Instrumentation in Vegetable Oil Processing[1]

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ABSTRACT

The importance of instrumentation to control properly all processes in the manufacture of vegetable oil is now well accepted. Instrumentation and controls in oil processing can reduce manpower requirements, improve yields, improve quality, reduce energy usage, reduce regrade or rework, and allow reduction in inventories. The best instrumentation system for a particular operation is one that utilizes or takes into account the latest technologies, consistent with the total process involved, the level of sophistication required, and one that takes into account both the mechanical process and the chemistry of the process. This paper deals primarily with instrumentation improvements in existing plants, and several examples of proper selection and installation of instrument systems are given. Each example deals with choices that give the best control with the minimum of maintenance and the minimum of operator input. The use of a digitally controlled volumetric dry feeder for the automatic ratio control of bleaching clay to oil flow in a continuous bleaching system is described. The proper sizing of automatic caustic to oil ratio systems, including the use of digital blending for caustic control is discussed. A review of refinery loss monitoring systems is given. The advantages of automation of filtration systems by the use of automatic sequence control of filter cycle and cleaning cycle is explained. The importance of instrumentation maintenance in the success of automated systems is stressed.

GENERAL DISCUSSION

Most grass-roots refineries now under construction or that have started up within the last few years have a relatively high level of sophistication in automation of process monitoring and process control. This paper will deal more with upgrading the degree of instrumentation in existing plants.

As manufacturing processes are modernized or as additional processes are added to existing refineries, a proper instrumentation system should be designed into the total design of the system. Control systems added on after the fact, seldom perform as well as those designed for the system from the initial stages. A properly automated system can be brought on line with consistent quality product produced the first day with new operators and supervision, but only if the proper choices of instrumentation have been made and only if the instrumentation has been properly installed.

Instrumentation design for a total process can be simplified by breaking the process down into a series of unit operations and choosing the best system for each unit operation. Then, necessary changes can be made to make each unit operation an integral part of the total system.

INSTRUMENTATION IMPROVEMENTS

Justification of Instrumentation Improvements

Instrumentation modernization or improvements can often be justified as cost saving or productivity improvement projects. Instrumentation and controls improvements can accomplish one or more of the following: (a) reduce total manpower requirements; (b) reduce training time for new operators and supervisors; (c) improve yields; (d) improve quality control; (e) reduce energy usage; (f) reduce regrade or rework; (g) reduce raw material or supply usage; (h) reduce inventories of raw materials and finished product; (i) remove manual and drugery-type tasks from the operator. A reduction in manual tasks allows the operators more time to monitor the total process and become better trained in true process control; (j) A proper automated system gives line supervisors and managers the tools needed for rapid and effective evaluation of production rates, yields, and adherence to specifications.

The first eight items on the list can often be quantified and a reasonable payback in investment can be justified. The last two items on the list may be difficult to quantify, but both items are of upmost importance in a well operated, well managed plant.

During periods of tight economy, investments in improved automation may be even more attractive, especially if the investments are made wisely and incrementally. With tight economy, most organizations will tend to optimize their operations instead of maximizing (or expanding) their operations. In many cases, optimization is best accomplished with the proper application of instrumentation and controls.

Examples of Proper Application of Process Control Instruments in Vegetable Oil Processing

Process control instruments regulate the heart beat of any on-line continuous operation. For every unique process operation, there are unique control requirements critical to the operation. Some examples of proper application of instrumentation in vegetable oil processing are now given. Some of the examples explain the importance of proper sizing in flow meters, control valves, and other control devices. Some of the examples describe the advantages offered by relatively recent instrumentation technological improvements.

Automatic Ratio of Caustic Flow to Crude Oil Flow *in the Continuous Refining of Vegetable Oils*

One of the most important control loops in vegetable oil processing is the automatic ratio of caustic flow to crude oil flow in the continuous refining operation. Precise ratio of caustic flow to oil flow is mandatory to obtain optimum refining yields and optimum refined oil quality.

