IMPACT OF CONTROL SYSTEM IMPROVEMENTS WITHIN AN ETHYLBENZENE & STYRENE MONOMER PLANT

Dong Eon Lee[a], Donald L. Snowden[b], Stephen G. Finlayson[c]

[a] Samsung Total Chemicals
Manager – Production & Technology Solution Team

[b] Senior Consultant, Applied Manufacturing Technologies
Houston, Texas

[c] Senior Vice-President, Applied Manufacturing Technologies
Houston, Texas

Corresponding Author's E-mail: deon.lee@samsung.com

ABSTRACT

In 2007, Samsung Total Petrochemical Company began a "Controls Improvement Initiative" to improve the performance of their Ethyl-Benzene and Styrene Monomer complex at the Daesan Chemical Works. The aim of the process controls improvement initiative was to upgrade the plant control systems from its simple regulatory control to state-of-the-art model predictive control using commercially available technology.

This paper will discuss several of the key regulatory control improvements, outline the MPC control system design, show the inferential product quality predictor performance as well as document the energy reduction results. The time line for the project and key project steps will also be discussed.

Keywords: Process Control; Multivariable; Optimization; APC; MPC; Dynamic Matrix

1. BACKGROUND

The original design of the Ethyl-Benzene & Styrene Monomer plants consisted of two parallel ethyl-benzene units and two parallel styrene monomer units. The plants operated independently with crossover lines that allowed Samsung to take advantage of differences in capacities of the parallel units. As part of the expansion project, Samsung Total Chemicals re-engineered the two parallel Ethyl-Benzene purification units as well as the #2 Styrene Monomer unit. Modifications to the Ethyl-Benzene unit consisted of switching to liquid-phase reaction process technology and upgrading their #1 and #2 EB purification units. The re-engineering effectively combined to the two EB units into a single unit with a highly integrated but parallel product separation section.

The re-engineering of the #2 Styrene Monomer unit consisted of replacing the EB recycle column with a 2-stage multi-effect distillation column. Additional improvements were made in the process line-up of the separation section of the #2 SM unit. The net result was an increase in plant capacity as well as improvements to the overall energy efficiency of the separation process.

In 2007, after the start-up of the re-engineered EB/SM unit, Samsung undertook an effort to improve the operation performance and efficiency of this plant through a "controls improvement initiative". This initiative was broken into to two major phases: first a regulatory controls improvement phase followed by a model predictive control implementation phase. The regulatory control improvement phase began very shortly after the start-up of the re-engineered plant.

Shortly after completing phase I, a MPC project was undertaken to install model predictive control above the regulatory control system to further improve the operation of the unit. The scope of the MPC project included the development of inferential product quality measurements along with the implementation of plant-wide model predictive controls across both the integrated ethyl-benzene unit and the #2 styrene monomer unit.

2. REGULATORY CONTROLS IMPROVEMENT

Ethyl-benzene units are highly heat integrated making it important for the regulatory control system to provide a stable and robust platform for operations to run the unit both during normal operation and, more importantly, during load transitions. Integration of the #1 and #2 ethyl-benzene units had created a complex plant flow-sheet with significant heat and material balance integration. The end result was that is was difficult to operate the unit efficiently during significant plant disturbances and load changes.

Stabilizing the heat and material balance included a careful review of the plant operational performance followed by analysis of the basic regulatory system. The objective of this analysis was to develop a clear understanding of the impacts of the heat and material balance integration, identify those areas where the performance was less than desired and develop a strategy for improving plant performance. Once the review was completed several key areas were re-engineered to provide a more stable control system. This restructuring included making changes such as;

1. Switching several columns to material balance cutpoint control rather than heat balance based cutpoint controls. Columns where most of the material is vaporized and leaves the top of the column can be better controlled with a material balance approach for cut point control, using the column energy balance to maintain vaporization and keep the column in material balance.

2. Installing temperature measurements for control of column compositions that were previously controlled directly by operator adjustment of reflux.

3. Pressure compensating control temperatures in columns where the most efficient operation was to let the pressure float. This is extremely important for higher purity distillation columns.

4. The use of feedforward ratio control loops to insure that the fraction of material taken in overhead in several columns was enforced continuously. This allowed the operator to make fewer moves to control the slow responding compositions in the SM unit.

All of the key control loops (over 100) were retuned as necessary, and the plant was load tested to insure that the control system was performing adequately. This step provided immediate benefits to SamsungTotal's EB/SM operations group as it provided an improved basic controls system with which to run the plant.

3. MPC IMPLEMENTATION

With this first step completed, the initiative moved to the MPC implementation phase. The objectives of this phase of the control improvement initiative were as follows:

EB Unit

- Control the plant at optimum Benzene/Ethylene (B/E) ratios and drive column product compositions within their respective specification limits.
- Minimize energy consumption by running closer to the key product specification limits.
- Improved plant stability during normal operation & provide robustness to handle disturbances
- Economic flexibility – provide the ability to switch operating modes as the relative value of steam and fuel changes.

