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A FUZZY CONTROL SYSTEM FOR A THREE-PHASE OIL FIELD CENTRIFUGE

William J. Parkinson[1], Ronald E. Smith[1], Paul J. Wantuck[1], and Neal Miller[2]

Los Alamos National Laboratory[1]
Los Alamos, NM 87545
Centech Inc.[2]
Casper, WY 82604

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ABSTRACT

The three-phase centrifuge discussed here is an excellent device for cleaning up oil field and refinery wastes. These wastes are typically composed of hydrocarbons, water, and solids. This technology converts waste, which is often classified as hazardous, into salable oil, reusable water, and solids that can be placed in landfills. No secondary waste is produced. A major problem is that only one person can set up and run the equipment well enough to provide an optimal cleanup. Demand for this technology has far exceeded a one-man operation. The solution to this problem is an intelligent control system that can replace a highly skilled operator so that several centrifuges can be operated at different locations at the same time.

KEYWORDS

Fuzzy Logic; Process Control; Centrifuge

1. Introduction

We have brought together two quite different technologies in the work presented. The three-phase centrifuge technology is a unique method for environmental cleanup. Neal Miller, president of Centech Inc, developed the three-phase centrifuge. It is an excellent technique for cleaning up oil field wastes typically composed of hydrocarbons, water and solids [1]. The technology is unique and it completely cleans oil field and refinery waste products that often can be classified as hazardous wastes. It turns the waste into saleable oil, reusable water, and landfillable 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. Hence, the need for advanced, intelligent control system, the other technology.

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 [2,3]. The centrifuge, is a non-linear, time-variant, multi-variable plant. Three output variables are important. They are the amount of hydrocarbon in the solid and water products, and the BS&W (Basic Sediment and Water) in the product oil. Specifications are met, primarily, by controlling the feed rate and feed temperature. 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 rates and feed heater temperatures to solid, water, and oil product specifications. To date, we have been unable to obtain on-line sensors that are adequate for measurement of the water and the solids quality. Therefore, at this time, only the BS&W content of the product oil, feed rates, and temperatures are on automatic control. This handles 90% of the cases (since the product oil is usually the most important variable).

Fuzzy rules and membership functions were obtained in the field, working with the operator at several different sites.

DISCLAIMER

2. Process Description

Figure 1 is a schematic drawing of the Centech three-phase centrifuge internals. It is a continuous-decanting centrifuge with a helical conveyor. Spinning the feed mixture at high rpms, creating a large centrifugal force separates the three phases. Under the centrifugal force the high-density material is forced to the wall of the centrifuge bowl. The bowl is represented by the outline of the figure. The feed mixture is introduced at the centerline of the conveyor and enters the centrifuge bowl through entry ports (shown as dots in the figure) on the conveyor. The solid, shown in black at the bowl wall, is pushed from the centrifuge by the conveyor, which spins at a different rpm than the centrifuge bowl. The water and oil, shown in light and dark gray respectively, leave the centrifuge through ports on the cylindrical end.

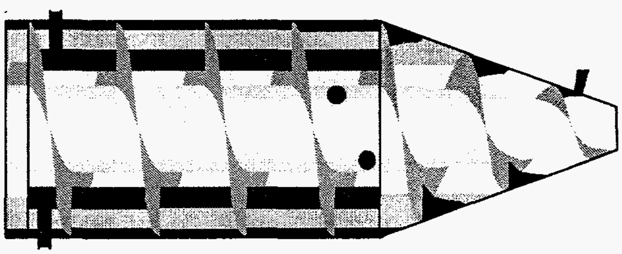

Figure 1. Continuous three-phase decanting centrifuge -- with helical conveyor.

The process requires pumps, a heater, and holding tanks in addition to the centrifuge. The heater is used to reduce the viscosity of the feed mixture and to improve the flow characteristics. A feed holding tank may be required because water or chemicals must occasionally be added to the feed mixture to achieve the desired separation. A feed tank is not always needed, or for that matter is available, for all operations.

