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Sulfur Recovery On-Line Analyzers From Front End Design Through Life Cycle Ownership

STUART SIMMONDS, STEPHANE CAPPE, RANDY HAUER
AMETEK Process Instruments
Pittsburgh, PA, USA

DOUG CICERONE
Cicerone & Associates, LLC
Houston, TX, USA

On-Line Process Analytics is a young industry. Born of necessity to optimize high value processes it found its way to sulphur recovery by the late 1960s. Since that time the tail gas analyzer has gone through two full generations and is about to enter a third. This paper covers the following topics relating to the specification, use and long term ownership of SRU process gas analyzers;

- *Results of an industry survey with questions relating to reliability, on-line control and best practices are presented.*
- *"Lessons learned" from the viewpoint of a start up engineer. How things go wrong from the initiation of FEED, through detailed engineering, to systems integration, to end-user hand over.*
- *The pitfalls of subcontracting analyzer engineering to a systems integrator*
- *The utility of feed forward analysis and control of the SRU.*

INTRODUCTION

The history of on-line process analytics is a relatively short one. Development was driven by the need for process control of high value hydrocarbon-based products. The first on-line analyzer applications came during the second war. Rapid development came in the 1970s with the advent of the microprocessor and resultant chemometric techniques. Led by Phillips Petroleum, Union Carbide and Dupont Chemical, amongst others, these initiatives were the antecedents of today's Siemens Applied Automation, ABB Analytics and Ametek Process Instruments.

Whether or not sulfur can be considered a high value product, in most cases the driving force for process measurement and control of the SRU is largely environmental. The US EPA Clean Air Act of 1970 and the ground-breaking study by Alberta Environment on *The Capability of the Modified-Claus Process*(1) coincided with the first attempts to control the Modified-Claus process using an on-line analyzer and closed loop control.

The first report of an on-line tail gas analyzer was a technical paper based on a gas chromatograph installed at the Dow Chemical Freeport TX (USA) facility in 1970(2). In 1972 Amoco Oil and Dupont Process Instruments published a paper on an Ultraviolet (UV) based tail gas analyzer installed at the Amoco Whiting IN (USA) refinery(3). Shortly after this, in 1974 Western Research participated in a pilot study using a prototype UV-based tail gas analyzer at the Shell Waterton AB (Canada) gas plant. Subsequent developments by various manufacturers were all based on UV spectroscopy and extractive sampling techniques and that remains the case today.

Now some forty years on there is the collective experience base of; ~2700 tail gas analyzers (Dupont, Western Research and the amalgamation of these two; Ametek Process Instruments); five models; two full generations; and now moving into a third generation tail gas analyzer, that serves the industry.

In order to gauge the level of understanding of the needs of the analyzer application and to obtain valuable user related experiences, a wide-ranging survey of professionals in three distinct stakeholder groups who are directly involved in the purchase and maintenance of SRU process gas analyzers was undertaken. The groups were;

- Front end engineering design and start up engineers
- Operations
- End user analyzer engineers and technicians

