Computer Monitoring of a Mini-Refinery[1]

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ABSTRACT

A laboratory-scale pilot plant is under construction so that problems involved in computer control of vegetable oil processing can be studied. Unit operations planned for this mini-refinery are continuous alkali-refining, bleaching, hydrogenating, and deodorizing. The alkali-refining step, similar to the Swedish "Zenith" process, is already in operation. Transducers for oil color, sodium content, and free fatty acid concentration have been constructed; both crude and refined oils are being analyzed. Provision has been made to perform the same analyses at later stages of processing on the bleached, hydrogenated, and deodorized oils. Under Phase I of implementing computer control, electronic signals from the analytical transducers are sent to the computer via appropriate interfacing hardware, and results are returned to the operator via Teletype. Phase II will involve monitoring by the computer but with decision making and instructions to an operator, and Phase III will involve "closing the loop," that is, having the computer directly control the process. Development of transducers, software and hardware such as is described here for the mini-refinery, should facilitate subsequent implementation of computer control on a plant scale.

INTRODUCTION

Today computers find more and more applications in industry for saving time, optimizing conditions, and increasing quality and quantity of product (1). Successful computer control of chemical processes (1-7), such as adapted by petroleum refineries, suggests that these techniques could be applied by soybean oil processors with benefits both to them and consumers. Indications are that computer control of vegetable oil processing plants may be the next major development in this industry.

A deterrent to on-line computer control of a vegetable oil refinery is the virtual absence of sensors for those chemical components essential to refining. These sensors or transducers are the chemical-electronic equipment that would convert free fatty acids (FFA), color, pH, soap, phosphorous, or even odor principles to the electrical voltages needed by a computer for monitoring or control. Developing these transducers and testing their performance in an actual vegetable oil processing environment are our research objectives. Described here will be (A) the construction of a mini-soybean oil alkali-refining unit operation; (B) the development and modification of transducers for such items as FFA, color, sodium (soap), pH, temperature, and column rotor speeds; and (C) the interfacing of these transducers to an on-line type computer.

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PROCEDURES AND APPARATUS

Figure 1 is a simplified diagram of the refining step of our mini-refinery. This laboratory-scale refining operation is similar in principle to the Swedish Zenith method developed some years ago (8). To expedite our development, we started with degummed soybean oil (SBO) to eliminate an involved pretreatment for phosphatides and gums; such a pretreatment could be incorporated at a later date. Alkali neutralization of the oil is carried out in a modified Short column (9) as shown as A in Figure 1. Caustic (0.5 N NaOH) is preheated in a steam-jacketed condenser (100 C) and introduced at the top of the column. Degummed oil is introduced at the bottom of the column after passing through a heat exchanger which raises the temperature to 77 C. The oil and caustic mix countercurrently with the aid of a rotor moving at 25 rpm. Oil droplets, which coalesce at the top of the column, flow to the bottom of the next modified Short column where the oil is countercurrently washed with distilled water.

The second column (B in Fig. 1) is fitted with a steam jacket for heating the water to aid in dissolving soaps carried over from the neutralization column. Although the oil is pumped to the next drying step (C in Fig. 1), it is actually sucked or "metered" into the vacuum drying section. The drying column is a jacketed Vigreux column,

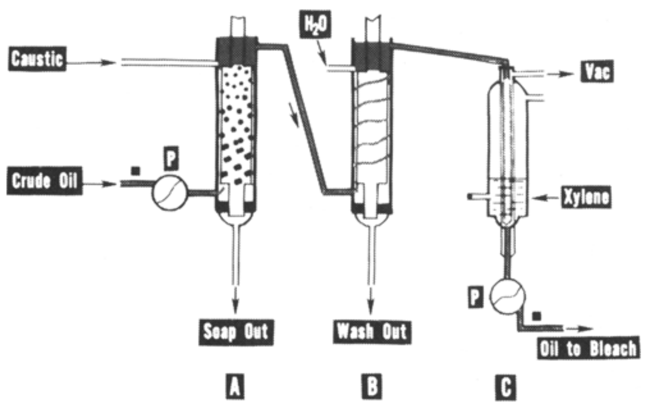

FIG. 1. Simplified diagram of alkali-refining step in a mini-refinery. A–Neutralization column. B–Water-wash column. C–Drying column. A and B are modified Short columns. C is a 3 ft steam-jacketed Vigreux column. P–One vein in a 4-vein peristaltic pump.

