APPLYING MODEL PREDICTIVE CONTROL IN A BORSTAR® PILOT PLANT POLYMERIZATION PROCESS

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Abstract

Cost and time efficient plant operations have become more and more important also in pilot plant scale and resources used per product development campaign have to be kept at a competitive level. Model predictive control (MPC) plays an important role in meeting these requirements from process control point of view.

Model predictive control methods have already shown their capabilities in various commercial scale processes, including Borstar® PE and PP plants. The nature of the polymerization processes - non-linearity, constraints in process conditions and equipment, interactions between process variables, transitions from one grade to another, long residence times and several reactors in series - make them difficult to control by traditional methods. Model predictive control includes features that make it possible to handle above conditions efficiently. Additional challenges in the pilot plant environment are naturally the scale of the process and more frequent transitions.

In this paper benefits of model predictive control for the Borstar Pilot Plant polypropylene process have been evaluated. Borstar Pilot Plant is a continuous plant for catalyst, product and process development. The installed MPC controller are based on Borealis' proprietary advanced process control concept, BorAPC, which consists of OnSpot control software - utilizing non-linear state space models - and a thermodynamic calculation package.

1 Introduction

Model predictive control (MPC) has been implemented to the pilot plant scale polypropylene process. The implementation was made to improve product homogeneity and shorten transition times from one grade to another especially in multi-reactor operation. The main target was to implement and commission stabilizing level controllers to the loop reactor and to two gas phase reactors.

MPC control is widely used in various commercial scale processes and has been implemented for polymerization reactors a lot too. However, implementation to pilot plant processes is different due to problems and challenges that are caused by the process scale. The target process was the polypropylene process of the Borstar Pilot Plant in Porvoo, Finland.

The benefits of model predictive control has been found out during last two decades and also in the Borstar Pilot Plant polyethylene production line a transfer function model based MPC has been in use since early 1990's. The nature of the process – several polymerization reactors in series, long residence times and strong interactions between process variables – are typical features, which are very difficult to control with traditional methods, but can be handled by model predictive control. The most used arguments for the investment in MPC are – like in this case – to improve product consistency, to push the plant against its limits and to fasten transitions from one product grade to another /1/. The advanced controls used are based on Borealis' own Borealis Advanced Process Control concept BorAPC, which is widely used in Borealis' polyolefin production plants /2,3/.

2 The process

The Borstar Pilot Plant is an essential part of Borealis' Research and Technology function. The objective for the pilot plant is to make test runs efficiently for product and catalyst development as well as for licensing purposes and process development. The plant has two separate production lines - one for polyethylene and the other for polypropylene. The process in the scope of this paper – the polypropylene production line - consists of a prepolymerizer, a loop reactor, two gas phase reactors and an extruder. MPC applications for the loop and gas phase reactors were implemented. The reactor combination used depends on the product produced. In the case of polypropylene, products can be divided roughly into three main categories: homopolymers, random copolymers and block copolymers. The first two product families are produced by the prepolymerizer, the loop reactor and the first gas phase reactor. For block copolymers one additional gas phase reactor is used to produce rubber part of the product.

The final product quality is a combination of several reactor conditions. The quality is possible to reach only if each of the reactors is controlled properly to reach desired melt flow rate and comonomer content and in addition the proper production rate ratio of the reactors.

Special features and main differences of the pilot plant compared to a commercial scale plant are:

- production rate level and equipment scaling,
- the range of produced product grades is wider,
- variety of catalysts,
- feed level of the components can be rather small and therefore sometimes difficult to measure and control,
- scaling problems due the physical features (particle size is same in both cases)

3 Model Predictive Control and BorAPC - OnSpot

Model predictive control has been implemented more and more during the last ten years, when increase in calculation power has made it possible to install more sophisticated applications also into commercial plants. Nowadays there are also many commercial model predictive controllers available. However, due to fact that the behavior of commercial applications has not been considered very successful in special cases like non-linear processes, there has been space and need for applications developed in-house. This has also been the reason for developing BorAPC – the advanced process control concept for Borstar polymerization processes.

OnSpot is a general model predictive control software in which the models are defined as non-linear state space models /4/. The control algorithm of OnSpot is similar to the other MPC controllers, where a model is used to predict the effect of changes in manipulated variables (MV) into the future. The controller is capable to take into account user defined constraints and disturbances so, that it optimizes the use of MV's to get proper behavior of the controlled variables (CV) /2/.

