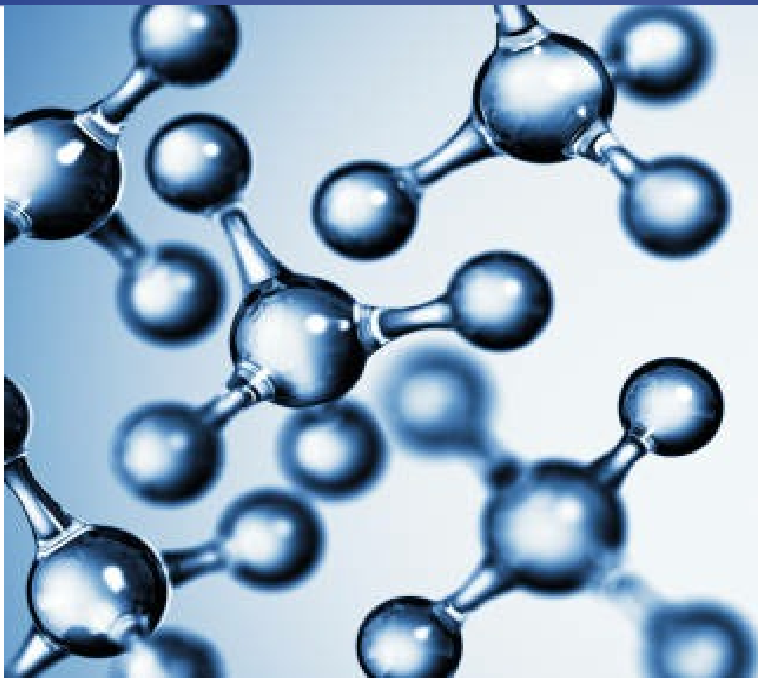
Popcorn Polymer

Early Detection and Alarming



The Application of Dynamic Imaging to Detect the Early Formation of Popcorn Polymer

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Popcorn polymer is a major concern for process safety within any facility manufacturing or utilizing butadiene, or other similar conjugated diolefins, which have the potential to undergo a proliferous polymerization mechanism. This problem was highlighted after the 2019 explosion at TPC Chemical Plant in Port Neches, TX, in which butadiene reacted to form popcorn polymer that, over time, ruptured a pipe that resulted in the explosion. It is now commonplace for facilities handling this material to monitor for the generation of popcorn polymer to prevent accidents like this from occurring again. Many facilities monitor for the formation of popcorn through periodic checks of filters designed to capture the polymer. This paper explores the application of CANTY's Inflow analyzer, a dynamic imaging technology, to both automate this detection and to detect this formation earlier by looking for small popcorn polymer particles in the process fluid.

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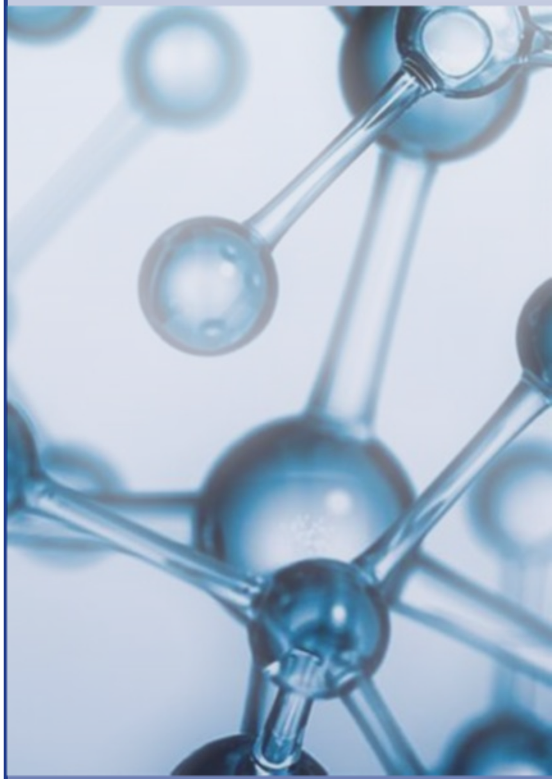


