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A Fuzzy Controlled Three-Phase Centrifuge for Waste Separation

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ABSTRACT

The three-phase centrifuge technology discussed in this paper was developed by Neal Miller, president of Centech, Inc. The three-phase centrifuge is an excellent device for cleaning up oil field and refinery wastes which are typically composed of hydrocarbons, water, and solids. The technology is unique. It turns the waste into salable oil, reusable water, and landfill-able solids. No secondary waste is produced. The problem is that only the inventor can set up and run the equipment well enough to provide an optimal cleanup. Demand for this device has far exceeded a one man operation. There is now a need for several centrifuges to be operated at different locations at the same time. This has produced a demand for an intelligent control system, one that could replace a highly skilled operator, or at least supplement the skills of a less experienced operator.

The control problem is ideally suited to fuzzy logic, since the centrifuge is a highly complicated machine operated entirely by the skill and experience of the operator. A fuzzy control system was designed for and used with the centrifuge.

KEYWORDS: fuzzy logic, process control, centrifuge.

INTRODUCTION

Continued production and storage of oil field and refinery wastes have created the need for efficient and economical techniques for remediation and recovery of hydrocarbon products. The three-phase centrifuge discussed in this paper is an ideal device for cleaning up three-phase oil field and refinery wastes that consist of hydrocarbons, water, and solids. This technique turns the waste into salable oil, reusable water, and landfill-able solids, with no secondary waste. Because of very successful field experience with this centrifuge, there is now a need for several centrifuges to be operated at different

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locations at the same time. A major problem is that only the inventor can set up and run the equipment well enough to provide an optimal cleanup. Demand for this centrifuge has produced a demand for an intelligent control system that could replace a highly skilled operator, or supplement the skills of a less experienced operator.

The control problem is a classical fuzzy logic problem, since the centrifuge is a highly complicated machine operated entirely by the skill and experience of the operator.

The control system is implemented on a personal computer (PC) in the control room of the centrifuge. The basic system contains fuzzy rules and membership functions connecting feed rate and feed heater temperatures to solid, water, and oil product specifications. The fuzzy rules and membership functions were obtained in the field, working with the operator at several different sites.

The three-phase centrifuge technology was developed by our Neal Miller, president of Centech, Inc. The fuzzy control system was developed by Los Alamos National Laboratory, with input supplied by Centech. The project was partially funded as a Cooperative Research and Development Agreement, by the Department of Energy (DOE) and partially funded as a joint project between Los Alamos, Centech and The Rocky Mountain Oilfield Testing Center (RMOTC). ROMTC was created by the DOE - Naval Petroleum Reserve No. 3 (NOSR-3) and is located near Casper, Wyoming.

We were able to finish a basic version of the intelligent control system, but not all of the features originally planned. However, the control system does work well and Centech is happy with it. Data shown in this report were part of the NOSR-3 study.

CENTRIFUGE SYSTEM

The centrifuge, is a non-linear, time variant, multi-variable plant. It is a continuous-decanting-horizontal-bowl type with a helical conveyor. The three phases are separated by spinning the feed mixture at high RPMs, creating a large centrifugal force. Under the centrifugal force the highest density material is forced to the wall of the centrifuge bowl. The feed mixture is continuously introduced at the center line of the conveyor and enters the centrifuge bowl through ports on the conveyor. The solids are pushed from the centrifuge by the conveyor. The water and oil leave the centrifuge through ports at the opposite end of the centrifuge.

In addition to the centrifuge, the process requires pumps, a heater, and holding tanks. The heater is used to reduce the viscosity of the feed mixture and to improve the flow characteristics. Three output or controlled variables are important. They are the amount of hydrocarbon in the solid product, the amount of hydrocarbon in the water product, and the BS&W (Basic Sediment and Water) in the product oil. The upper limits on these variables are dependent on the customer's needs and the location. For example, in New Mexico oil is salable if the BS&W content is below 1%. In Wyoming, the criterion is 0.3%. Similar variations are found for the solids and water, depending upon their final destination. These specifications are met by controlling the feed rate and feed temperature. Bowl and conveyor speeds are also important, but more difficult to control with this centrifuge. Lower limits for the controlled variables are determined by profit motives. The centrifuge operator is usually paid by throughput, so he wants to maintain the maximum feed rate. Higher feed rates generally reduce the quality of the products.

In order to make the largest possible profit, the control system must operate the centrifuge as close to the upper specifications as possible.

The centrifuge is a large portable machine that is transported to various waste sites by truck and trailer [1]. The waste material or centrifuge feed stream is different at each site. These wastes will always vary in composition and viscosity. The largest variation is in feed BS&W content, which can range from 90% to 10%. In addition, the feed will often vary significantly with time at any single site.

