Real Time Optimisation of ULSD Production

Francisco Arista, CEPSA, Huelva, Spain, francisco.arista@huelva.cepsa.es
Andres Porcel, CEPSA, Huelva, Spain, andres.porcel@huelva.cepsa.es
Pedro Villar, CEPSA, Huelva, Spain, pedro.villar@huelva.cepsa.es
&
Henrik Terndrup, TCA, Bergen, The Netherlands, henrik.terndrup@tcatech.com
Marco Smaling, TCA, Bergen, The Netherlands, marco.smaling@tcatech.com

Abstract

This paper discusses the experience with real time optimisation of the production of Ultra Low Sulphur Diesel (ULSD) at CEPSA's Huelva La Rabida refinery.

The La Rabida refinery is a fairly complex site including conversion units (Visbreaking and FCC), lubes, asphalt and petrochemicals. ULSD is produced in a dedicated hydrotreating unit receiving feeds from the crude unit, two vacuum towers, the visbreaker and the FCC unit. Depending on the mode of operation, a gasoil or off-road diesel grade is produced in parallel with the ULSD grade.

The optimiser implemented at the La Rabida refinery currently covers the following areas

- crude unit
- vacuum unit
- the distribution of components between the ULSD hydrotreater and the gasoil production line
- the ULSD hydrotreater
- kerosene bender unit
- two sulphur plants

The key objective of the real time optimisation system is to maximise the production of ULSD. This is a constrained blending optimisation problem, where the production rate is maximised subject to a variety of constraints, e.g.

- ULSD and gasoil product qualities
- component availability (most components are fed directly from the process units)
- crude column capacity and other crude unit constraints
- reactor temperatures and other hydrotreater constraints
- hydrogen availability
- sulphur plant capacity
- hydraulic constraints

The solution to this problem requires a combination of the typical functionalities of blending, multivariable control and large-scale real time optimisation software. The paper describes how these functionalities are integrated as well as some novel techniques used for the modelling and optimisation of this relatively complex system.

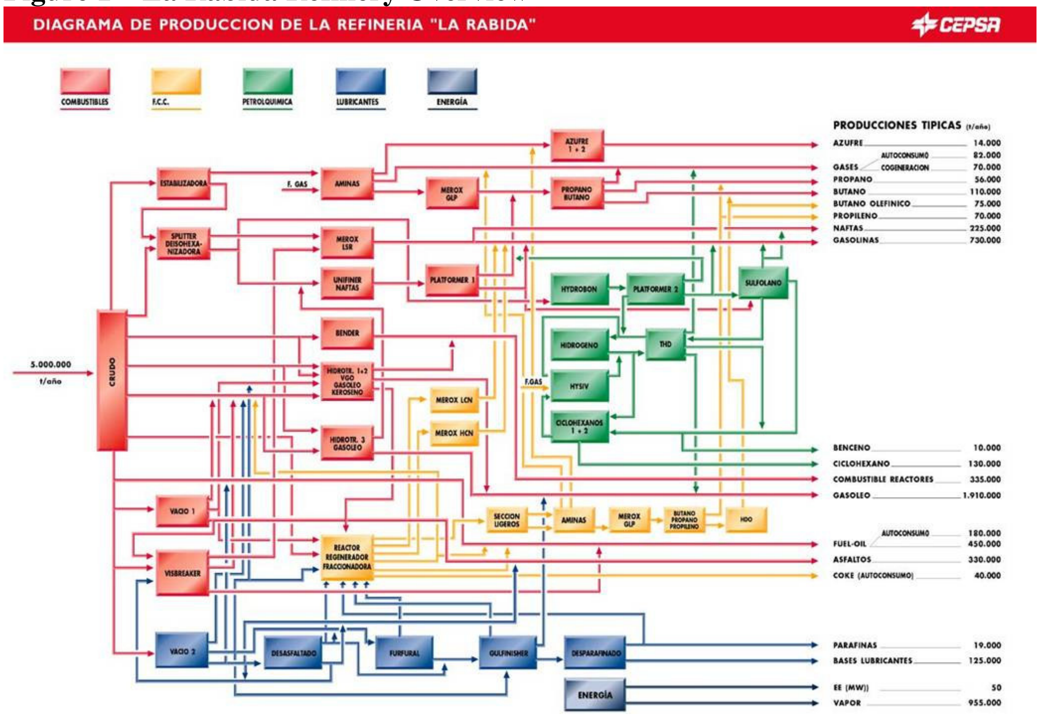
Introduction

La Rabida Refinery Overview

The CEPSA La Rabida refinery is located about 10 km south of Huelva, in the southern part of Spain. The original fuels refinery was constructed in 1967. Production facilities for Aromatics and Lube Oils along with a cogeneration plant and an FCC unit have since been added to the plant. A simplified block flow diagram of the refinery is provided in Figure 1. Recently, the extraction and dewaxing units have been decommissioned in connection with a strategic decision within Cepsa.

