

## Solve online analyzer time delays by improving sampling system design

Process design engineers may occasionally become involved in the design of online analyzers and their associated sampling systems. Here are proven and practical strategies to significantly reduce time delays without added or expensive investment. Time delay is key in sampling loop design: to use analyzer data to adjust process control, it should reflect the most recent process conditions. Specialist analyzer engineers are good at specifying components in analyzer systems based on experience with previous analyzer systems. However, if they have limited process engineering fundamental knowledge, analyzer sampling loop design is often copied “as is” from prior designs without understanding that a seemingly reasonable design may cause significant time delays. Too often, the time delay is not calculated, but is blindly assumed as acceptable by the process engineers who design the main process system, causing unexpected process control problems in service.

### WHAT ENGINEERING STANDARDS DO AND DO NOT TELL YOU

Process design engineers who specify online analyzer systems must define the maximum time delay that the process control can tolerate. The time delay should be designed as short enough for process operators to promptly use analyzer data to adjust process control, whenever analyzer readings are outside of a normal range.

Typical engineering standards require less than a 60-second time delay between the sample tap and the analyzer inlet. The distance of the analyzer house from the sample tap is critical in meeting this time constraint. Use small sample lines and small volumes to minimize the residence time between the sample tap and the analyzer.

Note that engineering standards may not always provide details about process engineering strategies to minimize time delays. For example, they may state only the use of short distances, small sample lines or fast loop to solve all time delay problems.

Standards also may not state that time delays occur not only due to a time delay between the sample tap and analyzer inlet, but also due to other factors, such as:

- Location of the sample tap relative to the point of process control

- Type and size of the sample tap nozzle chosen
- Sample conditioning (e.g., filtering, coalescing, vaporizing)
- Flow path components from the sample tap to analyzer (e.g., flowmeter, pressure gauge)
- Analyzer response time and analysis time
- Sample switching for multiple samples using the same online analyzer

This article provides proven and practical strategies to minimize time delays with low or no investment.

Well-designed sample tap location, and tap nozzle type, can significantly reduce time delay. For example, if a liquid sample contains unwanted small particulates generated from a process, then it is recommended to sample from an upward-flow vertical process line to ensure a liquid-full condition inside the process line. A 45° angle-cut probe, instead of a square-cut probe, prevents unwanted particulates moving into the analyzer sampling system. The right probe, properly installed, eliminates the need to install a particulate filter system—a cause of time delay and dead legs—in the analyzer sampling system.

Components on the flow path from the sample tap to the analyzer, such as flowmeter, pressure gauge and temperature gauge—used to monitor sample flowrate, pressure and temperature—are also crucial parameters increasing time delay. It is technically smart to move these components from the main flow path to the sample bypass line or the process return line to minimize time delay and dead legs.

Analyzer analysis time can also be a main cause of time delay, especially on samples with a wide range of composition (e.g., light gas to heavy liquid sample). Often, gas and liquid phases are pre-separated and then analyzed individually by two parallel analyzers to reduce the total time spent analyzing two phases sequentially.

Therefore, the process design engineer must see the overall big picture of time delays when designing the analyzer sampling loop system. Overall time delay of an analyzer system—including process delay, sample transport delay, sample conditioning delay and analyzer response time delay—should be consistent with the measurement and control requirements of a particular process. Limiting the “sample conditioning” time delay to no more than 30 seconds is recommended.

Two modes of sample transport from the sample tap to the analyzer are:

1. Single-line transport
2. Fast-loop transport.

FIG. 1 shows single-line transport vs. fast-loop transport and how the fast loop can reduce time delay. The fast loop allows the use of a higher flowrate and higher sampling line size up to the analyzer inlet. There, a specified amount of the fast-loop flow is split and sent to the analyzer, while most of the fast-loop flow bypasses the analyzer and returns to the process.

