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VARIOUS APPLICATIONS

A REVIEW OF CLOSED-LOOP CONTROL OF AN 85,000 BPD CRUDE UNIT

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ABSTRACT

The purpose of this paper is to present a review of a closed-loop control for a large crude unit in a petroleum refinery. Also, it will develop the philosophy and new approaches resulting from a look back at a first computer in terms of determining the needs and philosophies for this operating company's next venture into the field of an on-line digital process control computer system. This paper will present a critique of the user's ideas and thoughts resulting from his first experience in this area, with the hope of correcting the situation for his second and third computer projects.

INTRODUCTION

I wish to clarify my position as sole author of this paper. Originally, this was to be a joint endeavor between the user company and my own organization, a computer manufacturer. However, a recent development in the United States caused a drastic change in plans to be made. Specifically, I refer to the efforts by a major chemical processing company to prosecute a sweeping patent awarded to them in the field of sampled data and automatic closed-loop control systems. This effort by the unnamed company has caused great shock among all operating companies who feel they may, rightly or wrongly, be libel to legal suit by the operating company for patent infringement. Accordingly, my co-author was advised to withdraw from this paper so that his company's activities would not become public domain. However, I hasten to assure you that all of this data has been contributed by my co-author's company and is based upon their actual operating experiences.

OBJECTIVES

The approach to a computer control system was based upon the desire that the system would log and monitor all process conditions, calculate present operating conditions throughout the unit (such as tower loadings, heat recovery, furnace efficiencies, etc.), calculate the desired operating changes to produce the desired yield of specification products and, finally, thereby to lower operating costs. It is interesting to note that an over-detailed and optimistic schedule resulted from the lack of experience in estimating the completion time of programming effort, check-out and debugging of these programs, preparation of required documentation, and the actual delivery date of the computer for installation at the refinery site. From the initial date of negotiation until the computer was scheduled for delivery represented 12 months time. This schedule was met and the computer was operational in time for the startup of the unit.

The conception of the amount of time required for adequate programming was also satisfied and these actual programs for logging, scanning, and alarm functions were available at the time that the computer was delivered. However, the estimate for the control programs went awry in the time required. Typical actual times required were nine months after startup for computer control of a light lubricating oil vacuum tower, six months after startup for closed-loop computer control of an atmospheric furnace damper system and six weeks after startup for closed-loop computer control of the crude oil preheat loop.

From these various delays between desired objectives and actual deliveries, it was planned for the second computer installation that the goals for these objectives would be much more realistic. With this first experience, more adequate time was allowed for the development of the necessary programming and more importance was given the staffing of experienced programming people assigned to the project. The delivery for the second generation computer project was fixed with regard to working more realistically with the manufacturer's problems. The desire to startup the unit to first do only logging, scanning and alarming resulted in a reasonable postponement in the delivery of the control programs. This approach also resulted in a much more relaxed working atmosphere with full knowledge that the control programs would be given sufficient time for thorough development and debugging.

Another basic objective was to accomplish complete operator acceptance of the computer as a helpful tool, rather than a competitive entity that was attempting to put the operator out of business. The particular rapport in this refinery between operating and maintenance personnel and the management was such that this goal was achieved with a minimum of trouble and excessive hard work. In the beginning, the operators competed with the computer in accomplishing certain goals of closed-loop control. For example, the aforementioned crude oil preheater system is a rather simple loop in which a cold stream is split in its flow through parallel heat exchangers and then recombined. The operators attempted to control this flow in one of two ways; the flow would be split evenly through each side of the exchange system or the flow would be split unevenly to result in equal outlet temperatures from each individual preheater branch. Neither of these methods necessarily gives the maximum heat recovery.

The operators soon found that with close attention and application they were able to do this job as well as the computer. However, they very soon became tired of the frequent 10-minute adjustments and gave up this job willingly to the computer which did not tire in such a situation. The operator's time could be better spent in other and more demanding tasks. The operators quickly gained confidence in the success of the computer closing this loop and soon lost interest altogether in competing with the machine for this function.