3. Illustrative Example

The control system is best described with an example. The rules and membership functions shown here are similar to the ones that were obtained from the expert, but actual values are fictitious in order to protect confidential information. The rules and the membership functions shown in Figures 2-4 are a subset of the actual control system. The rules regarding the BS&W have been implemented in the control system. The rules regarding 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 discharge water.

The input membership functions with the example-input values, represented by the dotted lines, are presented in Figure 2. 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 of the membership for each function. In this example the BS&W reading of 0.75% has a membership of 0.3 in High (H) and 0.7 in Very High (VH). The percent oil in water product has only two membership functions, OK and High (H). From the example the percent oil in the product water is 0.95% and has a membership of 0.15 in OK and 0.85 in High (H).

Figure 3 shows the 16 rules that map the input membership functions, of Figure 2, to the output membership functions, of Figure 4. The eight rules from the example that were actually fired and their corresponding membership function values are shown in the two boxes that contain numerical values. There are two rule sets of eight rules each (four rules were fired from each set). One set relates the BS&W in the oil product and oil in the water product to the control action "Feed Rate Change". The other set relates the same inputs to "Feed Temperature Change".

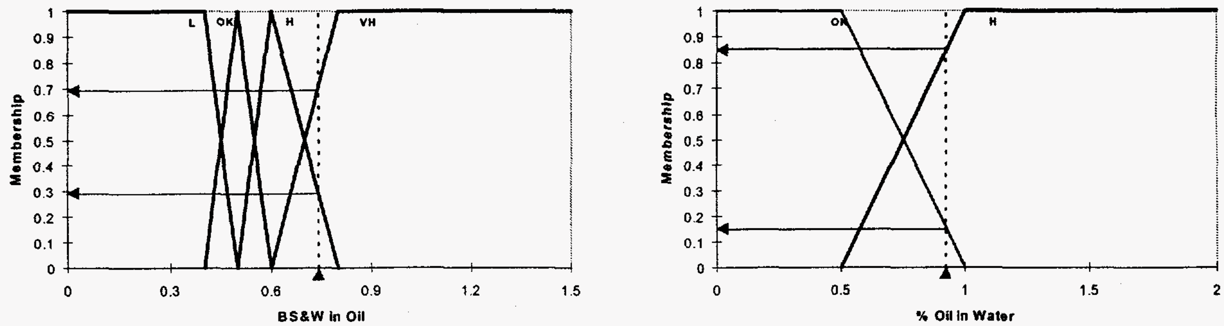

Figure 2. Control input parameters -- with example.

Feed Rate Change

BS&W		H	OK				
	VH	NB	NB	0.7	0.7	0.15
	H	NB	NS	0.3	0.3	0.15
BS&W	OK	NS	Z	→		
	L	Z	PS			
		H	OK		0.85	0.15

Oil in Water

Feed Temp. Change

	VH	PB	PB	0.7	0.7	0.15
	H	PB	PS	0.3	0.3	0.15
BS&W	OK	PS	Z	→		
	L	Z	NS			
		H	OK		0.85	0.15

Oil in Water

Figure 3. Fuzzy rule base (L= Low, H = High, VH = Very High; NB = Negative Big, NS = Negative Small, Z = Zero, PS = Positive Small, PB = Positive Big), with the eight rules and corresponding weights used in the example.

The boxes in Figure 3 are a shorthand representation of the rules. Each rule has two inputs and one output. The rectangle in the upper left-hand corner of the first box represents the rule: IF the BS&W is Very High (VH) AND the Oil in Water is High (H) THEN the "Feed Rate Change" is Negative Big (NB). The upper left hand corner of the second box represents the same rule after it has been fired with the values given in the example: IF the BS&W is (VH = 0.7) AND the Oil in Water is (H = 0.85) THEN the "Feed Rate Change" is (NB = 0.7). The feed rate change of 0.7 comes from the minimum portion of the min-max rule, MIN (0.7,0.85), which will be discussed next. The four numerical values in the second box, (0.7,0.15,0.3,0.15), are the minimum values of the four rules that were fired from the set that effects the "Feed Rate Change". The four numerical values in the last box are the minimum values that were fired from the set that effects the "Feed Temperature Change".

