BLENDING OPTIMIZATION SYSTEM

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We have developed a blending optimization system which calculates optimum blend ratios, based on values measured in a continuous on-line analysis of product properties, and corrects control setpoints automatically. The system is composed of the EXABPC property control package that calculates optimum blend ratios, a distributed control system (CENTUM CS or CENTUM-XL*[*2]), and next-generation InfraSpec near-infrared analyzers. This paper focuses on the EXABPC and introduces its features, structure, and functions.

INTRODUCTION

The purpose of blending in a petroleum refinery is to mix semi-finished products that have been rectified during various refining processes so as to manufacture a product that meets specification. Traditional blending operations have not been able to avoid the following issues involving property control:

- Manual adjustment by the operator cannot control the properties ideally and is liable to cause giveaway (an excess in quality).
- A conventional analyzer, typically a knockmeter, requires a large amount of labor and high costs for installation and maintenance.

The objectives of the development of this blending optimization system are, first, to employ an optimization calculation in the blend ratio calculation, and further, by structuring an integrated system package including analyzers, to reduce costs and labor drastically for users employing the system (the troublesome testing of system connections, etc.).

OVERVIEW OF BLENDING OPTIMIZATION SYSTEM

In this system, the properties of a product being blended are directly measured by an InfraSpec on-line near-infrared analyzer, and blend ratios are controlled by a closed loop. As shown in Figure 1, this system is composed of the following modules:

1) Blend ratio control (off-site instruments in CENTUM CS or CENTUM-XL)
2) Property control package (EXABPC)
3) On-line near-infrared analyzers (InfraSpec NR500)

1. Blend Ratio Control

Based on the prescribed blend ratios, off-site instruments in a CENTUM CS or CENTUM-XL distributed control system calculate the flow rate setpoint for each component and control flow rates.

2. Property Control (Multivariable Predictive Control for Optimum Blend Ratio Calculation)

This is the kernel module of the blending optimization system. The purposes for the use of multivariable predictive control in this module are to measure each property value of the product directly on-line, and accordingly to adjust the blend ratios so that each property value can meet specification. In multivariable matrix control, if the degree of freedom is one or greater, there are two or more solutions that satisfy the target variable, in general. If the optimization coefficient is set in this case, optimization calculations can be made. For instance, this makes it possible to calculate optimum ratios by setting the

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*1 Systems Business Division

*2 CENTUM is a registered trademark of Yokogawa Electric Corporation.

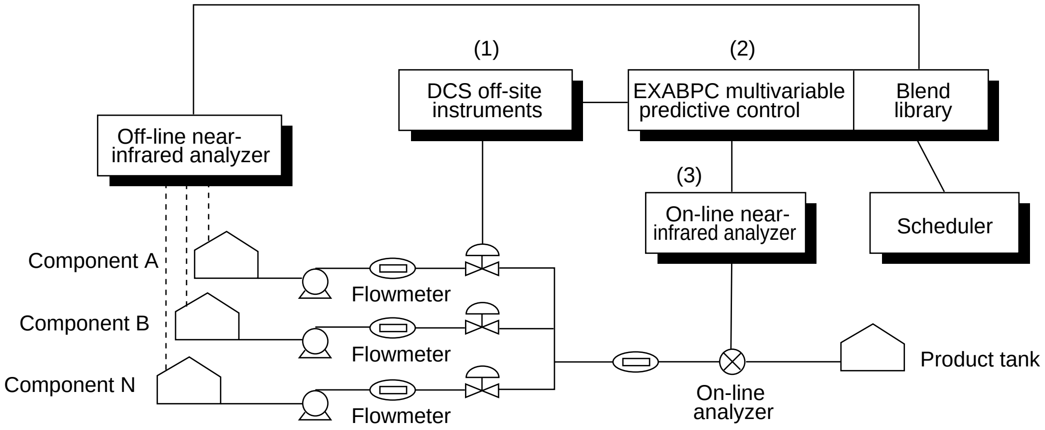


Figure 1 Blending Optimization System

maximum allowable ratio for the component which is lowest in terms of unit manufacturing cost as well as the minimum allowable ratio for the component which is highest in terms of unit manufacturing cost, to the extent that a certain property standard (RON) permits.