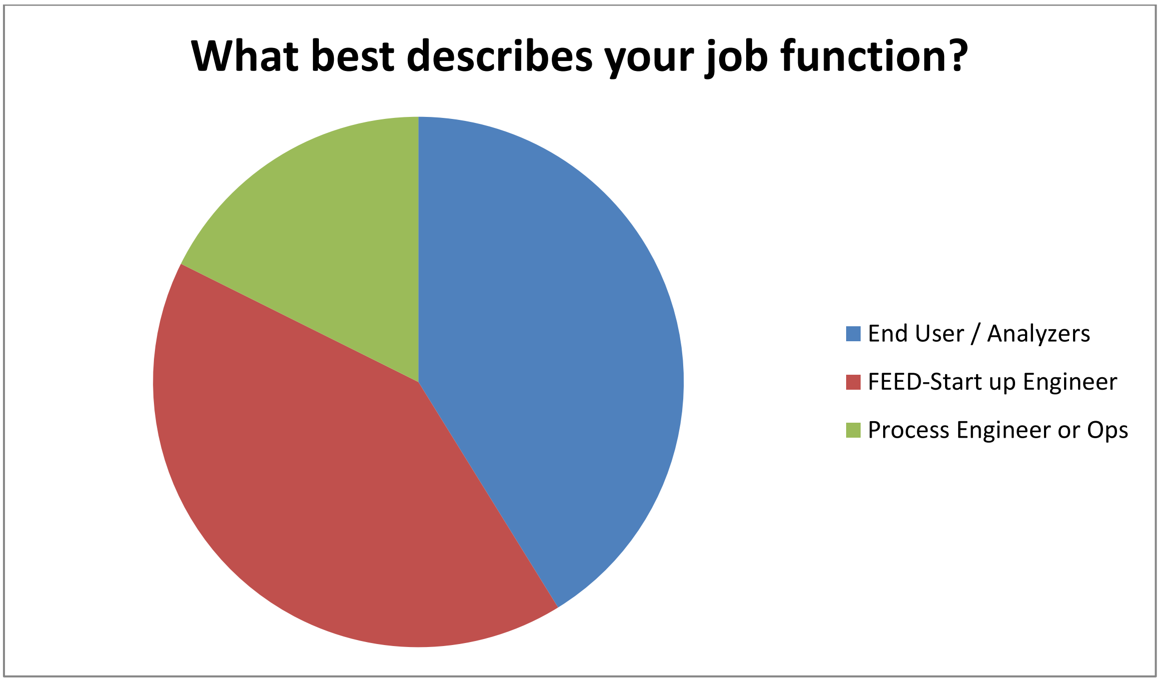

Fig. 1: What best describes your job function?

Many of the survey results confirmed prior experience and are briefly summarized with some best practice details worth repeating. Two of the questions were specifically worth expanding on; these related to **feed gas analysis (control)** and **third party supply of analyzers by a systems integration contractor**.

A start-up engineer was asked to weigh in on "analyzers lessons learned". The individual, experienced in a number of designs and processes, has been involved with major grass roots projects in Asia and the Middle East. Over the years the engineer has acquired a specific skill set in tail gas analyzer maintenance and offered a unique perspective.

RELIABILITY AND BEST PRACTICES

The survey confirmed that the industry considers tail gas analyzers to be reliable.

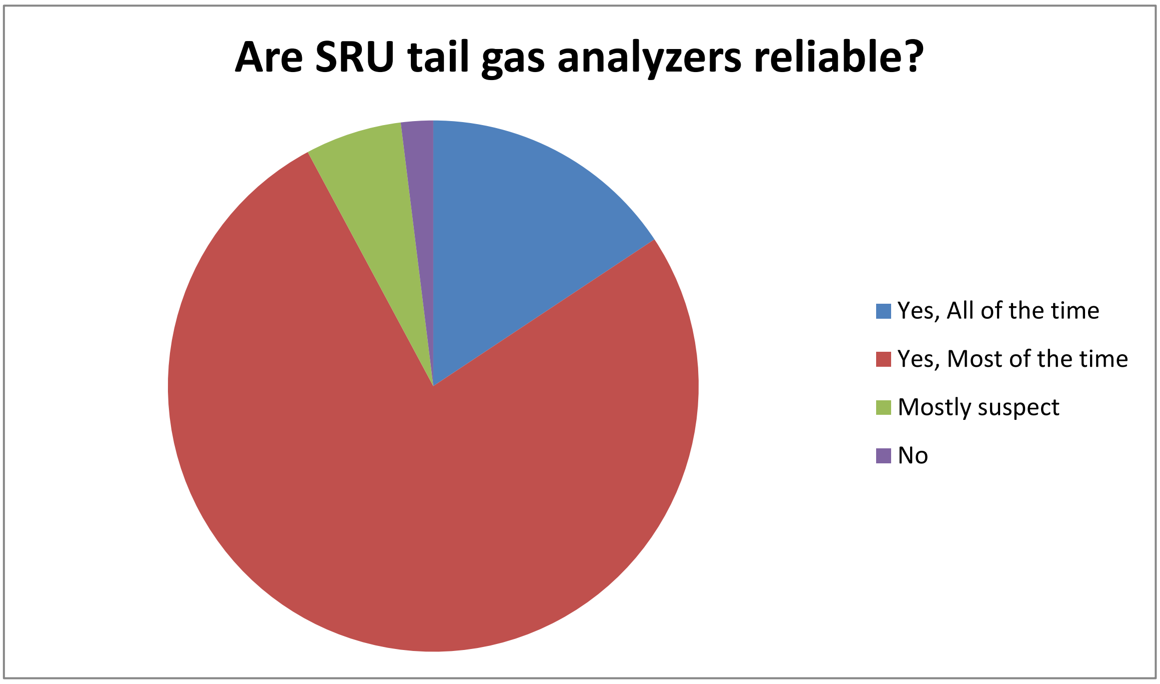

Fig. 2: Are SRU tail gas analyzers reliable?