### CALCULATING TRANSPORT TIME DELAY OF AN ANALYZER SAMPLING LOOP

Steps to calculate transport time delay are as follows:

1. Specify components needed in analyzer sampling system
2. Specify a target transport time delay, such as 60 seconds
3. Identify sample's flowrate required for analyzer + analyzer bypass, used as basis for sizing sampling line up to analyzer inlet (for single-line transport, analyzer bypass flow = 0)
4. Identify available pressure drop for the sampling loop
5. Specify sampling line sizes for high velocity without exceeding available pressure drop, and calculate sampling line volume.
6. Calculate transport time delay = (sampling line volume) ÷ (analyzer flow + analyzer bypass flow)

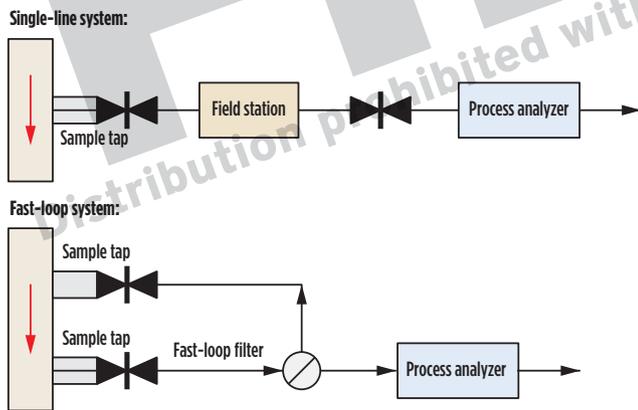


FIG. 1. Single-line vs. fast-loop sample transport system.

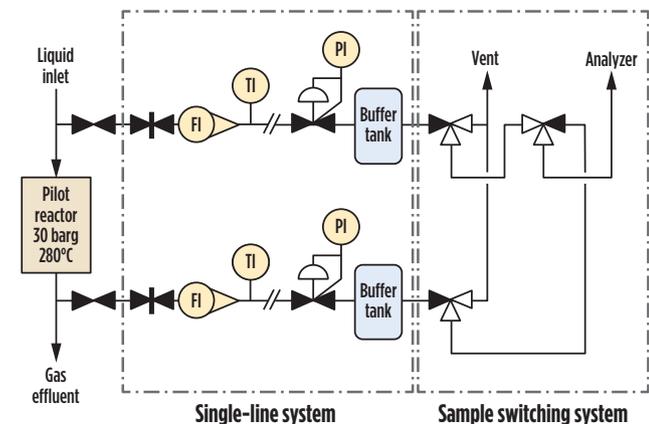


FIG. 2. Non-optimized pilot plant analyzer sampling loop system design.

7. If calculated time delay < target time delay, the calculation is finished; if not, then go back to Step 3. A common mistake in calculating time delays is the failure to account for the following:

1. Gas (compressible fluid) velocity increase along the gas sample line due to lower gas density when sampling line pressure decreases as a result of pressure drop. This expansion results in higher pressure drop along the line as gas flows. However, liquid (incompressible fluid) density remains constant, despite a drop in pressure. Therefore, liquid velocity stays constant, resulting in constant pressure drop per length.
2. Mixing volume time delay is at least three times the average residence time. The mixing volume refers to components with low length-to-internal-diameter ratio (e.g., L/D < 10) such as filters, pumps and droplet coalescers. When inlet concentration suddenly changes to a new value, it theoretically takes at least three times the average residence time in that mixing volume for the outlet concentration to approach 95% of the required concentration change. Therefore, in a time delay calculation, always multiply the mixing volume residence time by three. Special designs of filters, pumps and coalescers may reduce this time delay effect.

FIG. 2 shows an example of a high-pressure reactor pilot plant drawing a liquid sample from the inlet and a gas sample from the reactor effluent. The reactor operates at 30 barg at a temperature of 280°C. Single-line configuration is used with flow and temperature monitors for both liquid and gas samples. Both the liquid inlet and gas effluent's flow into the analyzer sampling system can be controlled using needle valves. A buffer tank in the analyzer sampling system should be installed to minimize fluctuation of sample flow and composition. Sample pressure is regulated from 30 barg down to 5 barg with a pressure regulator before the sample switching system. It is also recommended to use cascading double-block valve and bleed for the sample switching system to eliminate dead leg problems. Limit sample flows to the analyzer at not higher than 400 ml/min for liquid and 2,000 ml/min for gas (analyzer flowmeter condition = 25°C, 1 bara). TABLE 1 shows the total time delay in this example calculated at 133.8 seconds for the liquid sample and 375.7 seconds for the gas sample.