Another actual experience of this sort relates to the damper control in the atmospheric furnace. Here again, the operators could do as well as the computer in optimizing the operating cost function in such a loop. The computer used continuous measurement of oxygen in the flue gas which, along with its temperature, enabled the computer to calculate the excessive air and, hence, the efficiency of the combustion process in the furnace. The normal procedure for the human operator was to hold the excess air at a higher- or safer-level than is absolutely required for maximum fuel economy. They soon gave up the job to the computer.

The heat balance control about this light lubricating oil vacuum tower provided an interesting experience in reliability of computer results. The computer was programmed to announce when internal liquid loadings reached two possible dry points and two possible flooding points. The liquid (calculated - not measured) running back into the tower flash zone is used to set the furnace outlet temperature. This minimizes the over-flash and results in considerable fuel gas savings. The first results calculated by the computer indicated that the internal liquid runback at the flash zone was varying in a range of 50 to 100% of the total material being withdrawn from the tower above the flash zone. This could not be! The computer was wrong! Hand calculations, however, substantiated the computer. When someone had enough courage to tell this to the operating department, their expected reply was one of total disbelief. Further comparison of computer and calculated results could not budge them. So, the operating conditions were given to the manufacturer of the tower internals with the request for an estimate of the amount of runback. Their reply was that the runback could be as high as 70% of the sum of the material being withdrawn. The computer was then allowed to reduce the furnace outlet temperature by 30°F under closed-loop control.

STREAM ANALYZERS

The advent, success and universal acceptance of process stream analyzers has enhanced the computer capability in achieving its goals and payout. For the first computer project, analyzers were liberally ordered and installed in the hope that their input signals would enable the computer to more quickly achieve its goals. By and large, such was not the case. The flue gas analyzers were the main source of trouble in the control programming of this phase of the operation. The sample handling system in this area was the major factor in causing the use of the computer control program to be discontinued because the sample system plugged most of the time. This indicated that more design time and thought should have been given to the sample handling system not only in this area, but for all of the other analyzers. Once this was done, the flue gas analyzer inputs played their role in keeping the furnace dampers under computer control.

Other types of stream analyzers in this area were continuous viscosity analyzers on the side drawoffs of the light lubricating oil vacuum tower. Figure 1 is a simplified schematic of this tower. Viscometers continually measure the viscosity of the W-65, W-150 and W-450 streams. The viscosity instruments did not work out to everyone's satisfaction due to the sample time lag and the process lag. This resulted in an excessive interval between control calculations in the order of thirty minutes. The sample piping to the viscometers was redesigned and, by so doing, the interval between control calculations was reduced from thirty minutes to twenty minutes.

Figure 2 is a simplified schematic of the atmospheric distillation tower. Initially, boiling point analyzers were installed in the kerosene and gas oil streams. These were very reliable after their sample handling system deficiencies were corrected. These streams are drawoffs from the side strippers and are wet. The problem was the efficient removal of this water from the sample stream.

On the second computer installation it was decided to wait for process stream analyzer installations until the technical service and operating

