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Practical Aspects in Advance Gasoline Blending Control

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1. ABSTRACT

This paper addresses the closed loop control of octane and Reid Vapor Pressure for an in-line gasoline blending system. It reviews the transition from batch blending operation to in-line blending and the historical influences which caused this change. Some practical aspects in the handling and operation of on-line octane analyzers are then examined. Recommendations are then presented on the subject of using on-line analysis of both octane and Reid Vapor Pressure in closed loop control and the benefits of such control are detailed. Much of the material presented in this paper is based on an actual implementation of closed-loop octane and RVP control to an in-line gasoline blending system. Some data was obtained from integrating the process control logic to a dynamic process simulator of the blending system.

2. INTRODUCTION

As refiners continue to search for ways of improving plant efficiency and profitability, an increasing number have found that revamps of their gasoline blending systems have provided substantial increases in revenue. The prospect of substantially reducing octane giveaway, minimizing the production of material not meeting specifications and reducing inventory of both finished products and intermediate components have many refiners very interested in such projects. However, there are many practical aspects which must be considered before such projects can be undertaken. The purpose of this paper is to address some of the issues which arise in attempting to execute such projects. The experiences related here were encountered in an actual implementation of an Advanced Gasoline Blending Control Project.

The project which formed the basis for this paper deals with in-line blending. With in-line blending, gasoline product is blended directly to a product distribution pipeline with only a small surge tank providing a buffer between the blender and the pipeline. This is in contrast to a batch blending operation. Batch blending illustrated in Figure 1, entails blending the individual gasoline components, not necessarily simultaneously, to a tank, mixing the tank for several hours and then sampling the tank for lab analysis. If the material is not on-specification, additional components are blended to the tank, re-mixed and sampled again. This trial-and-error procedure could take several days, during which time several thousand barrels of gasoline are held up in storage.

In order to streamline their gasoline blending procedure, many refiners have converted their blending systems to in-line blending systems using on-line octane analysis. An in-line blending system, shown in Figure 2, simultaneously blends gasoline components to a product pipeline for distribution. Many of the gasoline components come from rundown lines directly off process units. Hybrid systems have also been installed which blend the individual components simultaneously to a tank which is then sampled. This method, which also uses the on-line octane analyzers, requires less reblending activity than that provided by batch blending. Tanks are on-specification a large percentage of the time, or when corrections are required, they are usually minor.

At the heart of the transition from a batch blending operation to an in-line blending operation are the on-line octane analyzers. The analyzers use the ASTM D2885-84 method, "Research and Motor Method Octane Ratings using on-line Analyzers", for the determination of octane values. These analyzers take a slipstream of the blended gasoline product and feed the sample to a standard internal combustion engine (referred to as the Knock Testing Unit in ASTM D2699 Method). Through the data supplied by the octane analyzers, the operator is kept abreast of the instantaneous octane of his gasoline product. If the blending quality of one of the components varies changing the quality of the final product, the blending control operator is immediately made aware of it. If the product is off specification the blending operator makes the proper adjustment to the various component flowrates to bring the product back on specification. In most installations, this correction for off-specification product is performed manually by the control operator. In many cases, this adjustment is based on experience and would vary as the control operator's experience varied.

Because of the difficulty involved in controlling octane and the necessity to produce on-specification product, many refiners leave themselves some "fat", called "Octane Giveaway", in their operation. That is, if the blended gasoline product is to have a Road Octane Number of 89, the refiner will shoot for a target of 89.3 thereby allowing himself a 0.3 swing in Octane Number before going off-specification. While this practice does enable the refiner to produce on-specification material most of the time, it is an expensive practice. Additional Octane barrels are normally achieved in a refinery by increasing the Severity of the Reforming Operation, a very expensive practice. Increasing Reformer severity increases energy costs on the unit and reduces Reformate yield. If tighter control and improved analysis are properly implemented, the amount of giveaway can be reduced providing substantial economic benefits to the refiner. Studies indicate that for a 0.1 reduction in Octane Giveaway, the refiner would save approximately $11,000/year per thousand barrels per day of gasoline production. Thus for a moderate size facility producing 50,000 B/D of gasoline, the savings would amount to over $500,000 per year.

While these ideas may sound very nice on paper, there are many practical considerations that the refiner must analyze before undertaking such a project. Many of these considerations will be addressed in this paper. The two main topics to be addressed are 1) the handling and the operation of the Octane Analyzers, and 2) the use of the octane analysis in closed loop control.

3. PROCESS DESCRIPTION

3.1 Gasoline Blending Equipment

Gasoline blending systems within refinery complexes are normally comprised of the following:

Tanks	- both product and blending component
Pumps	- to transfer individual components from their tanks to the blender - to pump finished product to pipelines, ships, trucks
Flow Meters	- normally turbine meters are used to measure the flow of both individual components and total product
Control Valves	- to control the flowrate of the individual components
Analyzers	- Octane analyzers (both Research and Motor), Reid Vapor Pressure analyzer, Vapor/Liquid analyzer, Boiling Point Analyzer (e.g. 10% point, 50% point, 90% point).

Figure 3 details a typical gasoline blending system.

Most blending installations deal with shared resources. For example, one refiner is blending gasoline to three separate pipelines. One set of component transfer pumps and two sets of octane analyzers (RON and MON) are shared by the three pipelines. The control system must easily handle the situation of shared resources without confusing the operator.

3.2 <u>Base Control of Blending Operation</u>

Prior to starting a blend, the operator is asked to perform the following functions:

- Enter Total Batch Size of Blend in Barrels
- Enter the Rate at which he wants to blend, in Barrels/day
- Enter the Volume % for all components which are to be used in the blend
- Enter the RVP Setpoint
- Enter the V/L Setpoint
- Select all the pumps which will be required to perform the blend. Specifically which, if more than one, of the individual component transfer pumps are to be used.
- Enter the target Motor Method Octane Number
- Enter the target Research Method Octane Number
- Choose the octane trim component. This is the component whose flowrate is to be manipulated to control octane. Note that for RVP, butane is normally chosen as the trim component.

Once the operator has entered all the required data, he presses the start switch. The control system then automatically begins blending operation as illustrated in Figure 4. Pumps are started automatically and only those pumps which were selected by the operator are started. The flowrate of the blend is then ramped up to the desired Blend Rate which was entered by the Operator. The setpoints for the blending component flow controllers are obtained by multiplying the Volume % of the individual component by the Master Flow Rate Signal. Thus as the Master Flow Rate signal is ramped, so will the individual setpoints for each component.

An important aspect of the blending control is that the Volume % of all the components are normalized to 100%. This action allows the blender to always operate at the desired Blend Flowrate. This is important from two aspects: 1) if the operator wants to adjust the amount of a component within this blend he can directly change the Volume % of that component and still be blending at the desired flowrate. Through normalization the amounts of all the other components will be proportionately adjusted, 2) when performing closed loop octane control, the octane controller will be adjusting the volume % of the trim component. Through normalization the volume % of all the other components will be reduced. Again this allows the blender to continue to operate at his desired blend flowrate.

Once the blend is running, the Octane Analyzers, RVP Analyzers and Boiling Point Analyzers will begin their analysis of the blend. These results are displayed continuously to the operator on the operators console. The goal is to keep the gasoline product within specifications by adjusting the volume % of the individual components. This procedure, while sounding quite straightforward, is very difficult. There are many factors which can contribute to making this process a complicated task. First, there can be substantial deadtimes between a change in blend composition and the octane analyzer reading. Second, there can be interactions between the RVP controller and the Octane controller. In addition, there is also the problem of the Octane trim component having a different effect on the Research number as compared to its effect on Motor number. The effect of a trim component can also change sign as different grades of gasoline are produced. For example, alkylate which was used as a positive octane trim component for regular unleaded, had a negative effect on octane when producing premium unleaded. These problems are compounded by a non-continuous octane analysis signal.

The next two sections discuss how to address some of these problems. The first section discusses the operation and interface to the octane analyzers. The second section deals with the closed loop control of both octane and RVP using the data from on-line analyzers.

4. PRACTICAL ASPECTS OF HANDLING THE OCTANE ANALYZERS

4.1 Octane Determination

Two octane analyzers are normally required when performing octane analysis on a gasoline blend. One analyzer determines the Motor Octane Number of the material while the other analyzer determines the Research Octane Number. Octane number is a measure of the Knocking characteristics of a specific fuel in an internal combustion engine operating under regulated conditions. The octane analyzer determines the octane number of a gasoline stream by comparing its knock characteristics, called Knock Intensity, to the Knock Intensity of a "prototype" fuel whose octane number has previously been determined. The Knock Engine is run on prototype fuel for a specified period of time (4-5 minutes, typical) and then switched to Product Fuel for the same period of time (4-5 minutes). The octane analyzer then compares the Knock Intensity readings for both the Prototype Fuel and the Product

Fuel. It then utilizes a previously determined calibration parameter called the Knock Intensity Spread to determine the Octane Number of the Product Fuel. The Knock Intensity Spread represents a ratio of octane number to Knock Intensity.