### PROCESS ENGINEERING STRATEGIES TO REDUCE TIME DELAYS

If the calculated time delay is too long, follow the strategies below:

1. **Regulate gas sample pressure at the field station right after the sample tap.** Regulating gas pressure at the field station after the sample tap with a pressure regulator allows the gas volume to expand (lower gas density) and velocity to increase. It reduces time delays, but at the expense of higher pressure drop at the same mass flowrate. The velocity increases by the absolute pressure ratio defined by the gas law equation. Pressure regulation is generally not desirable in liquid lines. Define flowrate at analyzer conditions: make a correction for temperature and pressure at transport

line condition. The temperature in the transport line can be assumed to be equal to ambient temperature unless insulated or heat-traced, because the heat loss to ambient is significant for small lines.

$$[\text{Time delay at } P_{\text{line}}] = [\text{Time delay at } P_{\text{analyzer}}] \times \left( \frac{P_{\text{line}} \text{ in bara} \div P_{\text{analyzer}} \text{ in bara}}{T_{\text{analyzer}} \text{ in } ^\circ\text{K} \div T_{\text{line}} \text{ in } ^\circ\text{K}} \right)$$

To reduce time delay, move the pressure regulator after the sample tap point according to the design strategy in FIG. 3. TABLE 2 shows the time delay reduced below the non-optimized case in FIG. 2 by 20% for the liquid sample and by 64% for the gas sample.

**Example 1.** A fast-loop system requires 50 ml/min (1 bara, 25°C) to the gas analyzer, and the sampling line volume from the sample tap to the analyzer is 300 ml.

- If the gas sample is tapped and transported close to analyzer conditions (1 bara, 25°C), what should the analyzer bypass flowrate be to obtain a 60-second transport time delay?

[Answer: Analyzer bypass flowrate = 250 ml/min, so that time delay at 1 bara = (sampling line volume) / (analyzer flow + analyzer bypass flow) = (300 ml) / (50 ml/min + 250 ml/min) = 60 sec]

- If the gas sample is tapped and transported at average 4 barg and kept heated at 60°C until the analyzer inlet, before dropping pressure across a needle valve into the analyzer, then what would the time delay be?

[Answer: Time delay at 4 barg = 60 sec × [(4 + 1) bara / 1 bara] × [(273 + 25)°K / (273 + 60)°K] = 268.5 sec]

- Change from single line to fast loop**, if regulating pressure is insufficient.
- Avoid mixing volumes in the loop.** The time delay effect of a mixing volume is three-fold, so it should be avoided whenever possible.
- Avoid dead legs in the sampling line to analyzer.** Many components cause dead legs, such as pressure gauges, pressure relief valves, lab sampling points, tee or purging connections, calibration or multi-stream manifolds. Dead legs not only increase sampling system volume, causing time delays, but also cause sample

composition to vary if the stagnant composition in dead legs contaminate the main sample stream. Dead leg effects are more dominant on low-flow lines. Solutions are to:

- Minimize dead legs in the flow path to analyzer
  - Move dead leg components (e.g., pressure gauges, pressure relief valves) to lines *not* flowing to the analyzer, such as the sample bypass line.
- Heating or heat-tracing the sampling line.** Gas volume expands (lower gas density) with increasing temperature, so velocity increases by the absolute temperature ratio defined in the gas equation. Heating lines can sometimes eliminate the undesirable mixing volume of a liquid knockout pot.
  - Avoid adsorption on the tube inner surface.** Measuring H<sub>2</sub>S at < a 10 mol ppm level can be inaccurate due to adsorption of H<sub>2</sub>S on the tube surface, resulting in less or no H<sub>2</sub>S content making it to the analyzer. Heating the tube to prevent adsorption or coating the tube's inner surface may help.
  - Use process pressure to drive samples instead of a sample pump.** Whenever possible, first consider the use of process pressure by relocating the sample tap to