One of the key characteristics of the refinery operation is related to the blocked operation of the crude unit, which operates in three different feedstock modes: Fuels, Asphalt and Lubes. Even after the decommissioning of the extraction and dewaxing units, three distinct modes continue to exist for other reasons, e.g. to allow segregation of the atmospheric residue into bitumen feedstock and residual fuels with different content of sulphur. The occurrence of very significant crude switches on a frequent basis (2-3 times per week) causes disturbances not just to the crude unit, but also to the downstream process units and makes the scheduling and optimisation of the facilities quite challenging.

Figure 1 – La Rabida Refinery Overview



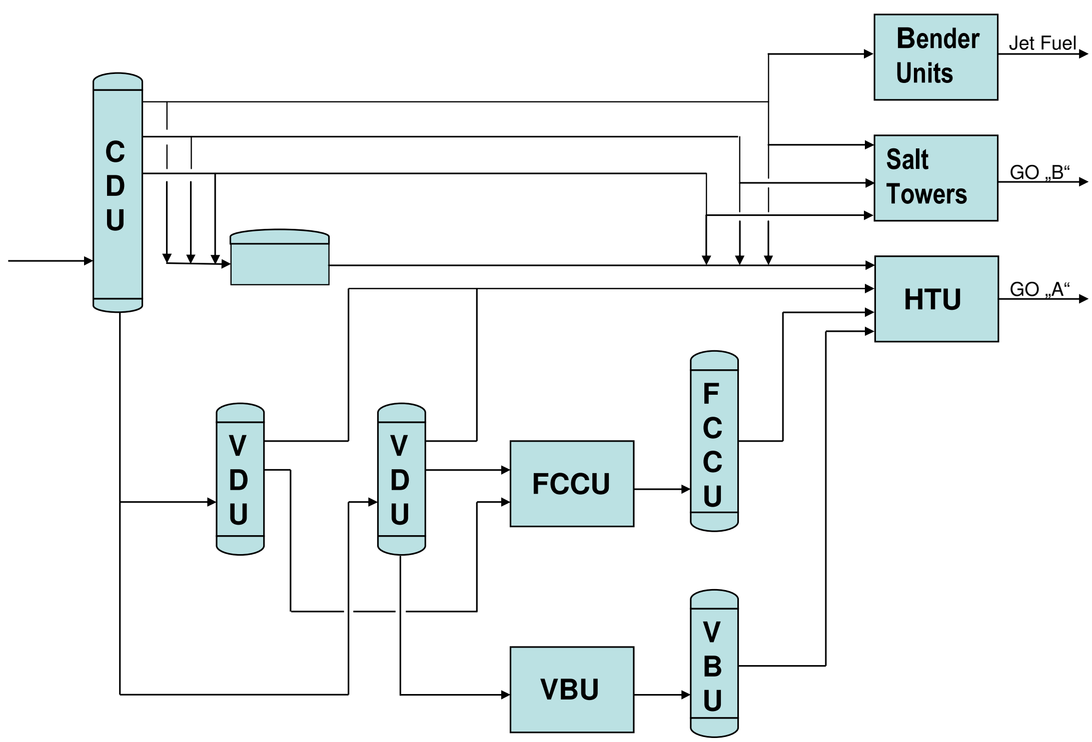
Another characteristic feature of the La Rabida crude unit operation is that the crude column is controlled in a heat balance fashion, i.e. each product draw is a total draw with pumpback reflux on flow control and the net product draw on level control, similar to the setup found on many vacuum distillation units. This control scheme has certain advantages, especially in relation to the very severe crude switches that the unit goes through on a regular basis. In relation to the optimisation of the downstream blending operations, however, the scheme has the disadvantage that the product draw flows, and hence the availability of blend components, changes from minute to minute.

