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Petroleum and Natural Gas Section

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FOREWORD

THE year 1937 was marked in the later months by a steady decrease in the market price which the Pennsylvania grade crude oil commanded on the eastern refinery market; the unsettled conditions of the eastern oil industry continued well into the first half of the year 1938 and it was a timely opportunity to have a prominent oil economist come and analyze the recent oil market collapse. Unfortunately it has not been possible to reproduce in extenso the talk which Mr. Gill presented at the meeting but we are happy to include in the proceedings the charts which illustrated his extemporaneous communication.

The application of rotary drilling for deep gas sands in the Appalachian region has long been debated. However, considering the present activity in rotary drilling in this territory, the presentation of a paper dealing with the types of equipment in use and the economic justification of rotary drilling in the East is of particular interest.

Other problems facing the oil and gas men of Pennsylvania are herein discussed and appear in this volume as a ready reference.

The success of the conference was due to the help, interest, and support of the following groups:

The Pennsylvania Natural Gas Men’s Association
The Pennsylvania Grade Crude Oil Association
The Bradford District Pennsylvania Oil Producers’ Association, whose splendid cooperation we gratefully acknowledge.

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## CONTENTS

<table>
<thead>
<tr>
<th>Title</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Salvaging Oil Field Equipment, by <strong>Winston L. Davis</strong></td>
<td>1</td>
</tr>
<tr>
<td>Reclamation and Maintenance of Oil Field Equipment, by <strong>E. J. W. Egger</strong></td>
<td>8</td>
</tr>
<tr>
<td>Application of Packers to Oil and Gas Well Drilling and Production, by <strong>John Pearson</strong></td>
<td>17</td>
</tr>
<tr>
<td>Safety on a Repressured Lease, by <strong>H. D. Brown, Jr.</strong></td>
<td>35</td>
</tr>
<tr>
<td>Economics of the Pennsylvania Oil Situation, by <strong>John D. Gill</strong></td>
<td>39</td>
</tr>
<tr>
<td>Rotary Drilling in the Appalachian Region, by <strong>Maurice E. Nicklin</strong></td>
<td>57</td>
</tr>
<tr>
<td>Progress in Industrial Utilization of Natural Gas, by <strong>D. A. Campbell</strong></td>
<td>79</td>
</tr>
</tbody>
</table>
ILLUSTRATIONS

Salvaging Oil Field Equipment—Winston L. Davis

Fig. 1.—Miscellaneous uses for salvaged equipment... 3

Application of Packers to Oil and Gas Well Drilling and Production—John Pearson

Figs. 1.—Oil well packer.......................... 19
2.—Regular oil well packer...................... 19
3.—Midget type oil well packer................. 19
4.—Four expanding tapered steps packer...... 19
5.—Special conical sleeve gas anchor packer... 21
6.—Regular oil well packer..................... 21
7.—Details of automatic packing ring........... 21
8.—Regular bottom set combination wall and anchor packer.......................... 21
9.—Hook wall packer—tubing size.............. 23
10.—Pressure relief packer..................... 23
11.—Packer with tapered hook engaged........ 25
12.—Pumping top.................................. 25
13.—Gas escape top............................. 25
14.—Disc and hook cave packers............... 25
15.—Tool set cave packer....................... 27
16.—Crumley hook wall fluid release packer... 29
17.—Comparison of a packer to the fluid end of a water pump......................... 29
18.—Use of packers in repressuring oil sands... 31

Safety on a Repressed Lease—H. D. Brown, Jr.

Figs. 1.—Frequency distribution of accidents according to their types.................. 37
2.—Effect of education on the reduction of lost-time and fatal accidents.............. 37

Economics of the Pennsylvania Oil Situation—John D. Gill

Figs. 1.—Inventories and prices, Pennsylvania grade steam refined................... 43
2.—Inventories and prices, Pennsylvania grade bright stocks......................... 44
3.—Inventories and prices, Pennsylvania grade viscous neutrals..................... 45
4.—Inventories, prices, and demand........................................ 46
5.—Inventories and prices, Appalachian region refinery gasoline................... 47
6.—Inventories and prices, Appalachian region kerosene............................ 48
7.—Inventories and prices, Appalachian region lubricating oils.................... 49
8.—Monthly average unit value of crude oil and petroleum products.............. 50
9.—Pennsylvania grade crude oil, supply demand ratio—demand and production..... 51
10a.—Economic relationships...................... 52
10b.—Economic relationships...................... 53
11.—Crude prices and well completions......................................... 54
12a.—Crude oil prices............................ 55
12b.—Crude oil prices........................................... 56

Rotary Drilling in the Appalachian Region—M. E. Nicklin

Figs. 1.—Mountainous terrain at location of 8500 feet. Deep test drilled with steam rotary rig in North Central Pennsylvania near Keating Summit......................... 59
2.—Rotary rig derrick floor showing drilling controls all conveniently located at driller's position........................................ 60
3.—An “Oilwell” portable No. 7 double engine drive................................ 60
4.—“Oilwell” portable superheated steam generators................................ 62
Salvaging Oil Field Equipment

BY WINSTON L. DAVIS, Engineer and Superintendent
Moore Producing Company, Bolivar, N. Y.

The present is an appropriate time for a discussion of salvaging equipment due to three existing conditions:
First—the low price of crude oil.
Second—the high cost of new material.
Third—the proration of production, with which some of us have had to contend for some time, and which to others is a comparatively new experience.

During the days when the price of, and demand for, crude were high, any producer could make money, regardless of whether he operated with any degree of economy or not. Any material that was needed on the lease was ordered from the supply store without a question as to price or as to whether something on hand would work just as well. Easy come, easy go, was the motto during prosperous times. However, we have a much different picture today. It is imperative now to operate just as economically as possible if one expects to make a profit, or even to continue in business. The point of proration is brought up not only because it affects the present income, but also because the time to practice the salvaging of material to an even greater degree is during proration in production, such as we have now.

During good times it is difficult to do any extensive salvaging of material due to the fact that all eyes are turned toward new developments, and most labor and equipment must be used for that purpose. With proration comes the curtailment of new development and, consequently, many good men must be laid off because of the lack of work. By salvaging equipment during these times of market distress, the producer can keep these good men on the payroll, thereby helping the whole community. Also, he can actually make money in the form of savings to be realized when material is again needed. Money saved is money earned.
The ideas and methods used in salvaging material are many, so it is the intention of the writer to point out just a few with which he is most familiar.

The first requisite, if one expects to salvage material intensively, is a centrally located and well equipped shop. This shop should be equipped with a pipe straightener, pipe cutter, pipe threading machine, boiler, steam rack, forge, power hammer, rod cutter, rod bender, electric drill, emery wheel, electric and acetylene welding outfits, and an electric hoist.

It has long been common practice to pull the casing out of wells which have been abandoned or put to pressure. However, the following method of pulling casing may be new to some. A pulling pole and tractor are used in the usual manner, but, in addition, hydraulic power is utilized wherever possible. It so happens that we have water pressure within a few hundred feet of any well on the property. From the nearest point a 1-inch line is run to the well which is to have the casing pulled. A full joint swing must be used at the well in order to take care of the vertical movement of the casing. On the top of the casing is screwed a cap made from a coupling which has a plate welded over one end with two 1-inch connections welded in. The water is turned into the well through one connection and the air released through the other. When the well is filled with water the air release valve is closed and the pressure builds up on the casing. If there are no leaks, the pipe will move upward slowly, controlled by regulating the valve on the water line, which is placed several joints from the well. After the casing is moved a few feet by this method, it can usually be pulled by the tractor without difficulty. The principle involved is simply that of hydraulics, in that a pressure of so many pounds per square inch acts upon a surface of a given number of square inches. In a 6½-inch hole the cross sectional area is 30.68 sq. in., which is acted upon by whatever water pressure is used. Let us assume 500 lbs. per sq. in. to be the pressure used; then there would be 500 times 30.68, or 15,340 lbs., acting to push the casing upward. This method has been very satisfactory, especially where long strings of 4½-inch casing are set on hook wall packers, which sometimes are impossible to pull with a pole and tractor alone. Here we have the area of a 4½-inch circle being acted upon by the applied pressure at the top of the string and the area which is the difference between a 6½-inch hole and that of 4½-inch being acted upon by the applied water pressure, plus the hydrostatic head at the bottom of the packer, thus pushing upward at the bottom as well as at the top. Assuming the packer set at 1000 feet and the applied pressure of 500 lbs. per sq. in., as previously mentioned, there would be 500 times 14.19, or 7,095 lbs., pushing upward at the top of the casing and 933 times 16.49, or 15,385 lbs., at the bottom.

Fig. 1. Showing uses for salvaged equipment. Top left: Tank supports from used pipe. Top right: Tie down. Left center: Miscellaneous parts. Right center: Taking bend out of used pipe. Lower left: Used equipment used in jack. Lower right: Miscellaneous parts.
When the casing has been pulled, it is inspected carefully and those joints which are in the best condition are either sent directly to the well in which they are to be used or put on the pipe rack to be taken out later. Those joints which are not in perfect condition are taken to the shop, where they are again inspected. Some joints need only to be retreaded, some have pits which have to be cut out, the rest of the joint being used for short nipples. Some joints are in such bad condition that they can be used only for slits, conduits for smaller lines in road crossings, or posts such as used in pipe racks or under small buildings.

Smaller pipe has very many uses in the salvaging process or program. When this pipe comes into the shop yard the crooked joints are straightened by the use of a simple homemade pipe straightener. This is composed of two 6x8 timbers connected together at one end with an inverted U-shaped strap iron and a sheave wheel which moves between the timbers. One end of the pipe is placed under the strap and the wheel is placed under the bend in the pipe with the bend concave upward. Then by pulling down on the end of the pipe, the bend is removed and the wheel is placed under the next one. When the lever arm becomes too short the joint is turned around and worked from the opposite end.

After being straightened, the pipe which can be again used as tubing or line pipe is retreaded, cleaned, and tested with 100-lb. steam. At this point it is separated, the tubing placed on one rack and the line pipe on another.

The pipe which does not pass inspection for tubing or line pipe is used in various ways, some of which follow.

Derricks for drilling are made from reclaimed pipe. These are usually made from 2-inch and 14-inch pipe, the legs and girts of 2-inch and the sway braces of 13-inch. The members, such as girts and sway braces, are cut the proper length and the ends flattened and drilled ready to be bolted to the castings on the legs. The pipe used for the legs is merely cut the desired lengths and clamped into the castings. Also, supports for water tanks, which must be elevated, are made in much the same manner, except that smaller pipe may be utilized. This type of derrick can be completely welded together, as it is usually not as high as standard drilling derricks and does not have to be taken down and reassembled.

The Oklahoma type pumping jack is another item in which reclaimed 2-inch pipe is used to good advantage. This pipe is used to make the pitman, legs, and braces. The pitman is made by simply cutting the pipe the desired length and putting the castings on the ends. The legs are cut and the ends to be used as the top are flattened and drilled to take the bolt which fastens the beam casting to the legs. The bottom ends of the legs are welded to a piece of 3-inch channel iron which was taken from an old V replaced by 4-inch channel. Short pieces of 2-inch pipe with ends flattened are welded to the legs and to the 3-inch channel for braces. The diagonal braces are cut, both ends flattened and drilled to be bolted, one end to the legs and the other to the sills. This construction makes a rigid pumping jack and eliminates the necessity of buying many castings, as well as creating another use for salvaged material.

Pull rod carriers or supports of different types utilize reclaimed pipe. The post type consists of a piece of 2-inch driven into the ground into which is inserted a grooved wooden plug that supports the rod. Another type, which we know as the “A” rocker, consists of two short pieces of 2-inch which have been drilled 4 or 5 inches from one end, driven into the ground at right angles to the direction of the rod line and about 3 or 4 inches apart according to the height of the rod line to be supported. Through the holes in these pipes is passed a rod which supports the two poles used as legs. The poles are bolted to the pull rod at the top. The bottom is fastened by the rod through the pipe. A piece of smaller pipe such as 11-inch or 13-inch is used as a spacer to keep the legs apart at the bottom instead of boards nailed to the legs as were previously used. The pipe spacer makes a more rigid and permanent job, as the wooden braces were broken when the rod line would break and the nails were continually shearing off.

The mentioning of “A” rockers brings up the subject of salvaging rods. When rods are brought into the shop, they are inspected and the ones which can be reused are straightened and placed on a rack to be taken out when needed. The others are cut into different lengths, depending on the service in which they are to be placed.

The reclaiming of old rods constitutes a major part of the salvaging process because there are so many ways in which they can be made into useful material.

Polished rods are worked up into D stirrups for Oklahoma packs, long D stirrups used on swings and stroke posts, and round rings used on tie backs and tie downs in a pull line. The repair of the worn D stirrups amounts to quite a saving in that most of the wear on these stirrups comes on the straight side of the D, where it is in contact with the stirrup box. The worn pieces are cut out and another piece of rod welded in. That portion which is cut out of the stirrup is welded into the stirrup box, which also has to be repaired. Another repair operation which is worthy of note is that of power eccentric connections. This is a very simple and inexpensive opera-
A few years ago when the jaws of wrenches or tongs were badly worn, they were discarded and new ones purchased. Today we are having these jaws reground and used again.