SM#2 Unit

- EB Conversion control while honoring all furnace, reactor, and exchanger constraints
- Improve the operational stability of the unit during disturbances and load changes
- Minimize energy consumption by running closer to key product specification limits

4. SCOPE OF MPC APPLICATION

AspenTech's DMCplus multivariable control software was used for the model predictive control technology. The MPC scope for the EB unit included the alkylation reactors, trans-alkylation reactors and the parallel separation trains. The SM application included the reactors, heaters, feed exchangers, and the styrene purification section. The Tables (1-3) below give the reader an idea of the scope of the EB & SM model-predictive controllers.

Table 1: EB Unit Controller Overview

Sub-Controller's	Equipment	MV's	CV's	FFWD's
RXS	1. Reactor Guard Bed 2. Alkylation RX 3. Trans-Alkylation RX	12	30	1
EB1	1. BZ Pre-Frac 2. Furnace 3. BZ Recovery Column 4. EB Recovery Column	10	17	
EB2	1. BZ Recovery Column 2. Furnace 4. EB Recovery Column	7	9	
DA2106	PEB Recovery Column	4	6	
Total		**33**	**62**	

Table 2: SM2RX Controller Overview

Sub-Controller's	Equipment	MV's	CV's	FFWD's
	1. DC01A: Styrene Reactor 2. DC01B: Styrene Reactor 3. DC01C: Styrene Reactor 4. Furnace (01A Temp Control) 5. Furnace (01B Temp Control) 6. Furnace (01C Temp Control)	8	20	3
Total		**8**	**20**	**3**

Table 3: SM2 Distillation Controller Overview

Sub-Controller's	Equipment	MV's	CV's	FFWD's
EBRECC	1. HP Recycle Column 2. LP Recycle Column	6	6	5
DA01	BZ/TL Column	3	6	
Total		**9**	**12**	**5**

5. INFERENTIAL PRODUCT QUALITY PREDICTIONS

The ethyl-benzene plant and the styrene monomer plant have a number of important product quality constraints that are measured by laboratory analysis only. In order to develop an adequate MPC control system that could drive compositions to their respective purity limits, real-time inferential product quality predictor measurements are needed. Additionally, the styrene monomer reaction is operated to achieve a ethyl-benzene conversion target that is not measured in real time. In order to control & optimize the SM reactor section, a real-time measurement of conversion was necessary.

5.1 EB Unit Inferentials

The EB unit has only a few analyzers to provide real-time measurements of the important product properties. Fig. 1 shows a simplified process flow of Samsung's EB unit. Also shown on Fig. 1 is the location and composition estimated for each of the inferentials developed for the EB unit. Only the benzene in the EB product has an on-line GC type analyzer (inferential # 3 and 7). The other product properties rely on lab data taken once per day. During the inferential property develop phase of the work, the sample frequency was increased (3/day) to generate additional lab data to develop high quality inferentials. Real-time plant data was used along with the lab data to develop correlations that accurately predict key product composition. The plant was intentionally moved to different operating points in order to obtain a rich enough data set to develop quality inferentials.