Trouble-shooting an analyzer for sudden failure of an electronic problem is not difficult and a large refinery or gas plant complex has access to adequate skill levels for this. Specialist help is required where the problem is intermittent or electronic component failure is occurring on a frequent basis.

The primary factor affecting reliability of the tail gas analyzer is heat integrity at the process connection and the second leading cause is inadequate design of the analyzer shelter. The list of best practices is a short list of critical items.

The following Best Practices have been covered in previous papers(4) and are worth reviewing again.

Best Practices (Heat Integrity)

- The process nozzle should be 150mm (6") or less, terminating in a 2" 150 lb raised face flange (maximum)
- For top of the pipe type analyzer the vendor must supply the steam jacketed ball valve. The steam needs to be of medium pressure (nominal 7 to 10 barg / 100 - 150 psig) as low pressure steam is, in practice, often wet and unsuitable.

- Use Contra-Trace™ or Contra-Heat™ to overcome any shortcomings. Do not allow the practice of wrapping steam trace tubing and insulation around a problem and thereby masking that problem.
- For sample line analyzers, if possible install the analyzer above the sample point and in all cases request the analyzer vendor confirm the length from on-site measurements and/or isometric drawings. When sample lines are estimated and then the numbers flow through more than one set of hands, the probability the lines will be too long, is almost a certainty.

Best Practices (Analyzer Shelter)

Ametek manufacture two types of tail gas analyzer; the close-coupled ("no sample line") type and the remotely located (with sample line) type. There is a distinct pitfall associated with each of these at the EPC detailed engineering stage.

The close-coupled analyzer is rated for ambient conditions of -20 to +50°C (soon to be rated to +60). While the analyzer is ingress-rated for IP65 (i.e. totally weatherproof, suitable for exposure) it is not protected against solar gain. A recent study by a major analyzer vendor quantified this in rather exact terms whereby the life of electronic semiconductor circuits is affected adversely by temperature as indicated by the Arrhenius equation. This equation predicts, approximately, that each 10 degrees C increase in operating temperature reduces mean electronic component operating life by 50% (5). There are many examples of solar gain increasing the observed interior temperature of the analyzer to some 20 degrees over the 50°C maximum specification with the resultant component failure predicted by the Arrhenius equation (typically the power supply board).

- The ***Best Practice*** point here is; provide an adequate shelter that shades the analyzer from direct sun at all times. The shelter is no different than what one would see over a local panel, quite inexpensive and almost always neglected at the EPC detailed design stage.

For sample line analyzers the problem is of a different nature. During detailed design the EPC company locates the shelter at a convenient level in the structure or as an afterthought it is located at grade some distance away. Worse yet, when a systems integrator is involved their revenue can be augmented by larger shelters, longer sample lines and more engineering change orders. A 30m sample line is unnecessary and was mentioned more than once in the survey as being a constant repeat of bad engineering[(6)].

- The ***Best Practice*** point here is; involve the analyzer vendor at an early stage preferably at front-end engineering design. As end-user insist upon it and continue the dialogue into the detailed design stage. Be very wary of surrendering all analyzer design to a systems integrator. This point is discussed in a subsequent section with supporting survey results.

The Impact of Health & Safety

Sample point selection for both tail gas and feed gas analyzers is more often than not compromised at the piping engineering stage[(6)]. It is the lack of analyzer specialists at the detailed engineering stage that is the root cause. A constricted and compromised sample point location can affect analyzer operability which in itself is bad enough. The problem can extend to safety concerns at HazOp review, requiring an expensive piping change to make it right.

Two major oil companies have implemented early review of existing tail gas analyzer installations. For those installations deemed to present a potential escape risk for analyzer maintenance personnel, a double block-in of the tail gas analyzer sample is now required. This is a question that must be raised at piping design and HazOp review.