Figure 4 presents the output membership functions for the variables "Feed Rate Change" and "Feed Temperature Change", with the results from the example, using the max portion of the min-max rule. Each variable has five membership 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). These membership functions are similar to the input membership functions.

We refer back to Figure 3 to demonstrate how the max portion of the min-max rule is used to determine what feed rate change the control system will actually make. There are four rules related to this change, three of them suggest a change of Negative Big (NB), MAX (0.7,0.3,0.15) = 0.7, and one suggests a change of Negative Small (NS), MAX (0.15). The right-hand diagram in Figure 4 shows that the NB triangular membership function is truncated at the maximum value of 0.7 (horizontal lines). The NS triangular membership function is truncated at 0.15 (vertical lines). The actual "Feed Rate Change" is the centroid of the shaded figure, in this case about minus 1.5 barrels per hour (BPH).

The left-hand portion of Figure 4 demonstrates the resolution for the four rules that were fired that effect the "Feed Temperature Change". Here the centroid value is about plus 7.5 $^{\circ}$F.

Figure 5 shows an actual output from a run near the end of the project.

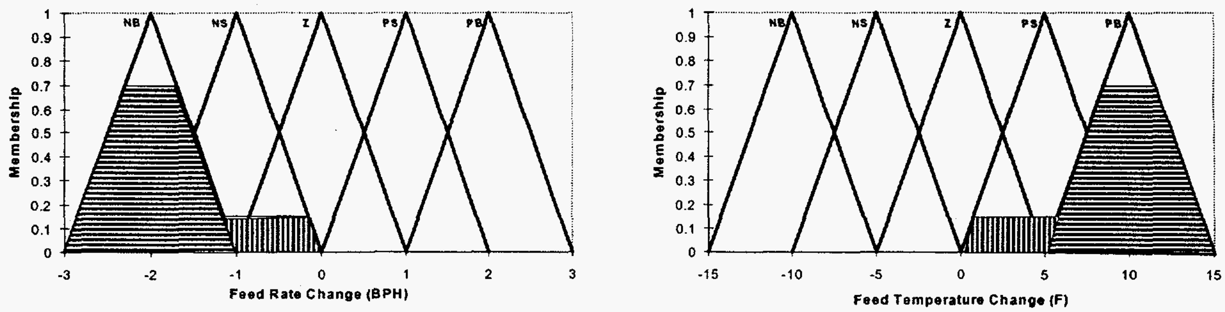

Figure 4. Output Membership Functions and rule results for the example.

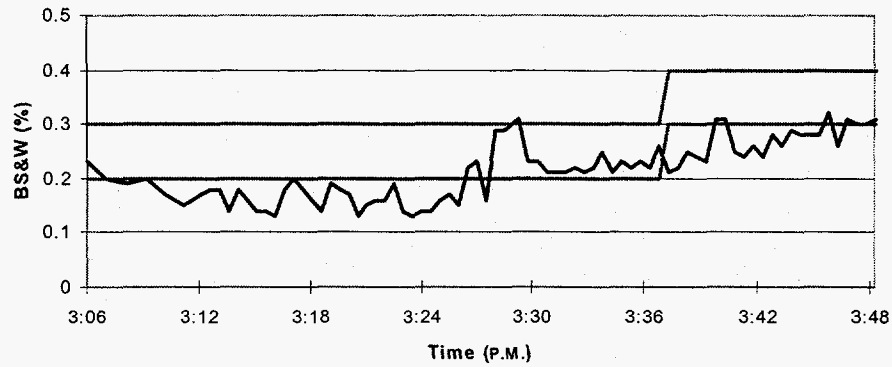

Figure 5. Product oil BS&W as a function of time -- actual run.

4. Conclusions

A complicated device, like this centrifuge, that requires expert knowledge to operate can be automated using fuzzy logic. Figure 5 represents the variable under control, the product oil BS&W as a function of time. From 3:06 to slightly after 3:36, the control band is between 0.2 and 0.3 % BS&W. The desired value for the BS&W was less than 0.3%. The plot shows that the control system brings the product oil into the desired range. After control was achieved, the set point was changed to see how quickly the control system would respond to a set point change. The figure shows the measured value of the BS&W coming into the new range before the centrifuge was shut down.

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