Abstract
Process Economics Program Report 174A
HIGH-OUTPUT FLUIDIZED-BED POLYETHYLENE TECHNOLOGY
(July 1999)

This Report deals with the technology and operating economics of producing linear low-density polyethylene (LLDPE) by high-output, gas-phase fluidized-bed technologies. In commercial practice, gas-phase plants are dedicated to the production of LLDPE or high-density polyethylene (HDPE; alternatively, plants may produce both LLDPE and HDPE in a blocked out mode (swing plants). The scope of the report is limited to the production of the butene-1 copolymers of LLDPE.

The principal suppliers of high-output technologies are Univation, a joint venture of Union Carbide and Exxon Chemicals; and BP Chemicals. Univation’s high-output technologies are called the Condensed and Supercondensed Modes; and BP Chemicals’ are called the Innovene® High Productivity and Enhanced High Productivity technologies.

High-output technologies are characterized by the cooling of reactor effluent gases below their dew point to allow the recycle of a mixture of liquid and gases. The heat of vaporization of the liquid in the recycle stream enhances the removal of the heat of polymerization, thereby increasing reactor output.

We have developed representative operating economics for the Univation and Innovene® technologies, based on the production of C₄-LLDPE with a melt index of 0.92 and a density of 0.91–0.92. For Univation’s process, we have selected the following capacities and modes of operation:

- 441 million lb/yr (200,000 t/yr), dry mode
- 705 million lb/yr (320,000 t/yr), condensed mode
- 1,103 million lb/yr (500,000 t/yr), supercondensed mode.

For Innovene®, we developed economics for a 705 million lb/yr (320,000 t/yr) high-productivity plant. We compare the economics of the Innovene® and Univation technologies for a 320,000 t/yr capacity. We also analyze the economics of doubling the capacity of a 200,000 t/yr dry mode Univation plant by line duplication and by switching to the supercondensed mode.

We conclude that the Univation process has a slight advantage in operating economics, which derives from a lower investment (about 3%) and lower raw materials costs. For capacity expansions, the favorable economics of high-output expansion are quite apparent: The incremental battery limits investment for the supercondensed option is approximately 65% of the corresponding figure for line duplication.
CONTENTS

GLOSSARY, ......................................................................................................................... xi
1 INTRODUCTION .............................................................................................................. 1-1
2 SUMMARY ....................................................................................................................... 2-1
   INDUSTRY ASPECTS .................................................................................................... 2-1
   TECHNICAL ASPECTS ............................................................................................... 2-7
   OPERATING ECONOMICS .......................................................................................... 2-9
3 COMMERCIAL ASPECTS .............................................................................................. 3-1
   TECHNOLOGY LICENSERS ......................................................................................... 3-1
   CAPACITY SHARE OF GAS-PHASE TECHNOLOGIES ............................................. 3-2
   CAPACITY EXPANSION OPTIONS ............................................................................. 3-7
4 TECHNOLOGY REVIEW .................................................................................................. 4-1
   PATENT REVIEW ....................................................................................................... 4-2
   UCC Patents ................................................................................................................ 4-2
   Exxon Patents ............................................................................................................ 4-2
   BP Chemicals Patents ............................................................................................... 4-7
5 UNIVATION TECHNOLOGIES ....................................................................................... 5-1
   DRY MODE PROCESS ................................................................................................. 5-1
   Process Description .................................................................................................... 5-1
      Section 100—Polymerization .................................................................................. 5-1
      Section 200—Product Finishing and Bagging ....................................................... 5-2
   Process Discussion ...................................................................................................... 5-7
   Catalyst ........................................................................................................................ 5-7
   Heat of Polymerization ............................................................................................... 5-7
   Reactor Design Parameters ....................................................................................... 5-7
   Product Finishing ....................................................................................................... 5-9
   Product Quality .......................................................................................................... 5-9
   Storage and Shipping ................................................................................................. 5-9
   Recycle gas compression .......................................................................................... 5-9
   Cost Estimates ............................................................................................................ 5-9
CONTENTS (Continued)

5 UNIVATION TECHNOLOGIES (Concluded)
CONDENSED MODE ................................................................. 5-18
  Process Description ............................................................. 5-18
    Section 100—Polymerization .............................................. 5-18
    Section 200—Product Finishing and Bagging ......................... 5-18
Process Discussion ............................................................... 5-24
Cost Estimates ........................................................................ 5-24
SUPERCONDENSED MODE .......................................................... 5-33
  Process Description ............................................................. 5-33
  Process Discussion ............................................................. 5-39
  Cost Estimates ....................................................................... 5-39
6 PROCESS ECONOMICS AND CAPACITY EXPANSION .................. 6-1
  CAPACITY EXPANSION ............................................................ 6-1
  ECONOMICS ANALYSIS .......................................................... 6-8
    Grassroots Plants .............................................................. 6-8
  Capacity Expansion Options .................................................. 6-10
7 BP’S INNOVENE® PROCESS ..................................................... 7-1
  PROCESS DESCRIPTION ........................................................... 7-1
    Section 100—Polymerization .............................................. 7-1
    Section 200—Product Finishing and Bagging ......................... 7-3
  PROCESS DISCUSSION ........................................................... 7-11
    Catalyst ............................................................................. 7-11
    Heat of Polymerization ...................................................... 7-11
    Reactor Design Parameters ................................................. 7-11
    Product Finishing ............................................................. 7-11
    Product Quality ................................................................... 7-12
    Storage and Shipping ......................................................... 7-12
  COST ESTIMATES ................................................................... 7-12

