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SUBSTITUTE FUELS AS A WAR ECONOMY.

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With the advent of total war throughout the world, the problem of securing sufficient motor fuel of high quality has become vitally important. When the United States entered the war the oil supplies of the Axis group presented a severe contrast to that of the United Nations, who control more than 90 per cent. of the world's petroleum resources.

The world's oil consumers present a different aspect, since the European continent was the second largest user of petroleum and its products before the war began. With the exception of Rumania, Poland, and Hungary, none of the nations under Axis domination has a petroleum industry sufficient to supply its needs, nor have they motor fuel of as high quality as that of the United Nations. The European volume of the world's 2,250,736,000 barrels petroleum production in 1941 was less than 3 per cent., consequently the major portion of their petroleum was previously imported.

The crude-oil production of the world during 1941 is shown in Table I.

When the Axis Powers established domination of the European continent, all oil production, storage, and refinery capacity were confiscated for the German military machine. During 1940–41 practically all the oil-burning motors remaining in civilian use in Europe were converted to the gas-, coal-, and wood-burning type. Progress in building additional plants for the manufacture of synthetic motor fuels also continued. The estimated quantity of petroleum and substitute fuels produced throughout Axis Europe amounted to a maximum of 11,268,000 barrels monthly, and consisted of gasoline from petroleum, hydrogenated coal and water-gas, compressed fuel gases, producer gas from wood, lignite, coal and coke, and alcohol, benzol, and shale oil.

Until Axis control is established in some large oil-producing country, the need for greater quantities of substitute fuels will be present.

The invasion of Russia has cost Germany about 21,250,000 barrels of oil and substitutes per month, of which at least 4,250,000 barrels must be used in maintaining communications and industry behind the battle-lines. It will be noted that Germany is using oil and its substitutes at approximately *double the rate* of their production capacity, which is based on the maximum estimated output of the European continent.

It is estimated that the year's military operations on all European fronts by the Axis Powers called for over 255,000,000 barrels of fuel, of which Germany, Rumania, Poland, Albania, and other occupied countries produced only 53,501,000 [1] barrels of petroleum, and substitute fuels of all kinds equivalent to 81,720,630 barrels of fuel, or a total of 135,221,630 barrels of fuel. From a fuel-production standpoint Axis Europe is short at about the rate of 120 million barrels of oil per year, based on the Russian campaign.

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TABLE I.
World Crude-Oil Production, 1941.

	1000 Barrels.	Per cent.
North America		
United States	1,405,830	62·46
Mexico	41,200	1·83
Canada	10,003	0·44
	1,457,033	64·73
Central and South America		
Venezuela	222,902	9·90
Colombia	24,442	1·09
Argentina	21,641	0·96
Trinidad	21,211	0·94
Peru	12,846	0·57
Ecuador	1,561	0·07
Bolivia	121	0·01
	304,724	13·54
Europe		
Russia	242,150	10·76
Rumania	40,563	1·80
Germany—		
Old Reich	4,438	0·19
Ostmark	692	0·03
Slovakia and Moravia	109	0·01
Poland	3,319	0·15
Hungary	2,474	0·11
Italian Empire—		
Albania	1,381	0·06
Italy	46	—
France	479	0·02
	295,651	13·13
Asia		
Iran	78,035	3·47
Iraq	12,650	0·56
Burma	7,762	0·34
Bahrein	6,846	0·30
Saudi Arabia	5,871	0·26
British India	2,270	0·11
	113,434	5·04
Oceania		
Netherlands East Indies—		
Sumatra	40,827	1·81
Borneo	13,848	0·62
Java	6,735	0·30
Molucca	721	0·03
British Borneo—		
Brunei	5,552	0·25
Sarawak	1,312	0·06
Japan	2,659	0·12
	71,654	3·19
Africa		
Egypt	7,659	0·34
Other Countries	581	0·03
World total	2,250,736	100·00

From time to time the question arises as to the Axis defeat because of oil shortage. The European continent is low in oil production, and to maintain a campaign based on the strategy of World War No. 1 would have depleted their oil resources. However, with modern " blitz " warfare the Western European campaign lasted but forty-five days from invasion to capitulation. In this forty-five-day war about 12½ million barrels of oil and oil products were used, and the captured stores in the defeated countries were estimated at about 20 million barrels.[2] The remaining European campaigns lasted less than a year—about 284 days of actual fighting up to the time of the Russian invasion on 22nd June, 1941. The actual expenditure of oil up to that date was less than had been expected, based on previous calculations of strategy. In contrast to the Western European campaign, the Russian campaign has cost about 12 million barrels of oil in a similar forty-five-day period, with no oil stores or production gained.

It has been reported that oil stocks in Germany were 59½ million barrels.[3] However, it is not clear as to what the German losses in actual capacity have been from aerial bombardment over Europe by the R.A.F. and the Russian Air Force. From the increasing frequency of bombing raids, the damage to Axis oil production should be relatively large.

A further indication of the prevailing European motor-fuel situation is reflected in a news item appearing in the *New York Times* on 28th April, 1942, describing a system of gasoline barter for Italian prisoners set up by the Yugoslav General Mikhailovitch. According to the dispatch, the system is as follows :

> One Italian soldier or non-commissioned officer for one can of gasoline.
> One Italian officer up to the rank of colonel for four cans of gasoline.
> One Italian colonel for fifty cans of gasoline.

These equivalents were considered unreasonable by the Italian Government, but were finally accepted, thus allowing the General to fuel the tanks captured at the same time as the soliders.

At the beginning of the war, September 1939, Europe had immense stores of crude oil and refined products, and in addition a relatively large synthetic-fuel production.

The extent to which substitute fuels have been necessary is shown by the fact that acetylene, garbage, artichokes, ammonia, and hydrogen are considered suitable for motor fuels, and by the great increase in the number of gas-generator (gasogene) and compressed-gas vehicles during the past two years. It is naturally difficult during war-time censorship and propaganda activities to obtain reliable figures on Axis production and consumption of fuels and fuel substitutes. Data are presented in Tables II and III for maximum and minimum amounts reported by different estimators of fuel substitutes. Both sets of figures are probably tinged with propaganda. The truth most likely lies somewhere between the two sets of data.

Tables II and III show the maximum and minimum fuel-production statistics. Some figures are available only as late as 1939, while others are given for as late as December 1941. In both tables the data presented are estimates.

TABLE II.

Maximum Estimates Axis Oil and Substitutes Production.

	Crude Oil Production.[1]	Hydrogenation, Bergius and Fischer–Tropsch.	Compressed Gases.	Shale Oils.	Benzol.	Alcohol.	Wood and Coal-gas Generators.	Refining Capacity.	Totals Crude Oil and Substitutes.
Germany . . .	5,239,000	42,500,000 [15] [16]	1,785,700 [4]	6,375,000 [16] (pit coal tar motor fuel) + 1,500,000 [6] (gas oil)	5,355,000 [16]	4,000,000 [16]	6,000,000 [5]	24,757,000 [2] (incl. Austria and Czecho-slovakia)	72,754,700
France	479,000	3,498,000[6]	238,000 [7]	85,000 [11]	600,000 [8] (1939)	1,600,000 [6] (1939)	1,190,000 [8]	54,558,000 [2]	7,690,000
Hungary . . .	2,474,000	—	—	—	—	80,000 [6] (1939)	—	4,201,000 [2]	2,554,000
Poland	3,319,000	—	—	—	—	100,000 [6] (1939)	—	8,298,000 [2]	3,419,000
Rumania . . .	40,563,000	—	—	—	—	—	—	80,712,000 [2]	40,563,000
Baltic States . . .	—	—	—	1,500,000 [9] (1940)	—	—	—	—	1,500,000
Norway	—	—	—	—	—	—	183,000 [10]	—	183,000
Denmark . . .	—	—	8,500 [11]	—	—	—	277,530 [11]	—	286,030
Holland	—	—	—	—	—	—	42,000 [12]	—	42,000
Finland	—	—	—	—	—	—	238,000 [13]	—	238,000
Belgium	—	—	—	—	300,000 [6] (1939)	—	143,400 [17]	—	443,400
Italy	1,427,000	3,025,500 [14] (1940)	255,000 [3]	—	—	340,000 [3] (1939)	255,000 [3]	20,628,000 [3]	5,302,500
Lithuania . . .	—	—	—	—	—	50,000 [6]	—	—	50,000
Total European .	53,501,000	49,023,500	2,287,200	9,460,000	6,255,000	6,170,000	8,328,930	193,154,000	135,025,630

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[1] Anon., *Petrol. Times*, 1942, **46**, 125.
[2] "Petroleum Facts and Figures," 7th Ed., 1941, p. 26.
[3] J. A. Kronstein, *Petrol.*, June 1941, **32**,
[4] Anon., *Foreign Commerce Weekly*, 8th Nov., 1941.
[5] R. H. Bost, Oakland, *California Tribune*, 13th Nov., 1941.
[6] V. R. Garfias and R. V. Whetsel, *Trans. A.I.M.E. Petrol. Div.*, 1941, **142**, 248.
[7] *Chicago Daily News*, 19th March, 1940.
[8] O. Tokayer, *Petrol. Press Service*, Aug. 1941, **8**, 8, 98 (Sec. (6)).
[9] Anon., *Fortune Mag.*, Sept. 1941, **24**, 3, 73.
[10] O. Tokayer, *Petrol. Press Service*, Nov. 1941, **8**, 11, 136.
[11] Anon., *Foreign Commerce Wkly*, 25th April, 1942, p. 18.
[12] O. Tokayer, *Petrol. Press Service*, March 1941, **3**, 3, 33.
[13] Anon., *National Petrol. Assoc. Gen. Bull.* 40—289, 7th Dec. 1940.
[14] W. H. Cadman, "Petroleum Technology in 1940," p 140, Inst. Petroleum, London, 1941.
[15] O. Tokayer, *Petrol. Press Service*, 1942, **9**, 4, 42.
[16] L. Lewis, *Petrol. Times*, 1941, **45**, 743.
[17] *Ibid.*, 1942, **46**, 151.

Table III.

Minimum Estimates Axis Oil and Substitutes Production.

	Crude Oil.	Hydrogenation, Bergius and Fischer–Tropsch.	Compressed Gas.	Shale Oils.	Benzol.	Alcohol.	Wood and Coal-gas Generators.	Totals Crude and Substitutes.
Germany	5,239,000 [1]	19,125,000 [5]	1,429,000 [4]	6,375,000 [6] (pit coal tar) + 1,500,000 [3] (gas oil)	5,355,000 [6]	4,000,000 [6]	1,190,000 [2]	44,213,000
France	479,000 [1]	297,500 [8]	137,700 [8]	85,000 [12]	—	—	—	999,200
Hungary	2,474,000 [1]	—	—	—	—	—	—	2,474,000
	—	—	—	—	—	1,071,000 [6] All occupied countries	—	1,071,000
Poland	3,319,000 [1]	—	—	—	—	—	—	3,319,000
Rumania	40,563,000 [1]	—	—	—	—	—	—	40,563,000
Baltic States	—	—	—	1,300,000 [3] (1939)	—	—	—	1,300,000
Norway	—	—	—	—	—	—	183,000 [7]	183,000
Denmark	—	—	8,500 [10]	—	—	—	277,530 [13]	286,030
Holland	—	—	—	—	—	—	143,000 [11]	143,000
Finland	—	—	—	—	—	—	42,000 [4]	42,000
Belgium	—	—	—	—	300,000 [3]	—	143,400 [8]	443,400
Italy	1,427,000 [1]	631,000 [3]	476,000 [9]	—	—	350,000 [3]	23,800 [3]	2,907,800
Lithuania	—	—	—	—	—	50,000 [2]	—	50,000
Total European	53,501,000	20,053,500	2,051,200	9,260,000	5,655,000	5,471,000	2,002,730	97,994,430

References.

1 Anon., *Petrol. Times*, 1942, **46**, 125.
2 W. H. Cadman, "Petroleum Technology in 1940," p. 140, Inst. Petroleum, London, 1940.
3 V. R. Garfias and R. V. Whetsel, *Trans. A.I.M.E. Petrol. Div.*, 1941, **142**, 254.
4 O. Tokayer, *Petrol. Press Service*, March 1941, **8**, 3, 33.
5 M. Friedwald, *Petrol.*, 1941, **4**, 98.
6 L. Lewis, *Petrol. Times*, 1941, **45**, 743.
7 O. Tokayer, *Petrol. Press Service*, 1941, **8**, 11, 134 and 136.
8 Anon., *Petrol. Times*, 1942, **46**, 151.
9 Anon., *ibid.*, 1st Nov., 1941, **45**, 628.
10 Denmark Automobile Census, 18th Sept., 1941.
11 O. Tokayer, *Petrol. Press Service*, 1941, **8**, 5, 58.
12 E. A. Bell, *Petrol. Times*, 1941, **45**, 756.
13 Anon., *Foreign Commerce Wkly*, 25th April, 1942, p. 18.

Composition Motor-Fuel Efficiencies.

On the technical side of the situation the efficiency of the fuels produced as substitutes for the more desirable petroleum products has enforced some limitations on their general adaptability. While it is perfectly feasible to use the various substitutes, there are a number of drawbacks. In compressed gas the weight of the tanks constitutes a decided drain on efficiency. In alcohol fuels separation occurs if water is present, and in the producer-gas vehicle the fuel and the added weight due to the retorts, coolers, etc., are a detriment to efficiency; in addition, an entire new driving and mechanical technique must be learned. Taking into account these major items, the heating quality of the gas is also a considerable item in their use. Table IV shows the heat content of the various fuel substitutes used in the countries without oil.[4] The equivalents are based on one barrel of gasoline as a standard.

TABLE IV.

Heat Content of Gasoline Substitutes.

	Equiv. Bbl. Gasoline 60° A.P.I.
One barrel	
Benzol	1·07
Natural gasoline	0·941—assuming 75° A.P.I. nat. gasoline.
Butane	0·823
Propane	0·730
Ethyl alcohol	0·671
Methyl alcohol	0·507
One thousand cubic feet	
Natural gas	0·219—assuming 1150 B.T.U./cu. ft.
Methane	0·196— „ 1009 „
Manufactured gas (city gas)	0·103— „ 537 „
Producer gas	0·019— „ 100 „

Coal Hydrogenation.