Introduction

Dynamic imaging involves flowing process material through an analyzer that takes microscopic images of the fluid and analyzes those images to detect the presence of “particles.” These particles could range from droplets to gas to solid materials. Since the acquired images are 2-dimensional and there is a physical difference in the appearance of these types of materials, dynamic imaging analyzers are capable of simultaneously detecting, sizing, and measuring concentrations of all of these materials independently from one another.

As pure liquid butadiene flows through a pipe, it should be free of contaminants. When a popcorn polymerization reaction begins, it forms small solids that grow over time in the liquid monomer. When a CANTY Inflow is installed inline where this monomer is flowing, the analyzer will be able to pick up on these solid particles once they reach only 1-2μm in size. When detected, the analyzer can output a signal indicating the size, count, and concentration of particles detected.

These outputs allow a control system to automate a response far earlier and faster than a detection via other common methods, like checking filters for clogging.

Overview of Popcorn Polymerization

Popcorn polymerization refers to the rapid polymerization of a conjugated diolefin by a proliferous polymerization mechanism. This occurs when a free radical instigates a chain reaction polymerization of the monomer molecules at a rate that continually grows. The result is the formation of a, typically, non-desireable, highly cross-linked polymer.

The most commonly known monomer that has this problem is butadiene, though it is possible in some other molecules, such as styrene in the presence of a cross-linker.

As this unwanted polymerization reaction occurs, the resulting cross-linked polymer comes out of solution and forms a solid. This solid can cause blockages in pipes, but, even worse, can damage or even rupture lines.

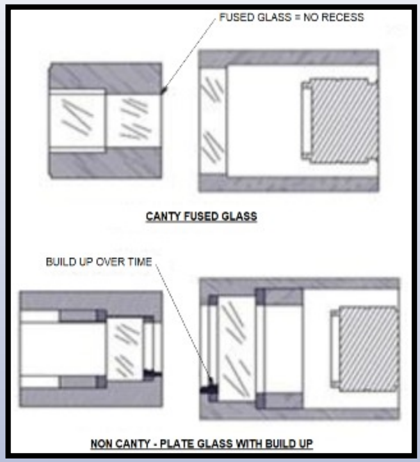
It is extremely important to identify popcorn polymerization early on and take steps to prevent it from continuing to avoid potentially deadly accidents. The most common method to detect popcorn polymerization currently is by the periodic checking of filters to see popcorn polymer is being caught. This has been used as a reliable method of detecting popcorn polymer, but it requires the polymer particles to become large enough to get caught in the filter and relies on operators being consistent with their filter checks.

To improve process safety, a CANTY Inflow can be installed inline to pick up on these particles when they are as small as 1µm. This early detection is automated and does not rely upon human interaction to catch the problem. By detecting these particles as early as possible, producers and users of these monomers can be given more time to react, resulting in a safer process and reduced costs. In the spirit of safety, it is still recommended to continue manually checking for popcorn polymer as well.

The Canty Inflow works on the premise of dynamic imaging. It is installed inline with process flowing through it. As particles are detected, the Inflow will quantify the size and concentration of the polymer and output these values as tags to a control system. This system can then be set up to alert personnel of the problem and even begin measures to mitigate the situation.

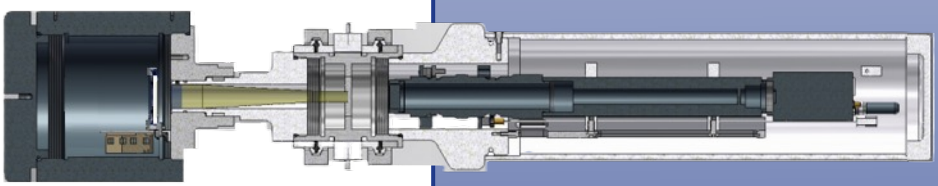
Inflow Hardware

The hardware involved in CANTY's Inflow includes 4 main key technologies: the flow cell, lighting, camera optics, and Vector Control Module.