As the knock engine runs, the operating conditions of the engine have a tendency to change. Things such as the fouling of spark plugs or intake valves, the exact fuel/air ratio, the clearances on piston rings, have a tendency to change as the engine runs. In order to take these changes in operating conditions into account, the machine undergoes a continuous two-step cycle of 1) product fuel octane number determination and 2) analyzer calibration as shown in Figure 5. This is accomplished, as mentioned previously, by continuously cycling the machine between prototype fuel and product fuel. For our particular installation the total cycle was ten minutes in duration. The machine would run five minutes on the product fuel and then five minutes on the prototype fuel. Should the operating conditions of the machine not change, the Knock Intensity reading of the constant octane prototype fuel would remain the same. If the operating conditions of the machines change, the Knock Intensity of the Prototype Fuel will change. Monitoring the changes in engine operation enables the analyzer to more accurately determine the actual octane of the product fuel.

Due to the cyclical nature of the analyzer operation, an analyzer will only transmit a new octane reading every 5 minutes. That is, a new octane number will be generated at the end of the product cycle and again at the end of a prototype cycle. Thus we are dealing with a discontinuous signal whose value is updated only every 5 minutes. Note that if the operating conditions of the machine are constant, thus keeping the Knock Intensity of the constant octane prototype fuel unchanged, the octane number produced by the analyzer will change only once every 10 minutes. This change in octane number will occur only at the end of the product fuel cycle.

One of the practical problems has now been identified. The operators will only get an octane reading once every 10 minutes. Take for example the case where one of the components being blended undergoes a substantial change in composition. Assume that this change occurs at the time when the octane analyzer is beginning its prototype fuel cycle. In this case, the operator will not see the effect that this change in component quality has on the final product quality for 10 minutes. Off-specification product may have been produced for approximately 10 minutes without the operator ever knowing it.

To reduce the effects of this problem, the operation should be arranged such that the Motor Octane Number Analyzer and the Research Octane Number Analyzer are always operating on opposite cycles. That is, while the Motor Octane Number Analyzer is on the Prototype Fuel cycle the Research Analyzer will be on the Product Fuel cycle. In this fashion there will always be at least one analyzer which is operating on product fuel. For example, in the case where one of the blend components changes its composition at time t, the effect of this change on the Motor Octane Number will be observed at t + 5 minutes and the effect on the Research Octane Number at t + 10 minutes. Thus, even though the operator must still wait 10 minutes to see the total effect (the effect on Road Octane, (R+M)/2) at least a portion of the change is observed in 5 minutes.

The length of the cycle is determined by the analyzer supplier. In our case of 5 minute cycles, knock intensity readings are taken only in the final 2 minutes of the cycle. The initial three minutes are used to allow the engine to reach a steady state operating condition following a fuel switch (product fuel -- prototype fuel). After the initial 3 minute equilibration period, the analyzer takes 120 Knock intensity readings at 1 second intervals. At the end of the two minutes, the analyzer takes the average of the 120 Knock Intensity readings and uses this value in the determination of product fuel octane.

4.2 Fuel/Air Ratio Control

In switching from product fuel to prototype fuel, the engine must change it's fuel/air ratio. The ratio is adjusted by changing the position of a microvalve which is located in the carburetor of the engine. Adjustment of the microvalve position changes the fuel/air ratio of the mix going to the engine. The exact microvalve position is determined by performing a fuel/air search routine. A fuel/air search can be initiated by the operator. When a search is requested, the analyzer completes its regular cycle, and then begins the search.

The fuel/air search entails moving the microvalve position, thereby changing the fuel/air ratio, until the maximum knock intensity is achieved. The implication here is that for a constant octane fuel, the analyzer will obtain different knock intensity readings based on the fuel/air ratio. The object of the search routine is to find the microvalve position that gives the Maximum Knock Intensity for the analyzed fuel. A different optimum microvalve position exists for both the product fuel and the prototype fuel.

The important aspect to note here is that the Fuel/Air Search can be requested by the operator during a blending operation. When the analyzer is performing a Fuel/Air Search routine it is no longer performing on-line octane analysis of the product and prototype fuel. During this time, which normally can range from 8 - 15 minutes, the octane controller should take no action and should hold all the component flowrates at their last setpoints prior to invoking the Fuel/Air Search routine.

4.3 Analyzer Requirements for On-Line Certification of the Blend

In addition to the effects of the analyzer on the octane control, there are many accounting/reporting aspects which are heavily dependent upon analyzer operation. In order to obtain certification, the analyzer must be operational for a certain percentage of the time, or a certain volume % of the blend as shown in Figure 6. It is also critical that the octane number of the product fuel be within a certain range near the octane number of the prototype fuel. For example, a prototype fuel whose octane number is 87 can not be used when producing a gasoline product whose octane number is 91. There are several important operating parameters involved with the octane analyzer. Specifically, they are:

1. Percent of blend time that the analyzer were performing on-line octane analysis. Note that this figure must take into account those period of time when the analyzer was not performing on-line analysis (e.g. Fuel/Air Searches, Knock Intensity Spread Checks, Prototype Calibrations),
2. Percent of blend volume for which on-line octane analysis was performed, subject to the same conditions as #1,
3. The percent of the time, during which on-line octane analysis was being performed, that the difference in octane number of the product fuel and the prototype fuel was less than a certain number (e.g. 1 ON). That is, the prototype fuel octane and the product fuel octane were within a certain range of each other.

4.4 Integration of Blender Controls and Analyzer Controls

All the previous items were mentioned to illustrate the criticality of the octane analyzer on the octane control and the blending reporting system. Historically, octane analyzers have been equipped with their own computer based control system. The computer would handle the tasks of switching the analyzers between product and prototype fuels, keeping the Research and Motor engines on opposite cycles, entering data to the octane analyzer and generating reports. All operator actions were performed at a console provided with the computer system. The console provided for the entry of data such as Prototype Fuel RON and MON, Knock Intensity Spreads for the engines, microvalve Positions for each engine (for both Prototype Fuel and Product Fuel) and several other parameters. The console also contained the Fuel/Air Search request command, requests for operating reports, start/stop commands for analyzers, etc. In most plants, laboratory personnel have been responsible for interfacing to the octane analyzer. Once the analyzer has been set up and running the operating personnel are then given the "go-ahead" to start blending gasoline.

In order to provide for a more integrated system, the computer system logic can be transferred to the Distributed Control System (DCS) that performs the blender controls. This is illustrated in Figure 7. The computer system can be replaced by providing the same control logic in the DCS. The computer console is easily replaced by additional screens on the operator's console. The report generation and storage of archived data can also be performed by the DCS. Interface to the analyzer is accomplished via RS-232 communication between the DCS and the Octane Analyzer, as well as standard 4-20 mA signals and contact inputs/outputs. Integrating the control of the analyzer and the control of the blender into the same device has many benefits, such as:

1. Reduction of system cost by eliminating the need for the analyzer control computer. The cost of the additional DCS hardware is small in comparison to the computer cost.

2. There is no need for personnel to learn the operation of two separate consoles. The same console which used to operate the blender is used to control the analyzer. Also the operator becomes more involved in the operation of the analyzer.

3. With the analyzer logic residing in the same control system as the blender logic it is easier to integrate analyzer operation with the closed-loop octane control algorithm.

5. CLOSED LOOP CONTROL OF GASOLINE PRODUCT OCTANE AND REID VAPOR PRESSURE (RVP)

5.1 Integrated Error Control of Octane and RVP

While gasoline product contains many specifications, those specifications which are most variable and which have the greatest impact on the blending economics are octane and RVP. Octane, as discussed previously, is a measure of the knocking characteristics of the gasoline in an internal combustion engine. The RVP of the gasoline is a measure of its volatility, relating to its ability to vaporize within a carburetor. Because of the aforementioned reasons, it is these two product quality parameters which are placed on closed loop control.

Each of these parameters are controlled by adjusting the blend ratio of an operator selected trim component. For RVP, butane is nearly always selected at the trim component. Octane may be controlled with several trim components. A trim component will have its initial blend ratio modified to control a specific attribute of the blend. This occurs through a cascade control loop where the trim controller is the outer loop and the flow controller is the inner loop. When a controller modifies a blend ratio, the blend ratios of the other components are normalized to maintain a total of 100%. Note that the relative ratios of non-trim components stay constant.

In order to insure that the target octane and the target RVP are maintained for the entire blend, a special form of controller is employed. This form of controller is called an integrated error controller, as illustrated in Figure 8. Whereas normal controls act to bring the <u>instantaneous</u> values of control parameters back to setpoint, and integrated error controller acts to drive the process variable's <u>average</u> value over the entire blend to its setpoint. For example, if the octane number of the blend was less that setpoint for a short period of time, the integrated error controller would act to not just bring the octane back to target, but would shoot for an octane slightly higher than target to make-up for the lost octane-barrels. These lost octane-barrels would be made up gradually over time. The length of time is adjusted based upon the percent completion of the blend. As the end of the blend approaches, these accumulated errors must be eradicated in shorter periods of time.

5.2 Internal Model Control of Octane

The control of octane requires some special consideration. As previously detailed, the octane value is supplied by an analyzer in two phases, the RON and the MON. The values are supplied at 5 minute intervals. Applying a typical digital mimic of an analog PID controller would not work well. During the 5 minute sampling period, the controller would continue to integrate on the previous error. This would require that the integral rate be set very slow. An alternative is to put the controller in auto for a short period of time when the new value arrives, then transfer it to manual for the bulk of the sampling period. This is not a clean solution and tuning is not easy.

A better solution is implementation of a sample data controller synchronized to the analyzer transmission signal. The controller performs one calculation for each new sample. The general form of the controller is presented here in terms of a z transform:

$$\frac{(\ a0 + a1*z^{-1} + a2*z^{-2} + a3*z^{-3} + a4*z^{-4}\ )*z^{-N}}{b0 + (\ b1*z^{-1} + b2*z^{-2} + b3z^{-3} + b4*z^{-4}\ )*z^{-D}}$$

This is implemented as a single function block algorithm in the digital control system.

