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# ADVANCED CONTROL STRATEGIES FOR POLYOLEFIN GAS PHASE PROCESSES

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## Keywords

Polymerization reactor, polyolefin gas phase process, nonlinear inferential estimator, nonlinear model predictive control (NMPC), model predictive control (MPC) cascade

## Abstract

Advanced control strategies have been implemented on various polyolefin gas phase processes including reactor temperature, gas compositions, polymer properties, production rate and bed weight/level controls. The strategies consist of nonlinear inferential estimators to provide estimates of disturbances and quality soft sensors (*VOA*s), nonlinear model predictive controllers (NMPC) to describe nonlinear process dynamic behavior, and MPC which is adopted in a hierarchical structure for staged implementation. Temperature and gas composition (GC) ***Process Perfecter*®*s*** are designed to stabilize the operation and handle highly interactive controlled variables. Quality (QC) ***Process Perfecter*®** is used to manipulate the concentration ratio setpoints of GC ***Process Perfecter*®**, control polymer quality properties, perform automatic grade transition, and maximize prime production. The implementation methodologies and controllers' performance are presented to illustrate the usefulness of these advanced control strategies to industrial polymer manufacturing facilities.

## 1.0 Introduction

Gas phase process technology is one of the dominant polyolefin process technologies in polymer manufacturing. This process technology, consisting of several reactors in series or in parallel, requires minimal investment or operating costs to increase overall throughput across many product ranges. However, due to the complexity of gas phase operations, companies are faced with the following operational challenges:

- High performance temperature control within defined process constraint
- Very long reactor residence time
- Process is highly nonlinear; the process gain of key quality variable MI/MFR to concentration ratio varies significantly
- Process is highly interactive; monomer feed effects concentration ratio, reactor temperature, condensing efficiency, etc.
- Subprocess dynamics vary a few minutes to hundreds of minutes
- Production rate coordination and optimization
- Bed weight/level control for reactor in series operation
- Grade transition control

Because linear model-based predictive controllers (MPC) must change the internal controller models based on resin grades and cannot handle transitions, they result in sub-optimal performance. Thus, nonlinear advanced control strategies have been designed, developed and implemented on these gas phase processes to overcome and address the aforementioned challenges.

This paper describes these control strategies including nonlinear inferential estimators to provide estimates of disturbances based on their dynamics and quality soft sensors (*VOA*s), nonlinear model predictive controllers (NMPC) to describe nonlinear process dynamic behavior, and MPC cascade design which is adopted in a hierarchical structure for staged implementation. The strategies discussed here employ various versions of ***Process Perfecter***®. Temperature and gas composition (GC) ***Process Perfecter*** [1] are designed to stabilize the operation and handle interactive controlled variables (CVs) such as concentration ratios. Quality (QC) ***Process Perfecter*** is used to achieve maximum prime production, perform automatic transition control, and manipulate the concentration ratio setpoints of GC ***Process Perfecter***. The implementation methodologies are discussed in detail in Section 2 and closed-loop ***Process Perfecter*** application performance is presented in Section 3.

## 2.0 NMPC Implementation

### 2.1 Estimator Design

The inferential estimator used in Temperatiure ***Process Perfecter*** provides varying anticipatory control actions based on the dynamics of the disturbances. One of the inferential estimators utilizes an advanced dead-time compensation technique [2] designed to predict the delta change of the controlled variable (*i.e.*, reactor temperature, CV). The second estimates slow drifts associated with the process state.

The purpose of the polymer property estimator is to provide a reliable, real time "pseudo" measurement to the NMPC controller at a much higher frequency than regular lab analyses. Several nonlinear estimators have been developed to provide polymer property predictions such as MI/MFR density, ethylene content, rubber fraction, etc. in order to close the quality control loops. Variable time delays and dynamics plus optimal lab noise filtering techniques have been incorporated in *VOA* feedback mechanism to take advantage of the infrequent lab data and eliminate the bias resulting from unmodelled pieces and/or temporary unknown disturbances. The so-called instantaneous and cumulative properties approach has been adopted [3] and the designed *VOA*s are used to estimate polymer properties at the reactor exit to speed up the NMPC control actions.