APPENDICES
  A PATENT SUMMARY
  B DESIGN AND COST BASES
  C CITED REFERENCES
  D PROCESS FLOW DIAGRAMS
FIGURES

2.1 Gas-Phase Capacity Share of Technologies for LLDPE Production, 2004 ................. 2-2
2.2 Gas-Phase Capacity Share of Technologies for Swing LLDPE/HDPE Production, 2004 ................................................................. 2-2
2.3 Gas-Phase Capacity Share of Technologies for HDPE Production, 2004 ............... 2-3
2.4 Regional Distribution of Gas-Phase PE(?)LLDPE Capacities, 2004 ......................... 2-3
2.5 Regional Capacity Increments, 1998 to 2004 ......................................................... 2-4
2.6 Gas-Phase Polymerization System .......................................................................... 2-7
3.1 Comparison of Regional HDPE Capacities, 1998 and 2004 ...................................... 3-5
3.2 Comparison of Regional LLDPE Capacities, 1998 and 2004 .................................. 3-6
3.3 Comparison of Regional LLDPE/HDPE Swing Capacities, 1998 and 2004 ............. 3-6
3.4 China’s Capacity Share of Asian Gas-Phase PE Supply .......................................... 3-7
4.1 Gas-Phase Polymerization System .......................................................................... 4-1
4.2 Fluidized Bed Operations .......................................................................................... 4-3
4.3 FBD/SBD Plot .......................................................................................................... 4-4
5.1 Gas-Phase Polyethylene Process (Dry Mode) ............................................................ D-3
5.2 Gas-Phase LLDPE Process (Dry Mode) 
   Cooler Load Resulting from the Heat of Polymerization ........................................... 5-8
5.3 Gas-Phase LLDPE Process (Dry Mode) 
   Effect of Ethylene Price on LLDPE Production Costs and Product Value ............... 5-16
5.4 Gas-Phase LLDPE Process (Dry Mode) 
   Effect of Operating Level on LLDPE Production Costs for Different Plant Capacities .................................................................................. 5-17
5.5 Gas-Phase LLDPE Process (Condensed Mode) ......................................................... D-7
5.6 Gas-Phase LLDPE Process (Condensed Mode) 
   Effect of Ethylene Price on LLDPE Production Costs and Product Value ............... 5-31
5.7 Gas-Phase LLDPE Process (Condensed Mode) 
   Effect of Operating Level on LLDPE Production Costs for Different Plant Capacities .................................................................................. 5-32
5.8 Gas-Phase LLDPE Process (Supercondensed Mode) ................................................ D-11
5.9 Gas-Phase LLDPE Process (Supercondensed Mode) 
   Effect of Ethylene Price on LLDPE Production Costs and Product Value ............... 5-46
5.10 Gas-Phase LLDPE Process (Supercondensed Mode) 
    Effect of Operating Level on LLDPE Production Costs for Different Plant Capacities .................................................................................. 5-47
6.1 Investments for a Grassroots Dry Mode LLDPE Plant and for the Three Capacity Increase Cases .............................................................................. 6-11
FIGURES (Concluded)

6.2 Percent Difference in Investment:
Grassroots LLDPE Dry Mode Plant versus the Three Capacity Increase Cases ........... 6-12

7.1 Innovene® Gas-Phase Polyethylene Process (High-Capacity) ................................ D-15

7.2 Innovene® Gas-Phase LLDPE Process (High-Capacity)
Reactor Productivity as a Function of Recycle Gas Cooling Requirements .......... 7-19

7.3 Innovene® Gas-Phase LLDPE Process (High-Capacity)
Effect of Ethylene Price on LLDPE Production Costs and Product Value............ 7-20

7.4 Innovene® Gas-Phase LLDPE Process (High-Capacity)
Effect of Operating Level on LLDPE Production Costs for Different Plant Capacities ................................................................. 7-21
TABLES