The design problem which remains is the selection of the coefficients for the controller. A discrete version of the PID equation could be used, but other techniques will provide better control.

Recall that a change in blend ratios will take at least two sample periods for the total effect on the Road Octane Number (R+M/2) to be determined through analysis. This statement represents a model of our process. The model is represented in Z-transforms as follows:

$$G = a_1*z^{-1} + a_2*z^{-2}$$

With a model in hand, an Internal Model Controller can be designed. The structure of an Internal Model Controller is illustrated in Figure 9. The filter, F, sets the designated trajectory for a change in setpoint and also provides stability when modeling errors are present. In the blending process, the desired trajectory should match the natural process trajectory. The dynamics of the process come from the analyzer dynamics and the transport delay and mixing in the pipeline. Forcing the analyzer reading to respond too quickly will cause the real octane to over-shoot. Therefore a filter is selected with the same dynamics as the process.

$$F = b_1*z^{-1} + b_2*z^{-2}$$

The resulting controller is

$$Gc = \frac{F/Gp}{1 - F} = \frac{b_1 * z^{-1} + b_2 * z^{-2}}{(a_1 * z^{-1} + a_2 * z^{-2})\ (1 - b_1 * z^{-1} - b_2 * z^{-2})}$$

and is implemented in a single function block. The features of that block provide a sample trigger input, tracking in manual mode, and output limiting.

To test these controllers, a simulation was performed using a linearized blending model and simple dynamics for the valves. The simulations was run 5 times faster than real time. The analyzers sampled every two minutes one minute out of phase. Figure 10 shows the response of octane when TEL is the trim component. At t=17 the simulation is changed creating a 50% increase in effect of TEL on octane. The controller is not retuned, but maintains good tracking during the following setpoint changes. A further disturbance was provided by slowing the valves down creating a higher order process. The controller was not retuned and the results appear in Figure 11. The gain was reduced by 50% at t=25 (back to original gain).

The performance in the simulations was good despite significant variation in the process. A PID controller could not perform as well.

5.3 Other Issues in Controller Design

The IMC design handles the trim component control nicely, but other issues arise in blending. There are various trim components available for octane control, there is the simultaneous control of RVP, and there are grades produced with different specifications.

When trim components change, the octane controller requires different tuning. When the octane of the blend changes, the gain of the trim component also changes. The steady state gain matrices for unleaded regular and unleaded premium are given below.

GAIN MATRIX FOR REGULAR (87 Octane)

	Butane	Hvy Ref	Alkylate
RVP	0.618	-0.074	0.051
OCT	0.051	0.074	0.024

GAIN MATRIX FOR PREMIUM (92 Octane)

	Butane	Hvy Ref	Alkylate
RVP	0.617	-0.073	0.024
OCT	0.002	0.030	-0.039

This data implies that each trim component should have separate tuning parameters for each product grade. This can be accomplished easily in a digital control system with a data table and the adapt function to the tune controllers.

Beyond the tuning issue, there are some practical considerations. For this example, alkylate will only work as a trim component for premium if the rest of the blend has a higher octane number than the desired product. When making premium, RON responds to heavy reformate, but MON has a zero gain. The effective model is a single 10 minute delay synchronized only to the RON analyzer. Triggering the controller every 5 minutes with a model as shown above leads to significant modeling error and degraded but acceptable performance. Improved performance would be obtained by reformulating the problem with a 10 minute sample period.

Figure 12 illustrates the use of heavy reformate to control octane when producing unleaded regular. Note that the controller saturated at t=7 and exited saturation at t=12 without any problems. The response of RON is double the response of MON. This is evident at the first setpoint change at t=7. This controller was tuned for both grades of gasoline and used an average process gain of 0.052. The performance is satisfactory.

The control of RVP with butane is shown in Figure 13, with the time axis as the previous heavy reformate illustration. Disturbances are coming from the octane controller trimming with heavy reformate. Note the butane controller responds quickly and has little affect on octane when the RVP setpoint is changed at t=3. In this case decoupling is not required. A simple PI controller is used for RVP control in this example. In some installations the RVP analyzer has significant transport lag in the piping system. In those cases a continuous version of IMC is used to compensate for the dead time.

6. CONCLUSION

Improved control of the gasoline blending system within a refinery complex can provide substantial economic benefits. Tight control over the blending operation begins with good, accurate process measurements. On-line analyzer technology has improved markedly over the past several years. These improvements in analyzer technology now allow the refiner to know his gasoline product properties with much greater accuracy. But simply knowing your properties with greater accuracy is not enough to provide the economic incentives for these projects. The refiner must now take his more accurate data and use them to optimize his blending operations. He must make operational changes to reduce Octane Giveaway and RVP Giveaway. Once the Octane Giveaway has been reduced he must now make changes to upstream operations to take advantage of the reduced need for octane barrels.

But this tighter control does not come easily. The simultaneous control of RVP and Octane is a formidable task. However, with the aid of today's modern control systems and the analysis tools which they provide, the problems are no longer insurmountable and solutions are achievable.

FIGURE 1

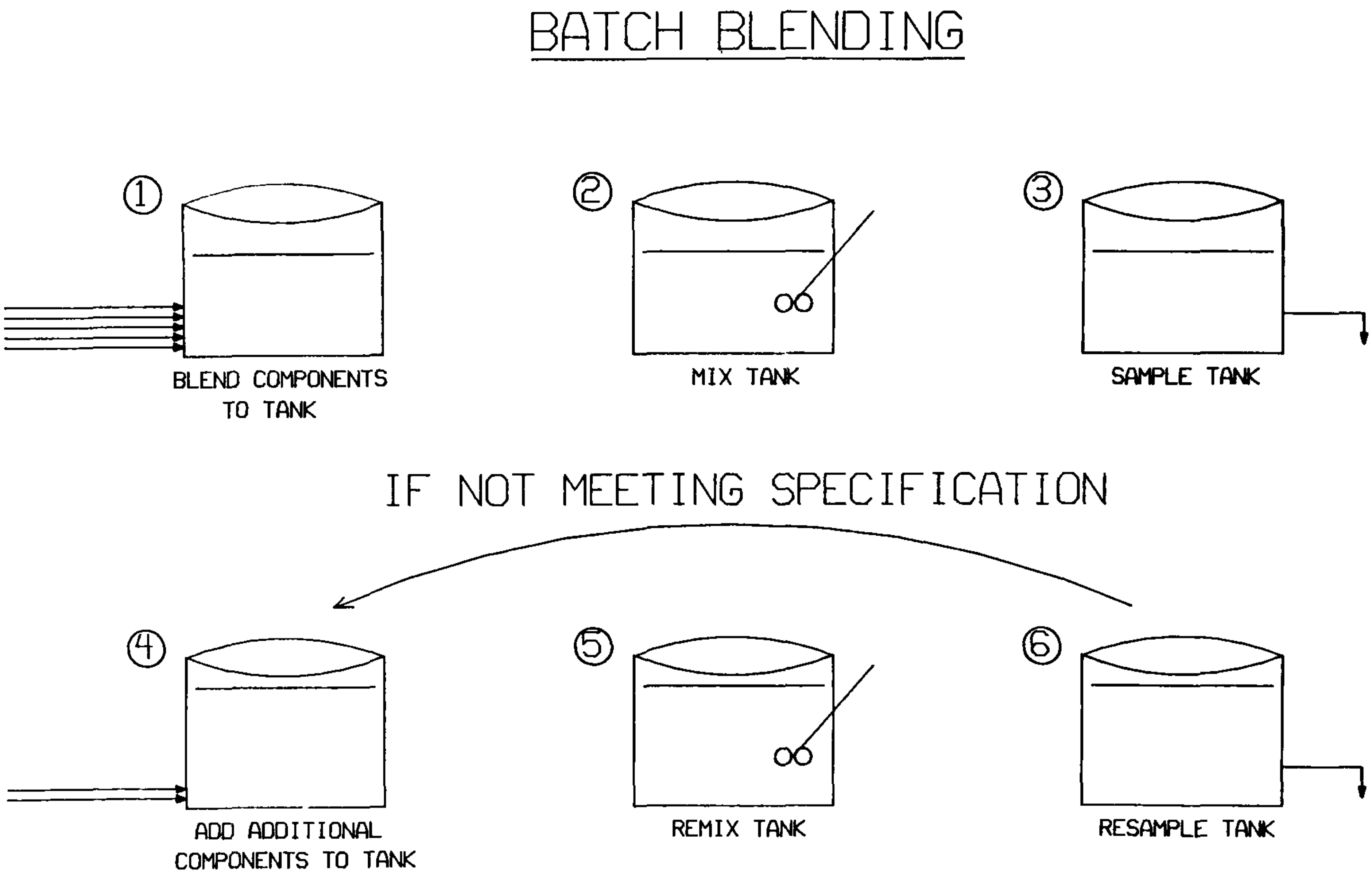

BATCH BLENDING
①
BLEND COMPONENTS TO TANK
②
MIX TANK
③
SAMPLE TANK
IF NOT MEETING SPECIFICATION
④
ADD ADDITIONAL COMPONENTS TO TANK
⑤
REMIX TANK
⑥
RESAMPLE TANK