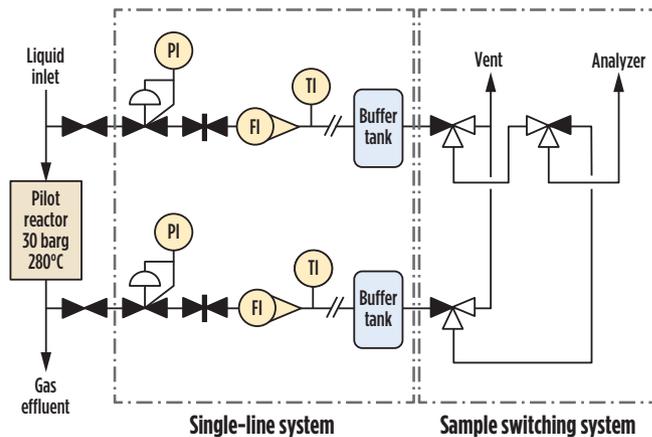


FIG. 3. First optimized pilot plant analyzer sampling loop system design.

TABLE 1. Time delay of the non-optimized sampling system

		Main components on the flow path that contribute to time delay				
Non-optimized sampling system:		Single-line system		Buffer tank**—mixing volume	Sample switching	Totals
Sample	Components	20 m of ¼-in. tube	Flowmeter—mixing volume	5 barg, 30°C	6 m of ½-in. tube	
Liquid inlet, 400 ml/min	Condition	30 barg, 30°C	30 barg, 30°C	5 barg, 30°C	5 barg, 30°C	-
	Actual volume	240 ml	16 ml	196 ml	15 ml	467 ml
	Corrected volume*	240 ml	48 ml	588 ml	15 ml	891 ml
	Time delay	36.0 sec	7.2 sec	88.4 sec	2.2 sec	133.8 sec
Gas effluent, 2,000 ml/min	Condition	30 barg, 30°C	30 barg, 30°C	5 barg, 30°C	5 barg, 30°C	-
	Actual volume	240 ml	18 ml	196 ml	15 ml	469 ml
	Corrected volume*	7,323 ml	1,619 ml	3,477 ml	86 ml	12,505 ml
	Time delay	220.3 sec	48.5 sec	104.3 sec	2.6 sec	375.7 sec

\*Notes: Details of corrected volume used in calculating time delay (1 and 2):

1. Correction for mixing volume = 3 × actual volume for the flowmeter and the buffer tank

2. Correction for pressure and temperature = actual volume × (P<sub>line</sub> in bara/P<sub>analyzer</sub> in bara) × (T<sub>analyzer</sub> in °K/T<sub>line</sub> in °K) only for gas (P<sub>analyzer</sub> = 1 bara, T<sub>analyzer</sub> = 25°C)

\*\* Located after regulator

a higher pressure point and the analyzer effluent return to a lower pressure location. Sample pumps tend to be unreliable and create undesirable mixing volume. If a pump is unavoidable, use a rugged high-quality standard fast loop pump. For example, specify gear pumps or other positive displacement pumps for liquid samples.

### VELOCITY LIMITATION VS. PRESSURE DROP LIMITATION

Two extreme cases of analyzer sampling loop design are:

1. Extremely long distance from sample tap to analyzer
2. Extremely small available pressure drop.

With extremely long distances, consider using a fast loop to allow higher velocity with a larger sampling line size without exceeding available pressure drop. If the available amount of the sample is too small for fast-loop configuration, choose to inject an inert diluent, such as nitrogen, to accelerate the sample transport right after the sample tap through the long line to the analyzer. **Note:** It is necessary to re-calibrate the analyzer for a nitrogen dilution case.

With an extremely small available pressure drop, avoid high-pressure-drop needle valves and send the analyzer sample effluent to a low-pressure location, such as a flare or vent to atmosphere—if it is safe to do so. The process design engineer may also install a sample pump. However, simply relocating the sample tap and sample return locations may eliminate the low-availability-pressure-drop problem. It is also important to prevent two-phase flow formation—flashing liquid or condensing vapor—that leads to excessive pressure drop or undesirable flow regime inside the sampling line. Liquid slugs can also damage the analyzer.