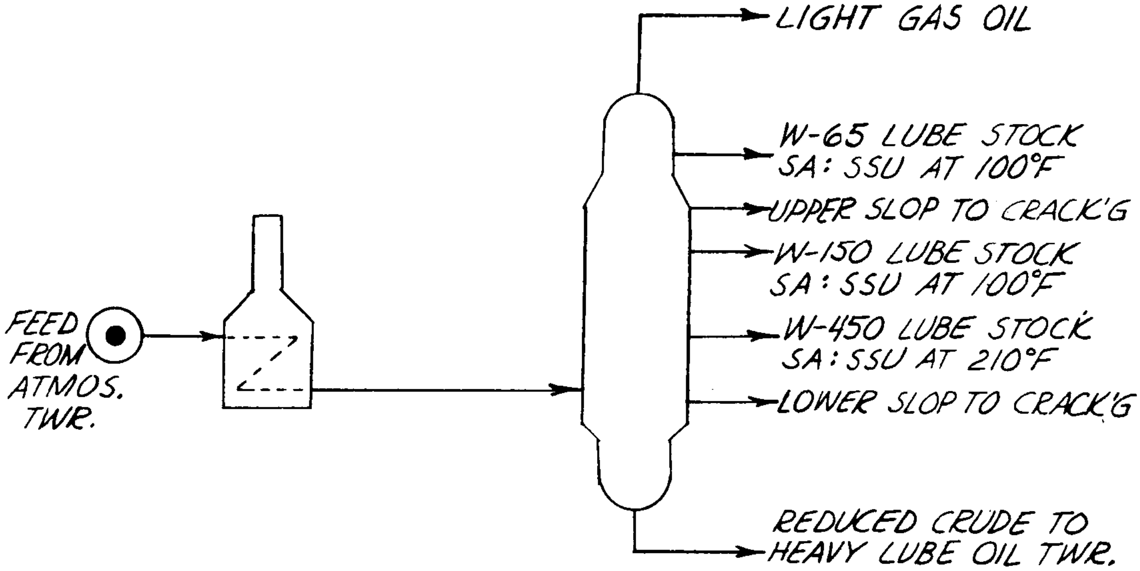

FIGURE 1. LIGHT LUBRICATING OIL VACUUM TOWER

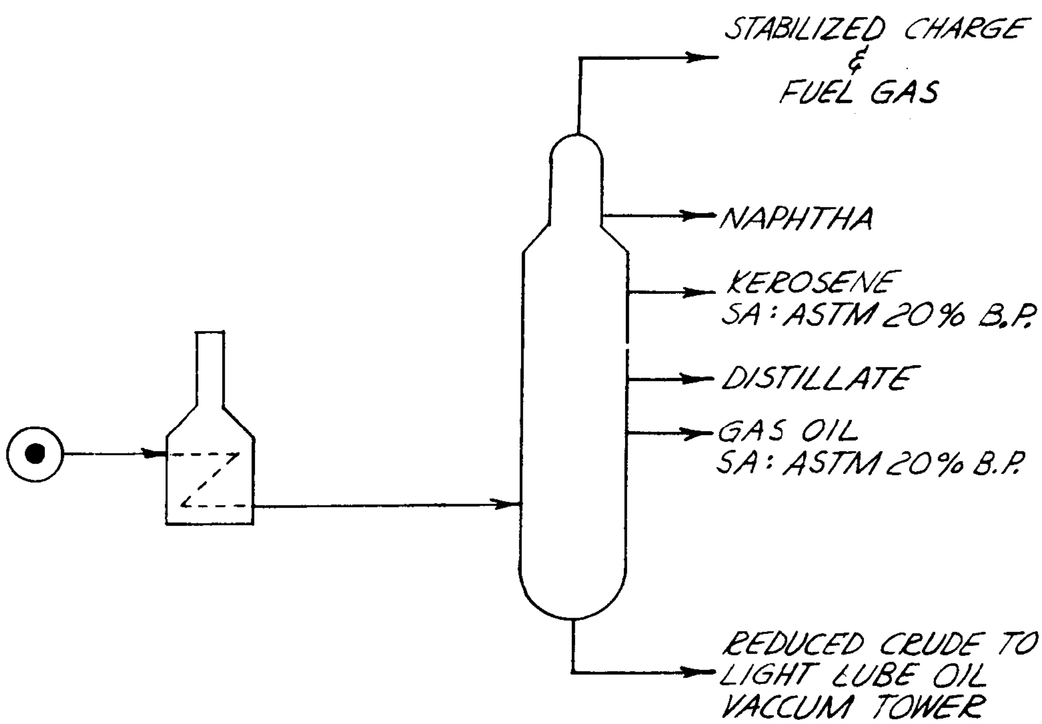

FIGURE 2. ATMOSPHERIC DISTILLATION TOWER

departments could both most carefully study the requirements as they determined them and then report to management where these findings were in agreement. Then, and only then, would analyzers be ordered. This means that the new unit would startup without the benefit of input signals from on-line stream analyzers. However, the achievement of successful control by the computer has been re-scheduled so that this delay will not be a detriment but, rather, will give everyone time enough to study the process, the justifiable applications of analyzers, and, finally, allow enough time for the most comprehensive design of the sample handling systems. In this way, when the analyzers are available as computer inputs they will have had time to be checked out and seasoned and not cause any trouble in the achievement of computer control of the applicable loops.

SAVINGS

That the computer was successful in achieving dollar savings through the reduction of fuel gas consumption is evident from the recapitulation shown in Table 1. This table gives a comparison between operator control and computer control from the standpoint of a heat balance control approach. The three operating loops are as noted; the atmospheric furnace, the light lubricating oil vacuum furnace, and the heavy lubricating oil vacuum furnace. It may be seen, then, that the computer did better than the operator in achieving this reduction in costs.

Table 2 shows the corresponding reduction in cost of fuel gas consumption in the atmospheric furnace damper control loop. Here the computer showed significant advantage over operator manipulation. Table 3 again approaches the reduction in cost of fuel gas consumption by control of the crude flow through the preheat exchanges. In