FIGURE 2

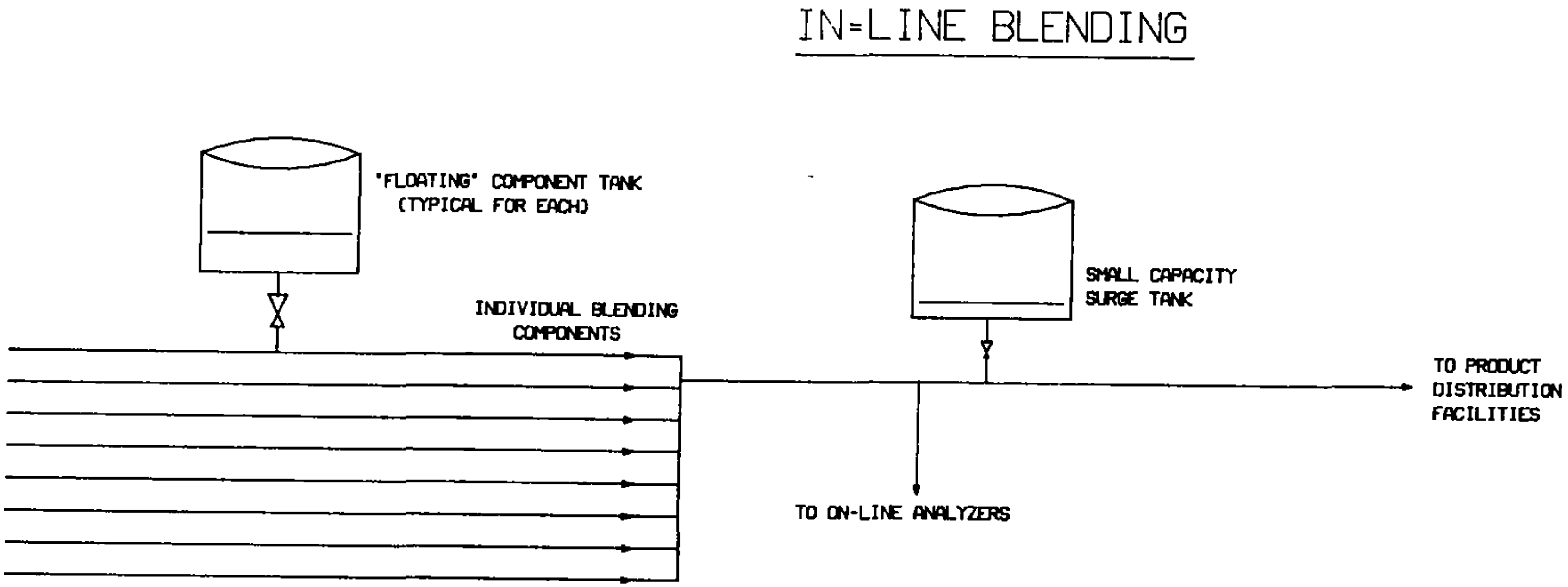
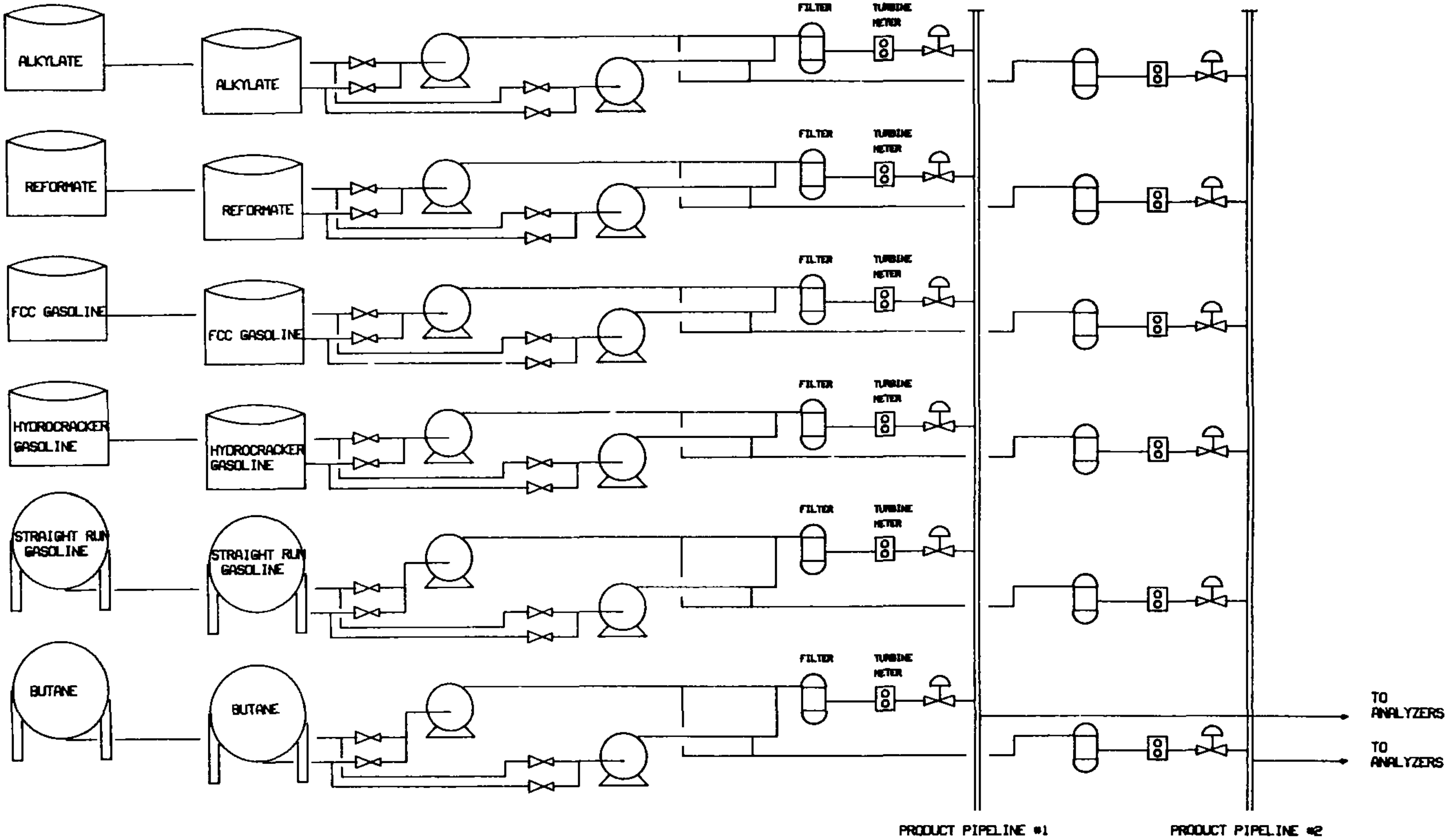

IN-LINE BLENDING
'FLOATING' COMPONENT TANK
(TYPICAL FOR EACH)
INDIVIDUAL BLENDING
COMPONENTS
SMALL CAPACITY
SURGE TANK
TO PRODUCT
DISTRIBUTION
FACILITIES
TO ON-LINE ANALYZERS