### 2.2 Controller Scheme Design

The controller scheme design includes the following:

1) Temperature ***Process Perfecter*** and GC ***Process Perfecter*** aim to meet control requirements against inherent polymerization process constraints and to accomplish control objectives such as steadier reactor operation and coordinated control,
2) QC ***Process Perfecter*** aims to reduce quality variance, maximize production against equipment constraints/problems, perform automatic transition control, and
3) The flexible MPC cascade structure reduces implementation time and provides control flexibility.

Temperature ***Process Perfecter*** has one MV (recycle gas temperature), two estimated (or computed) disturbance variables (CDVs), and one CV (reactor bed temperature). The controller executes on a 15-second interval.

Process constraints due to high performance catalysts, or even some down stream constraints, are included in GC ***Process Perfecter*** design to stabilize not only reactor operations but also the down stream equipment. For some applications, after implementing the GC ***Process Perfecter*** , the well-controlled reactor also stabilized the down stream operations; therefore, no noticeable or identifiable down stream limitations exist. An MPC cascade structure is adopted in a hierarchy, where Quality ***Process Perfecter*** (residing on the upper layer) manipulates setpoints of concentration ratios of the GC ***Process Perfecter*** (residing on the lower layer). This design not only reduces the implementation time for this portion of potential application benefits to be realized, but also provides additional control flexibilities and easier maintenance (through well defined controller scope with smaller controller matrices). The QC ***Process Perfecter's*** built-in product grade historical information makes automatic product grade transition possible.

### 2.3 Staged On-line Commissioning

Inferential and Quality *VOA*s were implemented first, followed by the GC ***Process Perfecter*** and Temperature ***Process Perfecter***. The closed-loop response of the GC ***Process Perfecter*** and "continuous" *VOA* measurements during grade transition periods generate the required step test data for the quality ***Process Perfecter*** (another benefit from the MPC cascade design).

The interconnection between gas phase reactors has been built into the *VOA*s and QC ***Process Perfecter***®*s* to coordinate production rates and desired polymer properties.

## 3.0 Application Performance

### 3.1 Temperature ***Process Perfecter***

Temperature ***Process Perfecter*** was used in a gas phase polyethylene process line to control reactor temperature. Figures 1-2 compare the application, performance and robustness with and without the Temperature ***Process Perfecter*** controller.

During steady-state operation, the Temperature ***Process Perfecter*** controller demonstrated improvement in reducing the variation as compared to a well tuned PID controller (Figure 1). The ethylene feed (represented on the same scale) has been included for comparison.

Controlling transitions between polymer grades is one of the most challenging objectives in polymer manufacturing. For polyethylene gas phase processes, reactor temperatures typically deviate several degrees from target for large grade change transitions. The upper trend in Figure 2 illustrates a small change in grade that resulted in a temperature deviation under the use of cascade PID controllers. The lower trend in Figure 2 reveals that the Temperature ***Process Perfecter*** is able to reject disturbances associated with a large grade transition, while maintaining a tighter reactor temperature control. The composition variable used in the example, the ratio of hydrogen to ethylene (used to execute polymer grade transitions), is included on the trends for comparison.

Temperature ***Process Perfecter's*** ability to reject a catalyst injection rate change of more than 30% was deliberately tested, which helps determine the required balance between performance and robustness of the controller.

### 3.2 GC ***Process Perfecter***

GC ***Process Perfecter*** was used in gas phase polypropylene reactors to control interactive reactant components. Figure 3 compares the performance before and after the GC ***Process Perfecter***® controller.