Non-returnable oil drums have found a place in the salvage program. Besides being used as rubbish cans, they are now used for sluice pipes. The ends are cut out and the drums are spot welded together to make any length sluice needed.

In conclusion, the writer wishes to point out again that the items which he has mentioned are few, but representative of the salvaging program. Material which a few years ago was regarded as useless is being examined thoroughly and much of it is being repaired or made into some other usable material.

Production costs must be kept to a minimum, and the salvaging of old equipment is a big step in that direction.
Reclamation and Maintenance of Oil Field Equipment

BY E. J. W. Egger


The severe conditions encountered in the oil industry necessitate frequent maintenance of machinery and equipment in order to minimize interruptions and replacement costs. The oxyacetylene process plays a very important part in this maintenance work. The flexibility and ease with which it can be adapted to meet many different repair problems makes it indispensable to oil field operators everywhere.

Welding

Welding applications are encountered every day in repairing broken metal parts, fabricating temporary and semipermanent structures, replacing old plant piping and overland pipe lines, and in many other miscellaneous jobs that keep the blowpipe in constant demand.

Bronze-welding

Bronze-welding is widely used for repairing castings and is of great benefit to oil field operations because, in most cases of minor damage, the part can be repaired right in place without having to remove it from the machinery for preheating. Bronze-welding has won the enthusiastic approval of many companies as a result of its economy and reliability under actual working conditions.

In one oil refinery, excessive pressure in a pump had cracked the head badly. The pump manufacturer was unwilling to supply a separate head, stating that the bottom and top heads were machined at the same time and that they would not guarantee the efficiency of a new separate head made independently of the pump. A new pump would have cost about $350.

The pieces of the head were taken to the welding shop and a "boss," or ridge, ¼-inch wide and ½-inch high was built up with bronze on each broken piece about ⅛-inch back from the edge of the fracture. The separate pieces of the head were then bolted to a ⅜-inch steel plate in correct position to each other and carefully lined up. One welding operator quickly completed the bronze-welding. A light cut was then machined across the face of the head and the pump reassembled at a total cost of about $50. This pump is again back on the job pumping crude oil from tankers to the refinery and refilling the tankers with fuel oil. The pump attendant, who has been operating the pump for over a year and is consequently in a position to know, states that the pump is every bit as efficient as before.

On another pump outside the pump house, a sudden freezing spell caused entrapped water to push out the entire twin head. The head had pulled with it a large section of the cylinder and some of the web between the cylinders. Here the use of bronze-welding saved the company over $300. Bronze-welding is now standard practice at this refinery for repair work of this sort.

Larger breaks and more complicated castings sometimes necessitate preheating before bronze-welding. Such an example occurred at an oil well drilling company in connection with a repair to a mud hog casting. Mud hogs are heavy-duty pumps used in the drilling of oil wells. A mud hog pumps mud and water at a pressure of 500 lbs. per sq. in. or more into the drill stem of the drilling equipment. These mud hog pumps are large machines, sometimes measuring more than 7 by 18 feet. Every oil well that is drilled requires the use of at least one or two mud hogs. A single casting which is just a part of one of these pumps costs about $1200.

In this instance, the section of the casting that was broken weighed 2 tons. It was taken from the machinery end of the pumping unit. The part of the casting that was broken was from 2 to 3 inches in thickness and was cracked for a total distance of 13 feet. Besides this crack, a hole 12 inches in diameter had been broken out and the pieces lost.

Four natural gas torches were used for the preheating, which was started early in the morning. About 3½ hours later the casting was ready for welding. Nearly 8 hours of continuous bronze-welding was required. A casting obtained from a nearby foundry was fitted as a patch into the 12-inch hole that had been broken out. Another piece of cast iron 8 by 18 inches and 2 inches thick was welded on as a web where the original web had been broken and lost. The job required 125 pounds of bronze-welding rod.

The drilling company was very much satisfied with the bronze-welding of this casting and with the resultant saving of more than
$1000. Ten days later another type of mud hog pump was brought in for repair. This one was in far worse condition but was reclaimed as readily as the previous one. The original value of this casting was more than double the cost of reclamation.

**Bronze-surfacing**

Bronze-surfacing is also widely used to build up worn surfaces and give longer life to moving parts. Such items as pistons, bearings, brake drums, impellers, rotary joints, pump plungers, valve rods and valve caps, crane drums, spindles, and packing glands are regularly bronze-surfaced.

**Pipe Welding**

Old plant piping and overland pipe lines frequently need replacing or reconditioning and the oxyacetylene blowpipe is ready to do the job quickly and economically. Although the oxyacetylene welding of pipe lines dates back to before the World War, it was not until 1930 that the technique now widely employed was first introduced. This process, known as Lindewelding, involved the use of backhand welding, a special flame adjustment, and a special welding rod. Using the Lindewelding technique, welds were made in half the time and at half the cost of methods formerly used.

This was followed in 1934 by the development of a 3-flame tip which was designed especially for making rolling welds and which further speeded the Lindewelding of pipe lines and plant piping. In addition to the main welding flame, this tip had two smaller auxiliary flames positioned so as to preheat the V directly ahead of the point of welding. Savings of more than 25 per cent in rods and gases and of 30 per cent or more in welding time were effected by the use of this multi-flame tip, as compared with single-flame Lindewelding.

The success of the 3-flame tip led quite naturally to extensive investigation of the possibilities of other multi-flame tips for making position or bell-hole welds, as well as for making rolling welds. This investigation, spurred by the recent popularity of the all-bell-hole method of construction, resulted in the development of two new tips—a 4-flame tip for position welds and a 6-flame tip for rolling welds.

Higher quality welds, increased speeds of 25 per cent or more, and a reduction in gas consumption of at least 25 per cent are now made possible by the new 4- and 6-flame tips and a new low-alloy steel welding rod. The 4-flame tip provides, in addition to the main welding flame, two flames for preheating the V and a fourth flame for preheating the rod. The jet for the rod preheat is so located that the operator has control of the amount of rod preheated and melted regardless of the point of welding. The 6-flame tip is similar in design to the 4-flame tip except that it has two additional V preheat flames. Four flames of this tip preheat the walls of the pipe, a fifth flame preheats the rod, and a sixth flame does the actual welding.

A new low-alloy, high-strength steel welding rod has been specially developed for insuring uniformly high-quality welds in high-strength pipe welded by the multi-flame Lindeweld process. This rod develops an average tensile strength of 10,000 to 12,000 lbs. per sq. in. greater than rods previously used for pipe welding, yet has sufficient ductility to meet any requirements.

This rod is particularly suitable for use with the 4- and 6-flame tips. When applying the rod, the weld metal sets up more rapidly, making it easier to control the puddle. This makes greater welding speed possible and also effects a reduction in gas consumption per weld.

**Heating**

While the oxyacetylene blowpipe is nearly always associated with welding or cutting, the oxyacetylene flame also provides a most convenient source of intense heat, particularly useful for many heating operations. When metal parts become bent, twisted, or warped, the blowpipe affords a ready means of applying heat at the desired spots, thus making it an easy task to bend the part back into correct shape. In fabricating parts to repair a piece of equipment, the blowpipe provides a handy heating unit that will do the job quickly and effectively.

**Cutting**

The oxyacetylene cutting blowpipe finds active use in both its forms, namely, hand cutting and machine cutting. The hand cutting blowpipe is indispensable for repair and conversion work when steel or cast iron parts or shapes must be cut or removed. Also, when preparing steel shapes, such as T-bars, angle irons, I-beams, and the like, the hand cutting blowpipe makes it a simple task to cut out sections, pierce holes, or cut the pieces to the desired length.

Under proper procedure, the removal of nuts from bolts and collars from pipe is readily done without damaging the threaded portions of the bolt or pipe. Many oil companies use the cutting blowpipe for removing drill stem collars from drill stems, and the
threads of the drill stems are kept intact. This operation is analogous to removing rivets from plate without marring the plate. This use of the blowpipe on drill stems has saved many dollars.

Oxyacetylene machine cutting offers many advantages for the repair and maintenance departments of oil companies. Steel shapes that become damaged beyond repair in operation or transportation are quickly duplicated with an oxyacetylene shape cutting machine. Typical of the parts shaped by portable machine cutting are the following: gusset plates and flanges for sampson posts; plates and hangers for walking beams; stirrups, flanges and gusset plates for drilling and pumping pitmans; beams, flanges, gusset plates, and footing angles for jack posts; spokes, channels, center plates, and rims for band wheels and tug rims; plates, angles, and flanges for reduction gear base supports.

Anchor blocks for the oil well cementing operations of one company were formerly shaped in a lathe and shaper. Now they have found that 10-inch anchor blocks can be shaped in about 8 minutes by oxyacetylene cutting. After this there is only about 10 minutes spent in final machine work on each block, whereas it previously had taken about 1 hour and 15 minutes for the job. Inasmuch as several hundred blocks are made by this company each month, this one saving in time alone makes a notable reduction in the monthly costs.

Sprockets and gear wheels are important items that are fabricated by the cutting machine. Without the cutting machine, a stock of these items had to be kept on hand because of their high rate of wear. If the parts were not on hand, they had to be ordered from the manufacturer or machined. With an oxyacetylene cutting machine available, however, the inventory of sprockets and gears is eliminated and the parts can be readily made when they are needed.

Hard-facing

Hard-facing is the process of welding on to wearing parts a coating, edge or point of a metal highly capable of resisting abrasion. In other words, a metal surface, which due to its use is normally worn away rapidly, is protected by a layer of special alloy which possesses exceptional resistance to abrasion. The process can be applied equally well to new parts before their first use or to old, worn parts. Experience has shown hard-facing to be an easy and economical method for keeping equipment on the job without losing time for repair or replacement of worn parts.

Drilling Tools

Hard-facing practice in the oil fields began with the Haynes Stellite of fishtail bits in California. The first runs made with hard-faced bits resulted in such an amazing increase in life over shop dressed and tempered bits that drillers immediately began to demand not only hard-faced fishtail bits and core heads but also equipment to run them that would be capable of making full use of the remarkably long life of the new hard-faced tools.

Although the drilling tool is only a small part of the equipment required for drilling a well, it is a most important part. Its efficiency limits the efficiency of the entire rig. Good tools properly hard-set with cast tungsten carbide inserts and then hard-faced have enabled drillers to use the latest improved types of drilling equipment with maximum efficiency because of the exceptional ability of such tools to make fast, straight, cut-to-gauge holes with long life between round trips.

To produce a tool of maximum efficiency, not only is it necessary to use the best available hard-setting and hard-facing materials, but it is also of equal importance to use the best possible procedure in applying these materials. This procedure includes preliminary forging or building-up, grinding and preheating of the bit, followed by hard-setting and hard-facing, and finally by finish grinding and heat-treatment. The use of hard-faced and hard-set bits in present-day drilling operations affects costs in a number of ways, as follows:

1. A reduction in the number of round trips to replace dull bits. This represents a distinct saving as the average cost of a round trip is greater than the cost of the bit.
2. A reduction in the time required to finish the well because the tool is on bottom longer on each round trip.
3. Fewer bits to drill the well and, therefore, less capital investment in drilling tools.
4. A saving in the cost of power because the sharper bits require less weight for efficient digging.
5. Less wear and tear on the wire line, draw works and drill pipe. A large percentage of the wear and tear on the line and draw works is due to coming in and out of the hole and, therefore, the efficiency of a bit directly affects the cost of repairs and replacements. This also is true of the drill pipe and tool joints. In drilling a well, de-
preciation on the wire line alone may often be equal to even more than half the total bit cost.
6. A reduction in overhead charges because the well is completed in less time.
7. Elimination of the cost of reaming, another factor directly affected by the quality and efficiency of the bit.
8. Elimination of one of the hazards which accompanies the setting of casing—crooked hole. A straight hole, true to the desired line, is always dependent on the quality and efficiency of the bits used.

In the eyes of most oil well drillers the loss of a string of tools in the hole is one of the worst accidents that can happen. If fishing fails, cutting the hole out and around the tools is a troublesome and often a costly operation. Especially when the top of the lost tools is in a rock formation, as is often the case, side-tracking consumes much valuable time and expense.

To reduce such extraneous expense to a minimum, drillers have found it necessary to side-track a hole as quickly as possible. To do so they must have mills with long, efficient cutting life. Accordingly, side-tracking mills, like the regular drilling tools, are almost always hard-faced with an extremely wear-resistant alloy. The success which this method of application has enjoyed has made it possible not only to side-track a string of tools much more easily, but even to mill through tool joints when necessary.

Machinery and Equipment

Many uses have been found for the hard-facing process other than for facing the cutting edges of milling cutters, reamers, and core heads. The life of parts subjected to extreme abrasive wear such as hot oil pump impeller tips and shaft sleeves, still tube cleaners, rotary spear parts, blow-off valves, slush pump valves, pump valves for pipe line stations, underreamer cutters, rock bit bearing pins and thrust washers, water courses, swivel sleeves, casing cutter parts, go-devil blades, and ditcher teeth is greatly prolonged by applying a thin coating of Haynes Stellite to the wearing surfaces.

