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CHAPTER 15

Gasoline Blending Simulator Whose Octane Authority Shrinks as the Tank Fills

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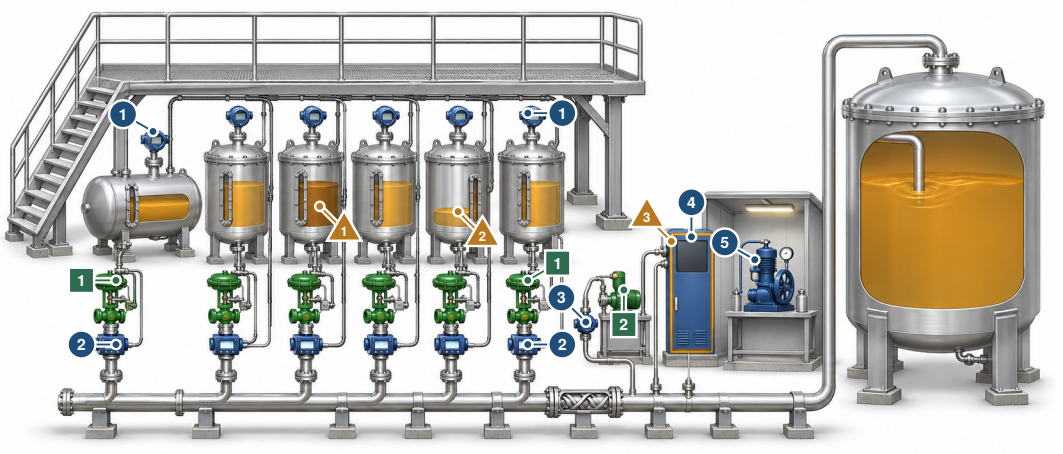
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CHAPTER 15

Gasoline Blending Simulator Whose Octane Authority Shrinks as the Tank Fills



The controller moves 1 six component valves, which set the recipe 2 additive pump

The controller reads 1 level in each component tank 2 flow of each component 3 additive flow 4 online analyzer 5 laboratory knock engine

What disturbs it 1 a weaker reformate tank 2 alkylate taken for another blend 3 an analyzer that drifts or freezes

Every instrument sits on the feed legs and the header at the left, and none reads the quality of the product tank at the right, whose average is what the certificate is written on. Illustration, not to scale.

IN PLAIN TERMS A Tank Remembers Every Barrel

The main idea. Gasoline is mixed from six refinery streams in one pipe that fills a large tank. It is graded once, from a sample of the full tank, so what counts is the average of all that went in.

The challenge. Poor fuel in the tank can only be made up by better fuel still to come, and the fuller the tank, the better it must be. The instrument that checks the mix reports three minutes late and can drift while it reads on target.

Why it matters. A tank that fails must be blended again, and one that passes with room to spare gives costly ingredients away.

THREE WAYS TO READ THIS CHAPTER

Explore	12 min	This page, the History boxes in Sections 15.2 and 15.5, the Did you know? boxes in Sections 15.1 and 15.6, the Try it boxes in Sections 15.4 and 15.5, and Key points in Section 15.9. No equations.
Study	50 min	The whole chapter in order, stopping at the three pause points, then Exercises 1 to 12.
Practice	15 min	This page, Section 15.6 with Figure 15.4, Section 15.7 and Section 15.8 with the Open challenge box that closes it.

The control question Gasoline is certified from a sample of its full product tank, so the blender is judged on the average of everything it has made, while every loop works on the header. How should a late analyzer, a biased blend model and a recipe optimizer be layered so that the tank lands on its octane target, when a deficit already in the tank can only be repaid by the blend still to come?

Learning objectives

- Compute the vapor pressure and octane of a recipe from the blending index and the interaction model, including the octane boost and the vapor-pressure bump of ethanol.
- Derive the header target $T + \Delta/f$ of cumulative-average targeting and predict what its stopping floor and header clip cost the certificate.
- Explain from the four-report delay why an octane trim tuned like a flow loop oscillates, and what the gain and the integral time each do.
- Show by a run that a bias update follows a drifting analyzer, and that only an independent laboratory check brings the tank back.
- Judge which control layer can answer a quality change, a component shortage and a late deficit in one batch.

Prerequisites Sections 1.4.6, 1.4.7, 1.6.2 and 1.6.4. Chapter 9 for the reformate and its inferred octane, and Chapter 10 for the alkylate.

The app https://apmonitor.com/apps/gasoline-blending/

See also Volume 9, Chapter 4 for an estimator that carries a bias and Volume 9, Chapter 8 for an optimum that sits on a moving constraint. Volume 3, Chapter 7 for a ratio blend trimmed on an analyzer. Volume 5, Chapter 3 for a loop on a slow analyzer and Volume 5, Chapter 4 for a late, drifting analyzer checked by a laboratory.

15.1 Introduction

A refinery's gasoline is made in its last unit. An in-line blender draws butane, naphthas, reformate, cracked gasoline, alkylate and an oxygenate from their tanks, meters them into one header in the proportions of a recipe, and sends the blend to a product tank that is certified once, from a sample of its full contents [1]. Two of the properties on the certificate do not blend linearly. The octane number of a blend departs from the volume average of its components' octane numbers [2], and vapor pressure is blended through an index rather than through the pressures themselves [1]. Ethanol adds a third departure, because its contribution to octane depends on the base fuel it enters [3] and a small addition raises the vapor pressure of a hydrocarbon base although its own is low [4]. Model-based real-time optimization of such a blender re-solves the recipe as the operation proceeds [5], and the feedback control and optimization of fuel blending remain an active problem [6].

This chapter corrects one belief, that a blend is on specification whenever its header is. The certificate is written on the tank, and the tank remembers every barrel. In case 4 of this chapter a tank 80 percent full averages an anti-knock index (AKI) of 86.90, one tenth below its limit, and the remaining fifth of the batch must be blended at 88.40 for the tank to land on its 87.20 target. The same deficit found with 5 percent of the batch left would need five times the correction of one found with 25 percent left. A second belief follows, that the online analyzer is the truth. It reports each parcel 3.0 min after the blend point, it can drift, and a model corrected only against it inherits its error, so a drifting analyzer takes the tank off specification while it reads on target. A step test from a recipe fraction to an octane reading would return a gain and a delay and say nothing about either belief.

✦ DID YOU KNOW? A Real Tank Found Off Specification

An industrial gasoline blend reported in 2010 began with about 20 000 m^3 of off-specification product already in the tank and 15 000 m^3 still to add [6]. Its controller ran every five minutes, and the tank came near its targets after about six hours. Case 4 of this chapter starts with 6400 m^3 and adds 1600 m^3.

The class of problem is general. Any product certified by an accumulated average has the same shape, a quality that is the integral of what has already been made, a measurement that arrives late, and a correction whose weight in the average falls as the batch grows. Cement raw materials are blended to a target chemistry by blending systems with control technologies of their own [7], and the exponentially weighted correction of a model offset that the blender's optimizer uses is the estimator that run-to-run control applies between runs in semiconductor manufacturing [8]. Economic optimizers whose model is corrected by a bias alone have been analyzed as a class [9], and blend scheduling ties the recipe to the tanks that must supply it [10].

However, the refining literature treats blending as a problem of planning and optimization [10, 11], and the control literature treats ratio control, analyzer loops and bias updating as separate structures [9, 12], so neither offers a plant on which a tank can be watched falling off specification while every loop reads on target. This chapter studies that failure on an in-line gasoline blender that runs in a browser and in which the header and the tank are separate objects, the analyzer and the laboratory are delayed and fallible instruments, and the certificate is computed from the tank's composition by the same blending rules as everything else. The blending correlations, the linear program, the bias update and the PI trims are all established practice. Section 1.4.6 of Chapter 1 introduces the tank average and the bias update in general terms, and this chapter works them out on one plant.

Section 15.2 covers the history of knock ratings, blending indices and blend optimizers. Section 15.3 specifies the blender: a 39-state model with finite component inventories and volume-weighted property ledgers in the tank, an analyzer with transport, sampling, noise, drift, freezing and validation, and a bounded bias update, both introduced by this application and since shared by the framework with other apps. Section 15.4 shows why the specification does not add up, through the vapor-pressure index, ethanol and the cheapest recipe. Section 15.5 describes the controller layers and derives two results: a closed-form statement of what the stopping floor and the header clip of cumulative targeting cost the certificate, and a four-report delay model of the octane trim whose poles explain the tuning that oscillates. Section 15.6 reports the eight cases and the graded batch measured on the engine, each of which sets a header against its tank, an analyzer against the blend it reports, or a fast trim against a slow certificate. Section 15.7 sets the real analyzer, valves and control platform beside the model, Section 15.8 states the limitations and Section 15.9 draws the conclusions.

15.2 Knock Ratings, Blending Indices and Blend Optimizers

Octane numbers (ON) began as a way to rank knock, a story the History box below tells. A blend of rated components does not carry the volume average of their ratings, and correlations for blends transform or correct the component octanes before averaging them [2]. The application uses an interaction structure that it attributes to the Ethyl RT-70 method of 1959, the volume average plus a term in the covariance of octane and sensitivity and terms in the variances of olefin and aromatic content, with coefficients chosen for teaching.

Vapor pressure has the same difficulty and a simpler remedy. Butane, the cheapest stream in the pool, sets the vapor pressure of the blend, and refinery practice blends the Reid vapor pressure (RVP) through an index, $\mathrm{RVP}^{1.25}$, that is linear by volume [1], a form the application attributes to a 1959 trade article by Stewart and to Chevron. The summer ceiling on vapor pressure is an air-quality rule, and the effect of gasoline content regulation on ozone has been estimated from monitoring data [13]. Ethanol complicates both properties. Its contribution to octane depends on the base fuel and on the amount added [3, 14], a small addition raises the vapor pressure of a hydrocarbon base [4], and its octane has been argued to justify engines of higher efficiency [15].

> ⧖ HISTORY **1927: Two Hydrocarbons Make a Scale**
>
> In the 1920s knock was traced to the composition of the fuel and the compression ratio of the engine, and the Bureau of Standards asked a steering committee to work toward a standard reference fuel and a test method [16]. In 1927 Graham Edgar expressed the knock characteristics of a gasoline in terms of a standard fuel, a mixture of two pure hydrocarbons whose proportion defines the rating [17]. The research and motor tests that followed still rate a fuel against mixtures of normal heptane and isooctane [16]. United States rules define the octane rating posted at the pump as half the sum of the research and motor numbers, measured by ASTM D2699 and D2700 [18]. Regular grade is 87 on that scale and premium 92 [16]. The specification of this chapter asks for 87.0.

Linear programming came to blending early. The blending of aviation gasolines was posed as a linear program in 1952 [11], and a survey of 1957 described linear programming across the oil industry [19]. A recipe computed offline assumes component properties that are known only approximately, so blenders acquired online analyzers and model-based optimizers that re-solve the recipe as the analyses arrive [5]. The adequacy of a model corrected only by a bias for an economic optimizer was analyzed in 1994 [9], recipe optimization was later combined with the short-term scheduling of the blend [10], and feedback control of blend properties continues to be refined [6].