The stability of reactor operation has been improved immediately after the GC ***Process Perfecter*** implementation; it also eliminated large variations and oscillations observed from the original PID controller caused by the set point change, which was adjusted to eliminate off-spec polymer production.

### 3.3 QC ***Process Perfecter***®

QC ***Process Perfecter*** was used in gas phase polypropylene reactors to control melt flow rate (MFR), production and bed weight. Figure 4 compares the controller performance before and after the QC ***Process Perfecter*** solutions.

When reactors are working in series operation to manufacture specific product types, it is difficult to control bed weight of first reactor. Figure 4 shows typical bed weight control before and after the quality ***Process Perfecter*** implementation.

The Quality ***Process Perfecter***® successfully rejected an upset caused by the loss of a modifier agent. Both timer and catalyst rate worked together to quickly lower the bed weight to its desired set point in response to the catalyst activity change resulting from the loss agent.

The benefits of flexible production rate control include the ability to support control requirements for different product types at manufacturing facility (caused by operational constraints and difficulties resulting from producing resin properties), the capability to respond to market demands, and also temporary downstream equipment limitations and problems. Note that flexible rate control is a key component of production schedule execution, a critical path of production planning and scheduling.

In-grade quality (for example, MFR) control is always important for polymer manufacturing. Polymer properties with less variance can also improve the consistency or resin processability, which ranks highly on customers' requirements and demands. The QC ***Process Perfecter*** has reduced the variations by ~50%.

## 4.0 Summary and Conclusions

Using the rich polymer manufacturer's historical data, together with the capabilities and features of ***Process Perfecter*** control package, the *VOA*s and ***Process Perfecter*** applications were installed using only historical data. Without any step testing, the *VOAs* and ***Process Perfecters*** were put on-line with exceptional performance and robustness. To date the Temperature ***Process Perfecter*** has been successfully maintaining tight control during steady-state operation and rejecting larger disturbances. The GC ***Process Perfecter*** has been stabilizing reactor and down stream operation. The QC ***Process Perfecte*** adds flexibility not only for quicker transitions but also allows large desired production rate changes without disturbing resin properties.

## References

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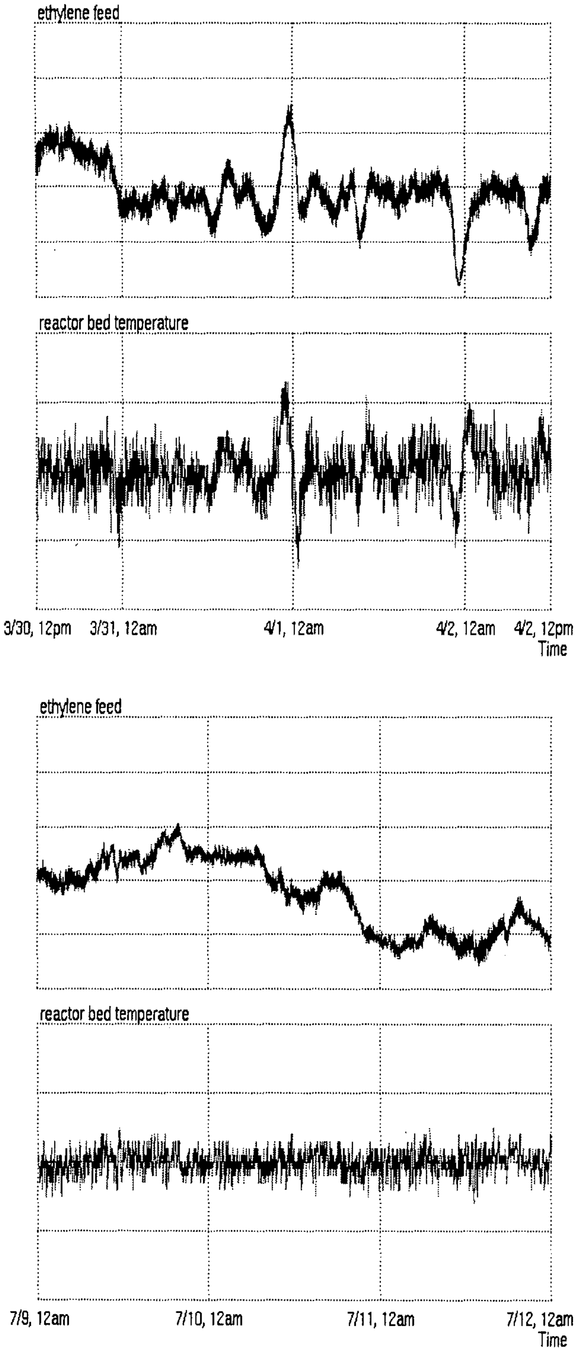