At one of the large gasoline plants in Oklahoma, eight 250-hp. gas engines are now equipped with hard-faced exhaust valve seats because continuous and maximum power is required of them. Cast iron valve seats formerly lasted only from six weeks to three months before refinishing became necessary and the valves had to be replaced. Hard-faced steel seats ran from 12 to 16 months and were still in excellent condition.

Besides having hard-faced exhaust valve seats, these engines are equipped with solid cobalt-chromium-tungsten alloy valve guide bushings. These bushings have been in continuous service over two years without any attention whatsoever.

Supplementary equipment is also operated more economically by hard-facing those wearing surfaces subjected to severe abrasion. On a 28-mile trenching job, a close check on the life of ordinary ditcher teeth disclosed that after 2000 feet of trench had been dug it was necessary to replace the entire set. A set of teeth was then hard-faced and, after digging 28,000 feet of trench, examination showed that only about one-third of the teeth required removal for rebuilding with more hard-facing alloy. By applying this wear-resisting alloy at a cost of a few cents per tooth, a saving of over 14 dressings, which would have had a total cost of approximately $250, was assured. Also, after 14 dressings these teeth would have been completely worn out, requiring complete replacement. It is calculated that hard-faced teeth will last indefinitely if merely rebuilt with hard-facing alloy when they become worn. Besides the actual dollar savings, there are fewer shutdowns with resulting loss in time and yardage of trench excavated, and fuel consumption is reduced 10 to 15 per cent because sharp teeth run very easily while a partially dull set becomes increasingly hard to pull.

Hard-facing reduces costs in a number of ways. Of primary importance is the longer life of hard-faced parts. Depending on the type of hard-facing alloy used and the service to which it is subjected, hard-faced surfaces will outwear steel from 2 to 25 times. As a direct result of increased life, fewer replacements are necessary. In many cases the replacement of a worn part results not only in a loss of production because the equipment must be shut down while the replacement is being made, but also in a loss due to idle labor during the replacement. Following are some of the hard-setting and hard-facing applications that save money for the oil industry:

- Fishtail bits and other drag bits
- Rotary disks
- Core heads
- Milling tools
- Side-tracking mills
- Undercutter reamers
Refinery valves and valve seats of all kinds
Underreamer lugs
Clutch jaws
Pins and bearings for rock bits
Ditch digger blades
Centrifugal pump impeller tips
Pump shafts and sleeves

The applications of the oxyacetylene process for oil field repairs and maintenance are without number, and time does not permit a complete summary of these activities. However, from the above illustrations, it is readily understood how indispensable the process has become in helping oil field operators keep their machinery and equipment constantly in efficient working condition.

Application of Packers to Oil and Gas Well Drilling and Production

By John Pearson, Sales Engineer
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Packers are used the world over. A better understanding of the purpose and operations of the many types of packers will suggest new and improved packer applications for individual well conditions. An intimate knowledge of packers leads to the safe, efficient control of wells and operating economies not to be attained in any other way.

Before we consider these applications, let us make certain that we all understand what a packer is. A packer is a mechanical device consisting of two telescoping body members and a packing medium so designed as to place the packing medium under compression and expand or displace it laterally to the wall of the hole or casing to form an effective sub-surface seal. The packing medium may be burlap, ducking, lead, rubber, or synthetic rubber as Neoprene, but the most common of all is rubber.

Types of Packers

Packers may be divided into two general classes, the anchor type and the wall type, the difference being in the method of supporting the packer in the hole. The anchor type of packer rests on bottom or is supported by an anchor string from the bottom of the hole. The wall type packer never rests on bottom but is held against the wall of the hole by a combination of mechanical parts which form a wedging-gripping action. The holding of one of the telescoping members stationary while the other displaces the packing element as much as the load on the packer will permit is known as the “setting” of the packer.

Strength of Body Pipes

The load on a packer consists of the weight of the tubing or casing string the packer is run on, the weight of the suspended string
hung below a packer of the wall type, the weight of any fluid or
cavings above the packer, and the downward thrust from anchor
clamps which may be used to tighten down the string. In consid-
ering this load we might compare a packer with the fluid end of a
water pump (fig. 17) in which the rubber packing element corre-
sponds to the fluid. Rubber and water are only slightly compres-
sible and so do not change much in volume. Rubber, like water,
transmits a force of equal intensity on all the surfaces with which
it is in contact, which in this case are the wall of the hole and the
body pipe of the packer. The load on the packer is transmitted to
the rubber by the packer top, which acts as a piston. This load exerts
a force through the rubber which is at right angles to the axis
of the telescoping body member. If the strength of the body mem-
ber is not sufficient to withstand the force exerted by the rubber,
the body member will collapse. Here is an important factor in
packer design—the strength of the body pipe. For any given con-
dition the total load on the packer can be calculated to determine
if the body pipe of that packer will withstand that load. When load
conditions on the packer are excessive, the strength of the material
of the body pipe must be increased, since the inside and outside
diameters of the pipe are usually definitely fixed by the size of the
packer. In some cases the packer manufacturers have had to resort
to special heat-treated alloy steel body pipes to manufacture pack-
ers to withstand excessive load conditions.

Packing Elements—Rubber and Synthetic Stocks

Packer rubbers have been developed after years of testing and
field service until the best composition for each type and size of
packer has been determined, considering the size of the hole, con-
dition of the hole, thickness of rubber, and load on the rubber. A
more recent development is the use of synthetic rubber stocks as a
packing medium. Chemical compounds are substituted for pure
rubber and the resulting stocks are such that they can be com-
pounded and vulcanized in the same manner as rubber. Synthetic
rubber stocks are harder and denser than regular packer rubbers
and so require a greater load for an equal travel. The advantage of
using synthetic stocks is that they are more stable than pure rub-
er stocks in the presence of gasoline or oil and have less tendency
to freeze or vulcanize to tubing or casing. Neoprene is the most
common of synthetic stocks and has proved very satisfactory after
several years of field service.
Special Construction Features

Thus far we have spoken only of two types of packers, wall and anchor. These are the basic types and all others are a variation of one or both of these general classes. Packer bodies, around which the packing elements engage, may be of the regular straight type or of the conical-sleeve or the step-expanding design. The straight body construction is standard and is furnished unless otherwise specified by the customer. The conical sleeve enlarges the diameter of the body pipe where it telescopes in the rubber. The increased diameter forces the rubber out to the wall of the hole before the telescopic action, due to the load on the packer, takes place. This construction increases the strength of the body pipe and provides a long, tight seal of solid rubber against the conical sleeve and the wall of the hole. The step-expanding type is for use in an open hole that is eccentric or oversize. It expands the rubber in successive steps and makes for a tighter seal under conditions where a straight packer would not be so desirable. On the wall type the slips are machined, serrated and heat-treated, and are dovetailed and hinged into a cage to make a flexible joint, so that they can move freely on the cone. The friction springs are riveted to the cage and rest in recesses in the cage and slips. This prevents the twisting off of the springs when the packer is set. When pulling the packer the friction of the springs against the wall of the hole holds the cage slip assembly in place below the cone and prevents the slips from catching in any of the pipe joints. These special features have been grouped together to make some of the types of packers as the bottom set combination wall and anchor packer with the conical-sleeve top or with the step-expanding top.

Importance of Detailed Packer Specifications

In running packers on casing, the size of the body pipe should be of the same size and weight as the casing string the packer is run on. Running a packer made for lighter weight casing obviously reduces the safety factor. Should the body be made heavier, it would be impossible to run the same size tools through the packer that are run through the casing. The weight of the casing or the size of the open hole in which the packer is run determines the outside diameter of the packer. This diameter is such that the clearance of the packer in the hole is held to a minimum, usually from one-quarter to one-half inch on the diameter, to allow maximum thickness for the working parts of the packer. Complete packer specifications are as follows:
1. Type of packer.
2. Size, weight per foot, threads per inch of the string that the packer is run on.
3. Size of hole or size and weight per foot of the casing in which the packer is to be run.
4. Length of rubber.
5. Size, weight per foot and threads per inch of the anchor string when it differs from the string that the packer is run on.

**Proper Location of Packer in Well**

With the packer properly constructed, the most important consideration is the selecting of a proper place to set it to obtain an effective seal. A solid rock formation in open hole or the wall of casing, tubing, or pipe is most desirable. Soft, caving formations, or those with cracks or crevices, are to be avoided. In places where there are cracks and crevices, a packer may be set perfectly, from a mechanical standpoint, but still not make a seal, as the fluid can by-pass the packer through a crack in the wall of the hole. Packer rubbers have been known to extend into a crack several inches but they cannot be expected to fill a large crevice. Oversize holes should be avoided, since the seal becomes less effective as the diameter of the hole increases over its nominal size. This is most important in wall packers, as the thickness of the slips is limited for a given packer size and wedging action is impossible in a hole of extreme oversize. In setting an anchor packer, it is important that there be a firm and solid foundation for the anchor pipe. Should this pipe settle after the packer is set, the seal will be broken and the whole string will settle.

**Use of Packers in Drilling Wells**

Now that we have become acquainted with what a packer is, its construction features, and some of its specifications, let us see where packers are used. The first place to be considered is a drilling well where casing is being run to shut off the fresh water. Here is a place where the use of a *midget bottom hole packer* makes more sure of a shut-off. The midget packer has a very short rubber and depends on a seal around the heavy shoe (fig. 3). The shoe and inside pipe or body pipe is made of one piece for those sizes where it is practical. The inside pipe and the outside pipe are locked together by a threaded shoulder so that, should the packer ever be pulled, all of it will come out together. The packer is kept from setting before

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**Fig. 9**

Hook wall tubing size

**Fig. 10**

Showing pressure relief packer set  Showing pressure relief packer ready to run
bottom is reached by a number of copper rivets which hold the two members in a fixed position. When bottom is reached, the weight on the packer shears these rivets and the telescoping member forces the rubber down on the shoe and out to the wall of the hole to make a seal. Drilling is then continued through the packer with a reduced hole size. Several casing strings may be run in the same hole to shut off various waters and caves and a midget packer can be used on each string.

On longer strings it is sometimes desirable to pack the wall of the hole above bottom. In such cases a bottom hole packer is used (fig. 2) with the packing element at the top of the packer instead of at the bottom as in the case of the midget bottom hole packer, so that a seal is made in the wall of the hole. When conditions require the packer to be set at an elevation in the hole, a casing anchor packer (fig. 1) is run with a casing anchor and casing shoe attached below the packer. However, no matter which type packer is used, the purpose is the same—to shut off water or caving formations.

Packers in Gas Wells

Drilling on down to the pay formation, it is found necessary to confine the oil or gas to the producing sand to prevent loss of production in crevices or porous formations and also to keep the water and cavings of these upper strata from getting into the pay formation. In gas wells, a special gas anchor packer (fig. 6) or a step-expanding packer (fig. 4) is generally the solution. The special gas anchor packer may have a conical sleeve (fig. 5), and in wells of high pressure it is sometimes best to use a special gas anchor packer with a packing ring (fig. 7). This gland ring prevents the gas from getting under the rubber and blowing through between the rubber and body pipe. The step-expanding gas anchor packer is used in holes where the wall is likely to be oversize or irregular.

Some operators run a larger size anchor string to support the packer and then run a continuous string of tubing through the packer so that they can swab through the packer without loss of load when swabbing and also have a good heavy anchor to support the packer.

For example, the packer can be made with 2-inch 11½ thread, double-threaded top and 3-inch 11½ thread anchor connection at the bottom of the packer. The 3-inch string supports the packer from the bottom of the hole and, therefore, must be longer than the 2-inch string suspended from the packer top. The packer top acts as a tubing coupling for the 2-inch tubing, giving a continuous string.
In a well where the condition of the bottom of the hole is uncertain, a bottom set combination wall and anchor packer (fig. 8) is used. This packer combines the features of the two general types, such that should the bottom of the hole wear away and allow the anchor to slip, the wall feature will continue to support the packer and string of tubing. Also the load is not all on the anchor, thus providing a distribution of this load, part on the bottom of the hole and part on the wall.

Packers in Oil Wells

The wall packer (fig. 9) is used in oil wells with a pumping top (fig. 12) so that the tubing string can be suspended from the packer into the pay sand. The slip cage construction has been previously mentioned. The hook on the cage is a heavy V type (fig. 11), so that there is no danger of its being bent. The pin engaged in this hook holds the slip cage assembly in place during the running of the packer. When the packer has reached the point at which it is to be set, the tubing string is turned to disengage the pin from the slot in the hook so that the cage held in the wall by the friction springs allows the cone traveling downward to engage the slips in the wall of the hole.

In the disc-wall type setting is accomplished by breaking a disc which releases the compressed spiral spring, which causes the slips to travel up on the cone. The advantage of the hook wall over the disc wall is that it can be reset at either a higher or lower level in the well by reengaging the hook and resetting. The disc-wall type can only be raised in the hole to reset, unless the packer is pulled out of the well and a new disc inserted. The wall packer can also be made with a conical sleeve or step-expanding top. For oil wells where gas interferes with the pumping of the well, a special gas escape top (fig. 13) is made so that a 3/4-inch or 1-inch string can be run along side of the tubing and seated in the packer top to carry away the gas.