The certificate adds one more layer. A blender that meets the specification in the header at every instant certifies its tank, but one that recovers from an upset in the header has still put off-specification blend into the tank, and only the blend still to come can offset it. The simulator makes that layer explicit. It aims the rest of the batch at the tank's own target through the cumulative average, and it computes the certificate that no instrument measures during the batch from the volume of each component the tank holds.

15.3 The Blender as Modeled

The simulated blender fills an $8000\,\mathrm{m}^3$ product tank at $1000\,\mathrm{m}^3/\mathrm{h}$, an eight-hour batch, from six streams numbered $i = 1$ to 6: n-butane (C4), light straight-run naphtha (LSR), reformate (REF), FCC gasoline (FCC), alkylate (ALK) and denatured fuel ethanol (ETH). Each stream passes its own flow controller into one header, a detergent additive is dosed into the blend in parts per million, a near-infrared (NIR) analyzer samples the header $15\,\mathrm{m}^3$ downstream of the blend point, and a knock-engine laboratory samples it every half hour, as shown in Figure 15.1.

The 39 states in Table 15.1 are the six component flows and the additive pump's flow, the volume of each component and of the additive in the product tank, the six inventories, eighteen property ledgers and the money spent on components, listed beside the measured, manipulated and disturbing variables. Internally the model works in SI units on a clock in minutes, the display switches between field units (bbl, bbl/h, psi, \$/bbl) and SI, and the exported file has 161 columns. Each exported row pairs the true header and tank properties with the NIR and laboratory readings and adds the biases, the recipes, the header targets, the remaining fraction, the give-away and the certificate.

15.3.1 Component Data and the Specification

The component table and the specification are illustrative teaching data, as the application declares, and they are listed in Table 15.2. The specification is a teaching grade in the manner of the summer regular gasoline of ASTM D4814, as the application states, and not a certified grade. It asks for an AKI, $(\mathrm{RON}+\mathrm{MON})/2$, of at least 87.0, an RVP of at most 7.8 psi (13.5 psi in the winter setting), at most 25 vol % aromatics, 10 vol % olefins and 0.62 vol % benzene, at most 10 mg/kg sulfur, 10 vol % ethanol and 3.7 wt% oxygen, and at least 36 ppm of additive. Two entries were set with the lesson in mind. The LSR naphtha carries 0.5 vol % benzene, because at 1.5 the benzene limit caps it and octane never binds, and ethanol is priced at \$130 a barrel, because at \$70 it would be the cheapest octane in the pool and the optimizer would add it to every blend.

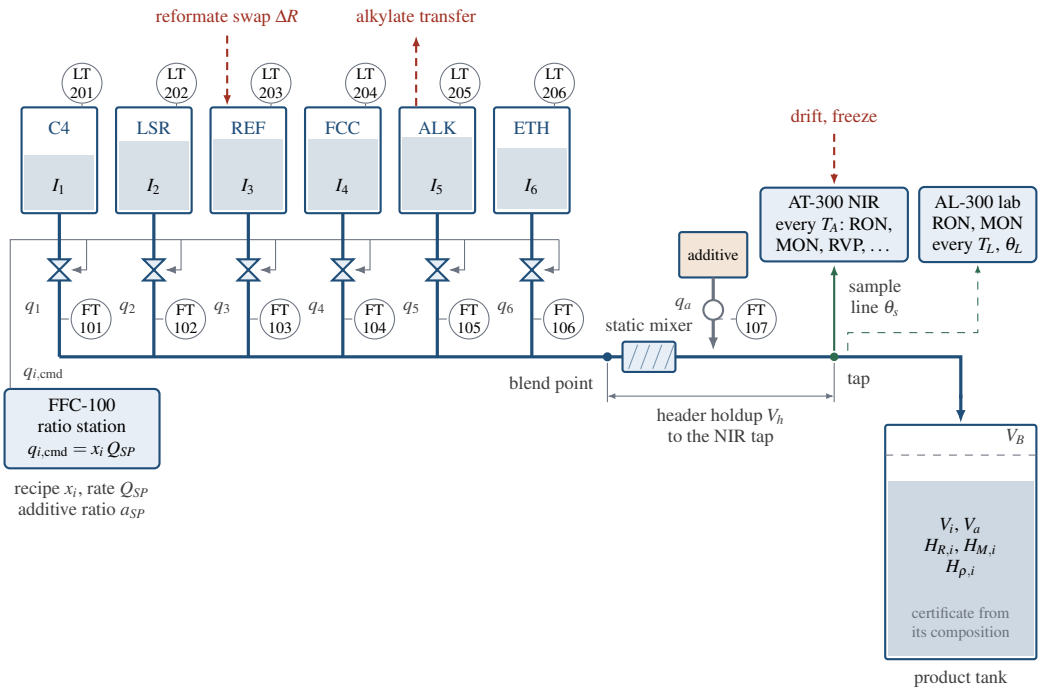


Figure 15.1 The in-line blender and its instruments. Six component tanks with inventories I_1 to I_6 and gauges LT-201 to LT-206 feed the header through valves commanded by the ratio station FFC-100, with each flow q_i metered by FT-101 to FT-106. The blend passes the static mixer, takes the additive q_a (FT-107), and travels the header holdup V_h to the tap of AT-300, which reports RON, MON, RVP, aromatics and benzene every T_A after the sample line's dead time θ_s. The laboratory AL-300 checks RON and MON every T_L with a turnaround of θ_L. The product tank holds each component's volume V_i with its volume-weighted RON, MON and density $H_{R,i}$, $H_{M,i}$ and $H_{\rho,i}$, up to the batch volume V_B. Thick dashed arrows (red) mark the disturbances.

15.3.2 Blending Rules

Every property of a blend is computed by one function from the volume fractions v_i of its components, and the header, the tank's certificate, the analyzer's truth, the optimizer and the operating map all call it. The compositional properties are averages by volume or by mass, as shown in Equation (15.1).

$$\begin{aligned} A &= \sum_i v_i A_i, \quad L = \sum_i v_i L_i, \quad Z = \sum_i v_i Z_i \\ \rho &= \sum_i v_i \rho_i, \quad S = \frac{1}{\rho}\sum_i v_i \rho_i S_i, \quad \omega = \frac{1}{\rho}\sum_i v_i \rho_i \omega_i \end{aligned} \tag{15.1}$$

where A, L and Z are the aromatics, olefins and benzene in vol %, the ethanol content is $E = 100\, v_6$, ρ is the density in kg/m^3, S the sulfur in mg/kg and ω the oxygen in wt%. Sulfur and oxygen are mass quantities, so they are weighted by volume times density. Vapor pressure is blended through its index, as shown in Equation (15.2).

$$\mathrm{RVP} = \left(\sum_i v_i R_i^{1.25}\right)^{0.8} \tag{15.2}$$

where R_i is the neat RVP of each hydrocarbon and $R_6 = 16.0\,\mathrm{psi}$ is the blending RVP of ethanol, far above its neat 2.3 psi. The index is homogeneous of degree one in the pressures, so Equation (15.2)

Table 15.1 Classification of Variables, With Values at the Start of Case 2

Variable	Role	Start value	Range
AKI_N, RVP_N	CVs, AIC-301 and 302	87.50, 7.36 psi	—
$\overline{AKI}$, $\overline{RVP}$	CVs, FY-400	—	—
tank AKI, RVP	certificate	—	—
Q_m	CV, FFC-100	1000 m^3/h	0–1200
x_i	MVs, recipe (vol %)	2, 16, 24, 26, 32, 0	0–60[a]
Q_{SP}	MV, blend rate	1000 m^3/h	0–1200
Δ_O, Δ_B	MVs, trims (vol %)	0, 0	±6, ±3
a_{SP}	MV, additive ratio	40 ppm	0–120
AKI_h, RVP_h	SPs, from FY-400	87.20, 7.70 psi	see text
ΔR	DV, reformate RON	0	−5 to +2
$\Delta\rho$	DV, FCC density	0	±30 kg/m^3
$\dot{b}_N$	DV, NIR drift	0	±2 ON/h
—	DVs, freeze, transfer	off	1500 m^3
c_i	DVs, prices ($/bbl)	40, 75, 95, 85, 105, 130	10–200
q_i, q_a	states, flows	$x_i Q_{SP}$, 667 mL/min	—
V_i, V_a	states, tank	0	—
I_i	states (m^3)	400, 2500, 3000, 3000, 3000, 1500	0–20000
$H_{R,i}$, $H_{M,i}$, $H_{\rho,i}$	states, ledgers	0	—
C	state, cost	0	—

[a] butane 0–12.

Table 15.2 Component Data. Illustrative Teaching Values, With RVP in psi, Aromatics, Olefins and Benzene in vol %, Sulfur in mg/kg, Density in kg/m^3, Oxygen in wt % and Price in $/bbl

	RON	MON	RVP	Aro	Ole	Bz	S	ρ	O	Price
C4	93.8	89.6	52	0	0	0	0	584	0	40
LSR	68	66	11.5	3	1	0.5	5	670	0	75
REF	98	88	3.5	62	1	0.6	1	815	0	95
FCC	92	80	6.5	28	30	0.8	30	745	0	85
ALK	95	92	4.5	0.5	0.5	0	1	700	0	105
ETH	109	90	2.3[a]	0	0	0	0	794	33.7	130

[a] neat, blended at 16.0 psi.

gives the same result in psi or kPa, and the ethanol value is calibrated so that E10 lifts a 7.0 psi base by 1.00 psi.

Octane is computed first for the hydrocarbon base, with $w_i = v_i/(1-v_6)$ for $i = 1$ to 5, as shown in Equation (15.3).

$$\begin{aligned} \mathrm{RON}_b &= \bar{R} + a_1\left(\overline{Rs} - \bar{R}\,\bar{s}\right) + a_2\left(\overline{L^2} - \bar{L}^2\right) \\ &\quad + a_3\left(\overline{A^2} - \bar{A}^2\right) \\ \mathrm{MON}_b &= \bar{M} + b_1\left(\overline{Ms} - \bar{M}\,\bar{s}\right) + b_2\left(\overline{L^2} - \bar{L}^2\right) \\ &\quad + b_3\left(\overline{A^2} - \bar{A}^2\right) \end{aligned} \tag{15.3}$$

where each bar is a w-weighted average over the base, R_i and M_i here denote the components' RON and MON, $s_i = \mathrm{RON}_i - \mathrm{MON}_i$ is the sensitivity, and the coefficients are $a_1 = 0.0322$, $a_2 = 0.00101$, $a_3 = 0$, $b_1 = 0.0445$, $b_2 = 0.00081$ and $b_3 = -0.00050$. The three interaction terms are a covariance and two variances, so they vanish for a single component. Ethanol then blends into the base with a

blending value that falls as the base octane rises, as shown in Equation (15.4).

$$\begin{aligned} \mathrm{RON} &= (1-v_6)\,\mathrm{RON}_b + v_6\,\beta_R \\ \mathrm{MON} &= (1-v_6)\,\mathrm{MON}_b + v_6\,\beta_M \\ \beta_R &= 128 - 1.5\,(\mathrm{RON}_b - 90) \\ \beta_M &= 100 - (\mathrm{MON}_b - 82) \end{aligned} \tag{15.4}$$

where β_R and β_M are ethanol's blending RON and MON, and $\mathrm{AKI} = (\mathrm{RON}+\mathrm{MON})/2$. The denaturant brings the oxygen of the ethanol from 34.7 to 33.7 wt%. The shipped recipe, 2 vol % butane, 16 LSR, 24 reformate, 26 FCC gasoline and 32 alkylate, blends to RON 91.39, MON 83.61 and AKI 87.50, with an RVP of 7.36 psi, 22.8 vol % aromatics, 8.36 vol % olefins, 0.43 vol % benzene, 9.24 mg/kg sulfur and a density of 732 kg/m^3, at \$91.30 a barrel.