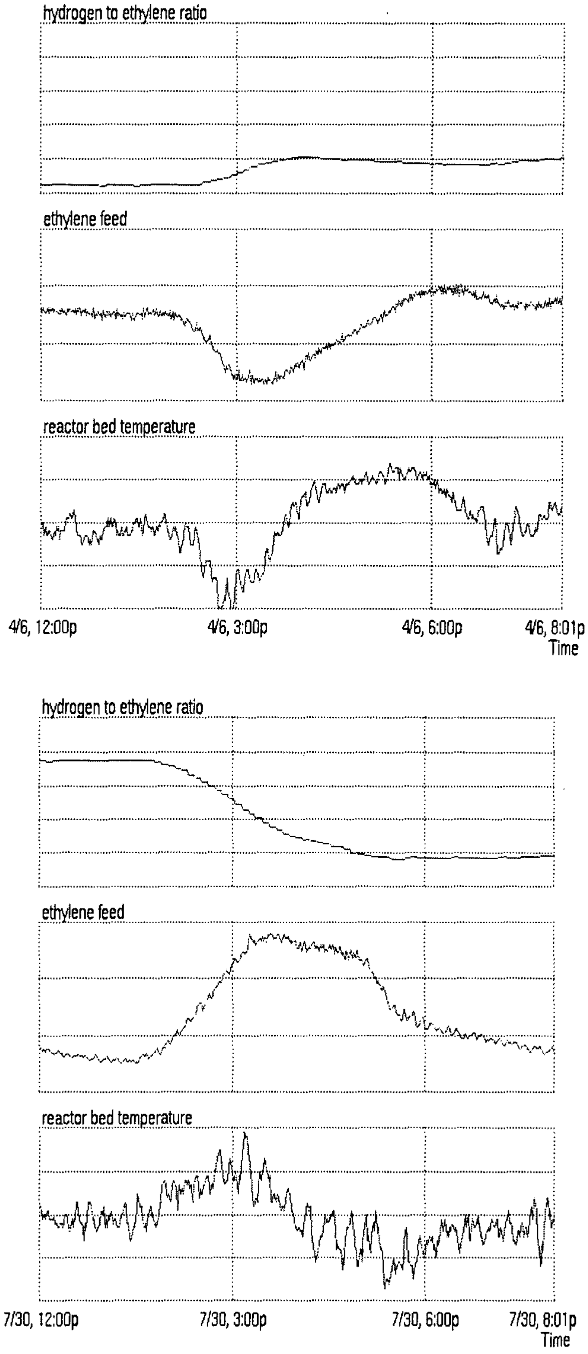

Figure 1 (L). Steady-state variance reduction over three- day period before (above) and after (below) Temperature ***Process Perfecter***® implementation.
Figure 2 (R). Polymer grade transition comparison before (above) and after (below) Temperature ***Process Perfecter***® implementation.