Hydrogenation of coal by the Bergius, and carbon monoxide by the Fischer–Tropsch processes has formed the major source of substitute fuels in Germany. At the present time, in spite of the relatively large installations necessary for fuel production, the Bergius process has the largest production of synthetic oils.

During the years preceding the present war considerable research was done on various hydrogenation processes, and a number of processes for production of oil from coal came into being. The data in Tables V and VI show the development [5] of 1939 through 1940 of Bergius and Fischer–Tropsch processes for the production of oil from coal, their location, capacities, and the year production started. The data are incomplete as to the actual number of plants operating.

The total 1940 figures presented for the hydrogenation processes show that approximately two-thirds of the synthetic oil is manufactured by the Bergius method. Table VI shows the same data for the Fischer–Tropsch process.

TABLE V.

*Hydrogenation (Bergius) Plants in Germany.**

Plant.	Date Placed in Operation.	Place.	Process.	Production (brls.).		
				1938.	1939.	1940.
Leuna, I.G.F.A. . .	1927 or 1933 (?)	Merseburg	Hydrogenation of lignite	3,410,000	3,612,500	4,250,000
Oppau, I.G.F.A. . .	1934	Ludwigshafen	,, ,, ,,	1,275,000	1,275,000	1,275,000
Wesseling (Cologne Co.) .	1939	Cologne	,, ,, ,,	—	425,000	1,700,000
Mines of Geiseltal . .	1938 (end)	near Merseburg	Carbonization and synthesis of lignite	—	637,500	637,000
Mines of Geiseltal . .	1940 (end)		Hydrogenation of mineral oils	—	—	637,500
Politz	1940–41	Stettin	Hydrogenation	—	—	2,975,000
Brux	1940–41	Sudetenland		—	—	3,400,000
Bleichhammer . . .	1941	Upper Silesia	Hydrogenation of Polish coals	—	—	—
Magdeburg (Brabag) .	1934	Saxe	I.G. Hydrogenation	3,782,500 with Schwarz-heide	5,100,000	5,100,000
Bohlen (Brabag) . .	1937	Saxe	I.G. Hydrogenation			
Zeitz (Brabag) . .	1938 (finished)	Saxe	I.G. Hydrogenation			
Gelsenkirchen . . .	1939	Ruhr	I.G. Hydrogenation	—	637,500	2,550,000
Bottrop	1938	Ruhr	I.G. Hydrogenation	—	—	—
Total . . .				8,467,500	12,112,000	24,225,000

* Anon., *La Revue Petrolifère*, 1924, p. 237.

TABLE VI.

*Fischer–Tropsch Plants in Germany.**

Plant.	Date Placed in Operation.	Place.	Process.	Production (brls.).		
				1938.	1939.	1940.
Schwarzheide	1937	Saxe	Fischer–Tropsch	(see Brabag group in Table V)		
Wanne Eickel	1939	Ruhr	Fischer–Tropsch	—	425,000	1,700,000
Bochum	1939	Ruhr	Fischer–Tropsch	—	425,000	1,700,000
Rauxel	1938	Ruhr	Fischer–Tropsch	340,000	425,000	1,700,000
Stercrade–Holten	1938	Ruhr	Fischer–Tropsch	255,000	637,500	850,000
Moers–Moerbeck	1936 and 1939	Lower Rhine	Fischer–Tropsch	255,000	765,000	765,000
Koln Neussen	1938	Cologne	Fischer–Tropsch	255,000	425,000	425,000
Dortmund	1939	Ruhr	Fischer–Tropsch	—	—	—
Deschowitz	1939	Upper Silesia	Fischer–Tropsch	—	212,500	425,000
Essen	1938–39	Ruhr	Carbonization and Fischer–Tropsch	212,500	425,000	1,870,000
Essen	1939	Ruhr		255,000	425,000	425,000
			I.H.P. Process.			
Recklinghausen	1936	Ruhr		850,000	1,062,500	1,275,000
Total				2,422,500	5,227,500	11,135,000
Total by I.G. Farbenindustrie				8,467,500	12,112,000	24,225,000
Total of both I.G. Farbenindustrie and Fischer–Tropsch				10,890,000	17,339,500	35,360,000

* Anon., *La Revue Petrolifère*, 1941, p. 237.

An advantage of the Fischer–Tropsch plants lies in the fact that they may be operated efficiently on a much smaller scale than the direct coal-hydrogenation plants operating on the Bergius process. Due to the possibility of decentralization of these plants, there is less danger from bombing, and even if a direct hit is scored, there is less loss of capacity.

In spite of the abundant potential supply of coal in Germany, Holland, Belgium, Northern France, Alsace, Lorraine, Poland, and Czechoslovakia, the aggregate production of which was of the order of 510 million tons per year (1938) figures, a factor limiting the maximum production capacity for war is doubtless man-power and alloy steels, which are scarce. In addition to furnishing the coal required for hydrogenation purposes, a further limitation imposed on extension of the coal-oil synthesis plants lies in the vastly increased coal requirements of the other war-production industries. According to previous data,[6] the amount of coal required to manufacture 1 ton of gasoline is 5 tons, and on this assumption the production of synthetic oil from coal will reach its approximate limits at around 42 million barrels (reached in 1941), although according to Lisle [7] the goal set for oil from this source has been placed at about 62 million barrels for 1942

France has some small coal-hydrogenation units producing motor fuel at the rate of about 2,800,000 barrels a year—a top estimate—whereas Italy hydrogenates heavy, high sulphur Albanian crude oil to motor fuel at an annual rate of about 3,260,000 barrels. The data are given in Table VII.[8]

TABLE VII.

Synthetic Fuel Plants in Axis-dominated Countries.

	Synthetic Fuels (brls.).
France	
Bethune	425,000
Lievin	425,000
Harnes (Pas de Calais) (Fischer-Tropsch)	85,000
*Projected building (1939), 4 plants	1,955,000
Italy	
Bari	1,520,000
Leghorn	1,520,000
Valdarno, Tuscany	165,500
Total oil output by hydrogenation outside Germany	6,095,500

* It is not known whether these plans were carried through, because no information has been available on their status since June 1940.

Compressed Gases.

With the severe rationing of gasoline from petroleum and synthetic oils from coal sources, the use of alternate fuels has become necessary in many nations of the world. Compressed-fuel gases were developed for some years before the second World War. Low-pressure combustible gas for gasoline-engine propulsion started during the last war.

The low-pressure installation developed during the first World War is definitely a makeshift appliance, since the container for the gas is approximately as large as the vehicle on which it is installed. These containers [9] vary in size from 100 to 720 cubic feet, and provide for a range of from 15 to 25 miles per filling. The life of the fabric containers is about one year. Provisions are made for refuelling the gas-bags at regular gasoline filling-stations, where the gas connection is made from the gas mains in the city. Two hundred and fifty cubic feet of this gas is equivalent to one gallon of gasoline.

Some of the chief drawbacks to the system have been, first, the size of the balloon necessary to be effective in driving; second, the wind resistance of the fuel-bag, which is considerable at regular automobile speeds; third, the tendency of the bag to leak after two or three weeks with dilution of the gas with air; fourth, to collect snow in the winter-time, and, because of this added weight, the pressure is great enough to force gas into the engine too quickly and cause backfiring, with subsequent stalling; a fifth difficulty is the inadequate height of the bridges and under-passes to accommodate trucks with gas-bags, although bridges 13 feet high or more give no difficulty even for trucks. In July 1940, despite all drawbacks, there were eighty gas-filling stations in London, and a survey made by the British Commercial Gas Association has listed the gas-filling stations in each county.

Compressed gases under pressures varying from 75 to 5000 lb., depending on the type of gas, are more efficient in utilization than the low-pressure gases just discussed. However, here, too, there are drawbacks which reduce their efficiency for automobile use; the one factor of greatest importance is the extra weight which must be carried as the steel cylinder. Table VIII shows the weights of the compressed gases and values in relation to gasoline.

Table VIII.

*Compressed Gases in Relation to Gasoline.**

Gas.	Cylinder Weight (lb.).	Pressure (lb. per sq. in.).	Gas (lb.).	Gasoline Equivalent (U.S. gal.).
Propane-butane	117	75–150	100	18·0
Methane	115	3000–5000	28	4·56
City gas	155	3000	12·6	1·8

* Based on figures presented in *Petrol. Times*, 1939, **42**, 1073, 189.

In this field, as well as in the manufacture of synthetic fuel from coal, Germany has gone the farthest in its development. In 1939 she had six types of bottled gas on the market: city gas, coke-oven gas, methane, propane, butane, and Ruhrgasol. The facilities for the utilization of these gases include more than fifty filling-stations and about 75,000 vehicles using compressed gases of the various types.[10] The propane and butane are derived from the hydrogenation and Fischer–Tropsch plants.

Methane and city gas are more widely available than propane and butane. Natural gas-fields, sewage-disposal plants, and coal hydrogenation, coal carbonization, and oil refineries provide a considerable source of methane.

Italy has a small gas-field near Milan which has been developed for providing methane. Probably the most outstanding development of a fuel-gas source has been the utilization of methane derived from fermentation of city sewage. In Sweden as well as in other countries there has been a development in this line. The sewage gas [11] as it comes from the disposal plant is 64 per cent. methane and 35 per cent. carbon dioxide. This product is considered richer in caloric content than city gas. Purification of sewage gas takes place before it is used in motor-cars, although forty care belonging to the Road and Street Commission in Stockholm use the unpurified gas. This unpurified gas is about 58–78 per cent. as efficient as benzol.

The cylinders for the use of sewage gas are about 1·4 cu. ft. capacity, and two to four cylinders are necessary for each car. Each cylinder contains 212 cu. ft. of gas compressed to about 2000 lb. per square inch. The installations are the same as for city gas and methane. At the compressed gas-filling station the filling time is the same as for gasoline.

In utilizing the gases the changes in the car involve a spark advance, a change in the carburetter, and a system of valves for stepping down the gas pressure before entering the carburetter. Many cars are so arranged that a change from benzol use to the gas may take place at the instrument-board. The cost of conversion to the gas-burning vehicles ranges between $150 and $175, and the steel cylinders from $20 to $22.50 per cylinder. There are very few cities having the type of sewage systems necessary to obtain the methane for fuel, hence the development is not widespread.

The Soviet Union, France, and Denmark have developed compressed gaseous fuels also, and in general the type of apparatus used has been much the same as in other countries. A study [12] which was made in Russia in 1940 has shown that while preference was given to the development of gaseous fuels, little utilization has been made. Authorities in Russia have claimed that yearly utilization of coal gases in the Don River Basin alone would be equivalent to approximately 8½ million barrels of gasoline. In addition to this supply, the Soviet Union has rich deposits of natural gas in the Caucasus, Central Asia, the Far East, and other localities. Liquid gases are further available in large quantities as by-products from the petroleum industry.

According to latest news from Italy, methane gas, compressed to 300 atmospheres over-pressure, has been used to run a gas-fed railway engine of 120 horse-power between Rovigo and Venice. At present it is planned to place more of these locomotives in service.[13]

Gas-Producer Development.

Wood, coal, and other solid combustible materials have been used for a number of years as motor fuel in countries lacking in oil resources. There are a number of factors to consider in the widespread adaptation of gasogene (gas producer) vehicles, although the present war has left no choice in the matter. The use of gasogene-propelled motor vehicles has increased greatly in the past few years. In 1938 the European continent had about 9000 trucks and buses in operation, whereas 1941 indicated about 450,000—a fifty-fold increase. The tonnage of producer fuel substituted for about

8,329,000 barrels of gasoline. There are, generally speaking, three types of fuels used in the gasogene vehicles : wood, charcoal, and coal or their mixtures. In many countries wood and charcoal are the main types of fuel used, while in others the use of coal has become as widespread as that of wood.

Four countries—Germany, France, Sweden, and Italy—have been more responsible for the use and improvement of the gasogene vehicle than any of the others. For a number of years only hard woods, well dried, were suitable for the gasogene engine; however, Germany [14] developed technical improvements in the engine, so that wet and soft woods may now also be used. Filters made of glass wool remove the dust from the soft woods, and special heat exchangers have been installed to compensate for the heat loss due to utilizing wet woods. These improvements, it is reported, together with others, have brought the efficiency of wood-gas vehicles close to that of the diesel engine. A light-weight bus has been adapted for the use of wood-gas from these sources.

In order that fuel may be available for the 231,000 gas-generator vehicles in Germany, the German Motor Roads Fuel Company [15] has arranged for more service stations to supply "chipped wood." Twenty-two wood stations were to be opened between Berlin and Dresden in May 1941 in connection with the gasoline filling-stations. Germany required 2,891,000 tons of wood to propel the producer-gas vehicles during 1941, although the distribution arising from such widespread use of wood places a considerable burden on an already overtaxed transportation system in Germany.

With the widespread use of the wood-gas generator, the difficulty of increasing the supply of wood has become apparent, and consequently more attention has been given to the utilization of coal and peat. A problem which is still of great importance in all countries utilizing the gas generator is to invent an engine of the type that will run on all types of solid fuel. Up to the present no development of this nature has been brought out.

Sweden, another country in which development of the gas generator has made much progress, has used the generator vehicle for a number of years. At the outbreak of the war there was little difficulty in turning from gasoline to gas-generator vehicles. As in most countries, the majority of Sweden's gas-generator vehicles are trucks, but other vehicles have also been adapted. In January 1941 there were twenty different types of solid fuel-burning motor vehicles on the roads in Sweden. The type of fuel most desirable for these was considered to be birch wood. A series of tests were run on coal and wood in comparison with gasoline, and it was found that use of coal producer gas resulted in less lubricating-oil contamination than wood gas. Since lubricants are strictly rationed in Sweden, coal gas was considered more economical than wood gas for the generator vehicles. More trouble was encountered in winter driving with wood gas because of its higher water content [16] due to its freezing.

In France a somewhat different note is being sounded in the use of the wood-gas generator vehicle. For while France for a number of years encouraged the building and use of gas generators, many of her experts had predicted that too wide a use would cause a wood shortage. In June 1941 an order was issued forbidding the use of charcoal; the reason stated was that wood supplies had fallen far below expectation. A report from Vichy, 13th February, 1942,[17] stated that the wood paving-blocks in the Place de la Concorde in Paris have been ripped out to use for fuel in wood-burning trucks, and that trees in the Bois de Boulogne had been cut down due to a timber shortage. The gas generators that were being built at that time were expected to be modified in order to burn other solid fuels.

