INDUSTRIAL EXPERIENCE AT THE ARABIAN
AMERICAN OIL COMPANY IN SAUDI ARABIA

AN INTERNSHIP REPORT

by

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Submitted to the Graduate College of
Texas A&M University
in partial fulfillment of the requirement for the degree of

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Major Subject: Petroleum Engineering
INDUSTRIAL EXPERIENCE AT THE ARABIAN AMERICAN OIL COMPANY IN SAUDI ARABIA

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[Signatures]

(Chairman of Committee)

(Head of Department)

(Member)

(Member)

(Member)

May 1977
ABSTRACT

Industrial Experience at the Arabian American
Oil Company in Saudi Arabia (May 1977)
Ruwaid Ahmed Akkad, B. S., The University of
Texas at Austin; M.S., Texas A&M University
Chairman of Advisory Committee: Dr. W. D. VonGonten

This report is a review of the author's six years of industrial work at Aramco in Saudi Arabia. The intent of the report is to establish that this experience fulfills the Doctor of Engineering internship requirement.

The author's work at Aramco was of two types, both of which are covered in this report. First, the assignment as a Development, Production, and Workover engineer, offered him application of academic training in real life situations. In addition to normal engineering design work, the author coordinated operations involving personnel from organizations other than Petroleum Engineering. Second, the assignment as Field Services Foreman gave the author the opportunity to demonstrate his leadership abilities as well as technical competence.

The author's contribution to each of the organizations served was the aggregate of small improvements in various phases of the work.
ACKNOWLEDGEMENTS

The author is deeply indebted to the members of his Graduate Committee who contributed to this report:

Dr. W. Douglas Von Gonten, Professor and Head of the Department of Petroleum Engineering and Chairman of the author's Committee, for his tireless guidance and support throughout the author's graduate program.

Dr. Joseph S. Osoba, Professor of Petroleum Engineering for his enthusiastic help and encouragement.

Mr. Robert L. Whiting, Professor of Petroleum Engineering, for making available to the author his invaluable experiences.

Dr. C. A. Phillips, Professor of Finance, for his encouragement and critique of the author's work.

Dr. W. A. Porter, Professor of Electrical Engineering, who offered the author a deep insight on the internship experience and many valuable comments.

The author also wishes to thank all his previous supervisors for their role in his professional development, and for allowing the use of Company information for this report.

Finally, the author's graduate education would have never been possible without the patient support of his mother Halimah, his wife Rabiah, and his daughters Arwa and Ruwaidah.
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INTRODUCTION

As part of the Doctor of Engineering degree requirements, the student is to intern a minimum of 9 months, or equivalent, under the supervision of a practicing engineer in industry, business or government. The internship objectives are: "(a) to enable the student to demonstrate the ability to apply both knowledge and technical training by making an identifiable contribution in an area of practical concern to the organization or industry in which the internship is served, and (b) to enable the student to function in a non-academic environment in a position in which he or she becomes aware of the organizational approach to problems in addition to those of traditional engineering design or analysis."

The requirements further stipulate that "students who have had extensive engineering experience may substitute equivalent academic course work ... provided that they submit an acceptable Internship Report".

The purpose of this report, therefore, is to identify parts of the author's six years of industrial experience and to establish fulfillment of the objectives of the Doctor of Engineering internship.

The author's experience was all gained while employed by the Arabian American Oil Company (Aramco) in Saudi Arabia from December 12, 1966 to January 7, 1973. The experience at Aramco may be divided into

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¹The citations on the following pages follow the style of the Journal of Petroleum Technology.
four areas based on organizations served with approximate service time. These areas were: (a) Development (Drilling) Engineering (2-2/3 years), (b) Production Engineering (2 years), (c) Field Services (2/3 year), and (d) Workover Engineering (2/3 year).

As an engineer (in areas (a), (b) and (d)), the author applied his engineering education and technical training to the design and implementation of petroleum engineering systems under real life pressure. The experience covered most of Aramco's concession area, onshore and offshore. The author's contribution to the organizations may be described as an aggregate of small ongoing improvements in the services offered by the organizations. Some of these contributions are cited in this report.

As a Field Services Foreman (area (c)), the author was involved in a different work environment from that of the normal engineering work. Here, the human relations factors were at least of equal importance to the technical capabilities. During the author's foremanship, this small organization grew in size from 19 to 34 (mostly semi-skilled) employees and in effectiveness to twice the original level. The implication of this growth was the need for careful training of new employees and proper distribution of work under the high demand for field service activities. The experience offered the author the opportunity to interact productively with numerous organizations within and outside the highly integrated Aramco organization. Some of these interactions will be outlined in this report.
During his employment with Aramco, the author attended many company-sponsored technical and non-technical courses which have greatly enhanced his professional development. Of these courses, the "Managerial Grid Seminar" and the "Kepner-Tregoe Genco Course" are worth mentioning. The experience obtained from these two courses and the "Field Services" job have influenced the author's decision to seek graduate education and to "be at home" with the Doctor of Engineering program.

This report, then, will endeavor to recapitulate, review, and analyze main events of the author's experience and relate them to the fulfillment of the internship objectives. Hence, it will not be a chronological listing of the events which were encountered during the years of employment at Aramco.
SCOPE OF THE REPORT

Two points are of importance in shaping this report:

(1). The author's experience was not served as an internship. Rather, it was a normal employment as a junior engineer in a large oil company.

(2). Generally, the work distribution in the organizations served by the author was not done on a "project" or a "team" basis. This was partly due to the operational nature of the work and partly due to the shortage of engineering manpower. As a result, the work was generally assigned on the basis of an engineer per rig(s), an engineer per field(s), or an engineer per area(s).

This report, therefore, will outline the duties and responsibilities of each position held by the author at Aramco. It will also treat in greater detail the work assignments which were of a "special" nature. The aim here is to demonstrate the fulfillment of the internship objectives. The amount of details on these "special" assignments may be limited, however, due to the time lag and difficulty of retrieving related information. Most of the details herein come from diaries kept by the author for personal reference during the years of work with the company.

It is further noted that the report will only briefly treat the Workover Engineering experience. One reason is that it may be considered as an extension of the Development Engineering experience. Another reason is that it would play a minor role in the accomplishment of the internship objectives.
The Company and The Organization

On May 29, 1933 a concession agreement was signed by the Government of Saudi Arabia and the Standard Oil Company of California. In November, 1933, the concession was assigned to California Arabian Standard Oil Company, formed by the Standard of California under the laws of Delaware. The name of this company was changed on January 31, 1944, to its present title - Arabian American Oil Company (Aramco). During the years 1936 to 1946, capital expansion and market requirements necessitated the sharing of Aramco ownership by other oil companies. The distribution of ownership was as follows:

<table>
<thead>
<tr>
<th>Company</th>
<th>Share of Aramco</th>
</tr>
</thead>
<tbody>
<tr>
<td>Standard Oil Company of California</td>
<td>30%</td>
</tr>
<tr>
<td>The Texas Company (now Texaco)</td>
<td>30%</td>
</tr>
<tr>
<td>Standard Oil Company of New Jersey (now Exxon)</td>
<td>30%</td>
</tr>
<tr>
<td>Socony Vacuum Oil Company (now Mobil)</td>
<td>10%</td>
</tr>
</tbody>
</table>

The original concession agreement covered all of eastern Saudi Arabia as far west as the western edge of the Dahna Desert and bounded by the lines running N 30°W and N 30°E. In 1939, a Supplemental Agreement extended the Exclusive Concession Area to cover about 440,000 square miles, about the size of Texas and California combined.

Through successive relinquishments of development rights, the area under the concession was reduced to 125,000 square miles by 1963. The concession area was further reduced to 105,000 square miles in 1968 (Figure 1).

The life of the concession agreement was extended three times to
Figure 1. Aramco Concession Area of 1968. (After Ghazzawi and Taylor).
run for a period of 66 years from 1933.

The Agreement granted the Company the exclusive right to "prospect for, manufacture, transport, deal with, carry away, and export oil and oil products," and the right to "use all means and facilities it deems necessary or advisable to carry out the purposes of the enterprise". When the concession expires, the fixed facilities become the property of the Government and will remain in the country. The Agreement also provided for royalty payments, proper oil measurement, and the keeping of accounts. The tax structure, the concept of "participation", and the latest developments in the pricing of Middle East oil are beyond the scope of this report.

The first commercial oil was encountered in the seventh exploration well drilled on the Dammam Dome. Dammam Well-7 was drilled to 4727 feet and completed in the Arab Zone in March, 1938, nearly three years after the drilling of Dmmam Well-1 had commenced. Exploration efforts continued and new fields were discovered both onshore and offshore.

Table 1 shows the oil fields of Aramco as of December 31, 1959. Noteworthy is the giant Ghawar Field which is made up of six producing areas totaling 559,300 acres. Table 2 shows a detailed status of Aramco wells as of November 30, 1972 which nearly coincides with the time the author left the company on January 7, 1973. The active producing fields then were thirteen (counting the six areas of Ghawar Field as one). Other potential producing fields (e.g. Marjan and Zuluf) were in the development stage.
A. Saudi Arabian Oil Fields at End of 1959

<table>
<thead>
<tr>
<th>Field</th>
<th>Discovered</th>
<th>Productive Zona</th>
<th>API Gravity</th>
<th>Size in Acres</th>
<th>Minimum Depth to Top Pay</th>
<th>1959 Production in Barrels Per Day</th>
<th>Cumulative Production in Barrels</th>
</tr>
</thead>
<tbody>
<tr>
<td>DAMMAM</td>
<td>MARCH, 1938</td>
<td>ARAB A, B, C, D</td>
<td>34.35</td>
<td>10,500</td>
<td>4.45º</td>
<td>34,964</td>
<td>394,295,542</td>
</tr>
<tr>
<td>ABU HADRIYA</td>
<td>MARCH, 1940</td>
<td>ARAB A, B, C, MID-JUBAILA, HADRIYA</td>
<td>35</td>
<td>7,400</td>
<td>8.44º</td>
<td></td>
<td>9,579</td>
</tr>
<tr>
<td>QATIF</td>
<td>NOVEMBER, 1940</td>
<td>ARAB D*</td>
<td>29.38</td>
<td>89,300</td>
<td>5.88º</td>
<td>267,314</td>
<td>1,519,803,146</td>
</tr>
<tr>
<td>FADHILI</td>
<td>JUNE, 1945</td>
<td>ARAB C, D</td>
<td>31.38</td>
<td>71,300</td>
<td>6.91º</td>
<td>16,002</td>
<td>104,090,497</td>
</tr>
<tr>
<td>NOVEMBER, 1949</td>
<td>FADHILI</td>
<td></td>
<td>37</td>
<td>1,900</td>
<td>9.71º</td>
<td></td>
<td>Shut-in</td>
</tr>
</tbody>
</table>

B. Status of Wells at End of 1959

<table>
<thead>
<tr>
<th>Field</th>
<th>Discoverd</th>
<th>Producing or Producible Fields</th>
<th>Producing</th>
<th>Shut in or Standing</th>
<th>Observation</th>
<th>Injection</th>
<th>Suspended</th>
<th>Abandoned</th>
<th>Drilling</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>ABQAIQ</td>
<td>MARCH, 1938</td>
<td>56 (a) 6(b) 4</td>
<td>12(2b)</td>
<td>0</td>
<td>2</td>
<td>1</td>
<td>5</td>
<td>90</td>
<td></td>
<td></td>
</tr>
<tr>
<td>ABU HADRIYA</td>
<td>MARCH, 1940</td>
<td>0 (a) 1 (b) 1</td>
<td>0</td>
<td>0</td>
<td>2</td>
<td>1</td>
<td>5</td>
<td>90</td>
<td></td>
<td></td>
</tr>
<tr>
<td>DAMMAM</td>
<td>MARCH, 1944</td>
<td>27(c)</td>
<td>4(d)</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>42</td>
<td></td>
<td></td>
</tr>
<tr>
<td>FADHILI</td>
<td>JANUARY, 1949</td>
<td>0 (a)</td>
<td>1 (b)</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td></td>
<td></td>
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<tr>
<td>GHAWAR</td>
<td>JUNE, 1948</td>
<td>44 (a)</td>
<td>6(b)</td>
<td>6(1)</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>61</td>
<td></td>
<td></td>
</tr>
<tr>
<td>AIN DAR</td>
<td>JUNE, 1945</td>
<td>34 (a)</td>
<td>1(b)</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>17</td>
<td></td>
<td></td>
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<td>SHEQUM</td>
<td>JUNE, 1946</td>
<td>33 (c)</td>
<td>10(d)</td>
<td>0</td>
<td>1</td>
<td>2</td>
<td>0</td>
<td>49</td>
<td></td>
<td></td>
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<tr>
<td>UTHMANIYAH</td>
<td>JUNE, 1947</td>
<td>0 (a)</td>
<td>1(b)</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>HAWITAH</td>
<td>JUNE, 1948</td>
<td>0 (a)</td>
<td>1(b)</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>HARADH</td>
<td>JUNE, 1949</td>
<td>0 (a)</td>
<td>1(b)</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>FAZRAN</td>
<td>JUNE, 1950</td>
<td>0 (a)</td>
<td>1(b)</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>2</td>
<td></td>
<td></td>
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<tr>
<td>KURRASAIYAN</td>
<td>JUNE, 1951</td>
<td>0 (a)</td>
<td>1(b)</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>KHURSANIYAH</td>
<td>JUNE, 1952</td>
<td>0 (a)</td>
<td>1(b)</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>MAFITA</td>
<td>JUNE, 1953</td>
<td>0 (a)</td>
<td>1(b)</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>NOVEMBER, 1954</td>
<td>0 (a)</td>
<td>0 (b)</td>
<td>1(b)</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>TOTALS</td>
<td>NOVEMBER, 1955</td>
<td>203(c)</td>
<td>72(2d)</td>
<td>18</td>
<td>4</td>
<td>24</td>
<td>3</td>
<td>346</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

(a) Including one gas cap observation well.
(b) Including three gas injection and nine water injection wells.
(c) Including two gas wells.
(d) Including two gas wells
(e) Including two gas wells
(f) All are gas injection wells.

Table 1. Aramco Oil Fields at the End of 1959 (After Aramco Handbook)
<table>
<thead>
<tr>
<th>Field</th>
<th>Producing</th>
<th>Abandoned</th>
<th>Oil Drilling</th>
<th>Standing</th>
<th>Shut-In</th>
<th>Observation</th>
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*Offshore (Berri, Qatif, and Safaniyeh include onshore wells)*

(a) Includes two producing gas wells; (b) Includes two abandoned gas wells; (c) Includes ST-55 Birjah Observation Well;
(d) Includes AW, modified oil; (e) Water Injection Well; (f) Includes three water Injection Supply; (g) Basmati Injection Well; (h) Includes sixteen Water Injection Wells; (i) Includes three water Injection Supply; (j) Includes three Water Injection Wells; (k) Includes six power water injectors.
This report will not describe any of today's Aramco operations. However, the author will attempt to briefly portray the work environment in the relevant Aramco organizations from 1967 to 1972, inclusive. The Company was an "integrated" oil company inasmuch as it explored, drilled, produced, transported, refined, and marketed oil and gas from the vast fields of Saudi Arabia. The author's experience at Aramco, covered only drilling and production activities.

Aramco's operations covered most of its concession areas. The company maintained three major districts (Dhahran, Abqaiq, and Ras Tanura) and three smaller districts (Safaniya, 'Udhailiyah, and Nairiya). Dhahran was the largest district and was the Company's administrative headquarter. Abqaiq was the headquarters for drilling and oil treatment and LPG plants. Ras Tanura was the home of Aramco refinery (capacity 500 + MBPD) and the largest oil shipping port in the world (5,000 + MBPD). The smaller districts were operational posts in remote areas with limited facilities and populations.

The Company followed a decentralized organizational scheme whereby each district had full autonomy over its operations. This scheme was very advantageous when modern means of communication were not available in the area. It also implied the functional duplication of many activities among the districts. For example, within the Petroleum Engineering (Pet. E.), Abqaiq District (Figure 2) and Dhahran district each had reservoir engineering, production engineering, and oil operations laboratory units.

In 1968, Aramco underwent company-wide reorganization and consolidation plans. In the Pet. E. Department, the Abqaiq reservoir
Figure 2. Organization Chart of the Abqaiq
District Petroleum Engineering Division
on June 5, 1967. (Before Reorganization)
and production units were eliminated. The position of District Petroleum Engineer was also eliminated. The only Pet. E. units that remained in Abqaiq were the Development Unit and the Oil Operations Laboratory. The former logically had to remain at Abqaiq to serve the Drilling Department. The laboratory activities were limited to mud, cement, and some oil analysis work. All major laboratory work was moved to Dhahran.

The net result of the "reorganization" was the reduction of manpower in most organizations. However, the Pet. E. Department headquarters in Dhahran was expanded to accommodate the additional personnel from Abqaiq. The reservoir engineering work was thus performed by three separate units: (1) Reservoir Research, (2) Reservoir Systems, and (3) Future Oil Development.

The reorganization had an immediate effect on the author's training with the Company. It made it difficult for him to transfer from the Development Unit in Abqaiq to the Production Unit in Dhahran by the expected mid 1968. Stagnation of recruitment to the Development Unit combined with the manpower saturation at the Production Unit delayed the transfer until September 1, 1969.

Figure 3 shows the main fields and operating areas of Aramco during the author's work period with the Company. Not shown is the Shaybah Field, which was in the Empty Quarter approximately 375 miles southeast of Dhahran.
Figure 3. Aramco Fields and Communities (After Aramco^5).
SUPERVISORS OF THE AUTHOR’S WORK

The following is a list of the engineers under whose supervision the author performed his work at Aramco.

At the Development Engineering Unit in Abqaiq (12-12-66 to 9-1-69), the supervisors were: Mr. Arthur H. Davis, Mr. Thomas O. Mohr, and Mr. Joseph T. Williams. Mr. Davis is now General Supervisor, Technical Services Laboratories at Aramco, Dhahran, Saudi Arabia. Mr. Mohr is Operations Manager for International Consultants, London, England. Mr. Williams is Manager of Operations, Chevron-UK, London, England.

At the Production Engineering Unit in Dhahran, (9-1-69 to 8-1-71), Mr. John P. Calligeros was the author's supervisor. During the absence of Mr. Calligeros, he was relieved for short periods by either Mr. John H. Rebold or Mr. Robert O. Williams. It is noteworthy that the author worked more closely with Mr. R. O. Williams, then Senior Production Engineer, who inspired him in much of his work. Presently, Mr. Calligeros is District Petroleum Engineer, Aramco, Abqaiq; Mr. Rebold is Superintendent, Safaniya Producing Division, Aramco; and Mr. Williams is representing Aramco in a large water injection construction project at Abqaiq.

At the Well Services Division of the Producing Department in Dhahran (8-1-71 to 3-18-72), Mr. Phillip O. Thorman supervised the author's work in the Field Services Unit. Mr. Thorman is now a Lead Engineer at the Aramco Production Engineering Unit in Dhahran.
At the Workover and Stimulation Segment of Production Engineering (3-18-72 to 1-7-73), Mr. Bob Davidson was the author's supervisor. Mr. Davidson is still in the same position at Aramco.
DEVELOPMENT ENGINEERING WORK

This was the author's first work experience. He had not received any summer training during his school years. The need for such training was particularly felt during the initial period of this job. Summer training on a drilling rig would have familiarized the author with the equipment, tools, operations, and especially with the people at work. This lack of training was overcome through extra hours of self-education.

At the Development Engineering Unit in Abqaiq, the author was assigned the responsibility of providing drilling engineering assistance to the operation of a company drilling rig. This was later expanded to a simultaneous two land rig operations separated by thirty to fifty miles. The author's offshore drilling work included three months on the Aramco Drilling Tender (ADT-1) in the Qatif and Berri fields.

The Development Engineering work offered the author a practical implementation of the academic training in drilling engineering and drilling fluids technology. It gave him a feeling for the meaning of numbers (e.g. 3000 psi pressure, 130,000 BPD water flow rate, 60 to 130 pcf fluid density, etc.) Moreover, this job introduced the author to the real world with its human imperfections and the non-academic approach to problem solving.

The development engineer at Aramco performed a dual function. First, he had the staff engineering responsibility of preparing drilling, completion, workover programs, and well completion reports.
Second, he was responsible for supervising and following up various parts of the drilling, completion, and workover operations. This second function was a temporary line supervision of relevant aspects of the operations. These aspects will be discussed later in this report.

During the author's drilling work, six land rigs and two offshore rigs were operating in the Aramco fields. All of the rigs were company-owned and operated except the ADC-1 land rig which was owned by the Arabian Drilling Company (ADC) and manned by French and Arab personnel. The rigs were as follows:

**Land Rigs:**  
- N-80-1  
- N-80-E-2  
- N-100-5  

**Offshore Rigs:**  
- T-32-1  
- T-32-2  
- U-1  
- ADT-1 (Drilling Tender)  
- AMDP-2 (Three-Leg-Jackup)

During the thirty three months in the Development Unit, the author wrote nearly sixty (60) drilling, completion and workover programs. These programs covered different areas of the onshore giant Ghawar field, Abqaiq field, Khurais field, and Abu Hadriya field. They also covered offshore activities in the Qatif and Berri fields.

The following discussion will cover three aspects of the author's "drilling" experience. First, the engineering programs of drilling, completion, and workover will be treated in some detail. Second, the jobs which required the author's supervision will be outlined to identify his role in these operations. Third, additional activities performed by the author will be reviewed which
ENGINEERING ACTIVITIES

This section deals with the drilling, completion, and workover programs. A brief discussion of the well completion report (ARAMCO PRO-18) will end this section.

1. The Drilling Program

This was a comprehensive plan containing the engineering design of all the major activities during the drilling of a well. It was prepared by the engineer and directed towards the drilling (operations) foreman who had the physical responsibility over the drilling rig and its personnel. The program was an official memo from the Chief Petroleum Engineer to the Manager of the Drilling Department.

An example of an Aramco drilling program is shown in Appendix A. This program for Abu Hadriya Well-13 (AHW-13) was engineered by the author while working in the Development Unit. The example program illustrates most of the features of a typical Aramco drilling program. In the following discussion, items of a drilling program will be reviewed with particular reference to the example of AHW-13.

The drilling program contained hole data (e.g., location, expected formation tops, etc.) based on geologic maps and past experience in the specific area of the well. Throughout the drilling operations, the actual and the expected formation tops would be compared by correlating drill time and other logs. If the actual tops were consistently higher than expected, the bottom formation could be higher than expected. In an anticlinal structure, this would
mean that the producing well was further above the oil-water contact than expected. The opposite situation, however, would mean a higher oil-water contact and a reduced hydrocarbon column. In cases where the actual formation tops were much deeper than expected (200 ft. to 300 ft.), the well could be abandoned before reaching the bottom depth (e.g., Berri Well-14). This would save tens of thousands of dollars that would otherwise be spent in further drilling.

The program specified the blowout prevention (B.O.P.) equipment necessary for the safety of drilling the well. The pressure rating of the BOP was a major point in the selection of the proper system for a given drilling situation. In most of Aramco's development drilling, a pressure rating of 3,000 psi was satisfactory. The most commonly used B.O.P. at Aramco was the conventional gate type preventer.

The drilling program also outlined the expected well problems and offered alternative solutions. For example, the loss of circulation in the Shu'aiba limestone was a very common problem in most Aramco wells. The use of various lost circulation material proved successful for regaining circulation in more than half of Aramco wells. If the circulation loss was due to natural cavities (e.g., 30 ft. to 60 ft. in some Ain Dar wells), no attempt was made to regain circulation. Another hole problem was the water flows which were experienced in many aquifers (Rus, Biyadh, Sulaiy, etc.). These were not excessive flows and were generally controlled by circulating drilling mud of the proper weight. Another source of hole problems was the water-sensitive sloughing shale of the Biyadh formation (Greenish Gray Shale). The wells were usually drilled with water to depths just above the top
of the shale zone. Then, low solids mud of proper density was circulated and the shale was generally drilled without problems. Some fields (e.g., Abu Hadriya) had pockets of high pressure gas zones which could be extremely hazardous if the mud weight was not sufficient to overcome the high pressure. In the example program, the gas at AHW-13 was expected at 9630 ft. below the derrick floor. The mud required to balance the expected high pressure (plus 300 psi overbalance) had a density of 130 pcf. For practical purposes, the program called for building up the mud density from 76 pcf to 110 pcf before drilling into the section containing the expected gas. This was a precaution. The mud density was to reach the required value when a depth of 9570 ft. had been reached. The result was a trade-off of 60 feet (9570 ft. to 9630 ft.) of slow drilling to avoid a potential blowout.

The drilling program also specified the sections of the hole to be cored. Coring was generally minimal in the "development" fields. The coring requirement of AHW-13 was probably an exception, since further core data were needed on the Arab-A and the Hadriya reservoirs in that field. Most of the coring at Aramco was done in the exploration wells (e.g., Jathum-1, Shaybah-1, etc.) where a wellsite geologist was usually present throughout the coring operation. The cores were collected in core trays and sent to the Exploration laboratory in Dhahran for analysis.

The drilling program further specified the number and position of centralizers to be used with different casing strings. Casing
centralizers are flexible springs attached to the casing to insure the centering of the casing in the hole and provide a more uniformly cemented casing string. Figure 4 shows a typical casing centralizer used in Aramco wells. The use of centralizers was most critical in deviated holes (e.g., offshore wells on multi-well platforms). To allow for a continuous clearance between the casing and the hole a larger number of centralizers was used in the deviated holes than in the straight holes. Charts from Halliburton Oilwell Cementing Company were used to determine the centralizer requirement for each well. Company experience was also utilized in the determination of centralizer programs.

The drilling program also outlined procedures for any special activities to be performed on the specific well. Some of these activities included logging, directional drilling, special formation testing, fluid and/or drill cuttings sampling. The example program for AHW-13 (Appendix A) included only logging and sampling requirements.

The program also specified the drilling fluids required to drill each section of the hole. The cheapest and best fluid was water, but it could not be used to drill most of the hole. One function of a drilling fluid was to apply enough hydrostatic pressure to overcome the pressure in the drilled formations. Water, with a density of 62.4 pcf could not supply sufficient pressure to overcome pressures in the deeper formations. Hence, drilling mud was the fluid used to drill most sections of Aramco wells. Water-base, low solids mud (LSM) was the most commonly used type of fluid. To the author's knowledge, air or gas had never been used as drilling fluids in any
A. Halliburton's Model S-3 Casing Centralizer

B. Positioning of casing Centralizers Relative to other Cementing Equipment

Figure 4. Typical Casing Centralizer and Cementing Equipment Used by Aramco.
of Aramco's wells. Figure 5 shows a simple example of calculating the required mud weight for a well section in the Shedgum area of the Ghawar field. It was a practice to design for 300 psi overbalance in oil wells and 200 psi overbalance in water and water injection wells. In the example of Figure 5, a mud weight was specified for 150 psi overbalance to give the drilling foreman a range of acceptable mud weight.