### BEWARE OF PHASE CHANGE

Sampling loop design is much more complicated when dealing with sampling line phase change. Some phase changes are intentional, while some occur by design mistakes. Three major types of potential phase change that engineers should be aware of are:

1. **Gas sample close to or at the dewpoint.** Reducing gas pressure right after the sample tap can make the gas move away from the dewpoint and reduce the possibility of condensation. Condensation can significantly change

**TABLE 2.** Time delay of the relocated pressure regulator case

Main components on the flow path that contribute to time delay							
First optimized sampling system:		Single-line system				Sample switching	
Sample	Components	1 m of ¼-in. tube	19 m** of ⅛-in. tube	Flowmeter—mixing volume	Buffer tank—mixing volume	6 m of ⅛-in. tube	Totals
	Condition	30 barg, 30°C	5 barg, 30°C	5 barg, 30°C	5 barg, 30°C	5 barg, 30°C	-
Liquid inlet, 400 ml/min	Actual volume	12 ml	46 ml	16 ml	196 ml	15 ml	467 ml
	Corrected volume*	12 ml	46 ml	48 ml	588 ml	15 ml	891 ml
	Time delay <sup>1</sup>	1.8 sec	6.9 sec	7.2 sec	88.4 sec	2.2 sec	106.5 sec
	Condition	30 barg, 30°C	5 barg, 30°C	5 barg, 30°C	5 barg, 30°C	5 barg, 30°C	-
Gas effluent, 2,000 ml/min	Actual volume	12 ml	46 ml	18 ml	196 ml	15 ml	469 ml
	Corrected volume*	317 ml	270 ml	313 ml	3,477 ml	86 ml	4,463 ml
	Time delay <sup>1</sup>	9.5 sec		9.4 sec	104.3 sec	2.6 sec	133.9 sec

\* Notes: Details of corrected volume used in calculating time delay

<sup>1</sup> 20% reduction in time delay for liquid inlet sample

<sup>2</sup> 64% reduction in time delay for gas effluent sample

\*\* Located after regulator

**TABLE 3.** Time delay of the fast loop and new sample switching system

Main components on the flow path that contribute to time delay			
Final optimized sampling system:		Fast-loop system	Sample switching
Sample	Components	20 m of ¼-in. tube	5 m of ⅛-in. tube
	Condition	30 barg, 30°C at 600-ml/min flow	5 barg, 30°C at 400-ml/min flow
Liquid inlet	Actual volume	240 ml	12 ml
	Corrected volume*	240 ml	12 ml
	Time delay <sup>1</sup>	24.0 sec	1.8 sec
	Condition	30 barg, 30°C at 8,000-ml/min flow	5 barg, 30°C at 2,000-ml/min flow
Gas effluent	Actual volume	240 ml	12 ml
	Corrected volume*	7,323 ml	71 ml
	Time delay <sup>1</sup>	54.9 sec	2.1 sec

\* See notes in Tables 1 and 2

<sup>1</sup> 80% reduction in time delay for liquid inlet sample

<sup>2</sup> 85% reduction in time delay for gas effluent sample

\*\* Located after regulator

the multi-component gas mixture composition to the analyzer because heavy molecules are selectively condensed more than light molecules, changing gas composition.

2. **Liquid sample close to or at the boiling point or bubble point.** Sub-cool the liquid before tapping the sample to get below the bubble point and reduce the possibility of flashing. Flashing alters liquid sample composition because of selective loss of light molecules into the vapor phase.
3. **Liquid sample vaporization before entering the gas analyzer.** The sample vaporizer is a major cause of time delays because vapor volumetric flow at the analyzer is typically > 300 times the liquid volumetric flow at the vaporizer inlet. Therefore, significant time delay occurs on the liquid side upstream of the sample vaporizer. Without proper measures, liquid-side time delay can exceed 300 seconds. Recommended solutions are:
  - Use small lines on the liquid side to minimize volume and liquid residence time. The recommended practice is a maximum 300-mm length of 1/8-in. tubing.
  - Use the liquid bypass line to allow high liquid flowrate up to the vaporizer inlet by splitting only small liquid flow to the vaporizer and most of the flow to the liquid bypass line.
  - For clean and narrow-boiling-range liquid samples, vaporize the liquid sample at the sample tap.

Other practices for the sample vaporizer are to:

- Keep liquid pressure as high as possible at the vaporizer inlet to avoid pre-flashing.
- Vaporize across a heated valve at the lowest pressure and temperature possible for a given composition.
- Use electric heating with controlled temperature as low as possible.
- Do not use steam heat due to the difficulty of temperature control.
- Do not overheat the vaporizer body because the inlet tube may get hot and flash some liquid before entering the vaporizer, causing sample phase separation and unexpected results.