this case the computer did not do as well as the operator. However, as mentioned earlier, the small difference in performance made it worthwhile for the operator to give up this control to the computer and, thereby, save the tedious and repititious task of controlling this loop manually. Table 4 is a summary of these foregoing tables and indicates the total daily savings resulting from computer control applied to the reduction of fuel gas costs. The dollar figure of $194.40 per day may be further expanded, the operating company feels, to approximately $250 a day because of the intangible savings in reduction of cooling water costs resulting from less heat input to the unit.

Other savings that were not evaluated were felt to be the improvement of yields and downstream processing costs because of closer control to specification limits with the computer.

TABLE 1. REDUCTION OF FUEL GAS CONSUMPTION FROM HEAT BALANCE CONTROL

CONTROL MODE	MM BTU PER HOUR ABSORBED BY OIL	MM BTU PER HOUR LIBERATED BY FUEL GAS
A. ATMOSPHERIC FURNACE		
OPERATOR	207.6	276.8
COMPUTER	192.7	256.9
	14.9	19.9
B. LT. LUBE OIL VAC. FURN.		
OPERATOR	42.5	56.7
COMPUTER	36.2	48.3
	6.3	8.4
C. HVY. LUBE OIL VAC. FURN.		
OPERATOR		
COMPUTER		
	-2.2	-2.9
D. NET REDUCTION	19.0	25.4

TABLE 2. REDUCTION IN FUEL GAS CONSUMPTION FROM ATMOSPHERIC FURNACE DAMPER CONTROL

CONTROL MODE	EXCESS AIR %	STACK TEMP. °F	DAMPER POSITIONER % OPEN	FURNACE EFFICIENCY %	NET MM BTU/HR. ABSORBED BY OIL	NET MM BTU/HR. LIBERATED BY FUEL GAS
OPERATOR	60	710	75	75	192.7	256.9
COMPUTER	27	670	50	80	192.7	240.9
DIFFERENCE					0	16.0

TABLE 3. REDUCTION IN FUEL GAS CONSUMPTION FROM CONTROL OF CRUDE FLOW THRU EXCHANGERS

CONTROL MODE	CONDITION	TEMP. °F	BBLS. PER HR.	LBS. PER HR.	BTU PER HR.	MM BTU PER HR.	MM BTU * PER HR. LIBERATED BY FUEL GAS
OPERATOR	LIQUID	373	3000	870M	196	170.5	
COMPUTER	LIQUID	375	3000	870M	198	172.3	
DIFFERENCE						1.8	2.4