The pressure relief packer (fig. 10) is another form of the hook wall packer which has a relief valve top to run in a well against heavy pressure. When running in, the valve is open, allowing the fluid to flow through the packer until it is set, and the weight of the tubing closes the valve. Should the packer be pulled, this valve is opened when the tubing is raised a short distance, thus allowing the fluid and cuttings above the packer to run down through the packer, relieving the packer load and reducing swabbing.

Packers Used as Liner Hangers

In some sections it is desirable to hang a perforated liner in the pay formation or suspend a liner through a caving formation. A special form of packer has been developed for suspending a liner and is commonly called a cave packer (fig. 14). It is essentially a wall packer, either hook or disc type, the latter being the most common, without any packing medium. The general practice is to run the liner with the disc-cage packer into the bottom of the hole and break the disc. Then a trip spear is run in and the liner picked up to the determined location and released. It can also be run in on tub-
ing and set as a disc-wall packer. The tubing can then be withdrawn, as there is a left-hand thread on the top of the packer which permits the unscrewing of the letting-in tool.

The tool set cove packer (fig. 15) is a similar liner hanger with a special setting device. The packer with the liner suspended below is lowered on a string of tools connected to the packer with a letting-in tool. When they have reached the desired position, the tools are raised a foot which releases the hook on the packer cage from the pin. The string is then lowered and the cone forces the slips against the wall of the hole, thus supporting the liner. The weight of the tools will break a disc, thus disengaging the letting-in tool, which may then be removed from the hole. This type of packer enables the operator to set a liner very quickly and with little expense.

Packers Used in Repressuring

Repressuring or secondary recovery has opened up a new field for the use of packers. In water flooding it is common practice to seal off input wells by cementing in the tubing immediately above the sand being flooded. In order to keep the cement from getting down into the pay sand an inexpensive packer used as a bridge was developed and is called the full expanding tubing anchor packer (fig. 18). A short, thick wall rubber usually eight inches long is used in conjunction with a sleeve that may be either straight, tapered, or a combination of the two. This gives a maximum wall contact when the rubber is upon the sleeve even before the full load is applied. In those sections where well surveys are made after the tubing is run to determine the characteristics of the sand, the anchor on the full expanding tubing anchor packer is objectionable and it becomes necessary to use a wall packer as a bridge. This permits full access to the sand for any instruments that might be used.

The cementing of the tubing makes a very costly job should it ever be necessary to clean out the well. This led to the development of the automatic expanding pressure anchor packer for confining the water to the pay sand. This packer is made with conical sleeve and 20- to 24-inch rubber and with the special feature of a perforated body pipe which allows the water pressure to help exert force on the rubber to make the seal. The packer top and the end of the rubber are beveled so that the wedging action of the rubber into the top makes a tight seal. The body diameter is increased by the conical sleeve so that the rubber completely fills the space between the conical sleeve and the wall of the hole. The perforations in the body pipe below the sleeve allow the water pressure to shove the

![Comparison of a Packer to the Fluid End of a Water Pump](FIG. NO. 17)

Cross-section of "Oilwell" Crumley fluid-release packer head

"Oilwell" Crumley hook wall fluid-release packer

Wall of hole as cylinder

Rubber as water

Body pipe as piston rod

Ball bearing tubing clamps

Packer top acting as a piston
rubber out to the wall of the hole. Increasing the water pressure increases the force against the rubber. It is recommended that 2-inch tubing with tubing clamps be used with this packer to help furnish load enough to hold it down tight. Several hundred of these are now in use and work very successfully.

In the early stages of air-gas repressuring, a single well was used as an intake well and either a special gas-anchor or a step-expanding packer was used to confine the gas to the producing sand. As the air-gas repressuring operations increased, field tests proved that the full expanding tubing anchor packer effectively confined the air-gas to the producing sand. This packer with a 10-inch rubber has now become standard equipment for this work.

As development went along, it became advisable to repressure two sands in the same well with different pressures. This problem of dealing with two pressures was solved by using four packers (fig. 18), three of which are full expanding tubing anchor packers all on the tubing string. The bottom one, No. 3, is set at the top of the lower sand, the middle one, No. 2, at the bottom of the upper sand and the top one, No. 1, at the top of the upper sand. Open couplings, or perforated pipe suitably located, give an outlet for the air-gas mixture. A seat coupling is put in the tubing string below the vents for the upper sand to serve as a seat for the fourth packer. This packer, No. 4, is a small anchor packer usually a 1-inch x 2-inch or ¾-inch x 1½-inch, commonly called a pony packer. This small string and packer run inside the tubing serves as the pressure line for the lower sand. The annular space between the small diameter string and the tubing serves to supply air-gas under pressure to the upper sand. Should the need arise for repressuring three sands, each with a different pressure, the same arrangement can be used with the addition of a hook-wall packer set at the top of the upper sand, run on large-size tubing string, probably 3½-inch. The space between the large-size tubing and the regular tubing will serve the third sand.

Repressuring has spread to many eastern and mid-continent fields, and packers of proper size to meet local field conditions are now available. Some fields require only a small volume of air-gas so that the tubing diameter may be reduced. Packers have been made to run on ¾-inch pipe and set in 1½-inch tubing. In another section the two-pressure hook-up is used with 2-inch tubing running inside of 3-inch tubing. No matter what the tubing program is, the packers serve the same purpose of confining the pressure to the pay sands and keeping the different pressures separated, using the least amount of tubular goods.

Acidizing of wells presents packer problems similar to those of repressuring. Here, however, it is the acid that is to be confined to the pay formation. Again the full expanding tubing anchor packer serves as an inexpensive seal, either above the pay when it is in the bottom of the hole or below the pay when it is up in the hole. In the latter case, two packers may be separated by perforated tubing to cover the span of the sand to be treated. The lower packer has a plug in it so that the acid is forced through the perforations to the pay sand. In wells that are cased to the top of the sand, a tubing string and packer are often used to run the acid so that none of it comes in contact with the casing. No matter what strata are to be
acidized, whether they be at the bottom or up in the hole, a packer arrangement can be used to confine the acid to those strata.

Very recently sands have been acidized under pressure to force acid farther back into the formations. A hook-wall packer is run on a tubing string and set just below the stratum to be treated. The tubing is plugged below the packer and perforated on a level with the sand. The acid is run in through the tubing and enters the sand through the perforations. Oil is then pumped down the casing and pressure built up to from five- to seven-hundred-pound pressure. By using the oil as a medium to transmit the pressure, the acid does not come in contact with either the casing or pumps. An extra-strong-walled packer is needed for this type of work because of the excessive pressure.

"Oilwell" Crumley Fluid Release Packer

Another new packer application is the Crumley hook wall fluid release packer (fig. 16), used for controlling the gas pressure and increasing oil recovery in those wells where gas builds up under the packer, putting a back pressure on the sand and reducing production. The Crumley packer consists of a regular hook-wall packer and a special valve top that can be controlled from the top of the well without disturbing the packer. An added feature is that this valve and the tubing string can be pulled and rerun without disturbing the packer. Opening and closing the valve port is accomplished by giving the tubing a quarter turn after breaking the union at the surface. The tubing is partially suspended on ball bearing tubing clamps resting on the casing head. The valve is closed while the well is being pumped. Then as the well stands, gas collects below the packer, building up pressure. When the valve is opened, this gas blows up through the valve and into the tubing and will continue to flow as long as the port is open or there is gas in the well. On pumping the well again, the port is closed. When tubing is being pulled, a baffle ring between the tubing and the packer body prevents a rush of water down the hole which might cause the well to cave.

Some of the Crumley packers have been used in gas wells to blow out the fluid. The fluid in the tubing above the valve is blown out by opening the valve and allowing the gas to come through the port from under the packer. When the port is closed, the rest of the fluid is blown out by the gas at the bottom of the tubing. By alternating the procedure, blowing from the packer and the bottom of the hole, all the fluid can be removed. The success of this idea depends on placing the packer at the right elevation with respect to the amount of fluid that the well makes.

Maintenance of Wells

Packers also play a big part in the maintenance of oil wells. A common occurrence in old wells is leaky casing. Pulling this casing to replace it with new is an expensive job, especially if the well has seen its best production days. The old casing can be left in the well and a new liner to seal off the water run on and supported by a hook-wall packer. Should leaks develop below the liner, the packer can be reset lower in the well by using more liner. The same applies to tubing strings. This solution has become particularly important on intake wells in water flooding. Leaking tubing that is cemented would mean an expensive cleaning-out job as previously mentioned, so a 1-inch string with a 1-inch x 2-inch hook-wall packer is run in 2-inch tubing to shut off the leaks. This type packer is also made in the ¾-inch x 1½-inch size to take care of 1½-inch tubing which is common in the water flooding fields.

In some cases these small packers are run to test tubing to determine if there are any leaks and where they are. By setting a packer at the bottom of the tubing and building up a pressure in the tubing, leaks can be detected. Then by resetting the packer at various elevations and testing, the exact location of these leaks can be determined.

In flowing wells, packers confine the oil in the tubing and conserve and prolong the life of the wells. In some sections where gas lifts are used to flow wells, packers play an important part in confining the oil and gas.

Occasionally a situation arises where water breaks in through a stratum, but the well is not worth casing to the top of the hole. The duplex screw down liner packers, a combination of wall and screw type, are used with enough casing between them to bridge the water stratum. This string is run in and set with the aid of a letting-in string and the water is shut out of the well. The top packer is unnecessary in those cases where the water level never exceeds a certain height which the casing will blank off.

Individual Control of Packer Setting

Where more than one packer is run on the same string of casing or tubing, there might arise the doubt as to which packer sets first. The greatest load is on the bottom packer, which causes it to set first, and so on successively up the line. In special cases packers are
made that are individually controlled. The lower packer is set first by the weight alone. The others may be set by breaking a disc in the disc type, turning the string four turns in the screw type, or turning in the opposite direction in those that have a locking device.

Conclusion

Thus it is seen that if the wall of the well bore will permit, it is possible to shut in or shut out, as desired, any gas, fluid, or cavings in a well by the use of tubing and casing and a packer or a series of packers.

Safety on a Repressed Lease

By H. D. Brown, Jr.

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I HAVE been allotted 15 minutes to discuss safety in oil field operations. Since my experience has been limited to that of the company with which I am associated, the Brundred Oil Corporation of Oil City, I will confine my remarks to the work of that company. Our experience should be more or less typical of the Pennsylvania producing industry, at least in the type of accidents.

Comparatively little attention was devoted to safety education or accident prevention until several years ago. A pipe wrench would slip and injure a man’s hand or back. The wrench would be damned at the time but would remain in use, a potential instrument of injury. Under the safety program instituted late last year, recurring injuries from the same causes are obviated, since we require our men to return unsafe equipment to the shop for repair. This is one of the measures in our program which has assumed major importance in the eyes of the company, and apparently it is becoming increasingly important among the men.

It is of great importance to the company, not only because it lowers compensation costs, but also because it gives us greater assurance of the uninterrupted services of men who know their jobs and, therefore, are not readily replaceable.

Our program was instituted with a meeting of all employees. A list of 108 accidents, mostly minor, which occurred during the previous two and one-half years was read, and after each accident had been described, the employees were asked to decide for themselves whether or not these mishaps had been avoidable. They decided that no less than 82 per cent of these accidents could have been avoided and would have been avoided if the men had been aware of danger and had acted accordingly. It was obvious then that to eliminate a majority of accidents, our job was to make these men aware of danger, or “safety-conscious.”
This point is further stressed by a compilation of accidents over the past 35 months. During this period, there were 108 accidents which have been subdivided into the following types:

- Slips and falls .................... 15
- Struck by falling objects .......... 9
- Struck by tools and flying objects 16
- Cuts and bruises .................. 27
- Lifting and pulling ................. 15
- Burns ............................. 6
- Gas explosions ..................... 4
- Eye injuries ....................... 10
- Miscellaneous ..................... 6

Among the most numerous are cuts and bruises, slips and falls, and lifting and pulling, all of them avoidable. Accidents of these three types totaled 57, or more than half of all accidents.

The above statistics have been plotted in Fig. 1, which graphically reveals the scope of the field for safety education. These columns represent the number of accidents of the types previously specified: Column 1 is gas explosions; 2, burns; 3, miscellaneous; 4, struck by falling objects; 5, eye injuries; 6, lifting and pulling; 7, slips and falls; 8, struck by tools and flying objects; 9, cuts and bruises. Types 6, 7, and 9 are accidents which ordinarily result from momentary carelessness on the part of the worker and, therefore, accidents which can be avoided by educating the worker to be careful at all times. As mentioned previously, there were 57 accidents of these types, or 53 per cent of all accidents suffered in the past 35 months.