2.1 The Economics of Capacity Expansions ................................................................. 2-5
2.2 Typical Process Variables for the Gas-Phase PE (?LLDPE Process: Supercondensed Mode) ................................................................. 2-9
2.3 Operating Economics for Univation Technology ...................................................... 2-10
2.4 Production Costs for Univation Technology ............................................................. 2-11
2.5 Comparison of the Operating Economics of Univation and Innovene Technologies ................................................................. 2-12
3.1 Unipol PE (?LLDPE Licensing ............................................................................... 3-2
3.2 Innovene Licensing .................................................................................................. 3-2
3.3 Global Capacity Distribution, 1998 and 2008. ......................................................... 3-3
3.5 The Economics of Capacity Expansions ................................................................ 3-9
4.1 Reactor Productivity as Function of Process Variables ............................................ 4-6
5.1 Gas-Phase LLDPE Process (Dry Mode) Design Bases and assumptions .............. 5-3
5.2 Gas-Phase LLDPE Process (Dry Mode) Stream Flows ........................................... 5-4
5.3 Gas-Phase LLDPE Process (Dry Mode) Major Equipment ..................................... 5-5
5.4 Gas-Phase LLDPE Process (Dry Mode) Utilities Summary .................................... 5-6
5.5 Gas-Phase LLDPE Process (Dry Mode) Total Capital Investment ....................... 5-11
5.6 Gas-Phase LLDPE Process (Dry Mode) Capital Investment By Section ................ 5-12
5.7 Gas-Phase LLDPE Process (Dry Mode) Production Costs .................................... 5-13
5.8 Gas-Phase LLDPE Process (Condensed Mode) Design Bases and assumptions ...... 5-19
5.9 Gas-Phase LLDPE Process (Condensed Mode) Stream Flows ............................... 5-20
5.10 Gas-Phase LLDPE Process (Condensed Mode) Major Equipment ....................... 5-22
5.11 Gas-Phase LLDPE Process (Condensed Mode) Utilities Summary ....................... 5-23
5.12 Gas-Phase LLDPE Process (Condensed Mode)
Total Capital Investment ................................ ................................ .............................. 5-26

5.13 Gas-Phase LLDPE Process (Condensed Mode)
Capital Investment By Section ................................ ................................ ..................... 5-27

TABLES (Continued)

5.14 Gas-Phase LLDPE Process (Condensed Mode)
Production Costs ................................ ................................ ................................ ......... 5-28

5.15 Gas-Phase LLDPE Process (Supercondensed Mode)
Design Bases and assumptions ................................ ................................ ................... 5-34

5.16 Gas-Phase LLDPE Process (Supercondensed Mode)
Stream Flows ........................................................................................................... 5-35

5.17 Gas-Phase LLDPE Process (Supercondensed Mode)
Major Equipment ..................................................................................................... 5-37

5.18 Gas-Phase LLDPE Process (Supercondensed Mode)
Utilities Summary ..................................................................................................... 5-38

5.19 Gas-Phase LLDPE Process (Supercondensed Mode)
Total Capital Investment .......................................................................................... 5-41

5.20 Gas-Phase LLDPE Process (Supercondensed Mode)
Capital Investment By Section .................................................................................. 5-42

5.21 Gas-Phase LLDPE Process (Supercondensed Mode)
Production Costs ..................................................................................................... 5-43

6.1 Capital Investment for Case 1:
Addition of a Second Dry Mode Equipment Train ................................................. 6-3

6.2 Capital Investment for Case 2:
Supplemental Equipment for the Supercondensed Mode ......................................... 6-4

6.3 Capital Investment for Case 3:
A Larger Extruder, Pelletizer, and Conveying System
for the Supercondensed Mode .................................................................................. 6-4

6.4 Production Costs for the Supercondensed Mode Case 2: Five Operators .......... 6-4

6.5 Production Costs for the Supercondensed Mode Case 3: Four Operators ........ 6-5

6.6 Process Economics for the Three Modes for Grassroots LLDPE Plants
of Different Capacities ................................................................................................. 6-9

6.7 Process Economics for the Three Modes for Grassroots LLDPE Plants
of the Same Capacity ................................................................................................. 6-10

6.8 Overall Comparison of Economics for Expansion of Existing Capacity ............ 6-11

6.9 Comparison of Process Economics for a
Univation™ and Innovene™ Grassroots Plant .......................................................... 6-13

6.10 Production Cost Details: Univation and Innovene® Processes ......................... 6-14

7.1 Innovene® High-Capacity Gas-Phase LLDPE Process
Design Bases and assumptions ................................................................................... 7-4
TABLES (Concluded)

7.2 Innovene® Gas-Phase LLDPE Process (High-Capacity)
    Stream Flows ........................................................................................................ 7-6

7.3 Innovene® Gas-Phase LLDPE Process (High-Capacity)
    Major Equipment .................................................................................................. 7-8

7.4 Innovene® Gas-Phase LLDPE Process (High-Capacity)
    Utilities Summary ................................................................................................ 7-10

7.5 Innovene® Gas-Phase LLDPE Process (High-Capacity)
    Total Capital Investment ....................................................................................... 7-14

7.6 Innovene® Gas-Phase LLDPE Process (High-Capacity)
    Capital Investment By Section ............................................................................. 7-15

7.7 Innovene® Gas-Phase LLDPE Process (High-Capacity)
    Production Costs .................................................................................................. 7-16