Holland is another country cancelling permits for the use of the wood-gas-burner motor-cars.[18] There are approximately 1770 trucks in service using wood gas, but in future the manufacturers of the vehicles will be compelled to design the machine for burning peat, since this is available in Holland.

Italy in 1938 had 2200 wood-burning motor-buses and trucks, whereas in 1941 there were 5000 in operation. Italy is a country possessing very small forest reserves and less coal, hence the producer-gas-type motor vehicle has not alleviated the fuel shortage.

Denmark operated 11,656 wood-burning vehicles, according to *Foreign Commerce Weekly*; Norway, Belgium, and Finland, with 5563, 6023, and 10,000 gas-generator vehicles, respectively (see Table XI), were also finding a solution to their fuel situation by this means, since they had sufficient forests to provide the gas-generator type of fuel.

Throughout the occupied countries in Europe and those affected by the blockade the effect of the oil shortage has been to force the use of substitutes, and in many instances these substitutes have been wood or coal-producer-gas vehicles. Switzerland and Sweden, two of the four neutrals left on the continent of Europe, have felt the pinch of fuel scarcity to practically the same degree as the occupied countries. Switzerland only licences the gasogene vehicles considered vitally necessary.

Embattled Russia, in spite of her vast oil resources, has also turned to the gas-generator vehicle for motive power.[19] Tractors and trucks in the Soviet Union[20] have had considerable development, since many of the agricultural centres are far from liquid fuel supplies, but in or near the forests and peat-beds. The design of the vehicles has been in some instances for charcoal and anthracite, and in others, especially the heavy trucks, for peat and bituminous coal. Other tractors with producer gas units

TABLE XI.

Producer Gas (Gasogene) Vehicles.

Country.	Number of Vehicles, 1941.
Germany	231,000
France	57,000
Denmark	11,656
Finland	10,000 (1940)
Belgium	6,023
Norway	5,563
Italy	5,000
Holland	1,770
Sweden	75,000
Russia	40,000 (1940)
Total	443,012

have been tried on straw briquettes, but up to the time the article from which this information was taken was written no practicable results had been achieved.

In France and Denmark a number of boats have been adapted to the use of charcoal or wood. Germany is reported to be operating 1000 boats, with 1400 to be in use early in 1942.

Table XI shows the number of vehicles in use in the various countries that have had to adopt solid producer-gas fuels rather than liquids to provide transportation.

The fifty-fold increase in producer-gas-propelled motor vehicles during the last three years has been confined to land vehicles and boats. It is interesting to note to what extremities some countries are being driven in the use of substitute fuels, as an Associated Press report out of Rome, 16th December, 1940, said:

ITALIAN PLANE MAKES FLIGHT ON CHARCOAL GAS

Rome, Dec. 16—(AP)—A flight by a charcoal-burning airplane, said to have been the first ever made, was reported today by the newspaper *Il Messaggero*.

The newspaper said the flight was made by Constantino Mazza in a Breda plane powered by a "gasogene" motor yesterday over Taliedo Airfield, near Milan. A test flight from Milan to Rome is planned next.

A special apparatus said to have supplanted the plane's gasoline tanks was described as weighing 176 pounds—99 pounds of charcoal and a low-temperature furnace to convert the charcoal into gas.

Power Alcohol.

Power alcohol consisting of both methyl and ethyl alcohol was fostered by a number of countries short of petroleum in an endeavour to make themselves self-sufficient from their own natural resources, not alone for peace-time, but for war. Methyl or wood alcohol is derived from distillation of wood or sulphite pulp from paper-making, and hydrogenation of carbon monoxide. The raw materials used for ethyl alcohol production are mainly foodstuffs, such as sugar, beet, and potatoes. It became a question of balance as to whether power alcohol is more important than food in the war economy.

It has been generally conceded that the alcohol industries were kept going in peace-time for the primary purpose of furnishing sufficient ethyl alcohol for the munitions industries in case of war. The events of the past three years or so have borne out this idea. It was reported in 1939 that Germany reduced the ethyl alcohol content of motor fuel from 8·2 to 2·3 per cent., and discouraged the use of methanol entirely.[21] It appears as if ethyl alcohol will also be eliminated due to food shortage.

The occupied countries of Europe are using alcohol as a motor fuel, although a general curtailment has been evident since 1936 for technical reasons and because of food shortages.[22 23]

In 1941 France was utilizing grape alcohol[24] as one of the substitutes for gasoline. The alcohol was distilled from the pulp after the wine was pressed, and oil was obtained from the grape-seed. Grapes have also been the source of much of Spain's motor fuel. The Government instituted the use of alcohol in order to utilize the great surplus of grapes.

The Swiss Government has designed a plant for the purpose of distilling wood which will produce 16,000 tons yearly of methyl alcohol and 10,000 tons of "alkaeton," a motor-fuel substitute. Sweden also utilizes wood alcohol and some turpentine. These products are derivatives of wood pulp by special processes. It has been estimated that wood alcohol could be produced to the extent of 290,000 barrels per year in existing plants.

Table XII shows the extent of alcohol production in the principal European countries for 1939; for other countries the figures are for 1941 wherever possible.

TABLE XII.

Power Alcohol Production (Brls.).

Country.	1939.*
France	1,600,000
Germany	4,000,000
Italy	350,000
Poland	100,000
Hungary	80,000
Lithuania	50,000
Sweden	290,000 (1941)
Switzerland	195,000 (1941)
Total for Axis Europe, based on 1939 figures	6,480,000

* V. R. Garfias and R. V. Whetsel, *A.I.M.E. Trans., Petrol. Div.*, 1941, **142**, 246.

Many sources of power alcohol have been exploited, but perhaps the most unique of all is the one reported in Sweden, where a baker adapted his ovens so that the alcohol produced during baking was condensed and used as a motor fuel. His fleet of thirty trucks are fuelled by means of the alcohol extracted from the steam of baking bread.[25]

Japan.

The Asiatic part of the Axis—namely, Japan—has through the years endeavoured to increase her fuel supplies by means of discovery, research, and conquest. Japan's primary sources are petroleum, coal hydrogenation, coal carbonization, and oil shale. Fuel substitutes include alcohol, wood-burning and compressed-gas vehicles, and other miscellaneous fuels such as sardine oil and garbage.

Japan's status in oil and its substitutes prior to the outbreak of the war with the United States, Britain and Holland and the conquest of the Netherlands East Indies, British Borneo, and Burma is indicated in Table XIII.

Various authors have given the synthetic fuel production expected under Japan's Five- and Seven-Year Plans. B. O. Lisle[26] has estimated 22,180,000 barrels, H. S. Norman[27] reports 16 million to 18 million barrels for this production, and *Business Week*[28] quoted 7 million to 9 million barrels. Due to the preceding estimates being based on *plans* for substitute fuel production in Japan and the considerable doubt of their having been carried out, it was thought advisable to use in Table XIII the lower figure of 4 million barrels of synthetic oils, as reported in *World Petroleum* of January 1942.

The foreign crude oil and products therefrom given in Table XIII are direct shipments to Japan. To give an estimate of the volume transhipped

TABLE XIII.

Oil Economy in Japan.

Source of Oil.	Barrels.
Japan	
Crude petroleum (includes Formosa and part of Sakhalin)	3,800,000 (1941)
Synthetic oils (coal and carbon monoxide hydrogenation)	4,000,000 (1940)
Manchurian shale oils	3,000,000 (1940)
Motor alcohol	2,396,000 (1939)
Total oil indigenous to Japan	13,196,000
Foreign oil imports to Japan	
United States	24,889,000 (1940)
Netherlands East Indies	7,000,000 (1940)
Iran	1,000,000 (1940)
Mexico	1,600,000 (1940)
Total imports	34,489,000

through neutral ports was not possible, as the data are not available. Just how much oil Japan had in storage on 7th December, 1941 is not clear, although it is considered "large." The oil-refining capacity of Japan in 1941 was reported to be about 64,000 barrels a day in twenty-eight refineries. The U.S.A. has a daily refining capacity of over 4 million barrels of crude oil.

The consumption rate of petroleum and products for civilian use in Japan during 1940 was about 26 million barrels, and for military and navy needs about 14 million barrels, or a total of 40 million barrels peace-time needs. At the present war rate of oil consumption Japan is probably using more than twice the latter volume, despite drastic civilian curtailment.

The Netherlands East Indies in 1941 produced about 62 million barrels of crude oil, while British Borneo yielded 9½ million barrels. The oil-fields and refineries (in a highly damaged state) are in the hands of the Japanese.

According to Kessler,[29] oil installations in the Dutch East Indies valued at $500 million were developed over a period of fifty years and thoroughly destroyed before Japanese occupation. Many of the oil-wells were plugged with cement so that a reopening of the well could not be accomplished without completely redrilling. In the destruction of Tarakan, Balik Papan, and Palembang alone, 88 per cent. of the total oil available in the East Indies was cut off by the Dutch. Only at Tarakan, where the crude needs no special refining, could redrilling give the Japanese oil they need. According to the most authoritative statements from Batavia, the time required to obtain the necessary drilling equipment, pipe-lines, pumps, tanks, special refinery fabricated materials, fine instruments, etc., and actual drilling to production again would require from 18 to 24 months.

Burma Oil Production.

Burma in 1941 produced 7,762,000 barrels of crude oil with several operating refineries. A thorough "scorched earth" policy was carried out by the British, which is borne out by a Calcutta, 7th May, dispatch,[30] as follows:

" It will take the Japanese ten years to restore the blasted Burma oil-fields to capacity production, American drillers said today on arrival here from Yenangyaung and Chauk, where they helped demolish more than 4000 wells in eight days."

" 'We left behind nothing the Japanese could use,' said G. Whitley, of Batson, Tex., an employee of Burmah Oil Company, who helped with the Yenangyaung destruction. 'We destroyed 3021 wells with explosives which dropped the pipes to the bottom and by firing the free-flowing wells.'

" He said they also fired thousands of barrels of oil stored in tanks, then tore down tank and derrick superstructures, and cut up the machinery with torches.

" The demolition was carried out between 10th and 18th April, but most of the work was packed into the last two days after British authorities ordered total scorched-earth destruction.

" Mr. Whitley said it would take at least ten years to get the fields going to capacity, and G. W. Akers, Long Beach, Calif., another Burmah employee, said it would take the invaders months to realize any flow, even if they got equipment promptly."

The 1941 production of the areas now in Japanese hands is shown in Table XIV.

TABLE XIV.

Area.	1941 Production (brls.).
Dutch East Indies	63,130,000
British Borneo	6,864,000
Burma	7,762,000
	76,756,000

These oil-producing areas in the hands of the Japanese have been subjected to a " scorched-earth " programme, and the oil from these sources is unavailable for some time to come. On this basis the substitute fuel production assumes a more important place in Japan's fuel economy than the outputs shown in Table XIII would warrant, since this production is indigenous to Japan.

The substitutes in use in Japan at the present time are: (1) gas generated from charcoal, wood, coalite, and acetylene from calcium carbide, and (2) natural gas, petroleum gas, and methane from garbage, etc. Natural and compressed gas is used only in the area of its production because of a lack of steel containers for further distribution. The oil synthesis programme [31] (Fischer–Tropsch and Bergius) has been slowed down considerably by the lack of steel and alloys both in Germany and Japan, and the absence of suitable coals for hydrogenation purposes in Japan.

Charcoal and wood are the only substitutes that have received particular encouragement from the Government, and even the charcoal substitutes are limited for motor fuel use, since industrial and domestic demands far exceed the production. In addition to the fuel limitations, the manufacture of the gas generators has also been curtailed due to a steel and labour shortage.

Alcohol still remains as a source of motor fuel, and according to laws reported enacted in Japan [32] all oil companies were required to maintain emergency reserves of alcohol equivalent to at least 20 per cent. of the gasoline on hand for six months' sales.

The tanker fleet in Japan, which is now of the utmost importance in fuel transport to the war theatre in the Far East, is reported to have consisted of forty-seven vessels (in 1940), the majority of which were the largest and fastest type (19 knots per hour in contrast to 10–12 knots), with a gross tonnage of over 440,000 tons, and probably has been augmented during the past year. The Japanese law [33] required that all companies operating in the Japanese market carry a six months' supply of petroleum products. The Government provided storage tanks for lease to the companies and covered any losses that might occur from evaporation or catastrophe. In addition to the commercial petroleum stocks on hand. the army and navy were known to have accumulated "large" inventories which were stored underground for protection.[34]

Conclusion.

Many types of motor fuels and substitutes are being used by the Axis Powers. There is a decided stringency in the allowable use of even substitute fuels, due to lack of raw materials, manufacturing facilities, and man-power for their preparation. The relatively poor quality of the Axis fuels has curtailed the manœuvrability of their automotive transportation, including airplanes.

The successful conclusion of this war will be based largely on the superior quality and quantity of the motor fuels available to the United Nations in unlimited volume.

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THE VALUE AND ACCURACY OF FIELD MEASUREMENTS.*

By C. J. May and R. Pike.

The Uses of Production Data.

Modern oilfield exploitation calls for at least a certain minimal scientific background—the absolute minimum would be provided by a purely short-term approach to the problem. Here a study of surface and sub-surface geology would be used, broadly speaking, to minimize the number of dry holes drilled, but once a well was completed it would be produced and treated as an individual and in accordance with the dictates of short-term economic factors only.

Even with such a development policy both the geologist and the operating engineer are progressively receiving more and more assistance from physical or chemical measurements of one kind or another. Bottom-hole pressures, production data, analyses of oils and waters, and so on, are increasingly used both as evidence of sand continuity or discontinuity, and also in determining completion repairs and beaning programmes.

However, the importance of physical data is very much more marked when we come to consider long-term development policies—that is to say, the problem of making the maximum profit in the long run and not merely a sufficient profit in each successive year. There are then, broadly speaking, three additional factors to be considered :—

1. It is not merely desirable that each individual well should pay off and show a profit ; we must aim at drilling the absolute minimum number of wells which will produce all the profitable oil.
2. If two or more wells are mutually interfering, then these wells should be produced to the best advantage as a group, and not as individuals.
3. After the field has been exhausted by primary methods, we should be in a position to consider the possibilities of secondary methods of production.