FIGURE 3

TYPICAL GASOLINE BLENDING SYSTEM



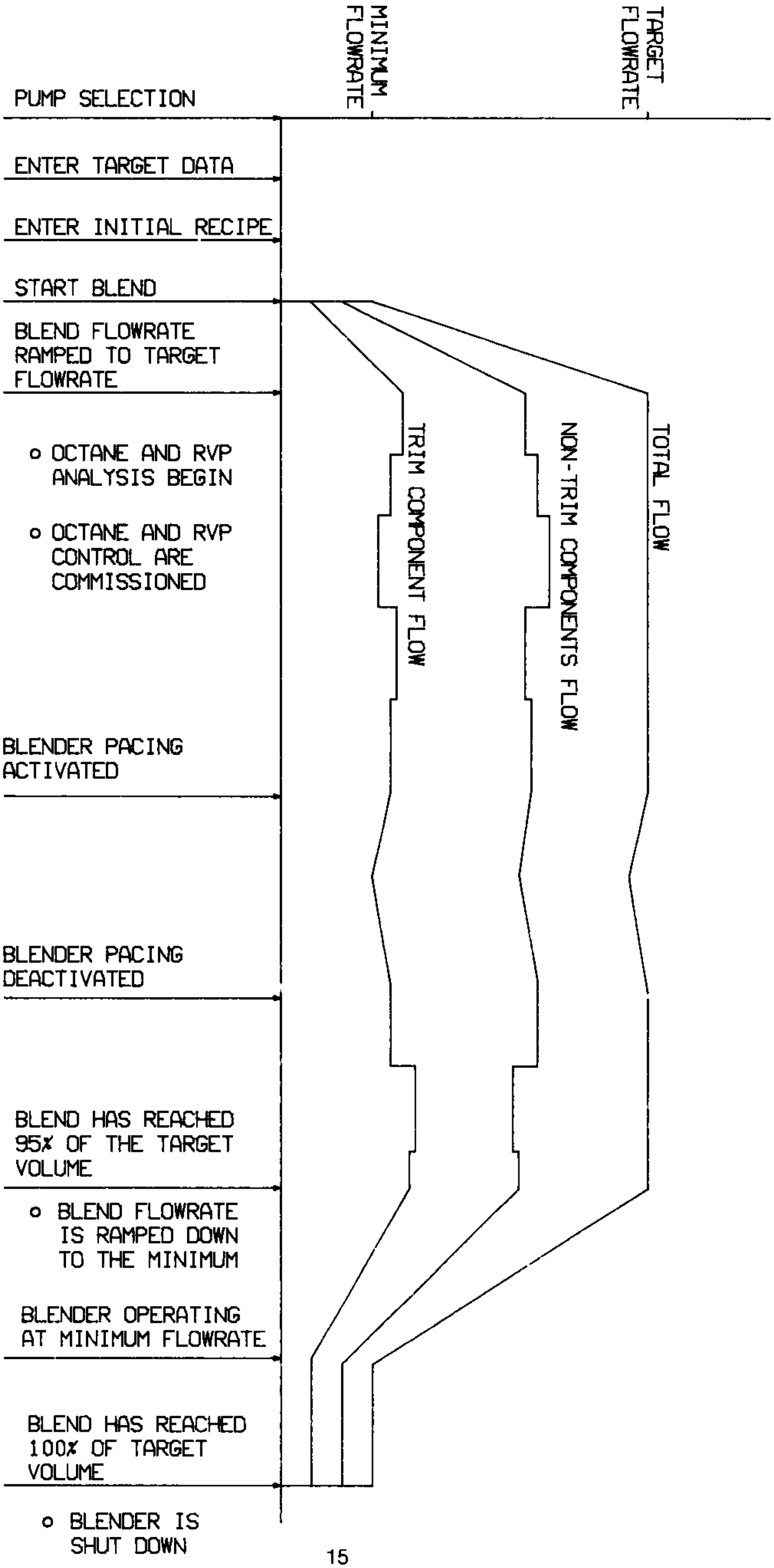


FIGURE 4

BLENDING CONTROL TIME LINE

FIGURE 5

ANALYZER TIME LINE

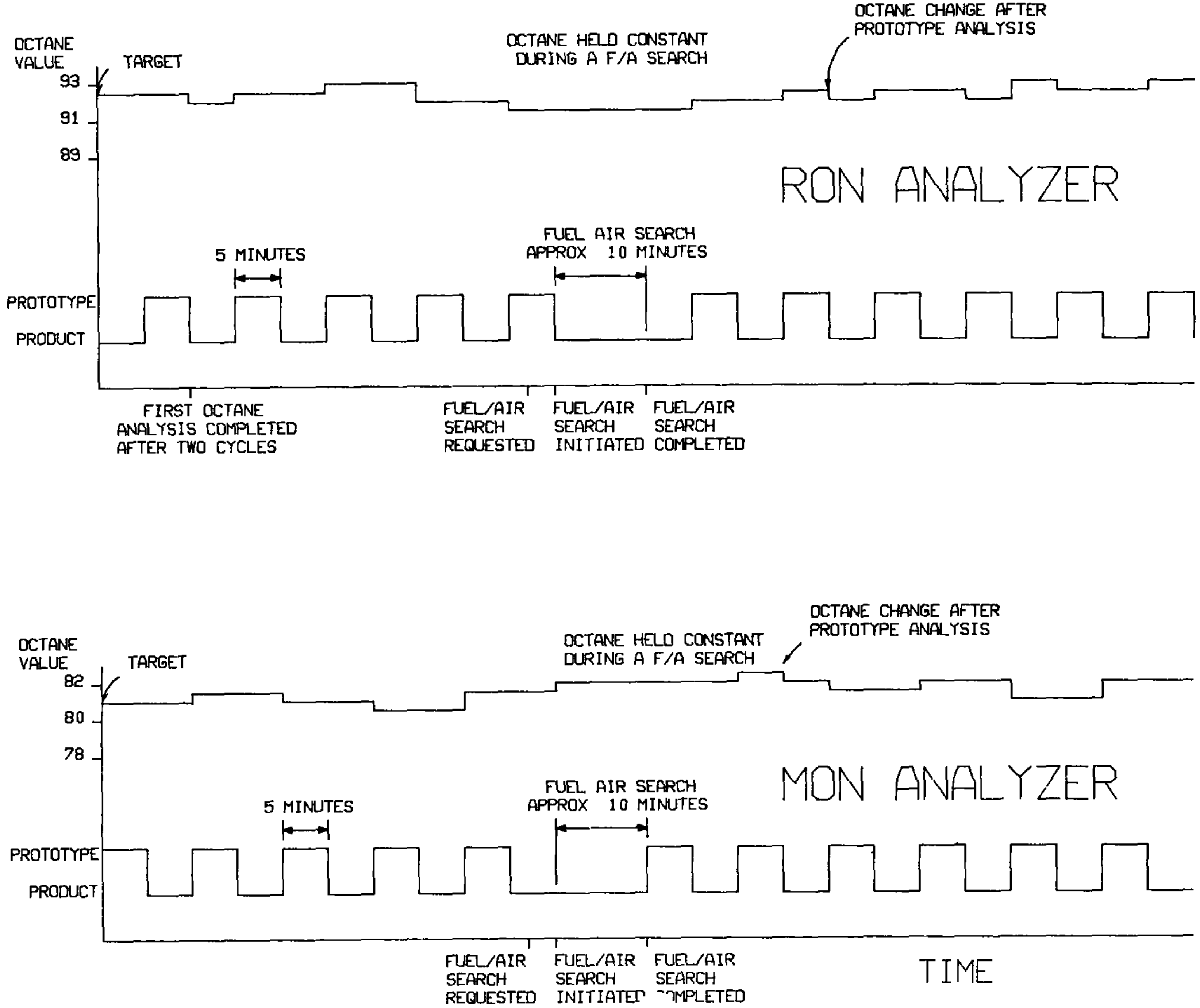


FIGURE 6

OCTANE CERTIFICATION REPORT

BATCH NUMBER 5

Target Octanes	
RON	97.2
MON	86.8
ROAD	92.0

Prototype Fuel Octanes	
RON	96.9
MON	86.5

Instantaneous Analyzer Data	
DELTA RON	0.1
DELTA MON	-0.1
DELTA ROAD OCTANE	0.0
RESEARCH OCTANE NUMBER	97.3
MOTOR OCTANE NUMBER	96.7
ROAD OCTANE NUMBER	92.0
PERCENT ON-LINE TIME OF OCTANE ANALYSIS	97.4
RESEARCH ENGINE NUMBER	#2
MOTOR ENGINE NUMBER	#1
PERCENT OF TIME BLEND WITHIN 1 FIXED OCTANE +/- OF PROTO FUEL VALUE	99.2

Integrated Analyzer Data	
DELTA RON	0.2
DELTA MON	-0.3
DELTA ROAD OCTANE	-0.1
RESEARCH OCTANE NUMBER	97.4
MOTOR OCTANE NUMBER	86.5
ROAD OCTANE NUMBER	91.9
PERCENT VOLUME OF BLEND WITH OCTANE ANALYSIS	97.0