* HEAT LIBERATION ON BASIS OF 75% FURNACE EFFICIENCY

TABLE 4. COMPUTER CONTROL REDUCTION IN FUEL GAS COSTS

REDUCTION – MM BTU/HR.				REDUCTION @ .185 $/MM BTU	
HEAT BAL. CONTROL	DAMPER CONTROL	CRUDE EXCHG. CONTROL	TOTAL	$/HR.	$/DAY
25.4	16.0	2.4	43.8	8.10	194.40

Another savings example is the better control of the boiling range of lube oil base stocks, resulting in better flash, color and carbon residue features. On the personal side of the advantages accruing from the first computer installation have been the voluntary help and suggestions given by the operating staff. Once the computer had been accepted, the operators studied the guides more carefully and, as a result, understood their tasks much better. This plant reports that many of the operator's ideas have been incorporated into the control logic.

SECOND COMPUTER INSTALLATION

From the aforegoing illustrations, it is seen that the approach to the control problem has been somewhat classical, insofar as the aspects covered in the control philosophy included heat balance control, damper control, and crude preheat exchanger control. The process and the equipment involved are as standard in the processing field as perhaps any operations can be. However, for the second project, this user chose a lube oil plant. This second project is quite different in its control approach. For example, the lube oil plant units consisted of both existing and newly constructed units. In the crude oil unit, the mode of operation remains rather fixed and constant with the major changes occurring in changes of feedstock. In the lube oil plant, there will be 10 different and distinct operations, involving 10 distinct base stocks processed in blocked operations. Naturally, this affects the processing conditions. Any one operation can be run only once, where the processing approach is to run the solvent-to-oil ratio in the solvent extraction unit and solvent dewaxing. Others however, may be run much more often. Figure 3 is a very simple schematic showing the processing path through this lube oil unit.

OBJECTIVES

Based on the wide variations in both charge stocks available, the way in which they were to be combined for processing and the complexity of both wax products and lube base stock products, the following objectives were drawn up to be the target for the second computer installation:

1. Monitor the passage of the interface between blocked operations. By being able to monitor and control this aspect, it is predicted that these advantages will result:

    (a) Cut down on slop product cut.

    (b) Minimize slop product cut density measurement.