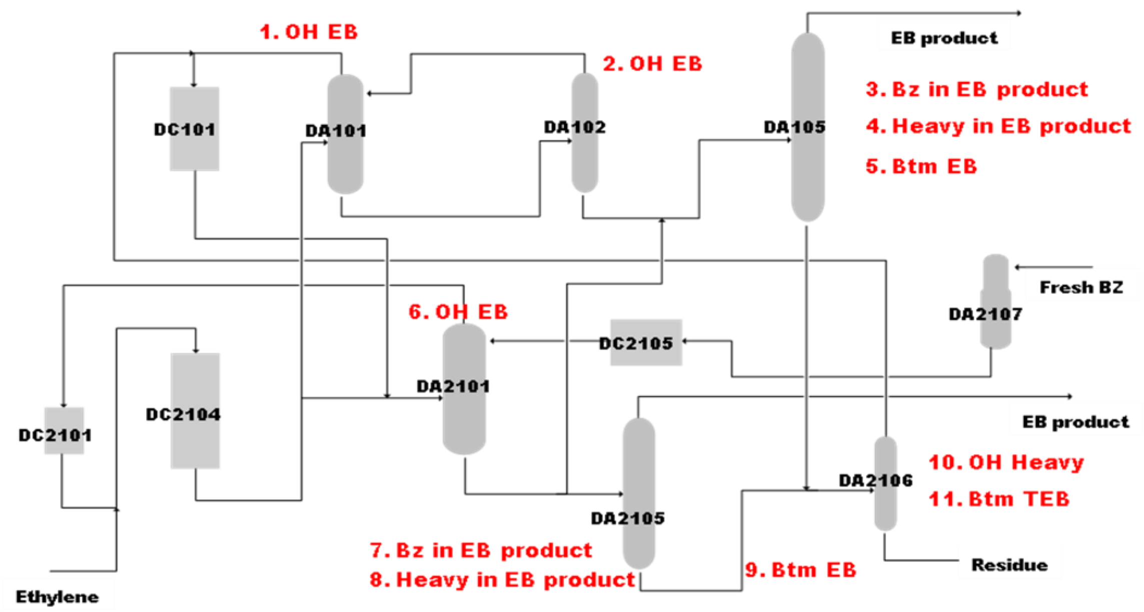

Figure 1: EB Process Flow & Unit Inferentials

The performance of these inferentials was for the most part better than expected. The quality of the predictors was good enough to not require online lab updating. Instead the location staff can simply adjust a "bias term" to better match the lab if the inferential shows a sustained shift from the lab results. The follows figures (Fig. 1-4) demonstrate the match between the lab and the on-line inferential for several of the critical inferentials that were developed for the MPC application on the EB unit.

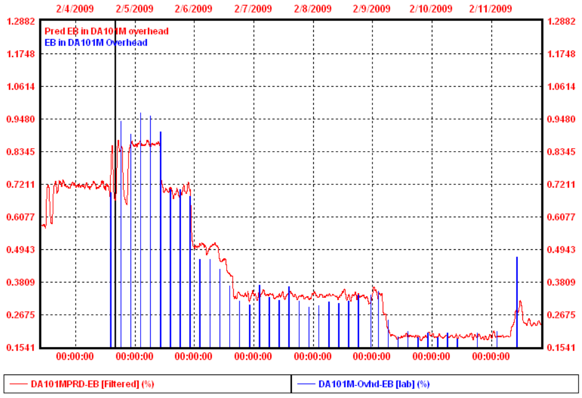

Figure 2: EB in DA101 OH

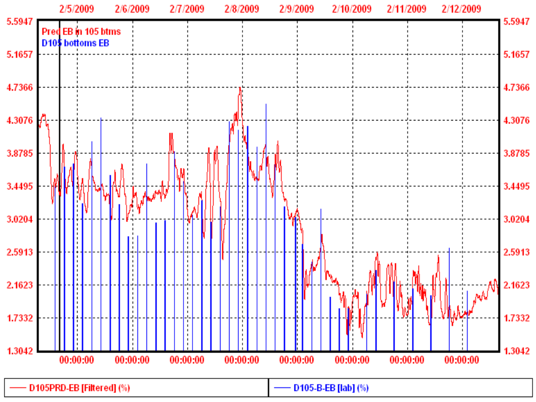

Figure 4: EB in DA105 Bottoms

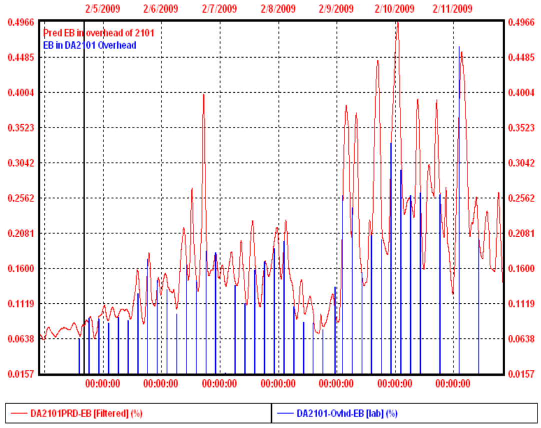

Figure 3: EB in DA2101 OH

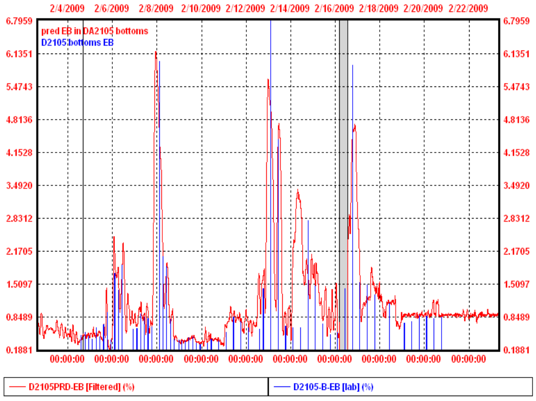

Figure 5: EB in DA2105 Bottoms

5.2 SM Unit Inferentials

Since the SM unit has several on-line analyzers, the effort to develop inferentials (against Lab data) was significantly less extensive than in the EB unit. The Figure (Fig. 6) below shows the SM Unit process flow along with the location and composition type for each of the developed inferentials.