A good control system for this purpose (and the most popular for the last 15 years) consists of an oil flow control loop made up of a transmitting oil flow meter, an indicating flow controller, and an oil flow control valve. The caustic flow control loop consists of a magnetic flow meter, a caustic flow indicator, a ratio control station, and a caustic flow control valve. The caustic flow is automatically maintained in the proper proportion with the entry of the proper ratio into the ratio control station.

The proper sizing of the oil flow meter and the oil flow control valve is relatively straightforward. The type of oil meter chosen should be consistent with the accuracy desired. The use of a positive displacement meter with an

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accuracy of ca. 0.20% is a good choice, if the commitment is made to give this meter the proper maintenance it requires.

The proper sizing of the caustic magnetic flow meter and the caustic flow control valve demand some attention to detail. Depending on the vendor to size these units properly can lead to costly mistakes if he is not given correct and complete information.

The magnetic flow meter has almost become the standard for caustic flow measurement because the flow tube is made of corrosive resistant teflon, the unit is obstruction-free, and the absence of moving parts gives excellent reliability and minimum maintenance. Flow can be measured with ± 0.5% accuracy (1).

Fouling of the flow meter tube can be eliminated by sizing the flow meter such that the velocity through the tube is sufficiently high to prevent a coating of the electrodes. A velocity of 10 ft/sec (minimum of 5 ft/sec) is desired for the average flow rate through the system. Magnetic flow meters are sized according to the inside diameter of the flow tube. The most common sizes used in caustic flow in vegetable oil refining are the 1/10 in., 5/32 in., 1/4 in., and 1/2 in.

A refinery that handles a wide range of free fatty acid (FFA) content in the crude oil and/or one that has a wide range in oil flow rate, may require a low treat and a high treat magnetic flow meter. The meters would be installed parallel and the proper meter, or "treat" system, is chosen that will give the best flow control (and the more ideal velocity through the flow tube).

The proper size magnetic flow meter(s) for a particular refinery can only be chosen by first determining the minimum and maximum flow of caustic required. This information can be obtained as follows.

Minimum caustic flow. This occurs with: (a) lowest practical oil flow; (b) lowest estimated FFA of crude oil; (c) lowest estimate of caustic excess; and (d) highest estimate of caustic strength.

Maximum caustic flow. This occurs with: (a) highest practical oil flow; (b) highest estimated FFA of crude oil; (c) highest estimate of caustic excess; and (d) lowest estimate of caustic strength.

The percent flow in respect to oil flow (% treat) is calculated by the formula:

$$\%\ \text{treat} = \frac{\%\ \text{FFA (factor)} + \%\ \text{excess}}{\%\ \text{NaOH}/100}$$

$$\text{Factor} = \frac{\text{MW NaOH}}{\text{MW oleic acid}} = \frac{40}{282} = 0.142$$

where

$$\underset{\text{(in units/hr)}}{\text{oil flow rate}} \times \underset{\text{(caustic)}}{\%\ \text{treat}} = \underset{\text{(in units/hr)}}{\text{caustic flow rate}}$$

An example of the calculations for minimum and maximum flow of caustic for a refinery with one primary separator and one waterwash separator is as follows. (In this example, the primary separator has a minimum practical oil flow of 20,000 lb/hr and a maximum practical oil flow of 40,000 lb/hr).

Minimum caustic flow.
(a) 20,000 lb/hr crude oil flow.
(b) 0.30% FFA.
(c) 0.05% excess.
(d) 20° Bé caustic strength (14.33%NaOH, 9.67 lb/gal)

$$\%\ \text{treat} = \frac{0.30\ (0.142) + .05}{14.33/100} = 0.65\%$$

$$20{,}000\ \text{lb/hr} \times 0.65\% = 130\ \text{lb/hr}$$

$$130\ \text{lb/hr} \times \frac{1\ \text{gal}}{9.67\ \text{lb}} \times \frac{1\ \text{hr}}{60\ \text{min}} = 0.22\ \text{GPM}$$