In this blend optimization system, EXABPC performs multivariable predictive control and optimum recipe calculation. EXABPC uses an HP9000 as its hardware platform.

3. On-line Near-infrared Analyzers

This system uses InfraSpec NR500 near-infrared analyzers for the on-line property analyses. Recently, many users have become increasingly interested in near-infrared analyzers because of their ability to handle on-line measurement of gasoline octane numbers and other reasons. When used as an on-line analyzer, a near-infrared spectrum analyzer delivers the following merits to the user in comparison to conventional analyzers:

- Real-time measurement of multiple property values
- Continuous measurement without destruction of the sample
- Remote measurement using a fiber-optic cable
- Simplified sampling system
- Great reduction of maintenance costs and labor

4. Operation Environment of Blending Optimization System

Figure 2 shows the operation environment of the overall blending optimization system.

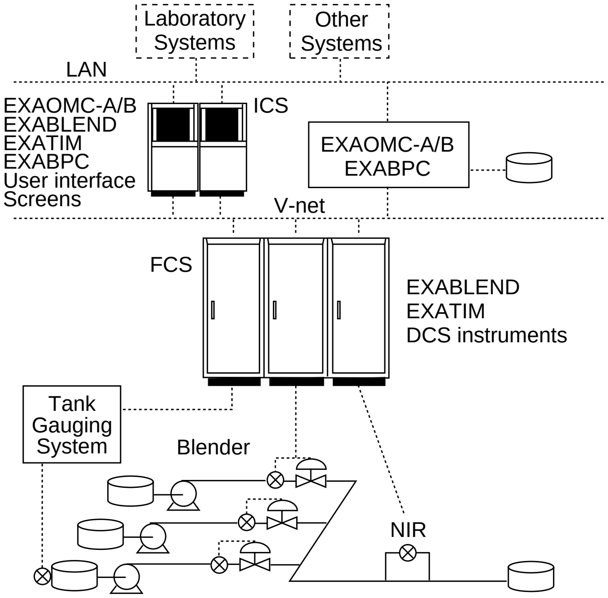


Figure 2 Operation Environment of Blending Optimization System

FEATURES AND STRUCTURE OF EXABPC PACKAGE

1. Features of EXABPC

This package has the following features:

- Estimation of product quality in the header and the integrated product quality in the tank

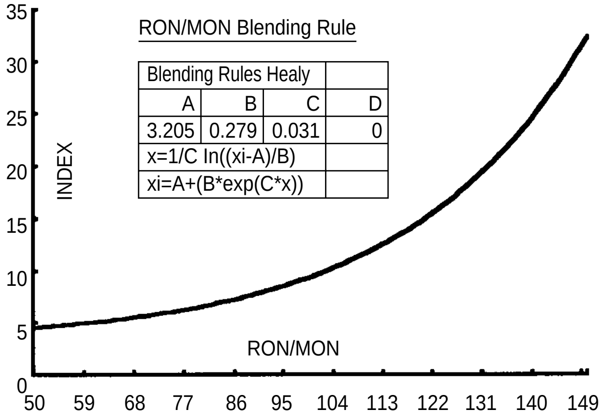
  The model-based prediction formulas of the EXABPC estimate not only the properties of the product in the blend header (i.e., instantaneous product quality) but also the properties of the product in the tank including heel(integrated product quality).

- Calculations of property values (FVI, cetane index, etc.)

  The EXABPC not only handles values measured directly by analyzers but also calculates other property values internally from those values from analyzers. For instance, the FVI value can be calculated from the RVP and E70 values.