A further characteristic of the La Rabida gasoil system is that there is only limited tankage available to store components that are not consumed in the current blends. Typically, there is a strong incentive to minimise the use of intermediate tankage, partly because it involves premixing of components, which may impair blend flexibility, and partly because the intermediate tankage may be required for other purposes, such as import of components.

A simplified flow diagram of the middle distillate processing at the La Rabida refinery is provided in Figure 2. The middle distillate pool consists of kerosene, light diesel and heavy diesel from the crude unit, two VGO feeds from the two vacuum units, LCO from the FCC unit and VBGO from the visbreaker. ULSD (Gasoil A) is produced in a dedicated hydrotreater. When processing low sulphur crudes, an undesulphurised gasoil or off-road diesel grade (Gasoil B) is produced in addition to the ULSD grade. Kerosene is routed partly to the ULSD hydrotreater, partly to the undesulphurised rundown line and partly to a Bender sweetening unit for jet fuel production.

Important specifications for the gasoil grades produced at La Rabida include cloud point (winter case), distillation, density, flash point, sulphur content and cetane index.

Figure 2 – Simplified Diagram of the La Rabida Middle Distillate Processing



Project History

The basis for the project was a feasibility study conducted in 2003. The feasibility study made a number of recommendations to improve the planning, scheduling and control of the La Rabida refinery gasoil production. Among the recommendations were the implementation of multivariable control on the crude unit and the installation of blend ratio controls and blend property controls for the hydrotreater that produces the ULSD grade. For multivariable control, CEPSA selected RMPCT from Honeywell; for the blending applications, the ANAMEL software from TOTAL was selected.

The availability of accurate and reliable on-line analysers to measure the actual quality of the blended products is obviously very important to the success of this type of project. For this project, conventional analysers were preferred over NIR technology, partly because some analysers were already available and partly because it was suspected that some of the required properties could be difficult to infer with sufficient accuracy from NIR information. The following analysers are now in operation:

- Sulphur
- Distillation
- Flash point
- Cloud point
- CFPP
- Density

During the initial design phase of the project it became apparent that the optimisation of the hydrotreater feed composition would have to take into account the variable availability of components from the crude unit as well as various hydraulic constraints. Also, it was clear that the optimisation of the feed blend ratio, and potentially the feed rate, would require adjustments of the hydrotreater reaction temperatures. Finally, there was a significant incentive to optimise the operation of the hydrotreater stripper to minimise the production of wild naphtha.

To address these issues, three RMPCT applications were implemented on the hydrotreater feed system, the reaction section and the stripper. The original intention was that the hydrotreater feed system application would implement the desired blend ratios, initially from manual entry, but eventually coming from the ANAMEL blend property controller. The implementation of blend ratio control on the ULSD hydrotreater was required for the blending project and seemed reasonable from the perspective that Gasoil A was the more valuable product. However, this control philosophy was fundamentally different from the manual operation, where the composition of the Gasoil B rundown line was set up on flow control, with the rest of the available components typically being routed to the ULSD hydrotreater to produce Gasoil A. The shift foreman would then adjust the Gasoil B recipe and the cutpoints on the crude and vacuum units in order to bring both products on target. It quickly became clear that tight ratio control on the hydrotreater feed streams was not a good way to control the split of the crude unit components. In order to control the hydrotreater blend ratios with fixed flows to the Gasoil B rundown line, it would be necessary to operate with significant excess of each of the crude unit side products to storage, which was unacceptable from a scheduling point of view. Alternatively, the Gasoil B rundown would have to take all the available components on pressure control. However, this was also not acceptable, partly because the crude unit side draws make up 100% of the Gasoil B recipe, making this product more sensitive to fluctuations in the availability of crude unit components than the Gasoil A product, which also includes VGO, LCO and VBGO. Also, the Gasoil B rundown system, which includes salt drier facilities, has limited capacity and in contrast to the hydrotreater, there is no surge drum to smooth out flow variations.

Consequently, it was decided that a more appropriate solution would be to implement a gasoil system optimiser that would replicate some of the important aspects of the manual operation of the system, i.e. the simultaneous optimisation of the recipes of both products and the optimisation of the cutpoints of the crude and vacuum units. The design of this optimiser is described in the following sections.