The flow cell on an Inflow is designed to mount directly inline with standard sizes up to a pipe size of 3". (Note that custom units may be provided for line sizes greater than 3". Consult the factory for details.) The flow cell is designed to orient particles such that the analyzer is always able to capture an image of the longest side of each particle. This is key to accurately sizing each particle seen. Critically, the flow cell seals the light and camera from the process using CANTY's fused glass technology. This fused glass barrier, unique to CANTY, can sustain extremely high temperatures and pressures while still allowing for a view into the process. Unlike with other analyzers, this fusion of metal to glass creates a hermetic seal and does not utilize gaskets or O-rings at the glass interface that the camera and light look and shine through. That smooth surface doesn't leave any crevices and makes it difficult for contaminants to stick to or build up on the surface of the glass.

CANTY always says that there are three keys to a perfect image: lighting, lighting, and lighting. CANTY has been leading the industry and innovating in process lighting since the 1970's and applies all of that knowledge in the Inflow analyzer. The LED light used is the brightest in the industry with a guaranteed lifetime of 5 years. Unlike many other analyzers, the light in the Inflow back-lights the process, resulting in sharp, crisp images of each in-focus particle.

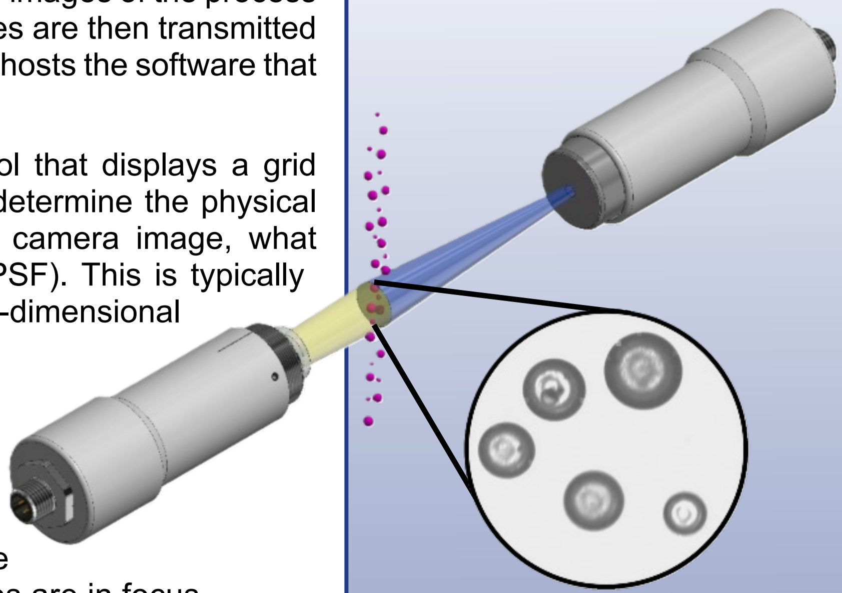


The camera optics used in each Inflow are high resolution gigabit Ethernet CCD's that undergo significant testing to ensure they will be robust for long-term use. Optics are always improving, so CANTY is constantly evaluating the latest and greatest cameras and lenses to provide the highest quality images without compromising on quality and reliability of the analyzer. Optics used in any given analyzer are picked according to the requirements of the application. The latest generation of optics used in the Inflow utilize a 4K resolution camera that can pick up on particles as small as 1µm.