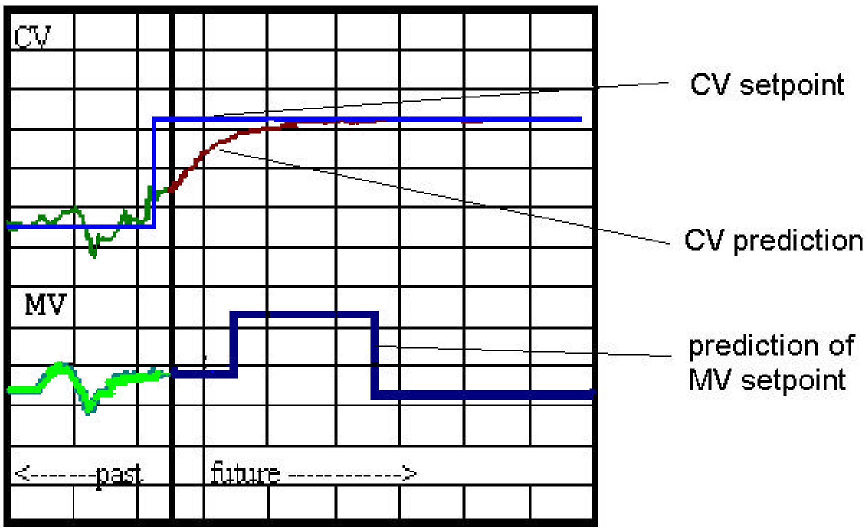

Figure 1 Example of future graph /2/.

OnSpot consists of several modules: controller, model and application specific routines, as well as different kind of system, calculation, interface and database routines. In OnSpot a model based on catalyst activity profile is used. The model includes factors like the polymerization rate of propylene and comonomer and the termination rate of hydrogen. The rate factors are updated by process measurements to keep the model up to date. The controller itself is implemented in a process computer, while operations like setpoint changes and control on/off selections are made via DCS displays.

In installation of OnSpot, the predicted values for CV's and MV's are shown to the operators via future graphs (figure 1.) From these pictures the operator can see, what kind of control actions the program has calculated to achieve desired setpoint for the CV.

4 Process Control

In order to achieve the right properties for polypropylene products, there are many variables to control. The main control variables affecting to the quality of polypropylene are: the reactor pressure and temperature, the residence time in each reactor, the average molecular weight (measured by melt flow rate - MFR), the ethylene content of the product and isotacticity. These variables are defined separately for each reactor. The molecular weight distribution of bimodal product is adjusted by the ratio of production rate between reactors.

In BorAPC model predictive control applications there are normally two different control levels defined:

1) Stabilizing control level, in which control variable like hydrogen/propylene molar ratio adjusts setpoint of manipulated variable – in this case hydrogen feed. This control level is used to stabilize process conditions and thereby make production and product more consistent.

2) Quality control level, in which quality factor like melt flow rate controls directly manipulated variable to meet final product properties.

Due to the nature and the way to operate the plant, it was decided to install stabilizing level controllers for hydrogen/propylene and ethylene/propylene molar ratios. For the gas phase reactors also production rate was selected as a control variable to enable easier production rate ratio control between reactors. In commercial scale plants a separate quality control level has been installed to control product final properties like comonomer content and melt flow rate /2,3/.

5 Experiences

In the project stabilizing level MPC controls for the loop reactor and two gas phase reactors were implemented and experiences have been very good. In figures 2 and 3 the results of hydrogen and propylene molar ratio as well as ethylene and propylene molar ratio control in 1st gas phase reactor are shown.