Under our safety program, it is mandatory that employees return unsafe equipment to the tool houses for repair. We have also installed fully-equipped and constantly-replenished first aid boxes at convenient points. However, we have found that measures of this latter type, while seemingly most important, are actually minor in a complete safety program, the first requisite of which is education of the employee. No supply of guards, rules, or equipment will prevent injury to those who refuse to abide by the rules and, for this reason, we are holding frequent meetings of the employees at which they are addressed by competent authorities on accident prevention.

In this respect, it should be mentioned that there is the type of worker who is no more receptive to safety education than Venango county sands are to water flooding. This type has no regard for his own well-being nor that of his fellow employee. We are trying to eliminate this type of worker for several reasons:
(1) He is a constant menace to all with whom he comes in contact.

(2) He is a probable source of increased compensation costs for the company.

(3) He is not as dependable as others because we do not know when an injury will deprive us of his services.

Most workers, however, have shown a definite interest in our safety program and apparently are doing their part, as fig. 2, showing accidents by quarters in the past two and three-quarters years, indicates. During the first quarter of the current year, the first full period in which our program has been in effect, it will be noted that, while there were four accidents, none of them was a fatal or lost-time accident. In the corresponding quarter of 1937, when operating conditions were virtually the same, there were eight accidents, two of which were lost-time and one of which was fatal; and in the same period of 1936, under similar conditions, there were 10 accidents, 5 of which were lost-time.

While the company does not expect this record of no lost-time accidents to continue indefinitely, this does provide an eloquent testimony to the effect of our program and its possibilities. Our conclusion is this:

(1) By educating employees to be constantly conscious of safety through frequent talks,

(2) By making accidents as few as possible by forbidding the use of unsafe equipment, and

(3) By minimizing the effect of accidents which will happen, through first aid teaching and equipment, we can substantially lower our accident rate with consequent benefits both to the employees and to the company.

Economics of the Pennsylvania Oil Situation

BY JOHN D. GILL

(Resumé of the extemporaneous talk)

Making a good living out of production and refining of Pennsylvania grade crude oil depends a lot on whether the individual adopts a long or a short view of the industry. Because of the non-monopolistic nature of crude oil and its products, it is possible to make good profits during short periods of time, but in the long run, good and bad periods will somewhat compensate and it is thus preferable to look at the longer view. For good business practice a certain degree of stabilization is essential and the violent fluctuations which have characterized the oil industry should be avoided. When production is at a low ebb, there is waste of both personnel and equipment, whereas during prosperity periods, both are over-worked. It is the purpose of this talk to show and analyze the fluctuations which have affected the Appalachian oil industry.

Figs. 1 to 7 depict in a graphic manner the economic situation of the Pennsylvania grade oil refined products during the years 1934-38, taking in succession the study of steam-refined lubricants, bright stocks, viscous neutrals, finished lubricating oils, gasoline, and kerosene. Each graph shows the actual inventories of the product under study compared to an assumed economic average calculated over the period 1932-36. In the same graph are inscribed the corresponding average price fluctuations. In fig. 1 an accumulation of steam-refined stocks appears clearly from the middle of the year 1934 to the beginning of 1936, which corresponds to the indicated period of depressed prices. From the middle of 1936 to the middle of 1937 inventories are normal and prices are gradually gaining when in July 1937 a sharp increase in steam-refined stocks is indicated and inaugurates a period of over-supply which is still lasting. This had for effect the bringing down of prices sharply. In fig. 2, the fluctuations of inventories and prices of bright stocks are pictured.
There do not seem to be any abnormal stocks of these products up to the middle of 1937 and one must look for a cause other than economic inventories to explain the drop in price during 1934; perhaps the price movement came out of sympathy for the other petroleum products. But by the middle of 1937, a sharp increase in inventories above normal coincides with the price drop. Similar relationships are pictured in figs. 3 and 4 for the viscous neutrals and the finished lubricating oils as recorded by the National Petroleum Association. Fig. 5 does not show any feature of particular significance except, perhaps, that the Appalachian region gasoline refinery price has had a marked tendency to drop below the average corresponding price for the total United States. It thus appears that the manufacture of gasoline out of Pennsylvania crude has become more and more of the nature of an unprofitable by-product business. Fig. 6 presents a similar study for the kerosene market in the Appalachian region, which appears more steady than for any of the preceding items. It shows in particular that the inventories of kerosene have been on the decline for the past two years with a corresponding increase in the price per gallon; one wonders why the refiners do not take advantage of this situation in order to increase their profit margins.

Fig. 7 is a graph which refers to the Appalachian region as a whole (as do figs. 5 and 6) where other crudes besides Pennsylvania grades are processed for lubricants. It shows the general tendency noticed in the previous charts, but the price chart is very conclusive in showing the reduced margin between the United States and Appalachian prices of lubes. As one evidence of narrowing margins, one may cite the following instance: In the seven years preceding January 1, 1930, Bradford crude averaged $1.70 above Oklahoma crude, whereas in the ensuing eight years this margin dropped to $1.25. One can also point out the declining refinery prices: Contrasting 1923 with 1937, one notices a drop from 13.73 to 5.54 for straight run gasoline; 7.66 to 5.21 for kerosene; 5.70 to 4.46 for fuel oils; and from 1929 to 1938, 24.28 to 18.0 for lubricating oils.

Fig. 7, which compares the actual and economic inventories and prices of lubricating oils in the Appalachian region, shows that in late 1936 and to almost mid-year 1937 actual inventories were below what was regarded as economic, but this trend was reversed with a decline in prices that became pronounced after May 1937. Inventories have now risen to 1934 levels but the prices are considerably lower. The decline is faster now because we are facing a depression, whereas previously we were building toward recovery.

One may also point to the fact that the price of Bradford crude oil at the well exceeds the average price of a barrel of finished products throughout the country; this may be interpreted as an indication of the remarkable job done in obtaining full value of this crude.

Fig. 8 shows the value of products at Appalachian region refineries and indicates the decline in gross margins available to the refiner. These margins, declining steadily since July 1937, have actually collapsed and the refiner is now operating with a very meager profit. The margins are now the lowest since 1934. Maintaining balanced inventories is a difficult task for the refining division of the industry; it is a technical problem which requires balancing the output of refineries according to the market demand.

As an explanation of what made the price drop so abruptly, one can say that the Appalachian refining area and the Pennsylvania producing area, important and valuable as they are, cannot live unto themselves and are dependent for their position and welfare on forces outside the area. There has been a strong downward trend in prices of all commodities. The depression which started last July hit the demand for all products, especially lubricating and fuel oils. This region continued at a peak producing rate in face of the record demands of the preceding periods when the depression reduced this demand and the resulting increased competition accomplished the rest. Thus upward and downward trends cannot be solely attributed to the statistical position of the industry, but may only reflect a condition more powerful than ourselves.

Conditions within the industry are also responsible for some long-term trends. In 1926 gasoline and kerosene accounted for 55 per cent of the income, but this percentage dropped to 46.5 per cent in 1937. Lubricating oils, on the other hand, represented 32.2 per cent of the income in 1923, increased to 36.6 per cent in 1929, and to 40 per cent in 1937. One may ask the question, is there not too much of a load on the lubricating oil group; is the lubricating oil group not being expected to do too much in view of the trend in demand? From 1925 to 1937 this demand increased 14 per cent, as a drop of 6 per cent in industrial consumption was affected by an increase of 37 per cent in automotive demand. In the same time, the Appalachian area increased runs to stills a little over 60 per cent and production of Pennsylvania crude rose over 67 per cent. Even if all of these oils were marketed to automotive demand, we would still have the difference between a 37 per cent increase for the automotive demand as against a 67 per cent increase for production with respect to the year 1925.
Another problem is that of the larger share which the Pennsylvania grade crude is taking in the Appalachian refinery market; in 1926 it was only 50 per cent; in 1937 it had increased to 61.5 per cent.

Fig. 9 shows the relationship of supply and demand of Pennsylvania grade crude oil. The supply is made up of the current production, whereas the demand is identical with run to stills. An oversupply period is marked by values of the ratio larger than one. From this chart one would normally conclude that supply and demand are fairly well balanced during the latter years and one must look to other reasons to explain the drop in the market price.

Figs. 10a and 10b show the economic relationships between different factors: Appalachian region crude run to stills, inventories, supply and demand ratio, refinery gross margin, average demand, well price Bradford crude, and estimated refinery value of products.

The price of crude has a very marked influence on the number of oil wells drilled. This may be illustrated very well by a comparison of the Bradford crude price and the number of wells drilled per month in the Bradford and Allegheny fields, as is done on fig. 11. There exists a very high degree of correlation between the two curves.

It is often claimed that Pennsylvania grade crude prices are affected by the mid-continent crude situation. A comparison of the two prices indicates that such is not the case, at least for the last few years, as is apparent from figs. 12a and 12b. With the advent of proration in the western fields, prices have been maintained steady over a period of about four years, whereas Pennsylvania prices have fluctuated violently during the same period. This is largely due to the corresponding variation in product prices. As an instance, one may refer to the price of bright stock, which was 55 cents in 1929. Such extremes in prices represent an invitation to other producing and refining interests to participate. The fact that the invitation was accepted has a definite bearing on the situation. These fluctuations are bad because they invite, or create, a kind of speculation that is opposed to the business interest in the long run. Another problem for the industry is to reduce this speculative quality to a minimum. This can be achieved by cooperation and without collusion, by a kind of cooperation in which each unit of the industry makes it a point never to have uneconomic stocks.
Fig. 11. Crude prices and well completions (monthly averages quarterly).

Fig. 12a. Crude oil prices.
 Rotary Drilling in the Appalachian Region

BY M. E. Nicklin, Sales Engineer
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It hardly seems necessary to review the history of drilling methods employed in oil and gas production, other than to mention that the cable-tool method had its inception with the drilling of the Drake Well, while the rotary method did not come into domestic use until the early 1900's on the Gulf Coast. Today the rotary rig is in almost universal use in the West, and it was inevitable that sooner or later the rotary rig would be tried in Pennsylvania and throughout the Appalachian region.

Until recently, economic factors seemed to favor the continuation of the cable-tool method in the East. However, with the ever-increasing consumption of oil and gas and their by-products, and as a result of geological and geophysical surveys, much interest has been created in the deeper Pennsylvania horizons, especially those below 5000 feet. The experience of drilling deep tests in Pennsylvania during the past two or three years with cable tools has brought to the foreground the question of the practicability of the rotary rig for deep drilling in eastern fields.

Operating Conditions In Pennsylvania

As most of you know, the credit for pioneering the rotary rig in Pennsylvania belongs to Mr. J. H. Isherwood, general manager of the New Penn Development Corporation of Port Allegany, Pa. It may be of interest to review briefly the physical, economic, and operating factors that led to the installation of the first complete rotary rig at Keating Summit, Pa., (fig. 1).

Caving formations and gas pockets, resulting in long delays and expensive fishing jobs, presented operating problems for which a satisfactory solution had never been worked out with cable tools. A method, then, which would offer control where large gas pockets...
at high pressure have to be taken into account was an important factor which favored the rotary system. Further, the rotary system provides a more satisfactory means of studying formations through unbroken cores made possible by the use of rotary core barrels, and by the routine method of studying the drilling returns at the slush pit or shale shaker.

A pertinent economic factor is the high cost and expense of carrying unproved acreage. Frequently the free-time clause allowing for the developing of geological and geophysical information was insufficient when drilling with cable tools, and rentals came due before blocks of acreage had been tested or proved. The rotary rig offered quick developments in proving acreage, thus substantially reducing costs incidental to the long delays encountered before completing wells with cable tools.

A comparison of well logs with other similar logs in successful rotary territories of the West indicated that the rotary method was practicable. An analysis indicated that there were no apparent factors which the rotary rig could not overcome and, in addition, there was the expectation of much faster drilling which more than justified the greater initial investment in a rotary rig.

The pioneer rotary well at Keating Summit was completed from a 6090-ft. cable-tool hole to a depth of 8482 feet. Since its completion, three complete rotary rigs are now drilling in Pennsylvania—one near Pittsburgh for the South Penn Oil Company, (fig. 8); one near Greensburg for the Peoples Natural Gas Company; and the third on its second location, having been moved from Keating Summit to a location near Germania, Potter county, for the New Penn Development Corporation.

**Drilling Time**

Drilling time will vary with each well according to the problems encountered. Assuming all wells were of the same depth, there would be a difference in completion time, due to the variables in the hole itself. But there is another point, right here, which we have to recognize—the variation in efficiency of cable tools as depth progresses. Therefore, in operating, we have to worry not only about hole conditions, but about the control which can be exercised.

The following cable-tool records were obtained from the New Penn Development Corporation, which has had wide experience with various depths of wells in the East. One well drilled to a depth of 3979 feet was completed in 65 days, making a daily average of 61 feet. A 5700-foot well drilled in 237 days averaged 24 feet per day.