Maximum caustic flow.
(a) 40,000 lb/hr crude oil flow.
(b) 1.0% FFA.
(c) 0.25% caustic excess.
(d) 14° Bé caustic (9.45%NaOH, 9.23 lb/gal)

$$\%\ \text{treat} = \frac{1.0\ (.142) + 0.25}{9.54/100} = 4.11\%$$

$$40{,}000\ \text{lb/hr} \times 4.11\% = 1{,}644\ \text{lb/hr}$$

$$1{,}644\ \text{lb/hr} \times \frac{1\ \text{gal}}{9.23\ \text{lb}} \times \frac{1\ \text{hr}}{60\ \text{min}} = 2.97\ \text{GPM}$$

However, since the caustic flow should be scaled in the same units as the oil flow, the caustic flow range chosen is 0–2,000 lb/hr (rounding off the 1,644 lb/hr). Therefore, the maximum flow in GPM is:

$$2{,}000\ \text{lb/hr} \times \frac{1\ \text{gal}}{9.52\ \text{lb}\ (18^\circ\ \text{Be}')} \times \frac{1\ \text{hr}}{60\ \text{min}} = 3.50\ \text{GPM}$$

The range chosen is 0 – 3.5 GPM, or 0 – 2,000 lb/hr caustic flow.

Using the Fischer and Porter chart (Fig. 1), the 1/4 in. magnetic flow meter is the ideal size for this application. The 1/4 in. meter can be scaled for any flow rate between a velocity of 1 ft/sec (0.17 GPM) and a velocity of 30 ft/sec (5.0 GPM).

The chart also shows that if we set the range of the 1/4 in. magnetic flow meter at 0 – 3.5 GPM (0 – 2,000 lb/hr), the velocity at 3.5 GPM (full scale for that range) is 20 ft/sec, which is ideal to prevent fouling. At the minimum expected flow of 0.22 GPM, the chart indicates a velocity of 1.5 ft/sec. This is low but acceptable for minimum flow.

A velocity of 5–10 ft/sec gives a flow rate of 0.80–1.7 GPM, which is the average flow expected for the system; therefore, the 1/4 in. magmeter is the ideal size.

If calculations indicate that flows above 5.0 GPM caustic are needed for high free fatty acid oils, then a 1/2 in. magnetic flow meter should be installed in parallel with a selector switch on the panel board to choose the "low treat" or "high treat" system.