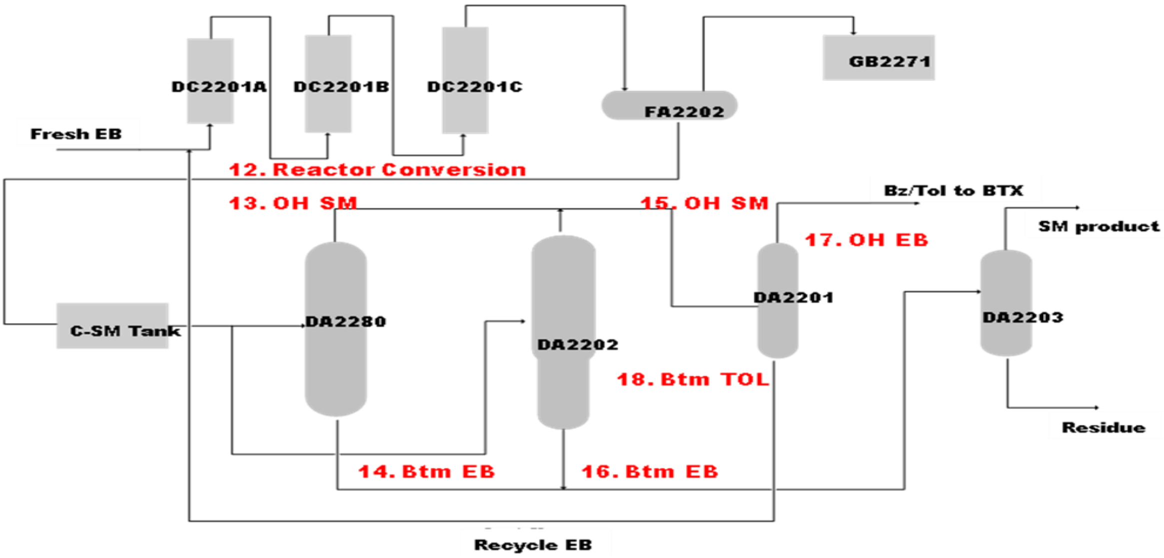

Figure 6: #2 SM Unit Simplified Process Flow

Once again, no online lab updating was required. If a noticeable bias is present, the operations technical team can adjust the bias as necessary to match lab results. For predictors that have online analysis, the online predictors are dynamically updated to match the online analyzers.

The EB concentration in the final SM product depends on the operation of both multi-effect columns. Since these columns can be operated somewhat independently the EB concentration in the bottom of both columns was needed to develop the MPC model and develop the necessary detail in the MPC model to allow the MPC application to optimize the two columns. During the MPC implementation phase, additional analyzers were installed around the multi-effect recycle columns to insure that each column could be modeled independently. The response of EB to changes in the column operation was found to be extremely slow (greater than 24 hours). Inferential property predictors were developed for each of the column bottoms EB concentration in order to shorten the controller overall response time. The plots in figures Fig. 7 through Fig. 10 show the inferential product predictors without any analyzer updating. In the online implementation, the inferential properties are dynamically updated to match the on-line analyzers.