QUESTIONS RELATED TO CONTROL MODE, START-UP AND TURNDOWN

The three questions relating to these topics did not produce any startling revelations but there is some feedback worth highlighting.

Is the Analyzer in control mode as a matter of standard operating practice?

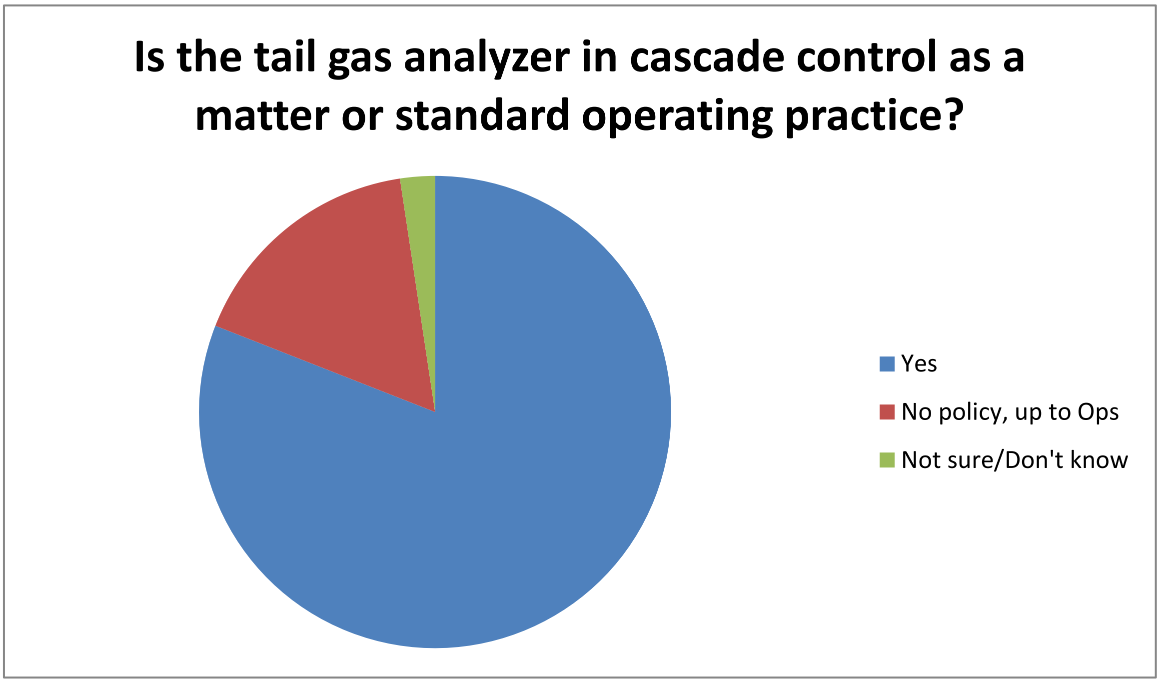

Fig. 3: Is the tail gas analyzer in cascade control as a matter or standard operating practice?

This confirms what is seen in the field when presenting seminars or conducting service and uptake is still considered to be on the low side. Some of this may be related to running at high turndown. Following are some of the verbatim comments from FEED and start-up engineers in response to the question;

"Do you have trouble with the analyzer or the controls at turndown of the SRU?"

> *"Not with the analyzer, sometimes the AC tuning because of the increased lag time"*

> *"Not with the analyzer per se, possibly with trim air FIC tuning….Suggest Ametek provide trim air FIC tuning guidance document and optional service"*

Slow response is sometimes attributed to the analyzer when in fact it is process lag time. The best response to this is "*it is a dumb analyzer that we ask to do a smart thing*". That is, a simple algorithm calculation from the [H_2S] and [SO_2] values is used to arrive at a single (control) value to send to the DCS. Although asked frequently to help configure control loops this is typically not a core competency of analyzer companies and more the domain of the FEED and EPC control engineering team

After start-up, how soon do you expect the analyzer to be in control mode?