15.3.3 Flows, Inventories and the Tank

Each flow controller is a closed loop of first order around its command, and the tank accumulates volumes and property ledgers, as shown in Equation (15.5).

$$\begin{aligned} \tau_F \frac{\mathrm{d}q_i}{\mathrm{d}t} &= q_{i,\mathrm{cmd}} - q_i, & \frac{\mathrm{d}V_i}{\mathrm{d}t} &= -\frac{\mathrm{d}I_i}{\mathrm{d}t} = q_i \\ \frac{\mathrm{d}H_{R,i}}{\mathrm{d}t} &= q_i\,\mathrm{RON}_i^*, & \frac{\mathrm{d}H_{M,i}}{\mathrm{d}t} &= q_i\,\mathrm{MON}_i^* \\ \frac{\mathrm{d}H_{\rho,i}}{\mathrm{d}t} &= q_i\,\rho_i^*, & \frac{\mathrm{d}C}{\mathrm{d}t} &= \sum_i c_i\,q_i \\ \tau_a \frac{\mathrm{d}q_a}{\mathrm{d}t} &= q_{a,\mathrm{cmd}} - q_a, & \frac{\mathrm{d}V_a}{\mathrm{d}t} &= q_a \end{aligned} \tag{15.5}$$

where flows are in m^3 per minute of the model's clock, $\tau_F = 5\,\mathrm{s}$, $\tau_a = 2\,\mathrm{s}$, and the starred properties are the true ones. A reformate tank swap moves the true reformate to $\mathrm{RON}_3^* = 98 + \Delta R$ and $\mathrm{MON}_3^* = 88 + 0.833\,\Delta R$, and a feed change moves the FCC density to $\rho_4^* = 745 + \Delta\rho$, while the optimizer keeps the declared table. Because the ledgers carry the octane each component had when it went in, the reformate already in the tank keeps its octane after a swap. The certificate evaluates Equations (15.1) to (15.4) on the tank's composition V_i with each component at $\mathrm{RON}_i^T = H_{R,i}/V_i$, $\mathrm{MON}_i^T = H_{M,i}/V_i$ and $\rho_i^T = H_{\rho,i}/V_i$, so the tank's average is exact under nonlinear blending and no analyzer reading enters it. Two events are applied after each step. A component tank that runs dry stops its flow at once, the overdraw of the last step is returned so that the balance still closes, and COMPONENT SHORT is raised. The batch completes when $\sum_i V_i$ reaches V_B.

The header holdup is represented only as the analyzer's transport delay. The tank receives the blend at the blend point, since everything in the header reaches the tank anyway, which keeps the balance $V_i(t) - V_i(0) = I_i(0) - I_i(t)$ exact. Give-away, the quality paid for and not needed, is scored on the tank as shown in Equation (15.6).

$$G = V\left[(\mathrm{AKI} - 87.0)^+\,v_{oct} + (\mathrm{RVP}_{\max} - \mathrm{RVP})^+\,v_{rvp}\right] \tag{15.6}$$

where the tank volume is V, $(\cdot)^+ = \max(0,\cdot)$, and v_{oct} and v_{rvp} are \$1.00 per octane number and \$1.00 per psi for each barrel.

15.3.4 Instruments

The flow meters FT-101 to FT-106 lag their flows by 1 s and carry 0.2 % white noise, and the tank gauges LT-201 to LT-206 lag by 10 s with a resolution of 0.5 m^3. The NIR tap sees the header composition V_h behind the blend point, a transport delay keyed by volume, so it lengthens as the

Table 15.3 Parameters and Where They Can Be Changed. Visible Ones Appear as Sliders in the Model Dialog, Hidden Ones Do Not, and Fixed Ones Are Written Into the Source

Symbol	Meaning	Value	Class
V_B	batch volume	8000 m^3	visible
—	already in the tank	0, case 4 6400 m^3	visible
$I_i(0)$	starting inventories	Table 15.1	visible
$q_{i,\max}$	valve capacities (m^3/h)	60, 400, 450, 450, 450, 150	hidden
R	valve rangeability	30:1	visible
τ_F	flow-loop time constant	5 s	visible
—	meter noise, lag	0.2 %, 1 s	hidden, fixed
—	gauge lag, resolution	10 s, 0.5 m^3	fixed
V_h	header holdup to the tap	15 m^3	visible
θ_s	sample-line dead time	1.1 min	visible
T_A	NIR cycle and analysis	1.0 min	visible
—	NIR noise, octane, RVP	0.10 ON, 0.35 kPa	hidden
—	bad analyses	2 % of reports	hidden
T_L, θ_L	laboratory interval, turnaround	30 min, 20 min	visible
—	laboratory repeatability	0.15 ON	hidden
$q_{a,\max}$	additive pump capacity	1500 mL/min	visible
N_a	additive pump turndown	10:1	visible
τ_a	additive pump time constant	2 s	hidden
—	additive required	36 ppm	visible
v_{oct}, v_{rvp}	give-away, per bbl	\$1.00/ON, \$1.00/psi	visible
—	NIR gate, octane, RVP, aro, Bz	1.0, 3.0 kPa, 2.0, 0.1	fixed
$b_{\max}$	bias bounds, same order	4, 14 kPa, 4, 0.3	fixed
—	laboratory correction gain	0.7	fixed
—	inventory reserve	20 m^3	fixed
—	targeting clip, AKI, RVP	1.5, 1.0 psi	fixed

blend rate falls. The analyzer draws a sample every T_A, the fluid now at its inlet after the sample line's dead time θ_s, and publishes the result one cycle later, as shown in Equation (15.7).

$$y_k = P\big(x(t_k - V_h/Q - \theta_s - T_A)\big) + b_N(t_k - T_A) + \varepsilon_k \tag{15.7}$$

where P is the property from Equations (15.1) to (15.4) on the true table, x the header composition and Q the blend rate. The noise ε_k has standard deviations of 0.10 ON on RON and MON, 0.35 kPa (0.05 psi) on RVP, 0.15 vol % on aromatics and 0.01 vol % on benzene, a bad analysis in 2 % of reports moves every channel the same way by 2.0 ON, 6.0 kPa, 3.0 vol % and 0.15 vol %, and the instrument's own error b_N integrates a drift in RON and MON. At 1000 m^3/h the header adds 0.9 min, so each report describes blend made 3.0 min earlier. A frozen instrument keeps publishing its last reading, and validation flags the analyzer STALE after three identical reports, or after three cycles without a fresh one. The knock-engine laboratory draws a header sample every $T_L = 30$ min and reports its RON and MON $\theta_L = 20$ min later, with a repeatability of 0.15 ON.

15.3.5 Initial States, Clock and Integration

Table 15.3 lists the parameters. Each case starts with the flows on the commands of its recipe, the additive pump on its ratio, the inventories at their starting values and the tank holding whatever the case places in it. Case 4 starts with 6400 m^3 of the optimizer's recipe blended from a reformate 1.108 RON weaker, an AKI of 86.90. The plant advances by fourth-order Runge-Kutta integration with a fixed step of 0.5 s, a tenth of the flow loops' time constant, the controllers execute every second, and the historian logs a row every 5 s, twelve per analyzer cycle and 5760 for an eight-hour batch. Every random sequence is seeded at 20261102, so a run replays bit for bit (Section 1.6.1), and the speed selector spans 1 to 300 simulated minutes per second of wall time, 5 by default, without changing the trajectory, so a full batch takes under two seconds at the fastest speed. The application passes 44 checks. Among them, halving the step moves the true header RVP through the butane step of case 1

and the tank AKI of case 2 at 240 min by less than 0.001, the tank holds the integral of its component flows to 10^{-9} through a transfer and a tank run dry, and the certificate is unchanged when a frozen, biased analyzer reading is altered.

15.3.6 Assumptions

The component table, the coefficients of Equations (15.2) to (15.4) and the specification are teaching values, not the properties of any refinery's streams, a fitted correlation or a certified grade. One blending RVP of 16 psi serves ethanol at every concentration, while real ethanol lifts the vapor pressure most near 5 to 10 vol % and less above, and the ethanol octane terms are meant for less than about 15 vol %.

Volumes are additive, so the shrinkage of a few tenths of a percent that butane causes on blending is ignored, and sulfur and oxygen are mass averages through fixed densities. The product tank is well mixed and receives the blend at the blend point, which is exact for the certificate at the end of a batch and shifts the analyzed record of the tank by the 15 m^3 in the header during it.

Each flow controller is a first-order closed loop with a capacity and a rangeability, without valve dynamics, stiction or meter calibration error. The NIR is a sample-and-hold instrument with white noise, occasional bad analyses, a drift that is a ramp and a freeze, and it reads the header by the same blending rules as everything else, so it has no chemometric error of its own. The laboratory is an unbiased instrument with a repeatability. All sizes, prices and limits are teaching values for one grade, not a design basis.

15.4 Why the Specification Does Not Add Up

Vapor pressure is the property that the recipe sets most sharply. In index form butane counts for 139.6 $\text{psi}^{1.25}$ against 21.2 for LSR, 10.4 for FCC gasoline, 6.6 for alkylate, 4.8 for reformate and 32.0 for ethanol at its blending value, while the shipped blend's index is 12.1. Differentiating Equation (15.2) with butane replacing the rest of the recipe in its own proportions gives the slope of Equation (15.8).

$$\frac{\mathrm{dRVP}}{\mathrm{d}x_1} = 0.8\,\mathrm{RVP}\,\frac{R_1^{1.25} - I_r}{I} \tag{15.8}$$

where I is the blend's index and $I_r = 9.52\,\text{psi}^{1.25}$ is the index of the non-butane part. At the shipped recipe the slope is 0.632 psi per 1 vol % of butane, against 0.461 psi for a volume average of the pressures, so the index rule weighs butane 1.37 times as heavily. Three more percent of butane lift the RVP from 7.36 to 9.20 psi, a rise of 1.84 psi where the volume average predicts 1.38, as shown in Figure 15.2. A blender who sized butane by the volume average would put 4.06 vol % in the blend and ship 8.64 psi against the 7.8 psi limit, while the index rule allows 2.70 vol %. Octane barely moves with butane, 0.037 AKI per percent, because butane is itself of high octane, so butane is run against the vapor-pressure ceiling and nothing else.