### CONCERNS OF SAMPLE SWITCHING DESIGN

Typically, one analyzer is designed to analyze multiple samples from different sample taps, so sample switching is often required. Three conventional sample switching configurations (FIG. 4) are:

1. Conventional double block and bleed
2. Cascading double block and bleed
3. Outlet flow loop double block and bleed.

Advantages of conventional double block and bleed are cost and ease of installment. A disadvantage is the presence of dead legs, so cascading double block and bleed is preferred, even with a higher installation cost. However, a much longer time delay becomes the next problem for cascading double block

## HPI MARKET DATA 2016 WEBCAST

>> View on Demand Today!

Discover what's in store for the global refining, petrochemical and natural gas/LNG industries in 2016 and beyond. View on demand at [HydrocarbonProcessing.com/Webcasts](http://HydrocarbonProcessing.com/Webcasts)



### Lee Nichols

Editor/Associate Publisher,  
*Hydrocarbon Processing*

"Global Construction and Investment and Updates on the Global Refining Industry"



### Ben DuBose

Digital Editor,  
*Hydrocarbon Processing*

"Petrochemical Outlook for 2016 and Beyond"



### Adrienne Blume

Executive Editor,  
*Hydrocarbon Processing*  
and Editor, *Gas Processing*

"Natural Gas/LNG Market Status and Forecast"



### Mike Rhodes

Managing Editor,  
*Hydrocarbon Processing*

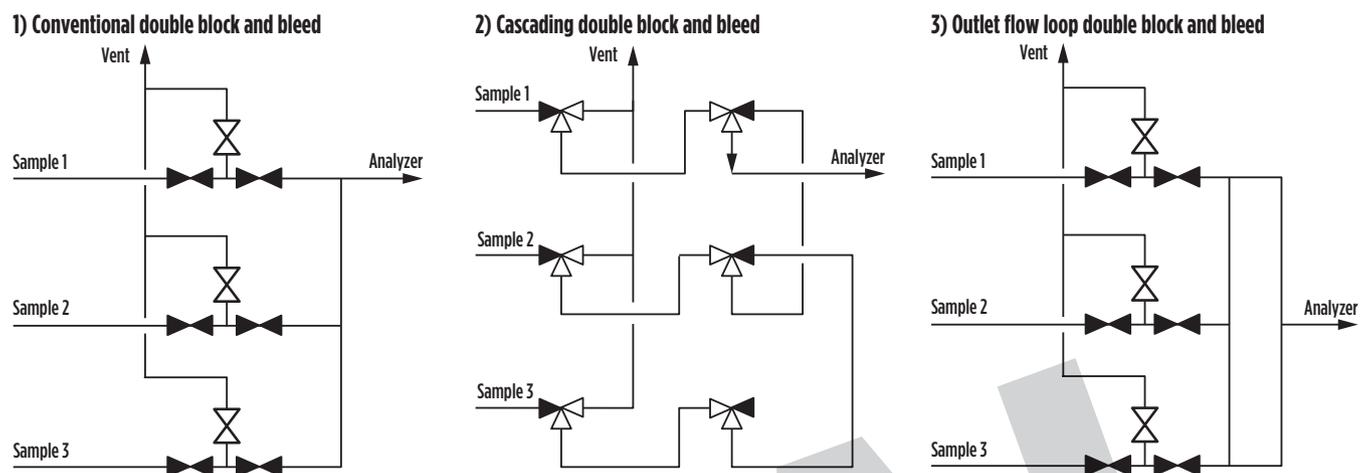


FIG. 4. Sample switching configurations.