*Fig. 1. Showing mountainous terrain at location of 8500 feet. Deep test drilled with steam rotary rig in North Central Pennsylvania near Keating Summit.*
third well finished at 6087 feet showed an average of 29.4 feet per day after 207 days. An extremely difficult well which was drilled to 6090 feet in 540 days made a daily average record of only 11 feet. In this well, 26 gas pockets were struck, resulting in fishing jobs, not to mention caving conditions throughout the hole with long delays and lost tools. Other comparisons of well depths and completion times will be found to show a similar dropping off in daily average footage as the depth increases. We have not had sufficient experience as yet with rotary drilling in the Appalachian region to be able to say what drilling time can be expected. We know from the history in other fields that hard formations are drilled successfully and economically with rotary tools. It has not been possible to assemble figures on the cost of rotary drilling in the East, but very likely at the next meeting at State College such data will be available.

First Complete Eastern Rotary Rig

The first complete rotary drilling rig in the eastern fields shown in fig. 1 was known as an “Oilwell” steam-saving rig. A summary of the factors which were decisive in the choice of rotary were:

1. Ability to control high gas pressures by means of drilling mud and surface fittings.
2. Elimination of fishing jobs due to gas pockets and cavings.
3. Decreasing of drilling time and lowering of costs of completed wells due to the ability of rotary to drill deep strata more efficiently.
4. Ability to obtain more accurate samples of strata through mud returns and core barrel.

A list of the major items of machinery and equipment used on this rig is given in the attached appendix.

Steam Generator

Steam is generated by an “Oilwell” portable superheated steam generator, (fig. 4), of a new design with superheater coils enclosed in a housing attached to the smokebox end of the boiler portion of the generator.

The design features of this unit are a large firebox chamber, short (8-ft.) flues, and the use of the flue gases, before entering the stack, to superheat the steam 150 to 250° F. above the temperature of saturated steam. The boiler portion of the steam generator designed for 350 pounds steam working pressure has 690 square feet of heating surface nominally rated at 69 horsepower. However, the super-
heated steam generator when gas fired will normally operate at 400 to 500 per cent of its nominal horsepower rating and will actually evaporate from 10,000 to 12,000 pounds of water an hour.

The fact that a single superheated steam generator was capable of generating the total steam requirements of the Keating Summit rig to a depth of 8000 feet was a source of no little comment among observers who were accustomed to seeing a battery of three to five boilers supplying steam to a rotary drilling rig.

**Engines**

From the steam generator, the superheated steam passes through a 3-inch steam line to two twin-cylinder vertical double-acting variable cut-off steam engines. Maximum energy is taken from the engines by means of the variable cut-off control which permits the use of the expansive power of the steam. Steam is admitted to the cylinder for a portion of the stroke on light loads and thus there is no wasteful drain on the steam generator's output. The exhaust steam then passes through a feedwater heater unit which delivers
the feedwater to the steam generator at a temperature of from 190 to 210° F., which assists in increasing the output of the steam generator. The remaining exhaust steam is available at from 5 to 10 pounds pressure to afford induced draft in the stack.

**Feedwater-Heater Pump Unit**

The “Oilwell” feedwater-heater pump unit, (fig. 5), is a combination of three power plant auxiliaries commonly found in an efficient stationary steam power plant. The unit consists of an open type of feedwater heater chamber, cold water pump, and hot water pump, used to force the heated feedwater into the superheated steam generator. In operation, the cold feedwater is sprayed into the heater chamber, where its temperature is raised by contact with exhaust steam.

This steam saving unit saves fuel and heat energy, otherwise wasted into the atmosphere as exhaust steam, and also reduces the amount of raw makeup water required. Fuel and water savings amount to from 10 to 15 per cent.

Raising the temperature of the feedwater liberates free oxygen in the heater chamber and thereby removes a corrosive oxidizing agent from the feedwater before it enters the steam generator. Preheating of the feedwater also precipitates impurities in the water, which may be blown out of the steam generator in the form of sludge, thus preventing formation of excessive scale (a relatively low heat conductor) on the flues.

**Hoist or Draw-Works**

Essentially the hoist or draw-works is nothing more than a combination of shafting, chain-driven by a prime mover through sprockets, with hoisting drum and brake, all mounted on suitable bearings in an integral frame designed and constructed to facilitate drilling operations. Except for the hoisting feature, the draw-works serve the same purpose as shafting in a machine shop used to belt drive machine tools.

Modern hoists, (fig. 2), and background, (fig. 7), are of the compact utilized type self-contained and mounted on skids to facilitate transportation and installation.

Frequently the hoists are equipped with water brakes which supplement manual braking by the driller. Important accessories of all hoists are the catheads which facilitate “breaking,” screwing, and unscrewing drill pipe joints.

**Rotary**

A typical modern rotary is illustrated, (fig. 7). Rotaries are built to rotate speeds as high as 250 r.p.m. The rotary table rotates on ball or roller bearings. The 274-inch “Oilwell” rotary has a rated supportable rotative and dead load capacity of 125 and 250 tons respectively. Gears and pinions are precision-cut and heat-treated. The rotary table may be either direct driven, (fig. 7), or chain-driven from the hoist.

**Weight Indicator**

The rectangular upright box, (fig. 2), in the foreground showing two dials is the weight indicator and is an absolute necessity in deep well rotary drilling. It is both a safety and operating requisite and a means of getting maximum efficiency from the equipment. The upper dial gives a visual record of torque at the rotary table, mud pump pressure, rotary table speed and weight on the lines. The lower dial contains graph devices which give a permanent record of the above functions for each 24 hours of operation. By knowing the torque input at the table, the driller is able to ward off “twist-offs”
in the drill pipe and also able to have a better idea, knowing the table speed at the same time, as to what the bit is doing. With the mud pump pressure indicated before him, the driller will know immediately if he should lose circulation due to crevices. On the same dial, he will see if the bit is balling up or not cleaning itself properly. The largest and most important indicator on the board is the weight indicator. With this, the driller gauges the weight on the bit so that he will get the best results from it in whatever type of formation he is drilling. He watches it religiously when fishing, as he can tell immediately when the overshot or fishing socket strikes the "fish" or an obstruction in the hole. The weight indicator is a life preserver in that there is nothing left to guess when pulling on a stuck bit or stuck drill pipe, and so no pull is made beyond the capacity of the equipment. Weight is gauged by "points" on the dial. Roughly speaking, a "point" is 2500 pounds when six lines are being used, and 3300 pounds when eight lines are strung up. Previous to the advent of weight indicators, the recognition of all these func-

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**Slush Pump**

Fig. 6 illustrates a power-driven slush pump complete with built-in gear reduction, V-belt drive, and steam prime mover. A decade ago it was the practice to use "mudhog" pumps with steam cylinder ends which took steam for the full stroke of the piston. Batteries of boilers were needed to provide sufficient steam; reduction gears and separate prime mover drive had not been thought of up to that time. "Oilwell" engineers tackled the problem of designing a geared power end and furnishing a steam engine with variable cut-off as prime mover. The steam consumption has been cut to a fraction of former figures and boiler investment reduced to a minimum, along with fuel costs. This is one of the most revolutionary advances in rotary drilling equipment in recent years.

**Slush Pit**

The slush pit, for the storage of mud and for the settling out of foreign material, has been the target of considerable discussion in possible future rotary drilling in the East. In flat country where the soil is clay and loam, without stones, roots, and stumps, a tractor bulldozer can "hog" out a hole 90 feet long, 16 feet wide, and 6 feet deep easily and at a cost of $50 or $75. At Port Allegany, Pennsylvania, little difficulty was had in digging the pit. In many places it would be prohibitive to dig such a pit, due to steep hillsides, rocks, and stumps, particularly since the pit has to be close enough to the pump so that the suction lift does not exceed 8 feet. To meet such a condition, there is a sectional steel vat now on the market which can be set up and taken down and easily moved. California has used steel vats and mud tanks successfully for many years.

**Sub-surface and Allied Items**

When we drill—whether we use cable tools or rotary, we must do two things: get the formation into solution and then get it to the surface. With cable tools, we do just that. Rotary does the same job and more, through its circulating mud.

Mud, which is highly important to a rotary rig, is basically made up of pulverized clay, plus other agents to give it viscosity and weight. Most commonly used constituents are products whose trade names are "Baroid," "Aquagel," and "Baroco." To achieve
Fig. 8. Deep rotary drilling on South Penn Oil Company lease north of Pittsburgh.

Fig. 9. Unitized portable draw works and rotary unit.

special functions, such agents as tannic acid and bentonite, which have respectively a thinning or thickening effect, are added to this mixture. The mud must have the proper consistency to pick up and hold in suspension such cuttings as the bit dislodges, and carry them to the surface. There, the mud and the kind of cuttings which would be harmful if recirculated by the slush pump are separated out, either in the slush pit or in the shale shaker. Such cuttings as would give consistency to the mud may be retained and the mixture thinned as desired. Sand must be separated from the mud at the surface, since it has an abrasive action on the slush pump parts with which it comes in contact. Mud with sand content has a sand blasting effect on bits when recirculated.

In addition to carrying out cuttings, the mud has several other important functions. It cools the bit as it cuts the formation. It cleans the teeth of the bit by its jetting action. It forms a sort of lubricant for the drill pipe against the walls of the hole, as the mud passes upward, and lastly and very important, it controls blowouts and caving. Control of blowouts should not be left to mud alone but should be supplemented by surface control fittings.

With cable tools when formation is drilled, the void is not replaced by any supporting material; this, rotary accomplishes with mud. Then, in addition to the pressure action, the mud plastering the walls of the hole.

The average consistency of drilling mud is approximately 70 pounds per cubic foot, which is a specific gravity of 1.12. Thus if we had a well 7500 feet deep, the hydrostatic pressure of the mud col-
umn on the bottom would be 3645 pounds per sq. in. or 1.12 times the pressure of a 7500-foot column of pure water. A rock pressure of 2200 to 2500 pounds per sq. in. which we might expect in the Appalachian region is, therefore, easily held in check by the hydrostatic pressure of the mud column. The crew of a drilling rig must check the mud weight at frequent intervals in order to maintain control and proper viscosity for carrying the cuttings.

Careful examination of the cuttings permits an accurate record of formations. It takes approximately two hours for cuttings to come from the bottom of a 7500-foot well to the surface. Accurate samples can be taken from the shale shaker, which is nothing more than a fine screen vibrating at high frequency. The mud drops through the screen and returns to the storage pit, and on to the pump suction.

Bits

Even with the best of surface equipment, much of the effectiveness of rotary drilling depends on the bits. The performance of bits is based upon three variables:

1. Formation
2. Equipment
3. Personnel

The first of these three variables is classified as follows:

1. Broken
2. Medium
3. Medium Hard
4. Hard
5. Hard Abrasive

By broken formation is meant a stratification of hard and soft layers such as hard shale and sticky shale. Successful bits in such drilling must have maximum clearance to permit the mud “jet” to clean the bit and prevent “balling up.” In such a formation, the bit manufacturers recommended a bit having two cones.

Medium rock formations comprising “top” shales, unconsolidated sands, chalk, salt, and some lime formation, carry the recommendation of a three-cone bit. This bit may be had with coarse, medium, and fine teeth; where the drilling is harder, the fine-toothed bit is used and the coarse-tooth in the softer range. These bits in the softer range of a medium formation have been known to drill as much as 1850 feet of hole per bit.

Lime rocks, shales, and some chalks or formations which chip readily are classed as medium hard formations. A bit with three cones and having less action on the bottom with consequent longer life in abrasive formations is recommended.

Hard formations comprise dolomite, dolomitic lime rocks, slate, and hard shales. These have high compressive strengths and toughness. The three-cone bit for such drilling has exceptionally strong and hard teeth with less space between them. Three types of bits are recommended—one where the rock is only slightly abrasive; a second which has more action on the bottom to combat combinations of hard rocks interstratified with waxy tough shale; and a third for abrasive rock. Sometimes this class of bit, having a tearing action from skewed teeth, is used.

In hard abrasive formations such as dolomitic sand rock, pyrite, granite, chert, quartzite, basalt and such, a bit having three cones with closely spaced teeth with long tooth crests is suggested. In order to make the bit last for the maximum run in such formation, it is built so as to run in an approximately true rolling manner.

Common ranges of sizes in inches of rotary rock bits are: \( \frac{3}{4}, \frac{5}{8}, 6\frac{1}{4}, 7\frac{7}{8}, 8\frac{1}{2}, 9\frac{7}{8}, 11, 12\frac{1}{4}, 13\frac{3}{8}, \) and 17\frac{1}{4}.
In rotary practice, the proper bit is selected for the formation to be drilled, in contrast to cable-tool procedure, which leaves the size, shape, and hardness of the bit to the judgment of the crew.

**Pump Volume Weight and Rotary Speed**

In order to get the maximum work out of a rotary bit, it is recommended that the circulation of mud be 50 gallons per minute for each inch of diameter of hole being drilled. Weight on the bit should be approximately 1000 pounds per inch of diameter of bit or hole. This may vary dependent upon hole conditions. Rotary speed will normally vary from 80 to 250 r.p.m., dependent upon drilling conditions.