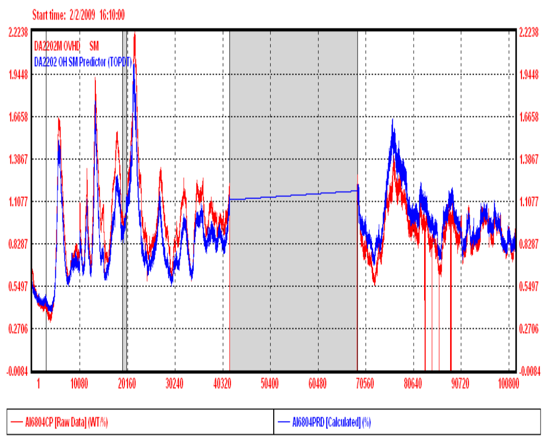

Figure 7: EB Recycle - Overhead SM

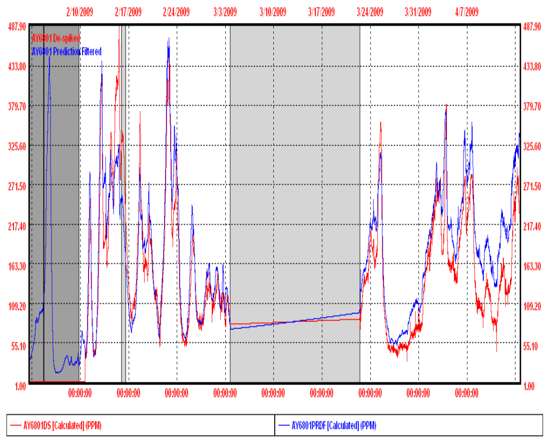

Figure 8: EB Recycle - Bottoms EB

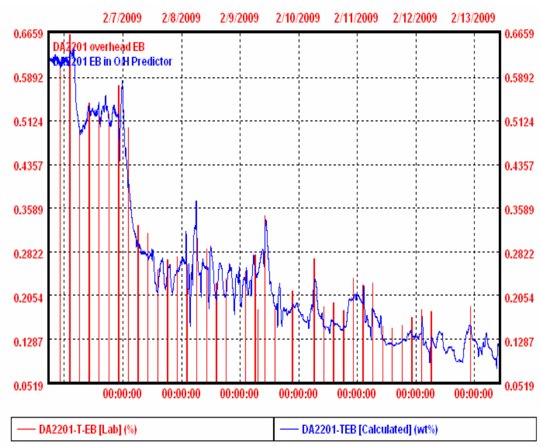

Figure 9: DA2201 Overhead EB

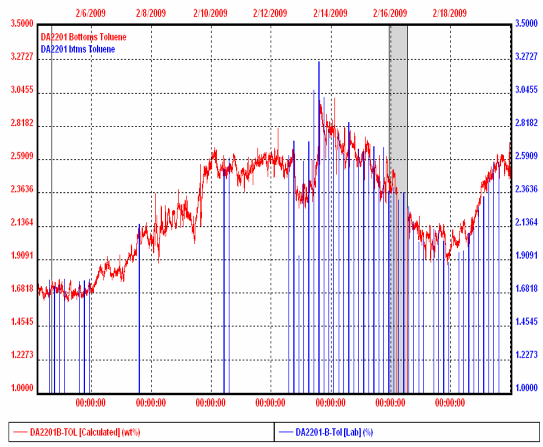

Figure 10: DA2201 Bottoms Toluene

As mentioned previously, a critical piece to controlling the SM unit is the EB conversion in the SM reactors. Changes in feedrate without proper adjustment in reactor conditions will create shifts in conversion and will significantly affect downstream control in the EB recycle column. A proprietary EB conversion calculation was developed that includes the effects of space velocity (e.g. feedrate), reactor pressure & temperatures and steam/hydrocarbon ratios. The EB Conversion calculation includes a deactivation correction based on the accumulated EB feedrate over the course of the run. The figure (Fig. 11) below shows how the uncorrected EB conversion prediction compares to actual lab data over a 13 month period.

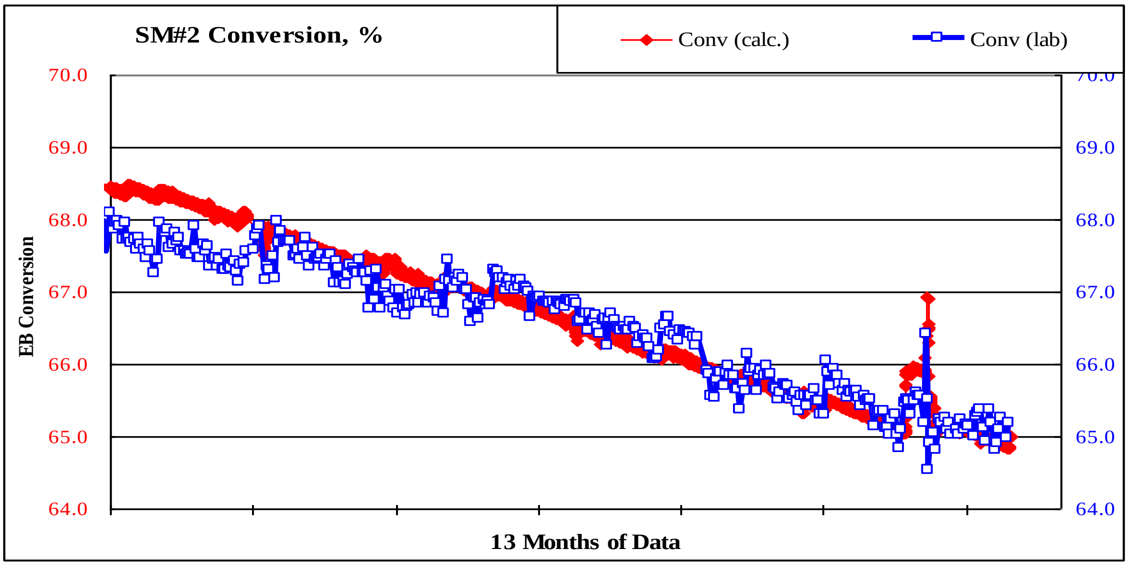

Figure 11: SM2 Ethylbenzene Conversion (Uncorrected Prediction vs Lab)

6 MPC IMPLEMENTATION

In 2009, the EB & SM plant MPC applications were commissioned over the course of four weeks. Commissioning was done in several phases. Initially, the project team provided 24-hour coverage to monitor the performance of the controller and make any necessary adjustments to the application(s). Once the MPC team and Operations gained confidence in the performance of the applications, coverage was reduced to “extended” days only.

