PI Techniques

a tool for sustainable debottlenecking of existing industrial plants

G. Cavaglià - Turin, June 2nd 2011
“...If we admit that world survival depends on (1) the capability of achieving economic growth, (2) supplying food and energy resources, while (3) conserving the environment, we must acknowledge that we cannot continue much longer to consume finite reserves of fossil fuels, the use of which contributes to global warming.”

Why PROCESS INTENSIFICATION?

CHEMICAL INDUSTRY today challenges:

- COMPETITIVE CAPEX & OPEX
- SUSTAINABLE PRODUCTION
- INNOVATIVE PRODUCTS
- OPERATION FLEXIBILITY
- QUICK MARKET RESPONSE
- MINIMIZED CARBONFOOT PRINT

PROCESSES NEED IMPROVEMENTS
WHAT IS NEEDED

WHAT TO IMPROVE ON PROCESSES:

- Yield & Selectivity
- Energy consumption
- Product attributes
- Water consumption
- Carbon footprint
- Off-Spec & Wastes
- Reliability
- Costs
- Plant Size
- Operation flexibility
- Control Philosophy
- Safety

“PROCESS INTENSIFICATION” = SOLE AVAILABLE OPTION !!!!
PROJECTS for PROCESS ENGINEERS

- 75% Process re-engineering on existing plants
- 25% New Plants design

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HOW TO START

Look for Front-runners
GETTING STARTED

“…There is always somebody, somewhere that is working and has expertise on the process issues you plan to tackle” (Tseng Yuen Ho)

➢ SEARCH FOR PUBLIC DOMAIN KNOWLEDGE
➢ USE NETWORKS TO ACCESS EXPERTISE
➢ LEARN WHAT OTHER HAVE ALREADY DONE

JUMP QUICKLY TO THE STATE OF THE ART
…AND THEN PROCEED

- SET BUSINESS/ECONOMICAL TARGETS
- SET TECHNICAL TARGETS
- MODEL THE PROCESS
- FILL KNOWLEDGE GAPS
- GENERATION OF ALTERNATIVE PROCESS ROUTES & SOLUTION SELECTION
- IMPLEMENT SOLUTION
PROCESS INTENSIFICATION

A set of often radically innovative principles ("paradigm shift") in process and equipment design, which can bring significant (min. factor 2) benefits in terms of process and chain efficiency, capital and operating expenses, quality, wastes, process safety, etc.

(European Roadmap of Process Intensification, 2007)
PROCESS INTENSIFICATION DOMAINS

4 GENERIC AREAS

STRUCTURE
(SPACIAL DOMAIN)

ENERGY
( THERMODYNAMIC
DOMAIN)

SYNERGY
(FUNCTIONAL
DOMAIN)

TIME
(TEMPORAL
DOMAIN)

Source: Andrzej Stanckiewicz
PROCESS INTENSIFICATION 4 PRINCIPLES

- Maximize the effectiveness of intra-and inter-molecular events
- Give each molecule the same processing experience
- Optimize the driving forces at every scale and maximize the specific areas to which those driving forces apply
- Maximize the synergistic effects from events and partial processes

Source: Andrzej Stanckiewicz
TOOLS OF PROCESS INTENSIFICATION

EXAMPLES:
- spinning-disk reactor
- static mixer reactor
- monolithic reactor
- micromixer
- membrane reactors
- ultrasonic reactors
- static mixer
- compact heat exchanger
- rotating packed bed
- centrifugal adsorber
- reverse-flow reactors
- heat-integrated reactors
- reactive separations
- reactive comminution
- reactive extrusion
- fuel cells
- chromatographic reactors
- membrane adsorption
- membrane distillation
- adsorptive distillation
- centrifugal fields
- ultrasound
- solar energy
- microwaves
- electric and magnetic fields
- plasma technology
- supercritical fluids
- dynamic (periodic) reactor operation
- process synthesis

Source: Frerich J. Kiel
APPLYING PROCESS INTENSIFICATION

- Enlarging search domain for process design
- "Phenomena-based representation" instead of "Unit-Operation-based representation"
APPLYING PROCESS INTENSIFICATION

Removing the physical rate limitations (i.e. mass transfer, heat transfer, mixing, solubility etc.) will accelerate the process to the point where it is limited by chemical reaction rate.
Case Study 1: PET SSP PLANT

SSP = Solid-State Polycondensation
Case Study 1: PET SSP PLANT
- before Process Intensification -

PET Precursor Chips (~0.60 IV)

PET chips
Nitrogen

Precrystallizer (Fluid Bed)

Crystallizers (Rotary)

Polycondensation Reactor (Moving Bed)

Catalytic Nitrogen Purification Unit

Finished PET Resin (0.75 ÷0,84 + IV)

SSP = Solid-State Polycondensation
Case Study 1: PET SSP PLANT
- before Process Intensification -
Case Study 1: PET SSP PLANT
- Limitation before Process Intensification -

PET Chips crystallization needed to have flowability

But crystallization = DIFFUSION-controlling phenomena

Higher Temperature \(\rightarrow\) higher STICKING RISK

Above 600 ÷ 700 tpd the “SWITCH PRESSURE” is such that PET chips flowability is no more acceptable and agglomeration risk is so high to be practically unaffordable.