- Compatible with nonlinear property changes by using exponential computations (compatible with blending rule)

  A property that shows a nonlinear change, such as RON and viscosity as shown in Figure 3, can be handled with exponential computations. A user can use the equations



Blending Rules Healy			
A	B	C	D
3.205	0.279	0.031	0
x=1/C ln((xi-A)/B)			
xi=A+(B*exp(C*x))			

Figure 3 Blending Rule (Exponential Computation for RON)

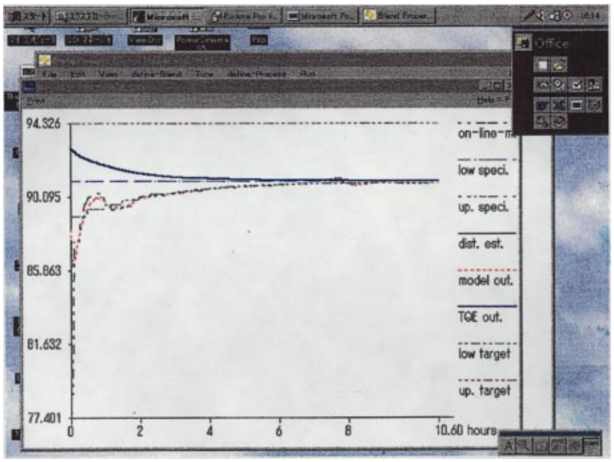


Figure 4 Simulation on PC

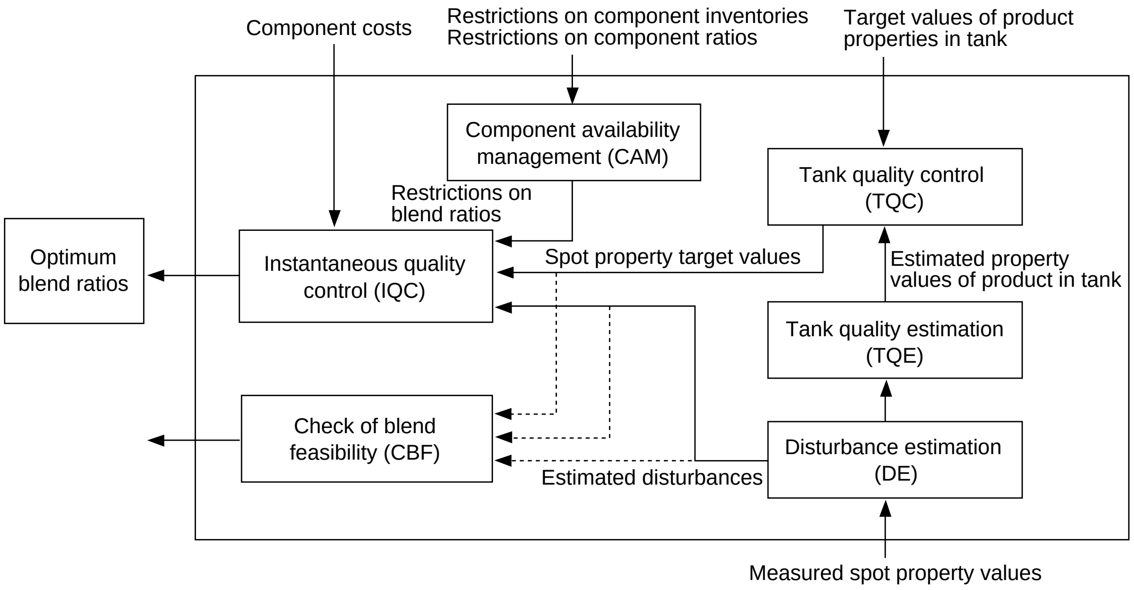


Figure 5 Blend Ratio Optimization Calculation

already contained within the EXABPC (that can be revised) and can even write the user's own equations.

- Optimization using nonlinear programming
  Many blend control packages from competitors use nonlinear programming for optimization calculation, but the EXABPC uses even more flexible nonlinear programming.

- Two different optimization scenarios
  The EXABPC can run two different optimization scenarios: optimization calculations for each blending job, and optimization calculations linked with the scheduler.

- Off-line simulation on a PC
  Although the EXABPC's main program runs on an HP 9000, the EXABPC package includes an off-line simulation program that can also run on a Windows[*3] PC. Figure 4 shows an example of a simulation on a PC.