It would take too long to discuss in any detail the methods that can be used in solving such problems, but we may mention, for example, the plotting and extrapolation of production data ; the estimation of the effects of interference ; the determination of the effects of various producing methods on water and gas encroachment, and on the ultimate percentage recovery ; the estimation of the effectiveness of gas drive, etc. It is very evident that if such work is to be tackled at all, the first essential is a sufficiency of reasonably accurate data on oil, gas, and water productions, surface and sub-surface pressures, and so on. We immediately come up against the question of what constitutes reasonable accuracy.

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The Desirable Order of Accuracy.

It has, of course, first to be recognized that no amount of care and expense can guarantee 100 per cent. accuracy. They can only reduce the magnitude of error without eliminating them entirely. Further, it is a waste of money and energy to strive after an unnecessarily high order of accuracy—the permissible range of error depends entirely on the purpose for which the data are to be used.

The first question to be decided, therefore, is whether and to what extent we are justified in attempting the long-term analysis of production data.

It might be suggested that sub-surface conditions in Trinidad are so complex that it will always be impossible to generalize, and that we are therefore not justified in attempting anything other than to increase and maintain the efficiency of short-term operations. For this purpose a rather limited amount of data of no very high order of accuracy might be sufficient. In any case, deficiencies in the data will readily reveal themselves from time to time, and accuracy will tend automatically to follow the law of short-term supply and demand. Regarded from this point of view only, the records of most oil companies are probably fairly adequate, and an investigation of errors would appear to be of little more than academic interest.

However, the amount of oil still to be recovered and the amount of money to be spent in the process are considerable, and if detailed analysis of field data can increase the first or reduce the second by only a few per cent. as compared with more empirical methods, a fairly considerable expenditure would be justified. From this point of view there are two or three important points to be considered.

The amount and accuracy of the data collected doubtless vary from one company to another, but even in the case of those companies which pay the greatest attention to this subject, it is probable that some of the complexities of the long-term production problems are more apparent than real and would be resolved by a still further increase in the standard of field measurements both in quantity and in quality.

This is particularly true since the long-term value of adequate and accurate data is not always immediately apparent. Frequently it is only after the lapse of some years that accumulated data can be studied in proper perspective, and the errors and omissions of perhaps ten years ago begin to be important.

In this connection it should also be remembered that the science of production engineering is a comparatively new one. Our ideas as to the behaviour of fluids in the reservoir, for example, have been revolutionized during the last ten years.

There seems every prospect that the near future will see the practical application of what are at present little more than academic theories, and these applications will certainly call for the use of accurate data accumulated in the past.

There seems, therefore, to be every justification for accumulating more data and for aiming at a higher order of accuracy than appears to be necessary for immediate practical purposes. Furthermore, the value of any data, however accurate, is very greatly diminished if we have no idea as to their probable error—this is particularly true in the circumstances with which we are concerned, where we are working to a large extent with an inadequate basis of established theory.

Unless we have such an idea, we shall always be coming up against the question of whether apparent variations are significant or whether they may merely be due to error.

In order to establish what the maximum errors may be, and to ensure that any specified degree of accuracy is continuously achieved, it is necessary that all the possible sources of error should be investigated in detail, and that methods, instruments, and records should be constantly checked.

If detailed and comprehensive records are aimed at, the supervision necessary to guarantee *any* reasonable degree of accuracy is an expensive item, and one to which insufficient attention is frequently paid. It should, however, be recognized that the mere fact of carrying out a detailed study of accuracy will automatically eliminate many of the grosser errors. To take a simple example: if we wish to know what range of errors is likely to be introduced into gas measurements by variations in gas gravity, we must carry out a detailed survey over the field, and we can then use the information so obtained to eliminate errors due to incorrect estimation of gas densities.

There will, of course, always be a residue of errors due to the instruments or methods used, but these can generally be comparatively easily estimated, and the question of whether it is worth while to try to reduce them can be dealt with as a separate problem.

In this paper we do not attempt to lay down absolute limits of permissible error. We shall enumerate and briefly discuss some of the more obvious sources of error which should be the object of investigation on any field where attempts are being made at detailed analysis of field data.

Types of Error.

In discussing the accuracy of methods, there is a common and natural tendency to assume that over a period of time errors can be largely "averaged out," and that their absolute value is therefore not of great importance. This assumption is sufficiently true in some cases to make it a dangerous generalization. It has to be remembered that there are many different types of error, and also that data are used for many different types of calculations, and it is by no means generally true that the errors of individual measurements are unimportant.

Of the different types of error we may refer specifically to four :—

1. Random errors vary in magnitude, but are equally likely to occur in either direction. These are the most likely to average out, and are therefore probably the least important.

We have to consider, however, that in oilfield work we do not often measure exactly the same quantity more than once. A good deal of our averaging is done by smoothing curves—for example, drawing a production-time curve and extrapolating to estimate the ultimate production of a well. But just as runs of good or bad luck at cards or roulette, for example, are not uncommon, so there will be periods when for a consecutive series of readings the errors all tend to be in one direction. If such a run occurs at a critical point in a curve it may seriously upset extrapolation, or lead to the assumption of some non-existent production anomaly.

2. Constant systematic errors are errors which always have the same value in the same direction. A simple example is that of an error in tank calibration which means that all measurements of oil made by gauging in that particular tank are affected by a constant percentage error.

For the purpose of some types of calculations, errors of this kind may not be very important—if, for example, we are only concerned with the percentage decline of production of a well which is always gauged in the same tank. Also in taking an overall field average, the systematic errors of each installation may become, in effect, random errors. But if we wish to compare the actual productions of two wells which are gauged in different tanks, it is clear that systematic calibration errors may seriously affect our conclusions.

Constant systematic errors are liable to occur in any type of measurement, and are important from two points of view. Firstly, for a given mechanical installation and method of measurement they cannot be averaged out; and secondly, they are generally much more difficult to detect than are random errors.

3. Variable systematic errors are errors arising from the method or instruments used which have a definite value at a particular time but are liable to change either continuously or abruptly during the course of a series of measurements.

Again, to take a simple example. If the orifice plate of a gas-metering system slowly erodes or cuts out, then, so far as any one measurement is concerned, there will be a definite error due to the oversized orifice; in subsequent measurements the error will always be in the same direction, but will be continually increasing.

It is clear that if they are large, such errors as this can seriously affect the shape of curves in which the measurements are incorporated, and hence upset extrapolation or deductions drawn from comparisons between curves.

These errors, again, cannot in general be averaged out, and are difficult to detect and eliminate, unless a complete and rigid system of frequent inspection and calibration, etc., is enforceed.

4. Finally, there are the gross errors due to accident or carelessness which occasionally occur even in the most carefully conducted investigations. The magnitude of such errors is generally outside the normal range of random errors, and they can frequently be spotted by inspection if there is a sufficient basis of theory to work on. In a good deal of our work, however, we are not sufficiently sure of our theory to know whether an apparently large discrepancy may not be significant. Furthermore, much of our data is collected by employees who can scarcely be classed as scientific observers. They may continue to make the same gross errors over a long series of measurements (so that these errors almost become systematic), and will frequently tend to return the sort of answer they think is expected rather than the one they have actually observed.

In field measurements, unless there is very adequate supervision, gross errors may outweigh all others in importance and make it impossible to carry out any but the roughest of calculations.

Sources of Error.

The actual accuracy of a multitude of field measurements warrants a much more detailed consideration than is possible or desirable in this paper, but it is hoped that the several points which will follow will assist the discussion which is the main object of this meeting.

The measurements with which petroleum engineering is most concerned are those of volumes of oil, volumes of gas, and various types of pressures. The sources of errors in each of these groups are somewhat different in origin, and points will be made under these separate headings.

Oil Volumes.

Tank-dipping is the most common method of measuring quantities of oil. Whether gauge-rods or tapes are used the main sources of error are the same, although there may be individual preferences for either measuring device.

Errors are introduced by approximating the position of the oil-mark to the nearest prescribed fraction of a foot, dipping with an oblique gauge-rod or tape, adjusting for stable foam, and dipping from B. S. on tank bottoms.

Any dips must, of course, be converted into volumes by the use of calibration figures, and while in small new tanks without deadwood an error in calibration may be constant for a particular tank, for tanks *with* deadwood, and for older tanks which may have suffered from heavy handling, the percentage error for various depths of oil may be very different.

Modern tanks of small capacity are supplied with makers' calibrations, which are issued as standard, but actual checking of their figures may show discrepancies. The accurate strapping of tanks is not a very simple procedure, and due consideration must be given to the accuracy of the method used before any true comparison can be made.

It is quite common practice to test individual wells in two separate tanks at intervals and with, say, a + 5 per cent. calibration error in one tank and a − 5 per cent. error in the second, variations of less than 1 per cent. in oil volumes prior to the time the discrepancy was discovered would not be significant.

In the type of analysis of production data which should be possible, a rapid but true change of 10 per cent. in the production of an individual well might be very significant.

The calculation of oil volumes must, in field practices, often be combined with the determination of volumes of both free and suspended water. While the former is subject to the same type of dipping errors as the oil, the latter is very much affected by errors of sampling. On this point it will suffice to say here that poor methods of sampling, especially the use of non-standard technique, may introduce errors which, although possibly unimportant from the point of view of bulk oil receipts, will seriously limit the application of data either to routine problems or pure research.

Although there is a possibly small random error in the actual process of dipping oil, the evidence is that tanks are commonly gauged to contain a greater height of oil than is actually the case.

For this type of measurement we must rely largely on field employees who are not all as reliable as might be desired—consequently the accuracy of gauging is very often impaired by gross errors. The only method of reducing the number of such errors to a reasonable minimum is by systematic and continuous checking, and this can be simplified by organizing some form of instruction for the employees.

Gas Volumes.

The orifice meter is by far the most common method used to obtain gas volumes, and a brief survey of the errors involved in such measurement will illustrate both random and systematic errors as well as a plentiful source of gross errors.

The random errors occur in the mechanical accuracy of the meter used (some meters have a tolerance of $\pm$ 1 per cent.) and the reading of the static or differential outline on the chart.

The orifice meter method allows a large number of systematic errors to affect the accuracy of results obtained, and unless these sources are carefully checked, gross errors may result.

A simple source of such an error is in the diameter of the orifice plate, and the accuracy of this will depend on the reliability of the machinist as well as on the amount of erosion after installation. Large percentage errors are not easy to prevent in the smaller orifices.

Faulty zeroing of either the static or differential pen may introduce either constant or variable systematic errors.

It is also necessary to have a reasonable idea of the variations in the flowing temperature of the gas and the causes of the changes in temperature might warrant a close study. The temperature factors (for adjusting coefficients based on 60° F.), for flowing temperatures of 70° and 100° F. are 0·9905 and 0·9636 respectively, which for an average of 85° F. represents a range of about $\pm$ 1·4 per cent.

Similar comments will apply to the application of a flowing gravity factor, although the range is considerably greater. A range of gravities of 0·58 to 0·72 has been obtained for local gases separated at 250 lb./sq. inch, and it is possible that more gases will be found to go outside this range. The factors for the gravities mentioned are 1·3131 and 1·1785 and for an average of 0·65, this is a range from +6 per cent. to − 5 per cent.

Any attempt to average conditions in this way will introduce systematic errors which will not necessarily stay constant over a period of time.

The supercompressibility factors for the various gravities will vary with both gravity and temperature, and an average condition must be struck. This, of course, will introduce more errors, and these are likely to be large if the full range is not explored.

In normal field operations it is common practice to use published coefficients, and if various sets are compared, it will be seen that there are important differences in the values for basic orifice coefficients. A range of differences from + 2 per cent. to − 1 per cent. has been found in comparing two accepted tabulations.

Gross errors in gas metering can be very frequent, and usually result from failure to service either the primary or secondary elements sufficiently often. The use of a non-standard metering manifold may introduce flow disturbing apparatus too near to the plate, and gross inaccuracies may result.

Gas chart computation is an operation which may introduce errors again of the three general types, although gross errors may be more common.

Average flowing wells in Trinidad do not give gas charts which lend themselves readily to visual computation. Considerable advantage can be obtained by utilizing at least 50 per cent. of the scale of the chart, and all-round efficiency in computation can be improved by using the correct planimeter. Whenever possible it should be preferable to eliminate unscientific estimation.

Pressure Instruments.

In pressure instrument data the three general types of error are again found. There is the normal random error of observation, which will depend on the scale of the instrument. It is clearly not generally good practice to use a 3000-lb. gauge to measure a pressure of a few hundred pounds.

The constant and variable systematic errors of calibration, etc., are to a large extent dependent on the amount and quality of the instrument servicing.

Gross errors are introduced by manhandling of the instrument, as well as the possible inability of the operator to appreciate small intermediate scales. Occasional freak errors do occur, and may be caused by trapped water between a cracked glass and the face of the instrument, for example.

The same general comments will apply to sub-surface pressure records.

Data of the three groups outlined form the basis of the simplest analysis of individual or group well behaviour, but for the purpose of correlation some consideration must be given to the choke or bean size.

Flow Beans.

Various types of bean are used, and while the effective orifice diameter is initially subject to the usual errors of machining, some " cut " and/or erode faster than others.

A fast cutting bean is naturally located quickly, but very slow erosion (which has been observed over a considerable period of time) may cause the records of a declining well to show a more or less constant, or even slowly increasing rate of production. Thus close checking of bean diameters is of primary importance, if any use is to be made of decline curve analyses.

In conclusion, while there are considerable grounds for discussion as to the amount and quality of data that form adequate production records, there is little doubt that we should collect data in excess of our immediate requirements, and that the uses to which the data can be put are set by the limits of accuracy of the data.

We should not draw inferences from variations within the known zone of error, nor should we seriously restrict the uses to which the data can be put by making the zone of error too extensive.

Some of the errors mentioned above may appear to be small in magnitude, but the cumulative effect of a number of small systematic errors can be considerable. In any case, as we have already pointed out, without a detailed survey of the methods used on any particular field, coupled with constant supervision, there can be no guarantee of any specified limits of error.

Our comments have deliberately been kept brief, and amount to no more than a sort of agenda for discussion which we would suggest might reasonably be opened by considering the views of members on the amount of field data which it is desirable to accumulate, and might pass from there to a consideration of methods, equipment, and accuracy.

GAMMA-RAY WELL-LOGGING IN TRINIDAD.*

By Glenn M. Conklin.