In low pressure formations (e.g., Arab D. in Shedgum), lighter muds were used which varied with locations. For Shedgum wells, the author made a laboratory study of different combinations of a light drilling fluid called "drilling milk". He passed his recommendations internally in the Development Unit. The mud was mainly an emulsion of diesel oil and water in nearly equal amounts. The additives included Atlasol (emulsifier, supplied by Milwhite Co.), CMC (sodium carboxymethyl cellulose, fluid-loss control agent), Bentonite (viscosity control agent), and Quebracho (organic thinner, or dispersing agent). The proportions of water and diesel were varied to achieve the required mud weight (56 pcf to 62 pcf). Small amounts of Atlasol were used to prevent break-up of the emulsion. Quebracho and bentonite were varied to achieve the proper viscosity. As a result of this work, it was common to drill the Arab-D reservoir with "Atlasol" mud of 59 pcf-39 seconds-5 cc (mud weight; marsh funnel viscosity, and 30 minute water loss).

Among the major items in the drilling program which required engineering design were the casing, cementing, bit, and hydraulics programs. A detailed discussion of these items follows.
FIGURE 5
Example of Mud Weight Calculation for a Hole Section in a Shedgum Well

Given:

Well No.: ShW-66
Elevation: 930 ft. DF (derrick floor)
Top Wasia Formation = 3150 ft. DF
Average Wasia data for Shedgum Area:
  Pressure = 2369 psi at 4641 ft. ss (subsea).
  Pressure Gradient = 0.429 psi/ft.

Required:

Calculate the mud weight necessary to overbalance the Wasia by: (a) 150 psi, and (b) 300 psi

Solution:

Wasia Depth = 3150 - 930 = 2220 ft. ss
Depth above Average = 4641 - 2220 = 2421 ft.
Pressure difference = (2421 ft.)(0.429 psi/ft) = 1038.6 psi
Estimated Wasia pressure (at ShW-66) = 2369-1038.6=1330.4 psi

(a) For 150 psi overbalance, pressure = 1330.4 + 150=1480.4 psi

\[
\text{Mud Weight} = \frac{\text{pressure(psi)}}{\text{depth (ft)}} \times 144(\text{in}^2/\text{ft}^2)
\]

\[
\text{Mud Weight} = \frac{1480.4}{3150} \times 144 = 67.7 \text{ pcf}
\]

(b) For 300 psi overbalance, pressure = 1330.4 + 300 = 1630.4 psi

\[
\text{Mud Weight} = \frac{1630.4}{3150} \times 144 = 74.5 \text{ pcf}
\]
A. The Casing Program. This presented the design of the casing strings to be run in the well. Three types of casing strings were normally used at Aramco: (a) a conductor string, (b) three or four intermediate strings, and (c) a production string. The production string was usually a liner (a shorter string with its top not reaching the surface) to allow higher flow rates of the produced fluid. In the example of AHW-13, the conductor string was 26" in diameter; the intermediate strings were 18-5/8", 13-3/8", and 9-5/8"; and the production string was a 7" liner. The well was to be completed as open hole, i.e., the casing does not cover the producing Hadriya formation. However, if the Fadhili formation was hydrocarbon-bearing, a 4-1/2" liner was to be run to prevent communication of the Hadriya and Fadhili reservoirs. Table 3 shows typical casing setting positions in Aramco onshore and offshore wells. It also indicates the reason for setting each casing string.

In most Aramco development wells, the casing strings were uniform, i.e., each string was of the same weight and type of steel throughout. However, deep wells required the efficient use of combination strings. A combination string is one made up of casing pipes of the same outside diameter, but composed of sections of various weights and grades dictated by the stress distribution along the string. The result of this design is the most economical combination, consistent with good engineering practice. An example of a combination string is shown in the AHW-13 program where the principle was utilized in both the 9-5/8" casing and the 7" liner. The casing string is designed to withstand three significant forces which result from (a) external
TABLE 3

Typical Casing Setting Programs for Aramco Development Wells

(A). Land Wells

<table>
<thead>
<tr>
<th>Casing Size</th>
<th>Setting Position</th>
<th>Purpose</th>
</tr>
</thead>
<tbody>
<tr>
<td>26&quot; to 36&quot;</td>
<td>Below surface sands</td>
<td>Prevent washout of surface sand.</td>
</tr>
<tr>
<td>18-5/8&quot;</td>
<td>In Eocene</td>
<td>Protect aquifers and support the hole.</td>
</tr>
<tr>
<td>13-5/8&quot;</td>
<td>In Lower Aruma Shale</td>
<td>Protect aquifers and shut off lost circulation in order to drill the Wasia with mud.</td>
</tr>
<tr>
<td>9-5/8&quot;</td>
<td>In Biyadh</td>
<td>Shut off the Wasia flow, lost circulation zones and sloughing shale.</td>
</tr>
<tr>
<td>7&quot;</td>
<td>At top of oil reservoir</td>
<td>Production string.</td>
</tr>
</tbody>
</table>

(B). Offshore Wells

<table>
<thead>
<tr>
<th>Casing Size</th>
<th>Setting Position</th>
<th>Purpose</th>
</tr>
</thead>
<tbody>
<tr>
<td>30&quot; to 38&quot;</td>
<td>Varies with sea bottom conditions</td>
<td>Conductor pipe</td>
</tr>
<tr>
<td>13-3/8&quot;</td>
<td>In Rus</td>
<td>Shut off Umer Radhuma workflow and separate it from lower zones.</td>
</tr>
<tr>
<td>9-5/8&quot;</td>
<td>In Lower Aruma</td>
<td>Shut off lost circulation and allow drilling the Wasia with mud.</td>
</tr>
<tr>
<td>7&quot;</td>
<td>At top of or through oil reservoir</td>
<td>Production string.</td>
</tr>
</tbody>
</table>
pressure, (b) internal pressure, and (c) longitudinal or axial loading. External pressure tends to collapse the casing and internal pressure tends to burst it. Axial loading may be tension due to dead weight of casing or compression due to buoyancy in hole fluid. Axial tension has a dual effect: it tends to pull the casing apart, and it lowers the casing's collapse resistance. The problem of casing design was then one of selecting the most economical grades and weights of casing which would withstand the forces to which the casing was subjected. Since the design forces were not uniform but varied with the well depth, the use of combination strings offered an economical advantage. The basic criterion in selecting the casing for each section of the hole was to design against the worst possible condition and apply design (or safety) factors. The design factors used by Aramco were 1.125, 1.125 and 1.80 for collapse, bursting, and tension, respectively.

There was no special method for casing design at Aramco. Instead, the conventional text book method was used. The equations used for casing design are listed in Appendix B. In designing casing to prevent collapse, the most serious problems were encountered at the bottom of the hole due to the hydrostatic head of the drilling fluid. By contrast, the greatest tension occurred at the top of the casing string since the top joint had to support the weight of the string. Thus, the resistance to collapse dictated that the casing should be thick-walled at the bottom, tapering to thin walls at the top. The opposite was dictated by tension consideration. Bursting considerations were most critical at the top of the hole since the casing
would tend to fail by longitudinal splitting due to excess internal pressure over external pressure.

In casing design calculations at Aramco, the important phenomenon of biaxial stress was taken into consideration. The collapse strength of casing is reduced when tensile stresses are applied and increased when compressive forces are applied. This is illustrated by the ellipse of biaxial yield stress as shown in Figure 6. The general equation of the ellipse is:

\[
\frac{S_c^2}{S_0^2} + \frac{S_t^2}{S_0^2} = 1
\]

which may be rewritten as

\[r^2 - rt + t^2 = 1\]

where:

\[r = \frac{S_c}{S_0} = \text{fractional collapse resistance}\]

\[t = \frac{S_t}{S_0} = \text{fractional tensile yield stress}\]

\[S_0 = \text{average yield strength of the steel, psi}\]

\[S_c = \text{peripheral or hoop stress, psi}\]

\[S_t = \text{tensile stress, psi}\]

Steel manufacturers supply charts depicting the reduction of collapse strength under tensile loads for various weights and grades of steel. Similar charts were used in the casing designs of AHW-13. It should be noted that casing design is readily adaptable to programming on a digital computer. The author feels
Figure 6. Ellipse of Biaxial Yield Stress (After Moore and Cole\textsuperscript{6}). The example shows 86.5\% collapse resistance reduction when pipe was subjected to 22.8\% tensile load.
that considerable engineering time could be saved by computer-
ising the casing design calculations.

B. The Cementing Program. The drilling program
also specified the types and quantities of cement, and the cemen-
ting procedure for every casing string. Cement was used to provide
a positive seal between the casing and the formations. Ordinary
Portland cement was the principal constituent of most oilwell
cements. Table 4 shows the various components of Portland cement.
Actual percentages varied with different applications. Portland
cement was chemically treated to make it suitable for oilwell cementing
operations. The main considerations in oilwell cements were the
thickening time and the cement strength. Thickening time is the time
necessary for the cement slurry to reach a viscosity of 100 poises.
It is important since it determines the length of time (in hours)
a certain cement slurry could be pumped before it sets. Compressive
strength requirements (a few hundred psi) for oilwell cements are
generally much lower than those for construction cements; hence,
the difference in the cement constituents. Increasing the cement's
thickening time, and therefore, pumpability was done by either
(1) finer grinding, (2) reducing fast hydrating materials, or (3)
adding chemical retarders (e.g., calcium lignosulfonate).

The American Petroleum Institute, API, established specifications
for seven classes of oilwell cements (Table 5). The main difference
between these classes is their pumpability (thickening time). Classes
D, E, and F have longer thickening times at depths below 10,000 ft.
The effect of adding chemical retarders on thickening time is shown
Table 4. Components of Dry Cement (After McCray and Cole)
Table 5. API Classification of Oilwell Cements, (After McCray and Cole).

<table>
<thead>
<tr>
<th>Class</th>
<th>Recommended Use</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>Intended for use to 6,000-ft. depth,* when special properties are not required. Available in regular type only (similar to ASTM C 150, type 1).</td>
</tr>
<tr>
<td>B</td>
<td>Intended for use to 6,000-ft. depth,* Available in the regular type (similar to ASTM C 150, type II) for conditions requiring moderate sulfate resistance, and in the high sulfate-resistant type.</td>
</tr>
<tr>
<td>C</td>
<td>Intended for use to 6,000-ft. depth,* for conditions requiring high early strength. Available in the regular type (similar to ASTM C 150, type III), and in the high sulfate-resistant type.</td>
</tr>
<tr>
<td>N</td>
<td>Intended for use to 9,000-ft. depth,* for conditions of moderate temperature and pressure. Available in the regular type (having moderate sulfate resistance) and in the high sulfate-resistant type.</td>
</tr>
<tr>
<td>D</td>
<td>Intended for use to 12,000-ft. depth,* for conditions of moderately high temperature and moderately high pressure. Available in the regular type (having moderate sulfate resistance) and in the high sulfate-resistant type.</td>
</tr>
<tr>
<td>E</td>
<td>Intended for use to 14,000-ft. depth,* for conditions of high temperature and high pressure. Available in the regular type (having moderate sulfate resistance) and in the high sulfate-resistant type.</td>
</tr>
<tr>
<td>F</td>
<td>Intended for use to 16,000-ft. depth,* for conditions of extremely high temperature and extremely high pressure. Available in the regular type (having moderate sulfate resistance) and in the high sulfate-resistant type.</td>
</tr>
</tbody>
</table>

* These depth limits are based on the conditions imposed by the casing-cementing well-simulation tests (Schedules 1–9, incl., RP 10B), and should be considered as approximate values.


<table>
<thead>
<tr>
<th>Well-Depth API Casing Cementing Conditions*</th>
<th>Temperature</th>
<th>Pumpability Time*</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Static</td>
<td>Cement</td>
</tr>
<tr>
<td>2,000 ft.</td>
<td>110°F</td>
<td>91°F</td>
</tr>
<tr>
<td>4,000 ft.</td>
<td>140°F</td>
<td>103°F</td>
</tr>
<tr>
<td>6,000 ft.</td>
<td>170°F</td>
<td>113°F</td>
</tr>
<tr>
<td>8,000 ft.</td>
<td>200°F</td>
<td>125°F</td>
</tr>
<tr>
<td>10,000 ft.</td>
<td>230°F</td>
<td>144°F</td>
</tr>
<tr>
<td>12,000 ft.</td>
<td>260°F</td>
<td>172°F</td>
</tr>
<tr>
<td>14,000 ft.</td>
<td>290°F</td>
<td>206°F</td>
</tr>
</tbody>
</table>

* API Testing Code RP–10B.
in Table 6, where pumpability time at 8000 ft. was increased from 2:07 hours to 6:00 + hours.

Diatomaceous earth cement (e.g., Diacel D) was commonly used by Aramco for reducing cement density. This was necessary for long casing cement jobs where loss of circulation was possible. For example, a Class B cement containing 30 percent Diacel D would have a slurry density of 85 pcf as compared to 116 pcf for the pure Class B cement. The program for AHW-13 (Appendix A) offers examples of cementing programs prepared by the author.

By contrast to long string cement jobs, shallow string jobs required much shorter thickening time. Hence, it was a common practice to include 1 to 2 percent calcium chloride (CaCl₂) in the cement to accelerate cement setting in the top two jobs.

At Aramco, casing was cemented by either a one-stage method or a two-stage method. A typical procedure for one-stage cementing is depicted in Figure 7. This procedure was generally followed in cementing Aramco's two surface casing strings and the production liners. Dry cement was hauled to the wellsite in silos containing the cement and additives. Circulation was first established with drilling mud after the casing had been set. A rubber plug was dropped inside the casing which would rupture and set on top of the float collar. Dry cement was continuously transferred into a hopper where it was mixed by a high jet mixer. The required volume of cement slurry was then pumped down the casing followed by a second rubber plug. Then immediately, displacing fluid (usually mud) was pumped behind the second plug. The second plug had a solid core
Figure 7. Typical One-Stage Cementing Procedure. (After McCray and Cole)
which allowed it to seat in the float collar (Figure 7). As the second plug seated, the surface pump pressure would build up indicating the end of the job. At that point, the casing below the float collar, and the annulus to the surface would be full of cement slurry. If excess cement was circulated through the annulus, it would indicate a successful primary cement job. Otherwise, a survey (temperature, cement bond log, etc.) of the cement top behind the casing was made, followed by a squeeze cement job as the conditions would require.

A popular method of cementing long casing strings at Aramco was the two-stage method. It was particularly used in cementing intermediate strings (e.g., 13-3/8" and 9-5/8") where the primary single-stage cement job was questionable. The two-stage method was based on the reduction of the hydrostatic head on incompetent formations such as the Shu'aiba limestone. The procedure increased the probability of maintaining circulation while cementing and achieving a full cement sheath behind the casing strings. Figure 8 illustrates the two-stage cementing procedure. A cementing collar with a differential valve (DV) was run as part of the casing string and positioned approximately 200 feet above the shoe of the previous casing. The DV was run in the closed position. After landing the casing, the first stage was cemented in a manner similar to the one-stage process. The first stage cement was followed by a plug which set in the float collar. Following the first stage, a shut-off plug was dropped which separated the sections below and above the DV collar and opened the DV posts for circulation. Second-stage cement was then pumped followed by a closing plug and displaced by drilling fluid. Closing the DV ports was also
Figure 8. A Typical Two-Stage Cement Job.
indicated by a pressure increase at the surface pump. Cement returns on the second stage were normally assured by using 10 to 15 percent excess cement slurry. Examples of two-stage cementing are the 13-3/8" and the 9-5/8" cement jobs for AHW-13 as shown in Appendix C.

C. The Bit Program. The drilling program also included a subprogram indicating the type and number of bits required to drill each section of the well. The bit selection was a function of the formations to be drilled and the drilling conditions. Drilling experience in the different Aramco fields was also important to the proper selection of drilling bits. Figure 9 shows a geological cross section in Central and Eastern Saudi Arabia. Most Aramco fields were in the eastern coastal areas. Table 7 offers a generalized lithologic description of the formations encountered in Aramco drilling. The lithology ranged from the soft marl and shale of the Dammam formation to the hard anhydrite of the Hith formation.

The drilling conditions included the hole depth, weight on the bit, straightness of the hole, the nature of the drilling fluid, the rate of circulation, the jetting action employed, the rotary speed, and caving formations. These conditions were considered separately for each section of the hole. The size of bit(s) to drill each section was governed generally by the size of casing to be run in that section. Sufficient clearance must be allowed for cementing between the hole and the outside diameter of the casing pipe. Table 8 illustrates the clearance between the casing and the hole for the different parts of AHW-13. The program for AHW-13(Appendix A) shows that the most popular bit type used by Aramco was the jet type tri-cone rock bit. Figure 10
Table 7. Lithologic Description of Formations in Eastern Saudi Arabia. (After Aramco®).

<table>
<thead>
<tr>
<th>AGE</th>
<th>FORMATION</th>
<th>GENERALIZED LITHOLOGIC DESCRIPTION</th>
<th>MAJOR STRATIGRAPHIC DIVISIONS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Quaternary &amp; Tertiary</td>
<td>Quaternary &amp; Tertiary</td>
<td>Gravel, sand, and silt.</td>
<td>Miocene-Pliocene Clastics</td>
</tr>
<tr>
<td>Miocene-Pliocene</td>
<td>Kuhai</td>
<td>Limestone, limestone, dolomite, and gypsum.</td>
<td>Miocene-Pliocene Clastics</td>
</tr>
<tr>
<td></td>
<td>Haidif</td>
<td>Cherty shale, dolomite, and limestone.</td>
<td>Miocene-Pliocene Clastics</td>
</tr>
<tr>
<td></td>
<td>Haidif</td>
<td>Limestone, dolomite, and shale.</td>
<td>Miocene-Pliocene Clastics</td>
</tr>
<tr>
<td>Cretaceous</td>
<td>Lutetian</td>
<td>Limestone, dolomite, and shale.</td>
<td>Upper Cretaceous and Eocene Carbonates</td>
</tr>
<tr>
<td></td>
<td>Ypresian</td>
<td>Limestone, dolomite, and shale.</td>
<td>Upper Cretaceous and Eocene Carbonates</td>
</tr>
<tr>
<td></td>
<td>Thanatian</td>
<td>Limestone, dolomite, and shale.</td>
<td>Upper Cretaceous and Eocene Carbonates</td>
</tr>
<tr>
<td></td>
<td>Turonian</td>
<td>Limestone, dolomite, and shale.</td>
<td>Upper Cretaceous and Eocene Carbonates</td>
</tr>
<tr>
<td></td>
<td>Aptian</td>
<td>Limestone, dolomite, and shale.</td>
<td>Upper Cretaceous and Eocene Carbonates</td>
</tr>
<tr>
<td></td>
<td>Barremian</td>
<td>Limestone, dolomite, and shale.</td>
<td>Upper Cretaceous and Eocene Carbonates</td>
</tr>
<tr>
<td>Jurassic</td>
<td>Valanginian</td>
<td>Limestone, dolomite, and shale.</td>
<td>Upper Jurassic and Early Lower Cretaceous Clastics</td>
</tr>
<tr>
<td></td>
<td>Hauterivian</td>
<td>Limestone, dolomite, and shale.</td>
<td>Upper Jurassic and Early Lower Cretaceous Clastics</td>
</tr>
<tr>
<td></td>
<td>Berriasian</td>
<td>Limestone, dolomite, and shale.</td>
<td>Upper Jurassic and Early Lower Cretaceous Clastics</td>
</tr>
<tr>
<td></td>
<td>Toarcian</td>
<td>Limestone, dolomite, and shale.</td>
<td>Upper Jurassic and Early Lower Cretaceous Clastics</td>
</tr>
<tr>
<td></td>
<td>Oxolitnian</td>
<td>Limestone, dolomite, and shale.</td>
<td>Upper Jurassic and Early Lower Cretaceous Clastics</td>
</tr>
<tr>
<td></td>
<td>Callovian</td>
<td>Limestone, dolomite, and shale.</td>
<td>Upper Jurassic and Early Lower Cretaceous Clastics</td>
</tr>
<tr>
<td></td>
<td>Kimmeridgian</td>
<td>Limestone, dolomite, and shale.</td>
<td>Upper Jurassic and Early Lower Cretaceous Clastics</td>
</tr>
<tr>
<td>Jurassic</td>
<td>Oxfordian</td>
<td>Limestone, dolomite, and shale.</td>
<td>Lower and Middle Jurassic Clastics and Carbonates</td>
</tr>
<tr>
<td></td>
<td>Bathonian</td>
<td>Limestone, dolomite, and shale.</td>
<td>Lower and Middle Jurassic Clastics and Carbonates</td>
</tr>
<tr>
<td></td>
<td>Bajocian</td>
<td>Limestone, dolomite, and shale.</td>
<td>Lower and Middle Jurassic Clastics and Carbonates</td>
</tr>
<tr>
<td></td>
<td>Toarcian</td>
<td>Limestone, dolomite, and shale.</td>
<td>Lower and Middle Jurassic Clastics and Carbonates</td>
</tr>
<tr>
<td>Triassic</td>
<td>Lower</td>
<td>Red and green shale.</td>
<td>Permo-Triassic Clastics</td>
</tr>
<tr>
<td></td>
<td>Middle</td>
<td>Sandstone and shale.</td>
<td>Permo-Triassic Clastics</td>
</tr>
<tr>
<td></td>
<td>Upper</td>
<td>Sandstone and shale.</td>
<td>Permo-Triassic Clastics</td>
</tr>
<tr>
<td>Permian</td>
<td>Upper</td>
<td>Limestone and shale.</td>
<td>Early Paleozoic Clastics</td>
</tr>
</tbody>
</table>

| PERMIAN       | Upper | Limestone and shale. | Early Paleozoic Clastics |

| PERMIAN       | Upper | Limestone and shale. | Early Paleozoic Clastics |

| PERMIAN       | Upper | Limestone and shale. | Early Paleozoic Clastics |

| PERMIAN       | Upper | Limestone and shale. | Early Paleozoic Clastics |

| PERMIAN       | Upper | Limestone and shale. | Early Paleozoic Clastics |

| PERMIAN       | Upper | Limestone and shale. | Early Paleozoic Clastics |

| PERMIAN       | Upper | Limestone and shale. | Early Paleozoic Clastics |

| PERMIAN       | Upper | Limestone and shale. | Early Paleozoic Clastics |

| PERMIAN       | Upper | Limestone and shale. | Early Paleozoic Clastics |

| PERMIAN       | Upper | Limestone and shale. | Early Paleozoic Clastics |

| PERMIAN       | Upper | Limestone and shale. | Early Paleozoic Clastics |

| PERMIAN       | Upper | Limestone and shale. | Early Paleozoic Clastics |

| PERMIAN       | Upper | Limestone and shale. | Early Paleozoic Clastics |

| PERMIAN       | Upper | Limestone and shale. | Early Paleozoic Clastics |

| PERMIAN       | Upper | Limestone and shale. | Early Paleozoic Clastics |

| PERMIAN       | Upper | Limestone and shale. | Early Paleozoic Clastics |

| PERMIAN       | Upper | Limestone and shale. | Early Paleozoic Clastics |

| PERMIAN       | Upper | Limestone and shale. | Early Paleozoic Clastics |
**TABLE 8**

Example of The Clearance Between Casing and the Hole - AHW-13

<table>
<thead>
<tr>
<th>Depth</th>
<th>Hole Size</th>
<th>Casing Size(O.D.)</th>
<th>Clearance*</th>
</tr>
</thead>
<tbody>
<tr>
<td>200'</td>
<td>34&quot;</td>
<td>26&quot;</td>
<td>4.0000&quot;</td>
</tr>
<tr>
<td>750'</td>
<td>24&quot;</td>
<td>18-5/8&quot;</td>
<td>2.6875&quot;</td>
</tr>
<tr>
<td>4070'</td>
<td>17-1/2&quot;</td>
<td>13-3/8&quot;</td>
<td>2.0625&quot;</td>
</tr>
<tr>
<td>6790'</td>
<td>12-1/4&quot;</td>
<td>9-5/8&quot;</td>
<td>1.3125&quot;</td>
</tr>
<tr>
<td>9444'</td>
<td>8-1/2&quot;</td>
<td>7&quot;</td>
<td>0.7500&quot;</td>
</tr>
<tr>
<td>10357</td>
<td>5-15/16&quot;</td>
<td>4-1/2&quot;</td>
<td>0.7188&quot;</td>
</tr>
</tbody>
</table>

*Clearances were simply calculated as one-half the difference between the hole diameter and the O.D. of the casing. The clearances at casing joints would normally be smaller. The figures are useful for qualitative illustration of the clearance reduction with the reduced casing size.
Figure 9. Geological Cross Sections in Central and Eastern Saudi Arabia. (After Aramco®)
<table>
<thead>
<tr>
<th>ROCK BIT CLASSIFICATION</th>
<th>BIT* TYPE</th>
<th>FORMATION</th>
<th>DESIGN FEATURES</th>
<th>CUTTING ACTION</th>
</tr>
</thead>
<tbody>
<tr>
<td>Soft Formation</td>
<td>OSC-3A</td>
<td>Soft formations having low compressive strength and high drillability (soft shales, clays, red beds, salt, soft limestone, unconsolidated formations, etc.)</td>
<td>Tooth Spacing</td>
<td>Tooth Depth</td>
</tr>
<tr>
<td></td>
<td>OSC-3</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Medium Soft</td>
<td>OSC-1G</td>
<td>Soft to medium formations or soft interspersed with harder streaks (firm, unconsolidated, or sandy shales, red beds, salt, anhydrite, soft limestone, etc.)</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>OSC</td>
<td>Soft to medium formations interspersed with hard streaks (medium hard and unconsolidated shales, red beds, salt, anhydrite, medium hard limestones, unconsolidated sands, etc.)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Medium Hard</td>
<td>OWV</td>
<td>Medium to medium hard formations (harder shales, sandy shales, shales alternating with streaks of sand and limestone, etc.)</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>OWC</td>
<td>Medium hard abrasive to hard formation (high compressive strength rock, dolomite, hard limestone, hard silty shale, etc.)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hard</td>
<td>W7</td>
<td>Hard semi-abrasive formations (hard sandy or chert bearing limestone, dolomite, granite, chert, etc.)</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>W7R-2</td>
<td>Hard abrasive formations (chert, quartzite, pyrite, granite, hard sand rock, etc.)</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>WR</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Available with jet or conventional watercoors for fluid drilling or as "aerobits" or "aerojetbits" for air, gas or mist drilling

Figure 10. Typical Milled Teeth Rock Bits Used in Aramco Drilling Operations. (After Hughes⁹)
shows design features of the different standard milled rock bits used by Aramco. Figure 11 shows design features for the "x-line" sealed bearing rock bits which were introduced at Aramco in 1967.