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*3 Windows is a registered trademark of Microsoft Corporation, USA.

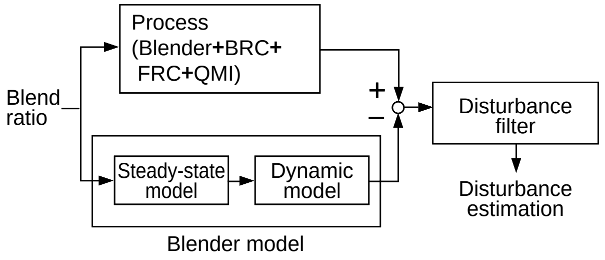

Figure 6 Disturbance Estimation (DE)

2. Structure and Functions of EXABPC

Blend ratio optimization calculation, the main function of the EXABPC, is composed of the sub-functions shown in Figure 5.

(1) Disturbance estimation (DE)

To compensate the blend model, modeling difference between the model prediction of the product quality and the analyzer measurement is estimated as disturbances using the following equation (see also Figure 6):

$$Dej(k) = EXP(-1/Tdj)*Dej(k -1) + (1- EXP(-1/Tdj)*(Pmj(k)- Ppj)$$

Where
De = disturbance estimation
Td = time constant of disturbance filter
Pm = property measurement index
Pp = predicted property
j = property j
k = sampling time

(2) Tank quality estimation (TQE)

The properties of a product batch (in a product tank, tank on a ship, etc.) are estimated based on volume and properties of remaining oil (heel), and blending volume and properties (see also Figure 7). The index of the estimated tank property Tqj is obtained by the following equation:

$$Tqj = (Qhj*Vh + qkj *V)/Vh + V$$

Where
V = product volume produced since the last TQE run
qk = quality of the added volume
Vh = heel volume
Qh = heel property index
j = property j

(3) Tank quality control (TQC)

Tank quality control, which is the upper level control in the instantaneous quality control (IQC) described later, calculates the spot property target values so that the product property in the tank is finally on specification. The calculated spot property target values are transmitted to instantaneous quality control (see also Figure 8).

The heel correction speed (SPEED FACTOR) is provided as a coefficient to decide to finish heel correction on the basis of total blending volume. The spot property target values are calculated by the following equations:

$$Qspt\_highj = \{Qspec\_highj*(Vh + Vc) - (Qcj*Vh)\}/Vc$$
$$Qspt\_lowj = \{Qspec\_lowj*(Vh + Vc) - (Qcj*Vh)\}/Vc$$
$$Vc = (Vb + Vhl)*Kc$$

Where
Qspt_high = upper limit of spot property target
Qspt_low = lower limit of spot property target
Qspec_high = upper limit of product specification for product tank
Qspec_low = lower limit of product specification for product tank
Vh = heel volume at this period
Qc = estimated properties of a product tank at this period
Vc = heel correction volume
Vb = total blending volume
Vhl = heel volume at blending start
Kc = heel correction speed factor
j = property j

(4) Component availability management (CAM)

From the highest constraint among the following, the upper and lower limits of each component ratio is calculated.

- Limit of component ratio
  Limited to the maximum and minimum component (oil) ratios set by the operator.
- Limit of component volume
  Limited to the maximum and minimum component (oil) volumes set by the operator.
- Limit of flow rate
  Limited to the maximum and minimum allowable flow rates set by the operator.
- Rate-of-change limit of component ratio
  Limited to the maximum change rates of component (oil) ratios set by the operator.