Figure 1 presents a flow diagram of the centrifuge process or plant, the object of the fuzzy control system.

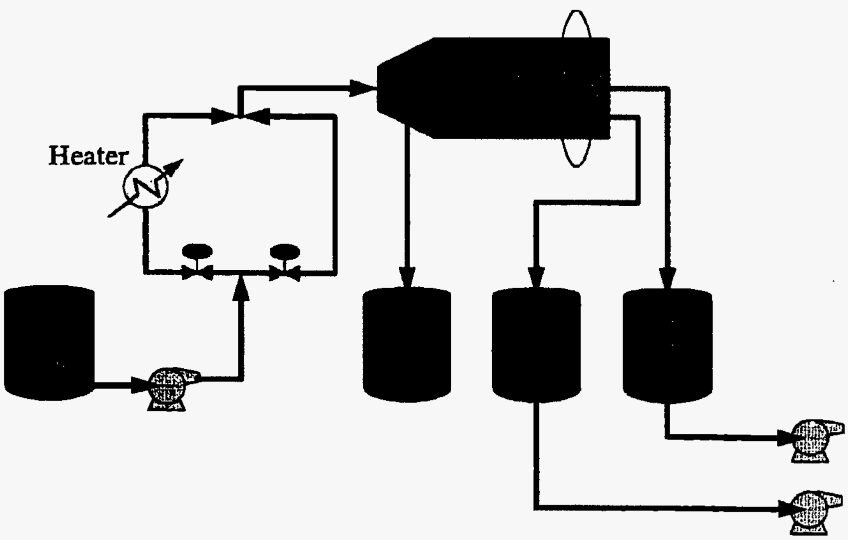

Figure 1. Flow diagram for the three-phase centrifuge process, or plant.

FUZZY CONTROL SYSTEM

The control system is a fuzzy-intelligent system [2,3]. The rules and membership functions shown here are similar to the ones that were obtained from the expert. But, in order to protect Centech's confidential information, fictitious membership functions are shown. The rules listed below in figure 2 and the membership functions shown in figures 3 and 4 are a subset of the actual control system. The rules regarding the BS&W have been implemented in the control system. The rules about oil in the product water are in the control system software, but they have not been implemented because we were unable to find suitable sensors for detecting the quantities of oil that are commonly found in the centrifuge water product.

The input membership functions are presented in figure 3. The BS&W membership functions are Low (L), OK, High (H), and Very High (VH). The abscissa of the figure shows the range of BS&W values that belong to each membership function. The ordinate of the figure shows the value, or strength, of the membership in each function. The percent oil in water product has only two membership functions, OK and High (H).

Figure 4 presents the output, or manipulated variables, feed rate change and feed temperature change, and their membership functions. Each variable has five membership locations at the same time. A major problem is that only the inventor can set up and run the equipment well enough to provide an optimal cleanup. Demand for this centrifuge has produced a demand for an intelligent control system that could replace a highly skilled operator, or supplement the skills of a less experienced operator.

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functions, and they have the same labels. The labels are: Negative Big (NB), Negative Small (NS), Zero (Z), Positive Small (PS), and Positive Big (PB).

Feed Rate Change

BS&W \ Oil in Water	H	OK
VH	NB	NB
H	NB	NS
OK	NS	Z
L	Z	PS

Feed Temp. Change

BS&W \ Oil in Water	H	OK
VH	PB	PB
H	PB	PS
OK	PS	Z
L	Z	NS

Figure 2. Fuzzy Rulebase (L = Low, H = High, VH = Very High; NB = Negative Big, NS = Negative Small, Z = Zero, PS = Positive Small, PB = Positive Big)