FIGURE 7

BLENDING CONTROL HARDWARE ARCHITECTURE

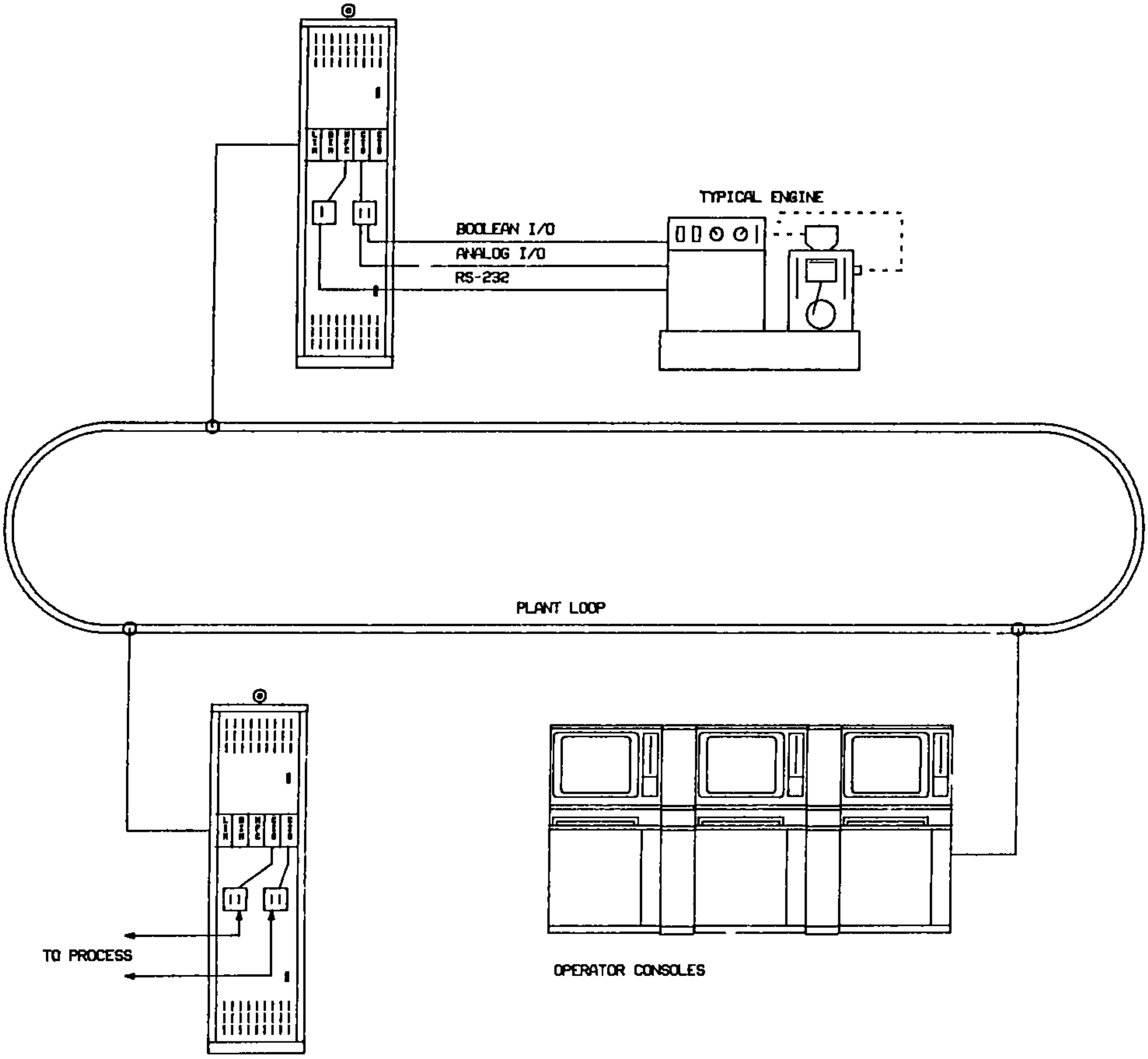
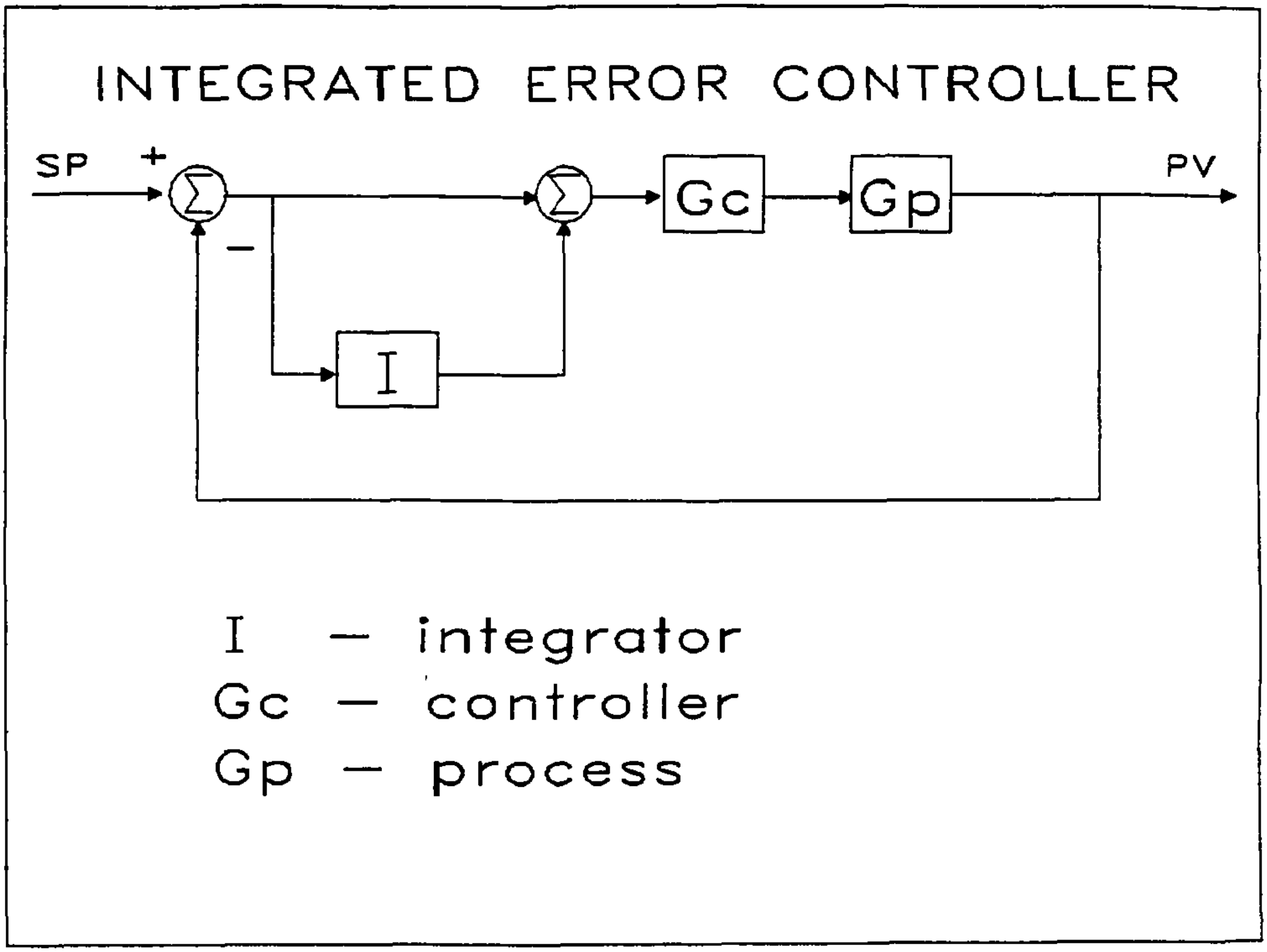


FIGURE 8



INTEGRATED ERROR CONTROLLER

I — integrator
Gc — controller
Gp — process

FIGURE 9

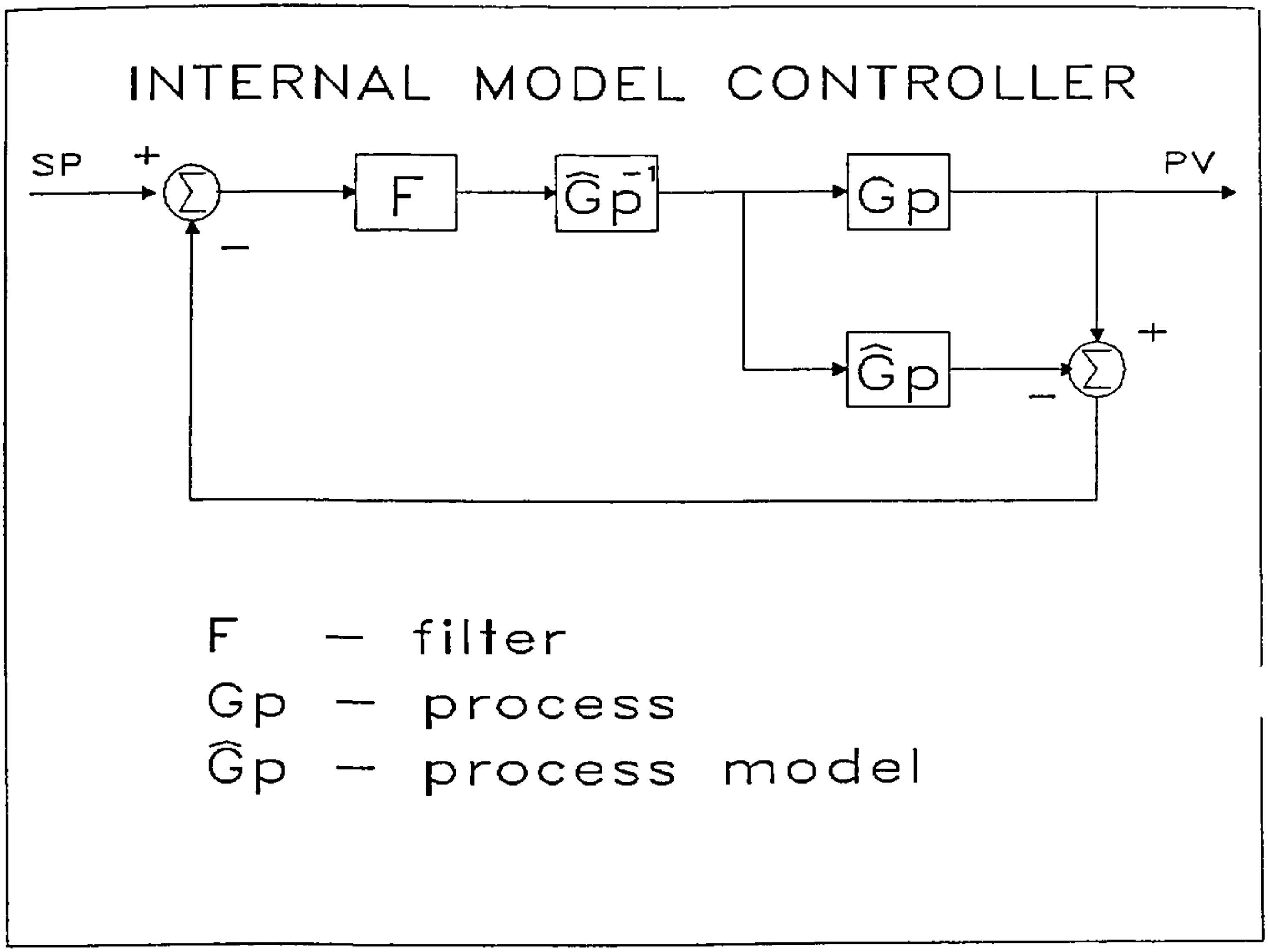

INTERNAL MODEL CONTROLLER
SP
+
Σ
−
F
$\hat{G}p^{-1}$
Gp
PV
$\hat{G}p$
+
Σ
−
F — filter
Gp — process
$\hat{G}p$ — process model