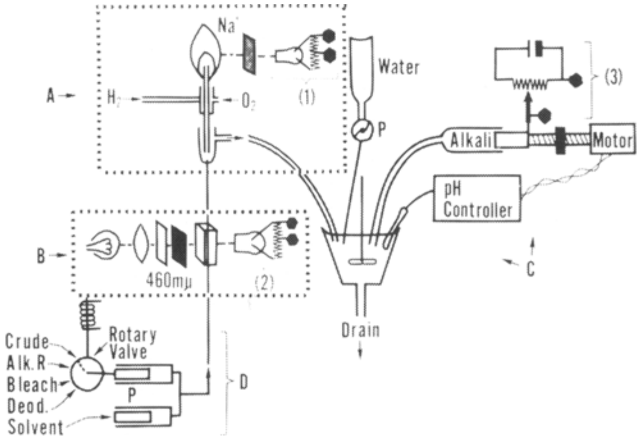

FIG. 2. Diagram of hybrid instruments for automated analyses now in use for mini-refinery. A–Sodium or soap analysis. Beckman hydrogen atomizer-burner. H_2 = Hydrogen gas; O_2 = oxygen gas; Na^+ = sodium in flame. (1) Transducer. B–Oil color instrumentation, from left to right: light source, focusing lens, 2 glass filters, sample cell, and (2) transducer. C–Free fatty acid (FFA) analysis. (3) Potentiometric transducer. P–Pump. D–Sample-collecting arrangement. P–Pump. Transducers (1) and (2) are modified photographic light meters.

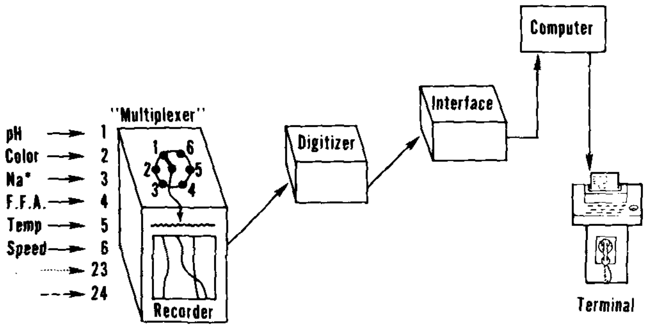

FIG. 3. Block diagram of signal path for Phase I or Phase II for computer control of mini-refinery. Left to right: Transducer signals, "multiplexer"–1 through 24 points available, digitizer–convert signal to digital form, interface–signal conditioning to computer requirements, computer–Phase I or Phase II calculations, terminal–Teletype for hard copy results. Broken arrow for 24 indicates future sensor connections.

which uses boiling xylene (140 C) for heating and is held at 20 in. Hg vacuum by a mercury pressurestat (manostat). Length of the Vigreux column is 3 ft, and inside diameter is 15 mm. The dried oil will, in the future, be pumped to the bleaching step. Although some equipment has been assembled for the bleaching, hydrogenation, and deodorization steps, they have not yet been incorporated into the working model.

The transducer apparatus for color, soap, and FFA analyses, now automated, is diagramed in Figure 2. Photocell detection and filter photometry are used for oil color and sodium (soap) analysis, whereas FFA results are taken potentiometrically from a modified Beckman titrator. The sample, whether oil or standard solution, is selected by an electro-pneumatically operated 6-way rotary valve and mixed with methyl ethyl ketone (MEK) as solvent in a ratio of 1:4 (sample:solvent v/v) with a micro Buchler pump. Mixing the sample with solvent achieves 3 results: (A) provides the best dilution with which to make a sodium analysis (10), (B) substitutes alcohol in the FFA titration, and (C) lowers the time lag in the transfer lines. Since little sample is used for sodium detection and since the sample is not altered by color photocell detection, all 3 analyses can be performed on the same sample.

Most of the detection apparatus of Figure 2 is of the "hybrid" variety, partially "home brew" and partially commercial. The filter photometer for oil color has a Corning glass filter (CS No. 5-75) to obtain the wavelength maximum (460 nm) specified by AOCS methods (11), a cell made by our within-house glassblower, and a CdS photgraphic-type light meter; sodium detection method is based upon a Beckman-type 4020 hydrogen atomizer-burner, a Corning glass filter (CS No. 3-68) to isolate the yellow sodium line of 589 nm, and another CdS photographic-type light meter; FFA determinations are made with a Beckman automatic titrator (Model K) and a clock motor drive to an ultraburet containing alkali. A voltage divider across each light meter and a potentiometer, coupled to the ultraburet motor, give the proper analog D.C. (10 mv max) signals to the recorder and digitizer.