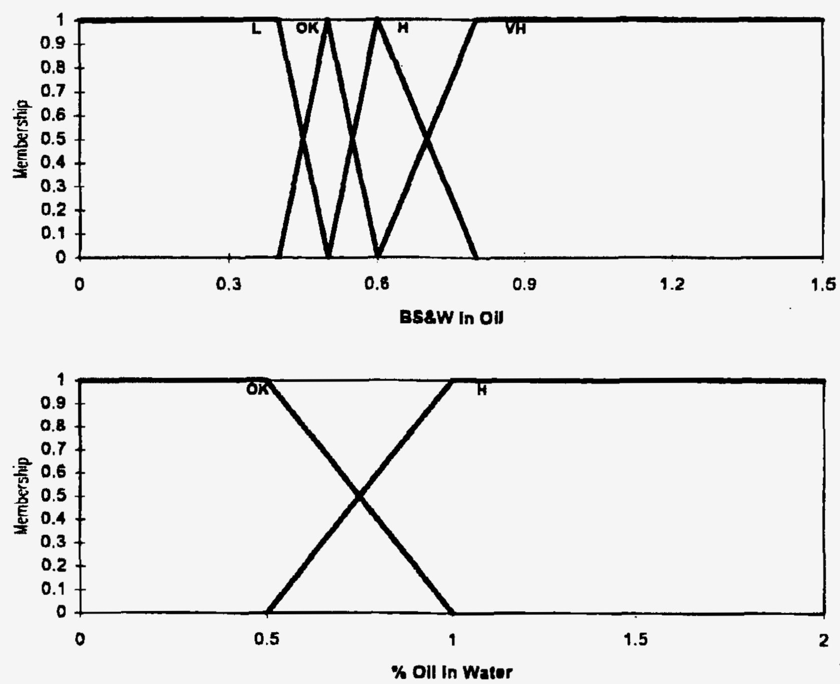

Figure 3. Control input parameter membership functions.

CONTROL IMPLEMENTATION

The control system is implemented on a personal computer (PC) in the control room of the centrifuge. LabWindows/CVI software from National Instruments was used to develop the man-machine interface. Figure 5 is a snapshot of the computer control screen from the centrifuge control system. The data presented in figure 5 are fictitious, in order to protect confidential information. The snapshot was taken from the actual control screen, however, at the time it was being run from a test file rather than the actual operation. The screen gives the operator instant access to all pertinent information. The current oil and water product tank levels are shown graphically. Important input and output variables are shown both with their current values in a digital format and with an analog display as a strip chart, showing their time history.

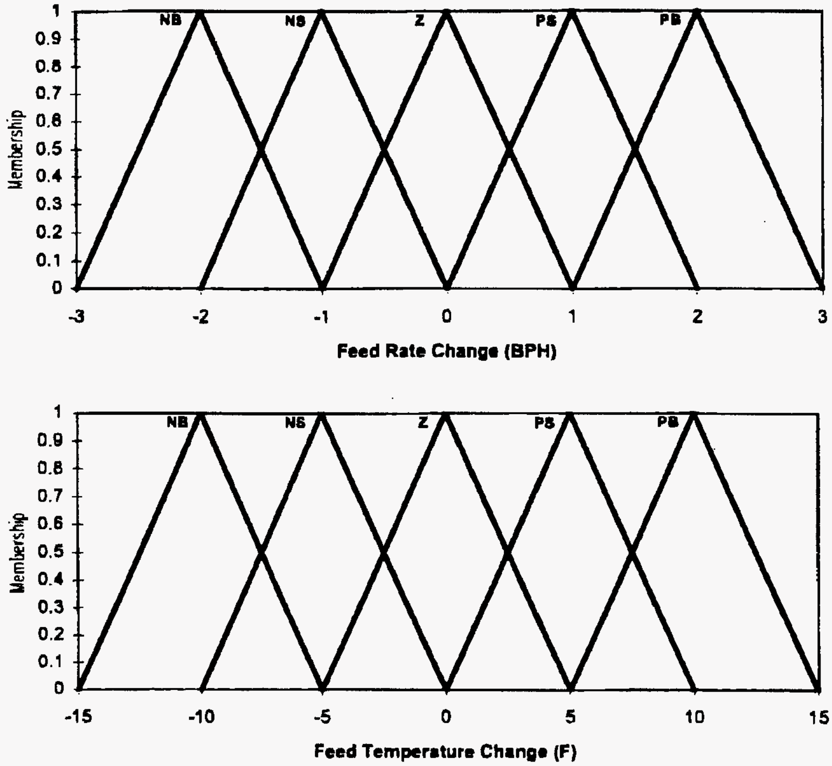

Figure 4. Control output parameter membership functions.

Some interesting options (some accessed through drop-down menus) available in the control system are: the ability to operate with either the feed rate or feed temperature or both in manual mode, the option to set alarms on the plant variables, the option to display plant variable trends for any given time period, and the ability to redefine the membership functions on the fly. This last option allows the operator to change the setpoint (or setpoint range) by changing the membership functions.

Figure 6 presents an actual output from our project's last afternoon run. It represents the variable under control, the product oil BS&W, as a function of time. From 3:06 to slightly after 3:36, the setpoint range (indicated by the dashed lines) is between 0.2 and 0.3% BS&W. The plot shows that the control system bringing the product oil into the desired range and maintaining it there. The system sluggishness, in this case, was due primarily to the fact that power line voltage was low at the work site, because of large power demands elsewhere. This problem kept the feed heater from responding as quickly as requested by the control system. After control was achieved, the setpoint was changed to see how quickly the control system would respond to a setpoint change. The figure shows the measured value of the BS&W coming into the new setpoint range before the centrifuge was shut down for the day.