Real Time Optimisation Solution

The general ULSD optimisation problem

Although the Huelva refinery has certain unique aspects due to the complexity of the operation, in particular the distinctly different operating modes, the Huelva ULSD optimisation problem is actually quite similar to what can be found in many European refineries: the introduction of ULSD specifications has in many cases transformed the diesel blending problem from an off-sites, batchwise operation to a real time optimisation problem. This presents a number of new challenges, but also some new opportunities. The new challenges are primarily related to the fact that all components generally need to be hydrotreated and that off-spec ULSD product can be extremely difficult to correct. By the same token, these difficulties provide new opportunities for both multivariable control and optimisation, because the optimisation of the targets for certain key variables in the crude and vacuum units can now appropriately be performed by a minute-by-minute real time optimiser rather than as a daily scheduling exercise.

Generic Dynamic Optimisation Technology

In order to capture large-scale optimisation opportunities such as those presented by the Huelva ULSD system, a Generic Dynamic Optimisation Technology (GDOT) package has been developed by TCA. GDOT optimises a set of independent variables to maximise plant profitability subject to a set of constraints using a sparse matrix QP solver. The relations between the independent variables and the dependent variables of the system are described in terms of a user-defined process model.

A process model that is to be used for optimisation must satisfy certain consistency criteria, e.g. it must be in material balance as a very minimum. Taking a flexible approach to modelling, GDOT enables the user to build consistent models using proven modelling techniques from related disciplines, such as inferred property modelling and refinery-wide LP modelling. This modelling concept has a number of important advantages over other real time optimisation techniques.

On the one hand, purely empirical models, such as those used for multivariable control, are not inherently in material balance and will typically not provide the necessary consistency to ensure correct optimisation. Hence, a large-scale optimiser based solely on such models carries a significant risk of incorrect optimisation due to model inconsistencies. Also, many of the model relationships within the ULSD system would be extremely difficult to establish from step test data without putting the products significantly off-target.

Furthermore, many process gains vary significantly over time, partly due to different modes of operation and partly due to the nature of blending operations such as those that are part of the La Rabida ULSD system. In fact, most industrial processes are inherently non-linear. Taking this into account is particularly important for solving large-scale optimisation problems involving parallel process units or product blending operations.

On the other hand, a traditional real time optimiser based on a flow sheet simulation approach is unnecessarily complicated for many real-life optimisation problems such as the ULSD system described in this paper, and often requires very significant implementation and maintenance effort. Equally important, a traditional steady-state optimiser will typically not be able to provide the reliable minute-by-minute optimisation that is very often important for capturing the benefits.

Description of ULSD Application

The optimiser implemented at the La Rabida refinery currently covers the following areas

- crude unit
- vacuum unit
- the distribution of components between the ULSD hydrotreater and the gasoil production line
- the ULSD hydrotreater
- kerosene bender unit
- two sulphur plants

The generic optimiser discussed in this paper uses a simplified non-linear process model that has been engineered with emphasis on consistency, robustness and simplicity. The crude unit model is based on a cutpoint representation of the crude fractionation and the models of the downstream blending processes take into account the non-linear blending behaviour of the various product properties.

The real time optimisation system maximises an expression of the gross margin of the ULSD system per unit of time. One of the key objectives of the optimiser is of course to maximise the production of ULSD. This is a constrained blending optimisation problem, where the production rate is maximised subject to a variety of constraints, e.g.

- ULSD and gasoil product qualities
- component availability
- crude column capacity and other crude unit constraints
- reactor temperatures and other hydrotreater constraints
- hydrogen availability
- sulphur plant capacity
- hydraulic constraints

The La Rabida ULSD system optimiser currently has 101 decision variables that are optimised subject to 147 constraints. The GDOT optimiser supplies 48 ideal resting values for selected key variables residing in 9 RMPCT multivariable controllers running on two different types of hardware (Honeywell APP node and DCS-based Application Module). The RMPCT applications are distributed between three console operators located in two different control room buildings.

The system architecture of the application is shown in Figure 3. The GDOT optimiser is executed on an application server at a frequency of once per minute. Each execution takes less than 10 seconds including data I/O. The user interface for the optimiser (GDOT Console, shown in Figure 4) is available on the application server itself and on various office PC's and GUS stations on the control network. The multivariable controllers are executed partly on an APP node, which also serves as a gateway to the DCS, and partly in a regular Application Module. The ANAMEL blend optimiser is also executed on the APP node. A data historian node (PHD node) is available for collection of history, including key data from the GDOT optimiser.