FIGURE 10

TEL CONTROLLER

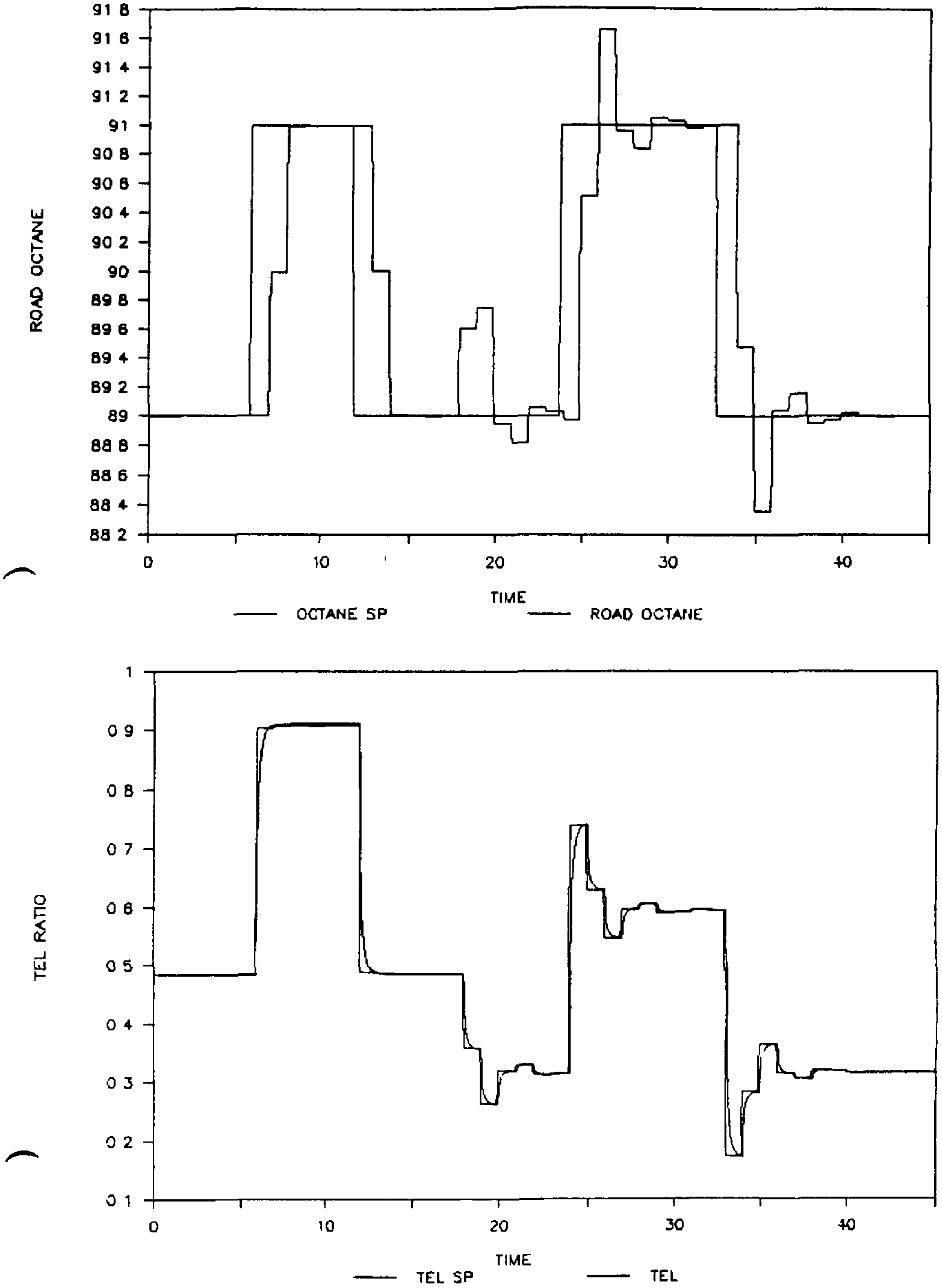


FIGURE 11

TEL CONTROLLER

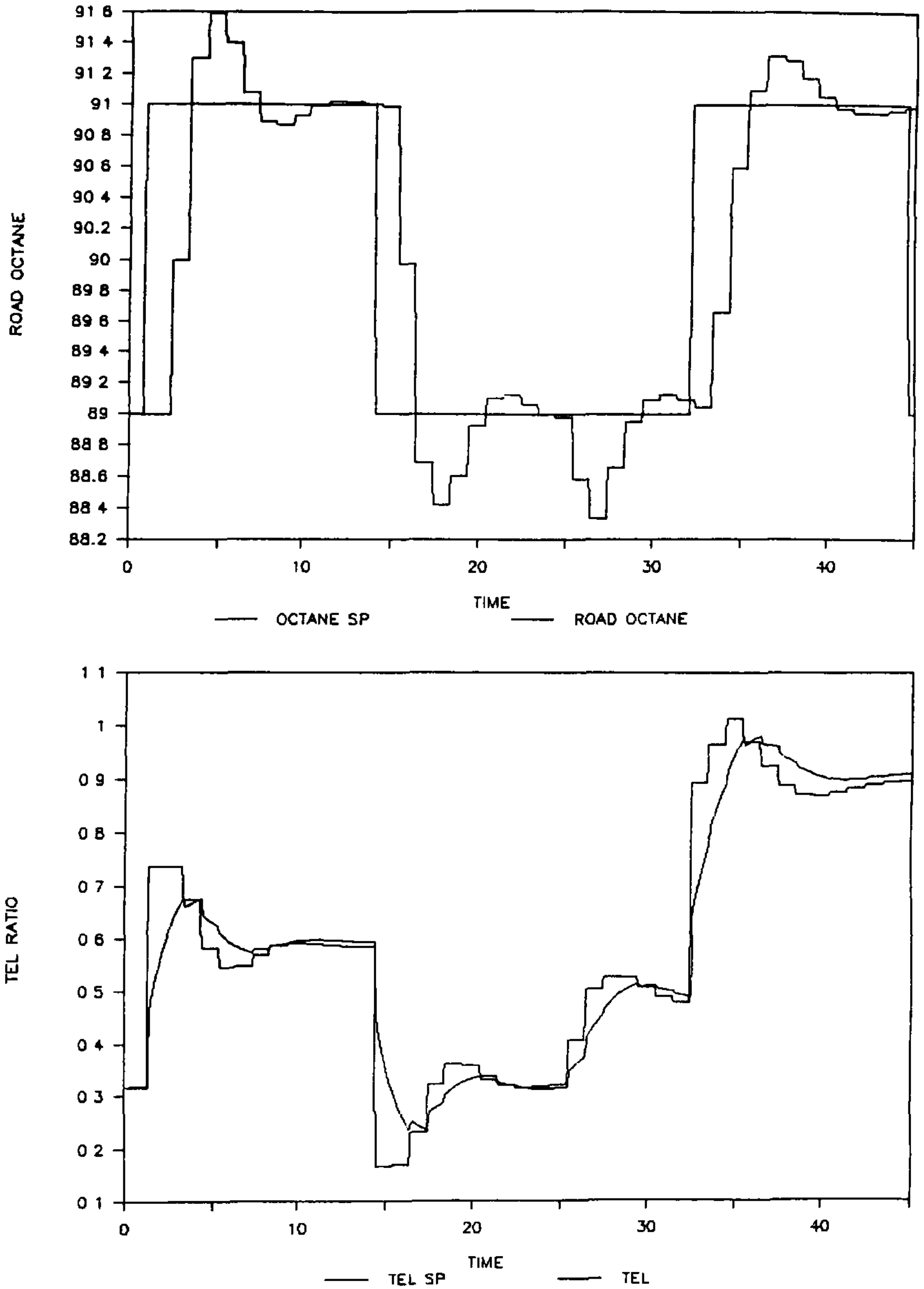
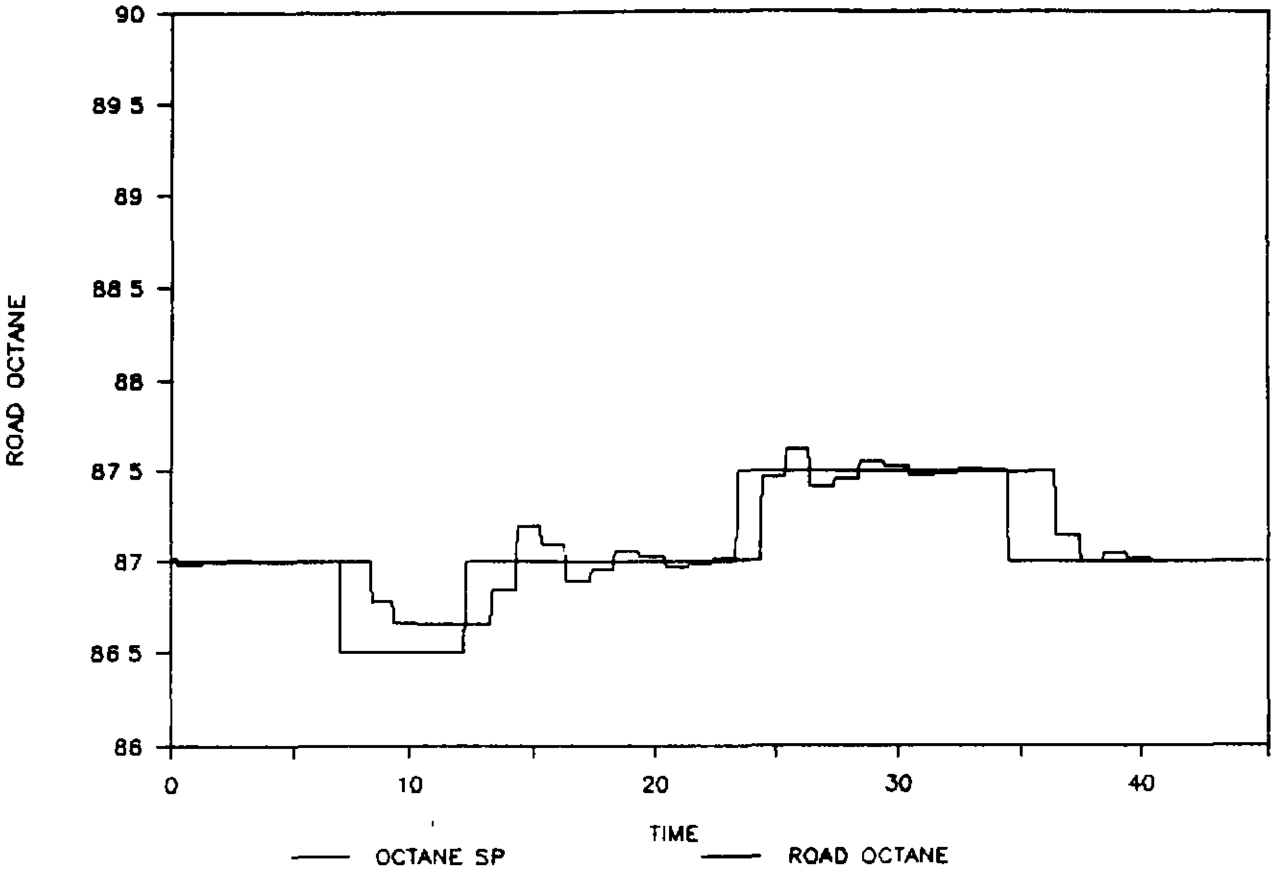