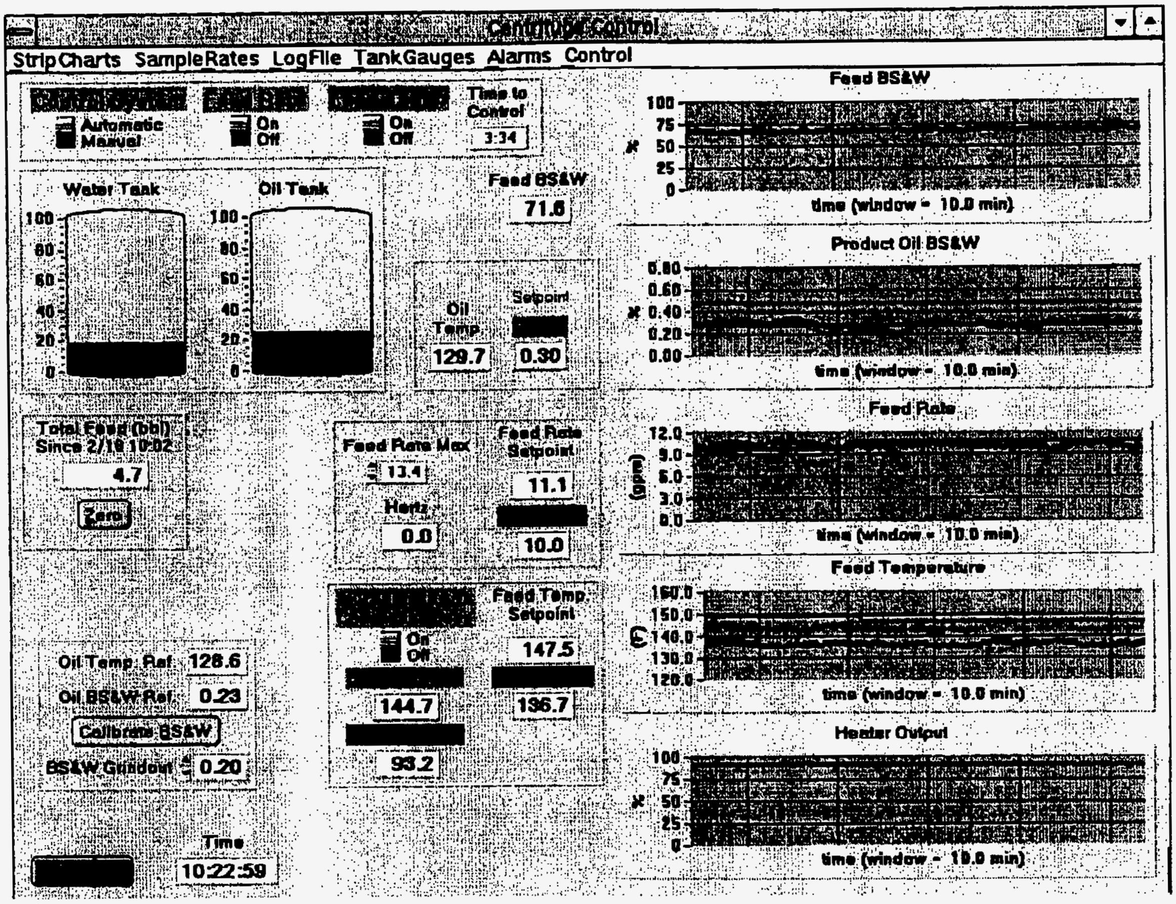

Figure 5. The control screen from the centrifuge control system.

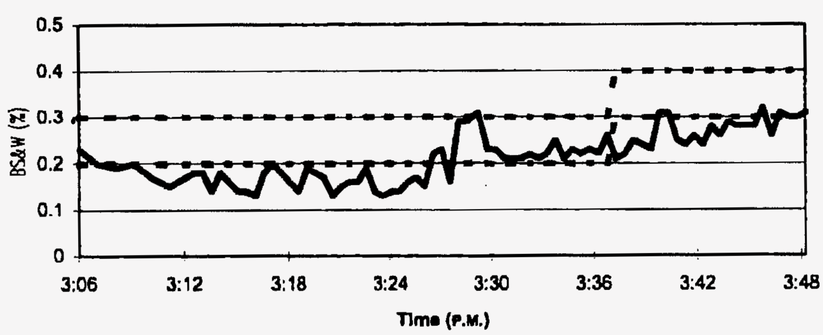

Figure 6. Product oil BS&W as a function of time – actual run.

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