The velocity through any magnetic flow meter can be

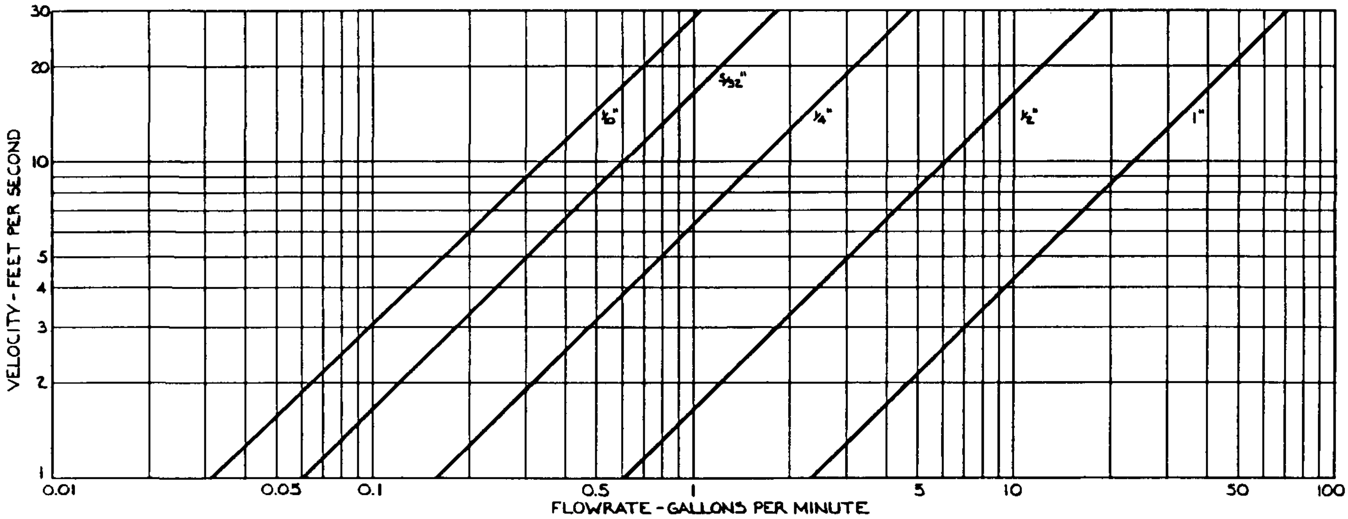

FIG. 1. Magnetic flow meters: velocity vs flow rate (1/10 in., 5/32 in., 1/4 in., 1/2 in., and 1 in. sizes). (Reproduced from Fischer and Porter Mag-X Magnetic Flow Meter Brochure, Model 10D1419 A/U).

determined by the formula:

$$V = \frac{GPM \times 0.408}{d^2}$$

where V = velocity (ft/sec), GPM = caustic flow rate (gal/min), 0.408 = constant for all magmeters, and d = diameter of tube (ft).

Fisher and Porter uses the term "meter factor" for the diameter, since the precise diameter for each magnetic flow meter manufactured is determined and permanently stamped on the meter. For example, a 1/4 in. (0.250 in.) magnetic flow meter may have an actual "meter factor" of 0.246 in. This factor should be used in the velocity computation.

Also the magnetic flow meter signal converter chosen should be the type that has the vernier scale range adjustment. By changing this range adjustment, which is actually a velocity setting in ft/sec for full scale, the range of the particular system can be easily changed as needed. For example, the range can be changed from 0 – 2,000 lb/hr to 0 – 3,000 lb/hr by computing the velocity and resetting the range on the magmeter signal converter.

The caustic flow control valve also must be properly sized for the flow rate range and the pressure drop allowed across the valve. A low treat and a high treat valve may be required to control the full range of the system properly. Microflute or microport stainless steel control valves are appropriate for this application.

Digital Blending of Caustic Solution and Crude Vegetable Oil

Most automatic ratio caustic to oil flow control systems utilize analog controllers, either pneumatic or electronic. Recently, automatic "caustic to oil ratio" control systems have been applied using the digital blending technique.

Digital in-line blending is the precise method of continuously combining two (or more) streams to desired specification by digitally computing error and accurately controlling ratio of the components making up the blend. The ratio of the two components is maintained digitally by comparing a digital flow signal from each component stream to a given digital setpoint and a final control element; in this case, the caustic flow control valve is actuated to maintain the desired relationship. The corrections are made instantaneously and very precisely (2).

Since the setpoint is digital, the percent treat desired is entered directly into the digital blending system. Errors introduced by converting signals to analog signals are eliminated. Conversion to analog for output to the control valve takes place only on the output of the digital ratio station. The digital blending system can reduce maintenance cost since the rugged circuit boards have the latest state-of-the-art integrated circuits and are designed for optimum reliability. The self-contained "package" assembly, with all instruments mounted, prewired and checked, ready for panel mounting, minimizes installation costs and start-up time (3).

The earliest use of digital in-line blending was in the petroleum industry, and later used in the brewing industry. In vegetable oil processing, there are many applications for digital blending in addition to caustic to oil ratio control. Other areas are the blending of ingredients in recipe-type formulation, the blending of various base stock fats and oils, and the blending of finished oil for load-out systems to reduce tankage requirements.

Automatic Digital Ratio Control of Bleaching Clay to Oil Flow

Bleaching clay addition to oil in the continuous bleaching operation has normally been handled by a variable speed dry feeder. The operator is supposed to change the ratio setting manually to maintain oil color within specification. The fallacy in this is that the operator may not know the actual oil flow rate, and he may not take into account the small changes in flow that result from other influences in the system, such as blinding filter presses. Also, since he has no feedback from the feeder, out-of-specification product can be produced due to improper addition or loss of flow of bleaching clay. The current costs of bleaching clays, plus the cost of oil retained in the spent clay, has promoted the need to automate these systems.