> **TRY IT IN THE APP** **1 · Manual recipe: butane and RVP**
>
> Load the case and press Run. Nothing else has to be set. At 5 min the butane in the recipe steps from 2 to 5 vol %. Watch the header RVP climb from 7.36 to 9.20 psi while the AKI barely moves. The analyzer first shows the step at 9.0 min. By then the tank has already passed its 7.8 psi limit, at 6.6 min.

Ethanol is the opposite case, a stream whose own properties mislead in both directions. In the shipped base Equation (15.4) gives ethanol a blending RON of 125.9 and MON of 98.4, far above its neat 109 and 90, so E10 raises the AKI from 87.50 to 89.96. Blended at its neat 2.3 psi, E10 would lower the RVP to 6.91 psi. At its blending value of 16 psi it raises the RVP to 8.31 psi, over the summer limit, and it brings 3.62 wt% oxygen against the 3.7 wt% limit. At $130 a barrel the E10 recipe costs $95.17 against $91.30, and room under the vapor-pressure ceiling for the ethanol has to come from butane and LSR naphtha.

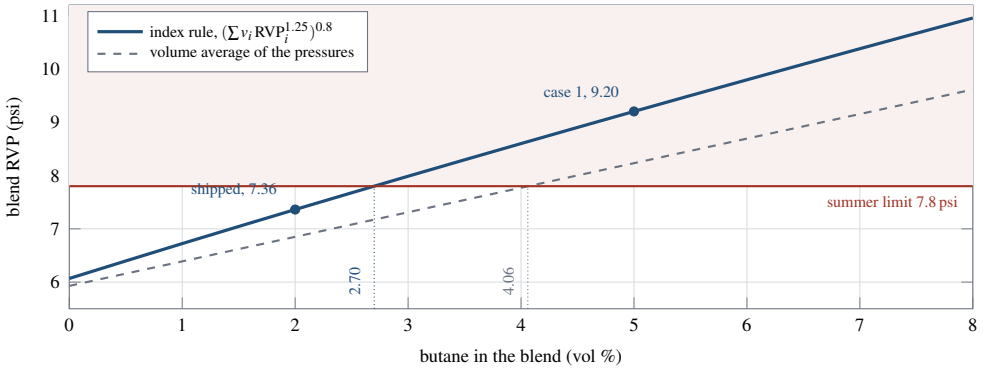


Figure 15.2 RVP of the shipped recipe against its butane fraction, with the other five streams in their shipped proportions. The index rule of Equation (15.2) (thick solid line) crosses the 7.8 psi limit at 2.70 vol % and the volume average of the pressures (dashed) at 4.06 vol %, and the two marked points are the shipped recipe and case 1 after its step.

The cheapest recipe is pressed against several of these limits at once. With every specification but AKI and RVP held a certification margin inside its limit (0.3 vol % aromatics and olefins, 0.02 vol % benzene, 0.3 mg/kg sulfur and 0.05 wt% oxygen), the linear program of Section 15.5, solved once from the shipped recipe at the base prices and targets of 87.20 and 7.70 psi, puts 2.40 vol % butane, 16.99 LSR, 26.36 reformate, 27.55 FCC gasoline and 26.70 alkylate in the blend. That recipe blends to AKI 87.21, 7.70 psi, 24.70 vol % aromatics and 9.70 mg/kg sulfur and costs \$90.19 a barrel against \$91.30 for the shipped recipe. Re-linearized at its own solution the program moves each fraction by less than 0.03 vol % onto AKI 87.20 exactly, and perturbing its targets there gives marginal values of \$1.004 per octane number and \$0.997 per psi for each barrel, the values that Equation (15.6) rounds to \$1.00. The feasible region around that vertex is a small pocket, which is why a recipe held by hand keeps a margin everywhere.

15.5 Implemented Controller

The control system reads only its instruments, the flow meters, the tank gauges, the NIR, the laboratory, the pumps' low-suction trips and the product tank's high level, and never the true header or the tank. It executes every $\Delta t_c = 1$ s, every second physics step, in the order of Section 1.6.1, and a row is logged every 5 s. A selector on the FY-100 card chooses where the recipe comes from, the recipe sliders with the trims' manual stations (fixed), the PI trims, or the optimizer, and a switch turns cumulative targeting on or off, as shown in Figure 15.3. In global manual the operator holds the recipe and both trim stations, every PI tracks, and the optimizer is still solved so that the map can show where it would go. In automatic the recipe sliders follow the optimizer's recipe and the trim stations follow the trims after every execution, so a switch to manual is bumpless.

15.5.1 Ratio Station, Flow Limits and Additive

FFC-100 multiplies the master rate by the recipe, and each flow command is limited by its valve, as shown in Equation (15.9).

$$q_{i,\mathrm{cmd}} = \mathrm{clamp}\big(x_i Q_{SP},\; q_{i,\max}/R,\; q_{i,\max}\big) \tag{15.9}$$

with $q_{i,\mathrm{cmd}} = 0$ when $x_i Q_{SP} < q_{i,\max}/(2R)$ or tank i is empty, so a valve controls no lower than a thirtieth of its capacity and shuts below half of that. Moving one recipe slider scales the other five to keep 100 percent. The additive pump is set in ratio to the metered header flow, $q_{a,\mathrm{SP}} = 10^{-6}\, a_{SP}\, Q_m$, and clamped between $q_{a,\max}/N_a$ and $q_{a,\max}$. At 40 ppm and 1000 m³/h it runs at 667 mL/min, and below 225 m³/h it sits on its 150 mL/min turndown, so at 150 m³/h it doses 60 ppm.

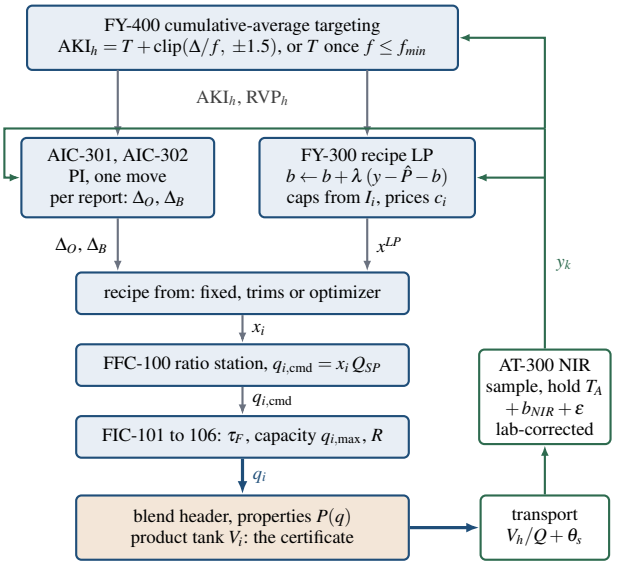


Figure 15.3 Control layers of the blender. Cumulative targeting sets the header targets, the PI trims or the recipe optimizer turn them into a recipe, the ratio station and the six flow loops deliver it, and the NIR reading y_k, delayed by the header, the sample line and the analysis cycle, returns to the trims, to the optimizer's bias update and to the analyzed tank average.

15.5.2 Property Trims

The two trims act on the recipe rather than on a valve. AIC-301 swaps reformate for LSR naphtha and AIC-302 adds butane with everything else scaled to make room, as shown in Equation (15.10).

$$\begin{aligned} d &= \text{clamp}(\Delta_O/100, -x_3, x_2) \\ x_3' &= x_3 + d, \qquad x_2' = x_2 - d \\ x_1'' &= \text{clamp}(x_1 + \Delta_B/100, 0, 0.5) \\ x_i'' &= x_i' \,\frac{1 - x_1''}{1 - x_1}, \qquad i \neq 1 \end{aligned} \tag{15.10}$$

Both are PI controllers in the framework's velocity form (Section 1.6.2), executed once for each fresh, valid NIR report while blend is flowing, as shown in Equation (15.11).

$$\begin{aligned} e_k &= \text{SP}_k - \text{PV}_k, \qquad P_k = K_c\,e_k \\ S_k &= S_{k-1} + P_k - P_{k-1}, \qquad v_k = S_k + I_{k-1} \\ u_k &= \text{clamp}(v_k, u_{min}, u_{max}) \\ I_k &= I_{k-1} + \left[\frac{K_c}{\tau_I}\,e_k + \frac{u_k - v_k}{\tau_I}\right]\Delta t_k \end{aligned} \tag{15.11}$$

where Δt_k, the time since the previous execution, is normally 1 min. These are Equations (1.16) to (1.19) of Chapter 1 with no derivative term, no output bias and $T_t = \tau_I$. Windup is handled by back-calculation on the integral alone, the clamp limits only what is emitted, and neither output has a rate limit. In manual, with a fixed recipe or under the optimizer, each trim tracks by setting $I_k = u_{op} - S_k$ for the value it is held at, so the return to the trims is bumpless. AIC-301 has SP = AKI$_h$, PV = AKI$_N$, output limits of ± 6 vol %, $K_c = 1.5$ vol % per ON and $\tau_I = 2$ min. AIC-302 has SP = RVP$_h$, PV = RVP$_N$, limits of ± 3 vol %, $K_c = 0.06$ vol % per kPa (0.41 per psi) and $\tau_I = 1.5$ min. Under the ISA convention both are reverse acting, since more reformate raises the octane and more

butane raises the vapor pressure, and positive gains with $e = \mathrm{SP} - \mathrm{PV}$ deliver that action. Volume 3, Chapter 7 trims a ratio blend of syrup into water on a refractometer in the same way. The split of Equation (15.10) adds one limit that the PI law does not know, the butane floor at zero, which would let the RVP trim's integral wind below -2 vol % on the shipped 2 vol % of butane. It never binds in the cases measured here, where the butane trim never falls below –0.94 vol %.

15.5.3 Validation, Laboratory Correction and the Bias Update

Each fresh report is first compared with the model's prediction for the very sample it analyzed. The controller keeps its own history of metered compositions keyed by metered volume, finds the metered volume V_m at the moment the sample left the tap, and predicts $\hat{P}_k = P(\hat{x}(V_m - V_h))$ on the declared table. A channel further than its gate width from the prediction plus its bias is rejected, unless three reports in a row are rejected on the same side, which is taken as a real change. With the laboratory correction on, each knock-engine result moves an offset c on RON and MON 70 percent of the way to the NIR's error on the laboratory's own sample, $c \leftarrow c + 0.7\,(y_N - y_L - c)$, and the controllers read $\tilde{y}_k = y_k - c$. The correction is off in the shipped cases. Chapter 9 corrects an analyzer and an inferred octane from its own laboratory engine. The bias of each measured property then follows Equation (15.12), the update of Equation (1.14) with a bound.

$$b \leftarrow \mathrm{clamp}\big(b + \lambda\,(\tilde{y}_k - \hat{P}_k - b),\; -b_{\max},\; b_{\max}\big) \tag{15.12}$$

with $\lambda = 0.3$ for RON, MON, RVP, aromatics and benzene, skipped when the reading is stale, rejected or taken while nothing flows. For a constant model error δ the bias after k updates is $\delta\,[1 - (1-\lambda)^k]$, 97 percent of the error in ten reports. The bias belongs to the model, and it cannot tell a drifting analyzer from a wrong model. The laboratory, an independent method, is the only element that can. An estimator that carries a bias as a state is the offset-free predictive controller of Volume 9, Chapter 4.