The x-line bits had four added features to the standard design:
(1) Fully sealed, self-lubricating bearings to increase bearing life,
(2) Fortified gage structure to maintain a full gage hole, (3) Enlarged bit legs to protect the bearing seals, and (4) Hardfaced shirttails of soft and medium formation bits to prevent wear at these points.

One important part of the jet bits is the design of their water courses. In the conventional bits, water courses are designed so that the fluid flow is directed to the bit teeth. In the jet bits, however, the fluid passing through the bit is directed towards the bottom of the hole as shown in Figure 12. The jet-type design thus offers efficiency in utilizing most of the fluid power below the bit to remove the cuttings.

The selection of bit type was based on a consideration of the factors involved in drilling each section of the hole. The type and number of bits utilized were selected to offer the minimum cost (per foot) for the given hole size. The cost was approximated by the following equation:

\[
\text{Cost}($/\text{ft}) = \frac{$/\text{bit} + $/\text{rig-hour} \left( \frac{\text{hours}}{\text{trip bit}} + \frac{\text{rotating-hours}}{\text{bit}} \right)}{\text{ft/bit}}
\]

Estimates of the parameters of the equation were normally available with reasonable accuracy from Company records.

In deep offshore wells, the high rig costs ($/rig-hour) and the long trip time (hours/trip bit) made the use of milled teeth rock bits less desirable. Tungsten carbide insert bits and diamond bits
## "X-Line" (Sealed Bearing) Milled Tooth Rock Bit Types in Relation to Formation Drilling and Basic Design Features

<table>
<thead>
<tr>
<th>ROCK BIT CLASSIFICATION</th>
<th>BIT TYPE</th>
<th>FORMATION</th>
<th>DESIGN FEATURES</th>
<th>CUTTING ACTION</th>
</tr>
</thead>
<tbody>
<tr>
<td>Soft Formation</td>
<td>X3A</td>
<td>Soft formations having low compressive strength and high drillability (soft shales, clays, red beds, salt, soft limestone, unconsolidated formations, etc.)</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>X3</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Medium Soft Formation</td>
<td>X1G</td>
<td>Soft to medium formations or soft interspersed with harder streaks (firm, unconsolidated, or sandy shales, red beds, salt, anhydrite, soft limestone, etc.)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Medium Hard Formation</td>
<td>XV</td>
<td>Medium to medium hard formations (harder shales, sandy shales, shales alternating with streaks of sand and limestone, etc.)</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>XC</td>
<td>Medium hard abrasive to hard formation (high compressive strength rock, dolomite, hard limestone, hard slaty shale, etc.)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hard Formation</td>
<td>X7</td>
<td>Hard semi-abrasive formations (hard sandy or chert bearing limestone, dolomite, granite, chert, etc.)</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>XWR</td>
<td>Hard abrasive formations (chert, quartzite, pyrite, granite, hard sand rock, etc.)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Available for jet circulation only

<table>
<thead>
<tr>
<th>Tooth Spacing</th>
<th>Tooth Depth</th>
<th>Gage Hard Facing</th>
<th>Chipping Crushing</th>
<th>Douging Scraping</th>
</tr>
</thead>
<tbody>
<tr>
<td>NO SCALE</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Figure 11.** The "X-Line" Bits Used by Aramco, particularly in Deep Drilling Operations. (After Hughes[9])
A. Conventional Bit

B. Jet-Type Bit

Figure 12. Water Course Design in Tricone Milled-Tooth Bits.
were more economical in these sections. The saving was mainly from the sharply reduced number of bit trips per section and the increased bit footage (ft/bit) which more than offset the high cost of these special bits. Other special bits and hole-openers were used at Aramco but they were of no significance to this report.

D. The Hydraulic Program. The hydraulics program was a part of the drilling program at Aramco. A rig hydraulics program was essentially an optimum balance between the circulating rate, the hydraulic impact, and the pressure losses through the circulating system. To achieve this balance, Aramco used a method that was introduced by the Humble Oil and Refining Company in December, 1956. The Humble method differed from other methods in the concept of an optimum circulating rate and the means for determining it. According to this concept, for a given rig and hole situation, there was one circulating rate that would maximize bottom-hole cleaning and allow drilling at an optimum rate. A discussion of the Humble method follows.

Hydraulic impact is defined as the product of circulating rate, Q, and the nozzle fluid velocity, V. The function of the hydraulic impact (QV) is to clean the hole and prevent re-grinding of the drill cuttings since the hole cleaning efficiency is directly proportional to QV. The bit loading (weight on the bit and rotary speed), however, is responsible for making the hole. For a given bit loading level, increasing QV will increase penetration rates up to a maximum impact value beyond which the increase diminishes. To achieve a greater penetration rate, a higher bit
loading level is necessary. Therefore, penetration rate is pro-
portional to both the bit loading and the hydraulic impact.

Mud pumps act as power generators and the circulating
equipment as a transmission system to deliver power to the bit. Power
losses (pressure drops) occur throughout the circulating system, and
they will rise as the circulation rate increases. There is a point
where the increases in the circulating rate are used up in pressure
drop without effecting an increase in QV. It is thus necessary to
achieve a balance between the circulating rate and the pressure
losses in order to obtain the most efficient pressure at the bit.
The problem of calculating a hydraulics program becomes that of de-
termining the circulating rate which minimizes pressure losses and
maximizes QV.

The procedure for using the Humble method to calculate the
optimum circulating rate for Aramco systems was outlined by Mohr\textsuperscript{10}
in a Company report (No. A-3-65). An example of an optimum circulat-
ing rate calculation based on the Humble method appears in Appendix D.

The calculation of an Aramco hydraulics program was accomplished
in the following four steps:

a. Evaluation of Hydraulic Limitations

(1) Available Rig Hydraulic Horsepower, HHP. This was
based on pump tests and evaluation of HHP in the equation:

\[
HHP = \frac{PQ}{1714}
\]

where \( P \) = pump pressure, psi
\( Q \) = flow rate, gallons per minute (GPM)
The density of the fluid used in the test must be specified and was normally 10 lb/gal (=74.7 pcf).

(2) Annular Velocity Requirement. This varied with fluid properties, cutting size, and hole size. Acceptable minimum annular velocities ranged from 90 to 150 feet per minute (fpm). The velocity of 125 fpm was common to most Aramco drilling situations.

(3) Nozzle Velocity Requirement. Minimum nozzle velocities (in feet per second, fps) for adequate hole cleaning were used by Aramco. The velocities were related to the bit size as follows:

<table>
<thead>
<tr>
<th>Bit Size</th>
<th>Minimum Nozzle Velocity</th>
</tr>
</thead>
<tbody>
<tr>
<td>6-3/4&quot; through 9&quot;</td>
<td>25 fps per inch bit diameter</td>
</tr>
<tr>
<td>9-5/8&quot; through 10-5/8&quot;</td>
<td>22 fps per inch bit diameter</td>
</tr>
<tr>
<td>11&quot; and larger</td>
<td>20 fps per inch bit diameter</td>
</tr>
</tbody>
</table>

(4) Pressure Rating of Surface Equipment. A maximum operating pressure was determined for each pump or pump combination at given pump strokes per minute, SPM. This was an important limitation since it could dictate how much of the available horsepower was applied.

b. Determination of the Optimum Circulating Rate. This was done by the Humble method which assumed that the drilling rate was maximum when three quarters (3/4) of the available pump pressure was expended at the bit. Therefore, the method established an optimum region (Phase I in Appendix D) where the pressure at the bit was between 50% and 75% of the available surface pressure.

The first step in evaluating the optimum circulating rate was the selection of a chart most nearly corresponding to the
situation in question. Minor variations did not reduce the accuracy of the final results. The charts reflected, for a given hole size and drill string, the variation of pressure losses with circulation rates for various hole depths. On the selected chart, the surface pressure limitation (adjusted to 10 lb/gal basis) was plotted as a horizontal line. One quarter and one half of the adjusted pressure were then plotted as two horizontal lines defining the pressure limitations which were constant at all circulating rates.

The hydraulic horsepower was then adjusted to the actual mud weight using the equation:

\[ HHP_a = HHP \times \frac{\rho_s}{\rho_m} \]

where:

- \( HHP_a \) - adjusted horsepower
- \( \rho_s \) = standard density (=74.7 pcf)
- \( \rho_m \) = actual mud density, pcf

Using the adjusted horsepower, pressures were calculated at three or more circulating rates using the equation:

\[ p = \frac{1714HHP_a}{Q} \]

where, \( P \), \( HHP_a \), and \( Q \) were defined above.

A tabulation was made of \( \frac{P}{2} \) and \( \frac{P}{4} \) corresponding to the chosen circulating rates. A curve was then plotted on the pressure loss vs. circulating rate chart using values of \( \frac{P}{4} \) and the corresponding circulation rates. This horsepower curve was the locus of circulating rates at which no more than one quarter of the available
horsepower would be lost to the system. This curve would intersect the lower pressure limit line at a point (point A in Figure D-1, Appendix D). The intersection point represented the point in depth at which the horsepower loss was one quarter or more of that available. The depth interval covered by this curve was termed Phase I which represented the most efficient hydraulics to be used in a given drilling situation. It was advantageous to drill as deep as possible in Phase I. To increase the depth of intersection would require higher surface pressures (More available pressure) or larger drill pipe (less pressure loss).

A vertical line was drawn from point A to intersect the horizontal P/2 line at point B (Figure D-1, Appendix D). This vertical line (AB) covered a depth interval of operation in which the pressure available to the bit would decrease from 3/4 to 1/2 of the total pump output. This region was termed Phase II, in which the pressure utilized at the bit steadily decreased. Phase II represented reasonably efficient hydraulics. It could be extended similarly to Phase I by upgrading surface pressure limitations, or by lowering downhole pressure losses, or both.

From the intersection of Phase II with the P/2 line at point B, a horizontal line was drawn in the direction of increasing depth. This was the last and least efficient stage of hydraulic operation, Phase III. It was characterized by constant surface pressure, steadily decreasing circulation rates, and a decreasing use of available surface horsepower. Phase III occurred in deep wells or when drilling with very heavy mud or small drill pipe.
The three-phase curve represented an idealized circulating rate program which could not be practically duplicated since it required continuous changes of pump liners. However, the curve could be closely approximated by judicious liner selections as follows:

In Phase I, an arithmetic average of the circulating rates was taken. It included the rates at the intersection of Phase I with selected depth lines and the constant circulating rate for Phase II. This average represented the "optimum" rate for Phase I. Phase II, of course, had one circulating rate which was also its optimum rate. Phase III, if it occurred, was treated similar to Phase I. This optimization was implemented by selecting a pump liner size which would closely approximate the three circulating rates. This was normally possible by varying the pump's strokes per minute, SPM, in each phase. If one liner size could not accommodate the three rates, a change of liner would then be justified. Matching of the calculated circulation rates was more critical in Phases II and III than in Phase I. Thus, any compromise was made in favor of the deeper sections of the hole.

c. Determination of Pressure Available to the Bit. Following the liner selection, the pressure available to the bit was calculated for each circulating rate. This pressure was obtained by subtracting the system's total pressure losses from the total available pressure. The total available system pressure, $P_t$, was calculated from the equation:

$$P_t = \frac{1714 \text{HHP}}{Q_o}$$
where:

\[ HHP_a = \text{horsepower adjusted to 74.7 pcf mud basis} \]

\[ Q_o = \text{optimum circulating rate, GPM} \]

The system pressure losses were then evaluated at convenient depths from Tables published by Hughes Tool Company. If the drill string and hole size in question exactly corresponded to one of the pressure drop vs. circulating rate charts, then pressure losses would be picked directly from the chart. After the pressure losses had been evaluated at each depth, they were subtracted from the total pressure at the same depth. The result was the pressure available to the bit, \( P_b \).

d. Selection of Nozzle Combinations. With the pressure drop at the bit (\( P_b \)), determined at various depths, the total cross-sectional nozzle area was evaluated from the equation:

\[
P_b = \frac{Q_o^2 \rho}{12031 A^2 C^2}
\]

where:

\( P_b \) = pressure drop at the bit, psi

\( Q_o \) = circulating rate, GPM

\( \rho \) = mud weight, lb/gal

\( A \) = nozzle area, in\(^2\)

\( C \) = nozzle factor (\( \approx 0.95 \))

For a 10 lb/gal mud, the equation reduced to:

\[
A = 0.03035 \frac{Q}{P_b^{1/2}}
\]
Figure 13 is a graphical representation of this equation. The total nozzle area was then matched against a three nozzle combination area to determine the combination matching the required area. Nozzles having less than the required area would overload the pump and those with total area greater than required would underload it. As a practical matter, small variations in the nozzle area were compensated for by minor changes in the circulating rates. Furthermore, the use of 1/4-inch nozzles was avoided, except when drilling with water, since they had a tendency to plug easily.

Hydraulic programs were evaluated by the relative drilling rate (RDR) phenomenon. The RDR is a dimensionless quantity which is proportional to the hydraulic impact (QV). Figure 14 shows the relationship between the relative drilling rate, nozzle area, and circulation rate. Once nozzle sizes had been selected, the RDR was determined from Figure 14. High values of RDR signified high hydraulic impact, and hence, high penetration rate potential. The use of RDR was only for qualitative comparisons of alternative hydraulic programs. Figure 15 indicates the superiority of circulating fluid at a rate of 300 GPM (RDR=30) over the rate of 450 GPM (RDR=21) in a given drilling situation.

e. **Weight on the Bit and Rotary Speed.** There is no rigorous theory for the effects of weight and speed on the rate of penetration. However, generalizations are possible on the basis of laboratory and field experiments. Generally, the penetration rate increased approximately linearly with increased weight on the bit, other parameters being equal. The penetration rate, however,
Figure 13. Pressure Drop vs. Nozzle Area for Various Flow Rates. (Basis: $A = 0.03035 \frac{Q}{(P_b)^{1/2}}$)
Figure 14. Relation of Relative Drilling Rate to Nozzle Area at Various Circulating Rates.
Figure 15. Effect of Circulating Rate on Pressure Drops and Power Losses (After Mohr).
varied less than linearly with the speed of rotation (RPM) for given weights on the bit.

For each section of the hole, the Aramco drilling program specified the weight and the speed to be used in drilling that section. Drilling practice curves developed for Aramco areas were used in the selection of weights and speeds for each hole size. For a given hole size, the normal practice curve showed a range of possible weight and RPM combinations based on experience. The shaded area in Figure 16 indicates the common practice combinations in West Texas. Curves similar to Figure 16 were used which reflected local experience in drilling Aramco wells. In the example of AHW-13 (Appendix A), the 12-1/4 inch hole was drilled with 70,000 lbs. at the bit and a speed of 110 RPM. This represented higher speed than was common for the same hole in West Texas. The slightly softer formations drilled by the 12-1/4" bit at Aramco could account for the higher speed. The AHW-13 program also shows the decreasing trend in weight and speed with the increased hole depth. This could be explained by the increased formation hardness and the reduced bearing strength inherent in the smaller bits.

2. The Completion Program

At Aramco, this was normally a part of the drilling program. For wells whose completion depended on the results of special tests during drilling, the completion program was issued separately. The main objective of the completion program was to develop a well which would yield the highest possible productivity (or injectivity) during its life. Considerations for the completion decision included
Figure 16. Drilling Practice Curves for 12 1/4" Hole in West Texas. (After Gatlin\textsuperscript{11}).
Note Point A Represents the Weight-Speed Combination Used At Aramco's AHW-13 by the Author.
the expected production (or injection) rate, investment requirement, number of producing formations, stimulation needs, and workover possibilities.

The major completion decisions included the following:

(1). Cased hole or open hole technique
(2). Single or multiple (normally dual) completion
(3). Casing or liner production string
(4). Tubing strings (none, one, two, etc.).
(5). Source of injection water (same well, supply wells, etc.).

Because of the lack of government proration laws and the absence of severe sand problems, Aramco completions tended to be simple. The use of liners instead of full casing strings, was common to both oil wells and water injection wells. Short liner completions were made possible by the success of cementing the intermediate casing strings (e.g., 13-3/8" and 9-5/8"). They allowed for larger volumes of produced oil or injected water. Longer liners, however, were used when the first stage of the 9-5/8" job was questionable.

Open hole single completions (Figure 17-A) were common in the Ghawar wells completed in the Arab D limestone. Besides the savings of casing pipe and perforation cost, open hole completions permitted the drilling with a completion fluid which minimized formation damage. Cased hole completions (Figure 17-B), were used in sandstone reservoirs (e.g., Safaniya) which displayed sand-shale interbedding. The liner was set and cemented at the bottom of the
Figure 17. Typical Aramco Single Well Completions in the Ghawar Field. Note: The 18 5/8" casing may be eliminated in some areas.
hole, then the producing zone would be selectively perforated in the clean sand.

Open-ended tubing was used in all oil wells to allow for well killing and treatment when necessary. A guide shoe and a landing nipple were commonly used at the bottom of the tubing string to permit the seating of production equipment. A sliding sleeve was installed in some Ghawar wells to permit the circulation of light fluids (e.g., Kerosene) to liven the wells without swabbing. No packers were used on the tubing since the oil flowed through both the tubing and the annulus.

When there was more than one productive formation in a well, dual completion was the most common practice. The crude oils from these zones were usually of different grades and had to be separated. To maintain simplicity, the zones were normally separated by a packer run on a single tubing string (Figure 18). The lower zone (Fadhili) was produced through the tubing and the upper zone (Arab D) through the annulus. The lower landing nipple was used to seat pressure and temperature measuring equipment, while the upper nipple was to seat a plug for isolating the bottom zone. The sliding sleeve allowed for producing the upper zone through the tubing and the annulus while the lower zone was plugged.

Dual completions using two parallel tubing strings (e.g., 2" and 3-1/2") had been used unsuccessfully in one Aramco field during the mid 1960's. The complexity of the dual string systems created numerous problems in the producing wells. As a result, the wells were worked over and recompleted in a manner similar to the example
Figure 18. Typical Aramco Dual Arab D - Fadhili Completion at Air Dar.
Water injection wells were completed at the bottom through perforations in short liners. There were two types of injection wells based on the source of injection water. In the conventional wells (Figure 19-A), water was injected at the surface from a nearby water source. Pump stations were used to supply injection wells with a steady source of water. This method of injection, however, had a limited use at Aramco.

The most common type of injection well was the gravity injection well shown in Figure 19-B. There, the injection water was supplied by an aquifer within the same injection well. The bottom reservoir was first perforated and acidized. Then, a plug was set inside the 7" casing near the liner hanger. The aquifer was then perforated, flowed to the surface for sand clean up, and the water flow rate was estimated. After clean up, the plug was pushed to the bottom of the hole, allowing the water to flow down into the injection formation by the aquifer's pressure and the water's gravity head. In such wells, a water flow rate to the surface of 130 MBPD would correspond to an actual injection rate of 90 MBPD as measured by a spinner survey.

In summary, the completion program outlined the procedure to prepare the well to fulfill its objective. It included specifications of logging, perforating, tubing and production equipment, acidizing, flow tests, and wellhead equipment. Sophisticated completions (e.g., multiple tubings, concentric completions, etc.) were avoided. Furthermore, Aramco wells flowed to the surface by their internal
Figure 19. Typical Aramco Water Injection Completions.
energy and required no artificial lifting mechanisms.

3. The Workover Program

Aramco wells, as most wells anywhere, were not problem-free. The problems were numerous, the most common problems which the author experienced will be listed below:

(a). Wet Oil Production. This problem was common and was indicated by excess salt in the produced crude from the problem well. From a crude sample, contaminating water was extracted and geochemically analyzed. The result of the analysis was then compared to possible source waters. A workover program to shut-off the source of the water production was then prepared by the engineer. Common sources of wet production included: (1) bottom reservoir water, (2) Sub-C stringer above the Arab D reservoir, (3) water leaking from an upper aquifer due to a casing leak or a poor cement bond. Different procedures were used for ascertaining the cause of the wet production. Temperature surveys, fluid density logs (FDL's), tubing caliper logs, and flowmeter survey were among the means of defining the suspected source of water. Cement bond logs with microseismogram were used to qualitatively detect poor casing cement jobs. The use of Halliburton's RRTS and bridge plug method also allowed pressure testing the various hole sections separately to determine the position of a water leak in the well. Remedial work generally involved squeeze cementing above the producing zone, plug-back cementing in the bottom portion of that zone, or running and cementing a liner across the problem zone. Appendix E shows a workover program written by the author to plug back wet production in
the offshore Abu Safah Well-9 (ASW-9). The program also outlined procedure for replacement of a faulty subsurface safety valve, perforating and acidizing the Arab D reservoir in that well.

(b). Corrosion Problems and Parted Casing. Corrosion due to high salinity formations was particularly severe in water injection wells. Pipe holes and parted casings were normally detected by use of Schlumberger's Electromagnetic Thickness Tool (ETT). Base ETT logs were prepared for various casing sizes and used for comparisons with ETT runs in problem wells. The ETT log recorded the phase shift in a magnetic field caused by the casing pipe. As an example, the casing thickness of a 9-5/8", 47 lb./ft pipe would be evaluated by the equation:

\[ d = \frac{\Delta \phi \sigma}{45.15} \]

where:

- \( d \) = casing thickness, inches
- \( \Delta \phi \) = phase shift difference (between air and casing)
- \( \sigma \) = skin depth

The skin depth was a parameter of the tool's current frequency, the casing's resistivity and magnetic permeability. The value of sigma (\( \sigma \)) was usually determined for a new casing pipe with the knowledge of \( \Delta \phi \) and \( d \).

Figure 20 shows the use of the ETT log to detect corrosion in a Wasia-Arab D gravity injection well. Severe corrosion and casing holes are indicated by the sharp phase shift to the left near the Wasia perforations. In the intervals 3948-3958 ft. and
Figure 20. The Use of ETT log to Detect Corrosion.
4040-4060 ft., the ETT log indicates no casing pipe at all. Figure 21 is an example of a parted casing from 7298 to 7310 ft. In this case, the casing joints uncoupled and left a 12 foot gap in the casing.

When gravity injection wells were converted to conventional water injection wells, salt water was injected down the casing past fresh water intervals. To prevent charging fresh water aquifers with salt water, the casing must withstand the corrosive condition. Figure 22 shows an ETT log run in the 9-5/8" casing of an Aramco well opposite fresh water intervals. The anomalies on the log at points A through C indicated large casing holes. A casing liner was run and cemented through this interval prior to the well's conversion to conventional water injection.

(c). Packer Leaks. This problem was experienced in dual producing wells. It was generally detected by field production engineers through abnormal changes in pressures or production rates from the individual zones. The workover normally involved testing to ascertain the absence of other well problems. Then, the original packer (generally permanent type) would be drilled out and a new packer installed.

(d). Subsurface Safety Valve Failures. This was a problem in some offshore fields (e.g., Berri, Abu Sa'fah, Mainfa). Details of the problem and solutions will be discussed as part of the production engineering work.
Figure 21. Detection of Missing casing with the ETT log.
Figure 22. Examples of Casing Corrosion Across Aramco's Fresh Water Formations. Severe corrosion is shown on the ETT log at points A, B, and C.
(e). **Wellhead Equipment Failures.** These were problems exhibited by leaks through casing or tubing hangers or frozen master valves on the wellhead. The workover simply involved temporarily killing the well, repairing or replacing the equipment and returning the well back to its original status.

(f). **Fishing Problems.** These were encountered during the drilling and were handled as part of the drilling operation. For production wells, however, fishing jobs were generally caused by dropping production tools inside the hole. The fish could include logging sondes, perforating guns, or any subsurface production equipment. Wireline fishing procedures would normally be attempted before engaging an expensive rig in the fishing operation. In fields with high sulfur crude oil (e.g., Berri), pulling the tubing was inevitable and a rig had to be used for the workover.

4. **The Completion Report (Aramco Pro-18)**

This report was the official record of all the activities performed on the well during its drilling, completion or workover. The report was compiled by the development engineer in charge of that rig's operation. It included the essential well data (e.g., location, total depth, plugged depth, type of completion, etc.). It contained casing, cementing, perforating, testing, acidizing, logging and tubing records for the particular well. It also had a bit and core record for the whole operation. The Pro-18 also contained a distribution of the rig time spent on the various operations on the well. It also had a record of the leading personnel involved in the operation. The report normally closed with a discussion
statement by the engineer summarizing significant points about the particular well or the particular operation. The main parts of a typical Pro-18 report are shown for the drilling of Abu Hadriya Well-13 in Appendix F. The author supervised the well's drilling since its commencement on July 29, 1969 through August 31, 1969, when he was transferred to the Production Engineering Unit. Mr. C. B. Eastham assumed the responsibility through the well's completion on September 24, 1969.

The Pro-18 report was of special importance in planning the drilling programs for "development" wells. Successes and failures in particular areas were essential to the improved drilling of subsequent "development" wells. These records were extensively utilized by the author in preparing "efficiency drilling" programs which will be discussed later in the report.

SUPERVISING ACTIVITIES

As a development engineer, the author took charge of many aspects of the drilling, completion, and workover operations. He was also responsible for determining the casing setting depths throughout the drilling operations. To determine these depths, he used drill cutting samples and drill time log correlations with nearby wells.

Among the operations which required the author's supervision were the casing and liner cementing, logging, perforating, acidizing, formation testing, squeeze cementing, and well plugging. The supervision there was unique, since it implied responsibility for the operation without direct authority over the people doing the work.
The Company's drilling crews were accountable to the drilling foreman, and the personnel of service companies had their separate supervisors. The author's role then was to coordinate the efforts of the various groups to perform the best possible job. He was to physically communicate the operation to the concerned people through their supervisors. Where a service company was involved, the author was responsible for ensuring the adequacy of the equipment, the availability of the necessary material and personnel, and the quality of the work done. He had the authority to reject material or equipment which was malsuited for a given operation upon his own judgement. Normally, such a decision was enforced by consulting with the Development Engineering supervisor.

Drilling and its related operations were performed continuously around the clock. These operations took place in remote areas requiring accurate planning and proper logistics. Failure to have all the necessary material and equipment on location at the proper time would result in delays costing thousands of dollars. These high costs made the coordinating responsibility especially important, and sharpened the author's appreciation of time and its costs.