SSP = Solid-State Polycondensation
Case Study 1: PET SSP PLANT
- After Process Intensification -

Amorphous PET chips

Fluid bed heater

Existing

NPU

Existing

1° inclination - Rotation 0,5 rpm

HCIRR® SSP Reactor

Existing

Fluid bed heater

Solid Stated PET chips

PATENT n. = EP1527119 + family

Sold to M&G Group
Case Study 1: PET SSP PLANT

- After Process Intensification -

It started as a patented IDEA
(EP1527119 + family)

Horizontal Continuous slightly Inclined Rotary Reactor
No chips-chips compaction pressure, no size limitation
perfect plug flow: more than 600 CSTR in series
Case Study 1: PET SSP PLANT
- After Process Intensification -

- HCIRR® SSP Reactor = kiln type reactor
  (PERFECT “PLUG FLOW → each chips same experience → product uniformity

- HCIRR® SSP Reactor ensures "rolling flow regime", no need for strong crystallization → no entrapped amorphous → Diffusion is no longer controlling phenomena → Chemical Kinetic is controlling

- Low bed depth + continuous chips-chips contact renewing, cancels sticking risk → process can be operated at higher temperatures → faster chemical kinetic
Case Study 2: PET SSP PLANT
- after Process Intensification -

- **CAPEX (-50%)**:  
  50% itemized equipment  
  30% building height

- **OPEX (-30%)**:  
  CO$_2$ as inert gas  
  less $\Delta P \rightarrow$ less electric power

- **PRODUCT ATTRIBUTES**:  
  Higher uniformity  
  Less AA  
  100% faster dryability  
  30% lower inj. Molding energy req.

- **SIZES**:  
  1,600 tpd (in operation)  
  2,500 tpd (under design)  
  NO SIZE LIMITATION
Case Study 1: PET SSP PLANT

- REVOLUTIONARY EFFECT of Process Intensification -

**EVOLUTION OF MAXIMUM SIZE X SINGLE LINE SSP**

**batch process**
- Batch SSP

**continuous process**
- Vertical Moving Bed SSP

**HYPERLANE® SSP**
- HCIRRE® 2000pd UNDER DESIGN
- HCIRRE® 1600pd INDUSTRIAL UNIT

**First bottle-grade PET Patent (Du Pont)**

**First HCIRRE® Patent**

**Forecast**

**Real**

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Case Study 2: VOC CATALYTIC OXYDATION ON N₂ CIRCUIT OF 350 tpd PET PLANT - before Process Intensification -

Conventional System

EXHAUST N₂ from SSP Process VOC = 3,000 ppm

240 °C

Economizer

300 °C

Pt/Pd catalyst

360 °C

350 °C

340 °C

Catalytic Reactor

Electric Heater

PURE N₂ VOC < 100 ppm
Case Study 2: VOC CATALYTIC OXIDATION ON N₂ CIRCUIT OF 350 tpd PET PLANT - after Process Intensification -

Reverse flow Reactor

Cycle A

240 °C

Cycle B

Inversion Time 20 minutes

EXHAUST N₂ from SSP Process VOC = 3,000 ppm

5 kW

240 °C

420 °C

PURE N₂ VOC < 100 ppm

Reverse Flow Catalytic Reactor
Case Study 2: VOC CATALYTIC OXYDATION ON N\textsubscript{2} CIRCUIT OF 350 tpd PET PLANT

- after Process Intensification -

- **CAPEX SAVINGS:**
  - No Electrical Heater
  - No Economizer
  - CuO Cat. Vs. Pt/Pd Cat

- **OPEX SAVINGS:**
  - Blower El Power ($\Delta P - 50$ mbar)
  - Electrical Heater Power
  - Catalyst replacement cost

- **TOTAL SAVING:** 150,000 €/y

- **PAYBACK TIME:** < 2 YEARS
“Only economists still put the cart before the horse by claiming that the growing turmoil of mankind can be eliminated if prices are right. The truth is that only if our values are right will prices also be so…”

(Georgescu-Roegen)
Route selection criteria (2)

Top Importance

**Ethyc/Thermodynamic**

- Second Law of Thermodynamics cannot be neglected!!!!
- Several features of thermodynamics—qualitative change, irreversibility, indeterminateness, true scarcity—stand in stark opposition to the mechanical model of the economic process.
- Humankind, so far, is by far the most significant contributor to entropic degradation by the increasing rates of extraction of natural resources and elimination of wastes into the environment.
- **WE MUST ALWAYS COMPLY WITH ENTROPY LAW!!**
QUESTIONS??