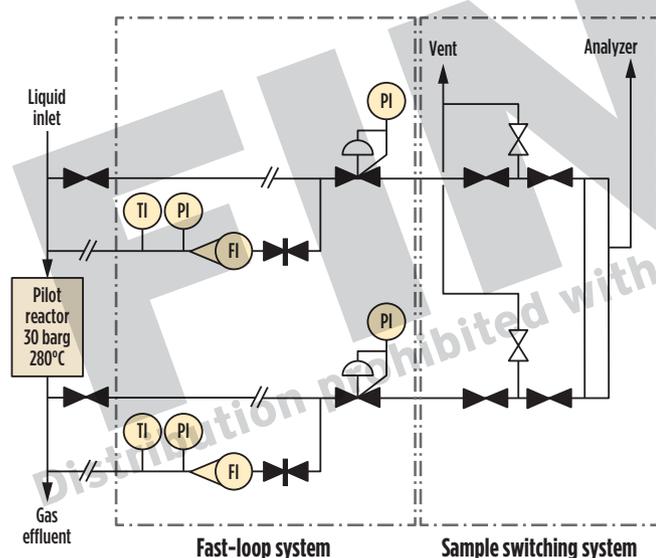


FIG. 5. Final optimized pilot plant analyzer sampling loop system design.

and bleed. To overcome these limitations, it is recommended to use an outlet flow-loop double-block-and-bleed configuration to significantly reduce both time delay and dead leg problems.

FIG. 5 shows the final optimized analyzer sampling loop system with various strategies implemented. A fast-loop configuration is used with the removal of the original buffer tank. An outlet flow-loop double-block-and-bleed configuration reduced dead legs and time delay. It also helped minimize the fluctuation of the sample's flow and composition after the removal of the buffer tank. The pressure regulator was moved to the position right before the sample switching system to not limit fast-loop high flowrate. Components were also moved from the main flow path to the fast-loop return line. There were limited sample flows to the analyzer at not higher than 400 ml/min for liquid and 2,000 ml/min for gas. TABLE 3 shows that the time delay was reduced below the non-optimized case in FIG. 2 by 80% for the liquid sample and 85% for the gas sample, in which the final time delays for both the liquid inlet and gas effluent are within the typical engineering standards at 60 sec.

## MANAGING TIME DELAYS IN A NUTSHELL

Time delays can be managed by using process engineering fundamentals to analyze the problem and correct root-cause phenomena, not only the problem symptoms.

Process design engineers should never blindly believe that analyzer engineers or other discipline engineers are doing everything right. It is the duty of competent process design engineers to cross-check the design from other discipline engineers by studying relevant engineering standards and utilizing sound process engineering fundamental knowledge. **HP**

### REFERENCES

- <sup>1</sup> T. Waters, *Industrial Sampling Systems*, Swagelok, 2013.
- <sup>2</sup> *Instrument Engineers' Handbook*, 4th Edition, Chapter 8, ISA, 2003.
- <sup>3</sup> Pichler, H. and O. Sauer, "Consider investing in a standard compliant process analyzers," *Hydrocarbon Processing*, July 2009.
- <sup>4</sup> Benton, A. and C. Valiz, "Use online analyzers for successful process monitoring," *Hydrocarbon Processing*, January 2011.



**WIROON TANTHAPANICHAKOON** is a process technology leader for the Process Technology Center of SCG Chemicals Co. Ltd. in Thailand. He has authored several international papers and technical articles and holds technology patents. He is now in charge of developing and implementing in-house and external process technologies for SCG Chemicals. His expertise also includes process and equipment design plus the conceptual, basic and detailed design of new processes. He has had experience as a process engineer with an ExxonMobil subsidiary refinery in Thailand and as an energy improvement engineer for SCG Chemicals. He obtained his BE and ME degrees in chemical engineering from Kyoto University, Japan, and is a senior licensed engineer in Thailand and a senior member of AIChE. He was also a member of the Elsevier Editorial Board in Process Plant Design during 2014–2015.



**KONGKIAT SURIYE** is a senior researcher for the Research and Development Center of SCG Chemicals, Co. Ltd. in Thailand. He is now a group leader for the advanced catalytic process research team. He has authored more than 30 international papers and one book chapter in the fields of heterogeneous catalyst and catalytic processes, and has invented several patents in these fields. One of his developed technologies has been implemented on a commercial scale, and three are now at pilot scale. His expertise also includes laboratory and pilot-scale reactor design and scale-up, and also a design of reaction online analysis with sampling loop systems. He obtained his BE degree (1st ranking in class) in chemical engineering from King Mongkut's University of Technology in Thonburi, Thailand, and also a PhD degree in chemical engineering from a joint program between Chulalongkorn University in Thailand and the University of California–Davis, in the US.