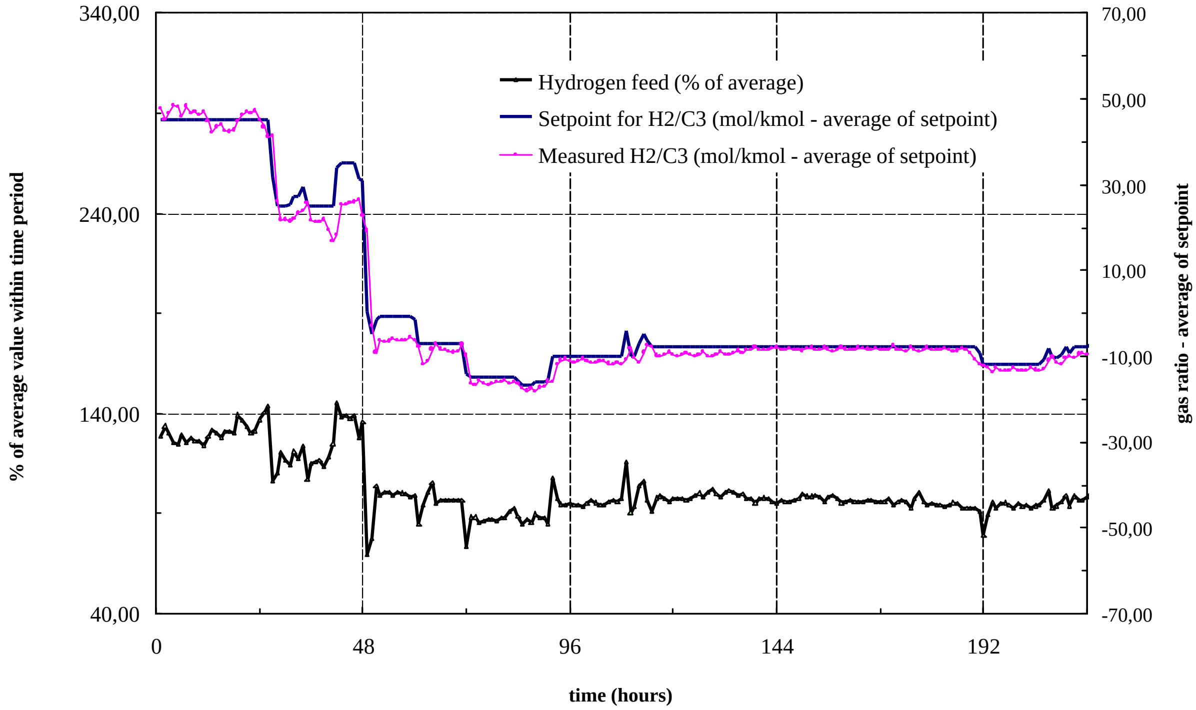

Figure 2 Control of hydrogen and propylene molar ratio in the first gas phase reactor.

In figure 2 the control of molar ratio of hydrogen and propylene using hydrogen feed as a manipulated variable is shown for a period of nine days. As can be seen, analyzed molar ratio of hydrogen and propylene follows changes of the setpoint well. During some short periods of time there exists deviations between the measurement and the setpoint. These deviations are consequences of internal inconsistencies between measurements used for the model updating. Despite of deviations it has been possible to use controller by increasing setpoint to get measurement to desired value. During the whole period the controller behavior is relatively good despite of other changes in the process.

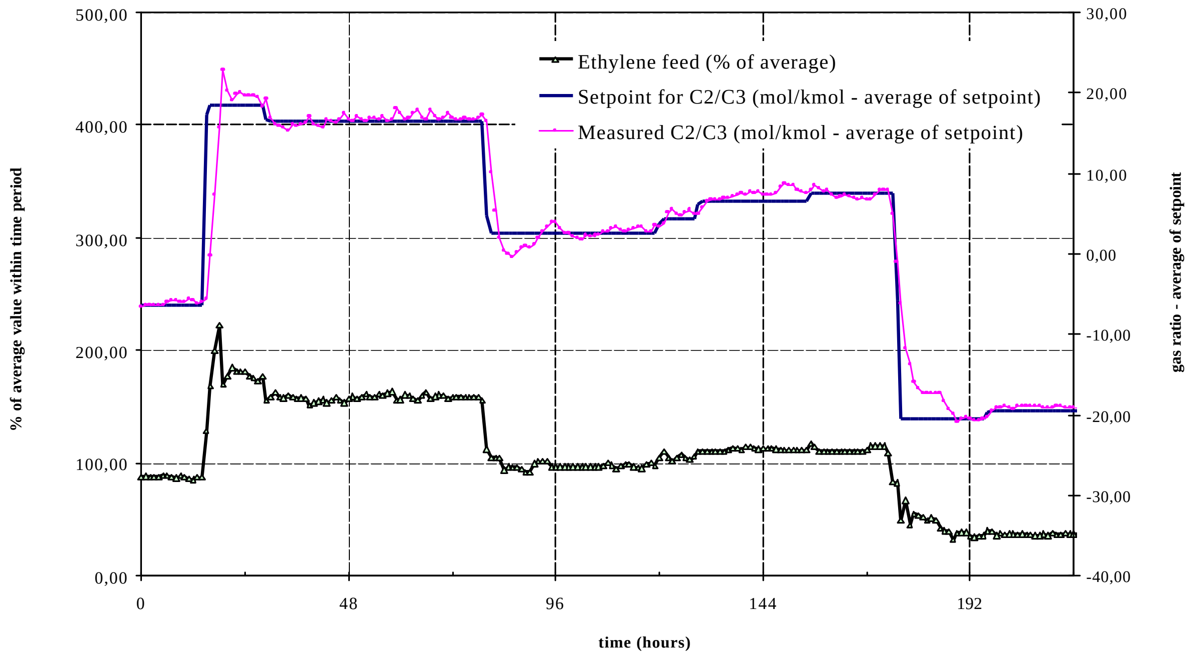

Figure 3 Control of ethylene and propylene molar ratio in the first gas phase reactor.

In figure 3 another nine-day period is shown. During this period the molar ratio of ethylene and propylene is controlled. Controller behavior is relatively good despite of overshoot, which effect is minor in the case of 1st gas phase reactor.

6 Conclusions

The main target of the project – to implement stabilizing level controls to enable more stable and consistent operation – was reached. The controllers have been able to keep hydrogen/propylene and ethylene/propylene molar ratios close to the setpoint despite of changes in the process variables. The controllers have worked also well in the case of higher and smaller setpoint and can thereby be used both for grade quality control and grade change purposes. The experiences in MPC control of the loop reactor and the second gas phase reactor are congruent with the results of the first gas phase reactor. The implementation will continue by commissioning controls for the ratio of production rates.

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