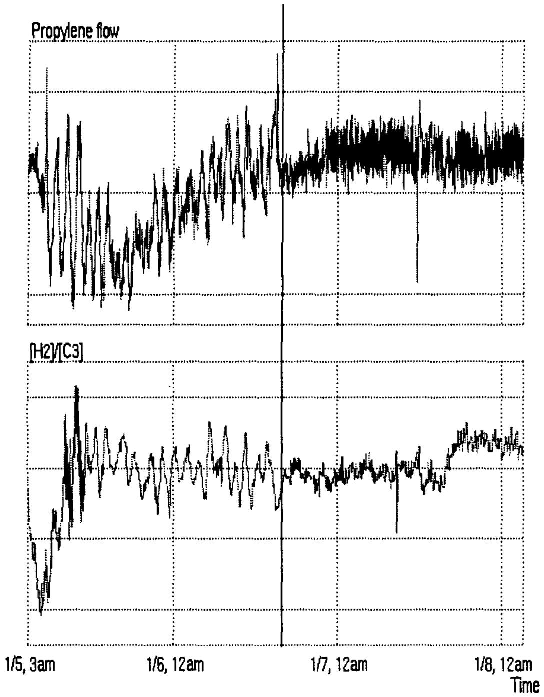

Figure 3. The GC ***Process Perfecter***® stabilized the reactor operation immediately after its implementation (indicated by the marker line).

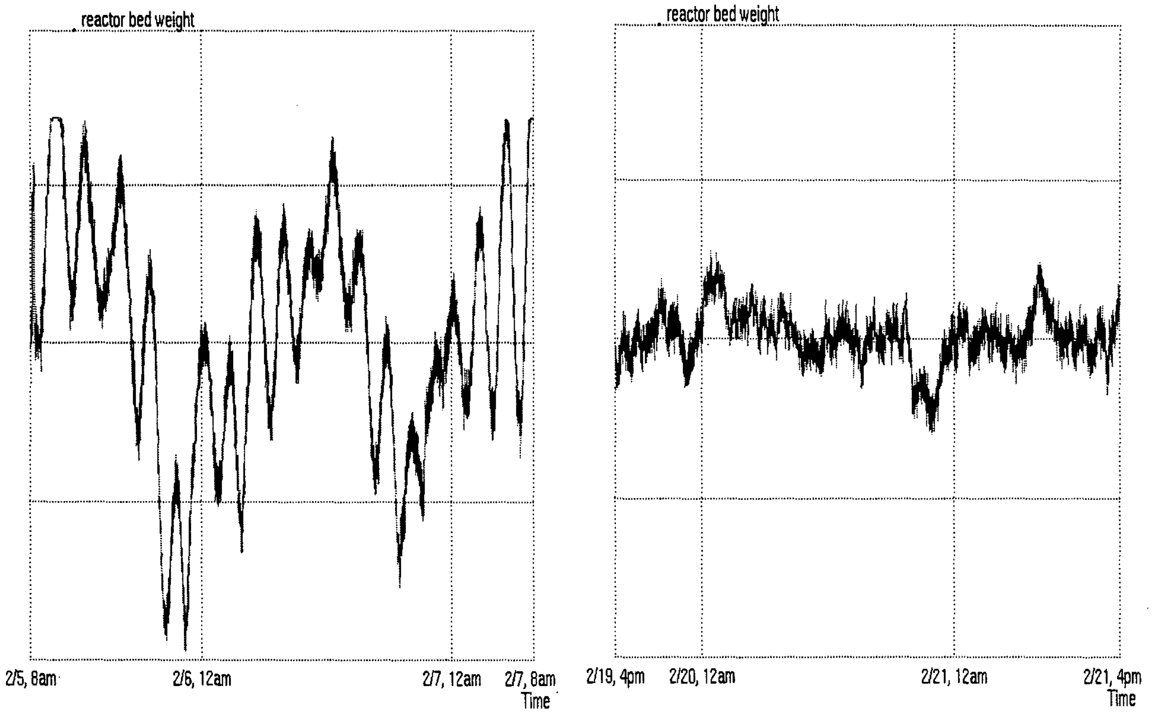

Figure 4. The reactor bed weight control improvement.