Several manufacturers of gravimetric and volumetric dry feeders (Example: K-Tron[R] and Acrison[R]) have made considerable improvements in reliability and accuracy of their systems in the last few years. These companies have also developed highly reliable and accurate microprocessor or minicomputer feed rate control systems. These systems make use of the digital control technique to control the variable speed silicon-controlled rectifier-direct current (SCR-DC) motor-driven feeder. The units have tachometer feedback to the panel board to give positive indication of shaft speed and feed rate. The feed rate can be displayed in lb/hr or any units desired. The percent bleaching clay desired is entered into the digital controller. In the totally automatic systems, the control system maintains the proper ratio, allowing minimum material usage and excellent quality control. Built-in alarm systems alert the operator of any out-of-control situations.

Another important part of the totally automatic ratio control loop is the oil flow meter. This is also a good application of the positive displacement meter with a pulse contactor. A signal converter furnished by the meter manufacturers delivers a 4–20 milliampere signal proportional to oil flow.

Automatic Ratio Control of Filter-Aid to Oil Flow in Filtration Systems

The above information given for bleaching clay addition would also apply to filter-aid addition for filtration systems that require continuous body-feed addition, such as corn oil or sunflower oil dewaxing. As in bleaching, the accurate automatic feed rate control minimizes material usage, minimizes oil lost in spent filter cake, and maximizes filtration cycles, thus improving productivity.

These systems require very little operator attention, material usage rates are accurately displayed on the panel board for occasional confirmation by the supervisor, and with properly installed systems, maintenance is practically nonexistent.

A Review of Refining Loss Monitoring Systems

The purpose of continuous refining loss monitoring systems is to give refinery managers a continuous read-out of refining loss. With this information, the manager can follow the trend in % loss, while altering refining conditions, to determine the set of conditions that gives the minimum refining loss. In most larger refineries, investment payback of one year is possible by reducing refining losses only 0.10%.

The current cost of loss monitoring systems can vary between US $20,000 and $100,000 each, depending on the degree of sophistication. Costs can be much higher if the monitoring system is designed to accomplish other tasks such as "controlling" part of the process. It is my opinion that loss monitoring systems should be kept totally independent of the process, and be used to measure and display percent loss only. This promotes success of the system since it can be shutdown at anytime for preventative maintenance or zero calibration without having any effect on the process.

Loss monitoring systems first became popular about 10 years ago. A few of the early systems are still operating while many others have been shutdown, or they have been totally redesigned or replaced with newer and better designed systems. Recent improvements in electronics using digital microprocessors, more attention to proper selection of the meters and proper location of the meters in the systems, and improved techniques of meter zero calibration have greatly improved the potential for success of these systems.

A loss monitoring system is comprised of positive displacement flow meters that measure the volumetric flow of oil into and out of the refining process. A photo pulser on each flow meter produces electrical pulses directly proportional to volumetric flow. Elliott Automation Company (4) recently introduced the "Micro-2000" loss monitor. This microcomputer receives volumetric flow signals from each meter plus the transmitted temperature at each meter station, and the computer automatically compensates for changes in liquid volume due to temperature fluctuations. The various constants such as meter calibration factors, temperature coefficient of expansion and base temperature are easily entered via the data entry keyboard on the side of the unit. Recent microprocessor technology has allowed the cost of the electronics to go down, while improving accuracy, improving reliability, and greatly reducing maintenance.

A very important part of the loss monitoring system is the zero balance calibrating system. Since the target is to reduce refining losses by an amount as low as 0.10%, the meters must be calibrated within this accuracy. Actually the meters are balanced to zero per loss while passing the same oil through both meters. The meter factor for one of the meters is changed until zero percent loss is displayed on the loss monitor. This can be done while the refining process is running, if the proper valve system is installed. By properly setting the calibrating valves, the crude oil meter is bypassed, the output of the refined oil meter is passed through the crude oil meter. Setting the valves properly is somewhat tedious and time consuming, and as a result many plants did not perform the zero balancing of the meters often enough. Elliott has simplified this by automating the valves so that zero balance can be simply performed at any time.