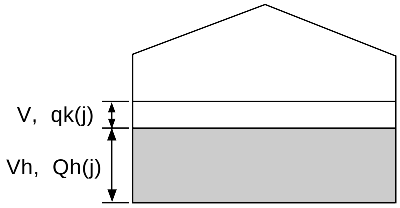

Figure 7 Tank Quality Estimation (TQE)

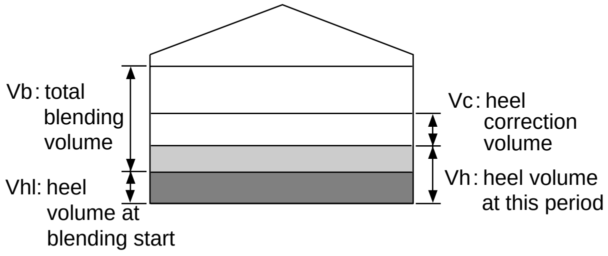

Figure 8 Tank Quality Control (TQC)

(5) Instantaneous quality control (IQC)

Instantaneous quality control decides the optimum blend ratios for the spot property target values (see also Figure 9), lower level controller in tank quality control controls the properties in the blend header. To do so, it calculates the optimum blending recipe and ensures that it is within constraints.

- IQC mode

  There are two modes for the IQC. Either one is selected for use according to the economic and control purposes within the petroleum refinery.

(a) Minimum cost

In the minimum cost mode, the IQC calculates the component ratios (Ri) that can minimize the result of the following equation:

$$\sum i\{Ci* Ri \}**2 + \sum i\{Ri - Ri'\}**2*Pi**2$$

Where
Ci = component (oil) cost
Ri = optimum ratio of component i
Ri'= optimum ratio of component i in the last period
Pi = optimization continuity factor of component i

Constraints

- $Hjmin \leqq \sum i(Pji*Ri + Dj) \leqq Hjmax$
  Where
  Hjmax = spot property target upper limit of property j
  Hjmin = spot property target lower limit of property j
  Pji = property j of component i
  Dj = estimated disturbance of property j
- Lower limit of ratio $\leqq$ Ri $\leqq$ upper limit of ratio
- Total of Ri = 1 (= 100%)

(b) Minimum distance

In the minimum distance mode, the IQC calculates the component (oil) ratios (Ri) that can minimize the result of the following equation:

$$\sum i\{Ci*(Ri -Ropt)\}**2 + \sum\{Ri - Ri'\}**2*Pi**2$$

Where
Ropt = component optimization mode

Depending on the value of Ropt(i), one of the following ratios is calculated:

— When Ropt(i) = 1, then the minimum ratio calculated by the component availability management (CAM);
— When Ropt(i) = 2, then the off-line optimum ratio recipe*[4]; and
— When Ropt(i) = 3, then the maximum ratio calculated by the component availability management (CAM).

(c) Secondary solution method

The EXABPC has a function to decide ratios by loosening the constraints partially when the aforementioned optimization problem cannot be resolved.

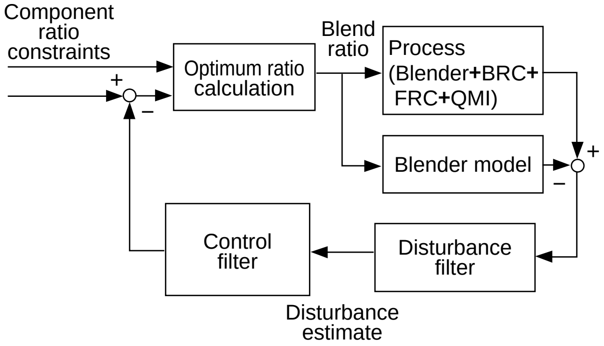

Figure 9 Instantaneous Quality Control (IQC)

(6) Feasibility check (CBF)

The check for blend feasibility (CBF) checks whether or not the product tank properties are within the range of product specification when the blend operation ends.

BENEFITS OF SYSTEM

The blending optimization system delivers the following benefits to the user:

- User-friendly operations

  The system can be operated via an ICS of a CENTUM CS system, allowing single-window and user-friendly operations with high operability.

- Prevention of quality giveaways

  Properties such as the octane number in a gasoline blender or the viscosity and sulfur rating in a fuel oil blender can be within the range of target values of the specifications. This minimizes costs caused by quality giveaway, and can make a big benefit for the user.