Pause. Try Exercise 15.2 before reading on.

15.5.4 Cumulative-Average Targeting

FY-400 keeps the tank's analyzed average. Each report stands for the metered volume that passed the tap since the previous one and is booked at its corrected AKI and RVP index, or at the model's prediction plus the bias when the reading cannot be trusted. With $\bar{V}$ the analyzed volume and $\overline{\mathrm{AKI}}$ its average, the targets follow Equation (15.13).

$$\begin{aligned} f &= \frac{V_B - \bar{V}}{V_B}, \quad \Delta = (T - \overline{\mathrm{AKI}})(1 - f), \quad D = \frac{\Delta}{f} \\ \mathrm{AKI}_h &= \begin{cases} T + \mathrm{clamp}(D, -1.5, 1.5), & f > f_{min} \\ T, & f \le f_{min} \end{cases} \end{aligned} \tag{15.13}$$

where T is the AKI target, 87.20 by default, Δ is the tank's deficit spread over the whole batch and $f_{min} = 0.05$. The header target $T + D$ is Equation (1.15) of Chapter 1 with $\overline{\mathrm{AKI}}$ as the average so far and f as the share still to blend. The RVP target is set the same way in index form, with a clip equivalent to 1.0 psi. The few tens of cubic meters in the header and the sample line that have not yet been analyzed count as remaining.

Pause. Try Exercise 15.1 before reading on.

The law has a closed-form cost. Blending a small share $\mathrm{d}\phi$ of the batch at a header AKI H changes the deficit by $\mathrm{d}\Delta = (T - H)\,\mathrm{d}\phi$. While the header delivers $T + D$ exactly, Δ falls in proportion to f, so D stays at its first value $D_0 = \Delta_0 / f_0$. While the clip holds the header at $T + c$, the deficit falls by c for each unit of batch blended. Either way the rest of the batch after f_{min} is blended at T, and the tank

finishes at the value of Equation (15.14).

$$\mathrm{AKI}_{end} = \begin{cases} T - f_{min}\,\Delta_0 / f_0, & D_0 \le c \\ T - \Delta_0 + c\,(f_0 - f_{min}), & D_0 > c \end{cases} \tag{15.14}$$

The floor therefore costs a shortfall of $f_{min} D_0$ even when the header meets every target, and without targeting the tank finishes at $T - \Delta_0$.

> **TRY IT IN THE APP** **4 · A late upset with 20 % left**
>
> Load the case and press Run. The tank starts 80 percent full at AKI 86.90, one tenth below its limit. Watch the header target rise to 88.40 and hold there while the tank average creeps up. At 75.0 min the targeting stops and the header returns to 87.20. The batch completes at 96.0 min and certifies at 87.15, short of its 87.20 target.

15.5.5 Recipe Optimizer

FY-300 solves a linear program on every NIR report around the recipe x^0 it last applied, as shown in Equation (15.15).

$$\begin{aligned} \min_{x,\,s \ge 0} \; & \sum_i c_i x_i + \sum_k w_k s_k \quad \text{subject to} \\ & \sum_i \bar{a}_i x_i + \tfrac{1}{2}\left(b_{\mathrm{RON}} + b_{\mathrm{MON}}\right) + s_1 \ge \mathrm{AKI}_h \\ & \sum_i R_i^{1.25} x_i - s_2 \le \left(\mathrm{RVP}_h - b_{\mathrm{RVP}}\right)^{1.25} \\ & \sum_i A_i x_i - s_3 \le A'_{\max} - b_A, \qquad \sum_i L_i x_i - s_4 \le L'_{\max} \\ & \sum_i Z_i x_i - s_5 \le Z'_{\max} - b_Z \\ & \sum_i \rho_i (S_i - S'_{\max}) x_i / \rho_r - s_6 \le 0 \\ & \sum_i \rho_i (\omega_i - \omega'_{\max}) x_i / \rho_r - s_7 \le 0 \\ & \sum_i x_i = 1, \qquad \ell_i \le x_i \le h_i \end{aligned} \tag{15.15}$$

where the primed limits carry the certification margins of Section 15.4, $\rho_r = 740\,\mathrm{kg/m^3}$, and $\bar{a}_i$ are the blending AKIs of the components, the forward-difference gradient g_i of Equations (15.3) and (15.4) at x^0 shifted so that $\bar{a}_i = \mathrm{AKI}(x^0) + g_i - \sum_j x_j^0 g_j$ and the linear model is exact at the recipe it starts from. The RVP row is exact, since the index is linear in volume. The elastic slacks s_k carry penalties of \$20 000 per cubic meter of blend for each unit of violation (\$200 000 for benzene and \$5882 per index unit for RVP), so they are zero whenever the specification can be met and report by how much it cannot. The bounds are $h_i = \min(\kappa_i, x_i^0 + \Delta x_{\max})$ and $\ell_i = \max(0, x_i^0 - \Delta x_{\max})$ with a step limit $\Delta x_{\max}$ of 2 vol % per analysis, and the caps are $\kappa_i = \min\left[1,\; (I_{i,m} - 20)/V_{rem},\; q_{i,\max}/Q_{SP}\right]$, so each component's gauged inventory less a $20\,\mathrm{m^3}$ reserve is spread over the volume V_{rem} still to blend (at least $20\,\mathrm{m^3}$), with ethanol further capped at 10 vol %. A dense two-phase simplex with Bland's rule solves the problem twice, once with the step limit for the recipe it applies and once without it for the map, the cost trend and the FY-300 card.

> ⧖ HISTORY **1980s: Blend Control Goes Online**
>
> Blend controllers that close the loop on online analyzers drew research effort for some forty years before 2010 [6]. Commercial blending control packages were available by the late 1970s, but none had a satisfactory answer to component properties that were poorly known. One refiner dates its first online applications to the early 1980s. In the late 1990s it took up the uncertainty problem, and the version in service since 2001 joins an optimization problem to a feedback loop with an observer of the component properties. By 2010 it ran on 17 blenders in six refineries [6]. The optimizer of this section answers the same uncertainty with the bias update of Equation (15.12).

15.5.6 What the Trims See and What the Controllers Assume

Section 15.3 describes the simulation model, and the application fits no control model of the plant. Manual steps of the trim stations in case 2, each made from the shipped recipe at 10 min, before the reformate swap, or at 40 min, after it, measure what the trims see. One percent of reformate for LSR raises the true header by 0.226 AKI within seconds (0.198 after the reformate swap), and half a percent of butane raises its RVP by 0.314 psi. A move made at one report first appears in the fourth report after it, because 3.0 min of transport and analysis and the phase of the sampling separate the blend point from the result. Volume 5, Chapter 3 meets the same limit on a column composition loop. The trim therefore sees $y_k = Ku_{k-4}$. Equation (15.11) emits u_k with the integral carried in from the previous report, so at $\Delta t_k = 1$ min the closed loop has the characteristic polynomial of Equation (15.16).

$$z^5 - z^4 + KK_c z - KK_c (1 - \Delta t_k/\tau_I) = 0 \tag{15.16}$$

For $K_c = 4$ and $\tau_I = 1$ min its dominant roots lie at $|z| = 1.13$ to 1.16 for $K = 0.198$ to 0.226, a growing oscillation with a period of 12 reports. For the shipped $K_c = 1.5$ and $\tau_I = 2$ min the slowest root is real, at 0.72 to 0.77, and at that integral time the loop turns unstable above $K_c = 3.9$ to 4.5. The shipped RVP trim, at $K = 4.33$ kPa per percent of butane, has its slowest root at 0.76. The controllers' internal models are the linearized blend model with its biases in Equation (15.15), the aligned prediction $\hat{P}_k$ on the declared table, the volume average in Equation (15.13), and the recipe split of Equation (15.10). None of them knows the true reformate, the analyzer's drift or the composition of the tank.

🕮 **Pause.** Try Exercise 15.3 before reading on.

15.6 Scenarios and Measured Results

The cases of Table 15.4 share one reference configuration, that of Table 15.1 with the outlier gate on, the laboratory correction off, $\lambda = 0.3$, a step limit of 2 vol % and a floor of $f_{min} = 0.05$, and each departs from it only where its row says so. Every number in this section was measured headlessly on the engine at its default seed, with each configuration set on the case as loaded before the run starts. The application pauses a run when the batch completes, and Table 15.5 gathers the scorecard of each batch at that pause. Times are simulated minutes counted from the start of each case. Reloading a case after a run, or pressing Reset with the same settings, reproduces these numbers exactly, and the spread over six noise seeds is given beside the results that the noise moves most. Figure 15.4 draws the certificate AKI and the give-away of Table 15.5 as a chart.

15.6.1 Butane, Ethanol and the Analyzer's Delay

In case 1 the butane goes from 2 to 5 vol % at 5 min, in manual. The butane flow reaches 90 % of its step 11.5 s after the recipe changes, as its 5 s loop requires, and the true header RVP rises from 7.36 to 9.20 psi while the AKI moves only from 87.50 to 87.61. The first NIR report that shows the step arrives at 9.0 min. Its sample left the tap at 6.9 min, carrying blend made at 6.0 min, so the report is 4.0 min after the step and 3.0 min after the blend it describes. The tank passes the 7.8 psi limit at 6.6 min, before the analyzer has reported anything, and holds 8.74 psi at 20 min. Case 5 adds 10 vol % of ethanol at 5 min, in manual, and the header goes from AKI 87.50 to 89.96 (RON 91.39 to 94.84, MON 83.61 to 85.09) and from 7.36 to 8.31 psi, the numbers of Section 15.4.

Table 15.4 Cases, Their Events and What Each Teaches

#	Scenario and event	Teaching point
1	manual, butane 2 to 5 vol % at 5 min	index rule, analyzer delay
2	fixed, reformate −3 RON at 30 min	a recipe is its data
3	trims at $K_c = 4$, $\tau_I = 1$, swap at 10 min	PI on a dead time
4	optimizer, tank 6400 m^3 at 86.90	Δ/f and the floor
5	manual, ethanol 0 to 10 vol % at 5 min	octane and RVP together
6	butane \$25 at 5 min, optimizer at 10	an LP sits on its limits
7	optimizer, NIR drift +0.2 ON/h at 10	bias follows the analyzer
8	optimizer, 1500 m^3 alkylate out at 60	plan the inventory
9	fixed, swap at 120 min, 1600 m^3 alkylate	graded batch

Table 15.5 Scorecard of Full Batches: Certificate AKI and RVP, Result, Give-Away and Blend Cost

Case and configuration	AKI	RVP	Certificate	G (\$)	\$/bbl
2 fixed	86.79	7.36	off, AKI	22 062	91.30
2 trims	87.19	7.70	certified	14 769	91.27
2 optimizer	87.19	7.70	certified	14 396	90.95
4 targeting on	87.15	7.70	certified	12 610	91.14
4 targeting off	86.96	7.70	off, AKI	5 131	90.18
4 trims, targeting on	87.15	7.70	off, aromatics	12 473	90.72
6 full batch	87.20	7.70	certified	15 493	89.85
7 correction off	86.45	7.70	off, AKI	4 854	89.43
7 correction on	87.06	7.70	certified	7 835	90.04
8 optimizer	87.18	7.71	certified	14 001	90.86
8 fixed[a]	86.67	8.02	off, four	0	88.60
9 as shipped[a]	85.97	7.84	off, four	0	88.88
9 trims[a]	86.69	7.70	off, three	4 793	89.50
9 optimizer	87.19	7.71	certified	14 041	91.56
9 suggested	87.19	7.70	certified	14 511	91.57

[a] alkylate ran dry, and the batch completed after 480 min, at 532, 565 and 564 min. RVP in psi.