The newer systems have the added advantage of both "short-term" and "long-term" percent loss. The system is normally selected in the "short-term" mode, which is updated every 2–3 min. This position is sensitive enough to pick up sudden upsets in the system that affects loss. The "long-term" loss can be displayed as desired to indicate the overall or cumulative percent loss to date. Both short-term and long-term losses can be reset to zero at any time. The long-term loss is normally reset to zero only at the beginning of each refining batch feed tank.

Loss monitoring systems can be a very valuable aid for reducing refining loss and thereby improving profitability, but the commitment must be made by the refinery manager and the plant manager to make it work. That is, preventative maintenance and emergency maintenance must be performed as required, zero balancing of the meters must be performed on a routine basis, and corrective action must be taken when higher losses are being indicated, so that the savings are actually generated.

Automation of Filtration Systems

One of the most widely used filtration systems in vegetable oil processing is the vertical leaf-horizontal tank filter. These filters can be used in crude oil filtration, prebleaching, hydrogenation catalyst filtration, postbleach filtration, and winterizing and dewaxing operations. Generally, these filters are sized between 300 and 1,000 sq ft of filtration area each.

These filters are popular because of the minimum manpower required to operate and clean the filters. In most cases, the operator of the process handles the filtration and cleaning of the filters with no assistance.

Even though no additional manpower reduction may result, a trend is taking place to automate or semiautomate these filters for a number of reasons. A semiautomated filter is one that has automatic sequence control, but the operator initiates each sequence by pressing the cycle advance button on the panel board. The sequence for a particular filter could be as follows: (a) fill and vent; (b) precoat; (c) filter cycle; (d) blow heel; (e) dry cake; (f) open filter; (g) drop cake (start vibrator); (h) close filter; (i) ready for start-next cycle.

An automatic ball valve is installed on each line of the filter. The valves are operated in the proper sequence by the sequence controller. The sequence controller can be a conventional motor driven cam timer or it can be a programmable controller. The advantages of this system over totally manual systems are as follows. (a) A new operator can learn the process very quickly, reducing nonproductive training time. (b) The automatic valves change instantly and simultaneously for each filter sequence. It is impossible for even an experienced, conscientious operator to change all the various valves rapidly enough and in the correct sequence. The automatic valve sequence will reduce oil loss by promoting drier spent filter cake, better cake release, less filter blinding and better overall filtration performance. (c) Less manual work by the operator gives him more time to monitor the rest of the process or to perform other tasks.

Most filter manufacturers can provide the panel mounted electronics to handle the automatic sequence control of the filter. The filter can be totally automated for no operator attention, but this should be evaluated closely.

The advantage of the semiautomated or manual sequence advance system is the fact that the operator is there to observe the open filter, drop cake, and close filter sequence. He can therefore interrupt or delay the cycle if he observes any malfunction.

Filtration Rate Monitoring and Control Systems

Filters such as the vertical leaf-horizontal tank filters are designed for a particular flow rate (gal/min/sq ft of filter area). This is well known, but most filtration systems do not take this into account, that is, the flow is not controlled to meet the specification. A clean filter can handle a much higher flow rate than the design rate; however, if the flow is not controlled, the filter will blind out prematurely, reducing the overall productivity.

This can be simply handled by installing a flow control loop consisting of a flow meter on the outlet (filtrate) of the filter, a flow controller, and a flow control valve. The flow controller is set for the design flow rate of the filter, the automatic valve restricts the flow during the early part of the cycle. The valve will gradually modulate open as the filter cycle advances, and as the pressure drop across the filter increases.

The same flow meter can be used to operate a digital rate of flow meter and a flow totalizer. The digital rate of flow indicator gives the operator and the supervisor a quick and convenient indication of productivity. The flow totalizer can be used for daily production and accounting purposes. The key to productivity improvement is first to measure the productivity.

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