> "*We like to see the analyzer on control in 8h. However, many times the analyzer does not work until vendor is brought to site*"

This relates to the phenomenon of the Claus catalyst preferentially absorbing H_2S over SO_2 with the result producing values that do not represent the true air control situation. Our guideline (provided by Sulphur Experts test crews) is that the analyzer should only be used for control some 8 hours after start-up, perhaps more depending on individual plant conditions.

There was quite a spread in the answers. Following are some more verbatim comments from experienced start-up engineers confirming our assumption that 8 -24 hours is the norm.

> *"Need at least a day for new catalyst to stabilize"*

> *"With new catalyst, 1 day. Hot restart, less than1 hour. Cold bed restart, 6 hours"*

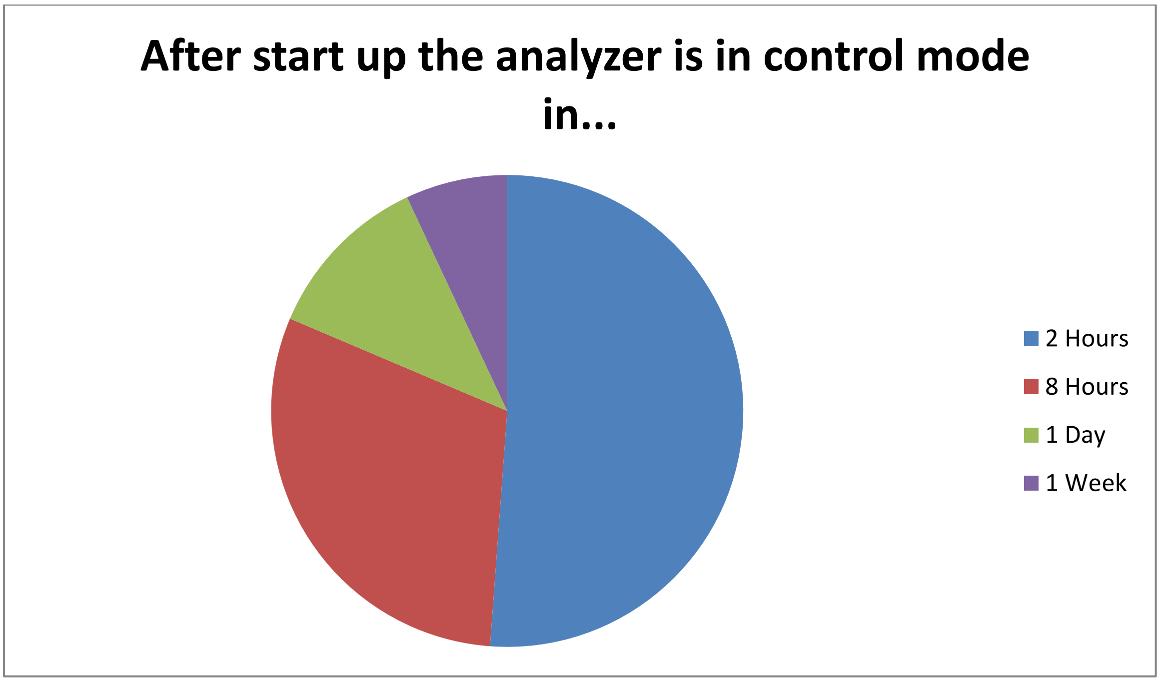

Fig. 4: After start up the analyzer is in control mode in...

THE PERSPECTIVE FROM A START-UP ENGINEER

Perspective was sought from a start-up engineer with extensive experience in all aspects of start-up and plant hand-over, much of this experience gained on very large grass roots SRUs in Asia and the Middle East. By necessity the expert has been compelled to develop process analyzer skills because factory resources or trained personnel were not available. Three experiences are provided here;

Project #1:

Construction ran a year behind schedule at an Asian client in a remote location. The acid gas feed, air demand and stack analyzers (three trains, nine analyzers total) all sat on-site for a year in a hot and dusty climate. When time came for commissioning, the analyzers were started as-is with no preventative maintenance measures taken. None of the analyzers worked on start-up.

The local service representatives had limited experience and were not prepared for the work required for the overhaul of each analyzer. Commissioning spare parts at site were misplaced during construction and commissioning, and parts from Train 3 analyzers were used to fix Trains 1 and 2. No records were kept of which parts were taken, which caused difficulty when troubleshooting the Train 3 analyzers. The local service representative did not keep many spare parts in stock, and waiting for spares from North America and Europe caused delays in commissioning.