15.6.2 A Recipe Is Only as Good as Its Data

In case 2 the blender runs the shipped recipe into an empty tank, and at 30 min the reformate is drawn from a tank 3 RON and 2.5 MON weaker. The header falls from AKI 87.50 to 86.74 within a minute, and the NIR first reads below 87.0 at 33.0 min. Nothing acts on it. The tank average crosses 87.0 at 87.5 min, and the batch completes at 480 min at AKI 86.79, off specification, with about 309 m^3 of alkylate needed to correct it. With the PI trims, selected before the run, the octane trim ends at 2.21 vol % of reformate for LSR and the butane trim at 0.82 vol %, and the tank certifies at 87.19 with \$14 769 of give-away (\$14 769 to \$15 133 over six noise seeds). The optimizer certifies at the same AKI for \$90.95 a barrel against \$91.27 for the trims, because it re-optimizes the whole recipe while the trims move only reformate against LSR and butane against the rest.

15.6.3 An Octane Trim on a Dead Time

Case 3 ships the octane trim tuned like a flow loop, 4 vol % per ON with a 1 min integral time, and swaps the reformate at 10 min. Three corrections go out before the first is seen, the true header swings between AKI 85.59 and 87.93 in the hour, crossing 87.20 downward every 11.3 min (11.0 min to 11.6 over six noise seeds), and the trim sits on its ±6 vol % limits 38 % of the time from 12 min to 60. The growth that Equation (15.16) predicts for this tuning is held by those limits in a limit cycle, and its period of 11.3 reports lies near the 12 of the linear model. With the shipped 1.5 vol % per

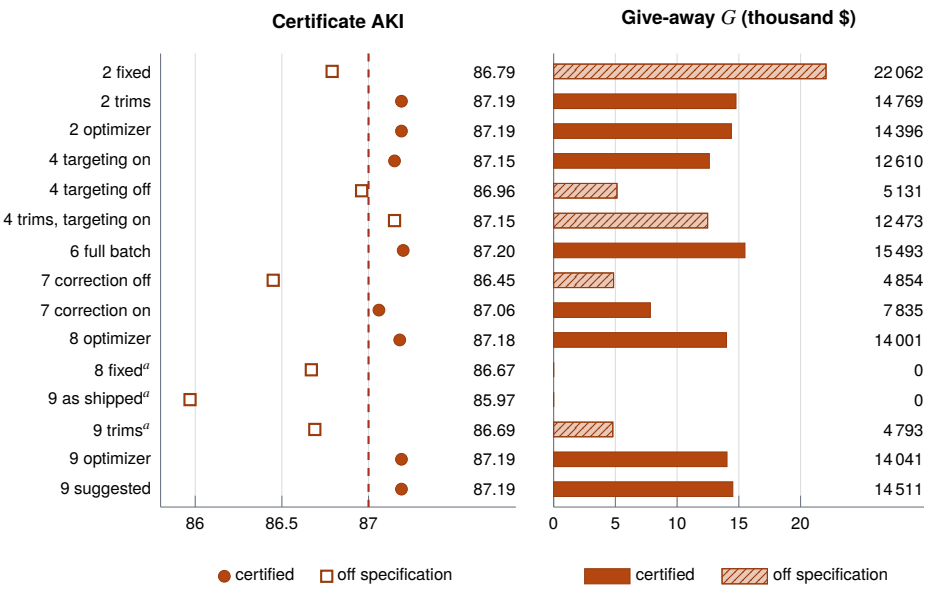


Figure 15.4 The certificate AKI and the give-away of Table 15.5 as a chart. The dashed line is the 87.0 limit. Filled circles and solid bars are certified batches, open squares and hatched bars are batches off specification. Notice that every certified batch lands between the limit and the 87.20 target and gives away $7 835 or more, that the batches with the least give-away are all off specification, and that one batch, the trims of case 4 with targeting on, clears the octane limit and still fails, on aromatics. Rows marked *a* ran the alkylate dry.

ON and 2 min set before the run, the header dips to 86.47 and is back within 0.1 AKI of its setpoint 9.0 min after the swap (6.1 to 9.3 min over the seeds). At 0.5 and 2 min it dips only to 86.62 but takes 33.1 min (28.3 to 33.1), the slow root of 0.94 to 0.95. Holding 2 min and raising the gain, the header's noise-driven swing over each half hour from 60 to 240 min grows from 0.18 to 0.26 AKI peak to peak at $K_c = 2.5$ to between 0.30 and 0.72 at 4.5, where Equation (15.16) puts the root for the weaker reformate at $|z| = 1.00$. On a loop that is almost pure delay the integral action does the work, and the gain mainly decides how hard the first correction is.

15.6.4 A Late Deficit and Its Floor

Case 4 starts with 6400 m^3 in the tank at AKI 86.90 and blends the last 1600 m^3 with the optimizer and cumulative targeting on. The deficit is $\Delta_0 = 0.30 \times 0.8 = 0.24$ at $f_0 = 0.2$, so $D_0 = 1.20$ and the header target rises to 88.40, then to between 88.40 and 88.44 as blend made before the optimizer reached the new target enters the analyzed average. The optimizer meets it within 3 min, since it may move each fraction 2 vol % per analysis. While its steps are limited it borrows up to 2.0 vol % of ethanol, gone again by 4 min, and from 10 to 70 min its recipe averages 31.3 vol % of alkylate instead of 26.7 and 3.1 of butane instead of 2.4, with LSR cut from 17.0 to 11.0. The demand D stays between 1.21 and 1.24 from 5 to 75 min, as the analysis of Equation (15.14) requires. The targeting stops at 75.0 min, when the analyzed share left falls below 5 percent, and the header returns to 87.20. The batch completes at 96.0 min and certifies at AKI 87.15, on specification but short of target, with $12 610 of give-away, as shown in Figure 15.5. Without targeting, switched off before the run, the last fifth is blended at 87.20 and the tank certifies off specification at 86.96, exactly $T - \Delta_0$, and needs about 63 m^3 of alkylate.

Equation (15.14) predicts 87.14 for this case, and the engine lands 0.011 higher because the targeting stops on the analyzed volume, 7615 m^3, while the tank already holds 7650 m^3, 50 m^3 past



Figure 15.5 Tank view of case 4, listed in the scenario menu as 4 · A late upset with 20 % left, at $t = 1.60$ h (96.0 min), the instant the batch completes and the application pauses the run, with the optimizer writing the recipe and cumulative-average targeting on, cropped to the plant view with numbered callouts. The scene reads batch complete with 50 318 bbl in a tank of 50 318 bbl and the header still metering 6278 bbl/h, since the valves close at the next control execution. The badges (1) give the tank at AKI 87.15 and 7.70 psi, $12 610 of give-away, $91.14 a barrel, 0.46 vol % benzene and 0 bbl remaining. Beside the product tank (2) its record shows the 6400 m^3 that started the case hatched below the 87.0 limit and the brighter slices blended near 88.4 above them. The remaining-authority chart draws Δ/f for the 0.049 AKI still missing against f from 0.5 to 0, with the present point (3) at the top of its scale, marked stopped below $f = 0.05$, and the floor at $f = 0.05$ crossing the +1.5 header limit (4). The certificate (5) passes all nine rows, with $7 578 of octane and $5 031 of RVP give-away, and the status line reads batch complete, tank certified. In the full window, outside this crop, the FY-400 card reports the analyzed AKI of 87.15 below the 0.05 floor, stopped, and the trends show the header AKI target near 88.42 until the stop at 1.25 h and 87.20 after it.

the floor, and the header needs another 131 s, about 36 m^3 of blend, to come back down. Four variants of the case, run headlessly with the starting tank made weaker by lowering only the reformate octane of its fill, a change the application does not offer, test the clipped branch. For starting averages of 86.80, 86.70, 86.67 and 86.60 the header target runs on its +1.5 clip at 88.70 from start to stop, the formula predicts 87.105, 87.025, 87.001 and 86.945, and the engine finishes at 87.115, 87.035, 87.011 and 86.955. The shipped floor and clip can therefore certify a tank found 80 percent full at an average as low as 86.67 and no lower. With the floor moved to 0.02, 0.10 and 0.15 instead, the formula gives 87.176, 87.080 and 87.020 for the shipped case and the engine finishes at 87.187, 87.089 and 87.027. The trims can meet the same octane demand, but by swapping reformate for LSR, and with targeting on they certify the octane at 87.15 while the aromatics end at 25.17 vol %, over the limit, a constraint that only the optimizer knows about.

15.6.5 An Optimizer on Its Constraints

In case 6 butane drops from $40 to $25 a barrel at 5 min and the optimizer takes over at 10 min. Moving each fraction 2 vol % per analysis, it reaches its optimum at the analysis at 12.0 min and then

follows it as the bias moves with the analyzer noise. From 30 to 60 min the applied recipe averages butane 2.40, LSR 17.05, reformate 26.31, FCC gasoline 27.54 and alkylate 26.69 vol %, and the header averages AKI 87.19 and 7.70 psi, on its targets. The optimum is pressed against AKI, RVP, aromatics and sulfur at once. At $25 butane the recipe costs $89.82 a barrel against $91.00 for the shipped one, a saving of $1.18 a barrel or about $59 000 on an 8000 m^3 batch, and the give-away of the blend falls from $0.94 to $0.29 a barrel. Run to the end, the batch certifies at 87.20 for $89.85 a barrel. Over the same half hour the bias-corrected linear model judges the true blend with a mean error of 0.008 AKI and −0.005 psi, inside the 0.05 AKI and 0.03 psi of one of the application's own checks.

15.6.6 An Analyzer That Drifts

In case 7 the optimizer blends the on-target recipe and, from 10 min, the NIR's octane drifts upward by 0.2 ON an hour, with the laboratory correction off. The bias update cannot tell the analyzer from the model. The model's RON bias follows the NIR to +0.68, and the optimizer cuts the octane it believes it has in excess, alkylate falling to 23.9 vol %. By 240 min the NIR reads 87.15 while the header is truly 86.50, the NIR's own error is 0.77, and the tank has fallen to AKI 86.85, off specification. The laboratory sees the discrepancy, the NIR reading 0.74 high on its last result, at 230 min. With the correction set on before the run, each result moves the NIR most of the way back, and the tank is at 87.03 at 240 min (87.03 to 87.15 over six noise seeds, against 86.84 to 86.85 without it), on specification, with the header lagging the drift by one laboratory interval. Run to 480 min, the tank certifies at 87.06 with the correction and fails at 86.45 without it, needing about 840 m^3 of alkylate.