The immediate impact seen from the commissioning was that Operations had now been provided with a “tool” to help them run the plant more effectively & efficiently. Definitive results are discussed in subsequent sections.

6.1 EB Unit Controller Performance

After commissioning, the SamsungTotal technical team evaluated the performance of the two MPC applications in detail. Due to the efficient design of this process, it was initially believed by both the application development team and SamsungTotal staff that potential energy reductions would be significantly lower than other less-efficient processes. However the post commissioning analysis showed that significant energy reduction benefits were achieved. The Figures (Fig 12-15) below show key parameters before and after the MPC implementation.

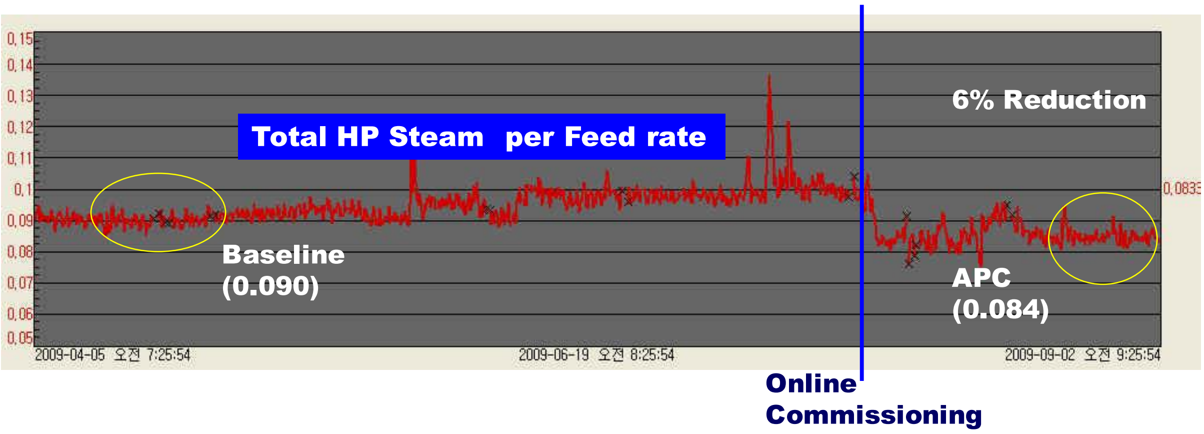

Figure 12: EB Recovery Columns, DA2105 and DA105 HP Steam Reduction

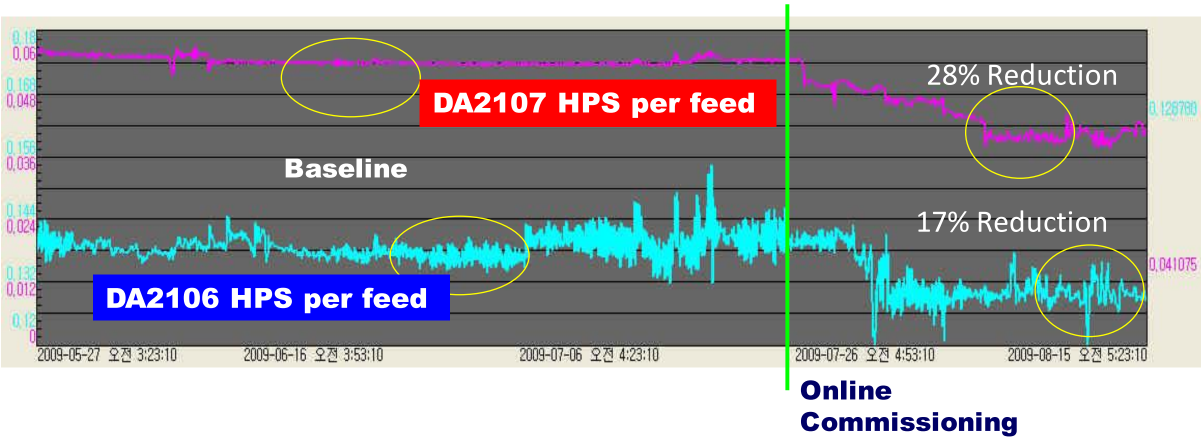

Figure 13: PEB and BZ Stabilizer Steam Reduction (DA2106 & 2107) HP Steam Reduction