It took four months to get the analyzers working correctly. In that time the client lost all faith in the analyzers and it took another year before they fully trusted them.

Project #2:

An EPC contractor inexperienced in SRU design and construction hired a third-party systems integrator to supply all of the analyzers for a project in the Middle East. A financial dispute between the two parties resulted in a delay for field support during commissioning. The systems integrator and EPC contractor did not communicate effectively during the design phase, and the air demand analyzer was set up for *Excess Air* output while the controller was expecting an *Air Demand* signal with the result being the controller acted in the opposite direction to what was expected. There was also disagreement between the systems integrator and construction E&I as to who was in charge of loop checking. The result was no loop checks were performed, and the H_2S and *Excess Air* signals were crossed. Additionally, the scaling of the SO_2 signal from the analyzer did not match the scaling in the DCS.

These many problems and lack of field support contributed significantly to a six month delay in performance testing.

Project #3:

A few days after start-up, the *H_2S, SO_2* and *Air Demand* signals all went to zero. The analyzer didn't show any alarms and appeared to be working. The analyzer was back-purged, and the signals came back to a normal operating range then slowly dropped to zero again. This was repeated several times and each time the signals started healthily and slowly dropped to zero. An experienced analyzer technician thoroughly checked the analyzer and could not find the problem. Finally the unit was shut down and the sample probe removed. The sample inlet pipe had fallen off the probe assembly, so the sample exhaust was flowing directly into the sample inlet port, essentially forming a closed loop. As the H_2S and SO_2 reacted to form sulfur within the sample loop, the *H_2S, SO_2* and *Air Demand* readings dropped to zero. The sample pipe was reinstalled and tack welded in place, and the analyzer worked normally.

Lessons Learned:

- Systems integrators typically add another level where things can go wrong. Many of the other problems seen occur at the interface points; one group buys the analyzer, another buys the shelter, a third buys the sample line, a fourth buys the isolation valve (or nobody buys it), and none of them matches.
- Require certified proof from the EPC or systems integrator that they have factory trained technicians who are capable of start-up and troubleshooting non-routine problems
- By far the main issue seen is no spare parts at site. So analyzers in parallel units are scavenged or there is a long wait for parts to be shipped.