An example of coordination would be that required for squeeze cementing a problem zone in a well being worked over. The job engineering required: (1) perforating the casing for cement passage, (2) squeezing cement slurry to seal off undesired communication, and (3) logging to check the cement bond quality. The perforating interval was normally selected from logs previously run on the same well. Perforating was done either by a steel carrier jet perforator
or by a through-tubing capsule perforator (Figure 23). Next, a test was made of the ease of pumping fluid into the perforations. This was immediately followed by squeezing a predetermined amount of specific cement slurry. Halliburton's retrievable squeeze packer, RTTS, was normally used for squeeze cementing since it required minimum rig time. An operational diagram of squeeze cementing with the RTTS packer is shown in Figure 24. After the squeeze, a cement bond log (CBL) with variable density log was run to determine the efficiency of the squeeze job. The CBL was compared on location to previous CBL and a decision was made whether or not a second squeeze job was necessary. Figure 25 shows a CBL with variable density log showing a successful squeeze job through perforations at points A and B.

The coordination involved informing the logging, perforating, and cementing companies' personnel of their respective job details; and estimating the time when their equipment should be on the well site. The rig foreman was also informed of the job details and the rig requirement for the total operation. During the job, the author would inspect the perforating tools and witness the perforating and squeezing operations. He would assign rig personnel to measure cement density during the squeezing and ascertain using the proper type and quantity of cement. He would record times and pressures during the testing and squeezing processes for reporting and evaluation. He would supervise the squeezing and displacing of cement to ensure the required accuracy of the total operation. By proper coordination, the CBL logging tools would be ready to run in the
Figure 23. Common Types of Perforating Tools Used by Aramco.
Figure 24. Operational Diagram of Squeeze Cementing With the RTTS Packer.
Figure 25. Qualitative Use of Cement Bond Log to Evaluate a Squeeze Cement Job (After Anderson et al.)
wellbore following the squeeze cementing.

Failure to have the proper material, tools, equipment, or personnel in any phase of the above operation would result in a loss of expensive rig time. Most of the lost time could have been avoided by cautious planning and follow up.

Imperative for good job coordination, in the author's opinion, was the knowledge of people and their attitude towards work. He made it a point to know the people involved at least by name. Personal relations with all levels of concerned people made the coordination both easier and effective in achieving the job objectives.

SPECIAL DRILLING EXPERIENCE

The following is a brief discussion of work done by the author which was beyond the normal duties of a development engineer.

1. Analysis of the 17-1/2" Bit Usage. This was an analysis of the 17-1/2" bits used throughout Aramco wells in the two year period, 1965 and 1966. The result of the analysis was the recommended reduction of 17-1/2" bits usage from three or four to two or one bit in some situations. An example of the successful use by the author, of two 17-1/2" jet bits to replace four bits, was in drilling Shedgum Well-49. Another example was the record drilling of the 17-1/2" hole with one bit at Abqaiq Well-108 (AW-108). At AW-108, a record penetration rate of 106 ft. per hour was achieved for this section of the hole.

2. Study of the "Drilling Milk". This was an independent laboratory study of different combinations of a light emulsion completion fluid. This was discussed earlier as part of the drilling
3. Study of Lost Time Due to Fishing. This was a critical analysis of the lost rig time on fishing for the various types of fishing jobs for the years 1963 through 1967. One of the major recommendations was to spend no more than three days (72 hours) fishing before deciding to sidetrack and bypass the fish. The main consideration was the economics of rig time and lost drilling effort.

4. Efficiency Drilling Work. The author was assigned as member of a three-engineer efficiency drilling team on Aramco's U-1 rig operating in the Ain Dar area of the Ghawar field. The other members were Mr. H. E. Zirger (team leader), and Mr. G. W. Spaid.

The first efficiency drilling program was initiated at Aramco in September, 1964 on the Company's N 80-2 rig. The success of the program in substantially reducing drilling times and costs encouraged its extension to other rigs. The U-1 rig was a new diesel-electric rig put in operation during mid 1967, and subjected to the efficiency effort in late 1967. The efficiency program included three phases and two interim periods as shown in Figure 26. The author joined the efficiency supervisory team during Phase II, the drilling of ADW-98. He shared in supervising the operations at ADW-98 and the interim review for Phase III. He also shared in the supervision of Phase III, drilling ADW-94, and co-authored the final report on the efficiency drilling. A copy of the team's report was not released by the Company. However, a letter was made
PHASE I - Form Supervisory Team
- Indoctrinate Team Members
- Evaluate Rig Equipment
- Plan Equipment Modification
- Study Previous Well Records
- Prepare Drilling Program for First Well

PHASE II - Team Supervises and Observes Entire Well
- Make Detailed Time Record of Entire Rig Operation
- Test Hydraulics & WT - Speed Combinations
- Observe Bit Wear
- Begin Rig Floor Improvement of Rig Personnel

PHASE III - Team Supervises Second Well
- Drill Per Detailed Program
- Try to Improve Time Targets
- Compare Results with Previous Records
- Establish Uniform Targets for Future Wells
- Continue Rig Floor Training of Rig Personnel

Figure 26. The Three Phases of Aramco's Efficiency Drilling Program.
available to the author, which outlined the detailed records to be used by the team in analyzing operations at ADW-94. A copy of the well's Pro-18 report was attached to the letter. Appendix G shows the letter and the summary of operations from the Pro-18. The summary indicates that ADW-94 was drilled to 7100 ft. and completed as an Arab D open hole producer in a record 12.9 days.

A vital part in preparing efficiency drilling programs was the extensive and critical review of previous drilling records in the area. From these records, the team prepared operational time targets for the repetitive operations. Such operations included connection time (for drill collars and drill pipe), trip time, casing running time, and tubing running time. The records from the rig's drilling recorder (known as Geolograph) were used to evaluate these operations. Bit usage was continuously reviewed and specific changes were based on the actual condition of the used bits.

The author recalls the following remarks from the successful efficiency operation:

a. Prior evaluation of rig capability, especially the rig, mud and pumps, proved effective in optimizing equipment usage.

b. No single item was responsible for the total success of the operation.

c. Use of the desanders to reduce mud solids and the kelly spinner to reduce connection time, enhanced the speed of the operation.
d. The motivation and enthusiasm of the rig crews and their supervisors resulted in their commitment to the success of the Program. The drilling management, under Mr. G. A. Covey, should be credited for that enthusiasm. Reporting record wells with photographs of the rig's crew in the Company's weekly paper was a very effective method of recognition.

e. Thorough inspection of the rig equipment by the rig's foremen and engineers before the operation was effective in saving rig servicing time. The use of only one-half hour on rig servicing at ADW-94 (Appendix G), offered a saving of many hours not spent drilling.

As a follow up of the Ain Dar efficiency program, the author prepared a target efficiency program for drilling Abqaiq Well-108 and supervised its operation. AW-108 was drilled and completed in 14.5 days which compared favorably with the record 14.2 days for drilling AW-101 under complete efficiency coverage.

5. Drilling Material and Equipment Projection. The author was assigned to prepare a forecast of drilling material and equipment for the years 1969-1970. This was an estimate of the required drilling bits, drilling mud and additives, lost circulation materials, cement and additives, casing, tubing, and production equipment requirement.

The author took a systematic engineering approach to arrive at the required estimates as well as to facilitate future estimates. He used the "typical well" concept for the various well
types to be drilled during that two-year period. He prepared
typical well designs for oil, water, and water injection wells in the
different involved areas. Total material and equipment requirements
for each typical well were estimated. The projection for the two-
year period was then simply made by multiplying by the number of
such wells to be drilled in that period. These estimates were passed
to the Drilling Department's Accountant for use in planning the order-
ing and inventory of material and equipment. The estimates included
none of the rig equipment or rig maintenance material.
PRODUCTION ENGINEERING WORK

At the Production Engineering Unit in Dhahran, the author was assigned as Relief Engineer throughout most of his twenty-three months at that Unit. This assignment offered him an exposure to most Aramco fields and production operations, onshore and offshore. The longest single assignment was for seven months on the offshore Berri, Abu Sal'fah, Marjan, and Zuluf fields.

At the Production Unit, the author performed chores of staff and operational production engineering work as outlined in Appendix H. Moreover, due to manpower shortage at the Development Engineering, the author prepared completion, acidizing and workover programs for wells in his fields of responsibility. Since most of the author's production work was in offshore fields, it complemented his Development experience which was mostly onshore.

Throughout the production work, the author supervised one or more engineering aides who performed many jobs which did not require engineering training. The engineering aides were employees with less than a college degree education and whose number depended on the manpower requirements for each assignment. The author assigned his aides to perform routine well/trunkline tests, small acidizing jobs, salt in the crude tests, flowmeter surveys, and similar field work. The engineering aides further helped the author in running field separator tests, particularly offshore and in remote areas.

At the office, engineering aides helped the author in updating production files and well records. More than half the aides were from
Saudi Arabia; the rest being mainly from Pakistan and India.

Table 9 lists the remote area and offshore testing performed by engineers and aides in the Production Unit during 1970. The asterisks refer to the tests performed by the author.

Field tests on oil wells were generally of the build-up type; they were performed at the wellsite using mobile vertical gas-oil separator units (for onshore and offshore tests). The author performed such tests on Berri Wells 1, 5, 7 and Shaybah Wells 4 and 8. The buildup analysis calculation for Shaybah Well-8 is shown in Appendix I. The test was performed following a matrix acid job. The calculation indicated a formation permeability of 94.2 millidarcys, a capacity \((K_h)\) of 7065 md-ft., and a productivity index \((PI)\) of 23.5 BPD/psi. Composite permeability and capacity were calculated at 209 md, and 15,650 md-ft, respectively. The productivity ratio of 2.22 (greater than one) indicated the stimulation effectiveness.

The author also performed other types of field tests during his production engineering work. These included fall-off tests at Abu Hadriya (water injection) Wells-16 and 17; and surface flowing tests with insertion meters at Berri Wells-17 and 31. The insertion meter tests will be described later in the report. AHW-16 and AHW-17 were on the flank of Abu Hadriya anticlinal structure; they were tested for feasibility of water injection into the Hadriya Reservoir. The author programmed, supervised and interpreted the results of the injectivity tests which were performed with a drilling rig using Wasia water. The injectivity data available to the author from the AHW-16 injectivity test analysis are shown in Table 10.
### Table 9. PRODUCTION ENGINEERING

**FIELD ASSIGNMENT: TESTING & OFFSHORE, 1970**

<table>
<thead>
<tr>
<th>WELL NO.</th>
<th>ENGINEER</th>
<th>AIDE</th>
<th>DATES</th>
</tr>
</thead>
<tbody>
<tr>
<td>Berri Well – 20</td>
<td>F.A. Yahya</td>
<td>H.Y. Al-Jassir</td>
<td>Not available</td>
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<tr>
<td>Berri Well – 19</td>
<td>I.S. Iliyan</td>
<td>M.A. Al-Baz</td>
<td>1/16 thru 1/25</td>
</tr>
<tr>
<td>Abu Sa'fah Well – 8</td>
<td>I.S. Iliyan</td>
<td>–</td>
<td>2/1 “</td>
</tr>
<tr>
<td>Shaybah Well – 8</td>
<td>F.P. Bobrowski</td>
<td>–</td>
<td>3/30 ”</td>
</tr>
<tr>
<td></td>
<td>* R.A. Akkad</td>
<td>M. Rafiq</td>
<td>4/1 ”</td>
</tr>
<tr>
<td></td>
<td>A.M. Nabanna</td>
<td>M.A. Joseph</td>
<td>4/13 ”</td>
</tr>
<tr>
<td></td>
<td>W.R. Bartlett</td>
<td>M.A. Al-Baz</td>
<td>5/11 ”</td>
</tr>
<tr>
<td></td>
<td>H.A. Yamany</td>
<td>M. Rafiq</td>
<td>5/17 ”</td>
</tr>
<tr>
<td></td>
<td>M.H. Hardy</td>
<td>J.B. Al-Shukhis</td>
<td>5/24 ”</td>
</tr>
<tr>
<td></td>
<td>F.P. Bobrowski</td>
<td>–</td>
<td>7/14 ”</td>
</tr>
<tr>
<td>Marjan Well – 10</td>
<td>* R.A. Akkad</td>
<td>M.A. Al-Baz</td>
<td>7/19 ”</td>
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<tr>
<td></td>
<td>M.H. Hardy</td>
<td>H.Y. Jassir</td>
<td>7/25 ”</td>
</tr>
<tr>
<td></td>
<td>–</td>
<td>M.A. Joseph</td>
<td>7/29 ”</td>
</tr>
<tr>
<td></td>
<td>C.B. Eastham</td>
<td>M. Rafiq</td>
<td>8/3 ”</td>
</tr>
<tr>
<td></td>
<td>M.N. Hardy</td>
<td>M.A. Al-Baz</td>
<td>8/10 ”</td>
</tr>
<tr>
<td></td>
<td>C.R. Davis</td>
<td>M.A. Joseph</td>
<td>8/17 ”</td>
</tr>
<tr>
<td></td>
<td>I.S. Iliyan</td>
<td>R.A. Hujali</td>
<td>8/24 ”</td>
</tr>
<tr>
<td></td>
<td>–</td>
<td>M.A. Joseph</td>
<td>8/31 ”</td>
</tr>
<tr>
<td></td>
<td>–</td>
<td>R.A. Hujali</td>
<td>9/7 ”</td>
</tr>
<tr>
<td></td>
<td>–</td>
<td>M.A. Joseph</td>
<td>9/21 ”</td>
</tr>
<tr>
<td></td>
<td>–</td>
<td>H.Y. Jassir</td>
<td>9/28 ”</td>
</tr>
<tr>
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<td>–</td>
<td>M.A. Joseph</td>
<td>10/6 ”</td>
</tr>
<tr>
<td></td>
<td>–</td>
<td>M.A. Al-Baz</td>
<td>10/12 ”</td>
</tr>
<tr>
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<td>–</td>
<td>M.A. Joseph</td>
<td>10/19 ”</td>
</tr>
<tr>
<td></td>
<td>–</td>
<td>H.Y. Jassir</td>
<td>10/27 ”</td>
</tr>
<tr>
<td></td>
<td>–</td>
<td>M.A. Joseph</td>
<td>11/7 ”</td>
</tr>
<tr>
<td>Berri Wells – 17</td>
<td>* R.A. Akkad</td>
<td>H.Y. Jassir</td>
<td>9/2 ”</td>
</tr>
<tr>
<td>Shaybah Well – 10</td>
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<td>M.A. Al-Baz</td>
<td>10/6 ”</td>
</tr>
<tr>
<td>Shaybah Well – 12</td>
<td>C.R. Davis</td>
<td>M.A. Al-Baz</td>
<td>10/12 ”</td>
</tr>
<tr>
<td>–</td>
<td>–</td>
<td>H.Y. Jassir</td>
<td>10/19 ”</td>
</tr>
<tr>
<td>–</td>
<td>–</td>
<td>M.A. Joseph</td>
<td>10/27 ”</td>
</tr>
<tr>
<td>–</td>
<td>–</td>
<td>M.A. Joseph</td>
<td>11/7 ”</td>
</tr>
<tr>
<td>W.R. Bartlett</td>
<td>–</td>
<td>–</td>
<td>11/17 ”</td>
</tr>
<tr>
<td>Berri Well – 31</td>
<td>* R.A. Akkad</td>
<td>–</td>
<td>11/18 ”</td>
</tr>
<tr>
<td>Shaybah Well – 13</td>
<td>M.M. Hardy</td>
<td>–</td>
<td>12/1 ”</td>
</tr>
<tr>
<td>Berri Well – 17</td>
<td>* R.A. Akkad</td>
<td>–</td>
<td>12/5 ”</td>
</tr>
<tr>
<td>Abu Hadriya Well – 7</td>
<td>–</td>
<td>M.A. Joseph</td>
<td>12/15 ”</td>
</tr>
<tr>
<td>–</td>
<td>–</td>
<td>M.A. Joseph</td>
<td>12/22 ”</td>
</tr>
</tbody>
</table>

* Tests performed by the author.
TABLE 10
Injectivity Test Analysis, AHW-16

Static Bottomhole Pressure, SBHP = 4650 psig at 10,363 ft.
Avg. Injection Bottomhole Pressure, IBPH=5350 psig at 10,363 ft.
Surface Injection Pressure = 1755 psig
Injection Rate into Hadriya, Q_w = 25,200 BWPD
Permeability to Water, K_w = 83 md.
Hadriya Thickness, h = 122 ft.
Hadriya Capacity, K_w h = 10,126 md.-ft.
Skin Factor, S = -.354 (indicating stimulation)
Ideal Injectivity Index, II = 20 BWPD/psi
Actual Injectivity Index, II = 36 BWPD/psi
Radius of Investigation = 1275 ft.
The author's coordination of the injectivity tests included the following:

1. Insure a continuous water supply (minimum 800 GPM) through 8 inch invasion pipeline from a nearby water well.
2. Insure sufficient water storage (three 500-barrel tanks).
3. Check pressure and temperature measuring devices (bombs) for calibration and appropriateness for the job.
4. Inspect pumps (rig and Haliburton pumps) for capacity and working condition.
5. Assign personnel for collecting injection data during the injection process.
6. Have a field chart scanner ready for reading pressures at the well site for a preliminary evaluation of the job's success.
7. Test all surface lines and connections at 3000 psi (actual injection pressure was 1750 psi). Repair any leak before the injection.
8. Inform pump operators of pumping procedure and duration. Observe the whole process and report its details.

Besides the normal production engineering work, the author performed additional assignments which diversified his experience. A few of these assignments will be outlined in the following.

Investigation of Abqaiq Well 115 Blowout

The author was assigned to handle a near blowout which occurred at AW-115 on October 28, 1969. Three set screws (studs) broke off the Grayloc Type CWC unitized wellhead allowing oil and
gas to blow out of the well (Figure 27). Field Services crews reported the blowout. Mud tanks and Halliburton's pumper truck were rushed to the well. Flarelines were connected to the tubing crown valve and injection lines to the 4" casing annulus valve. Mud was pumped into the annulus with the tubing valve cracked open until the well was killed. Temporary studs were welded in place of the broken studs and a rig was moved to the well. The tubing was pulled and the remaining broken studs were inspected by Aramco's metallurgist.

The set screws were broken approximately 3 inches from the threaded ends and nearly one inch was protruding outside the casing head (Figure 28-B). There were no scale deposits on any of the screws which ruled out corrosion as a cause of the studs' failure. Erosional forces were also ruled out because no fluid had flowed through the well since its completion a few days before the incident. The suspected cause was then a form of stress fatigue. The manufacturer's installation instructions showed the proper position of the set screws with a 2-1/2" protrusion from each (Figure 28-A). It was then clear that the broken studs at AW-115 had been screwed in place before setting the tubing hanger (Figure 28-B). The hanger was then set on the screw ends which failed from the nearly 30,000 lbs. tubing load. The main reason for the blowout was the drilling personnel's lack of experience with the Grayloc wellheads.

The author wrote a report on the blowout at AW-115 issued in November, 1969. A copy of the report was requested, but was not released by Aramco. In the report, the author recommended
Figure 27. Grayloc Wellhead Showing the Position of Blown Off Set Screws at AW-115.
Figure 28. Schematics of the Proper and Improper Position of Set Screws in Grayloc Wellhead.
that use of the Grayloc wellheads on oil wells be temporarily discontinued. He scheduled the utilization of the thirty-two wellheads in stock on water and water injection wells where a leakage was less hazardous. This decision was further influenced by the frequent leaks through the Grayloc clamp at many oil wells (e.g., AW-111 and AW-114). The clamp offered a saving in installation time since it had only two bolts while the conventional flanged connection had twelve to twenty bolts depending on size. The clamp, however, relied on a metal-to-metal seal between the R-137 seal ring and the internal wellhead body. The major cause of the ring leaks was the rough handling before (or during) installation. The Grayloc principle was thought too delicate for the normal drilling crew handling.

**Aramco Standard Wellheads and Trees**

The author was assigned to prepare designs and full specifications for various types of wellheads and Christmas trees for use in all Aramco wells. The designs were used as standards for each of the different well types with room for modification to accommodate special cases. The author acknowledges the help and guidance offered by Mr. R. O. Williams, then Senior Production Engineer. There were no standard wellhead and tree designs prior to this assignment. The development of wellhead equipment through time and the change of suppliers may explain the absence of a Company standard wellhead package.

The first problem of this assignment was to decide on the criteria for grouping wells under a "standard". The type of well completion, the fluid flow rate, and the subsurface formation
pressures were considered for the decision. Six wellhead and tree designs evolved as standards:

- WH-1. Onshore Single Producer
- WH-2. Offshore Single Producer
- WH-3. Dual Oil Producer
- WH-4. Gravity Water Injection Well
- WH-5. High Pressure Single Producer
- WH-6. Water Supply Well

Figure 29 shows the standard wellhead and tree for a single Aramco onshore oil producing well. The design was simple and utilized API specifications for the various components. The use of a standard 3000 psi working pressure in designing casing heads and flanges offered sufficient protection against any subsurface pressure in development onshore wells. Flange sizes were specified in accordance with API Standard 6E, Specification for Wellhead and Drilling-Through Equipment. Casing hangers were designed to suspend the casing string and provide a seal between the suspended casing and the casing head housing. Automatic slip and seal casing hanger, e.g., Cameron's Type "CA", was selected on the basis of its successful use by Aramco. The hanger assembly was composed of a set of slips to latch around the casing and a sealing mechanism which was automatically energised as the slips assumed the casing weight. The tubing hanger was of the Boll Weevil threaded suspension type which offered full seal between the tubing and the tubing head. The tubing head had a 2-inch and a 6-inch side gate valves 180 degrees apart. The 6-inch valve was the well's annular
Figure 29. Standard Aramco Onshore Single Wellhead and Tree, 3000 psi Mean Service Pressure.
oil production outlet which was connected to the flowline. The 2-inch (x-casing) valve was used for monitoring annular pressure, livening, killing, or stimulating the well. A 10" x 2"-3000 psi working pressure adapter was used to connect the Christmas tree to the wellhead.

The single onshore Christmas tree was simple (Figure 29). It consisted of three 2-inch valves bolted to three sides of a studded cross, with the fourth side covered by a blind flange. The tubing master valve provided emergency control of the tubing flow, supported by the crown and wing valves. The wing valve was connected to the well's flowline. Full opening tubing master and crown valves were specified to provide for running wireline tools and subsurface equipment without obstruction. The 3"-3000 psi unibolt cap was used to connect a wireline lubricator to the wellhead, a process frequently used when making well surveys (e.g., pressure, temperature, logging, spinner, etc.).

Except for the standard water supply wellhead (WH-6), designs of WH-2 through WH-5 were modified variations of WH-1. The modification included the pressure ratings, the sizes and numbers of valves, and other related details. For example, for the single offshore wellhead, WH-2, a 10" x 4"-3000 psi adapter flange was used as a conduit for safety valves control line. Another example was the use of a test weld pack-off type adapter flange (e.g., Cameron's Type "MW") to adapt the tubing head to the tree of a high pressure wellhead, WH-5. The pack-off flange provided a primary seal below the flange, an auxiliary seal around the casing, and a means for pressure
testing the seal.

The Standard Water Supply Wellhead, WH-6, was the simplest of the standard wellheads. It used larger size valves and conduits for the large volume of water flow from such a well. A special three-way corrosion protection was used for preventing flange leakage from the corrosive Wasia injection water. Figure 30 is a schematic of the standard WH-6 and the flange protection.

To effect a smooth transition toward the standard wellheads and trees, the author provided blank drawings which were filled with particulars of wells attended by engineers or engineering aides. This proved not only helpful in planning workovers, but also in performing routine well surveys.

The author also designed wellhead and tree modifications to accommodate recompletion of wells and to use available (non-standard) equipment. Appendix J shows an example modification for converting AinDar Well-3 from a dual to a single oil producer, following workover operations.

Subsurface Safety Valve Problems at Berri

The author presented a paper entitled, "Berri Field Safety Valve Problems" at a meeting of Aramco Board's Technical Representatives Executive Committee on March 7, 1971. He was the second Saudi engineer to present a paper to such a meeting; he was preceded only by Mr. A. M. Hokail in 1968. An edited summary of the paper is shown in Appendix K.

The paper explained the type of subsurface safety valve problems, their extent, temporary and long range solutions to the problems.
6" Lubicator

12" x 6" Double Studded Adapter

10" - 2000 psi Gate Valve

12" x 12" x 8" 2000 psi Tee Spool

Flange Corrosion Protection:
(1) Rubber Protector
(2) Petromex (rubber-lined steel) Ring
(3) Double Seal Gasket

Figure 30. Standard Water Supply Wellhead and Tree

18 5/8" Casing
13 3/8" Casing
9 5/8" Casing

13 3/8" x 9 5/8" Annulus

18 5/8" x 13 3/8" Annulus
The author estimates a Company loss of oil sales due to the Berri valve problems in the tens of millions of dollars, the exact figure being extremely difficult to obtain.

Figure 31 shows the two types of safety valves used at Berri; tubing retrievable, TRSV, and wireline retrievable, WLRSV. The TRSV was run on a packer as part of the tubing, while the WLRSV was installed after running the tubing string. The WLRSV had the advantage of being removable for servicing or replacement without the costly use of a drilling rig. However, the largest available WLRSV had a diameter of 2" compared to a diameter of 4" for the TRSV. The valves were used in all Aramco's offshore fields to prevent potential disasters from the heavy vessel traffic in the Arabian Gulf.

The valves operated on a piston principle with hydraulic pressure supplied by a surface pump through a steel control line (1/8" or 1/4" O.D.) to maintain the valve in the open position. The control line was strapped externally to the tubing by steel clamps from a point above the valve's ball to the surface. The line left the wellhead through a special exit assembly and was connected to the hydraulic pump in the control manifold (Figure 32). The valve's ball was mounted between two seats such that when the hydraulic control line pressure was reduced below the well pressure at the ball, the bottom spring would force the piston upward. This would immediately rotate the valve to the closed position. The valve would be reopened by exerting hydraulic pressure through the surface pump. Both the TRSV and the WLRSV had the same opening and closing mechanisms.
Figure 31. The Two Types of Subsurface Safety Valves Used in Aramco Offshore Fields. (After Otis Engineering 13).
A. Control Line
Surface Adapter

B. Surface Control Pump and Manifold.

C. Hydraulic Pump and Manifold Diagram

Figure 32. Surface Control of Subsurface Safety Valves (After Otis Engineering13).
Berri oil flowed both through the valve and around the tubing-casing annulus as shown in Exhibit 2, Appendix K.