Well-logging by Radioactivity, or Gamma-Ray Well-Logging, as it is usually called, involves the process of measuring the gamma-ray activity in the aggregate of the material adjacent to a bore-hole and plotting a graph of the gamma-ray intensity *versus* depth. This type of logging was developed rationally to fulfil the great need of the oil industry for a method of securing accurate knowledge of the lithology of the strata cased off before the advent of electrical logging. Because the gamma-ray unit works equally well in holes with several strings of casing or in open holes, it is suited admirably to the purpose of locating cased-off oil-sands or horizons for identification and correlation. In order to discuss this type of logging it is necessary to touch briefly upon the phenomenon of radioactivity, to describe the methods of measurement, and to enumerate the possible uses of the gamma-ray log.

Radioactivity is the spontaneous disintegration of atoms which, by the emission or the release of alpha-rays (helium nuclei) and beta-rays (electrons), causes the parent element to change its physical characteristics, and hence its place in the periodic table. Concurrently with the alpha- and beta-rays are emitted electro-magnetic radiations called gamma-rays, which are much more penetrating than either of the other two. Because these gamma-rays will penetrate the several inches of iron necessary to successful logging, they are the only ones of importance to us. Of the several known radio-elements, uranium, actina-uranium, and thorium are the parent elements of three highly radioactive series. (The well-known radium is an intermediate member of the uranium series.) These three parent elements disintegrate into at least forty distinctive members of the radio-active series, with non-radioactive lead as the end-point in all three transitions. Of the other elements known to be slightly radioactive, potassium is the most widely distributed, and no doubt contributes considerably to the over-all gamma-ray effect.

Table I.

Relative Radioactivity of Sedimentary Rocks.

Formation.	Grams of Radium Equivalent per Gram of Rock $\times 10^{-12}$.
Black shales	25·0–60·0
Grey shales	15·0–25·0
Sandy shales	5·0–15·0
Sandstones	0·5– 5·0
Salt and coal	Less than 2·0
Volcanic ash	15·0–25·0
Potash rock	50·0–70·0

* Paper read at Meeting of Institute of Petroleum at Apex Club, Fyzabad, on Friday, 27th March, 1942.

Extensive laboratory experiments have shown that radioactive materials in one form or another are found in all substances. Fortunately, sedimentary rocks in general have radioactive properties which are characteristic to each particular substance, and in most areas well-defined strata have definite "radioactive breaks" that may be easily identified. Table I gives a few comparisons of the relative radioactivity of sedimentary rocks expressed in terms of the radium equivalent per gram. These samples are taken from all over the world. In the case of Trinidad, measurements were made of eight samples from the oilfield district with the following results in Table II :—

TABLE II.

Radioactivity of Cores from Trinidad.

Sample.	Grams of Radium Equivalent per Gram of Rock $\times 10^{-12}$.
Forest sand	2·0
,, clay	7·1
Cruse sand	3·7
,, clay	8·4
Mayaro sand	4·1
,, clay	10·5
Montserrat sand . . .	5·4
,, clay . . .	10·1

More than likely the variation in the values obtained in the cases of the four sands are caused by the clay contamination of the sand, which in Trinidad is rarely pure. In most instances a relatively pure sand has a radioactivity of 2×10^{-12} grams of radium per gram of rock.

MEASUREMENTS.

Since it has been proved that sedimentary rocks have radioactive properties that are identified fairly easily, and in many cases are much more continuous than fossils or the parameters used in electrical logging, it was necessary only to devise a means of measuring the radioactive properties of the strata without bringing cores to the surface for laboratory study. Of the several ways to measure the gamma-ray intensity of the rocks adjacent to the drill-hole, the ionization chamber is the most satisfactory. This method is not new. Fundamentally, it consists of two electrodes immersed in an inert gas under pressure and connected externally to a circuit containing batteries. When gamma-rays or any other radiation enter the chamber and ionize the gas, a current flows in the circuit which is directly proportional to the ionization or the intensity of the radiation. For practical purposes, and for convenience of operation, the ionization chamber used in gamma-ray well-logging is enclosed in a cylinder, the outside diameter of which is 3⅝ inches for the small instrument and 4⅝ inches for the large one. Also contained in the same cylinder is a very high-gain amplifier with appropriate batteries. The over-all length of the tool is about 9 feet, and when in operation is hermetically sealed and attached to a single-conductor cable ⅜ inch in diameter. This cable is covered with two layers of steel wire wound in opposite directions to prevent twisting. The average stretch is about 1 foot for the first 4000 feet.

At the surface this cable is wound on the drum of a hydraulically operated winch with a 12,000-foot capacity and capable of maintaining constant speeds of from 100 feet per hour to about 20,000 feet her hour. This winch is mounted on a $1\frac{1}{2}$-ton truck, together with an Onan AC generator of 110 volts 1500 watts rating; also on the winch truck are suitable indicators for cable speed, depth of instrument in the well, tension on the cable, and other pertinent information.

The purpose of the winch truck is to raise or lower the sub-surface tool in the well and to supply power for the amplifiers, lights, and other electrical apparatus. The actual log is made in a recording truck containing amplifiers and a Speedomax recording unit which, by means of a potentiometric pen, draws a graph of the variation of gamma-ray intensity of the strata being traversed *versus* depth. Also in the recording truck are depth indicator, an oscilloscope for studying the action of the various electrical circuits, and very complete testing equipment. Once the preliminary adjustments in scale values and logging speed are made, the entire operation of the equipment is automatic.

In order to ensure dependable depth measurements, a measuring wheel 10 feet in circumference is placed at the surface of the drill-hole. This wheel guides the cable and drives a master Selsyn motor, which in turn actuates two other Selsyns, one in the winch truck and one in the recording truck. In this way the winch operator and the recording engineer know at a glance the absolute depth of the instrument in the well. A remote control-weight indicator is placed under the measuring wheel at the well in such a way that the winch operator is aware at all times of the tension on the cable. Because of the extreme sensitivity of the device, it is possible to determine the bottom of the well very accurately and to observe in the hole any irregularities, such as semi-collapsed casing on other obstructions.

A slightly technical explanation of the process may be stated rather simply. As the ionization chamber passes the various strata, usually coming out of the hole at a speed 1500 feet per hour, the varying intensity of the gamma radiation causes variations in the ionization of the argon gas in the chamber, and hence variations in the current in the external circuit of which the electrodes in the ionization chamber are a part. This current is a varying direct current in the order of 10^{-13} amperes. Since it is too small to measure directly, and since it is direct current, a specially designed device is used to compare the IR drop of this current through a resistor of 10^{11} ohms to the IR drop through a resistor of 10 ohms. By automatically maintaining the voltage drop across the 10-ohm resistor equal to the voltage drop across the 10^{11} ohm resistor, it is possible to work with a measurable current which, because of the potentiometric characteristics of the circuit, is a linear equivalent to the ionization current. In order to avoid using direct-current amplifiers, this variation is changed into alternating-current equivalents which are sent to the surface, and by means of appropriate filters are changed back to the proper form. The final current in the recording truck is filtered and amplified and passed to the Speedomax recorder, which automatically draws the curve with ink on a continuous strip of graph paper.

The Log.

The gamma-ray log resembles the self-potential curve of the electrical log, in that sharp breaks are indicated at the contact of sands and clays or any other contact at which the radioactivity undergoes a change. The gamma-ray log indicates the sand-clay contact, it also shows considerable detail in the clay and indicates the contact between the silt and the clay. This differentiation has considerable value in Trinidad, because the radioactivity of the strata seems to be proportional to the percentage of sand or clay present. Thus a bed that is 50 per cent. clay and 50 per cent. sand gives half as much relative deflection on the log as a bed of pure clay. This enables the operator to estimate the clay content of the sands and hence the porosity.

The only effect of casing on the log is an over-all absorption of the gamma-rays, which effect can be overcome by raising the gain of the amplifiers at the surface. When an additional string of casing is encountered in the well, the pen of the recording unit shifts to the left on the log an amount equal to the absorbing effect of the casing. In order to compensate for this condition and to make the axis of the log essentially a vertical line, the recording pen is returned to its original position on the log and the gain of the amplifiers raised to a point to make the amplitude constant throughout the entire log.

Observations and Results.

Radioactivity well-logging has supplied considerable information in the old wells drilled and cased many years ago without the benefit of accurate coring or of electrical logging. Sampling at best was casual and often inaccurate, and in many cases sample lag was ignored entirely.

1. A gamma-ray log resembles the self-potential curve of an electrical log, except that more detail is shown in the silts and clays; and particularly, silts, clays, and sands are differentiated.

2. Definite correlation was established in certain areas by locating the base of the Forest Clay and other markers. It was found that the Forest Clay and the Intermediate Clay both have radioactive properties which make them easily recognizable over the oilfield district of Trinidad. In this area many fault problems were solved, and relatively complete geological information was obtained which was impossible to get in any other way.

3. The sands are identified easily on the gamma-ray logs, so that intelligent perforation programmes based on information from nearby wells can be outlined. A number of cased off sands in the old wells have been perforated with excellent results in most cases.

4. By comparing sands logged with the old perforations, it has been possible to rework some of the wells which were completed improperly when first drilled.

5. By using the cosmic-ray intensity at the surface as an arbitrary zero and using absolute deflection in inches per milliampere of ionization current, the log has been calibrated as essentially direct reading. This holds true for any one well, but because of the variation of the combined radiation of the cosmic rays and the gamma-rays of the material on the

surface, it has been found that the apparent cosmic-ray zero varies slightly from well to well.

5. Correct depths to the bottom of each string of casing and exact position of liners have been shown in most cases.

Conclusions.

Since in many cases oil and water are not radioactive to the extent necessary to influence the logging instrument, the gamma-ray unit does not differentiate between oil- and water-sands. In Trinidad, however, it is evident in many cases that the oil-sands show more deflection on the log than do the water-sands. This can be due to at least two causes : first, there may be less porosity of, or more clay in, the oil-sand ; second, the oil may be radioactive because of the presence of radon. It is known that radon is absorbed much more readily by oil than by water ; hence, if the oil were radioactive and the porosity of the oil and water horizons the same, then the oil-sand would show more deflection than the water-sand. Since a complete knowledge of porosity would be needed to prove or disprove this premise, it is practically impossible at this time to make any positive statement.

In addition to the logging of oil-wells by gamma-ray, another field is the logging of shallow holes for surface geological study. As considerable detail is shown in shales and clays, and as fresh or salt water has no effect on the log, it is believed that more information could be supplied in core-holes with gamma-ray logs than by any other logging technique. This is particularly true, because in many instances radioactive horizons are much more continuous than fossils or porosity values.

There is no doubt that as more areas are studied by the gamma-ray method, additional uses will be found for the device. In addition to gamma-ray logs, a Geiger counter for radioactive analysis of cores will be available and very soon the neutron method of logging will be introduced to Trinidad. This neutron method will provide another radioactive study of the strata and give a second curve from which much more information is expected.

RESERVOIRS UNDER HYDRAULIC AND VOLUMETRIC CONTROLS.*

A. H. Nissan, Ph.D. (Associate Member).

In his extremely detailed book on production of oil, gas, and water, Herold [1] specifies three systems of mechanics for reservoirs of these fluids—namely, hydraulic, volumetric, and capillary controls. The first two controls differ essentially in the nature of $f(t)$ in the formula

$$P = f(t),$$

where P = closed-in pressure of a well after a long time—*i.e.*, reservoir pressure; and t = time. In the hydraulic control, $f(t) = K$ or Kt^0, whilst in volumetric control $f(t) = Kt^2$. In other words, the reservoir pressure in hydraulic control is a constant independent of time—rain-water enters the formation at the outcrop at the same rate as the withdrawal rate of the reservoir fluid and maintains the pressure a constant. In volumetric controls the rate of withdrawal exceeds the rate of entry of water into the formation, and thus the reservoir pressure decreases with time. It is, therefore, admissible to treat the two controls as variants of essentially the same system of mechanics, inasmuch as both operate by virtue of the hydrostatic head on the reservoir fluids and not by any different system, such as the Jamin action. The third control operates, it is postulated, by Jamin principle, and need not be discussed here. Only oil reservoirs under volumetric or hydraulic controls will be studied.

By defining the relationship of pressure and time, and that of a third factor with respect to either pressure or time—such as velocity–pressure relationship—it is possible to construct a whole system of mechanics of reservoir behaviour. Thus if the velocity–pressure relationship is known, together with pressure–time relationship, then it is possible to derive such important functions of reservoir exploitation and evaluation as velocity and time, volume and time, pressure and volume, energy and time, etc.—*i.e.*, all derivatives and integrals of velocity–time, pressure–time, or velocity–pressure functions with respect to any of the three variables.

It is to be noted that, having defined the type of control to be volumetric—hydraulic control being only a special case of volumetric control—and further, having understood its mechanism to be that of flow of a fluid under hydrostatic pressure in a porous medium, it should be possible to derive a velocity–pressure relationship for this type of control from theoretical and experimental considerations. Such a derivation was attempted by Herold himself with the resultant formula :

$$Ve = KP^{\frac{1}{2}}$$

where Ve = velocity of production in units of volume per unit time, and P = the effective working pressure, the closed-in pressure at a depth

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* Paper received 24th July, 1941. Written contributions to the discussion of this paper are invited.

opposite the producing sand minus the back pressure against which production is taking place from the sand. The basis of the discussion was Torricelli's theorem.

Other workers, Muskat [2] being a prominent exponent among them, derived a relationship based on Darcy's formulæ and obtained

$$Ve = KP.$$

Thus, the anomaly of one function being derived in two different forms has existed without explanation. This fact was discussed in September 1940, with the suggestion that the anomaly be explained or removed, and a further suggestion for an experimental procedure was outlined by Herold.[3] However, before experiment can be undertaken to verify a theory, it is considered necessary that the theoretical derivation of the functions themselves be examined.

Darcy's work was made directly upon the flow of a fluid in a porous medium like sand, and has therefore been verified experimentally on a great number of samples. Theoretical derivations show that when flow is streamline, or viscous, then the velocity of a fluid in a sand body is related to the pressure by

$$Ve = KP.$$

However, it is pointed out that a relatively small block of a porous material with fluid flowing through it from one extremity to the other is not a reservoir. Thus Darcy's principle is being accepted by the school of thought following Torricelli's theorem, with the reservation that it may not be true for a whole reservoir. This reservation immediately imposes the obligation of studying the meaning of a " reservoir " and its definition in deriving the square-root formula. Herold visualizes a reservoir as a tank containing the liquid under a hydrostatic head with the well, or wells, forming an orifice—a multiple orifice in the case of a multi-well reservoir. In the case of such a tank, the flow is governed by the approximate orifice equation,

$$Ve = C\sqrt{2gH}$$

where H = head of fluid above the orifice, and C and g = coefficient of discharge and gravity constant, respectively. Thus it becomes essential to determine the validity of such a similarity.