Figure 3 – System Architecture

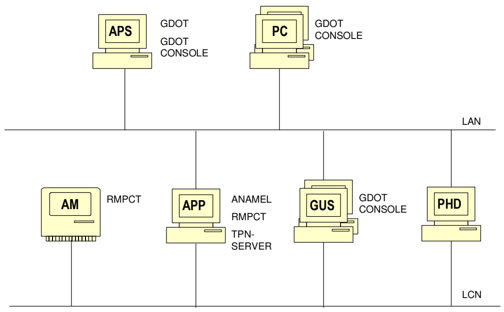
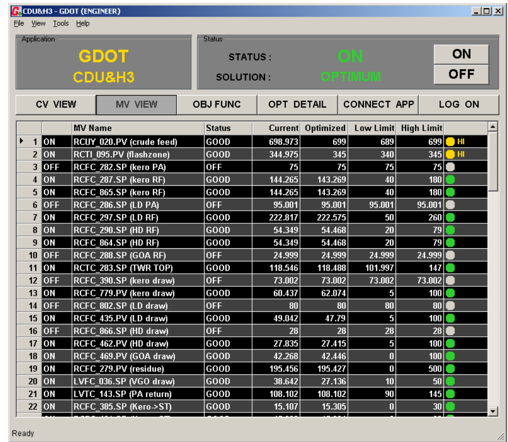


Figure 4 – GDOT User Interface



ANAMEL Integration

The ANAMEL blend optimiser provides an optimum recipe for the Gasoil A product. The optimum recipe is currently passed to the GDOT optimiser as a set of targets with user configurable weights. These weights determine the relative importance of the main objectives for GDOT on the one hand and the compliance with the ANAMEL recipe on the other hand. However, the real strength of the ANAMEL software in relation to the GDOT optimiser is the ability to operate in an integrating blend mode, taking into account the quality in the heel before the batch was started, the average rundown line quality for the completed portion of the batch, the final product specifications and the final volume of product to be produced in this batch. It is anticipated that this type of integration between GDOT and ANAMEL could lead to significant additional benefits.

Project Results

The version of the application with the full scope as described in the previous sections has been in operation for 3-4 weeks at the deadline for submitting this paper. Hence, due to the large number of different modes and constraint scenarios, the available data is not yet sufficient for a proper statistical post audit. However, data collected during and after the initial closed loop testing of the application illustrate the capabilities and can be used as indication of the benefits that can be expected from the application.

First of all, the application has demonstrated its stability and robustness, which, once the testing and training has been completed, should result in a service factor of close to 100%. In particular, the ability to automatically adapt both to very significant variations in the process gains as well as to changes to the regulatory control structure is very important for this type of application. For example, the Gasoil B rundown system is routinely shut down when switching to high sulphur crude, meaning that the crude unit side draws are then typically routed 100% to Gasoil A via the ULSD hydrotreater instead of being split into one stream on flow control and one stream on pressure control. It is crucial that the application continues to optimise correctly under all these different scenarios. As an extreme case, the hydrotreater had to be shut down for a couple of days due to a leaking flange, and even in this case the GDOT optimiser was able to remain on-line, optimising the rest of the system as far as possible.

So far, the application has been tested in a variety of scenarios, e.g.

- Hydrotreater feed rate constrained by feed availability, hydrogen availability and the sulphur content of the product (at maximum reactor temperatures)
- Gasoil A and Gasoil B both constrained on cloud point
- Gasoil A and Gasoil B both constrained on flash point
- Gasoil A constrained on distillation

Figure 5 illustrates a mode of operation where the hydrotreater feed is constrained by the sulphur content of the Gasoil A product at maximum acceptable reactor temperature. The first 25% of the data represents a 10 ppm mode with high sulphur asphalt crude. This is a very challenging mode, but the GDOT application performs the difficult task of controlling the sulphur content with the feed composition very well indeed. The remaining 75% of the data represents a 40 ppm mode on medium sulphur crude. In this mode, the Heavy Diesel and VGO cutpoints are increased towards the maximum dictated by the Gasoil A distillation specification. In fact, this means that reactor temperatures remain at or close to the maximum even at the 40 ppm sulphur limit. This medium sulphur crude had not been run before, at least not recently, which may explain the fact that it took a bit longer than expected to reach the new target, probably because some manipulated variable limits could have been released faster.