Numerous safety valve problems occurred since the offshore Berri wells went on stream on September 26, 1970. The initial production of 150 MBD could not be achieved from the first six wells due to the continuous valve failures. As more wells were connected and more failures occurred, the loss of the highly demanded Berri production increased. The potential 300 MBD production could not be met since efforts to maintain the valves open and operable failed.

Workovers indicated that failures were generally due to cracked or broken control lines and steel straps which effected the valve closures. In two cases, the WLRSV assemblies were dislodged upward by the strong flow velocity as high as 18 feet above the normal position. The failures were due to flexures of the 1/4" stainless steel control line caused by one or more of several factors. The main factor was the high flow rates (20 to 55 MBD per well), combined with Berri crude characteristics (e.g., highGOR, light crude, etc.). Vibration was also evident due to either slugging flow and/or high fluid velocities through the valve. This vibration was a possible cause for dislodging the WLRSV assembly with the smaller diameter.

The following actions were taken to temporarily solve the problem using available equipment.

1. Replaced the 4" WLRSV assemblies with 4" TRSV assemblies. This increased the flow diameter and reduced the fluid velocity.
2. Used 1/8" monel steel pipe for control line to replace the 1/4" stainless steel line. This increased flexing resistance and made tighter line strapping to the tubing.

3. Swaged to 7" casing above the 4" TRSV assembly and flowed only inside 7" casing to the surface. This relieved the 7" x 9-5/8" annulus, and hence the control line from vibrations and flexure.

4. Filled the 7" x 9-5/8" annulus with inhibited diesel oil to minimize corrosion of the control line.

5. Used a revised locking mandrel above the ball to prevent dislodging of the WLRSV assembly. The WLRSV was limited to low rate wells (up to 20 MBD).

The author's long run solution included the use of large diameter WLRSV assemblies to be used with 7" casing and the locking mandrel as shown in Exhibit 3, Appendix K. Larger prototype assemblies were manufactured and installed on a trial basis. To the author's knowledge, these were successful and Berri's offshore production was later boosted to nearly 900 MBD.

Insertion Meter Testing

During 1970, the author was assigned to test and evaluate a new type of turbine meter at different Aramco locations. The "insertion" meter was first introduced to the Middle East by Baker Automation Systems Inc. (Basic) to measure flow rates at some petrochemical plants in Iran. In Saudi Arabia, the author was the first to use the meter both onshore and offshore.
Figure 33 shows the meter assembly and the portable flowrate indicator (readout) which was powered by either, a 24 volt DC, or a 110 volt AC source. The meter was a 64" - 1-1/2" diameter steel rod, threaded through most of its length. The rod was screwed into a 6"-2000 psi flange with a protective stuffing box and was connected to a 2" turbine meter at its lower end. The readout was connected to the meter through wires that entered the top of the meter stem and were welded internally to a sensor just above the 2" turbine. The upper end of the meter had handles for manual insertion or removal from flow streams.

The meter was installed on flowlines with proper flange outlets and was inserted perpendicular to the flow direction. The fluid flow rotated the turbine and the sensor transmitted the rotation as a cubic feet per minute (CFM) flow rate. Calibration curves and correction charts were supplied by Basic, Inc.

The author tested the insertion meter's accuracy against other meters (e.g., Halliburton's turbine meter, and Smith's P.D. meter) at flowlines of Berri onshore wells 1 and 7. The accuracy of the results encouraged insertion meter testing by the author at Berri offshore wells 17 and 31.

The author reported preliminary remarks on the insertion meter issued as part of an Aramco Report, PE-18-70. The following were among the remarks:

1. The insertion meters are handy tools and could be useful in Aramco operations.
Figure 33. Typical Basic Insertion Meter Tested at Aramco. (After Basic).
2. The meters had acceptable accuracy at rates higher than 2000 BPD (compared against HOWCO's in-line turbine meters).

3. The insertion meter's main advantages over other meters were:
   a. Ease and low cost of placing in the flow stream.
   b. Requiring no interruption to the flow for installation.
   c. Capability of measuring normal flow stream in 3" to 42" pipe with the same turbine head assembly.
   d. Capability of measuring high rates of flow.

4. The meter's main disadvantages included:
   a. Being somewhat fragile, requiring protection for storage, transportation, and installation. The author proposed a carrying case for the meter assembly.
   b. Requiring experienced operator to measure the exact insertion depth and handle the tool.

5. The meters required further testing of their durability and diversified applications.

Communications Meeting Review

The author was appointed to a committee to review the effectiveness of the weekly Petroleum Engineering Communications Meeting. The author prepared most of the questionnaire for the study and offered a large share of the recommendations. A copy of the Committee's report is shown in Appendix L.
This type of "attitude and opinion survey" involved the author in utilizing an extremely effective management tool. Following the Committee's review, engineers' participation increased and the meeting became a source of effective, candid, two-way communication.

Shaybah Well-8 Pulse Testing Program

The author prepared a program to perform a sequence of pulse tests in the Shuaiba reservoir at SyW-8. The tests were designed to establish the extent of vertical communication within the limestone sections of the reservoir. A copy of the program is shown in Appendix M.

The pulse test was the first one to be performed at Aramco. Preparation of the program involved numerous contacts and searching for availability of suitable equipment and tools for the tests. The best available pressure measuring devices (bombs) were supplied by Sperry Sun Company with an accuracy of 0.01 psi at the depths in question.
FIELD SERVICES EXPERIENCE

Before leaving on his 1971 vacation, the author was told that he would be assigned to an operational job in the Producing Department to broaden his experience. Upon return on August 1, he was assigned to relieve the Field Services Foreman who had been on vacation for a few days. No transition period was possible.

On the same day, following a brief job review with the Division's Superintendent, the author was on the job location at offshore Berri Well-11. His work station, living quarters and transportation media was the Aramco owned 80-foot tug boat: "Safaniya-1". He remained offshore for three weeks after which he returned to Dhahran to run the "onshore" half of the Foreman's duties. While the author was offshore, the onshore duties were handled by a senior supervisor (see Figure 34) who was later promoted to Foreman. The onshore-offshore rotation continued throughout the author's eight months on this job. But, due to the weather, the onshore work far exceeded the offshore work.

The initial operation at BW-11, required the author's supervision of field services activities while repairing the subsurface safety valve. Such activities included pulling the flareline to the well platform, hooking up pumping and flaring lines, testing the lines, and igniting the flare as necessary. The personnel and equipment under the author's responsibility included:

1. A three-man field services crew (one senior operator).
2. One crane operator (on loan from Equipment Services Division).
Figure 34. Organization Chart of the Field Services Unit During the Author's Foremanship.
3. Safaniya-1 tug boat and its seven-man crew. The boat contained lodging and board facilities. A small crane (30-ft boom) was attached to the stern end for pulling the flareline during repairs and/or long distance moves.

4. "Ma'agla-5" crew transport boat and its two-man crew. The boat was also used to install the flareline, ignite the flare, and pull the flareline during short distance moves.

Since there was no production engineer at BW-11, the author was also responsible for coordinating service-company activities, such as the following:

1. The four-man Otis Engineering crew, who performed the subsurface valve wireline work.

2. The Halliburton crew on Halliburton's acidizing barge "Midnight Moon", which was used to pump inhibited diesel (with 4% Cronox) into the well's 7"x9-5/8" annulus.

This was a challenging experience which the author accepted. It required a number of clear communications with the many people involved, each in his portion of the job. The author prepared the job plan carefully. He discussed with his crew their role and sought their cooperation by showing them that he was "one of them". He arranged the flareline handling procedure with the captains of Ma'agla-5 and Safaniya-1, and both offered maximum cooperation. Coordination of the service-company jobs was easily done through their operating supervisors. The BW-11 repair job was performed smoothly, followed by other work in the Manifa and Safaniya fields.
The offshore field services crew was changed every two weeks to maintain an equitable overtime distribution among workers. Offshore work implied a 12-hour work day with a minimum 4-hour excess time for every worker. Onshore work, however, was performed on a normal 8-hour day, 5-day week basis. Weekend and holiday work was done as needed and was distributed on a rotational basis as the work allowed.

The normal work done by the Field Services Unit is shown in Appendix N.

The author's daily work onshore began with giving a brief morning report to the Superintendent on the unit's activities during the previous day. This was followed by a discussion of the expected work positions of the crews for the current day. Then, he would hold a brief safety meeting with the crews and issue the day's work assignment. The work distribution was adaptive and the number of men in each crew varied with the job type. For example, a routine annuli survey required only two men, while the dismantling of wellhead and manifold equipment required four to six men with hoisting equipment.

After doing the necessary telephone calls and paper work, the author would drive to the location which required the most supervision. The author set 3:00 P.M. for a midday report from each crew to be given by car radio. Based on these reports, he would report to his superior by 4:00 P.M.

The author participated with the Superintendent in interviewing prospective employees and shared the acceptance/rejection decision. The unit's work force increased from 19 men when the author joined to
34 men when he left the unit. The new employees were mostly transfers from other departments and required training, especially on the job safety.

The author's biggest impact on the unit was in motivating people to work, by making the work more interesting and meaningful. To achieve this motivation, the author sought and received participation of his employees in setting their own work targets. He frequently discussed job details with crew members and invited their suggestions for work improvement. He offered timely recognition to deserving crews for successful performances, either personally or through the Superintendent.

The effect of motivation was reflected on the gradual increase of the work load per crew. The job discussions further offered training for the new and less experienced employees who joined the unit during the author's assignment.

The field services experience introduced the author to many organizations within and outside Aramco. For example, to kill a well in Ain Dar and replace a valve, the following contacts were necessary:

1. Call the oil dispatcher for prior approval.
2. Notify the concerned plant (GOSP) foreman to adjust his production to the well closure.
3. Call Aramco Transportation and order tankers to haul the necessary killing and livening fluids. Record the truck and tanker numbers for followup.
4. Place an order of brine water with a contractor at a nearby brine mine. Brine was to be hauled in Aramco tankers.

5. Check the receipt of the Transportation orders at the Government's (Petromin's) bulk plant to fill in the required livening fluid (e.g., diesel oil, or kerosene).

6. Dispatch field services crew to install flarelines for the kill job.

7. Notify Halliburton of the proper timing to have their pumping equipment on location.

8. Follow up the movement of the fluids until arrival on the job.
WORKOVER ENGINEERING EXPERIENCE

For the purpose of this report, the workover engineering experience does not warrant details. The author was assigned as an engineer at the Workover and Stimulation Segment of Production Engineering at Dhahran. By 1972, workovers were performed by workover rigs and the related engineering services were rendered by the Workover Segment. There were three such rigs, but the author was associated with one during most of his nine months at the Segment.

The author was assigned to represent the Company at the contract onshore rig, Intairdrill-21 (ID-21). The job involved writing workover programs, observing the work done, and initiating necessary deviations from the program.

The ID-21 rig was operating mainly in the Khursaniyah and Abu Hadriya fields. Most of the problems encountered there were due to casing corrosion, cement channeling, or packer leaks. These problems were discussed as part of the drilling experience. There were no special problems or experiences at this job.

The author continued at the job until his resignation from the Company on January 7, 1973. Before his resignation, the author was offered a transfer leading to a line management position at the Southern Area Producing Department. He declined the offer in favor of pursuing graduate education. He accepted an "instructor" position at the College of Petroleum and Minerals which led to his scholarship grant to join Texas A&M University.
COMPANY-SPONSORED SPECIAL TRAINING

During the author's employment with Aramco, he was selected to attend technical, managerial, and general courses and seminars. All this training took place at the different Aramco districts in Saudi Arabia. The following is a brief chronological outline of such training.

- Aramco "Reading Improvement Course", Two-Hours/Week, Dhahran, (August 29-October 5, 1970).
CONCLUSIONS

1). The author believes that this review of his experiences at Aramco adequately serves the purposes of the internship report requirement. The variance of the author's experience from the normal industrial internship is readily explainable since his experience was not intended to be an internship.

2). The nature of the author's assignments at Aramco was operational and had little room for research or projects. This was more so at times of manpower shortage as was experienced at the Development Unit.

3). The author's six years with Aramco demonstrate typical stages of a petroleum engineer's training with an oil company. The author began working under the supervision of other petroleum engineers. He later performed petroleum engineering work on an independent basis. He also performed special assignments both individually and as a member of an engineering team. He was then assigned as a production foreman, supervising workers and coordinating production operations. This required not only technical competence, but also organizational and leadership skills.

4). The combination of these experiences are believed to fulfill the goals of the Doctor of Engineering internship.
REFERENCES


APPENDICES
APPENDIX A

Abqaiq
July 26, 1969

FRILL: YOUNG
ANALYST

The procedures for drilling and completing the Padilla Field 13 are outlined below. The well will be drilled through the Padilla reservoir and tested in both Padilla reservoirs if logs indicate hydrocarbon content in the Padilla.

A. Elevation: 60' FE (estimated)

B. LST: 799.6' E 120.5'

C. Distance: 220 kilometers (142 miles) from Abqaiq main gate

D. Complimentary Notes:

1. Completed Geophysical Drilling and Testing Program
2. Cementing Program
3. Fracture and Hydraulic Program

E. Field Conditions:

1. Lost circulation may be encountered at about 250' in the Bakut formation. The Bisk and Holsley formations could flow to surface while drilling 12'/ hole.
2. Large water flow is expected at about 1200' in the Um or Redhown formation (U.R.)
3. Lost circulation is expected at about 1200' in the Etin formation.
4. Water with a pressure of about 150' will be encountered at a depth of about 200' in the Um formation.
5. Water at a pressure of 250' or more at any depth, may indicate lost circulation. It is not expected that in such conditions all parties have the use of water as a drilling fluid. If water pressure is encountered below the setting point, a low gelled mud will be substituted.

6. A high pressure gas zone is expected at about 1200'. A test in the zone which was encountered in AB-5 and prevented the well from reaching the Early zone. This zone was encountered in
E. **Mud Conditions:** (Cont’d)

6. AHM-8, AHM-11 and AHM-12 and was successfully drilled with 130 pcf mud.

The mud should be built up to 110 pcf before drilling out of the 7” liner. The mud should be built up to 130 pcf at 9570’ and maintained at 130 pcf and 6cc water loss to total depth.

F. **Samples:**

Collect 10’ samples from 9700’ to total depth.

G. **Logging:**

- **At 7” Casing Point:**
  - Induction Electrical with SP from 7” casing point to 500’ above 9-5/8” shoe.
  - EHC Sonic-Gamma Ray-Caliper from 7” casing point to 100’ above 9-5/8” shoe.

- **At Total Depth-Open Hole:**
  - Induction Electrical with SP from total depth to 100’ above 7” shoe.
  - EHC Sonic-Gamma Ray-Caliper from total depth to 100’ above 7” shoe.
  - NL-MFL-ML may be run if required for interpretation, to be specified on rig floor.

- **At Total Depth-Cased Hole:**
  - Neutron-CCL across intervals of completion.

  All logs will be 2” and 10” resists. Catch mud samples while circulating prior to logging. Catch mud samples at least weekly from penetrating the top of the Arab formation to total depth. Maintain fresh water low salinity mud with low water loss (5 cc/30 min) after penetrating the Arab formation.

H. **Coring:**

1. Core 60’ of the top of the Arab-A reservoir, estimated top at 8440’. Start coring sufficiently above the Arab-A reservoir to guarantee recovery of the uppermost section. Particular attention should be taken while coring this section since the recovery of this portion of the reservoir is critical.

2. Core the top 180’ of the Nodriza reservoir. Estimated Nodriza top is 9710’.

I. **Centralizers:**

13-3/8” Casing: one centralizer about 10’ above float shoe; one on top of each of next four joints above float shoe; one on top of the 6th joint above float shoe; and one below 5' inside 10-5/8” casing. (Total 7).
I. **Centralizers:** (Cont'd)

- **9-5/8' Casing:** one centralizer about 10' above float shoe; one on top of each of next four joints; one on top of the 6th joint above float shoe; and one below BV inside 13-3/8" casing. (Total 7).

- **7" Liner:** one centralizer about 10' above float shoe; one on top of each of next 5 joints above float shoe; 15 across Arab formation 8440-9040'; 3 across Sulay formation 7460-7600'; one below liner hanger inside 9-5/8" casing and one at 9-3/8" casing shoe. (Total 26).

J. **Special Casing Requirements:**


- **7" Liner:** From bottom to top: 1200', 288', H-80, XL; 2200', 238', J-55, LTOA; 2380', 238', J-55, LTOA. Adjustments for actual depth to be made in the 238', J-55 casing.

- **41/2" Liner:** May be required if Fadhili reservoir contains hydrocarbons to separate communicating Kadriya and Fadhili reservoirs and to cease off high pressure gas zone.

K. **Pressure Data:**

- **Arab A/B** 4200 psi at 8500' as grad. 0.32 psi/ft.
- **Arab C** 4235 psi at 8500' as grad. 0.32 psi/ft.
- **Kadriya** 3600 psi at 9720' as grad. 0.32 psi/ft.

L. **BOP Equipment Requirements:**

Class IV hook up for 3000 psi WP rather than 5000 psi WP. Choke manifolding will be as similar to sketch as possible with available equipment.

A supplement indicating final approved hook up will be issued prior to the time the 9-5/8" casing shoe is drilled.

M. **Completion:**

Supplemental instructions will be provided at a later date. Rig will be released by the Development Engineer.

R. E. ZAGI
Chief Petroleum Engineer
Petroleum Engineering Department
APPENDIX B

EQUATIONS FOR CASING DESIGN

Tension Considerations

For Short Couplings:

\[ P = 0.80 \ c \ (33.71-D) \left( \frac{1}{t-0.07125} + 24.45 \right) A_j \quad \ldots \ldots (1) \]

For Long Couplings:

\[ P = 0.80 \ c (25.58-D) \left( \frac{1}{t-0.07125} + 24.45 \right) A_j \quad \ldots \ldots (2) \]

where:

- \( P \) = minimum joint strength, lb.
- \( D \) = OD of casing, in.
- \( d \) = ID of casing, in.
- \( t \) = wall thickness, in.
- \( A_j \) = area under root of last perfect thread, in\(^2\)
  \[ = 0.7854 \ (D-0.1425)^2 - d^2 \]
- \( c \) = constant depending on the grade of steel

Values of \( c \) are shown below:

<table>
<thead>
<tr>
<th>API Grade of Steel</th>
<th>Short Couplings</th>
<th>Long Couplings</th>
</tr>
</thead>
<tbody>
<tr>
<td>F-25</td>
<td>53.5</td>
<td>---</td>
</tr>
<tr>
<td>H-40</td>
<td>72.5</td>
<td>---</td>
</tr>
<tr>
<td>J-55</td>
<td>96.5</td>
<td>159</td>
</tr>
<tr>
<td>N-80</td>
<td>112.3</td>
<td>185</td>
</tr>
<tr>
<td>P-111</td>
<td>146.9</td>
<td>242</td>
</tr>
</tbody>
</table>
Collapse Considerations

(a) Grade F-25 Casing:

1. For values of $P_c$ less than 581 or $t/D$ less than 0.023:

$$P_c = 0.75 \times 50,210,000(t/d)^3$$ .................(3)

2. For values of $t/D$ greater than 0.023:

$$P_c = 0.75 \times 86,670(t/d) - 1386$$ .................(4)

(b) Grades H-40, J-55, N-80, and P-110 Casing:

Elastic Failure:

$$P_c = 0.75 \frac{62.6 \times 10^6}{(D/t)(D/t - 1)^2}$$ .................(5)

Plastic Failure:

1. For $D/t$ values greater than 14:

$$P_c = 0.75 \times \frac{Y_P (2.503)}{D/t} - 0.046$$ .................(6)

2. For $D/t$ values less than 14:

$$P_c = 0.75 \frac{(2Y_P)(D/t-1)}{(D/t)^2}$$ .................(7)

where:

$P_c =$ minimum collapse pressure, psi

$Y_P =$ average yield strength, psi

$D,t$ as defined above

Bursting Consideration

Barlow's formula

$$P_b = \frac{2S}{D}$$ .................(8-a)
Modified Barlow's formula:

\[ P_b = \frac{1.75 \cdot S}{D} \]  

where:

- \( P_b \) = minimum internal yield pressure, psi
- \( S \) = minimum yield strength, psi
- 1.75 = 2 x 0.875 to allow for 12.5% thickness tolerance
- \( D, t \) as defined above
## APPENDIX C

### CEMENT JOB DETAIL

<table>
<thead>
<tr>
<th>WELL NO.</th>
<th>DATE</th>
<th>NAME OF FIELD</th>
<th>TOTAL DEPTH</th>
<th>BIT SIZE</th>
<th>LAST CASING SIZE</th>
<th>CASING CEMENT JOB</th>
<th>DEPTH</th>
<th>SECTION GAUGE</th>
</tr>
</thead>
<tbody>
<tr>
<td>13</td>
<td>8/10/69</td>
<td>ABU HADRIYA</td>
<td>4070 FT.</td>
<td>17(\frac{1}{4}) in.</td>
<td>16-5/8 in.</td>
<td>13-3/8 in.</td>
<td>750</td>
<td></td>
</tr>
</tbody>
</table>

#### FIRST STAGE

**Pipe Run Freely to:**

- **Work Washed To:**
- **Shoe at:**
- **Circulated With:**
- **Water:**

**Type of Cement Used:**

- **30\%** Diacel D + Class B

<table>
<thead>
<tr>
<th>Slurry Volume</th>
<th>Time Started</th>
<th>Mixing Pressure</th>
<th>Circulation</th>
<th>Worked Pipe</th>
</tr>
</thead>
<tbody>
<tr>
<td>870 Diacel</td>
<td>590 Class B</td>
<td>2250 hours</td>
<td>500 PSI</td>
<td>115-116 PCF</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Type of Plug</th>
<th>Displacement Volume</th>
<th>Displacement Fluid Weight</th>
<th>Velocity</th>
<th>Displacement Press</th>
</tr>
</thead>
<tbody>
<tr>
<td>Houco</td>
<td>3439 CF</td>
<td>water</td>
<td>45 min.</td>
<td>1300 PSI</td>
</tr>
</tbody>
</table>

**Remarks:**

At the end of the first stage well flowing. Dropped bomb, opened DV. Filled casing to DV at 645' with 95 barrels of 86 PCF mud. Closed hydril and squeezed 76 barrels mud to kill well.
## Cement Job Detail

**Aramco 5003 (8/62)**

**Name of Field:** Abu Hadriya

<table>
<thead>
<tr>
<th>Casing Cement Job</th>
<th>Total Depth</th>
<th>Bit Size</th>
<th>Last Casing Size</th>
<th>Depth</th>
<th>Section Gauge</th>
</tr>
</thead>
</table>

**Pipe Run Freely To Work Washed To Shoe At Circulated With For D.V.**

<table>
<thead>
<tr>
<th>Date</th>
<th>8/18/69</th>
</tr>
</thead>
</table>

**Type of Cement Used:** 30% Diace 1 D Class B

### First Stage

- **Volume of Water Ahead of Cement:** 1150 hours
- **Volume of Dry Cement Used:** 900 w/30% Diace 1 D
- **Type of Plug:** Water
- **Circulation Time:** 1160 hours
- **Displacement Velocity:** 64 PCF
- **Plug Ramped At:** 2000 PSI
- **Time Finished:** 1335 hours
- **Type of Cement Used:** 30% Diace 1 D Class B

### Second Stage

- **Volume of Water Ahead of Cement:** 1440 hrs.
- **Volume of Dry Cement Used:** 750 cu.ft. 30% Diace 1 D
- **Type of Plug:** Water
- **Circulation Time:** 1440 hrs.
- **Displacement Velocity:** 64 PCF
- **Time Finished:** 1630 hours

**Remarks:** 20 minute circulate after opening DV.
APPENDIX D

EXAMPLE OF OPTIMUM CIRCULATING RATE DETERMINATION

The Situation:
It is desired to drill 8-3/4" hole from 2,000 ft. to 8,000 ft. using 3-1/2" IF, 13.3 lb./ft. drill pipe and 700 ft. of 7" x 2-13/16" drill collars. The following data were available:

- Mud Density = 80 pcf
- Minimum Annular Velocity = 90 fpm
- Pump: National C-350 (90% volumetric efficiency at 55 SPM or more and 95% vol. eff. at 55 SPM or less)
- Hydraulic Horsepower = 300
- Surface Pressure Limit = 2,000 psi

The Procedure:
See Figure D-1 for the family of pressure loss versus circulating rate curves constructed for depths from 2,000 ft to 8,000 ft. inclusive.

(a). Adjusted Pressure limits:
Adjusted surface pressure = 2000 x \( \frac{74.7}{80} \) = 1868 psi

Upper limit = \( \frac{P}{2} \) = \( \frac{1868}{2} \) = 934 psi

Lower limit = \( \frac{P}{4} \) = \( \frac{1868}{4} \) = 467 psi

(b). Adjusted Horsepower, HHPa:

HHPa = 300 x \( \frac{74.7}{80} \) = 280 HP
(c). Phase I Calculation:

\[ P = \frac{\text{HHP}_a \times 1714}{Q} \]

<table>
<thead>
<tr>
<th></th>
<th>(Q, \text{GPM} )</th>
<th>(P, \text{psi} )</th>
<th>(P/4, \text{psi} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>(1)</td>
<td>200</td>
<td>2400</td>
<td>600</td>
</tr>
<tr>
<td>(2)</td>
<td>300</td>
<td>1600</td>
<td>400</td>
</tr>
<tr>
<td>(3)</td>
<td>400</td>
<td>1200</td>
<td>300</td>
</tr>
</tbody>
</table>

These three points are used to plot the Phase I curve.

(d). Optimum Rate Evaluation:

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<th></th>
<th></th>
<th></th>
<th></th>
</tr>
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<tbody>
<tr>
<td>I</td>
<td>2000</td>
<td>294</td>
<td></td>
</tr>
<tr>
<td></td>
<td>3000</td>
<td>262</td>
<td>278*</td>
</tr>
<tr>
<td>II</td>
<td>3000 to 6300</td>
<td>262</td>
<td>262*</td>
</tr>
<tr>
<td>III</td>
<td>6300</td>
<td>262</td>
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</tr>
<tr>
<td></td>
<td>7000</td>
<td>245</td>
<td></td>
</tr>
<tr>
<td></td>
<td>8000</td>
<td>228</td>
<td>245*</td>
</tr>
</tbody>
</table>

*These represented the practical optimum circulating rates for the three phases.

(e). Liner Selection:

The use of 5" liners at 55 SPM gives a rate of 280 GPM which would satisfy Phase I and II conditions.