A reservoir may be assumed, for simplicity, to be a flat disc of diameter, D, say, 500 ft., containing a liquid under a hydrostatic head, H, of, say, 1000 ft. of the liquid, and being drained by a single well of diameter, d, say, 6 in., centrally situated. In the equivalent reservoir the tank diameter will be $D = 500$ ft., the orifice has a diameter, d, 6 in., and there will be a head of liquid (equal to 1000 ft.) above the orifice. It is assumed that liquid is fed in at such a rate that it is a constant after a time has been allowed for the velocity of the outflow to reach a steady value of Ve. By Bernoulli's theorem, applied to a liquid and taking any two sections in the tank, or the orifice, and working with a unit mass of fluid

$$H_1 + \frac{Ve_1^2}{2g} - W_f = H_2 + \frac{Ve_2^2}{2g}$$

where H_1 and H_2 = potential head (in feet of liquid flowing); $\left(\frac{Ve_1^2}{2g}\right)$ and $\left(\frac{Ve_2^2}{2g}\right)$ = kinetic energy head (in same units); and W_f = frictional head (same units).

$$\therefore \ \Delta H - W_f = \frac{\Delta Ve^2}{2g}.$$

The overall drop in pressure, from the level of the liquid in the tank to the outlet of the orifice, is H, and is, in fact, made up of a summation of pressure drops over a succession of sections. Three important sections exist. The first is from the top of the tank down a certain length L_1, where the flow, assumed viscous as turbulence in reservoir sands is improbable, is parallel to the sides of the tank. In this section $\frac{\Delta Ve^2}{2g}$ approaches zero, and therefore only W_f need be evaluated.

From normal viscous flow

$$W_f = \frac{128 VeL_1\mu}{\pi D^4 \rho g}$$
$$= kVe\frac{L_1}{D^4}$$

where μ = viscosity of the liquid, ρ = density of fluid, and k = constant, which is seen to be small in magnitude when values are substituted. Thus by the time the liquid has reached a level $(H - L_1)$ its energy content has dropped by an amount $\Delta_1 H$, which is the product of a constant k, the velocity, and the fraction

$$\frac{L_1}{D^4}.$$

This fraction in the example cited has the value of

$$\frac{1000}{(500)^4} = \frac{1}{62{,}500{,}000}.$$

The second section is from the end of this regular streamline flow to the top of the orifice. The flow here is converging towards the orifice, and the pressure drop is not easy to determine. As its exact value is not material in the final argument, let this second pressure drop be $\Delta_2 H$.

The third pressure drop is across the orifice itself, and is equal to $(H - \Delta_1 H - \Delta_2 H)$. Thus in the problem cited, Torricelli's formula would be:

$$Ve = K\sqrt{H - \Delta_1 H - \Delta_2 H}.$$

It is not $Ve = K\sqrt{H}$. However, $\Delta_1 H$ is a very small and, in fact, negligible quantity. Similarly $\Delta_2 H$ is a negligible quantity. Thus, in the case of the tank, it may be written that

$$Ve = K\sqrt{H}$$

without any measurable error. This statement can be easily verified by measuring the differential head across a similar orifice manometrically and comparing it with the total head above. In fact, in many orifice meters the height of liquid in a tank above the orifice is taken to be the pressure drop across the orifice with good results.

It is conceivable, however, that in certain circumstances $\Delta_1 H$ assumes much more importance relatively to the pressure loss across the orifice $(H - \Delta_1 H - \Delta_2 H)$. Thus if the length L_1 is filled with sand, the total pressure drop across the sand, $\Delta_1 H$, becomes large, and the flow across the entire length of the tank and the orifice will then be according to a compromise function of the first power of pressure for the capillary flow across the sand and the square root of pressure across the orifice. Taking the case to an extreme, the sand may be imagined to be thoroughly cemented and impervious, except for a single capillary tube running through it for the whole length, L_1. In such a case the flow will be governed completely by the linear equation $Ve = KP$, as $\Delta_1 H$ becomes far more important than $H - \Delta_1 H - \Delta_2 H$.

This qualitative analysis may be misleading. The whole flow from a tank 500 ft. in diameter is assumed to flow across a small orifice of only 6 in. in diameter, and thus it may be that however great $\Delta_1 H$ is, $(H - \Delta_1 H - \Delta_2 H)$ may still be predominantly greater. It does, nevertheless, demonstrate the necessity of investigating the adaptability of the model used, tank with an orifice, to represent a reservoir.* A true model would be as follows (see Fig. 1):

A flat horizontal disc of sand of diameter D ft., and thickness T ft., is covered on both its flat sides by impervious sheaths. Surrounding the outer rim is a ring of the fluid which permeates the disc, this fluid being under a pressure of $\Delta_1 H$ ft. At the centre of the disc is a hole, through which the fluid flows down, through a tube, to an orifice, diameter d ft., placed at a distance of H ft. below the top of the tank; $\Delta_2 H$ represents the pressure loss through this tube. Thus the total head across the sand, the connecting tube, and the orifice is H as before.

To derive the equation of the flow of such a reservoir it is possible to calculate Ve across the sand from $\Delta_1 H$ and the characteristics of the sands, and then determine the pressure drop across the orifice for the value of Ve so found. Thus the relative importance of $\Delta_1 H$ to the pressure drop across the orifice may be ascertained. To follow this procedure would, however, involve using Darcy's law for the radial flow of the fluid across the sand, and as the applicability of this law to flow in reservoirs is the point at issue, the step might not be justified, at least not at this point. Thus a yet simpler and more "ideal" model may be constructed.

The new model (Fig. 2) is the same in shape and dimensions as the previous reservoir, except for replacing the sand body by straight uniform capillary tubes of diameter δ ft. each, extending radially from the centre to the periphery of the disc. In order that these capillaries may represent the sand body of porosity M, the length of these tubes will be $\frac{D}{2}$ ft., and the total number is such that:

$$n \, . \, \frac{\pi}{4} \delta^2 \frac{D}{2} = \frac{\pi D^2 T M}{4}$$

* This is particularly the case as it has been stated: "A solution tank, filled with sand or other porous, insoluble material . . . performs in accordance with the same laws as one without the porous material."—Herold,[1] p. 331.

where n = number of capillaries, δ = diameter of capillaries, ft., D = diameter of disc., ft., T = thickness of disc, ft., and M = porosity of sand, fraction. (The central hole in the disc is ignored. The capillary model

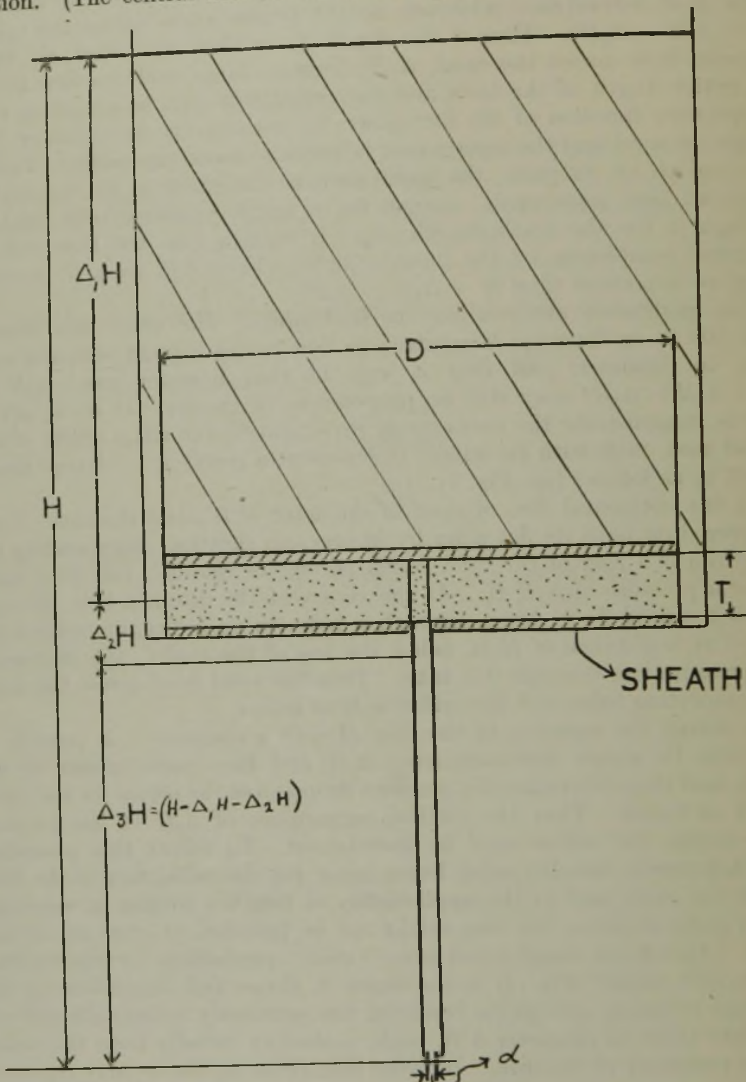

FIG. 1.

does not represent the sand from a permeability viewpoint, but this is immaterial to the argument.)

Before solving the problem it may be helpful to give typical figures for the various constants in order to appreciate their ratios and relative importance. The diameter D of the tank may be taken to be 1000 ft., as this figure is used in calculating the effective drainage of wells. The diameter of the orifice, d, may be taken as $\frac{1}{2}$ ft., and that of the capillary, δ, may be 0·001 ft. Thus :

$$\frac{D}{2} : d : \delta = 500{,}000 : 500 : 1$$

T, the thickness of the sand, may be taken as 50 ft., M, the porosity, as 20 per cent., whilst $\Delta_1 H$ may be considered to be, for simplicity, 1000 ft. of the fluid.

The flow will be assumed to be viscous in each capillary and will be calculated for a drop of $\Delta_1 H$ ft. in pressure. Then,

$$V_c = \frac{2\pi\delta^4 \Delta_1 H \rho g}{128\mu \, . \, D}$$

where V_c = volumetric rate of flow, cu. ft./sec., ρ = density of fluid, lb./cu. ft., μ = viscosity of fluid, poundle sec./ft.^{2}, and g = gravitational constant (32·2). The total flow through all the capillaries is then nV_c, where

$$n = \frac{2DTM}{\delta^2}.$$

Thus the total flow is given by

$$Ve = nV_c = \frac{4\pi\delta^2 TM \Delta_1 H \rho g}{128\mu}.$$

This volume is flowing through an orifice of d ft. in diameter. Hence the mean linear velocity through the orifice,

$$v_0 = \frac{16\pi\delta^2 TM \Delta_1 H \rho g}{128\mu\pi d^2} = \frac{16\delta^2 TM \Delta_1 H \rho g}{128\mu d^2}.$$

The pressure loss across the orifice, $(H - \Delta_1 H - \Delta_2 H)$ is given by

$$\begin{aligned} v_0 &= C\sqrt{2g(H - \Delta_1 H - \Delta_2 H)} \\ &= \frac{16\delta^2 TM \Delta_1 H \rho g}{128\mu d^2}. \end{aligned}$$

Thus calling $(H - \Delta_1 H - \Delta_2 H)$, $\Delta_3 H$, then,

$$\sqrt{\Delta_3 H} = \frac{16\delta^2 TM \rho g}{128 C\mu d^2 \sqrt{2g}} (\Delta_1 H).$$

Again, separating the properties of the fluid from those of the reservoir,

$$\Delta_3 H = \left[\left(\frac{\delta^2 TMg}{8Cd^2\sqrt{2g}}\right)\left(\frac{\rho}{\mu}\right)(\Delta_1 H)\right]^2.$$

It is instructive to solve the problem taking the dimensions given for the typical reservoir and using three types of liquids. The first will be an oil of 58 lb./cu. ft. and four poises/viscosity, the second an oil of the same density and one-fifth the viscosity—*i.e.*, 80 centipoise—and the third water. The porosity is assumed to be 0·20.

Case I. $$\Delta_3 H = \left[\left(\frac{(0{\cdot}001)^2 \times 50 \times 0{\cdot}2 \times 32}{8 \times 0{\cdot}6 \times (0{\cdot}5)^2\sqrt{64}}\right)\left(\frac{58}{4 \times 0{\cdot}067}\right)(1000)\right]^2.$$

$= 51{\cdot}8$ ft. of fluid flowing.

Case II. $$\Delta_3 H = \left[\left(\frac{(0\cdot001)^2 \times 50 \times 0\cdot2 \times 32}{8 \times 0\cdot6 \times (0\cdot5)^2 \times \sqrt{64}}\right)\left(\frac{58}{0\cdot8 \times 0\cdot067}\right)(1000)\right]^2.$$
$$= 1296 \text{ ft. of fluid flowing.}$$

Case III. $$\Delta_3 H = \left[\left(\frac{(0\cdot001)^2 \times 50 \times 0\cdot2 \times 32}{8 \times 0\cdot6 \times (0\cdot5)^2\sqrt{64}}\right)\left(\frac{62\cdot4}{0\cdot00067}\right)(1000)\right]^2.$$
$$= 9\cdot63 \times 10^6 \text{ ft. of fluid flowing.}$$

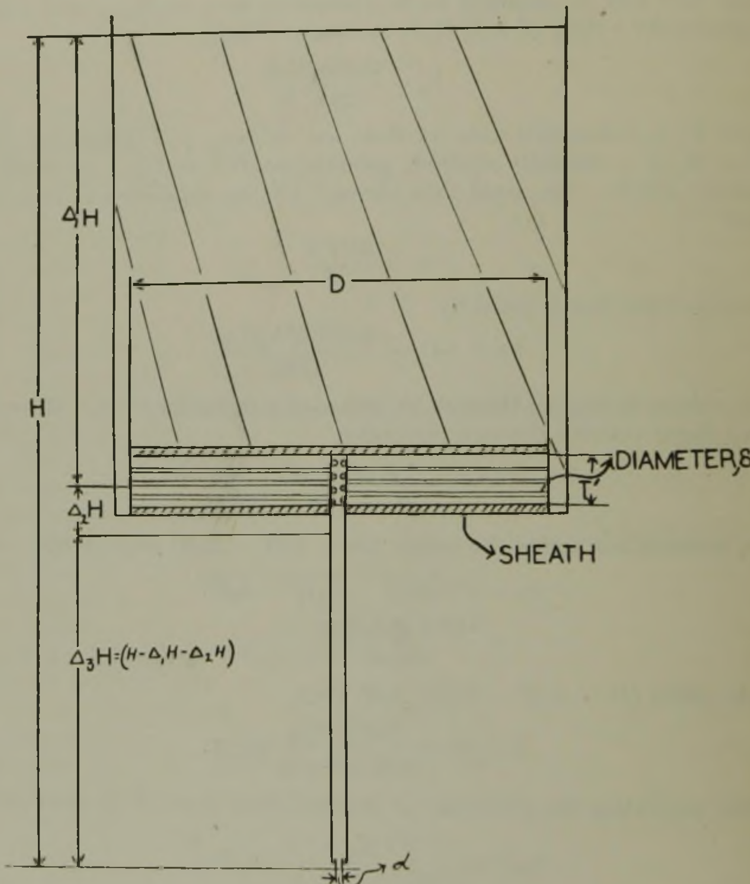

FIG. 6.