15.6.7 An Inventory That Runs Short

In case 8 a premium blend takes 1500 m^3 of alkylate at 60 min. The optimizer's cap on alkylate falls from 38.8 vol %, above the 26.7 it was using, to 17.4 vol % at the next analysis, the 1213 m^3 left above the reserve spread over the 6983 m^3 still to blend, and the optimizer then holds alkylate at 17.3 vol %. From the analysis at 63 min it has more than 5 vol % of ethanol in the blend, 5.5 vol % at 75 min, and it pays for ethanol's vapor-pressure bump by cutting butane from 2.4 to 0.7 vol %, a new vertex of the program. For the three analyses at 61, 62 and 63 min the step-limited program applied to the blender needs its elastic slacks, while the unlimited program shown on the FY-300 card stays feasible, and the header dips only to AKI 87.07. The batch certifies at 87.18 with 20 m^3 of alkylate left, at $90.86 a barrel. The fixed recipe, selected before the run, keeps drawing the case's 26.7 vol % of alkylate, runs the tank dry at 337 min, blends on without it and has only 7364 m^3 in the tank at 480 min. It completes the batch at 532 min at AKI 86.67 and 8.02 psi, off specification on AKI, RVP, aromatics and sulfur with no single stock left that could correct it.

> **+ DID YOU KNOW? The Cheapest Batches Give Nothing Away**
>
> From the simulator (Table 15.5). The two batches with $0 of give-away are also the two cheapest, at $88.60 and $88.88 a barrel, and both fail four specifications. Every certified batch gives away between $7 835 and $15 493. A scorecard of cost and give-away alone would rank the failures first.

15.6.8 The Graded Batch

The challenge blends the 8000 m^3 batch through a reformate swap at 120 min (−3 RON) with 1600 m^3 of alkylate in its tank, less than the shipped recipe draws. The target asks for the batch to finish within 8 h, certified on every specification with no reblend, with no component tank run dry and with less than $16 000 of give-away. As shipped, on the fixed recipe, the alkylate runs dry at 300 min and the blend goes on without it at 680 m^3/h, so only 7040 m^3 are in the tank at 480 min, at AKI 86.21 with 25.84 vol % aromatics and 10.31 mg/kg sulfur, and no single stock left can correct it. The batch completes only at 565 min, at AKI 85.97 and off specification on RVP as well. The trims

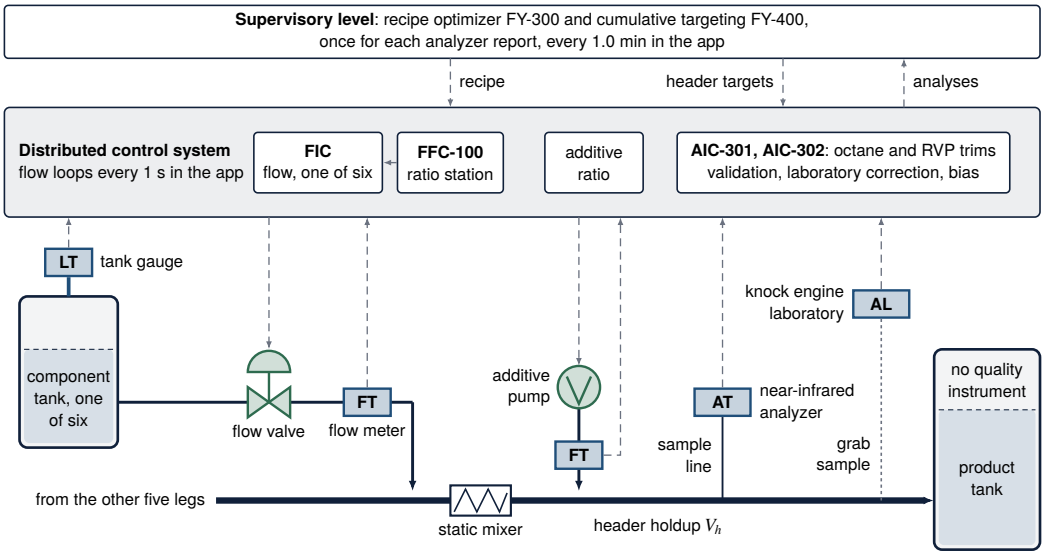


Figure 15.6 The loops of the blender with their hardware. Lettered boxes are sensing devices, namely the tank gauge (LT), the flow meters (FT), the online analyzer (AT) on its sample line and the laboratory (AL). Valve and pump symbols are final elements. Dashed arrows are signals. Notice that every quality reading is taken from the header, late, and that nothing reads the quality of the product tank, so the tank average that the certificate is written on exists only as a calculation at the supervisory level. Not to scale, and not a piping diagram.

do no better, with the alkylate dry at 301.9 min and the tank at 86.80 at 480 min, because they react to the octane and not to the inventory. With the optimizer and cumulative targeting, the suggested configuration, the optimizer spreads the alkylate over the whole batch from the start and covers the octane with ethanol, 5.45 vol % in the finished tank, its bias catches the reformate swap, and the batch completes at 480 min certified at AKI 87.19 and 7.70 psi with \$14 511 of give-away, at \$91.57 a barrel. The give-away limit was calibrated on that run with a margin of 10.3 %, and six noise seeds give \$14 511 to \$14 861, all passing. The optimizer does most of the work, and without targeting it certifies at 87.19 with \$14 041 of give-away. The batch is judged on the case as given, so a changed model parameter or disturbance voids the attempt.

15.7 Technology in Practice

Figure 15.6 draws one of the six component legs and the quality loops of Section 15.5 with the hardware a refinery installs.

What Measures It

The blend is read twice, by an online near-infrared analyzer (Figure 15.7) and by a laboratory knock engine that rates a sample by the research and motor methods, ASTM D2699 and D2700 [18]. Refiners install a limited number of analyzers, at the blender outlet. For cost and reliability the component properties are generally not measured on line, and the readings of the blend can suffer large and variable delays that depend on the sampling loop and the measurement technology [6]. The holdup V_h, the dead time θ_s and the cycle T_A of Equation (15.7) stand for that loop. Laboratory data have a very low time resolution and can be late or inaccurate, through a time stamp set half by hand, the location of the sampling point or a faulty entry [6]. The model's laboratory is late but unbiased.

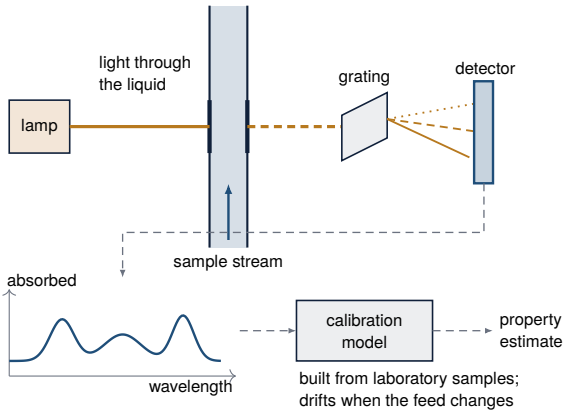


Figure 15.7 Principle of a near-infrared analyzer on a liquid stream. Notice that the detector delivers a spectrum and not a property. The octane and the vapor pressure come out of the calibration model, which is why Equation (15.7) gives the reading its own error b_N apart from the blend it describes.

> **TECHNOLOGY** **Sensor: Near-Infrared Analyzer**
>
> A near-infrared analyzer passes light through the fuel and records how much of each wavelength is absorbed. The bands are overtones and combinations of the vibrations of bonds such as carbon to hydrogen, and information on the different types of hydrocarbon is present throughout the region [20]. A measurement takes one minute or less and suits in-line use, and optical fibers let one instrument watch points up to 100 m away [20]. The analyzer does not measure octane. A multivariate model turns the spectrum into a property, and the method depends on a good reference method for the samples that teach it [20], here the knock engine. The 1.0 min cycle T_A of Table 15.3 stands for the scan. An analyzer fed by a blocked sample line goes on reporting stale sample with no way of knowing it [21], the frozen reading that validation flags STALE.

What Moves It

The recipe reaches the plant through six flow loops, each a meter, a controller and a valve. In ratio control a flow that is not controlled is called wild, and a flow held in proportion to it is called captive [21]. In this blender all six flows are captive to the master rate Q_{SP} of Equation (15.9), and the additive pump is captive to the metered header flow.

> **TECHNOLOGY** **Final Element: Flow Control Valve**
>
> Each component leg ends in a valve under a flow controller, and refiners call the set of these loops the ratio control system [6]. On an air-operated valve a positioner watches the stem and drives it to the position the controller's signal asks for [21]. The usual trouble is friction at the stem. The stem holds until enough force has built up and then jumps, so a smooth signal becomes a staircase, an effect called stiction. With integral action in the loop the controller output then ramps up and down without end, a slip-stick cycle, and detuning only lengthens its period [21]. The model's valves have a rangeability of 30 to 1, a 5 s flow loop and no friction.

Where the Controller Runs

A refinery runs such loops in a distributed control system, in which a supervisor sends set points to distributed controllers that act through actuators from sensor feedback, with cycle times from milliseconds to minutes [22]. The app executes its flow loops every 1 s, and the trims, the optimizer FY-300 and the targeting FY-400 once for each analyzer report, every 1.0 min. An industrial blend controller built from an optimizer and an estimator was reported to run on standard control systems

every 1 to 5 minutes [6]. The ratio station FFC-100 and the six flow loops would sit in the distributed controllers as function blocks, and the optimizer and the targeting at the supervisory level.

> **IN PRACTICE** **Certifying a Blend in the Line**
>
> United States fuel rules have a manufacturer test each batch of gasoline for sulfur, and each summer batch for vapor pressure, before it leaves the plant [23]. An in-line blender may ask for a waiver. The request describes how the automated system monitors and controls the proportions and the properties, and how composite samples are taken to ASTM D4177 and D5854. The operation is audited every calendar year, and a new request is due 60 days before a material change, such as new analyzer hardware or programming, a moved analyzer or new mixing control logic. The summer ceiling is 9.0 psi, or 7.8 psi in listed areas, with 1.0 psi more for blends of 9 to 10 percent ethanol [23].

What Is Modernizing It

Three developments bear on this chapter. The first is certification from the line. The waiver of the In practice box lets composite samples and an audited automated system stand in for a test of every tank [23]. The second is control that does not trust the component table. The industrial controller cited above estimates the component properties from the blend analyses in closed loop, and its estimates need not converge to the true values for the blend to reach its target [6]. The bias update of Equation (15.12) takes the same stance. For a tank that is not empty at the start, that controller uses a heel management strategy, a reference for the header computed from the tank's balance [6], which is the cumulative targeting of Equation (15.13). The third is the link upward. In many modern systems the distributed control system is interfaced with the corporate network to give business operations a view of production [22].

15.8 Limitations

The blending rules are correlations with illustrative coefficients, and the component table and the specification are teaching values for one summer grade, not the data of a refinery or a certified blend. Ethanol blends at one RVP whatever its concentration, and volumes blend without shrinkage.