WHEN THE ANALYZER SCOPE OF SUPPLY IS PROVIDED BY A SYSTEMS INTEGRATOR

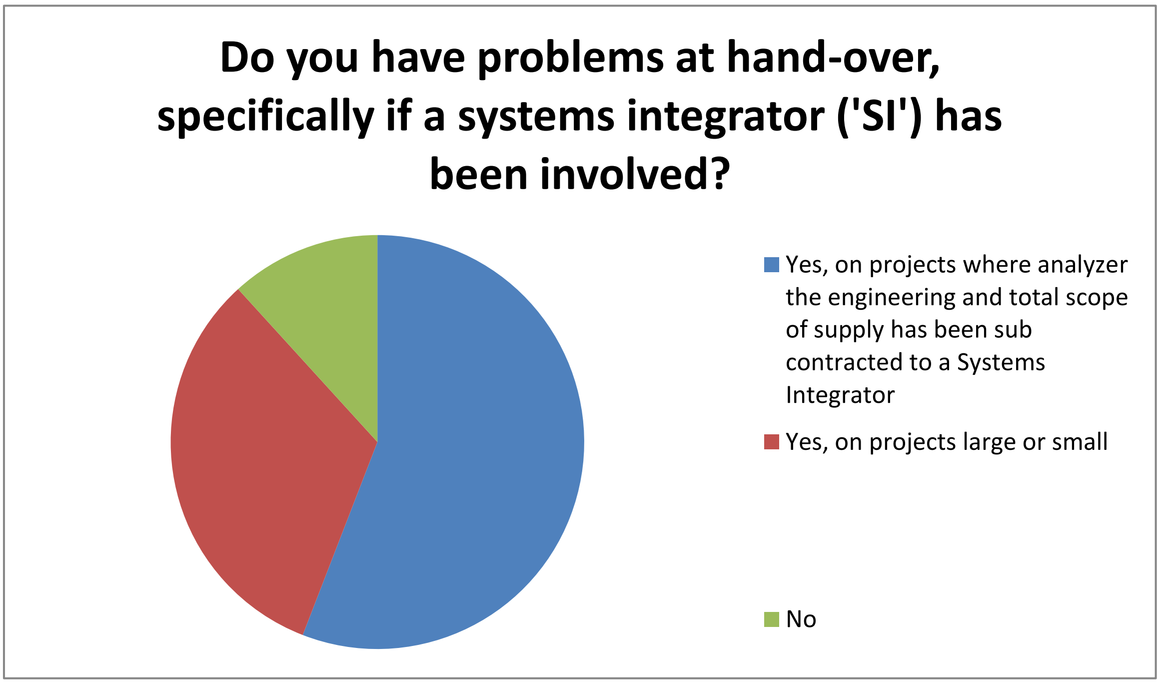

Fig. 5: Do you have problems at hand-over, specifically if a systems integrator ('SI') has been involved?

It was evident from the survey that the question of 'problems at hand-over' is at once both a hot topic for the selected audience but also one for which the vast majority of respondents were in agreement. They all believed that there were issues on larger scale SRU projects, in the cases where the analyzer engineering and scope of supply is wholly or mostly provided by a systems integration company. As one of the responses succinctly put it,

"Systems integrators typically add another interface where things can go wrong".

From experience these comments are not entirely surprising. Given the scale and the scope of most systems integration projects in relation to the specialized and period nature of a dedicated process analyzer project, it is not difficult to appreciate that they cannot be experts in these types of engineering processes. This, of course, is not true of the large scale process analyzer companies (like Ametek who are involved in such technologies as sulphur recovery analyzers) who rely on consistent field proven results to drive sales in what is a relatively small and specialized industry.

But perhaps more importantly it is also not true of the end-user companies, for which, such critical process measurements will invariably be assigned dedicated analyzer maintenance personnel. In the evolving world of the industrial process plants, instrumentation technicians are being asked to handle more instrumentation tags and technology than was seen in the past but the SRU (+ TGTU) plants are still likely to command special attention and a specialized team of analyzer technicians. This is borne out in the large number of technicians still attending the numerous sulphur recovery training courses held each year around the globe.

So, why should this be such an issue? The simple answer from the survey, *"It is critical that end-users be involved in analyzer system design - instrument engineers do not do analyzers*".

The design, integration and placement of a SRU tail gas analyzer is critical to its ability to provide accurate and useful information to the process control loop. So, naturally there are several ***Best Practices*** that are essential to ensure the success and this knowledge can only come from education and experience working in the SRU field. In most cases these can be provided by both the analyzer manufacturers and the experienced end-users. So, when considering a new project success will often rest on the ability for both these groups to work closely with one another. Thankfully, the survey clearly records that a good number of the respondents is already aware of this and therefore ensures any potential issues at hand-over will be avoided.

"I work closely with the project team on all analyzer applications",

"We are involved through the whole process. They let us decide which analyzers to purchase"

ACID GAS ANALYSIS FEED-FORWARD CONTROL

In addition to tail gas there are an additional five process analyzer tags in the SRU-TGTU complex and the acid gas (feed gas) analyzer is the current and most topical. The development of a full composition, real time acid gas analyzer for the purposes of feed-forward control is covered here in some detail as well as survey results which revealed some misconceptions on the value of feed gas analysis.

When considering the 'air demand' of the SRU process, primary air control using feed-forward flow ratio of air to acid gas accounts for ~90% of the combustion air. Secondary air control using tail gas analysis (ratio 2 [H_2S] : 1 [SO_2]) controlling a trim air valve by feedback control (or cascading to the feed-forward controller) accounts for the ~10% balance of the required combustion air. Feedback control based on process analysis provides the most precision, however, it is impaired by the ~30 second process lag time, especially if the composition of the acid gas changes rapidly(7).

Under steady state conditions air control is stable, but in the case of sudden changes in acid gas composition it is not uncommon for air control requirements to exceed the ability of the feedback control loop. In these cases the excursion from the set point of 2 [H_2S] : 1 [SO_2] can be extreme, and the cause of a serious loss of recovery efficiency and increased emissions(7).