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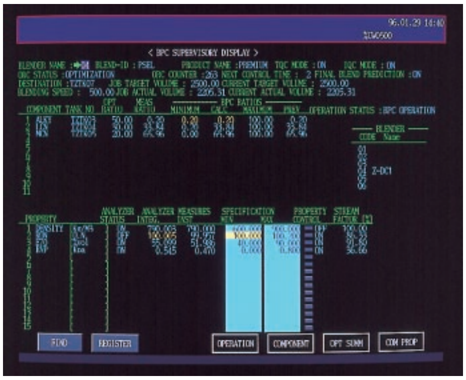
*4 The off-line optimum ratios are decided by the scheduler in consideration of the economy of the entire petroleum refinery. For instance, a component which was produced excessively should be used a lot even if it is a costly component, and using a lot of an inexpensive component is not allowed if there is little inventory of that component on hand. An off-line optimum recipe is provided by the off-line scheduler and optimizer. Normally a blend recipe is determined by the scheduler in consideration of the optimum consumption of components. A single blend optimization does not always mean using an optimum component. The optimum consumption of blend components depends on the availability of each component and storage capacity of component tanks.



< BPC SUPERVISORY DISPLAY >

BLENDER NAME : BLEND-ID : PSEL PRODUCT NAME :PREMIUM TQC MODE : ON IQC MODE : ON

ORC STATUS :OPTIMIZATION ORC COUNTER :263 NEXT CONTROL TIME : 2 FINAL BLEND PREDICTION :ON

DESTINATION :TZT607 JOB TARGET VOLUME : 2500.00 CURRENT TARGET VOLUME : 2500.00

BLENDING SPEED : 500.00 JOB ACTUAL VOLUME : 2205.31 CURRENT ACTUAL VOLUME : 2205.31

OPERATION STATUS :BPC OPERATION

Figure 10 Quality Control Monitor Screen

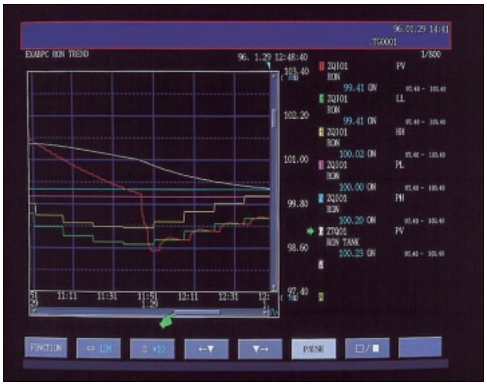


Figure 11 Quality Control Trend Screen

- Reduction of product tanks and product stock
  Direct loading from blender to a ship is possible because qualities of the product by blender are assured. This can reduces not only product stock tanks but also greatly reduces the product stock on hand.

- Minimization of re-blending operation
  Re-blending can be minimized by improving the qualities of blends. This results in great reductions in product stock and manpower.

- Implementation of integrated system
  By the adoption of relational databases (RDB), the integrated system can be implemented by easily connecting other systems such as the laboratory system.

- Reduction of product loss
  Oil remaining in the pipe line from a blender to a wharf and that remaining in a product tank after tank blending is handled as heels and automatically compensated. This prevents slop processing and product downgrading, and leads to a greater reduction of product loss.

Figure 10 shows a quality control monitor screen and figure 11 shows a quality trend screen.

FUTURE IMPROVEMENTS

- Multi-platform
  The current version of the EXABPC can run on an HP-UNIX-based computer (HP 9000/E series or compatibles). By developing a version that runs under a Windows NT Workstation, we are enabling further reduction in the initial costs to employ the system.

- Multiblending
  The current version of the EXABPC optimizes each blending job. We are studying a mechanism to optimize multiple blending jobs in a specified time period.

CONCLUSIONS

The blending optimization system introduced in this report was developed as a package through our expertise in two systems delivered to Japanese users and three systems for overseas users. Featuring a variety of original Yokogawa functions dedicated to blending control, this package is a great interest to customers.

From another aspect, it is meaningful that it is possible to develop an integrated system with high added value by integrating the application technology of our systems with our other measurement and control systems. ◆

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