Obtaining a high quality image of a process is only half of the battle. The magic happens when that image is processed on CANTY's VCM. The VCM platform is a series of powerful processors that host the CantyVision software. This machines are configured with the analyzers at the factory prior to shipping to make obtaining an image plug-and-play out of the box. In an age of remote connections, the VCM's have the ability for users to allow CANTY personnel to remotely access the unit to provide support and help troubleshoot the analyzers. These analyzers also provide the outputs to interface the data tags with a user's control system.

How Dynamic Imaging Works

Dynamic imaging makes use of image analysis on a video stream of microscopic images. CANTY's Inflow captures images of the process fluid and potential contaminants. These images are then transmitted back to a Vector Control Module (VCM) which hosts the software that performs the analysis.

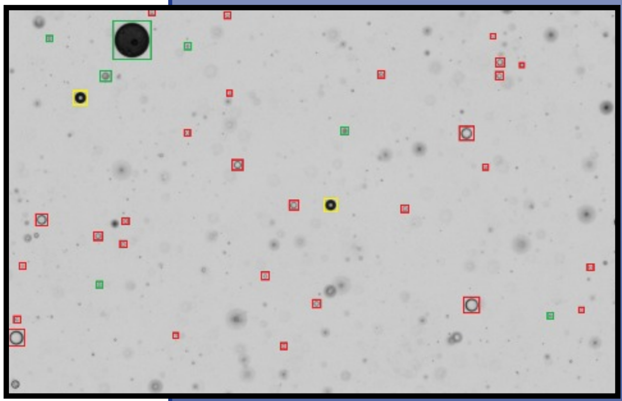


The analyzer is calibrated by installing a tool that displays a grid pattern on the camera. This grid is used to determine the physical distance that each pixel represents on the camera image, what CANTY refers to as the pixel scale factor (PSF). This is typically reported in μm/pixel. Knowing the PSF, the 2-dimensional area of each frame can be calculated.

The lens utilized in an Inflow has a known depth of field (DOF). The DOF is a measurement of the depth in which subjects, such as the particles in a fluid, are in focus. This now allows CANTY to measure the volume of each image taken in which particles are in focus.

On each image, the CantyVision software determines what might be a "particle" from what is the background fluid. At this stage, the "particle" could be anything - a solid, droplet, or bubble. After finding something that could be a particle, the software next makes a measurement that grades whether or not the particle is in focus. If it is in focus, then this particle is within the depth of field of the lens used. That means it should be included in the analysis. If a particle is not in focus, it is thrown out.

Each type of particle, solids, droplets, and bubbles, look morphologically different from one another. These differences are captured, numerically, in the various shape factors measured. The software is trained via AI to recognize the trends in these shape factors belonging to each type of particle. This is key because it allows CANTY to distinguish between different kinds of particles that were captured in the same analysis and quantify measurements for each class of particle differently.