The use of 5" liners at 50 SPM gives a rate of 254 GPM which would satisfy Phase III conditions.
Figure D-1. Determination of Optimum Circulating Rates by the Humble Method.
APPENDIX E

WORKOVER PROGRAM
ASB SAGA U-35 No. 2

The following program is for workover of ASB-9 to plug back the lower portion of the Arab "D" reservoir and isolate bottom water, replace the faulty tubing retrievable ball valve and stimulate the Arab "D" reservoir with acid.

Well History:

ASB-9 was drilled and completed in October 1964 as an open-hole Arab "D" reservoir producer. The well was worked over in January 1967 to replace a faulty 7" tubing retrievable ball valve.

In June 1969 the ball valve in ASB-9 was reported stuck in the open position. Subject well is currently producing through this stuck-open ball valve and, lacking the Safety Shut-in feature, the well is in a hazardous condition.

Well Data:

- Total Depth: 8620' (DP elevation 39'). DW to tubing spool 10.8 ft.
- Water Depth: 737'
- Completion: Open hole Arab "D" reservoir producer
- Perforations: None
- Tubing: 2-3/8" x 2-7/8" with Baker Shoe at 6579' DW and Otis ball valve at 238' DW.
- Pressures: Arab "D" reservoir bottom-hole pressure, 2000 psi at 6535' subs. Shut-in wellhead pressure 700 psi.
- 7" 23 3-55 & 6335' N-60 200 ska 40% Diacal "D" followed by 100 ska Class "B". 220 ska returns.

Work Requirements:

1. Move to ASB-9 and prepare for workover.
2. Run flow tube to circulate and kill well with 75 psi and for a 300 psi overbalance on the Arab "D". Pull tubing and ball valve.
3. Run to bottom with open-ended drill pipe and lay a cement plug. Plug depth should be 6566' referenced to DW above. Dress off plug to this depth.
6. Run 2-1/2" tubing and BW assembly with 4" casing to FAD and circulate well clean of perforating debris. A special Otis type "KOL" ball valve will be run with the assembly in this step.

7. Pick up the tubing to about 20' above FAD and set packer such that 3' to 3' approximately 150' below the Gulf floor and slightly below the old packer setting depth. The thru-tree will be modified and the upper 1/2 added to accommodate the "KOL". The tree will require an 8" x 6" - 3000 lb double studded exit adapter, three 4" - 3000 psig gate valves for water clean and stack, one 4" - 3000 psig cross and one 6" x 3" crown adapter.

8. Use Otis "KOL" ball valve assembly in to be run in place while running the BW assembly. (The "KOL" extension above BW blanks off ports). Special BW is to be used in this step and replaced with completion BW. With this type "KOL" ball valve in place, pressure test the 4½" steel control line for leaks. When packer is set, ball valve can be closed to give additional protection while removing MCP stock and nippleing up the tree. Apply 3000 psi pressure on casing to assure hanger packer is set and holding, packing in the exit bushing around the 4½" tubing, flanges on the exit bushing, valve on the casing, packing on the control line and the 4½ control line are all tight. Then test the tree above the closed cantor valve. Pull the ball valve and run a one piece flow line across upper and lower packed nipples.

9. Displace the mud in the well with diesel preceded by a 50 bbl water spacer.

10. Spot 500 gal 104 HCl acid across perforations. Squeeze 325 gal of acid into the formation by displacement with diesel.

11. Let the acid set for 10 min. then flow back acid and diesel for clean-up.
12. Pressure test all lines to 3500 psi.

13. Acidize the Arab "D" as follows:
   a. 1680 gal. diesel/hyflo (3%)—after pumping sufficient volume to fill tubing and annulus below the 7" casing shoe (approx. 1260 gal), close the casing valve and continue pumping.
   b. 2000 gal straight diesel.
   c. 16,000 gal. 15% HV-60 retarded acid emulsion.
   d. 340 gal. straight diesel.
   e. Displace with 5000 gal. diesel/hyflo (3%). Shut-in well.

NOTE: Pump all fluids at maximum rate limited by 3000 psi pumping pressure. Interruptions should be minimized.

14. Wait 1 hour. Flow and flare well for clean-up.

15. Pull flow tube. Run and seat 4" WLRDV. Flow will be through 7" x 4½" annulus and the 4¾" casing.

16. Check BV operation and release rig.

NOTE: Record in detail the measurements of all downhole equipment including the packer and ball valve. Record the Serial Number of the ball valve. Measure and record the distance from the DF to the top of the tubing spool.

R. E. ZAGST
Chief Petroleum Engineer
Petroleum Engineering Department
CROSS SECTION ABU S. FAN 9

Date: 11/16/69
Drawn by M/F.T.  Approved: 1/67

WORKOVER 2XK 67

CROSS SECTION
ABU SAFAN WELL 9
## APPENDIX F

### COMPLETION REPORT - NEW WELL

#### LOCALITY: ABU HAIL

- **AREA**: ABU HAIL
- **ELEVATION**: 60 ft

### FOLLOWING IS A COMPLETE AND CORRECT RECORD OF ALL WORK DONE ON THIS WELL

- **PLUGGED IN**: N. 793.6 E 150.5
- **DEPT.** 7/29/69
- **HEIGHT** 9/24/69
- **PLUGGED TO 5470'**

#### CASING RECORD

<table>
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<tr>
<th>SIZE OF CASING</th>
<th>LENGTH OF CASING</th>
<th>DEPTH LANDED</th>
<th>CEMENTED (DEPTH)</th>
<th>WEIGHT PER FOOT</th>
<th>THREADS PER INCH</th>
<th>MADE OF CASING</th>
<th>SEAMLESS OR WELDED</th>
<th>VAIL OF SHIP</th>
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<tbody>
<tr>
<td>7</td>
<td>1318</td>
<td>10,357</td>
<td>Yes</td>
<td>13.5</td>
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<td>Omega</td>
<td>No test</td>
<td>None</td>
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<tr>
<td>13-3/8</td>
<td>6771</td>
<td>6970</td>
<td>Yes</td>
<td>36 &amp; 40</td>
<td>8rd</td>
<td>Sumitomo</td>
<td>S</td>
<td>None</td>
</tr>
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<td>13-3/8</td>
<td>5560</td>
<td>9444</td>
<td>Yes</td>
<td>23 &amp; 29</td>
<td>8rd</td>
<td>Unknown</td>
<td>S</td>
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</tr>
<tr>
<td>20</td>
<td>737</td>
<td>750</td>
<td>Yes</td>
<td>61</td>
<td>8rd</td>
<td>Rheinrohr</td>
<td>S</td>
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<tr>
<td>10-5/8</td>
<td>737</td>
<td>750</td>
<td>Yes</td>
<td>80.7</td>
<td>8rd</td>
<td>Sumitomo</td>
<td>S</td>
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</table>

#### CEMENTING OR OTHER SHUT OFF RECORD

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<th>DEPTH LANDED</th>
<th>CEMENTED</th>
<th>SACKS USED</th>
<th>SACKS TREATED</th>
<th>NO. OF ROWS</th>
<th>SPACING</th>
<th>INCHES</th>
<th>KIND OF CEMENT</th>
<th>METHOD</th>
<th>TIME SP</th>
<th>RESULT OF TEST</th>
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<td>13-3/8</td>
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<td>1250</td>
<td>750</td>
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<td></td>
</tr>
<tr>
<td>9-5/8</td>
<td>7977</td>
<td>Class B</td>
<td>3977</td>
<td>1250</td>
<td>900</td>
<td>750</td>
<td>Class B</td>
<td>Displacement</td>
<td>1.0</td>
<td>Satisfactory</td>
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<tr>
<td>7</td>
<td>9444</td>
<td>Class B</td>
<td>1444</td>
<td>1400</td>
<td>900</td>
<td>900</td>
<td>Class B</td>
<td>Displacement</td>
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<td>10,357</td>
<td>Class B</td>
<td>10,357</td>
<td>200</td>
<td>---</td>
<td>---</td>
<td>---</td>
<td>Displacement</td>
<td>---</td>
<td>Satisfactory</td>
<td></td>
</tr>
</tbody>
</table>

#### PERFORATION RECORD

- **With 304 Diameter**: 2-1/8" capsule jets. Production perforated.
- **With 308 Diameter**: 2-1/8" capsule jets. Test perforated plugged off.

#### PLUGGING

- **Type**: Current
- **ADM MIX**: Banash-Ross Delayed Action
- **ADM MIX**: Banash-Ross Regular Type

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<th>SURFACE</th>
<th>TD</th>
</tr>
</thead>
<tbody>
<tr>
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<td>2</td>
</tr>
<tr>
<td>PLUGGED</td>
<td>2</td>
</tr>
<tr>
<td>BEECH-ATTACKED PIPE AND LAST TOOL RECORD</td>
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<tr>
<td>SHEET</td>
<td></td>
</tr>
</tbody>
</table>

**DATE**: [Signature]
SUMMARY OF OPERATIONS
ABU HADRIYA WELL NO. 13

Rig: ADC-1
Total Days: 56.5 days
Total Depth: 10,360' DF
Plugged Depth: 9,870' DF

Plugs:
No. 1: Cement inside 4 1/2" liner 10,100-10,357' (Float at 10,113)
No. 2: Cement inside 4 1/2" liner 9,870-10,100'.

Rig Move:
Rig was moved from Abu Hadriya Well 7
Distance of move: 4 kilometers
Days between wells: 3.0 days

Water Supplies:
From ABWW-11 via 8" invasion line.

Type of Completion:
Hadriya reservoir producer through perforated 4 1/2" liner.

Tubing:
2-3/8" landed at 9830'.

Lost Circulation:
1. Lost partial circulation at 491'. Drilled with partial returns (70%) to 750', the 18-5/8' casing point.
2. Picked up pipe 3' while coring at 9668' with 130 PCF mud in the hole and DP stuck. Circulation was also lost. Worked pipe free and pulled up to 7' liner shoe at 9444'. Spotted 50 barrels 117 PCF mud with 50/bbl LCM. Regained circulation. Filled annulus with 180 barrels 117 PCF mud. Lost circulation again. Spotted 60 barrels of 117 PCF mud with 200/bbl LCM. Regained 90% circulation. Reduced mud weight to 117 PCF.
3. Lost circulation at 9791' while coring with 117 PCF mud in hole. Reduced mud weight to 110 PCF with lost circulation material and regained circulation. Reduced mud weight to 90 PCF with no hole problems.

Water Flow:
1. Encountered large water flow from Umar Radhuma at 1602'. Drilled with water and mud cap from 1935' to 2042'. Repaired flow line drilled with water and flow from 2042' to 4070', the 13-3/8' casing point.
2. Water flow at 7040' in Biyadh formation. Rate unknown. Changed from water to 76 PCF mud because of sloughing hole. Water flow was killed with this mud.
Stuck Pipe: 1. While reaming 8½" hole at 7858', drill pipe stuck. Spotted 40 barrels of diesel with 1 barrel Pipe-Lax and worked pipe 3 hours. Spotted Shot-Free and pipe came free in 1 hour. Total lost time—7 hours.
2. See No. 2 under lost circulation.

Fishing: 1. Left 3 cones from bit No. 3 in the hole at 3278'. Recovered fish with junk basket. Total lost time—5½ hours.
2. While drilling at 3496', 8-5/8" x 6-5/8" crossover sub box failed leaving bit, junk sub and 3--10" drill collars in hole. Recovered on first attempt with 10-3/4" overshot. Total lost time—27 hours.
3. On bit trip at 9446', dropped 15--4-3/4" DC's. Recovered on first attempt with overshot. Total lost time—10½ hours.

13-3/8" Casing — Tested with 1000 psi with 74 PCF mud in hole. Test ok.
7" Liner — Tested with 500 psi with 115 PCF mud in hole. Test ok.
4½" Liner — Tested with 1000 psi with 90 PCF mud in hole. Test ok.

Perforations:

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<tr>
<th>Reservoir</th>
<th>Liner</th>
<th>Interval</th>
<th>Feet</th>
<th>Shots/ft</th>
<th>Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>Upper Fadhili</td>
<td>4½&quot;</td>
<td>9925-30</td>
<td>5</td>
<td>4</td>
<td>2-1/8&quot; capsule jets.</td>
</tr>
<tr>
<td>Reservoir</td>
<td>4½&quot;</td>
<td>9933-36</td>
<td>3</td>
<td></td>
<td>Test perfs, plugged after testing.</td>
</tr>
<tr>
<td></td>
<td>4½&quot;</td>
<td>9938-45</td>
<td>7</td>
<td></td>
<td>Test ok.</td>
</tr>
<tr>
<td></td>
<td>4½&quot;</td>
<td>9957-63</td>
<td>6</td>
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<tr>
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<td>4½&quot;</td>
<td>9983-89</td>
<td>6</td>
<td></td>
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</tr>
<tr>
<td></td>
<td>4½&quot;</td>
<td>9992-96</td>
<td>4</td>
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</tr>
<tr>
<td>Total</td>
<td>4½&quot;</td>
<td>31'</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Hadriya Reservoir</td>
<td>4½&quot;</td>
<td>9581-90</td>
<td>9</td>
<td>2</td>
<td>2-1/8&quot; capsule jets.</td>
</tr>
<tr>
<td></td>
<td>4½&quot;</td>
<td>9593-98</td>
<td>5</td>
<td></td>
<td>Production perfs.</td>
</tr>
<tr>
<td></td>
<td>4½&quot;</td>
<td>9616-39</td>
<td>23</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>4½&quot;</td>
<td>9641-46</td>
<td>5</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>4½&quot;</td>
<td>9655-9782</td>
<td>127</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>4½&quot;</td>
<td>9786-93</td>
<td>7</td>
<td></td>
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</tr>
<tr>
<td></td>
<td>4½&quot;</td>
<td>9801-04</td>
<td>3</td>
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</tr>
<tr>
<td></td>
<td>4½&quot;</td>
<td>9808-11</td>
<td>3</td>
<td></td>
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</tr>
<tr>
<td></td>
<td>4½&quot;</td>
<td>9814-18</td>
<td>4</td>
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<tr>
<td>Total</td>
<td>4½&quot;</td>
<td>186'</td>
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Core:

No.1: Arab A, 8410-8446, 36' cored, 36' recovered, 100% recovery.
No.2: Arab A, 8446-8506, 60' cored, 60' recovered, 100% recovery.
No.3: Hadriya, 9622-9668, 46' cored, 46' recovered, 100% recovery.
No.4: Hadriya, 9668-9672, 4' cored, 4' recovered, 100% recovery.
No.5: Hadriya, 9672-9689, 17' cored, 17' recovered, 100% recovery.
No.6: Hadriya, 9689-9744, 55' cored, 55' recovered, 100% recovery.
No.7: Hadriya, 9744-9804, 60' cored, 60' recovered, 100% recovery.

Formation Tests:

DST No.1: Upper Fadhili, 9925-30, 9933-36, 9938-45, 9957-63, 9983-89 & 9992-96. Flowed. Rate not measured. 100 psig FWHP. Final sample 36.86° API at 60° F. 92 PFB. 0.757 BS&W.

Acidizing:
The Hadriya reservoir perforations 9581-90, 9593-98, 9616-39, 9641-46, 9655-9782, 9786-93, 9801-04, 9808-11 & 9814-18 were acidized with 4000 gallons of 15% MCA and displaced with 1700 gallons of diesel. After pumping 1700 gallons of acid, the casing valve was closed and acid squeezed into formation. An additional 8300 gallons of diesel was circulated after acid had set for 1 hour.

Logging:

Induction - Electrical:
6796-9432
9300-10,351

BHC Acoustic Velocity-Gamma Ray-Caliper:
6796-9442
9290-10,343

Guard Log:
6796-9445

Contact Caliper:
9430-10,360

GR-Neutron-CCL:
9400-10,100

Average Drilling Rate: 183.3 ft. per day

Average Penetration Rate: 23.0* ft. per rotating hour

* Excludes coring.
### Time Distribution:

<table>
<thead>
<tr>
<th>Activity</th>
<th>Hours</th>
<th>Days</th>
<th>Per cent</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Drilled Time:</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Drilling</td>
<td>438.5</td>
<td>18.2</td>
<td>32.2</td>
</tr>
<tr>
<td>Coring</td>
<td>52.5</td>
<td>2.2</td>
<td>3.9</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>491.0</td>
<td>20.4</td>
<td>36.1</td>
</tr>
<tr>
<td><strong>Dead Time:</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Reaming; &amp; opening hole</td>
<td>21.5</td>
<td>0.9</td>
<td>1.6</td>
</tr>
<tr>
<td>Trips &amp; changing bits</td>
<td>283.0</td>
<td>11.8</td>
<td>20.9</td>
</tr>
<tr>
<td>Conditioning mud &amp; hole</td>
<td>68.0</td>
<td>2.0</td>
<td>3.5</td>
</tr>
<tr>
<td>Service rig</td>
<td>13.0</td>
<td>0.5</td>
<td>0.9</td>
</tr>
<tr>
<td>Casing run, cut, DOC, SOT</td>
<td>107.0</td>
<td>4.5</td>
<td>8.0</td>
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<tr>
<td>Logging</td>
<td>76.0</td>
<td>3.2</td>
<td>5.7</td>
</tr>
<tr>
<td>Lost circulation &amp; plugs</td>
<td>16.5</td>
<td>0.7</td>
<td>1.2</td>
</tr>
<tr>
<td>Testing incl. trips</td>
<td>25.0</td>
<td>1.0</td>
<td>1.8</td>
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<tr>
<td>Completion: run tubing thru release</td>
<td>53.5</td>
<td>2.2</td>
<td>3.9</td>
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<tr>
<td>Other</td>
<td>778.5</td>
<td>33.5</td>
<td>53.3</td>
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<td><strong>Total</strong></td>
<td>722.0</td>
<td>30.1</td>
<td>53.3</td>
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<td><strong>Lost Time:</strong></td>
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<tr>
<td>Stuck Pipe</td>
<td>7.0</td>
<td>0.3</td>
<td>0.5</td>
</tr>
<tr>
<td>Repair or replace</td>
<td>20.5</td>
<td>0.9</td>
<td>1.6</td>
</tr>
<tr>
<td>Miscellaneous</td>
<td>19.0</td>
<td>0.8</td>
<td>1.4</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>143.5</td>
<td>6.0</td>
<td>10.6</td>
</tr>
<tr>
<td><strong>Grand Total</strong></td>
<td>1,356.5</td>
<td>56.5</td>
<td>100.0</td>
</tr>
</tbody>
</table>

Core Record: See attachment

Bit record: See attachment

Assistant Drilling Foremen: Bruch Bildstien Schmidt

Drilling Foremen: ADC Manager: M. Galtier J. Schauffler (Relief)

Aramco Representative: W. L. Erwin E. G. Coggin
Summary of Operations
Abu Hadriya Well No. 13

Development Engineer: R. A. Akkad
C. B. Eastham

Discussion: Abu Hadriya Well No. 13 was drilled through the lower Fadhili reservoir on the crest of the structure. An oil-water contact was observed in the lower Fadhili reservoir. The upper Fadhili reservoir was drill stem tested and produced 36.8° API, sour crude. The well was completed as a Hadriya reservoir producer.

Compiled &
Checked by: C. B. Eastham

Attachments:
1. Daily drilling report
2. Casing details
3. Tubing detail
4. Cement Job details
5. Bit record
6. Core record
7. Water analysis
8. DST data sheets
9. Crude oil analysis
10. Well cross section
11. Correlation chart
12. Core and Sample description

* Attachments included are samples only.
7-29-69 0 days. 200'. Pulling out of hole 34" hole opener. 17½", 63-45-8, 100%, Ø1. Drilled time 5½ hours. Dead time 11 hours. Lost time 7½ hours. Drilled 17½" hole 0 to 58'. Drilled 58' to 200'. Opened 17½" hole to 34" to 200'.

7-30-69 0 days. 610'. Drilling. 24", 70-45-9, 90%, 26", 200'. Drilled time 12 hours. Dead time 12 hours. Displaced mud with water. Cemented 26" casing with 850 sacks cement, Class B. Had returns. Ran in hole with 24" bit. Top of cement at 160'. Cleaned out cement to bottom at 200'. Spudded well 18:00 hours. 7-29-69.


8-1-69 2 days. 1270'. Drilling. 17½", water & gel slip, 75%, Ø2, 18-5/8", 750'. Drilled time 4 hours. Dead time 20 hours. Finished running in hole 18-5/8" casing freely to bottom at 750'. Circulated. Cemented 18-5/8" casing with 1200 sacks Class B. No cement returns. Ran in hole with Bit Ø2 to cement top at 702'. Cleaned out cement to 750'.


8-3-69 4 days. 2842'. Drilling. 17½", water, water flow, Ø4. Drilled time 15 hours. Dead time 4 hours. Lost time 5 hours. Ran in hole with bit Ø2 freely to 1985', reamed to bottom at 2042'. Drilled to 2676'. Ran in hole freely to bottom with bit Ø3.

8-4-69 5 days. 3278'. Pulling out of hole. 17½", water & gel slip, water flow, Ø4, 18-5/8", 750'. Drilled time 9 hours. Lost time 15 hours. Drilled to 3278'. Pulled out of hole with bit Ø3, left 3 cones in hole. Ran in hole with magnet, no recovery. Ran in hole with junk basket recovered one cone. Ran in hole with magnet.
## CASING DETAIL

### Bottom
- **Size:** 7, **Type:** Houco
- **Float:** Wt 29, **Model No.:** Houco
- **Shoe:** Grd N-80, **Thd:** XL, **Mfr:** Sumitomo
- **Model No.:** 9444

### Vet
- **Size:** 7, **Wt:** 29, **Grd:** N-80, **Thd:** XL, **Mfr:** Sumitomo
- **Model No.:** 9369

### XL-Omega crossover
- **Size:** 7, **Wt:** 23, **Grd:** N-80, **Thd:** Omega, **Mfr:** Rheinrohr

### Omega-ord. crossover
- **Size:** 7, **Wt:** 23, **Grd:** J-55, **Thd:** 8rd, **Mfr:** Unknown

### Liner-Hanger, Size 7"x9-5/8"
- **Mfr:** Baasch-Ross
- **Type:** Delayed action
- **Model No.:** 9330

### Total
- **Joints:** 143
- **Pipe:** 3884' below rotary table
- **Cut off and recovered:**
- **Net pipe in hole:**

### Casing Landed
- **3884'** below RTP: 115,000, **indicated wgt:**

<table>
<thead>
<tr>
<th>Casing</th>
<th>Mfr</th>
<th>Model No.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Houco</td>
<td>9444</td>
<td>9406</td>
</tr>
<tr>
<td>Houco</td>
<td>9369</td>
<td>9330</td>
</tr>
<tr>
<td>Houco</td>
<td>9292</td>
<td>9255</td>
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<tr>
<td>Houco</td>
<td>9001</td>
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<td>Houco</td>
<td>8924</td>
<td>8886</td>
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<td>Houco</td>
<td>8842</td>
<td>8810</td>
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<tr>
<td>Houco</td>
<td>8772</td>
<td>8735</td>
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<td>Houco</td>
<td>8696</td>
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<td>Houco</td>
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<td>Houco</td>
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<td>Houco</td>
<td>8450</td>
<td>7554</td>
</tr>
<tr>
<td>Houco</td>
<td>7514</td>
<td>7475</td>
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</tbody>
</table>

*Centralizers and scratchers should be recorded as feet above the shoe.

<p>| Liner hanger at 3884' | 6784 | 3922 |</p>
<table>
<thead>
<tr>
<th>Bottom</th>
<th>.40</th>
<th>Collar</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>9811.64</td>
<td>2-3/8</td>
<td>Threaded</td>
<td>Plain Collar</td>
</tr>
<tr>
<td>Next</td>
<td></td>
<td>Threaded</td>
<td>Threaded Mfr Sustitute</td>
</tr>
<tr>
<td>Next</td>
<td></td>
<td>Threaded</td>
<td>Threaded Mfr</td>
</tr>
<tr>
<td>Next</td>
<td></td>
<td>Threaded</td>
<td>Threaded Mfr</td>
</tr>
<tr>
<td>Next</td>
<td></td>
<td>Packer &amp; Otis Equipment (Detail Below)</td>
<td></td>
</tr>
<tr>
<td>Next</td>
<td></td>
<td>Threaded</td>
<td>Threaded Mfr</td>
</tr>
<tr>
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<td>Threaded</td>
<td>Threaded Mfr</td>
</tr>
<tr>
<td>Next</td>
<td></td>
<td>Threaded</td>
<td>Threaded Mfr</td>
</tr>
<tr>
<td>TOTAL</td>
<td>9812.04</td>
<td></td>
<td></td>
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</table>

| Thg Landed | 18 | below R.T. 31,500 | |

| PACKER & OTIS EQUIPMENT DETAIL |
|---|---|---|---|
| Type | Size |

Next

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### CEMENT JOB DETAIL

**ARAMCO S032 (6-62)**

#### ABU HADRIYA

<table>
<thead>
<tr>
<th>WELL NO.</th>
<th>DATE</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>13</td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>Casing Cement Job</th>
<th>Total Depth</th>
<th>Bit Size</th>
<th>Last Casing Size</th>
<th>Depth</th>
<th>Section Gauge</th>
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</thead>
<tbody>
<tr>
<td>26 inch</td>
<td>200 ft.</td>
<td>3/4 inch</td>
<td>--</td>
<td>-- ft.</td>
<td>--</td>
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<table>
<thead>
<tr>
<th>Pipe Run Freely To</th>
<th>Work Washed To</th>
<th>Shoe At</th>
<th>Circulated With</th>
<th>For</th>
<th>O.V.</th>
</tr>
</thead>
<tbody>
<tr>
<td>200 ft.</td>
<td>-- ft.</td>
<td>200 ft.</td>
<td>Watot</td>
<td>30 min.</td>
<td>--</td>
</tr>
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</table>

#### Type of Cement Used

- **Class B w/2% CaCl₂**

<table>
<thead>
<tr>
<th>Volume of Water Ahead of Cement</th>
<th>Volume of Dry Cement Used</th>
<th>Weight Mixed At</th>
</tr>
</thead>
<tbody>
<tr>
<td>CF</td>
<td>850 CF</td>
<td>116-118 PCF</td>
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</table>

#### First Stage

- **MIXING TIME:**
  - 30 min.

