   Reactor-regenerator 43
   Process flow 51
   Integration 52
   Environmental 52
   Linde/BASF PDH 52
   Catalyst 52
   Reaction 55
   Regeneration 56
   Process flow 57
   Snamprogetti/Yarsintez FBD-3 58
   Catalyst 59
   Reactor-regenerator 60
   Process flow 64
   Emissions 65
5 Economic evaluation–Dow FCDh 67
   Process description 67
   Section 100—Reaction and regeneration 67
   Section 200—Product recovery 68
   Process discussion 73
   Feedstocks, products, and storage 73
   Reactor and regenerator 74
   Compression 74
   Propylene recovery 74
   Cold box 75
   Materials of construction 75
   Refrigeration 75
   Cost estimates 75
   Capital costs 75
   Production costs 76

6 Economic evaluation–Linde/BASF PDH 82
   Process description 82
   Section 100—Reaction 82
   Section 200—Product recovery 83
   Process discussion 89
   Feedstocks, products, and storage 89
   Reactors 90
   Compression 90
   Propylene recovery 90
   Cold box 90
   Materials of construction 91
   Refrigeration 91
   Cost estimates 91
   Capital costs 91
   Production costs 92

7 Economic evaluation–Snamprogetti/Yarsintez FBD-3 98
   Process description 98
   Section 100—Reaction and regeneration 98
   Section 200—Product recovery 99
   Process discussion 104
   Feedstocks, products, and storage 104
   Reactor and regenerator 105
   Compression 105
   Propylene recovery 105
   Cold box 105
   Materials of construction 106
   Refrigeration 106
   Cost estimates 106
   Capital costs 106
   Production costs 107

Appendix A—Patent summaries 113
Appendix B—Design and cost basis 132
Appendix C—Cited references 137
Appendix D—Patent references by company 143
Appendix E—Process flow diagrams 146
Tables

Table 2.1 Comparison of propane dehydrogenation process conditions and features  11
Table 4.1 OSHA permissible exposure limits for chromium  65
Table 4.2 Typical emissions in FBD-3 process  66
Table 5.1 Propylene from propane by Dow FCDh—Design bases  69
Table 5.2 Propylene from propane by Dow FCDh—Stream flows  70
Table 5.3 Propylene from propane by Dow FCDh—Major equipment  71
Table 5.4 Propylene from propane by Dow FCDh—Utilities Summary  73
Table 5.5 Propylene from propane by Dow FCDh—Capital investment  78
Table 5.6 Propylene from propane by Dow FCDh—Capital investment by section  79
Table 5.7 Propylene from propane by Dow FCDh—Variable costs  80
Table 5.8 Propylene from propane by Dow FCDh—Production costs  81
Table 6.1 Propylene from propane by Linde/BASF PDH—Design bases  84
Table 6.2 Propylene from propane by Linde/BASF PDH—Stream flows  85
Table 6.3 Propylene from propane by Linde/BASF PDH—Major equipment  87
Table 6.4 Propylene from propane by Linde/BASF PDH—Utilities summary  89
Table 6.5 Propylene from propane by Linde/BASF PDH—Capital investment  94
Table 6.6 Propylene from propane by Linde/BASF PDH—Capital investment by section  95
Table 6.7 Propylene from propane by Linde/BASF PDH—Variable costs  96
Table 6.8 Propylene from propane by Linde/BASF PDH—Production costs  97
Table 7.1 Propylene from propane by Snamprogetti/Yarsintez FBD-3—Design bases  100
Table 7.2 Propylene from propane by Snamprogetti/Yarsintez FBD-3—Stream flows  101
Table 7.3 Propylene from propane by Snamprogetti/Yarsintez FBD-3—Major equipment  102
Table 7.4 Propylene from propane by Snamprogetti/Yarsintez FBD-3—Utilities summary  104
Table 7.5 Propylene from propane by Snamprogetti/Yarsintez FBD-3—Capital investment  109
Table 7.6 Propylene from propane by Snamprogetti/Yarsintez FBD-3—Capital investment by section  110
Table 7.7 Propylene from propane by Snamprogetti/Yarsintez FBD-3—Variable costs  111
Table 7.8 Propylene from propane by Snamprogetti/Yarsintez FBD-3—Production costs  112

Figures

Figure 2.1 Comparison of propane dehydrogenation total fixed capital for Q2-17  13
Figure 2.2 Comparison of propane dehydrogenation production costs for Q2-17  13
Figure 3.1 World propane production by source  15
Figure 3.2 World propane production by region  16
Figure 3.3 World propane demand by sector  17
Figure 3.4 World propane demand by region  18
Figure 3.5 World total propane exports by major source  19
Figure 3.6 World PG/CG propylene production by technology  20
Figure 3.7 World PG/CG propylene demand by end use  21
Figure 3.8 World propylene net equivalent trade  22
Figure 3.9 Global propylene capacity additions versus demand  24
Figure 3.10 Global propylene capacity additions 2016–26  25
Figure 3.11 Global PDH capacity additions  30
Figure 3.12 Licensor market share in 2017  31
Figure 4.1 Reaction network of propane dehydrogenation  33
Figure 4.2 Equilibrium conversion of light alkanes at atmospheric pressure  34
Figure 4.3 Equilibrium conversion of propane at different pressures  35
Figure 4.4 UOP Oleflex™ simplified process flow diagram  37
Figure 4.5 CB&I CATOFIN® simplified process flow diagram  39
Figure 4.6 ThyssenKrupp/Uhde STAR® process flow diagram  40
Figure 4.7 Dow FCDh reactor/regenerator
Figure 4.8 Dow reactor feed distribution assembly
Figure 4.9 Dow reactor cyclone and plenum design
Figure 4.10 Dow low-velocity gas-solid separation devices
Figure 4.11 Dow grid-like internals
Figure 4.12 Dow reactor quench
Figure 4.13 Dow riser reactor support
Figure 4.14 Dow FCDh simplified process flow
Figure 4.15 Linde/BASF PDH reactor
Figure 4.16 Linde/BASF PDH simplified process flow
Figure 4.17 Snamprogetti/Yarsintez FBD-3 reactor-regenerator system
Figure 4.18 Snamprogetti/Yarsintez baffle designs
Figure 4.19 Snamprogetti/Yarsintez reactor fitted with baffles
Figure 4.20 Snamprogetti/Yarsintez simplified process flow
Figure 5.1 Propylene from propane by Dow FCDh—Capital investment
Figure 5.2 Propylene from propane by Dow FCDh—Net production costs
Figure 5.3 Propylene from propane by Dow FCDh—Product value
Figure 6.1 Propylene from propane by Linde/BASF PDH—Capital investment
Figure 6.2 Propylene from propane by Linde/BASF PDH—Net production costs
Figure 6.3 Propylene from propane by Linde/BASF PDH—Product value
Figure 7.1 Propylene from propane by Snamprogetti/Yarsintez FBD-3—Capital investment
Figure 7.2 Propylene from propane by Snamprogetti/Yarsintez FBD-3—Net production costs
Figure 7.3 Propylene from propane by Snamprogetti/Yarsintez FBD-3—Product value
Figure 5.4 Propylene from propane by Dow FCDh—Process flow diagram
Figure 6.4 Propylene from propane by Linde/BASF PDH—Process flow diagram
Figure 7.4 Propylene from propane by Snamprogetti/Yarsintez FBD-3—Process flow diagram