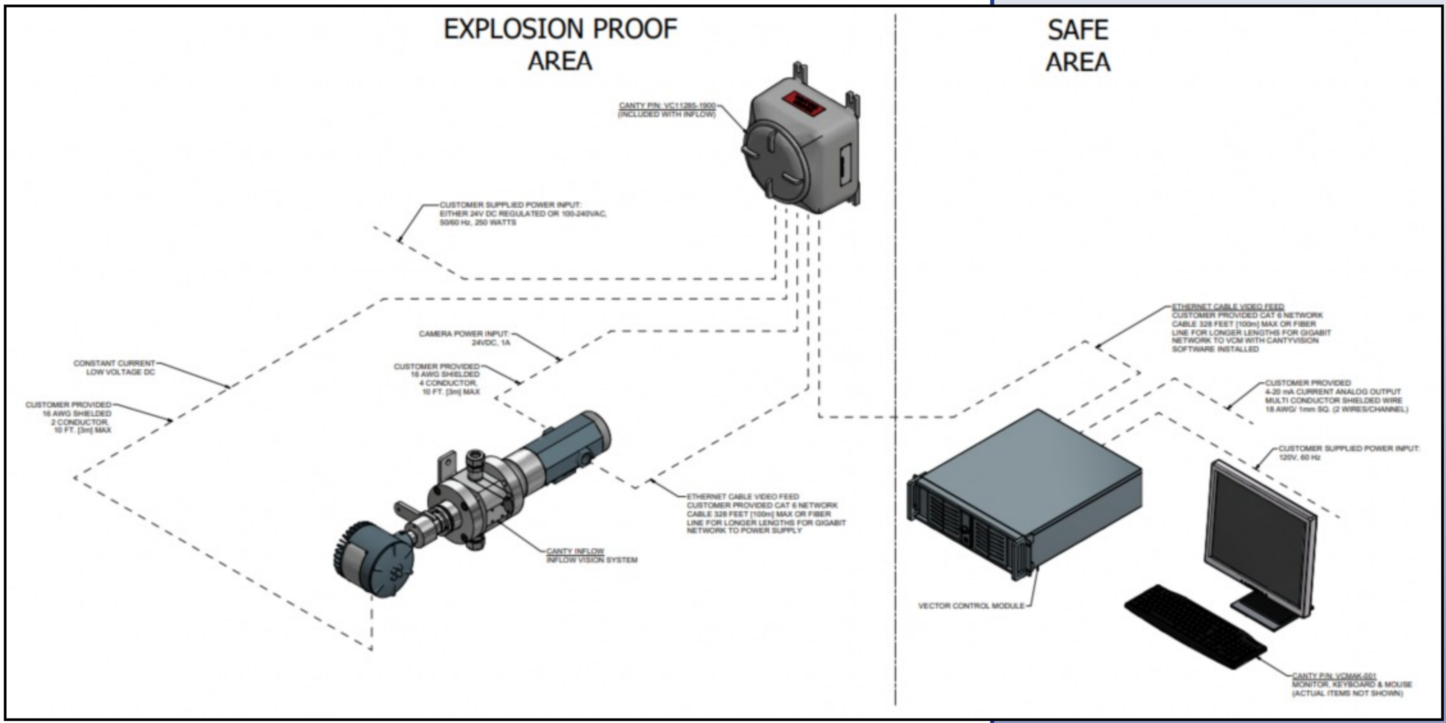


After a particle has been sorted into its correct class, the software calculates a volume of that particle based on its class. Since we already have the volume of each image being analyzed, the concentration of any given class of particle can now be calculated on a volumetric basis and can be converted into a mass concentration using the bulk density of the particle class in question.