**Crooked Holes**

Rotary is sometimes criticized for drilling crooked holes. Except in extremely soft formations, this is not a fair indictment, and even then, the deviation is in control of the drilling crew. Contracts usually specify no greater deviation than 3 to 5 degrees from the vertical. When this is exceeded, the hole is plugged back and redrilled. One of the most effective devices for checking the straightness of the hole is a surveying device in a cylindrical cartridge between 3 and 4 feet long which measures the angle of deviation as well as the direction. It may be lowered on a wire, or dropped into the drill pipe before pulling out.

**Testing Formations for Production**

One of the questions which was asked by interested visitors at the Port Allegany rig was concerning the striking of production with rotary tools. With the mud pressure on the producing sand, there may be no visible evidence to the casual observer of having tapped a pay sand. From a study of the drilling returns and from the action of the tools, the crew will know when it reaches the pay. After drilling far enough into the formation, the drill pipe is pulled and a seat with a valve incorporated in it is run back to bottom, on the lower end of the drill pipe. With this set in place, the valve is opened and any gas present will pass up through the drill pipe to the surface for volume and pressure testing. As a variation to the valve and seat, there is a packer similar to an anchor packer, which, in combination with a valve, gives similar results.

**Portability**

The first photograph, (fig. 1), shows the mountainous location of the first rotary rig in the Appalachian region. The experience in handling the various pieces of equipment in rigging up, tearing down, and moving to a new location during the worst of Pennsylvania weather conditions broke down the old conceptions on this point. Vehicles and moving tackle have been mechanized and improved to such a degree in recent years that moving and rigging up is a quicker and easier job. The rig shown can be drilling on the third day after everything is on location. This is due to the fact that the major items of machinery and equipment have been unitized or combined and placed on skid mountings. Truck loading and unloading is made easy with the powerful winch equipment, which is now a standard accessory on oil field trucks. After the machinery is spotted, the entire crew of 15 men is divided—one group to set up the engines; one to set up the steam generators; another to set and connect the hoist to the engines, and so on. Usually, the contractor has a tractor winch on the job to help move the heavier pieces into position. Actual drilling can begin before the minor jobs attendant to rigging up are finished—these usually being completed before the surface pipe is set.

**Other Types of Rotary Rigs**

The type of rig discussed up to this point is the dual steam engine driven combination where 800 horsepower is available for hoisting drill pipe from 8000- or 10,000-foot depths.

Obviously the heaviest machinery is required for deep drilling, but there are lighter weight rigs powered with steam or internal-combustion engines which have proved eminently successful for drilling in shallower fields. These rigs meet practically any drilling requirement either in proved territory or for wildcat drilling.
Considerable development work has been done on Diesel mechanical and Diesel electric power installations. Quite a few of these rigs are in operation, an example of which is the rig on the Peoples Natural Gas Company well at Greensburg. Exclusive of the power plant, the machinery and equipment follow conventional rotary rig specifications.

Another type is shown in fig. 9 where the hoist, single steam engine, and rotary table are mounted on a single frame carried by a caterpillar tread. This combination would be suitable for depths from 4000 to 6000 feet and would be supplemented by an engine driven slush pump shown in fig. 6. It would also be possible to use a third engine driven unit, directly connected to the rotary table as shown in fig. 7, for highest drilling efficiency and elimination of chain drive to the rotary table. This rig would have a maximum of 400 horsepower for hoisting duty since it does not combine the rotary and pump engines for hoisting.

Rotary rigs powered by internal-combustion engines are available in three general types; driven by natural gas, butane, or propane; gasoline or oil engines of slow, intermediate, or high speed characteristics.

The largest of these rigs is what may be termed an “adapted” or “composite” type, as distinguished from the unitized rig. This “composite” rig is shown in fig. 10 and is made up of two engines side by side, with provision for compounding or dualing, plus a reversing countershaft having two sprockets of different sizes to drive the hoist and rotary. Normally, the engine closest to the hoist drives the hoist and rotary, while the second engine drives the slush pump. If for any reason one engine is taken out of service for a time, the remaining engine can drive both the pump and rotary until the other engine is again ready for duty. Both engines can be thrown together to share the total load of pump and rotary, or for the hoisting operation. It has been customary to use six-cylinder engines of 300 to 350 hp. maximum for this rig. It is recommended for depths from 8000 to 10,000 feet. One feature of this rig is that if a customer already has his draw-works, it can be used successfully by taking his drive from the reversing countershaft unit. The clutches for interchanging or dualing the prime movers are usually of the positive jaw type. While reduction gears and chains may be used with a rig of this kind, it has been customary to use V-belts to minimize noise and the necessity of lubricating the drive. The maximum available horsepower on such a rig, dependent upon fuels used, is 600 to 700 hp. While it will not be as fast on the hoisting cycle as steam power, it will perform creditably in the territories for which it is recommended.

Fig. 12 illustrates the intermediate size rig of unitized construction ordinarily used at from 3000- to 6000-foot depths. Note that the engines are still set side by side and that the prime movers still retain the flexibility of drive of the large rig. Engines with such unitized draw-works and the compounding feature usually range in size from 150 to 225 hp. and practically all have six cylinders. All of the previous rigs discussed use 4½-inch drill pipe or larger.

A third and smallest type of rig used is illustrated in fig. 11, the truck-mounted design. These vary in size from the unit which will drill from 2500 to 3000 feet using 3-inch drill pipe down to the smallest rigs, which have a range of from 1000 to 1500 feet. In the larger rig, only one six-cylinder engine of around 150 hp. is used on the hoist and the truck is made to accommodate only the hoist and engine. In the smaller rigs, which are almost in the “core-drill” class, the truck mounts the hoist, rotary, and the mast, the truck engine furnishing power to the hoist and rotary. The maximum output of the truck engine will probably not exceed 85 hp. Both the large and small rigs in this class have light skid-mounted engines and pumps of suitable capacity for the range of the rig.

Machinery has thus been developed to cover the entire range of rotary drilling, which we might wish to use in the Appalachian region in the future. We have much to learn yet and no one can say with any certainty as to what the turn will be. Sufiice it to say that if our shallow territories were of soft formation with tendency toward excessive caving, we would expect to see rotary rigs for shallow drilling in use soon.

Adaptable Internal Combustion Engines

There are several combinations of fuel possibilities on internal-combustion rigs. The first is a natural gas-gasoline engine on which it is necessary to change the cylinder heads for whichever fuel is used. The second is a natural gas-propane or butane combination which requires no change whatsoever on the engines. The third and last grouping is the oil-natural gas engine on which it is necessary only to detach the oil-injection parts and install a gas carburetor. This type of oil engine is of the Hesselman design having low compression and spark ignition, the low compression being around 120 pounds per sq. in., which is satisfactory for gas operation. No internal part of the engine is touched when converting, which makes for practical field change-over. The contractor must consider all the
above types of engines because of the different locations where he may have to drill. Thus he can use the fuel which is most quickly available and cheapest. Up to this writing, we know of no Diesel or compression ignition engines of the oil-field type which may be converted easily in the field from one fuel to another. Any of the above engines can be had for either the heavy composite internal-combustion rig, or the lighter rigs described in this paper.

Conclusion

In conclusion, we hope that you have a better understanding of the operation of a rotary rig and the functions of the various items of machinery and equipment which go to make up a rotary rig. We are not here to predict the future for rotary in the Appalachian region, but in the event that we did, we could not be further wrong than those who predicted the failure of rotary with the opening of each new oil field in the West.

Fig. 12. Type of unitized draw works, power and pump drive applicable to shallower rotary drilling.

"OILWELL" STEAM-SAVING RIG

One 122-ft. x 24-ft. x 3-ft. 6-in. rotary steel derrick, complete with crown safety platform, 7-ft. substructure and engine and rotary supports, 24-ft. derrick base and quadruple safety platform—capacity 333,000 lbs.

One No. 200 "Oilwell" center pin type crown block complete with six 36-in. O.D. x 1\(\frac{1}{4}\)-in. wire line manganese steel sheaves—capacity 200 tons.

One 66-in. "Oilwell" streamline traveling block complete with five 36-in. O.D. x 1\(\frac{3}{4}\)-in. wire line manganese steel sheaves.

One No. 150 B.J. triplex hook—capacity 150 tons.

One 6-in. No. 150-B "Oilwell" Oilbath rotary swivel with 5x6-4 thread L.H. API gage stem connection and No. 106-A gooseneck nipple for 2\(\frac{1}{4}\)-in. rotary hose.

One 27\(\frac{1}{4}\)-in. "Oilwell" Model 35 Oilbath rotary complete with "Oilwell" roller drive bushing with cage for 4\(\frac{1}{4}\)-in. stem.

One 27\(\frac{1}{4}\)-in. I.D. x 4\(\frac{1}{4}\)-in. O.D. x 45-ft. No. 300 Thermoid rotary hose.

One set 4\(\frac{1}{4}\)-in. O.D. Mission slips.

One "Oilwell" No. 7-P unit type hoist with grooved drum, regular cathead, extended shaft for hydraulic brake and equipped with American automatic cathead and American Iron and Machine Works brake drum flange water cooling system, and link-belt hyper chain.

One "Oilwell" double steam engine drive mounted on skids and complete with two No. 7-7\(\frac{1}{4}\)-in. x 7-in. twin vertical steam engines with portable cut-off, reversing mechanisms, remote control, clutches, and sprockets with 36-in. P.D. V-belt pulley pump drive.

One Wilson-Snyder power slush pump No. 7-P 7\(\frac{1}{4}\)-in. x 18-in. complete with 8-in. suction strainer, suction hose, and relief valves.

Two "Oilwell" portable superheated steam generators, 350 lbs. per sq. in. operating pressure equipped with "Oilwell" gas burners.

One "Oilwell" boiler feedwater unit consisting of structural steel frame and skids on which is mounted with piping one "Oilwell" 5 and 10x6x12 feedwater-heater pump with packing and stainless steel piston rods, one auxiliary standby "Oilwell" 10-in. x 4\(\frac{1}{4}\)-in. x 10-in. boiler feed pump and one Turbolite 5 kw. steam turbine driven electric generator.

One "Oilwell" 4\(\frac{1}{4}\)-in. x 41-ft. SAE 3140 box and pin gage stem.

One "Oilwell" sub 4\(\frac{1}{4}\)-in. regular box and 4\(\frac{1}{4}\)-in. full hole pin, 12 in. long.

Two 4\(\frac{1}{4}\)-in. x 5\(\frac{1}{4}\)-in. O.D. x 20-ft. grade A 3140 drill collars.

One "Oilwell" Sub 4\(\frac{1}{4}\)-in. full hole box and 4\(\frac{1}{4}\)-in. regular pin, 12 in. long.

One B. J. type A 4\(\frac{1}{4}\)-in. center latch elevator.

Two B. J. 4\(\frac{1}{4}\)-in. extra heavy type rotary tongs complete.

One Martin-Decker quintuplex drilling control instrument complete.
One link-belt vibrating mud screen complete with 2 hp. motor.
One A.S. & W. Co. 1½-in. x 1350-ft.—6x9 Monitor steel silver strand
rotary line.
8500 ft. 4½-in. O.D. 16.60-lb. National Tube Company special alloy
grade D seamless API interior upset drill pipe, range II with 250
Hughes API full hole tool joints bucked on and welded.
One rat hole countershaft ("Oilwell").
One “Oilwell” double box sub 6½-in. API on one end and 4½-in.
API other end, 24 in. long over all.
One “Oilwell” No. 43 standpipe gooseneck and standpipe ell.
One 4-in. Walworth iron body back pressure valve.
One Badgett automatic gas fire control—double control, 2-in.
One 275-ft. Plymouth catline.
One 1½-in. x 45-ft. Plymouth spinning line.

Progress In Industrial Utilization of Natural Gas

By D. A. Campbell


It must be clear to anyone with even the most superficial knowl-
edge of the natural gas industry that a full discussion of this sub-
ject would demand much more time than any meeting such as this
could possibly devote to it. To do full justice to it would also require
an exceedingly wide knowledge of industry in general and of heat
applications in particular. The subject is really so large that it al-
most calls for a symposium, rather than a brief summary such as
this paper must be.

Although it has not been possible to assemble all of the pictures
I would have liked to show, I hope that the pictures I have will be
helpful. These will be shown at the end of the talk to illustrate
some of the points I hope to bring out.

In order to confine the discussion to a reasonable time and to hold
the subject matter to some definite limitations, it seems to me that
certain definitions are in order.

The term "Industrial Utilization of Natural Gas" could mean al-
most anything. It is almost as all-inclusive as the annual deficiency
appropriation bill that Congress passes each year to pick up all the
expenses that are not otherwise defined. However, for the purposes
of this paper, it will include only those applications where the heat
of natural gas made available by complete or partial combustion
is utilized directly in processing commercial articles. This very
arbitrary definition immediately excludes consideration of two
very large uses of natural gas: namely, steam generation and gas-
engine power generation. Although these two classifications prob-
ably actually account for more natural gas load than all other uses
put together, the use of gas for these purposes has to be considered
almost entirely on the basis of bare fuel costs only, with little or no
benefit accruing from the advantages of form, flexibility, control,
and cleanliness inherent in gas. This is because it makes no differ-


ence to the finished product whether the power used in its manufacture is made one way or another, except for the cost of the power. Of course, considering only the furnace end of a boiler, much that may be said about development of gas utilization equipment will apply.