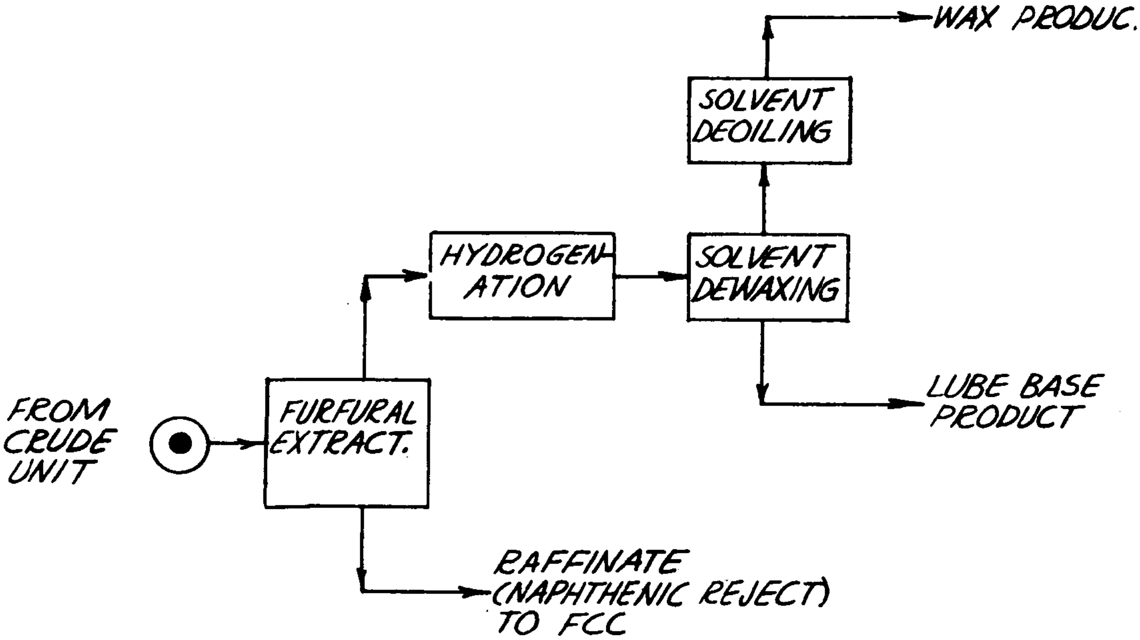

FIGURE 3. LUBE OIL PLANT SCHEMATIC

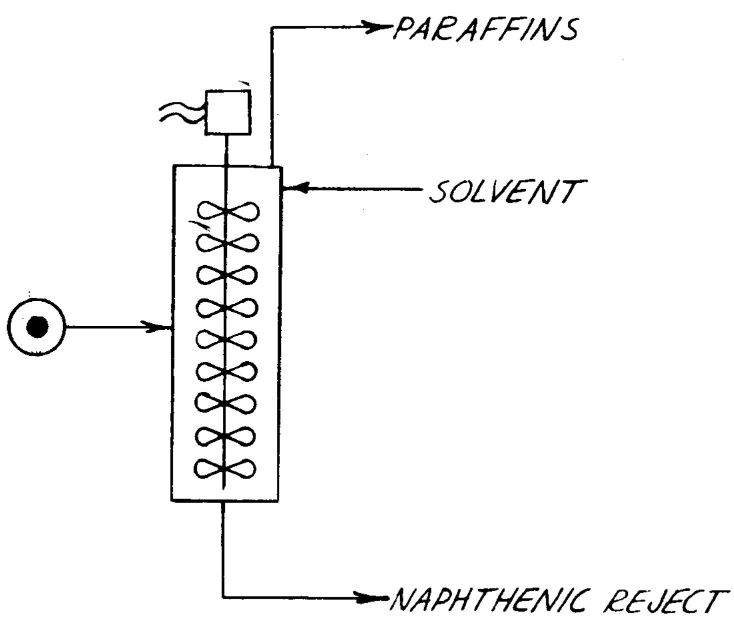

FIGURE 4. FURFURAL EXTRACTION

(c) Improve utility consumption when switching operations.

(d) Improve the product drawoff quality by monitoring and getting a hold of it at the outset in the furfural unit where the product is really made. The balance of the downstream is mainly devoted to solvent recovery. Figure 4 is a schematic of this furfural contacting unit.

2. To keep the physical refinery staff to a minimum and to work around any foreseen addition. From this aspect, pre-computer studies were not feasible. This same situation existed in the crude unit where the objectives were achieved without the usual and more normal pre-computer studies. This operating company feels that because of their size and staff limitations, they were justified in taking the calculated risk of not funding and indulging in the expensive luxury of exhaustive studies before purchase and installation of the computer.

   As stated, in the main the crude unit objectives were reached. All of the objectives, however, were not achieved because memory ran out before they could be reached. For example, the control of a debutanizer column in their gas recovery train was never accomplished. Notwithstanding, they felt that the computer adequately paid for itself on the basis of the objectives that it did achieve.

3. The minimizing of changes in operating techniques and philosophies for each shift. This aspect was achieved on the crude unit where the resulting more uniform control was one of the advantages that it was felt existed, but was never measured and evaluated. It is most profitable to remain at one single operating level as consistently as possible. Changes in shift operating personnel very often swing the plant due to changes in their approach as to how the plant should be controlled. Putting this aspect under computer control reduced these changes in the crude unit and it is felt will achieve the same end in the new lube oil plant.