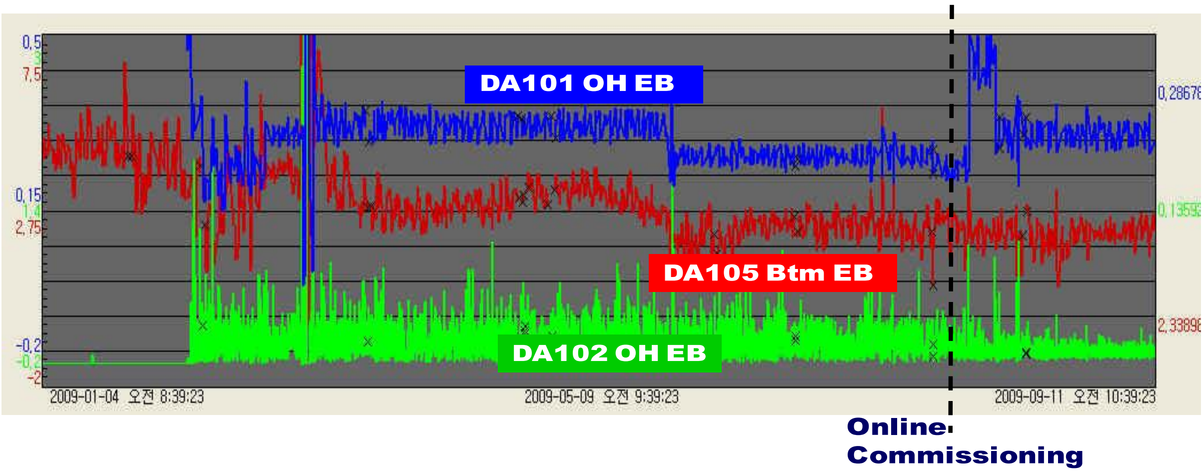

Figure 14: Key EB compositions in distillation section

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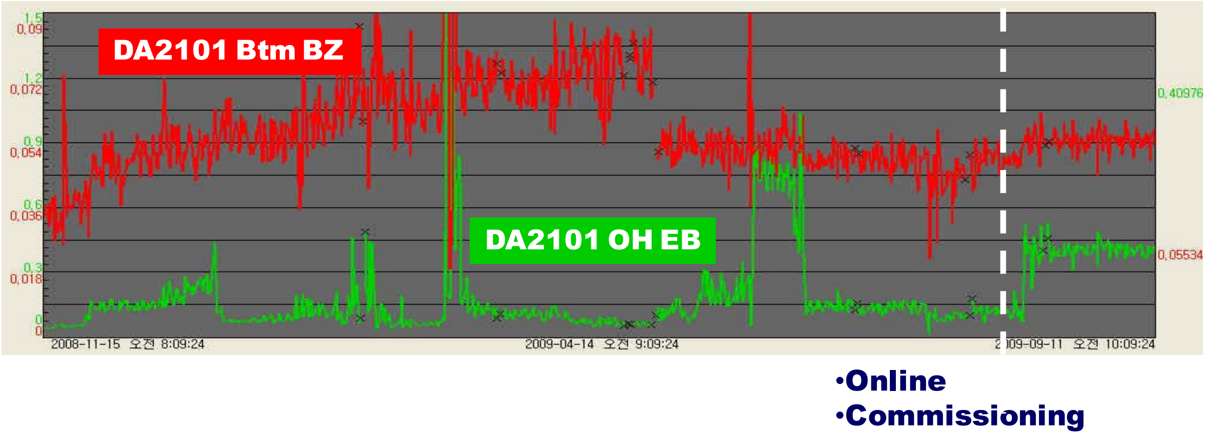

Figure 15: DA2101 composition control.

6.2 Performance Summary – EB Unit

- HPS steam reduction of 2.5 ton/hr
- The controller can be used to adjust plant load while holding all key product qualities on target.
- The ability to switch between minimum steam mode and minimum fuel mode.

6.3 SM Unit performance:

There were two major factors in the success of the SM unit controls. First the reactor conversion calculation that was developed provided a very good estimate of the conversion and was used to provide a real-time conversion measurement. Having this accurate estimate of conversion allowed the controller to manage the reactor operation while still maintaining conversion on target. The controller was able to reduce the IPS consumption in the reaction section. The second factor that enhanced the performance of the MPC application was accurately modeling the long response of the EB recycle columns coupled with having an online EB analysis on the bottom stream of each column. The Figures (Fig 16-17) below show key parameters before and after the MPC implementation.