Among the remaining very general classifications, the following might be listed as the most important:

1. Metallurgical melting.
3. Ceramic and clay processing.
4. Glass melting and processing.
5. Food processing (not cooking).
6. Industrial drying.
7. Miscellaneous specialty applications.

It is evident there can be no hard and fast rule made to cover the allocation of various processes to the above divisions. Any one of these general divisions could be further broken down into more detailed classifications.

In order to define progress in any industry or art, it is necessary to measure that progress either forward or backward by its effect on the finished product of that industry. Forward progress in gas utilization will be evident either in lowered manufacturing cost, improved appearance, salability of the product, increased production, decreased maintenance or overhead, improved working conditions, or all of the above. It is clear that proper evaluation of all of these factors cannot be made without a great deal of painstaking study over a considerable period of time by someone really qualified to understand such factors and their economic effects. Buyers of fuel do not use any particular fuel simply out of sentiment for that fuel or because it is clean or even because it is cheap in itself, but only because they are convinced it is making money for them when considered from an over-all viewpoint. More and more industry is awakening to the fact that better fuel use will sometimes produce indirect savings so great that the entire cost of the fuel required, even though large, appears insignificant compared to the savings. At this point I should like to read an editorial reproduced from the January 1897 issue of Industrial Heating.

"The heating of products in fuel-fired furnaces—which might include melting, forging, open-hearth, refining, and heat treating furnaces for metals, or glass melting tanks, or galvanizing and tinning kettles, or porcelain enameling furnaces, or oil stills—has progressed through several important stages of development within recent years.

"Starting out with a home-made burner consisting of a piece of pipe extending through a hole in the wall of a brick box-like structure, which today would hardly be called a furnace, the main object at first was to produce ample heat and to confine the heat to the article being heated. There wasn't very much concern as to quality of flame, efficiency or quietness of operation, so long as the part was thoroughly heated in a reasonable length of time. If scaling took place, that was taken for granted in most cases.

"In this early stage of industrial heating development, the importance of the quality of flame was, of course, recognized by some manufacturers but in the main this was still a subject for scientists and professors.

"What a contrast with present-day interest in this subject!

"The luminosity of the flame and its effect on the operation of open-hearth furnaces, glass melting tanks, billet heating furnaces, oil stills, and numerous other types of furnaces, is well recognized.

"The ability to produce and maintain the desired atmosphere conditions in fuel-fired furnaces is of great interest to users of forging furnaces, and all types of heat-treating furnaces.
there have been other factors that brought out improvements in natural gas utilizations totally unexpected a few years ago.

First, of course, should be mentioned the greatly increased general and fundamental knowledge of all phases of gas combustion. As practically all of the uses of natural gas listed above require gas combustion, it is evident that any great progress must be based on improved combustion and combustion knowledge. The American Gas Association, various gas companies, engineering schools, equipment and furnace manufacturing companies have all contributed to the ever-increasing general knowledge of many hitherto unknown phases of gas combustion. We might briefly define gas combustion as oxidation at a fast enough rate to produce heat. In general, the faster this process takes place, the greater the quantity of heat that can be liberated in a given space; also, the higher the temperature that may be attained. Means of controlling the rate of combustion, the character of the resulting flame, and its application can only be produced by development of equipment after the fundamental process is well understood. As a result of the increased general knowledge of gas combustion, improved types of equipment are now being accepted by buyers of furnace equipment and new applications are being continually developed because of users’ demands for improved results. To utilize to the fullest extent the flexibility of natural gas in point of application, temperature, quantity of heat, character of heat, and ease of control, a great variety of gas-air mixing devices and burners have been produced. By the use of pictures at the end of this paper, we will try to show some of the various types of equipment that have been developed.

In addition to the many improvements in gas combustion equipment itself, there have been a number of outside changes and developments that have been influential in determining the direction taken by some of the recent gas utilization developments. Some of the most important are:

(a) Development of insulating refractory.
(b) Improvement in heat-resisting alloys.
(c) Increasingly stringent specifications on finished products.
(d) More expensive and more critical labor.
(e) Development of accurate temperature controls and dependable ignition equipment.
(f) Improvement in technique of special gas atmospheres.

With the preceding general discussion as a background, it is possible to discuss in more detail some of the actual developments in
place a special atmosphere around the work to be heated, it was formerly necessary to use a very expensive gas muffle and heat through this muffle if gas were used to heat the furnaces. Now the gas is burned in individual tubes which act as radiators and the entire furnace can be filled with the protective atmosphere outside these radiators. Simple as this change sounds, it has taken a number of years to be well understood, and the developments still taking place along the line of greater uniformity of heat emission throughout the length of the tube, as well as improvement in the tube life, are moving rapidly. Tube furnaces, gas fired, have many uses, including treating various metals, firing chinaware, and annealing glass.

One of the most spectacular developments using tube firing has been the portable cover for annealing steel sheets and other products. Although a great deal of the early development work on this general type of furnace was done by the electric furnace companies, the general acceptance of the idea did not take place until the gas-fired radiant tube with a much lower operating cost, greatly simplified mechanical equipment, and better flexibility was well developed. The development of lightweight refractory with high insulating qualities applied to this type of furnace permitted making the whole structure much lighter and further improved the economies secured.

Radiant tubes are fired in a number of ways. There are three most commonly used at present. One uses an inspirator burner with high-pressure gas producing complete combustion very close to the burner nozzle. The second requires that a suction be maintained on the tube at the discharge end. Low-pressure gas and atmosphere air are then admitted to the tube inlet and burned slowly throughout the entire tube length. The third uses a partial mixture of gas and air through a burner at one end of the tube. The balance of the air required to complete combustion is discharged from an inner perforated pipe with the perforations so placed that the heat intensity throughout the tube is well controlled. The air in this pipe is considerably preheated by passing through a recuperator at the discharge end of the pipe.

When it is realized that the heating time has been greatly reduced and the gas required per ton of material treated has been reduced to less than one-third of what was commonly accepted as satisfactory only 10 years ago, while at the same time temperature and uniformity requirements have been made much more stringent, there can be no question that real progress has been made in gas utilization in this field.
Immersion Heating

Although not so spectacular as radiant tube heating, this form of heating has made rapid strides in the last 10 years, particularly in the melting and heating of low temperature soft metals. As the name implies, it consists of burning gas in tubes or other forms of immersed combustion chambers. As the heat is applied from the inside of the mass to be heated, it is easy to reduce radiation losses to a minimum and to secure very close temperature control with a relatively simple control system. Here again, much of the early development work was done by the electric industry using immersion heating elements. Immersion heating has not fully been exploited due to limitations in material for immersion elements, as well as reduced economy at higher temperatures. It is probable that the use of some form of economizer will result in immersion firing for work at a much higher temperature than now thought practicable. Some of the advantages that are easily seen are faster heating time, cooler operating conditions, smaller space requirements, better temperature control, automatic operation, greatly increased over-all savings.

Submerged Firing

As indicated by the name, this means burning gas directly under water or other liquid allowing the products of combustion to bubble up through the liquid. Although this method of heating liquid has been used for a considerable time in England, it has scarcely been tried in this country. Recently, however, there has been some development work done here and considerable interest has been aroused in this type of application. Although the thermal efficiency developed is very high, the initial expense of the equipment involved prevents any very general application.

The most common application places the burner well below the liquid level in a tube. The liquid is first forced out of the tube by the mixture of gas and air which is then ignited and combustion continued in the tube. Modifications of this idea are being developed which may popularize this method of solution heating, although there seem to be certain technical limitations such as a rather low temperature limit.

Convection Heating

To some extent all heating is done by convection heating due to hot gases passing over the material to be heated, but it has only been during the past few years that this form of heating has been really utilized to any great extent in industrial work. Again it is necessary to credit the electrical industry with the pioneer development of industrial furnaces utilizing convection heating to any great extent. The arrangement consisted of a bank of heating elements over which air was driven to absorb the heat. The air was then passed over or through the work to be heated and then passed back over the elements. By the use of rapid circulation all parts of the load to be heated came to temperature uniformly. The first gas-fired units simply replaced the electrical elements with gas-heated tubes or with a high temperature combustion chamber independent of air circulation. With the development of improved burners and combustion systems that permitted burning the gas in the air stream itself, the entire necessity for high temperature combustion chambers or, in fact, any high temperatures at all in the furnace.
Reforming of Natural Gas to Replace Producer Gas

This development is an outgrowth of considerable work done by the Bureau of Mines. By heating partial mixtures of gas and air to a temperature of around 2000° F. in a checker chamber, a low B. T. U. gas is produced which is fed directly into the producer gas ducts while hot. This reformed natural gas is thus used to replace producer gas without the necessity of changing the furnace to which it is applied, which would be an exceedingly expensive job in some cases. Another use to which reformed natural gas has been put is the diluting of other gases which are too rich to serve directly into distributing mains without causing considerable customer dissatisfaction due to B. T. U. variations.

Gas Atmospheres

Somewhat akin to the reforming process mentioned above is the preparation of special gases for surface protection of various metals during heat treatment. Although, relatively, the amount of natural gas used for this purpose is small, it is immensely important, as it provides a comparatively cheap source of raw material for the preparation of these protective gases wherever it is available. Most natural gas is entirely free of sulphur or any other impurities that cause serious difficulties in operation. In practice, the work to be protected or treated is surrounded by an atmosphere of the particular gas best suited for the condition desired. The protective gas is constantly produced by a reforming machine. These machines consist of a combustion chamber where the natural gas is burned at about 2000° in the presence of a catalyzer, but with insufficient air to complete the combustion. The resulting products of combustion, very high in carbon monoxide, are then cooled, cleaned, and in some cases completely dried of all water vapor and then delivered to the furnace. The protection afforded by the use of these special atmospheres has eliminated a great deal of expensive pickling and further treating so that much closer dimension tolerances can be maintained and the final cost considerably reduced.

Gas-Air Ratio Control

Even the above very brief description of some of the outstanding developments that have occurred in natural gas utilization shows that these advances have come slowly and more or less as continuous minor improvements—a little change here and a little there. Contributing to this progress have been a great many refinements in various devices, such as burners, air-gas ratio controls, air-gas
mixers. Where 10 years ago there were few available combustion systems that could be depended on to maintain a constant air-gas ratio even over a range of 50 per cent of their maximum capacity, there are now a number of relatively simple devices available that will maintain a constant ratio over as much as 90 per cent of their capacity, and new and more accurate machines are appearing. One of the results of the general improvement in mixing devices and the better general knowledge of their functions and advantages has been to make their use commonplace today on even the simplest operations. They are to the industrial furnace what the carburetor is to the motor car, enabling the operator to secure continuously the best economy and reproduce conditions from day to day at will. There are three general types available, all in common use and all having their place. The first type uses air to entrain gas, the second uses gas under considerable pressure to entrain air; and the third uses the suction of a fan or compressor to draw in and mix both the air and gas. Another arrangement in common use for controlling air-gas ratios is based on feeding the two gases to the
burner in separate pipes with the flow of the two varied together in constant proportions, either mechanically or by cross-connecting pressures.

The trend of burner and combustion design up to the past few years was definitely in the direction of more intimate mixing of the gas and air before combustion to produce short and completely burned flames in the shortest possible space. However, during the past 10 years a great deal of experimental work has been done and practical applications have been made using the opposite idea. This idea uses as poor mixing as possible to secure slow combustion taking place over a long travel, but in such a way that a certain amount of gas reforming takes place in the flame itself and carbon particles are liberated that become incandescent and radiate heat directly to the work. This general type of flame called luminous, radiant, diffusion, longflame, etc., has marked advantages where it can be utilized, but like many new developments it has been misapplied a great deal. However, so much work has been done along this line that the place for this type of combustion is becoming quite well defined. Particularly in the steel industry its use is proving very helpful in applying natural gas to heating large volumes of steel in slab furnaces, reheating furnaces, and the like, without the excessively high furnace temperatures that resulted from the use of short rapid combustion.

Fig. 8. Furnace with tangential gas firing.

Conclusion

Industry, generally, is applying better methods and demanding more precise tools. Natural gas is inherently desirable and its utilization has kept abreast of the general improvement in heat application. Some methods of gas utilization have had far-reaching effect on the finished products of a number of industries.

Publications of the Mineral Industries Experiment Station

Research results of the Experiment Station are disseminated through the following publications: (1) Bulletins which present the proceedings of technical conferences and the detailed results of the experimental studies of a problem which may be more comprehensive than a single project. (2) Information Circulars which present in nontechnical language the results of studies which are given in greater detail in other publications, statistical data or pertinent information gathered from other sources. (3) Technical Papers consisting of bound copies of papers published in scientific journals (reprints), of progress reports, and of results of experimental studies which represent isolated phases of research and which will be summated later in bulletin form.

A few of the publications are listed below. These may be obtained from the Director of Mineral Industries Research, The Pennsylvania State College, State College, Pa., at the price quoted.

Bulletins


**Technical Papers**


**Circulars**