4. The improvement of operator's skills and knowledge. On the crude unit it was observed that the operators became almost measurably better operators as they learned to adapt the computer results to their own operating techniques. In the beginning, they competed with the computer. However, they soon realized the advantages in allowing the computer to establish the operating guides and processing goals.

5. In this lube oil plant, the furfural extraction and hydrogenation units are new. The decision to buy a second computer was partly predicated on this fact based on the belief that it would be easiest to put the computer in operation in new units. Here again, there was no staff available to prepare pre-computer studies and the success from the crude unit of proceeding in spite of this carried on in the philosophy for the second installation.

CONCLUSIONS

By way of conclusion, I would like to summarize by way of comparison the problems that existed on the crude unit and the corresponding resolved approach taken on the new computer installation.

1. On the crude unit, the instrument alarm limits were arbitrarily established from design data. There were far too many of these limits arrived at empirically. When the computer operated on this data, the result was a great deal of meaningless alarm messages printed out by the computer peripheral typewriter. There were so many of these that occurred so often, the operators quickly disregarded them entirely. In so doing, they very often disregarded really important messages, such as dry and flood conditions being approached in the tower.

   On the second computer installation there will be no initial restrictive alarm points. Alarm messages will be printed out only for really essential points where the operator must control them. For startup conditions, these limits will be very broad in range.

2. On the crude unit computer installation it was found that not enough instrumentation was available. For example, many operating temperatures were calculated by the computer from material balances, rather than having available temperature signals from installed thermocouples.

   On the second computer installation the instrumentation design of the new units, together with a review of the instrumentation on the existing unit, has been very carefully studied and adequate instrumentation has been provided for. On the existing unit for the lube oil plant, older and less satisfactory electronic instrumentation has been completely removed and replaced by the newest acceptable electronic control systems.

3. On the crude unit, as mentioned earlier, process stream analyzers were installed somewhat arbitrarily and, in retrospect, without enough study of the process dynamics and lag times involved. On the crude unit, the computer was used to evaluate analyzer performance; i.e., boiling point whose lag time created dynamics problems.

   As stated previously, the new unit will start up with no analyzers installed. Instead, the computer will generate sufficient meaningful data for studies to determine specific services where analyzers may best be used.

4. On the earlier installation, it was not felt necessary to order more memory in spite of the shortage being keenly felt.

   The lube oil plant machine will allow the easy modular addition of memory capacity as required.

5. The user, in spite of his comparatively small size and corresponding small staff, decided to perform his own maintenance of his first system. However, he purchased the supplier's maintenance contract for one year and during this time trained plant personnel in this area. After this time, he took over his own service and maintenance and has operated successfully ever since on the first computer. The people performing this work were inexperienced plant personnel and technicians.

   The second installation will follow this same pattern. The computer maintenance man from the crude unit installation has taken training courses offered by the supplier and has closely followed the system through its final factory checkout. The user expects vendor support on any major maintenance problem that may arise.

REFERENCES

1. "The Justification and Payout of On-Line Stream Analyzers" by D. J. Fraade; presented at the Ninth Annual ISA Analysis Instrumentation Symposium, April 29 - May 1, 1963, Houston, Texas.

2. "The Hidden Benefits of Computer Control" - by R. F. Jakubik, S. L. Kader, and L. B. Perillo; presented at the Instrument Society of America's 18th Annual Instrument-Automation Conference and Exhibit, September 9 - 12, 1963, Chicago, Illinois.

3. "A Look Back at Computer Control of an 85,000 BPD Crude Unit" - by Donald G. Covert; presented at the National Petroleum Refiners Association Computer Conference, October 15 - 17, 1963, Pittsburgh, Pennsylvania.