The analyzer reads the header by the same rules that make the header, so it has noise, bad analyses, drift and freezes but no chemometric error, and the laboratory is unbiased. The targeting averages octane linearly over the analyzed volume, which ends case 4 within 0.001 of the tank's true AKI, and it fills an analyzer outage with the model's prediction plus its last bias, so a long outage is only as good as the model. The laboratory correction lags a drifting analyzer by about one laboratory interval.

The optimizer is a successive linear program with a step limit on one grade, and the valuation of give-away at $1.00 per octane number and per psi is fixed at the base prices. The map's feasible region is a small pocket around the optimum, there is no season switch within a batch, and blend scheduling across several tanks and grades is outside the model. The reformate swap and the alkylate transfer are applied as steps, which a refinery would seldom see, because a step isolates the effect of one cause.

> **OPEN CHALLENGE** **An Analyzer Model That Ages**
>
> The analyzer of this chapter drifts and freezes, but its model of the fuel is never wrong. Real calibration models are less sure. A near-infrared method depends on the quality of its reference values, a model may need a hundred to a thousand samples that span the natural variability, and a sample of different composition shows up as an outlier [20]. A 2025 study states that the usual linear model relies heavily on the match between calibration samples and new ones, that varied crude sources and processes compromise its accuracy, and that automated adaptive modeling needs further development [24]. Progress would be an analyzer that reports when a blend has left its calibration, before the laboratory of case 7 finds out.

15.9 Conclusion

The simulator of this chapter certifies the product tank from its own composition while every controller works from the header, which is the arrangement of a real in-line blender. Butane's index of 139.6 psi$^{1.25}$ makes three percent of it lift the RVP by 1.84 psi where the volume average predicts 1.38, and ethanol raises the AKI by 2.46 and the RVP by 0.95 psi at once. A fixed recipe through a reformate 3 RON weaker certifies at 86.79, and an octane trim tuned at 4 vol % per ON and 1 min oscillates with an 11.3 min period, near the 12 reports that a four-report delay model predicts. A tank 80 percent full at 86.90 needs 88.40 from the rest of the batch and certifies at 87.15 with cumulative targeting and at 86.96 without it, and the closed form for the floor's shortfall predicts the engine within 0.011 AKI down to the boundary at a starting average of 86.67. A drifting analyzer takes the tank to 86.85 through the bias update while the laboratory correction holds it at 87.03, and the graded batch goes from 7040 m^3 off specification at 480 min to a certified 8000 m^3 with \$14 511 of give-away. The model has no chemometric analyzer error, no shrinkage and one grade. A fuller model would add a season switch, blending across several product tanks, a moving-horizon estimate of the tank average and an analyzer whose calibration fails differently from the blend model. The blender shows why a batch that is certified by its average has to be steered from its first barrel.

KEY POINTS

- The certificate is written on the tank, and the tank remembers every barrel. A header on specification does not make a blend on specification.
- A deficit Δ found with a share f of the batch left asks the header for Δ/f more, five times as much at 5 percent left as at 25.
- Each analyzer report describes blend made 3.0 min earlier, so an octane trim tuned like a flow loop oscillates.
- The bias update cannot tell a drifting analyzer from a wrong model. Only the laboratory, an independent method, can.
- Butane is run against the vapor-pressure ceiling and nothing else.

Where else this applies. A late, drifting analyzer checked by a laboratory returns in Volume 5, Chapter 4, a ratio blend trimmed on an analyzer in Volume 3, Chapter 7, a loop on a slow analyzer in Volume 5, Chapter 3, and an estimator that carries a bias in Volume 9, Chapter 4.

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15.10 Exercises

15.1 ⌕ Concept check · 2 min

With cumulative-average targeting, a deficit found with 5 % of the batch left needs five times the header correction of the same deficit found with 25 % left. Why?

(a) The analyzer delay grows as the tank fills, so a late correction must be larger to show in time

(b) The optimizer may move each fraction only 2 vol % per analysis, a limit that binds harder late in the batch

(c) A nearly full tank mixes slowly, so late blend must carry extra octane to reach the sample point

(d) The header adds $D = \Delta / f$, the deficit spread over the batch divided by the share still to blend

15.2 ⌕ Concept check · 1 min

In case 7 the NIR's octane drifts upward and the bias update of Equation (15.12) follows it. Which element of the blender can tell a drifting analyzer from a wrong blend model?

(a) The knock-engine laboratory, an independent method that tests the analyzer on its own sample

(b) The outlier gate, which rejects a reading far from the model's prediction plus its bias

(c) The bias bound $b_{\max}$, which stops the bias once it grows past four octane numbers

(d) The cumulative-average targeting, which books every analysis into the tank's average

15.3 Concept check · 2 min

Case 3 ships the octane trim at 4 vol % per ON with a 1 min integral time, and the header swings between AKI 85.59 and 87.93 with a period of about 11 min. What causes the oscillation?

(a) The six flow loops resonate with the reporting interval, since their lag is close to one analysis

(b) A move first appears in the fourth report after it, so three more corrections go out before the first is seen

(c) The trim's ±6 vol % limits wind up the integral, since the velocity form has no anti-windup

(d) The NIR noise of 0.10 ON is amplified by the high gain into a sustained swing

15.4 Theory and calculation · 8 min

The shipped recipe has 2 vol % butane and an RVP of 7.36 psi. Butane's neat RVP is 52 psi, and the other five streams in their shipped proportions have an index $I_r = 9.52\,\text{psi}^{1.25}$. Use Equation (15.2).

(a) Compute the blending index of butane and of the shipped blend. *Checkpoint:* 139.6 and 12.1 $\text{psi}^{1.25}$

(b) Butane is raised to 5 vol %, replacing the other streams in their proportions. Compute the new RVP. *Checkpoint:* 9.20 psi

(c) Find the largest butane fraction that keeps the blend at 7.8 psi. The other streams' volume-average RVP is 5.93 psi. What fraction would a blender who used the volume average of the pressures allow, and what is wrong with it? *Checkpoint:* 2.70 vol % by the index, 4.06 vol % by the volume average

15.5 Theory and calculation · 6 min

Ten percent of ethanol is added to the shipped recipe, with the five hydrocarbons scaled down in their proportions, so the base keeps RON 91.39, MON 83.61 and RVP 7.36 psi. Use Equation (15.4) and Equation (15.2) with ethanol's blending RVP of 16.0 psi.

(a) Compute ethanol's blending RON and MON in this base. *Checkpoint:* 125.9 and 98.4

(b) Compute the RON, MON and AKI of the E10 blend. *Checkpoint:* 94.84, 85.09, AKI 89.96

(c) Compute the E10 blend's RVP and compare it with the 7.8 psi summer limit. *Checkpoint:* 8.31 psi, 0.51 psi over

15.6 Theory and calculation · 8 min

Case 4 starts with 6400 m^3 of an 8000 m^3 batch in the tank at AKI 86.90, with a target of $T = 87.20$, a header clip of $c = 1.5$ and a stopping floor $f_{min} = 0.05$. Use Equations (15.13) and (15.14).

(a) Compute f_0, Δ_0, D_0 and the header target. *Checkpoint:* 0.2, 0.24, 1.20, 88.40

(b) Predict the certificate AKI with the floor at 0.05 and at 0.10, and without targeting. *Checkpoint:* 87.14, 87.08, 86.96

(c) Find the lowest starting average, with the tank still 80 % full, that the shipped floor and clip can bring to the 87.0 limit. *Checkpoint:* 86.67

15.7 App challenge · 8 min

Load scenario 1, "1 · Manual recipe: butane and RVP", at the default seed with no change, and run 20 min at the default speed of 5 (about 4 s of wall time). Export the CSV. RVP columns are in kPa, and 1 psi is 6.895 kPa.

(a) In column `rvp_nir_kPa`, find the first row after the butane step at 5 min that shows the step, and give its time and value in psi. *Checkpoint:* 9.08 min, 9.21 psi

(b) In column `rvp_tank_true_kPa`, find the first row above the 7.8 psi limit. *Checkpoint:* 6.67 min

(c) Explain why the tank is over the limit about two minutes before the analyzer shows anything, using the header holdup, the sample line and the analysis cycle. *Checkpoint:* 3.0 min from blend to report

15.8 App challenge · 10 min

Load scenario 4, "4 · A late upset with 20 % left", at the default seed. Use speed 20, at which each batch takes about 5 s. The run pauses by itself when the batch completes at 96.0 min.

(a) Run as shipped. Read the tank AKI and the give-away from the badges. *Checkpoint:* 87.15, \$12 610

(b) Press Reset, set "Stop targeting below $f =$" on the FY-400 card to 10 % before Run, and run to completion. Read the tank AKI and compare it with the prediction of the theory exercise on case 4. *Checkpoint:* 87.09

(c) Press Reset, set cumulative-average targeting Off on the FY-100 card, and run to completion. Read the tank AKI, the certificate and the corrective volume tiles. *Checkpoint:* 86.96, off specification on AKI

15.9 App challenge · 8 min

Load scenario 7, "7 · Analyzer drift, bias update and the lab", at the default seed, with "Correct the NIR by the lab" Off as shipped. Run at speed 20 until the clock passes 240 min (about 12 s) and export the CSV.

(a) In the row at 240.0 min, read `aki_tank_true`, `aki_nir`, `aki_hdr_true` and `nir_error_RON`. Is the tank on specification? *Checkpoint:* 86.85, 87.15, 86.50, 0.77

(b) Press Reset, set "Correct the NIR by the lab" On on the AT-300 card before Run, run past 240 min again and read `aki_tank_true` at 240.0 min. *Checkpoint:* 87.03

(c) Explain why the bias update did not stop the drift in part (a), and what the laboratory adds.

15.10 Application area · 3 min

The shipped recipe blends to AKI 87.50 and RVP 7.36 psi against limits of 87.0 and 7.8 psi, and give-away is valued at \$1.00 per octane number and \$1.00 per psi for each barrel. An 8000 m^3 batch is about 50 318 bbl.

(a) What is the give-away per barrel, and over a batch? *Checkpoint:* \$0.94 a barrel, about \$47 300

(b) Why does a recipe held by hand keep such margins, and what must an optimizer have before it can remove them?

15.11 Application area · 4 min

The model blends ethanol at one RVP of 16 psi at every concentration, while the chapter's assumptions note that real ethanol lifts the vapor pressure most near 5 to 10 vol % and less above.

(a) With Equation (15.2) and the shipped base at 7.36 psi, what RVP does the model give for E5? *Checkpoint:* 7.84 psi

(b) In case 8 the optimizer brings 5.5 vol % of ethanol into the blend and cuts butane to make room. If a real blend's bump at this concentration is already close to its E10 size, is the real RVP above or below the model's, and what in the control system would notice?

15.12 Review the agent · 5 min

An AI assistant reviewing case 3 writes: "The oscillation at 4 vol % per ON and 1 min comes from the integral time. On a loop that is almost pure delay the integral does the work and the gain only sets the first correction, so keep $K_c = 4$ for a fast first move and lengthen τ_I to 2 min. That removes the oscillation." Find the flaw and say how you would check it.