Figure 3 is a simplified diagram of the electronic signal path for implementation of computer control. All transducer signals begin at the left of the figure and progress to the right, starting at the column listing transducers for pH, color, Na^+, etc., and ending at the Teletype terminal. The multiplexer, which in this system is a multipoint recorder (Honeywell-Electronik 16), can receive up to 24 signals. As each signal is printed on the recorder, it is simultaneously digitized by an Infotronics digitizer. The output of the digitizer must be changed or interfaced so it will conform exactly to the input requirements of the computer being used, in our case, an IBM 1800. From the interface, the

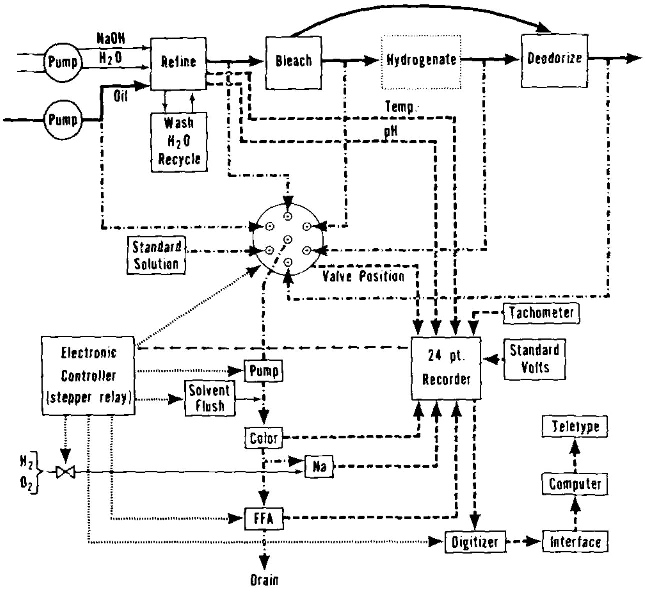

FIG. 4. System diagram of mini-refinery. Oil path, solid line (———); sample path, dot-dash line (•—•—•—); computer signal path, dashed line (- - - -); controller signal path, dotted line (• • • •); recorder stepper control, small arrows (→→→). Bleached, hydrogenated, deodorized, and wash-water recycle steps–not operational yet. Top of diagram–processing plant stages. Center including lower center portion of diagram–automated analyses and sample collection (see Fig. 2). Lower right–computer section (see Fig. 3). Lower left–electronic controller or stepper relay. FFA–free fatty acid. See Figures 1-3 for more explanation.

digital measurement signals go to the computer where they are tabulated or used in calculations and decisions that the computer has been programed to perform. The results of computer calculations with instructions for optimizing conditions, or simply the monitored results of transducer measurements, are returned to the operator in printed form on a Teletype (terminal in Fig. 3).

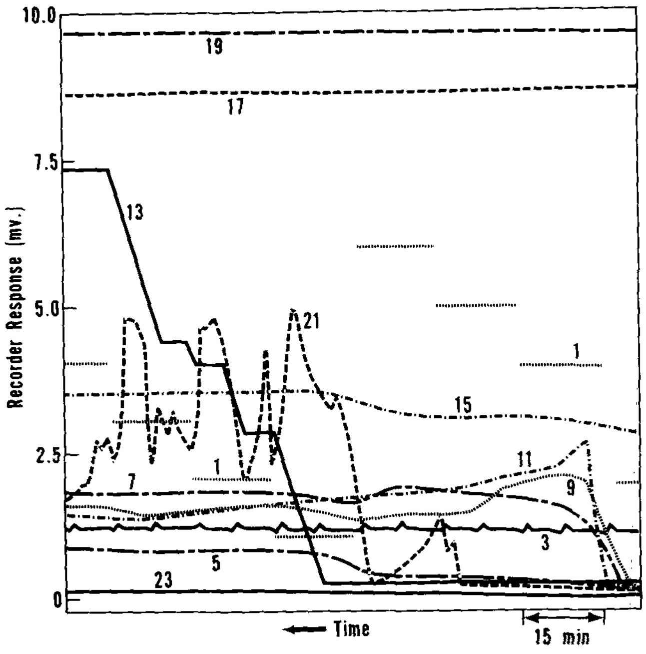

FIG. 5. Diagram of recorder-multiplexer chart. Typical recording during the initial phase of a test run. Data points: 1. Sample valve position. 3. Sodium analysis. 5. Oil temperature at inlet to neutralization column. 7. Oil temperature at outlet of neutralization column. 9. Oil temperature at outlet of wash column. 11. pH of waste wash water. 13. Free fatty acid titration. 15. Neutralization column rotor speed. 17. Oil color test. 19. Reference voltage. 21. Temperature at inlet to drying column. 23. Spare terminal–not in use.

MEASURE	DATA	VALUE	UNITS
VALVE POS	62571	6	
NA+ CONC	47595	9.55	PPM
TEMP # 1	5640	38.7	DEG C.
TEMP # 2	17317	65.8	DEG C.
TEMP # 3	13958	58.1	DEG C.
PH	57720	10.1	
FFA	32776	3	%
ROTOR SPD	30323	26.3	RPM
COLOR	43498	6.70	MG C/L
REF VOLT	99857	10.0	MV
TEMP # 4	49826	135.3	DEG C.
SPARE	427	0	

FIG. 6. Photograph of computer printout of mini-refinery data. Column 1 is measurement name; column 2, measurement in millivolts to fourth decimal place; column 3, converted value; column 4, units of measurement.