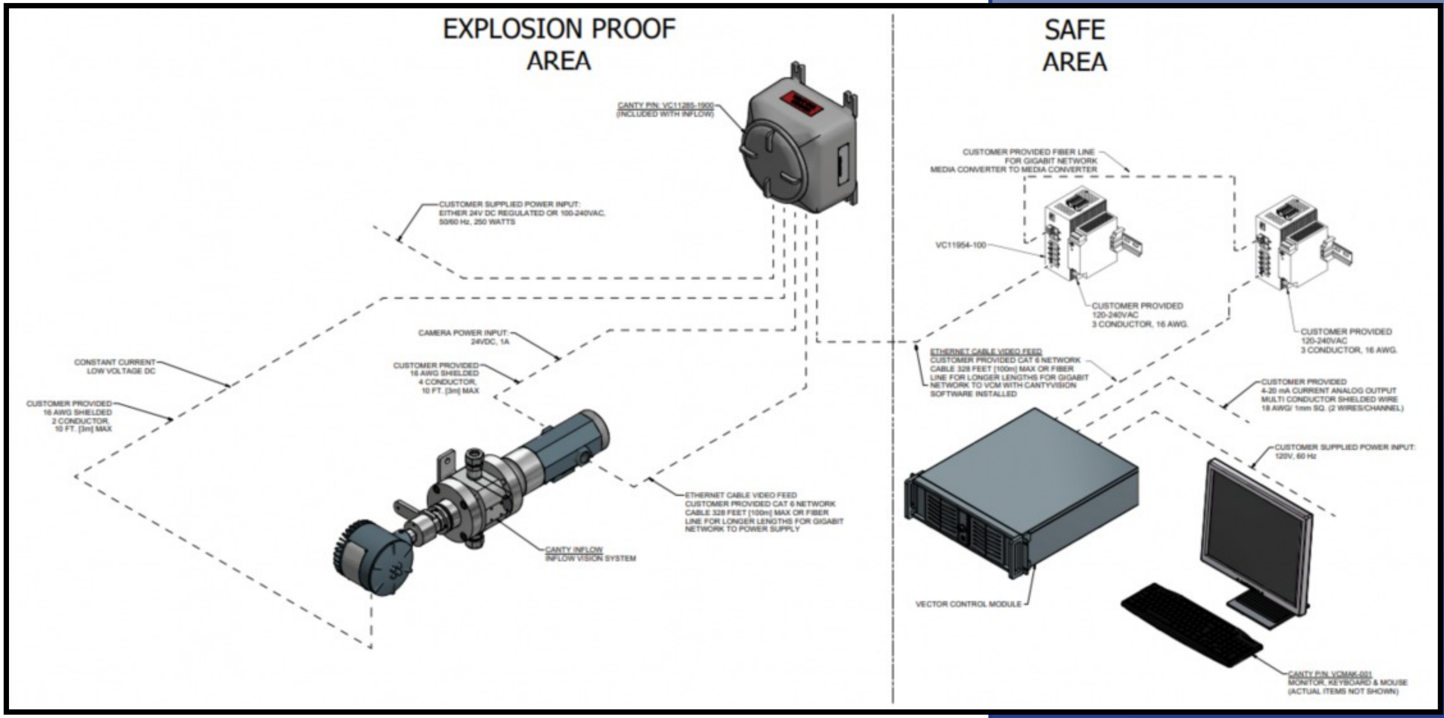
By averaging over hundreds of images, the Inflow is able to provide a representative concentration and particle size distribution for each particle class analyzed. Additionally, if there is ever skepticism about the reading, the images from the analyzer can be viewed live and/or saved as a recording for reference.

Connectivity

Due to the amount of data being transmitted between the Inflow and VCM, CANTY requires the use of CAT6 Ethernet running from the analyzer to it's power supply and from it's power supply back to the VCM. A typical layout of the components can be seen here.

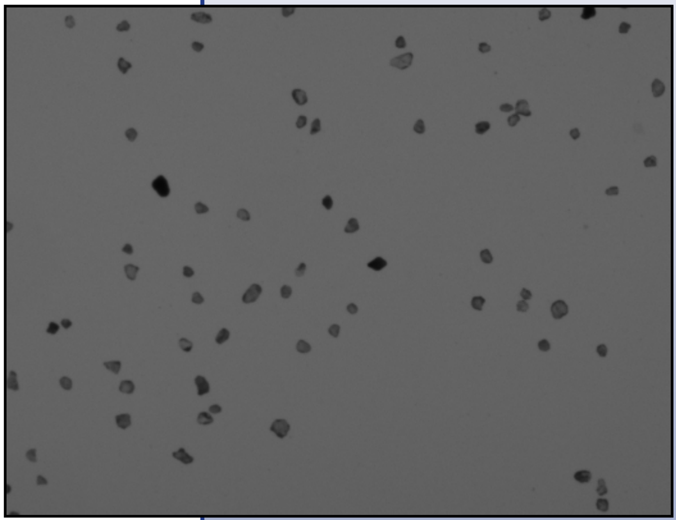


CAT6 Ethernet, however, has a distance limitation of 100m before there is signal loss that can interrupt analysis. In those situations, it is possible to convert the CAT6 Ethernet to fiber via CANTY's media converters. Refer to document TA11950-1024. Using this method, it is possible to run a fiber line up to 10km between the analyzer's power supply and then VCM. In this case, a typical layout of the components will look like the following.