Figure 5 – Controlling Gasoil A Sulphur with Feed Composition

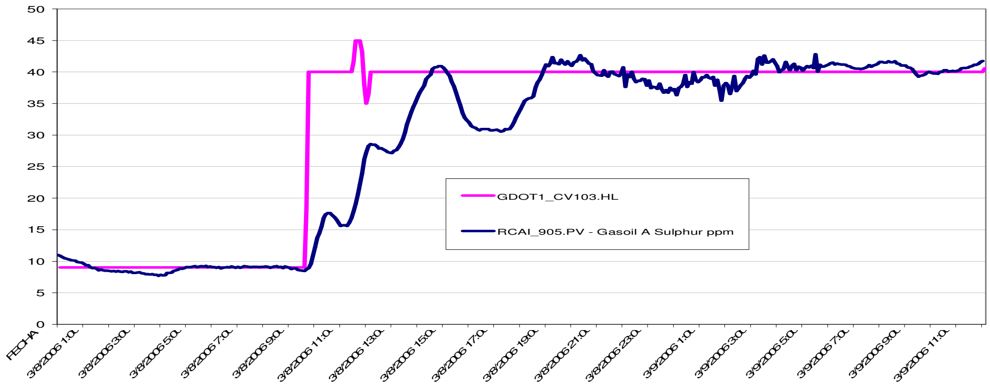


Figure 6 illustrates a mode of operation where both product lines are constrained on cloud point. The GDOT application uses the Heavy Diesel cutpoint and the distribution of components to the two product lines to control the cloud point on both lines. It is evident that the Gasoil B cloud point is controlled somewhat better than the Gasoil A cloud point. This could be due to the fact that the components to the Gasoil B line are on flow control whereas the components to the Gasoil A line are on pressure control. All in all, however, the average cloud points on both lines are managed well by the GDOT application in this mode.

Figure 7 illustrates a mode of operation where both product lines become constrained on flash point. In the initial period, there is some slack on the flash points, which are moving according to their natural variation. Towards the last third of the data, however, the flash points become limiting due to a more aggressive low limit for the naphtha cutpoint. The optimiser responds well controlling both flash points to the limits using the naphtha cutpoint and the distribution of components between the two product lines.

Figure 6 – Simultaneously Controlling Cloud Point of Gasoil A and Gasoil B

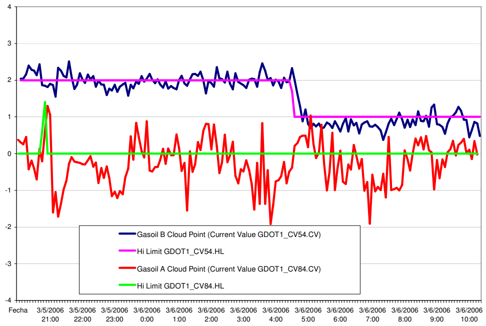
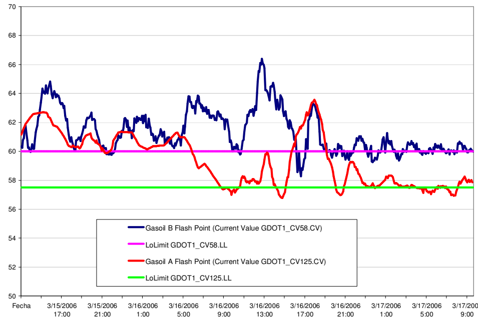


Figure 7 - Simultaneously Controlling Flash Point of Gasoil A and Gasoil B



Conclusions

An on-line optimiser for the production of ULSD and gasoil at the CEPSA La Rabida refinery has been successfully commissioned in a relatively short timeframe. The application is based on a novel approach to optimisation making use of a simplified non-linear process model and the GDOT optimisation package from TCA. Initial experience has demonstrated the robustness of the approach, in particular the ability to adapt to a wide range of expected as well as unexpected operating scenarios. Also, the initial experience confirms the ability to capture very significant benefits with this type of application. Further integration with the batch blending functionality provided by the ANAMEL package would make available additional opportunities.