A more detailed diagram of the processing plant is given in Figure 4, which combines Figures 1 through 3, and depicts all operations that are now implemented and some future additions. Oil path (solid line) is noted at the top of the diagram going through the 4 stages: refining, bleaching, hydrogenating, and deodorizing. The hydrogenation step is shown in a dashed box, since it probably will not be added to the scheme until the other 3 operations are relatively complete. Samples (dot-dash line •—•—•—) for analyses are taken before and after each step in the processing, selected by the 6-way valve, and mixed with the solvent MEK while being pumped through the automated analytical section of the plant system (Fig. 2).

One addition to the system diagram (Fig. 4) over those of Figures 1 through 3 is the electronic controller. This programer-controller is advanced one step at a time by each revolution of the 24-point recorder mechanism and controls all aspects of sample taking, testing, and disposing as well as signal digitizing. As noted by the dotted lines emanating from the stepper relay, the programer controls the pumping of the solvent-sample mixture, advancing the 6-way valve, pumping water to FFA analysis, draining for FFA analysis, opening of hydrogen and oxygen valves to sodium flame analysis, and operating a solenoid permitting flushing of the analytical system with solvent, etc.

Another addition to Figure 4 not previously noted is the proposed future modification of a wash-water recycle operation (12) in the refining step to reduce pollution.

Typical startup and operation of the mini-refinery is shown in Figure 5 which is a line drawing representation of a section of the multipoint recorder chart. The discontinuities between line segments labeled 1 correspond to the changing of the valve position and the start of each new 15 min cycle. Lines 5, 7, and 9 giving the temperatures of oil going into the neutralization column, out of it, and out of the wash column, respectively, rise and then stabilize during the startup operations. Line 3, indicating soap content, maintains a constant value except for the 1 min interval during data transmission when the hydrogen-oxygen flame is turned on and the readings of the yellow sodium line are measured. Acidity of the wash-water effluent varies with soap or alkali content as shown in line 11 as the startup of the process proceeds. Color of the oil represented by line 17 remains constant over this range of chart. The automatic titrator for FFA was turned on after 1 1/2 hr and gives rise to the "stairsteps" of line 13. As the oil sample is pumped into the titration vessel, alkali is delivered from the buret until the endpoint (pH 10) is achieved. The free fatty acid content of the sample is proportional to the height of the stairstep.

At the present stage of development of the mini-refinery computer system, voltages corresponding to the data points are digitized, transmitted to the IBM 1800 computer, and returned to refinery site via a Teletype alternately at 7 and 8 min intervals.

Figure 6 is a photograph of the station line printer output. The data table is self-explanatory. First column indicates what is being measured; second column, labeled data, is the electrical signal in millivolts; third column is the converted value in terms of the units given in the fourth column. Valve position 6 indicates that a standard sample is being analyzed. It is found to have 9.55 ppm sodium ion (equivalent to 0.01% soap as sodium oleate), a FFA content of 3% and a color content in terms of carotene of 6.7 mg/liter (13). Four process temperatures, as identified in the caption of Figure 5, pH of effluent and speed of rotor also are given. The data of Figures 5 and 6 demonstrate the operation of the mini-refinery including the performance of the transducers and show the extent of communication between process, computer, and operator that has been achieved at this point of development.

DISCUSSION

At the inception of this research, 2 alternatives presented themselves: use of scaled-down pilot-plant equipment of commercial design (50 gal/hr) and development of a laboratory bench-scale mini-refinery (1 liter/hr). For a variety of reasons, including cost, flexibility, and space, the second approach was chosen. The development of chemical transducers does not necessarily need a refining operation; just samples of oils at various refining stages are required. However, in anticipation of the overall process of using transducers for monitoring and eventual computer control, the availability of the unit operations of refining was mandatory.

Generally, implementation of computer control of a process follows 3 phases: I, monitoring; II, monitoring with instructions returned to operator for optimizing conditions; and III, closing the loop, or direct computer control of the process.

In the present stage of implementation, our work is primarily in Phase I. The presence of the Teletype at the refinery will permit rapid transition to Phase II. Entry into Phase III already is being planned and limited commercial control equipment has been acquired. The control equipment has been selected to operate in supervisory control mode or direct digital control mode. Set points on existent process controllers can be changed by the computer in supervisory control, whereas the more recent philosophy of computer control bypasses the process controller and the computer directly opens and closes valves, increases or decreases current, motor speed, temperature, etc. Experience on the relative merits of both modes of operation will be obtained with the mini-refinery.

Finally, work is underway to extend the application of the present, as well as other transducer and control systems to bleaching, hydrogenating, and deodorizing unit operations as time and support permit.

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