Data Outputs For Popcorn Polymer

When popcorn polymer is detected, it is critical that as much information as possible is learned as quickly as possible. The Canty Inflow will provide:



- Concentration of popcorn polymer present in liquid

  This is directly measured by the analyzer as a volume concentration and can be converted into a mass concentration if the bulk density of the polymer is known.

- Size distribution of the popcorn polymer particles

  The size distribution of the polymer will tell you if the polymer is large enough to be clogging filters or fittings, and will give you an idea of how long the reaction has been occurring.

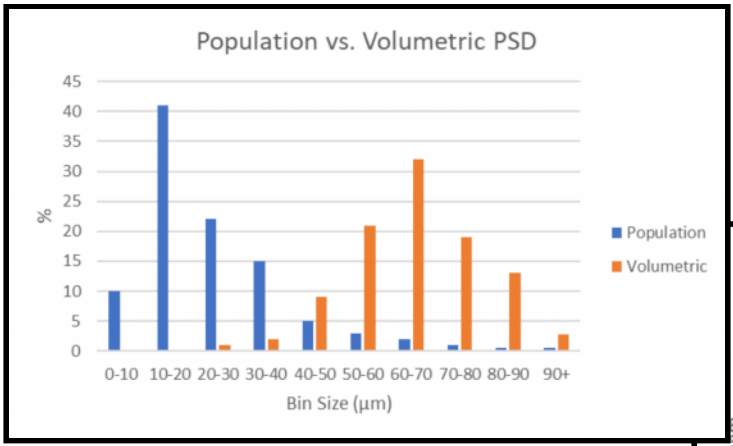
- Count of popcorn polymers seen per volume of process fluid

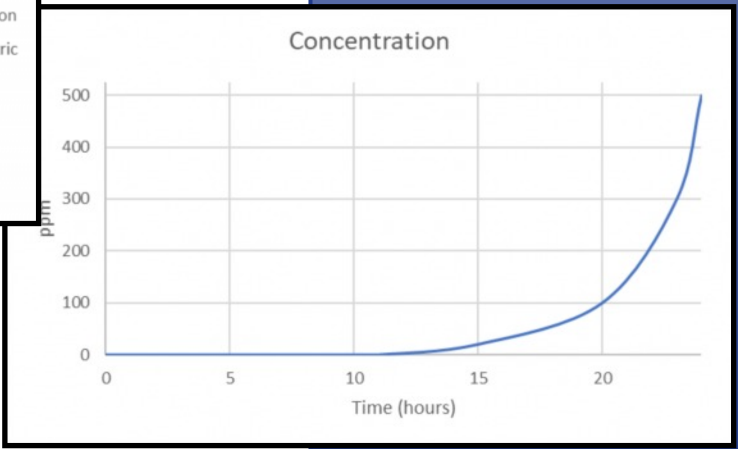
  Combined with the size and concentration, this information will help give an idea of how far the polymerization reaction has spread and help determine an appropriate reaction.

These outputs are in addition to generic system health alarms that would indicate if there is a problem with the analyzer, such as camera temperature and communication signals.

Each of these outputs can be trended over time in a data historian to monitor the rate of growth of the polymer and provide historical context. To communicate between the analyzer and your control system, outputs including OPC UA, Modbus TCP/IP, Modbus RTU, and Analog (4-20mA) are available. Reference the VCM brochure, TA12100-1012, which outlines the available communication methods for each VCM.

Graphs, Images, videos (A linked thumbnail), etc… On this side. Overlap Between the white and Blue sides is OK for Pictures and graphs





Conclusion

CANTY's Inflow analyzer is an effective tool for the automatic early detection of popcorn polymerization. It is installed directly inline, begins measuring particles at very small sizes, and has multiple outputs that can help inform an appropriate response to this reaction.

Get more information!
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