With advances in certain technology and process control, the implementation of a feed-forward analyzer for real time acid gas analysis has been seen with increasing regularity, particularly on new process projects. Jacobs Comprimo Sulphur Solutions (JCSS) developed the ABC+ system (three systems installed with a further six systems currently in start-up phase.) This is their Advanced Burner Control system for feed-forward control, using real time process analysis of the acid gas, to provide information to the closed-loop control[8].

From the survey it was clear that all respondents saw the benefits of feed-forward control but there were also many misconceptions that should be addressed.

Firstly, respondents were unclear whether feed-forward control can be used in the cascade control loop but from field experience this is exactly the intent.

> *"Not sure if operators or control engr. would use "full composition" info in real time for control."*

Rapid compositional analysis of the hydrogen sulphide, and a total hydrocarbon measurement provide the *air demand* components with the addition of a carbon dioxide and water measurement (and in the case of sour water acid gas, ammonia) provide full acid gas composition details.

Secondly, there was clear concern as to whether the information is fast enough for feed forward control.

> *"Analysis time is critical - cannot have a compositional acid gas analyzer that takes more than 1 minute to perform the analysis."*

Again this is exactly the intent of these control designs. With the use of real time spectroscopic technology (a combination of both ultraviolet and infrared) the system is able to provide useful data rapidly.

NEXT GENERATION TAIL GAS ANALYZER

The life cycle of an analyzer is expected to be 15-25 years and some analyzers can be in the field for 30 years or more if properly protected and maintained. The product life cycle of an analyzer is of the same order, 15 years or more and is mostly subject to the obsolescence of the electronic components. The current design of the close-coupled ("top of the pipe") tail gas analyzer was due for updating which presented an opportunity for some additional features. That said, given the close-coupled analyzer has an installed base in excess of 1,200 units and the well proven success of the technique, the goal was to be evolutionary not revolutionary. The principal improvements offered in the third generation are;

- **Ambient temperature rating:** Improved thermal isolation between the oven and electronics results in an increase in the ambient temperature specification from 50°C to 60°C. This makes installation in regions like the Middle East possible without the need for an air conditioned shelter (with the aforementioned need for protection from solar gain an important detail).
- **Automatic flow control:** This provides a method to automatically adjust the flowrate of the analyzer relative to process pressure (especially important if there is entrained sulphur)
- **Double-block isolation from the process:** This provides an option for any site specific safety considerations.
- **Web enabled interface and smart diagnostics:** The use of three intelligent diagnostic models (observational, model-based and functional to identify, communicate, and react to situations that would otherwise lead to unscheduled downtime and transmitting this information via ethernet so the technician can improve reliability at a safe distance[9].

CONCLUDING RECOMMENDATIONS

It is always a useful exercise to stop and take stock. With this survey it was possible to review a broad spectrum of responses from professionals from within the sulphur recovery industry, each a seasoned expert in their respective field, to gather insight on a number of key and pertinent SRU related topics.

Overwhelmingly, the broad stroke view of this commentary is that the analytical instrumentation on a SRU plant is a highly specialized field of such critical operational performance that knowledge and experience are essential to success. The key conclusions of which are;

- For large scale project where a systems integrator is involved, ensure close management of the project from field proven end-user analyzer technicians, in combination with close communication to the key SRU analyzer vendor.
- Ensure that the SRU analyzer vendor is involved in the entire project process from the early stages of the front end engineering design (FEED) right through the detailed design phase.
- A successful SRU analyzer start-up requires careful thought and planning. The end-user technicians (or alternatively the contractor analyzer technicians) need to be factory-trained and authorized to work on the respective analyzers, alternatively the analyzer vendor must be at site for start-up.

Secondly, as the industry drives to tighten control loops and reduce upsets in the process, the analysis of the feed-forward acid gas will become an industry standard. The results are clear that feed-forward control is both practical and worth the (relatively small) capital investment. The industry is still in the education phase and needs to be assured of certain practical implications but the need and benefits of feed-forward control are already well established.

In conclusion, if an acid gas analyzer has not been included in the FEED, then the design should be revised to at least make provision for the heated acid gas probe. As the industry moves to tighter control and feed-forward control becomes a standard feature, considerable time and effort would be saved if, at the construction phase, the probe had been provided to allow for simple installation of a feed-forward analyzer at a later date.

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