FIGURE 12

HVY REF CONTROLLER



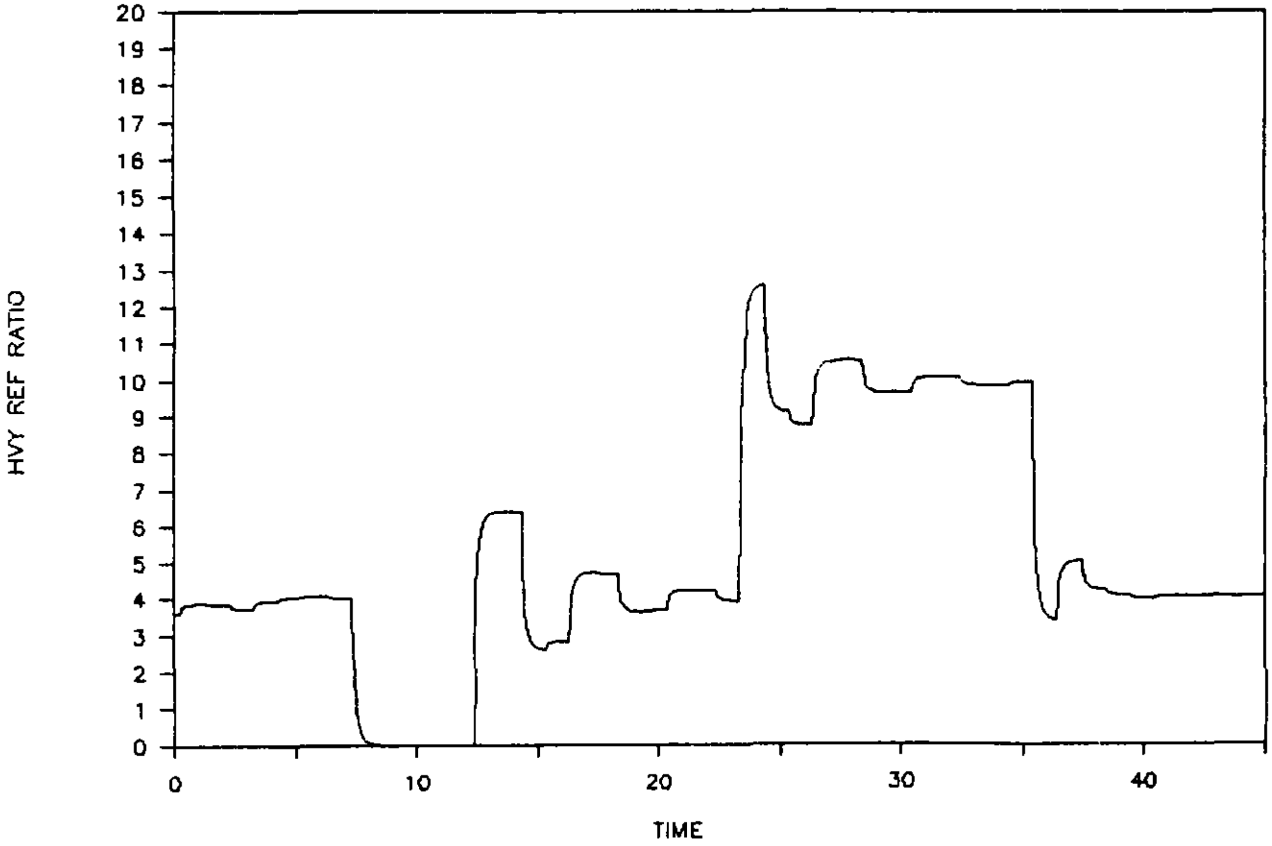
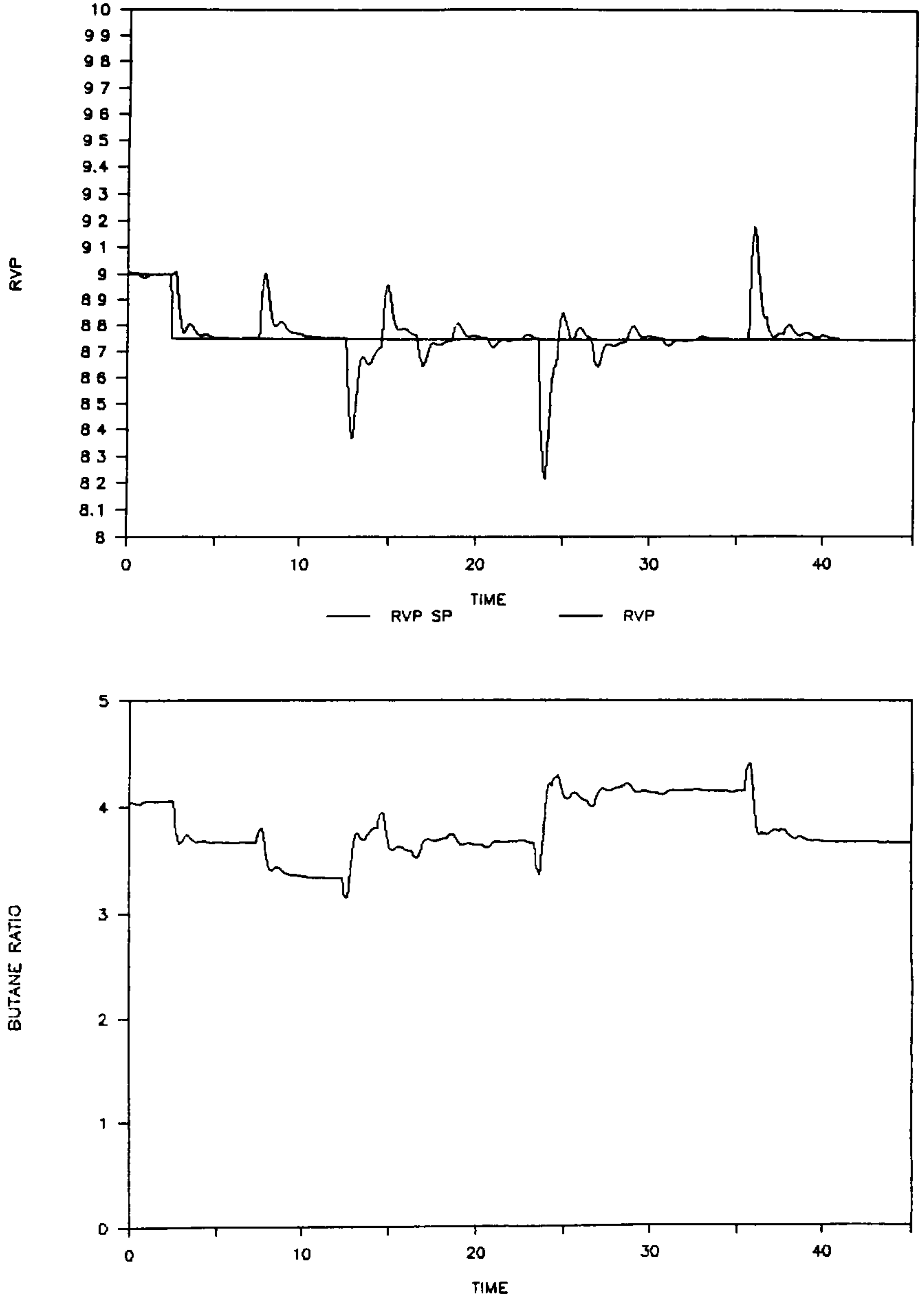


FIGURE 13

RVP CONTROLLER



Bailey Controls

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