<table>
<thead>
<tr>
<th>Slurry Volume</th>
<th>Time Started</th>
<th>Mixing Pressure</th>
<th>Circulation</th>
<th>Worked Pipe</th>
</tr>
</thead>
<tbody>
<tr>
<td>1003 CF</td>
<td>1015 hours</td>
<td>150 PSI</td>
<td></td>
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</table>

- **Type of Plug:**
  - None

<table>
<thead>
<tr>
<th>Displacement Volume</th>
<th>Displacement Fluid</th>
<th>Viscosity</th>
<th>Displacement Pressure</th>
</tr>
</thead>
<tbody>
<tr>
<td>561 CF</td>
<td>water</td>
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</table>

<table>
<thead>
<tr>
<th>Circulation</th>
<th>Displacement Time</th>
<th>Plug Bumped At</th>
<th>Time Finished</th>
<th>Float Held</th>
<th>Cement Returns</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
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<td></td>
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<td></td>
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</table>

<table>
<thead>
<tr>
<th>Volume of Water Ahead of Cement</th>
<th>Volume of Dry Cement Used</th>
<th>Weight Mixed At</th>
</tr>
</thead>
<tbody>
<tr>
<td>CF</td>
<td>CF</td>
<td>PC</td>
</tr>
</tbody>
</table>

#### Second Stage

<table>
<thead>
<tr>
<th>Type of Plug</th>
<th>Displacement Volume</th>
<th>Displacement Fluid</th>
<th>Viscosity</th>
<th>Displacement Pressure</th>
</tr>
</thead>
<tbody>
<tr>
<td>CF</td>
<td>CF</td>
<td></td>
<td></td>
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</table>

<table>
<thead>
<tr>
<th>Circulation</th>
<th>Displacement Time</th>
<th>O.V. Closed At</th>
<th>Time Finished</th>
<th>Cement Returns</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

#### Remarks

- **Remarks:**
  - 1115 hours Yes No 150 sacks
DST DETAILS

Wet (HMR - HMR)

ABJMEYA

AROMCO

IN II A (I OSI 1) AMW

AMIN TOOL

Pressures Readings

Field | Office Corrected
--- | ---
Initial Hydro. Press. | ----
Initial Closed in Press. | ----
Initial Flow Press. | ----
Final Flow Press. | ----
Final Closed in Press. | ----
Final Hydro. Mud Press. | ----
Cushion | ----

AVERAGE: 10/10

Casing Performance: 996'

Process Interval: 9925-30, 9933-36, 9938-45


Opened tool at 02:45. Work blow increasing to

strong, stated & stuck at surface at 03:32. Oil to

surface at 03:36. Started catching five samples at

6/4/68. RFT 90 psig. Finished catching 5 drum

samples at 8:40. RFT 100 psig. Took TC sample

and closed tool at 05:00. Unfed packer and

started out of the hole at 09:04. Final sample

33.5 API or 0.07. Salt 92 FTV. R/S 0.75%

Crude was sour.
TO:    Superintendent, Drilling Division

FROM: T. O. Mohr

A drilling efficiency study was made of the U-1 rig while it was drilling Ain Dar Well 98 in December of 1967. The results of this study are reviewed in Report No. A-1-68 dated January, 1968.

A follow-up study is planned for the rig when it drills Ain Dar Well 94. This well is the next well scheduled to be drilled by the U-1 rig. The results and recommendations contained in the above report will be compared with data obtained while drilling ADW-98. A report of which will be issued with an interpretation of the data obtained and progress on recommendations from the previous report.

The operation will be covered as extensively as possible with the available engineering manpower. The drilling recorder will be relied upon to fill gaps not covered by the presence of an engineer.

T. O. MOHR
Supervisor, Development Unit (Acting)

HEZimf
cc:  R. A. Akkad
     G. W. Spaid
     J. P. Calligeros
     Mgr, Drilling
     Mgr, Petr. Engr.
1. **Total time to drill well** - apron release
   - **Drilling Time** - Total operating hours
   - **Dead Time** - Total hours
   - **Lost Time** - Total hours (discuss each item)

2. **Penetration Rate**
   - Feet per hour - total well
   - Feet per hour - by hole size
   - Feet per day - total well

   Record for each bit size
   - Depth - high, low, average
   - Rotary Speed - RPM
   - Pump Pressure
   - Jet Sizes
   - Circulation Rate
   - Condition of bit when pulled
   - Number of feet drilled by each bit
   - Drilling fluid

3. **Connection Time**
   - Total for well
   - Average time per connection from drilling recorder

4. **Trip Time**
   - Total time
   - Average per stand for drill collars
   - Average per stand for drill pipe

5. **Casing Running Time**
   - Total time running casing
   - Average time per joint each size of casing

6. **Completion Time**
   - Total
   - Breakdown and discussion of total completion

7. **Compare with ADV-9C and discuss**

8. **Rig Move**

9. **Discussion of entire well including rig move plus drilling of well**
## COMPLETION REPORT - NEW WELL

**Ghawar**

<table>
<thead>
<tr>
<th>Depth</th>
<th>Steel</th>
<th>Type of Steel</th>
<th>Make of Steel</th>
<th>CSL</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>13-3/8</td>
<td>2609</td>
<td>2609</td>
<td>600</td>
<td>650</td>
<td>Class B Displacement</td>
</tr>
<tr>
<td>9-5/8</td>
<td>4500</td>
<td>4500</td>
<td>1000</td>
<td>700</td>
<td>Class B Displacement</td>
</tr>
<tr>
<td>7</td>
<td>6904</td>
<td>6904</td>
<td>1750</td>
<td>1350</td>
<td>Class B Displacement</td>
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</tbody>
</table>

**Ain Dar**

<table>
<thead>
<tr>
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<th>Steel</th>
<th>Type of Steel</th>
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<th>CSL</th>
<th>Remarks</th>
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<td>Class B Displacement</td>
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<tr>
<td>7</td>
<td>6904</td>
<td>6904</td>
<td>1750</td>
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</table>

**ADW-94**

<table>
<thead>
<tr>
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<tr>
<td>13-3/8</td>
<td>2609</td>
<td>2609</td>
<td>600</td>
<td>650</td>
<td>Class B Displacement</td>
</tr>
<tr>
<td>9-5/8</td>
<td>4500</td>
<td>4500</td>
<td>1000</td>
<td>700</td>
<td>Class B Displacement</td>
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<tr>
<td>7</td>
<td>6904</td>
<td>6904</td>
<td>1750</td>
<td>1350</td>
<td>Class B Displacement</td>
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### CEMENTING OTHER SHOULDER RECORD

<table>
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<th>Depth</th>
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<th>Make of Steel</th>
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<th>Remarks</th>
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<tbody>
<tr>
<td>13-3/8</td>
<td>2609</td>
<td>2609</td>
<td>600</td>
<td>650</td>
<td>Class B Displacement</td>
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<tr>
<td>9-5/8</td>
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<td>4500</td>
<td>1000</td>
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<tr>
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<td>6904</td>
<td>6904</td>
<td>1750</td>
<td>1350</td>
<td>Class B Displacement</td>
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### PERFORATION RECORD

- **Bass Ross Delayed Action**
  - **7" x 9-5/8"**
  - **4311**
WELL COMPLETION REPORT

SUMMARY OPERATIONS

U-1: AIR EXS WELL 96

Rig: U-1
Total Days: 12.9
Total Depth: 7100' DF
Rig Move:
- Rig was moved from ADW-87
- Distance of move: 31 kilometers
- Days between wells: 2.2

Water Supplies:
- ADGOSP-1 via 8" invasion line

Type of Completion:
- Arab D open hole producer

Tubing:
- 2-3/8" tubing landed at 7064' with Otis sliding sleeve at 3603'.

Lost Circulation:
- Lost complete circulation at 525'. Drilled to 13-3/8" casing point at 2609' with water.

Water Flow:
- 150 GPM water flow from the Biyadh while pulling out with a cracked drill collar at 4841'.
- 500 GPM water flow from the Sulaiy-Biyadh while drilling Sulaiy, Hith and Arab formations.

Shut-off Tests:
- 13-3/8" Casing:
  - Cleaned out cement to 2600' and tested casing with 1000 psi for 15 minutes. Test satisfactory.

  9-5/8" Casing:
  - Drilled DW at 2484' and tested casing with 800 psi for 5 minutes. Drilled baffle and float at 4459' and cleared out cement to 4490'. Tested casing with 800 psi for 5 minutes. Both tests satisfactory.

  7" Liner:
  - Cleaned out to 6900' and tested with 1000 psi for 10 minutes. Test satisfactory.

Average Drilling Rate: 550 ft per day
Average Penetration Rate: 59.5 ft per rotating hour

Time Distribution:

<table>
<thead>
<tr>
<th></th>
<th>Hours</th>
<th>Days</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Drilled Time</td>
<td>119.4</td>
<td>4.9</td>
<td>38.0</td>
</tr>
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</table>


### Time Distribution - Cont'd

#### Dead Time:
- Trips and changing bits: 52.5 hours, 2.2 days, 17.0%
- Conditioning mud and hole: 2 hours, 0.1 days, 0.8%
- Service rig: 0.5 hours, 0.0 days, 0.1%
- Casing run, cement, WOC, SOT: 91 hours, 3.8 days, 29.4%
- Completion: run tubing through release: 18.5 hours, 0.8 days, 6.2%

#### Total Dead Time: 164.5 hours, 6.9 days, 53.5%

#### Lost Time:
- Repair or replace: 9.5 hours, 0.4 days, 3.1%
- Miscellaneous: 16.5 hours, 0.7 days, 5.4%

#### Total Lost Time: 26 hours, 1.1 days, 8.5%

**GRAND TOTAL:** 180 hours, 12.9 days, 100%

### Bit Record:
See attachment

### Drillers:
- H. A. Raja
- M. A. Hirz
- A. E. Dhamin

### Assistant Drilling Foremen:
- A. W. Machen
- R. C. Gooch
- B. J. Harmon

### Drilling Foremen:
- R. J. Smith
- E. C. Gooch (relief)
- B. J. Harmon (relief)

### Development Engineers:
- H. E. Zirger
- R. A. Akkad
- G. W. Spaid

### Discussion:
Ain Dar Well 94 is a north Ain Dar development well. The well was drilled in the record time of 12.9 days with complete coverage for efficiency drilling observation.

Compiled & Checked by [Signature]

---

**ADW-94**

**-7-**

**Time Distribution - Cont'd**

<table>
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<tr>
<th>Activity</th>
<th>Hours</th>
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<td>Trips and changing bits</td>
<td>52.5</td>
<td>2.2</td>
<td>17.0</td>
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<tr>
<td>Conditioning mud and hole</td>
<td>2</td>
<td>0.1</td>
<td>0.8</td>
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<tr>
<td>Service rig</td>
<td>0.5</td>
<td>0.0</td>
<td>0.1</td>
</tr>
<tr>
<td>Casing run, cement, WOC, SOT</td>
<td>91</td>
<td>3.8</td>
<td>29.4</td>
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<tr>
<td>Completion: run tubing through release</td>
<td>18.5</td>
<td>0.8</td>
<td>6.2</td>
</tr>
</tbody>
</table>

**Total Dead Time:** 164.5 hours, 6.9 days, 53.5%

**Lost Time:**
- Repair or replace: 9.5 hours, 0.4 days, 3.1%
- Miscellaneous: 16.5 hours, 0.7 days, 5.4%

**Total Lost Time:** 26 hours, 1.1 days, 8.5%

**GRAND TOTAL:** 180 hours, 12.9 days, 100%
APPENDIX H

PRODUCTION ENGINEERING WORK

The following is a brief listing of normal work performed by the author during his assignment as relief engineer at the Production Unit in Dhahran.

1. Report daily production well problems. Contact production plant foremen in fields of concern, investigate troubles and recommend repairs. Request fluid samples, water analysis, temperature surveys, etc.. Follow up the failure until corrected.

2. Schedule static bottomhole pressure and temperature surveys in fields of responsibility. Interpret the results, update the Master File, and recommend any necessary action.

3. Schedule flowing multirate well and flowline/trunkline tests on well systems in fields of concern. Analyze the tests and update the Files.

4. Schedule oil wells for build-up tests, supervise the tests, and analyze the test data. Based on the analysis, recommend stimulation as needed to remove well damage and/or to enhance production. Test the wells after stimulation to evaluate its effectiveness and improvements in productivity.

5. Schedule annuli surveys once a year per well with the field services foreman. Annuli surveys may point to well problems due to poor surface cement jobs. Sometimes, the surveys may indicate wells requiring workover.
6. Schedule drawdown tests and spinner surveys in water injection wells to monitor injection projects. Interpret the results and recommend further work as necessary.

7. In all the work that required shutting in producing wells or producing shut-in wells, coordinate with the oil dispatcher, the concerned production foreman, and the field services foreman. The dispatcher had the total oil demand picture and could allow well closure only based on laxity of demand for the oil in question. The production foreman had to adjust his plant's production according to the action needed. The field services foreman supplied the crews to do the work.

8. Prepare annual status report on each field under the engineer's responsibility. The report included all major changes during the year including the addition of new wells, workovers, deepenings, recompletions, or plugging of existing wells. The report included recommended actions for the following years which would improve the production from the field. The author prepared status reports for AbuSafah, Berri and Qatif fields only, but contributed to the reports on each field he supervised.

9. Perform offshore and remote area production work. This included well tests and flowline/trunkline tests to establish production potentials of the various pipeline networks.

10. Perform miscellaneous production engineering work. Schedule and interpret gas-oil contact surveys (e.g., Neutron Logs or Formation Density Logs in Abqaiq Field). Test the flow rate of water supply wells with orifice meter (e.g., Shedgum...
Prepare monthly reports such as Priorities of Acid Jobs, Field Services Priorities, or Status of Wells. These routine reports were prepared rotationally by production engineers and the author wrote a few of each type. They involved compiling data or work requirement from the various engineers, each in his fields of responsibility.
APPENDIX I

BUILD UP ANALYSIS (AFTER ACIDIZING)

FIELD: SHAYBAH
AREA: SHAYBAH
WELL NO.: 8
TEST DATE: 4/12/1570
FORMATION: SHU'AIBA

A. Calculation of Formation K (md) and K (md-ft)

1. \[ K = \frac{162.6 \times 0.31 \times 38.0 \times 1.771}{49 \times 75} = 94.2 \text{ md-ft} \]

2. \[ K_h = \frac{94.2}{7.5} = 12.6 \text{ md-ft} \]

B. Calculation of Skin Effect S; and Pressure Loss Due to Skin \( \Delta p \) (psi)

1. \[ S = 1.151 \left( \frac{P_{1hr} - P_{wf}}{P_{lhr}} \right) - 1.151 \log \frac{Q B}{10.4 \text{ mh} B c \left( \frac{r_w}{r_i} \right)^2} \]

\[ S = 1.151 \left( \frac{2320 - 2226}{2320} \right) - 1.151 \log \frac{3840 \times 1.771}{49} \]

\[ S = 2.21 - 8.93 = -6.72 \]

2. \[ \Delta p_{skin} = 0.87 \text{ m s} \]

\[ \Delta p_{skin} = 0.87 \times 49 \times (-6.72) \]

\[ \Delta p_{skin} = -286.5 \text{ psi} \]

C. Actual Radius of Investigation, \( r_e \)

1. \( r_e \) under normal producing conditions 11000 ft.

2. Calculated \( r_i \) for test conditions.

\[ r_i = \sqrt{\frac{K}{0.04 \times 0.8 \times 0.04 \times 0.37 \times 1.4 \times 6.5 \times (0.3)}} \]

\[ r_i = \sqrt{\frac{0.0942 \times 1.05}{0.04 \times 0.37 \times 1.4 \times 6.5 \times (0.3)}} \]

\[ r_i = 1140 \text{ ft.} \]
D. Calculation of Productivity Index (BPD/psi) and Flow Efficiency

1. \( J \) (actual) = \( \frac{q}{p_{f}} \)
   
   \[ J \text{ (actual)} = \frac{3,860}{2390} = 1.61 \text{ BPD/psi} \]

2. \( J \) (ideal) = \( \frac{q}{p_{f} - p_{skin}} \)
   
   \[ J \text{ (ideal)} = \frac{3,860}{2390 + 28.5} = 1.47 \text{ BPD/psi} \]

3. Flow Efficiency = \( \frac{J \text{ (actual)}}{J \text{ (ideal)}} \)
   
   Flow Efficiency = \( \frac{1.61}{1.47} = 1.10 \)

E. Calculation of Composite or Average \( K \) (md) and \( K_h \) (md-ft)

1. \( K = \frac{M B}{0.00307} \log \frac{r_e}{r_w} \)
   
   \[ K = \frac{(23.5)(37)(1.45)}{0.00307} \log 4800 = 20.9 \text{ md.} \]

2. \( K_h = \frac{20.9 \times 75}{75} = 156.50 \text{ md-ft.} \)

F. Calculation of Productivity Ratio

\[ PR = \frac{\text{Composite } K}{\text{Formation } K} \]

\[ PR = \frac{20.9}{22.4} \]

\[ PR = 0.93 \]

G. Calculation of Effective Well Bore Radius After Acid Job

\[ r_w^* = r_w e^{-s} \quad e = 2.718 \]

\[ r_w^* = 0.3 e^{+6.72} \]

\[ r_w^* = 24.9' \]
FIELD: SHAYYAB
AREA: SHAYYAB
WELL NO.: 5

BASIC DATA

A. Completion Data and Production History

1. Type Completion: Perforations, 2" 60' in 4 1/2" 13.5 41/2 Uni.
2. Completion Date: 11/13/70
3. Hole or Casing ID (in): 3 1/2
4. Date of Initial Production: 4/1/70 (Date of Perforating)
5. Cumulative Production N_p (bbls): 4010 (after acidizing)

B. Formation Data

1. Producing Formation: SHAYYAB
2. Top of Pay or Perforations: 4840 ft
3. Bottom of Pay or Perforations: 4765 ft
4. Net Thickness (h): 75 ft
5. Porosity ($\phi$): 0.20
6. Source of Data: Preliminary Core Analyses

C. PVT Data

1. Formation Volume Factor ($B$): 1441
2. Viscosity ($\mu$): 0.37
3. Compressibility ($C$): 1.6 x 10^{-6}
4. Source of Data: PVT analysis - SYW.3

TEST DATA

A. Pressure Data

1. Static Pressure ($P$): 2340 psig Date: 4/15/70 C 45.5 C
2. Calculated Pressure at $p_c$ ($p$): __________ psi
3. Flowing Pressure ($p_f$): 2226 psig Date: 4/15/70 C 45.5 C
4. Pressure Drop ($\Delta p = p - p_f$): 164 psi
5. Slope of Build Up Curve (m): 49 psi/cycle

B. Production Test Data

1. Testing Mode: 2" Flow Turret Meter
2. Date Tested: 4/15/70 Readout Used: 9A5315
3. Uncorrected Rate: 4200 BPD
4. Corrected Rate: 3860 STBPD

Bomb: Used for calculations: 9310
Table I: SyW-8 Build-Up Calculations

\( t = 1500 \text{ minutes} \)

<table>
<thead>
<tr>
<th>( \Delta t )</th>
<th>( t + \Delta t )</th>
<th>( \Delta t / (t + \Delta t) )</th>
<th>Pressure, psi (Bar = 9310)</th>
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<tr>
<td>60</td>
<td>1560</td>
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<tr>
<td>90</td>
<td>1590</td>
<td>0.566</td>
<td>2329</td>
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<tr>
<td>120</td>
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<td>0.751</td>
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<td>2347</td>
</tr>
<tr>
<td>240</td>
<td>1740</td>
<td>1.429</td>
<td>2351</td>
</tr>
<tr>
<td>300</td>
<td>1800</td>
<td>1.647</td>
<td>2354</td>
</tr>
<tr>
<td>360</td>
<td>1860</td>
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<td>2359</td>
</tr>
<tr>
<td>480</td>
<td>1980</td>
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<td>2366</td>
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<td>3.750</td>
<td>2372</td>
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<td>2382</td>
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</table>
Figure I-1. Pressure Build-up Chart, Shaybah Well-8. $Q = 3860$ BOPD on a 32/64" Choke.
APPENDIX J

Dhahran
November 2, 1969

SINGLE PRODUCTION WELLHEAD
AND MANIFOLD
'AIN DAR WELL NO. 3

MANAGER, Drilling Department
MANAGER, Southern Area Producing
Abqaiq

In accordance with existing instructions, attached are sketches of the Single Onshore Production Wellhead and the wellhead manifolding for 'Ain Dar Well No. 3. The well is being worked over to be completed as a Fadhili reservoir producer with a full string of 4 1/2" casing to be run during workover.

It will be noted that a 3 1/2" casing landing spool is to be installed between the 7" casing landing spool and the 2-3/8" tubing head as per attached sketches. The addition of this spool will require that the well manifold be raised and adjusted accordingly. The block valve should be checked and operable. A 2"-3000 MSP kill connection is to be installed as per sketch upstream of the block valve.

The well will be completed as a single Fadhili producer. The chokes should be serviced by Producing while the well is being deepened. By separate letter, Engineering will be requested to check adequacy of flow line and manifold for Fadhili pressures.

B. H. GOLDING
Chief Petroleum Engineer (AA)

cc:
Chief Engineer - DH
Supt., Abqaiq Producing
Supv., Dvlp. Engr. - ABQ (w/40 copies ea. attach)
Drilling Equipment Engineer - ABQ
Well File: ADW-3
PE Files
Letterbook
SCHEMATIC WELLHEAD MANIFOLD
AIN DAN WELL 3
(Fadhili Single)

3" CAMERON PLUG VALVE
5-900

3" 3000 MSP NORDSTROM PLUG VALVE

1" NORDSTROM PLUG VALVE

2" 3000 MSP KILL CONNECTION

4" 5-900 - 2000 MSP BLOCK VALVE

GROUND LEVEL

LEGEND

PRESENT ITEMS

NEW ITEMS TO BE ADDED DURING WORKOVER

RAA 11/2/69
This paper discusses the production problems due to the subsurface safety valve failures encountered in the offshore Berri Field since start-up of the GOSP on September 26, 1970.

Standard practice is to equip all offshore wells with safety valves. Any defective safety valve must be repaired or at least the well must be placed in a secure position, i.e., the safety valve closed if possible or the well killed with mud, as soon as practical after a safety valve is known to be defective.

This discussion covers the causes of the safety valve failures, the temporary expedients utilized to get the wells back on production as quickly as possible, and the modification being made to eliminate future failures. The major cause of the safety valve failures was the flexing and failure of the control lines due to the high rates of flow of the particular Berri type crude.

INTRODUCTION

Actual production started on September 26, 1970 at a rate of 90 MBCD. This production was from three wells and three additional wells were readied for production to bring the total field potential to slightly over 150 MB/D. This production was not achieved due to subsurface safety valve problems. As a result of safety valve failures and the resultant workovers required, the targeted production of 150 MBCD was not achieved until early December just prior to the first trunkline rupture.

DISCUSSION

Exhibit 1 indicates the present Berri offshore tie line-trunkline system. At the time the field was brought on stream two wells had been completed on the northern four-well platform B-15/18, and two wells were completed on the southern four-well platform B-19/22. An additional two wells (BW-11 and BW-5) had been completed on single well platforms. The NDF-2 had just completed the first well on the eight slot, six producing well platform B-26/33.

In accordance with standard offshore safety practice, all wells were equipped with subsurface safety valves. As shown in Exhibit 2, a packer and safety valve are set at a minimum of 100' below the Gulf floor at approximately 300 feet from the derrick floor. Flow was through the safety valve up either tubing or casing or both. The safety valve is held open by means of hydraulic pressure applied through a small diameter (1/4" tubing or 1/8" pipe) strapped to the main tubing string and run in the annulus. When pressure on the control string is released, either by a flowline break which immediately
actuates a pressure sensitive pilot valve, or by rupture of the control line for any reason, the valve closes, securing the well.

At Berri, safety valve problems were encountered on the second day of production. Loss of pressure in the control line because of control line leaks caused frequent closures and required constant surveillance by the producing personnel. In the event of minor control line leaks, pressure can frequently be maintained by including the use of more viscous oil, teflon strips, nitrogen bottles, etc.

Shortly after being placed in service five of the installations developed serious malfunctions requiring the wells to be worked over and the valves changed out. This work was done by both the AMDP-1 and, where required, by the AMDP-2 during October and November of 1970. Thus production was severely restricted during this period both by the loss of production from the faulty wells and by the necessity of shutting in adjacent wells during rig moves.

All workovers indicated the control lines to have been cracked or broken. In addition, two wells with wireline retrievable valve installations had experienced difficulties with the retrievable valve assemblies becoming dislodged and found up the hole. Either the valves were not properly seated initially or became unseated during production.

Initially H₂S was suspected as being the cause of the control line failures. At Safaniya, for example, there are approximately 100 installations in sweet crude service. These safety valves have been in operation for over seven years with only 9 failures. Only four of these failures have been recorded as being due to control line failure. Flow in these wells is through the annulus with control line in the flow stream at rates up to 25 MBD.

However, analysis of the pieces of control lines recovered from the Berri wells indicated H₂S was not a contributing factor. The multiple hairline cracks and fractures in the 1/4" stainless steel lines were due to flexure. These multiple fractures due to flexing of the control line at Berri (while few were experienced at Safaniya) is attributed to one or more of several factors. The most likely factor is the higher velocities encountered due to higher flow rates and to the different PVT characteristics of the crudes, i.e., higher GOR, etc.

A second possible factor was vibration due to either slugging flow and/or high fluid velocities through the retrievable safety valve. This vibration is also a possible cause of the retrievable assemblies unlatching and being found up the hole. The stainless steel clamps holding the small diameter control line to the tubing also were found broken indicating there had been considerable vibration and/or flexing of the control line.
CONCLUSIONS

Based on the preceding discussion, it was concluded that the major cause of the safety valve failures at Berri was the flexing of the control lines due to high rates of flow of the particular Berri type crude. The rates of flow and resultant vibrations through the wireline retrievable valves also were possibly a contributing cause of the retrievable assemblies found up the hole on several occasions.

As a temporary expedient to put the wells back on production as quickly as possible, using equipment available in stock, the tubing retrievable safety valves were run using 1/8" nominal black steel pipe for the control line. The 1/8" steel pipe was used as it is more rigid than the 1/4" stainless steel tubing and could be fastened to the tubing string more securely to prevent flexing. The tubing retrievable safety valves were run as the ID of these valves is 3" and 4" whereas the maximum ID of the 4" OD wireline retrievable valves is only 2". The larger ID valves decreases the velocity of flow at the same rate of production reducing vibrations. Also since the tubing retrievable valve is an integral part of the tubing string there is no possibility of flowing this valve up the hole.

Presently the wells are being completed with 7" casing as tubing above the ball valve. Flow is through tubing only eliminating the possibility of flow causing vibration and fatigue of the control line. Corrosion and chloride stress is minimized by replacing the stainless steel control line with monel tubing and pumping inhibited diesel into the 7" x 9-5/8" annulus. Where wireline retrievable valves are installed, a revised locking mandrel has been utilized to minimize the possibility of flowing the valve up the hole.