Thus in the first case the flow will be almost entirely governed by the formula

$$Ve = KP$$

as only 51·8 ft. of head are lost across the orifice, compared with 1000 ft. lost across the "sand." In Case II the flow will be governed by a compromise between the two formulæ under discussion, since the head of fluid lost across the " sand " is approximately equal to the head lost across the orifice. Thus,

$$Ve = K_1P_1 + K_2P_2^{\frac{1}{2}}$$

where $P_1 + P_2 = P$, the total pressure. In the third case the head lost across the " sand " is almost negligible compared to the head lost across the orifice. Thus it would appear that the flow would conform to the law,

$$Ve = KP^{\frac{1}{2}}.$$

From these three cases it becomes evident that a general form of the flow formula is given by

$$Ve = K_1P_1 + K_2P_2^{\frac{1}{2}}$$
$$P_1 + P_2 = P$$

with either P_1 or P_2 vanishing in extreme cases.

Here it should be stated that the capillary tube model does not represent a true sand, as it differs in two major respects from reservoir formations. The model serves a purpose, however, and this will be elucidated before the differences between the model and a sand are discussed. It is seen that when a reservoir model is constructed in the shape of a tank and an orifice and further brought into approximate resemblance with a true reservoir, Torricelli's formula does not apply except in certain peculiar cases. These cases are peculiar in that the resistance offered to the flow by virtue of frictional forces is small. This may be either because the viscosity of the fluid is very low (cf. calculations above) or because the permeability of the formation is very high. Thus it is possible that a tank loosely filled with sand and fitted with an orifice will behave as if the sand were absent in so far as the flow formula may still be $Ve = KP^{\frac{1}{2}}$. This, in fact, explains the footnote on p. 149. It can only be supposed that that statement was based upon experiments conducted with a relatively wide and shallow tank filled with loosely compacted sand and using water for the fluid—*i.e.*, with a high permeability and low viscosity conditions. Deep sands are usually compact bodies, and oils are usually viscous, and thus it must be concluded that flow in sands cannot be represented by Case III in the problem, and that it must occur according to either Case I or II. Stated in different terms, it is highly improbable that the general formula

$$Ve = K_1P_1 + K_2P_2^{\frac{1}{2}}$$

would reduce to the form $Ve = KP^{\frac{1}{2}}$ in dealing with oil reservoirs. It is to be noted that this statement is based on the method of analysis proposed in formulating the square-root formula. Whether the general formula may not be reduced to a simpler form, as it is difficult to separate P into P_1 and P_2, is yet to be found.

The capillary model differs from a sand body, in the first instance, in that, while it represents its porosity, it does not necessarily represent the more important function of permeability. However, the disc of capillary tubes may be made to represent both these characteristics of the sand as follows : assuming the two discs to be both of the same diameter D, then the porosity is accounted for by making

$$n \cdot \frac{\pi}{4} \delta^2 \frac{D}{2} = \frac{\pi D^2 TM}{4}$$

as before. The model can then be made to represent the sand from a permeability viewpoint, *taking the sand as a whole* by making δ of such dimensions, that the resistance offered to flow by both discs *over the entire path* $\frac{D}{2}$, is the same—*i.e.*, making $\Delta_1 H/Ve$ the same in both. It was seen that for the capillary model

$$\frac{\Delta_1 H}{Ve} = \alpha \frac{\mu}{\delta^2 TM}$$

where α = constant which can be determined by substitution. The value of $\Delta_1 H/Ve$ for radial flow in a sand body of permeability K is given by

$$\frac{\Delta_1 H}{Ve} = \beta \frac{\log\left(\frac{D}{d}\right)\mu}{kT}$$

where β = a constant. Thus by making

$$\alpha \frac{\mu}{\delta^2 TM} = \beta \frac{\log\left(\frac{D}{d}\right)\mu}{kT}$$

or

$$\delta = \left[\frac{\alpha}{\beta} \cdot \frac{k}{\log\left(\frac{D}{d}\right)M}\right]^{\frac{1}{2}}.$$

The capillary model will represent the sand body as a whole statically (porosity) and approximately dynamically (permeability). In model experiments, at least, these relations should be satisfied. It is still important to realize that no section or part of the model represents a corresponding section or part of the sand. This fact constitutes the second major difference.

In the capillary model flow is in one dimension and at a uniform linear speed throughout the length $D/2$. In a sand body the flow is two-dimensional, converging towards the centre with the linear speed of flow increasing with approach to the centre. Thus at any radius, r, from the centre the linear velocity v_r is given by

$$v_r = \frac{Ve}{2\pi rT}$$

varying from nearly zero at the periphery of the reservoir to the maximum value at the well. This is the average linear speed per square foot of sand face at radius r from the well. The actual average linear speed of flow of the fluid can only be estimated by supposing that the sand is ideally uniform in porosity—*i.e.*, over each square foot of sand-face the voids occupy an area of M, the fractional porosity. Thus the actual average linear flow of the fluid at radius r is :

$$v'_r = \frac{Ve}{2\pi rTM}.$$

At the sand-face the average linear speed is, then, $\frac{Ve}{\pi dTM}$.

It becomes evident after this discussion that it is impossible to construct a model for a reservoir by means of capillary tubes. Thus, after serving its specific purpose of illustrating the remoteness of the probability that the square-root formula is the acting law for reservoir behaviour, this model has to be discarded, and work must be confined solely to studies of a reservoir composed of porous material. The only formula which can be used to calculate the loss of head due to frictional, or viscous, resistance in such a reservoir is the well-known radial flow equation based upon Darcy's law. By taking

$$v_r = \frac{-Ve}{2\pi rT}$$

$$\text{and } v_r = \frac{-k}{\mu} \cdot \frac{dp}{dr}$$

i.e.,

$$\frac{Ve\mu}{2\pi Tk} \cdot \int_{d/2}^{D/2} \frac{dr}{r} = \int_{P'_1}^{P'_2} dp.$$

Then

$$\Delta_1 H \propto \Delta P \propto \frac{Ve\mu}{2\pi Tk} \log\left(\frac{D}{d}\right).$$

Thus $\Delta_1 H$ may be calculated for a sand. This gives the frictional resistance or P_1 in the general formula

$$Ve = K_1 P_1 + K_2 P_2^{\frac{1}{2}}.$$

It is to be noted that while the fluid is practically at rest at the rim of the reservoir, it is accelerated to a definite velocity at the sand-face, or, to simplify the problem, at the horizontal cross-section of the well at the level of the top of the sand. The speed here is :

$$v_0 = \frac{4Ve}{\pi d^2}.$$

By applying Bernoulli's equation to the outer rim of the reservoir and this section of the well, it is found that :

$$P_D = P_d + \left(\frac{4Ve}{\pi d^2}\right)^2 \Big/ 2_g + W_f.$$

where P_D = pressure at rim of reservoir, and P_d = pressure at well opposite sand,

or

$$\Delta P = \left(\frac{4Ve}{\pi d^2}\right)^2 \Big/ 2_g + W_f.$$

In terms of head of fluid,

$$H = K'Ve + K''Ve^2$$

Thus, in this reservoir, as in the model, the pressure drop consists of two items : one, representing the loss in head due to the increase in the kinetic energy of the fluid from zero to that existing at the bottom of the well, is proportional to the square of the velocity; and the second, representing the frictional head, is proportional to the first power of the velocity. For a sand reservoir the velocity–pressure relationship may be written, as in the case of the inaccurate model,

$$Ve = K_1P_1 + K_2P_2^{\frac{1}{2}}$$

where $P_1 + P_2 = P$. Finally it remains to be ascertained whether P_1 or P_2 are of equal or of different relative importance.

Working again in heads of fluid, the kinetic energy head is given by :

$$v_0 = C\sqrt{2g\Delta_3 H}$$

or

$$\Delta_3 H = \frac{v_0^2}{2C^2g} = \frac{Ve^2}{4\pi^2d^4C^2} = \frac{Ve^2}{14{\cdot}2d^4}$$

where $\Delta_3 H$ = kinetic energy head, ft., Ve = volumetric velocity, cu. ft./sec., d = diameter of well, ft., and g and c are constants, 32 and 0·6 respectively. The frictional head may be calculated from the normal radial flow formula for liquids flowing in homogeneous porous media, as it is the only formula which is left and which represents the facts completely. Applying F.P.S. units to the formula,

$$\frac{\Delta_1 H \times \rho}{33 \times 62{\cdot}4} = \frac{\mu .\ Ve\ (28{,}320)\ .\ 2{\cdot}3 \log\left(\frac{D}{d}\right)}{2\pi kT(30{\cdot}48)}$$

where $\Delta_1 H$ = frictional head, ft., ρ = density of fluid, lb./cu. ft., μ = viscosity of fluid, centipoises, D = diameter of reservoir, ft., k = permeability of reservoir, darcys, and T = thickness of reservoir, ft.

Thus

$$\Delta_1 H = \frac{28{,}320 \times 2{\cdot}3 \times 33 \times 62{\cdot}4}{2 \times 30{\cdot}48\pi} \cdot \frac{\mu Ve \log\left(\frac{D}{d}\right)}{\rho kT}$$

$$= 7 \times 10^5 \frac{\mu Ve \log\left(\frac{D}{d}\right)}{\rho kT}.$$

Hence

$$\frac{\Delta_1 H}{\Delta_3 H} = 14{\cdot}2 \times 7 \times 10^5 \frac{\mu\left[\log\left(\frac{D}{d}\right)\right]d^4}{\rho kT\,Ve} = \frac{9{\cdot}94 \times 10^6 \mu \left[\log\left(\frac{D}{d}\right)\right]d^4}{\rho kT\,Ve}.$$

To see whether $\Delta_3 H$, the kinetic energy head, is important at all, an extreme case will be taken where the numerator terms will be given small values and the denominator variables large values obtained in reservoirs. Thus assuming,

D = 100 ft.,
d = 3 in. = 0·25 ft.,
T = 500 ft.,
k = 2000 millidarcys,
ρ = 58 lb./cu. ft.,
μ = 50 centipoises.

Thus:

$$\frac{\Delta_1 H}{\Delta_3 H} = \frac{10^7 \times 50 \times 2{\cdot}6 \times 0{\cdot}0039}{58 \times 2 \times 500} \left(\frac{1}{Ve}\right)$$

$$= \frac{87{\cdot}5}{Ve}.$$

With a production from this well of 1100 tons per day—*i.e.*, $Ve = 0{\cdot}5$ cu. ft./sec.—$\Delta_3 H$ is only $\frac{\Delta_1 H}{175}$.

It is therefore seen that, except in very special circumstances where both the permeability of the reservoir and the rate of production are extremely high, the kinetic energy head is a negligible quantity compared to the frictional head. Thus it must be concluded that in practically all oil reservoirs under volumetric control the flow of oil is accurately * represented by Darcy's law, *i.e.*,

$$Ve = KP.$$

Conclusions.

1. An anomaly appeared to exist in deriving the velocity–pressure relationship, for reservoirs under volumetric or hydraulic controls, by two methods. The two equations were $Ve = KP^{\frac{1}{2}}$ and $Ve = KP$.

2. A study of the two methods reveals the fact that the assumption made in applying only orifice equations to the problem are not justifiable, and that if a truly representative model be constructed the anomaly disappears and a single equation is the result:

$$Ve = K_1 P_1 + K_2 P_2^{\frac{1}{2}}.$$

3. It is further shown that P_2 is negligible in oil reservoirs under volumetric or hydraulic controls and therefore the equation becomes $Ve = KP$.

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[1] Herold, S. C., "Production of Oil, Gas and Water," Stanford University Press, 1928.
[2] Muskat, M., "Flow of Homogeneous Fluids Through Porous Media," McGraw-Hill Book Co., 1937.
[3] Herold, S. C., *Petrol. World*, 1940, **37**, (9), 55–56.
[4] Nissan, A. H., *Nature*, 1941, **148**, (3756), 503.

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* This is meant in a relative sense only. Experiments in this Department have shown that at extremely low rates of flow Darcy's law does not apply to the flow of air through rocks.[4]

ABSTRACTS.

AUTHOR INDEX.

The numbers refer to the Abstract Number.

The original papers referred to in the abstracts marked with an asterisk may be borrowed by Members from the Institute Library.

Geology and Development.

592.* Important Reserves may Exist in Sedimentary Structures Formerly Overlooked. N. C. Smith. *World Petrol.*, Feb. 1942, **13** (2), 30.—The possibility must be considered that favourable conditions exist for the accumulation of substantial amounts of petroleum solely controlled by primary sedimentational features. If such conditions occur and the resulting reservoirs are accessible to migrating petroleum, then the aim must be to search for the attributes which will aid in their location. The following are depositional features—pinching beds, reefs, lenses, porosity variations due to grain size and other primary sedimentary causes. Many have noted the association of oil accumulations with pinching beds, reefs, and lenses.

Considerable and irregular changes of grain size and rapid variations in thickness are typical developments in beds of the shoreward portions of the neritic zone and adjacent areas. Tides, winds, storms, and currents lead to interstratification of sands and muds, or to complicated lensing of sands and mud. Grain-size distribution depends on the transporting capacity of water, and rapid changes of transporting capacity are characteristic of the neritic zone. The greater the angularity, the greater the sorting and the less the orderliness of arrangement, the greater will be the porosity in general.