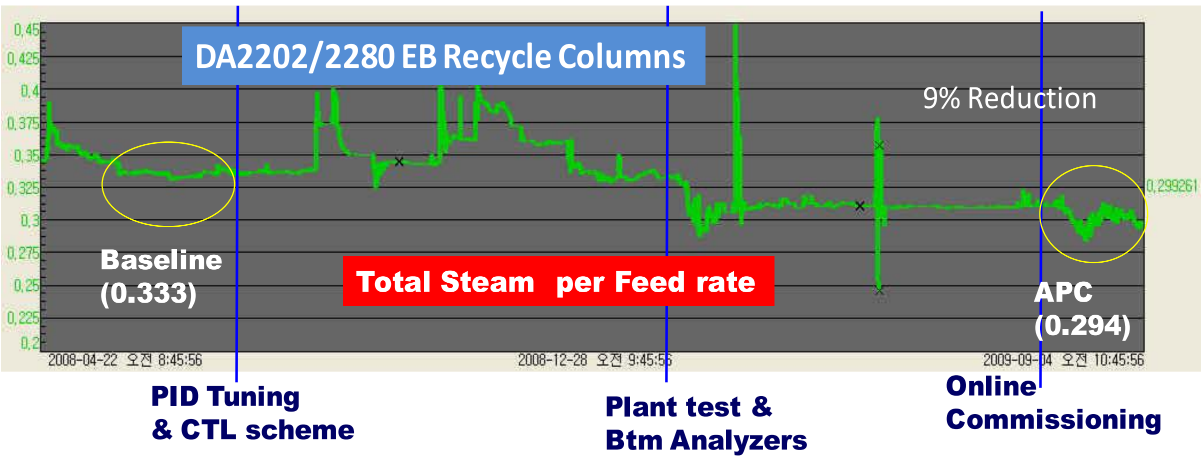

Figure 16: HPS Steam Usage in the EB Recycle Columns (DA2202/2280)

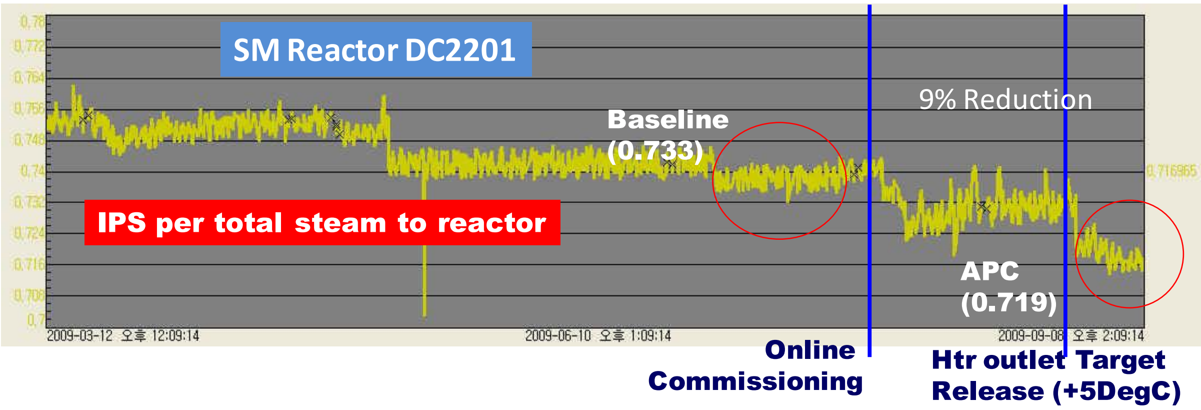

Figure 17: IP Steam Usage in the #2 SM Unit Reaction Section

6.4 Performance Summary

- The MPC can be used to adjust plant load while holding all key product qualities on target.
- Reduced the HPS steam to EB recycle column by 4.9 ton/hr
- Reduced the LP steam to Finishing column by 1.3 ton/hr
- Reduced the SM reactor dilution steam by 1.9 ton/hr

7 CONCLUSION

In mid 2009, the project team commissioned the MPC controllers. Initial results showed the product quality control to be extremely good, but more importantly the energy saving were in the range of 2MM$ per year. The significant energy savings insured a simple payback time of less than 6 months and exceeded the original expectations for the project. The inferentials have continued to perform well and only require an occasional bias adjustment based on the plant laboratory results. In addition to these very quantifiable energy benefits, the control system improvements (from basic regulatory control to MPC) have made day-to-day operation of these two plants much easier. The number of operator adjustments for a typical load change has dropped by an order of magnitude.

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Brief Biography of Presenter

Dr. D.E. Lee is a received is PhD in Chemical Engineering from Seoul National University. Dr Lee joined Samsung Total Chemicals working in their Daesan chemical complex. At the Daesan site Dr. Lee first joined the technical team working across the site on several high profile initiatives including the application of multivariable control and real time optimization application. In this technical area Dr. Lee was Samsung's lead engineer for the project(s) to apply DMCplus technology to the aromatics plant, olefins plant and finally the ethyl-benzene plant. Dr Lee was a key member of the project teams that completed this work and was also the critical resource in maintaining the high level of performance that Samsung Total has enjoyed since their commissioning. Dr. Lee is now a member of the aromatics plant operations team supporting the day to day operation of the aromatics plant.

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