FUTURE PLANS

Future plans call for the installation of large ID wireline retrievable safety valves (3.5" ID or greater) with modified hold-down equipment. Flow will be through large size tubing only (7" OD casing) with no flow in the annulus which will contain the control line, and sweep connections in the tree. This is illustrated in Exhibit 3. These modifications will eliminate control line flexing and reduce vibrations and thus minimize or eliminate future safety valve failures. These modifications have been developed with three different vendors. Since valves of the size desired are all prototypes, trial installations of various vendors will be evaluated. Products of two of the vendors (Otis and Page) have been selected and will be installed and the relative merits evaluated.

ACTIVITIES - SAFETY VALVE
1971  PAGE 3
REVISED BERRI OFFSHORE
SINGLE WELL COMPLETION

1/4" CONTROL LINE

OTIS SUBSURFACE SAFETY VALVE (RETRIEVABLE)

9 5/8" X 4" PACKER @ 300'

2 7/8" TUBING

7" CASING FOR TUBING

LOCKING MANDREL

CIRCULATING PORT

30" @ 200'

7" x 9 5/8" ANNULUS FILLED WITH INHIBITED DIESEL

HANIFA RES. @ 7830' (OPEN HOLE)

9 5/8" @ 7800'

T. D. @ 8000'

ACTIVITIES - SAFETY VALVE
1971 - EXHIBIT 3
APPENDIX L

Dhahran
November 24, 1970

COMMUNICATION MEETING

CHIEF PETROLEUM ENGINEER
Petroleum Engineering Department

As an outgrowth of the Phase II Grid, a committee was formed to investigate means of making the Petroleum Engineering Sunday Communication Meeting more effective. The committee was comprised of Messrs. R. A. Akkad, A. H. Davis, J. C. T. Dhahra, J. F. Foster, G. W. Spais and J. L. Turner. The first step of this committee was to analyze the problems and to issue a questionnaire to those attending the Sunday meeting. A total of 20 employees answered the questionnaire. These answers were analyzed and using the analysis plus opinions of committee members the data discussed below were developed.

Shown first are the questions asked in the questionnaire and the distribution of "Yes" and "No" answers received. Problems associated with the Communication Meeting are then discussed and are followed by recommendations to make the meeting more effective.

I. QUESTIONNAIRE

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<th>Question</th>
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<th>No</th>
<th>No Comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Is downwards communication adequate</td>
<td>11</td>
<td>15</td>
<td>3</td>
</tr>
<tr>
<td>2. Is upwards communication encouraged. Can you be candid?</td>
<td>20</td>
<td>9</td>
<td>0</td>
</tr>
<tr>
<td>3. a) Do you feel that communication between individuals and the group is necessary or desirable.</td>
<td>20</td>
<td>9</td>
<td>0</td>
</tr>
<tr>
<td>b) If answer is &quot;Yes&quot;, is lateral communication handled adequately.</td>
<td>8</td>
<td>12</td>
<td></td>
</tr>
<tr>
<td>4. Should special presentations be given.</td>
<td>25</td>
<td>4</td>
<td>0</td>
</tr>
<tr>
<td>5. Is current meeting time of 10:30 hours adequate.</td>
<td>26</td>
<td>3</td>
<td>0</td>
</tr>
<tr>
<td>6. Is there anything you dislike about the meeting. (Give reasons)</td>
<td>20</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>7. Should the Sunday Communications Meeting continue to be held.</td>
<td>17</td>
<td>10</td>
<td>2</td>
</tr>
</tbody>
</table>
II. PROBLEM AREAS

Downward Communication

1. A credibility gap exists between what is communicated and what can be communicated aside from SAG censorship and Aramco corporate confidential information. Examples of items in which employees feel they are poorly informed are labor law, social security law, political situations that affect the employee, salary administration and school, housing and medical issues.

   A very large percentage of information on the preceding types of items is obtained through unofficial sources. This leads to a credibility gap between the employee and official communication channels.

2. Persons conducting the Communications Meeting sometimes do not have sufficient background to be able to elaborate on questions arising during the meeting.

3. Reading from the "Highlights and Notices" sheet contributes little to the meeting unless there is something to add or on which to elaborate.

Upward Communication (Can one be Candid?)

1. Although the majority of those answering the questionnaire believe that a person can be candid in the meeting, one-fourth of those answering think they cannot be completely candid. The reasons given were that pertinent questions were rebuffed or discouraged and attempts to be candid concerning policies that management may not wish to discuss (Salary adjustments, stateside salaries, labor law) were thwarted. Techniques used to cut off too candid an approach were stated in the questionnaires as belittling or pigeonholing the question.

2. The large group in the Communications Meeting inhibits some persons from speaking candidly.

Lateral Communication

1. The majority believes that the exchange of information between individuals and units is desirable, but the majority also believes that it is not handled adequately. Complaints were that information presented becomes too routine and repetitious and occasionally wastes time. Some think that the group is too large to handle lateral communication as it is presently done.

Special Presentations

The overwhelming majority believes that special presentations should be made in order to obtain more complete communication.
Meeting Time of 10:30 hours

No particular problem.

Dislikes Concerning Meeting

These are listed according to order of frequency as obtained from answers in questionnaire. Some of these items were discussed in the preceding.

1. Too much reading of "Highlights and Notices" without elaboration.
2. Lack of information on non-departmental subjects (Company policies, labor law, etc.)
3. Holding meetings when there is insufficient new information to warrant meeting.
4. Failure of substitute chairman to be adequately prepared to explain material covered due to insufficient background.
5. Lack of follow-up on questions raised but unanswered at meeting.
7. Lack of understanding of scope and purpose of meeting.
8. Insufficient seating capacity.

Should Meeting Continue to be Held?

1. Although the majority voted "Yes", a number of the "Yes" votes, as well as some of the "No" votes, stated that it should be continued only if modified and improved. Also, some stated that it should not be held unless there is something worthwhile to contribute.

2. Some objected, because of repetition, to being in both a Departmental Communication Meeting as well as a Unit meeting.

III. RECOMMENDATIONS FOR IMPROVEMENT

It is the opinion of the Committee that the weekly Communication Meeting should provide an opportunity for downward, upward and lateral communication. The end result will be: (a) employees who are better informed concerning Aramco operations, objectives, policies and issues which affect their daily activities; (b) to offer an avenue for employee questions and suggestions and (c) to provide an opportunity for exchange of information between different Petroleum Engineering Units and other Departments.

Based on the preceding opinion, the following recommendations are presented.

1. In order to overcome the credibility gap between employees and management, it is recommended that the Chief Petroleum Engineer clarify Company policy on dissemination of information and, if feasible, the reasons
behind the policy. Clarification is needed on both Company and non-
Company events which affect the employee and in which he feels he is
inadequately informed. One of the main difficulties is that some
people in the Company are known to have information which affects all
(such as Governmental events), but the majority obtain the information
by rumor. Encourage more downward communication in order to attack
rumors.

2. Distribute the "Highlights and Notices" prior to the communications
meeting. This will allow a person to formulate his questions and ask
them during the meeting. It will also eliminate the need to read the
"Highlights", but would still allow elaboration on the information given.

3. The person representing Petroleum Engineering in Management's Commmu­
nication Meeting should have a good overall background and be familiar with
events that have taken place during the week. He should be able to add
comments and elaborate on what was given in Management's meeting.

4. The importance of the Communications Meeting should be demonstrated by
having the Chief Petroleum Engineer and Supervisors attend whenever
possible. If this level of personnel does not attend the "troops" soon
get the feeling that the meeting is not very important.

5. Upward communication should be stimulated and persons encouraged to be
candid even though their subject may not be popular. Some persons need
to be encouraged to participate because of their reluctance to speak
before a large group.

6. Work reports should be done by Unit and organized and directed by the
Unit Supervisor rather than to have each individual tell what he is
doing. The Supervisor should, generally, not give the report himself,
but delegate individuals from his Unit. The work report should be
brief, cover items which are not strictly routine and be of general
interest. If there is nothing of general interest in the Unit for that
week, it should be so stated. The above procedure is a more organized
approach than that currently used and higher quality information will
be given.

7. Special presentations should be given on the average about once per month.
Since the group is multi-national, presentations selected should, as much
as possible, be of general interest when given by outside departments.
The questionnaire answers favored outside department presentations over
presentations from within the Department although both were of interest.
The total time for the Communications Meeting, including special presenta­
tions, should be kept within one hour, except for unusual cases. Internal
presentations can be selected by the Chief Petroleum Engineer from
recommendations made by the Unit Supervisors. External presentations
can be determined based on the needs and desires of the group and the
judgment of the Chief Petroleum Engineer.

Objectives for special presentations are both technical and non-technical.
Technical presentations are for upgrading and exchange of information.
Work related general interest subjects will help show the direct and indirect relationships between Petroleum Engineering and other organizations. Non-work related general interest subjects are also of value owing to the special nature of our dependence on Aramco for services normally provided by local government or free enterprise.

7. For questions that are raised and cannot be answered during the meeting, someone should be given the direct responsibility to answer the question at a specific time.

8. Provide enough seating space for all attending.

9. It is recommended that after six months an evaluation be conducted to determine progress made in improving the Communications Meeting.

In conclusion, the Communication Meeting fills a need, aside from safety requirements, and should be continued. However, in order for the meeting to be more effective, changes are necessary. Underlying most of the recommended changes is the need to upgrade the importance of the meeting so that those for whom the meeting is held will become more committed to attend and participate. The committee believes that the desired effect will be achieved if the changes recommended are implemented and followed through.

COMMUNICATIONS MEETING COMMITTEE

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The following procedure is recommended for pulse testing Shaybah Well No. 8 in the Shu'aiba reservoir. Three zones will be pulse tested in six 5-foot perforated intervals in the following manner:

- For Interval (3)
- Static Test Pressure at Intervals (1), (2), (3)
- Flow Interval (5)
- Static Test Pressure at Intervals (5), (4), (5)
- Flow Interval (6)
- Surface Pressure at Intervals (5) & (6)

The well was completed on January 13, 1970 after the well was drilled to a total depth of 5605' and plugged back to 5211'. A string of 2-3/8' tubing was run and hung at 4601' with open ended tubing collar at bottom. The well was left with crude oil in the tubing and annulus.

Well Data

- Total Depth: 5205' DF
- Plugged Depth: 5211' DF

Casing:
- 9-5/8", 75#/#ft J-55 @ 853'. Cemented to surface
- 7", 25#/ft, 29/4XL @ 3421'. Cemented in two stages, returns on 2nd stage.

- 4½" liner, 13.5#/4-80 @ 3117-5253' cemented.

Tubing:
- 2-3/8", 13.5# with open ended tubing collar hung @ 4601'.

Mud to kill well: 32 PCF (for 300 psi overbalance)

Work Requirements

I Preliminary Work

1. Rig up 9-5/8" and run a 1-1/16" Neutron, CCL and microseismogram cement bond log from TD to 500' above top of Shu'aiba. If the MSG log indicates a weak bond, a supplementary program will be issued to perforate and squeeze intervals to be specified by the log analyst on site. A second MSG will be required to check results of the squeeze to fail assure a good bond. If bonding proves satisfactory, proceed to pulse testing.
I Preliminary Work (Cont'd)

2. Rig up the T-32 rig on SyW-8.

3. Displace the oil with 82 PCF mud. Remove the Xmas tree and nipple up the BOP.

4. Run a 3-3/4" bit and scraper with a junk basket and scrape clean inside the 4½", 13-5/8" casing. Circulate the hole with mud at least one casing volume.

II Flowing Intervals (3) and Observing Pressure at (1), (2), (3)

1. Perforate in and the bottom 3 intervals, 4 holes offset at 90° at intervals 5952-5048', 5012-5008' and 4972-4968'. Perforating depths refer to Sidewall Neutron-Calliper log, run #1, January 9, 1970.

2. Run a 4½" Otis "WB" packer on wireline and set at 5038' (10' above top perforation of interval (1) using Baker #10 setting tool.

3. With the tools made up and measured at the surface, run a 4½" Otis type "PA" packer on 2-3/8" EU tubing with all the tools shown on Schematic #1. Both sliding side doors are to be run in the closed position. When the "WB" packer depth is reached, tag the packer gently with the locator sub. Pick up and space out. Sit back down enough to seal the "WB" packer but not enough to set the "PA" packer.

4. Pump down the tubing at approximately 500 psig and check the annulus for communication behind the "WB" packer.

5. Set the "PA" packer by setting the weight of the tubing on the packer. Nipple up the Xmas tree and test for leaks.

6. Open the lower "XO" sliding side door. Test the "PA" packer by pumping mud through the annulus and observing the tubing. Close the lower "XO" SSD.

7. Open the top SSD and circulate the mud out by pumping diesel oil preceded by a 40-barrel water cushion.

8. Open the bottom "XO" SSD. Flow the three intervals to the surface until oil is free from mud contamination.

9. Keep the upper "XO" SSD open and close the lower "XO" SSD.

10. With the annulus valve open, pump 500 gallons 15% acid down the tubing and using dead Shaybah crude displace the acid to the top of the upper "XO" SSD. Close the annulus valve and close the upper "XO" SSD. Pump 500 gallons of dead Shaybah crude down the tubing displacing the acid into interval (1). Then flow back until sample is free from acid water contamination.
11. Run the first set of tandem Sperry Sun bombs on a Type "B" Otis hanger and hang in collar of the 6' pup joint above the "WB" packer.

12. Run "PS" plug and set in Position #1 "S" landing nipple.

13. Open the upper "XO" SSD. Spot 500 gallons of 15% acid to the top of the upper SSD; use dead Shaybah crude for displacement. Close the upper SSD in acid and open the lower SSD. Close the annulus valve.

14. Pump 500 gallons dead Shaybah crude down the tubing displacing acid into interval (2). Then flow back until sample is free from acid contamination.

15. Run the second set of tandem Sperry Sun bombs on a "H" hanger and set on collar below the lower SSD. Run "PS" plug and set in Position #2 "S" nipple.

16. Open the upper "XO" SSD. With the annulus valve open, pump 500 gallons of 15% acid down the tubing, and using dead Shaybah crude spot acid to top of the upper "XO" SSD. Close the annulus valve and pump 500 gallons more of dead Shaybah crude down the tubing thereby displacing the acid into interval (3). Flow back acid water until clear oil is received at the surface.

17. Run the third set of tandem Sperry Sun bombs and hang just below the upper "XO" SSD (as shown in Schematic #1) using Amerada shock absorbers.

18. Flow interval (3) observing pressures at intervals (1), (2) and (3). Flowing period is 24 hours.

19. Upon completing the test, pull the Sperry Sun bombs and the "PS" plug choking in the reverse order of their installation, closing the lower "XO" SSD after the bombs have been pulled.

20. With the upper "XO" SSD open, kill the well with 82 PCF mud pumped through the tubing. Check the weight of the returning mud to assure a kill.

21. Remove the X-mas tree and nipple up the BOP. Pull the tubing and tools leaving the "WB" packer in the hole.

22. Run a 4 1/2' 12 drill squeeze packer and set at 4998' + . Test the packer setting and pull out of hole.
III Flowing Interval (5) and Observing Pressures at (3), (4), (5)

1. Perforate in mud the intervals (4) and (5); 4 holes offset at 90° at 4932-4926' and 4892-4888' respectively.

2. Run a 4½" Otis "WB" packer on wireline and set at 4958' (10' above top perforation of interval (3)) using Baker #10 setting tool.

3. With the tools made up and measured at the surface, run a 4½" "PA" packer on 2-3/8" tubing with all the tools as shown in Schematic #2. Both sliding side doors are to be run in the closed position. When the "WB" packer depth is reached, tag the packer gently with the locator sub and note the depth. Back up and space out. Sit back down enough to seal the "TO" packer but not enough to set the "PA" packer.

4. Pump down the tubing at approximately 500 psig and check the annulus for communication behind the "WB" packer.

5. Set the "PA" packer by setting the weight of the tubing on the packer. Nipple up the X-mas tree and test for leaks.

6. Open the lower "XO" SSD. Test the "PA" packer by pumping mud through the annulus and observing the tubing. Close the lower "XO" SSD and open the upper "XO" SSD.

7. With the annulus valve open, displace the mud with 40 barrels water followed by diesel oil.

8. Open the lower "XO" SSD. Flow the three intervals to the surface until clean oil is received.

9. Close the lower "XO" SSD.

10. With the annulus valve open, pump 500 gallons 15% acid down the tubing and using dead Shaybah crude displace the acid to the top of the upper "XO" SSD. Close the annulus valve and close the upper "XO" SSD. Pump 500 gallons more of dead Shaybah crude down the tubing thereby displacing acid into interval (5). Flow back acid water until clean oil is received at the surface.

11. Run the first set of tandem Sperry Sun bombs on a Type "B" hanger and hang on the top collar of the 6' pup joint above the "WB" packer.

12. Run a "PS" plug choke and set in Position #1 "B" nipple.

13. Open the upper "XO" SSD. With the annulus valve open spot 500 gallons of 15% acid to the top of the upper SSD; use dead Shaybah crude for displacement. Close the upper SSD in acid and open the lower SSD. Close the annulus valve.
14. Pump 500 gallons more of dead Shaybah crude down the tubing thereby displacing acid into interval (4). Flow back acid water through the tubing until clean oil is received at the surface.

15. Run the second set of tandem Sperry Sun bombs on an Otis "B" hanger and set on collar below the lower SSD. Run "PS" plug choke and set in Position #2 "S" nipple.

16. Open the upper "XO" SSD. With the annulus valve open, spot 500 gallons 15% acid to top of the upper "XO" SSD; use dead Shaybah crude for displacement. Close the annulus valve and pump 500 gallons more of dead Shaybah crude down the tubing thereby displacing acid into interval (5). Flow back acid water until oil is received at the surface.

17. Run the third set of tandem Sperry Sun bombs and hang just below the upper "XO" SSD using Amerada shock absorbers.

18. Flow interval (5) observing pressures at intervals (3), (4), and (5). Flowing period is 24 hours.

19. Upon completing the test, pull the Sperry Sun bombs and the "PS" plug choked in the reverse order of installation, closing the lower "XO" SSD after the bombs have been pulled.

20. With the upper "XO" SSD open, kill the well with 82 PCF mud and pump through the tubing. Check the weight of the returning mud to assure a kill.

21. Remove the X-mass tree and nipple up the BOP. Pull the tubing and tools leaving the "WB" packer in the hole.

22. Run a 4½" EZ drill squeeze packer on 2-3/8" tubing and set at approximately 4918'. Test the packer setting and pull the tubing out of hole.

IV Flowing Interval (6) and Observing Pressure at (5) and (6)

1. Perforate in mud the uppermost interval No. (6) with 4 holes per four feet at 4852-4848'.

2. Run a 4½" Otis "WB" packer on wireline and set at 4876' (10' above top perforation of interval (5) using Baker #10 setting tool.

3. With the tools made up and measured at the surface, run the tool shown on Schematics #5 on 2-3/8" EU tubing. The "XO" sliding side door is to be run in the closed position. When the depth of the "WB" packer is reached, tag the packer gently with the locator sub. Pick up and space out. Set down the tubing weight enough to seal the "WB" packer.
4. Test the "WB" packer by pumping at approximately 500 psi through the tubing and checking the annulus for communications.

5. Nipple up the X-mas tree and test for leaks.

6. Open the "XO" SSD. With the annulus valve open, displace mud with 40 barrels water followed by diesel oil. Flow intervals (5) and (6) until oil is received at the surface.

7. Pump 500 gallons of 15% acid to the top of the "XO" SSD by displacing with dead Shaybah crude. Then close the SSD and close the annulus valve. Pump 500 gallons more of dead Shaybah crude down the tubing thereby displacing the acid into interval (5).

8. Flow acid water back until oil is received at the surface. Run the first set of Sperry Sun bombs in tandem on Amerada shock absorbers and hang at top collar of the 6' pup joint above the "WB" packer.

9. Run "PS" plug choke and set in Position #1 "S" nipple.

10. Open the "XO" SSD and open the annulus valve. Pump 500 gallons of 15% acid to top of the "XO" SSD by displacing with dead Shaybah crude. Close the annulus valve and pump 500 gallons more of dead Shaybah crude down the tubing thereby displacing the acid into interval (6). Flow back acid water until clean oil is received at the surface.

11. Run the second set of tandem Sperry Sun bombs on Amerada shock absorbers and hang on collar below the "XO" SSD.

12. Flow Interval (6) observing pressure at intervals (5) and (6). The duration of the test will be 24 hours.

13. At the end of the test, pull the Sperry Sun bombs and the "PS" plug choke.

14. Kill the well with 82 PCF mud pumped through the tubing with return out of the annulus. Check the weight of the returning mud to verify a kill.

15. Pull the tubing and tools leaving the "WB" packer in the hole.
February 15, 1970
Manager, Drilling - Abqaiq

16. Drill out the three "WB" packers and the two EZ drill squeeze packers. Circulate the well clean. A supplementary completion program will be issued.

Pulse Testing
Shaybah Well No. 6

Signature
Supervisor, Production Engineering

Signature
Supervisor, Development Engineering

Attachments

cc: Regular Distribution
SHAYBAH WELL-B PULSE TEST

II. FLOWING INTERVAL (3) AND OBSERVING BETWEEN (1), (2) AND (2), (3)

3rd Set Standard
Cement Plug

TEST INTERVAL 4948
(3) 4972

1/2", 13.5 FT, N:80' Casing
2 3/8" EU Tuning TO Surface

2 3/8" OTIS Type "XO" SSD

2 3/8" EU Pup Joint, 12'

2 3/8" EU Pup Joint, 10'

Top Pkr. @ 4992'

2nd Set Sperry
Bomb

TEST INTERVAL 5008
(2) 5012

4 1/2" OTIS Type "PA" Packer
(Tuning Set By Compression)

Pos. #2 5" Nipple For Pos. #2
1/2" Plug Choke

2 3/8" EU Pup (Mud Slotted, 1, 1)

2 3/8" OTIS Type "XO" SSD

2 3/8" EU Pup Joint, 12'

2 3/8" EU Pup Joint, 10'

1st Set Sperry
Bomb

Top Pkr. @ 5032'

TEST INTERVAL 5048
(1) 5052

1 1/2" EU Pup Joint, 6'

1'-Crossover 3 1/2" Nipple Down
2 3/8" EU Box Up

4 1/2" OTIS Type "WB" Packer

Seal Assembly (Wireline Set)

1/2" Perforated Pup Joint, 12'

1/2" Perforated Bull Plug

Schematic #1
SHAYBAH WELL-8 PULSE TEST

FLOWING INTERVAL (5) AND OBSERVING BETWEEN (3), (4) AND (4), (5)

TEST INTERVAL

TOP PKR. @ 4912'

2nd Set Tandem Sperry Sun Bombs

TEST INTERVAL 4928

12'

TOP PKR. @ 4928'

1st Set Tandem Sperry Sun Bombs

TEST INTERVAL 4968

12'

4 1/2", 13.5 WT., N°80 CASING
2 3/8" EU TUBING TO SURFACE
2 3/8" OTIS TYPE "XO" SSD
2 3/4" EU PUP JOINT, 12'
2 3/4" EU PUP JOINT, 12'

4 1/2" OTIS TYPE "PA" PACKER
(TUBING - SET BY COMPRESSION)
Pos. #1 5" Nipple for Pos. #1
1 7/8" Plug Choke 10 5/8 92
2 3/4" EU PUP JOINT, 12'
2 3/4" EU PUP JOINT, 10'

Pos. #1 "S" Nipple for Pos. #1
7/8" Plug Choke 10 5/8 92
2 3/4" EU PUP JOINT, 12'
2 3/4" EU PUP JOINT, 10'

1" CROSSOVER 2 3/4" Nipple Down
2 3/8" EU Box Up

4 1/2" OTIS TYPE "WA" PACKER AND
SEAL ASSEMBLY (WIRELINE-SET)
1 7/8" PERFORATED PUP JOINT, 12'
1 1/2" PERFORATED BULL PLUG, 1'
1 1/2" EZ DRILL PACKER @ 4998'

SCHEMATIC # 2

RAA 2/3/70
SHAYBAH WELL-8 PULSE TEST

IV. FLOWING INTERVAL (6) AND OBSERVING BETWEEN INTERVALS (5) & (6)

2nd Set Tandem Sperry Sun Bombs

Test Interval 4848 (6)

12'

4852

2 3/8" PUP JOINT, 12'

2 3/8" EU PUP JOINT, 10'

1/2" PERFORATED PUP JOINT, 12'

1/2" PERFORATED BULL PLUG, 1'

Schematic #3

RAA 2/3/70
APPENDIX N
NORMAL WORK DONE BY THE FIELD SERVICES UNIT

The following is the author's recollection of the normal work performed by the Field Services Unit, of which he was foreman from August 1, 1971 through March 18, 1972. The list is not exhaustive, and the work included all oil, gas, and water injection wells within the Aramco concession area.

1. Build, drag, and lay all flarelines. Flarelines were tubing joints (old or new) connected together and manifolded to the wellhead to allow discharge of the well's affluent which was flared at the end of the flareline. They were either single or tandem and were 300 to 350 feet long. Offshore flarelines had the addition of floats, anchor chains and buoys. An example of offshore flareline is shown in Figure N-1.

2. Revive all wells by injecting live crude from other wells, nitrogen from liquid nitrogen bottles, etc.

3. Bring-in, flare, and collect crude samples from all new or worked over wells. Where extensive flaring was required, contract watchmen were utilized who were under the supervision of the Field Services Foreman.

4. Prepare the hook-up for acidizing all wells and flaring as required until clean oil was produced to the concerned Gas-Oil Separating Plant (GOSP).
5. Assist GOSP foremen in returning wells to production during peak demand periods.

6. Dismantle and re-install remote controls, guard rails, wellhead manifolds, etc., for workovers or when required for other reasons.

7. Perform yearly annuli surveys (scheduled by production engineers), including installation of pipe and valves for such surveys.

8. Cement all annuli as required (e.g., many Safaniya wells).

9. Repair or replace all malfunctioning valves on wellhead including the block limit valve.

10. Stabilize well cellars. This was generally limited to old fields (e.g., Dammam).

11. Install meters (turbines, orifice, etc.) and manifolds for well tests (e.g., SyW-4, 8; BW-1, 2, 7; ShWW-14, 15; etc.).

12. Kill wells with brine or mud as necessary (e.g., AW-111, 114, 115, etc.).

13. Construct and install drum well markers, for all wells, and gin poles for gravity injection wells.

14. Repair high pressure equipment such as chicksans, valves, umbolts, etc.

15. Coordinate each job with the various concerned parties.
Figure N-1. Schematic of an Offshore Floating Flareline.
VITA

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The typist for this report was Mrs. J. C. Hodges.