Littoral oceanic currents are believed to induce eddy currents in the lee of promontories, causing characteristic concave and convex curvature in the coastline, and such curved forms may be related to the size distribution of the sediments.

Where the sea-floor is ridged, the velocity of the moving water will be greater over the ridges than in the depressions, and so the sediments will be coarser on the ridges than in the depressions.

The formation of intercalated beds may be the result of (*a*) exposure and dissection of the uppermost sediments laid down by a retreating sea; (*b*) reworking of the debris by the waves of an advancing sea; (*c*) final deposition and burial.

Although new methods may be developed for the detection of significant porosity variations, one of the first steps in the search for reservoirs controlled by porosity variations should be to study the great store of cores and records, surface geological data, and geophysical and geochemical surveys, and to re-interpret them with the sedimentational features in mind in order to reconstruct past conditions. G. D. H.

593.* Coordination and Research Hold Future to Oil Exploration. J. A. Kornfeld. *Oil Wkly*, 20.4.42, **105** (7), 42.—War needs require the discovery of important reserves near big-scale transportation facilities which will remain effective during the conflict, and also the furnishing of oils providing high-octane fuel and heavy fuel oil. The past few years have shown a declining rate of discovery, as well as few major discoveries.

Exploration policy has hinged around structural features, and this is now in the phase of diminishing returns, and to increase discovery rates demands a shift in exploration thought to the stratigraphic features. The change will involve financial risks, regional geological studies and stratigraphic core-drilling. Subsurface geological work should be directed towards the recognition of the existence, location and character of unconformity zones, whether structural, palæontological, or lithological. Cross-sections on a regional scale from the surface to the basement should be constructed. Regional isopach and conveyance maps should also be prepared. Careful study should be made of all types of well-survey charts.

There seems to be much in favour of the formation of a separate department charged solely with exploration, and the programme should be based on a long-term policy as far as possible. G. D. H.

594. Possibility of Future Discoveries in Eastern Colorado. F. N. Bosco. *Oil Gas J.*, 16.4.42, **40** (49), 66–68.—Eastern Colorado has six oilfields, and some closed-in gas structures. The Florence–Canyon City field has produced 13,500,000 brl., and is still giving oil at the rate of 35,000 brl./year. The oil is in fissures and flexures in the Pierre shale on the east limb of a syncline. The Boulder field has a dome and a plunging faulted anti-clinal nose with oil accumulated down-dip from minor transverse faults. Oil is obtained from the Hygiene (?) sand or from fissures in the Pierre shale. The wells are 200–3400 ft. deep, and the cumulative production is 645,379 brl.

A gentle, elongated, anticlinal fold gives shallow oil at Berthoud. Small amounts of gas have been found in a dome in the Beecher Island area.

Eastern Colorado has many oil-seeps and oil-saturated outcrops. Closed anticlines, anticlinal noses, and structural terraces, fault-traps, and fissuring are likely to cause oil-accumulating in this region, but the relationship to other structures, local or regional, to faults and to the possibility of artesian flushing must be borne in mind in assessing the value of structures. Stratigraphic traps may be expected in this area.

The Fort Collins–Wellington field lies on the west flank of the Denver–Cheyenne basin. A north–south anticline is divided into two parts by a saddle, and both the Wellington and Fort Collins structures have a steep western flank. West of the saddle is the Douglas Lake structure. Until 1939 production was wholly from the Muddy sand, and then a few wells found oil in the Lakota on the Fort Collins structure.

A Muddy sandstone lens, sealed up-dip by a fault, is the trap at Greasewood. The sand is about 6700 ft. deep, and while the production so far has not been high, the structure suggests that other accumulations may occur in the vicinity. G. D. H.

595.* Paloma Field Extended One Mile East by Small Well. L. P. Stockman. *Oil Gas J.*, 9.4.42, **40** (48), 68.—The Paloma field of Kern County, California, may be extended 1 ml. east, although the well may not be a large producer, since there is only 50 ft. of oil-sand. The well is 11,811 ft. deep, the oil zone being at 10,935–10,985 ft. After gun-perforating, a little high-gravity condensate and 190,000 cu. ft. of gas flowed.

In the Jacalitos district of Fresno County commercial production was found a short time ago in the Temblor at a relatively shallow depth. The oil-sand is 25–50 ft. thick and about 4000 ft. deep. G. D. H.

596.* Haynesville Field has Renewal of Activity. G. B. Nicholson. *Oil Wkly*, 6.4.42, **105** (5), 30.—The Haynesville field, after producing for 21 years, and appearing to be slowly approaching abandonment, has taken a new lease of life with the discovery of important deep production in the Pettit lime at 5448 ft. The old producing zone was the Blossom at 2800 ft.

Low Pettit permeability in the discovery well gave little hope of success, but acidization led to a flow of 1500–2500 brl./day on open flow, and 384 brl./day on a ¼-in. choke. The gravity of the oil is 40–41°, and the bottom-hole pressure 2123 lb./in.^{2}. A second Pettit well was brought in 1¾ ml. north of the first, being an abandoned 11,000 ft. well, which was perforated in the Pettit zone.

The Pettit is oolitic.

Other successful wells have been drilled, and indicate probable production over a greater area than the Blossom, which covered 7480 acres.

Haynesville is a dome discovered from surface geology. Gas was found in the Glen Rose at 4330 ft. and a non-productive oil-sand was discovered below 4500 ft. The Blossom has given 71,631,940 brl. of oil.

The Pettit wells have a low gas–oil ratio and give little water. An 80-acre spacing is in force. G. D. H.

597.* Wildcat North-west of Emma Pool Shows Oil in New Pay. R. Ingram. *Oil Gas J.*, 9.4.42, **40** (48), 77.—There are indications of an oil strike 2 ml. north-west of the Emma pool in southern Andrews, County Texas. Oil-staining was found at a depth of 4485–4495 ft., and a core at 4495 ft. showed limestone bleeding oil. There is no production at present in south Andrews County at this depth, but another wildcat has had a showing at a similar depth.

½ ml. south of the Ector County part of the West Andrews pool a well has found oil at 4192 ft., while in the Fullerton area of north-western Andrews County a second well has reached 6680 ft., the first well having found its first pay at about 7000 ft.

G. D. H.

598.* Half-billion-barrel Gain in U.S. Reserves Shown by A.P.I. Anon. *Oil Wkly*, 30.3.42, **105** (4), 46.—1,968,963,000 brl. of new oil were found in U.S. during 1941, some 564,781,000 brl. more than the production in that year. The net increase raised the total reserves to 19,589,296,000 brl. on 1st January, 1942. Most of the new oil was added by upward revision of fields found prior to 1941, and this amounted to 1,538,989,000 brl. The estimates include only reserves in known and proved fields, and recoverable by present production methods.

Tables show by states the proved reserves on 1st January, 1941, 1st January, 1942, the new reserves discovered and developed in 1941, the production during that period, and the reserves of the new pools found in 1941. G. D. H.

599. Arvin Area of Mountain View Oil-field. F. E. Kasline. *California Oil-fields, Summary of Operations*, Vol. 24, No. 4, April, May, June 1939.—The main Arvin field, which, as its name implies, lies near the town of Arvin, about 14 miles south-east of Bakersfield, Kern County, California, was discovered in February, 1939, when the Standard Oil Co. of California completed " Jewett Community Lease No. 2 " well in the Chanac sands. From this an initial yield of 3024 brls. of 31·4° A.P.I. gravity oil was obtained at a depth between 6060 and 6270 ft. The second well completed was not so successful, since, although the well flowed at a rate of nearly 800 brls. of 30° gravity oil, the water cut was 23·2%.

According to this report, twelve more wells were completed between 1st May and 31st December, 1939, to depths ranging from approximately 6100 to 6500 ft. Initial productions varied from 200 brls. to 2400 brls., with the majority between 1000 and 1900 brls.

Production in the Arvin field is obtained from an aggregate of about 70 ft. of oil-sand in a 200-ft. interval of predominantly continental clays, siltstones, and sands (Chanac, Pliocene). Oil accumulation is in faulted homoclinal strata against a major fault seal trending north-west–south-east. H. B. M.

600. Premier Area of the Poso Creek Oil-field. F. H. Updike. *California Oil-fields, Summary of Operations*, Vol. 24, No. 4, April, May, June 1939.—In the area known as the Premier Area of the Poso Creek Oil-field, the productive land lies in a narrow strip 3 miles long, running north to north-west, about 10 miles north-west of Bakersfield, Kern County, California. This report states that commercial production was obtained by the Ohio Oil Co. in April 1929, when No. " Midway Premier " 1 Well was completed and an initial yield of 190 brls. of 13·4° A.P.I. gravity oil obtained daily from 2804 ft. Subsequently no further wells were sunk until 1934, when a second well was completed to a depth of 2690 ft. with an initial production of 260 brls. of 13·4° gravity oil daily. During 1936–37 a total of thirty-three wells was drilled with initial yields as high as 200 brls. per day. This production, however, showed a rapid decline to an average of 17 brls. daily per well.

In July 1941 a total of seventy wells were producing from the field with a total daily average production of 1160 brls. of oil. The proved land, which includes practically all the potential producing area, is about 730 acres, and limited on the east by a main fault, on the north by cross-faulting, and on the west and south by edge-water.

H. B. M.

601. Canal and Strand Oil-fields. R. W. Walling. *California Oil-fields, Summary of Operations*, Vol. 24, No. 4, April, May, June 1939.—The Canal and Strand oil-fields are situated about 1½ mile north-west of Ten Section field, and approximately 14 miles south-west of the city of Bakersfield, Kern County, California. When the area was explored evidence pointed to the structures of these fields as being minor to those of Ten Section field. Consequently their exploitation was postponed in favour of the major project.

The history of Canal field as given in this report indicates that the first well was completed in November 1937. This was drilled and cored to a depth of 8175 ft. During the first 24-hour period the well produced 2267 brls. of 36·9° A.P.I. gravity oil. Development has been confined for the most part to the 900 ft. of " Stevens " zone (Miocene), which consists predominantly of friable, medium-grained, massive sands with occasional siltstone and hard sandstone-shell breaks.

Up to 31st December, 1940, thirty-nine wells had been drilled, of which thirty-eight were successfully completed. Initial potential rates of production varied from 522 to 3390 brls. of oil per day. Total production from the field up to that time was 4,767,574 brls. of oil and 5,284,023,000 cub. ft. of gas, in spite of drastic measures in force to prevent excessive production.

The Strand field was proved with a well sunk by the Tide Water Associated Oil Co. in June 1939, which was drilled and cored to a depth of 8364 ft. and which produced 1130 brls. of 34·0° A.P.I. gravity oil in the first 24-hour period. Up to 31st December, 1940, ten wells had been successfully completed, drilling was suspended in one, and one was in process of being drilled. Initial potential rates of production varied from 349 to 3638 brls. of oil and 2,333,000 cub. ft. of gas per day, and averaged 2197 brls. of oil and 1,535,000 cub. ft. of gas. Up to 31st December, 1940, 668,391 brls. of oil and 418,777,000 cub. ft. of gas had been produced from the field. H. B. M.

602.* Africa Without Important Production is Big Potential Market. K. N. Gess. *World Petrol.*, February 1942, **13** (2), 40.—Egypt is the only country in Africa which produces an appreciable quantity of crude oil, but its geographical position makes its output of more importance to the Near and Middle East than to the continent of Africa. The oil output from torbanite in South Africa is only 10,500 tons, against the country's annual consumption of over 1,100,000 tons, and only 2000 tons of motor spirit are derived from coal-tar. Oil-shows occur in the Karroo, but they give little hope of commercial accumulations at depth. Workable deposits of oil-shale are known only in the Ermelo district, although the Union is rich in coal, making hydrogenation or the Fischer–Tropsch process a possible source of oil. A relatively small amount of oil-shale is known in Madagascar, where small amounts of oil have been found by drilling.

A little oil is produced in Algeria, and French Morocco has a rather higher output. Gas and traces of oil have been found in Tunisia. Oil seepages and bituminous sands occur in the Cameroons. Three wells have been drilled in French Equatorial Africa. French West Africa also has shows. Test wells have been drilled in the Gold Coast Colony and in Angola without commercial success, while others have been drilled in Abyssinia, in Eritrea, on Great Dahlac Island and in British Somaliland. There has been exploration in Kenya, in the Belgian Congo and Mozambique, again without success.

In 1938 the African oil consumption was 4,400,000 tons, most of which had to be imported in the refined state.

Africa possesses rich sources for the production of vegetable oils of all kinds.

G. D. H.

Geophysics.

603.* Striking Expansion in Geophysical Operations. E. A. Eckhardt. *Oil Wkly*, 20.4.42, **105** (7), 38.—Since May 1941 there has been a striking expansion in geophysical prospecting in U.S.A.

New discoveries in 1941 added 429,974,000 brl. of oil to the U.S. oil reserves, a quantity which is only 30·6% of the 1941 production, but upward revision of estimates for previously discovered pools added 1,538,989,000 brl. to the reserves, so that the net increase in reserves was 564,781,000 brl. 170,364,000 brl. of the new reserves are in Texas, 62,946,000 brl. in Illinois, 58,911,000 brl. in Oklahoma, and 47,915,000 brl. in Louisiana. 39% of the 1941 seismograph operations were carried out in Texas, 29·4% in Louisiana, and 27·2% in Oklahoma.

Over fifty gravimeter parties were operating in 1941, and about nineteen magnetometer parties. Geochemical, electrical, and torsion balance work were carried out on a restricted scale, some of it sporadically. Neither the prospects nor the acceptance of geochemical work made any notable progress during 1941. G. D. H.

604.* Advanced Geochemical Well-logging. J. W. Merritt. *Oil Wkly*, 30.3.42, **105** (4), 32.—Chemical well-logging does not claim to supplant other forms of well-logging, but it is an excellent correlative tool in oil-well testing. Studies of chemical well-logs have shown that it is possible to detect the approach of the drill towards an oil or gas horizon several hundred feet before the drill has reached the horizon. Indications may also be given of the type of oil or gas horizon.

The geochemical log may prevent the abandonment of a well which if taken a little deeper might obtain oil, while if the intended horizon has been attained and the log gives negative indications, needless expense and additional drilling may be avoided. Favourable or unfavourable spots for coring may be indicated in advance, and the best position for running casing may be shown by signs of the nearness of an oil-sand. There may be lateral indications of oil in a horizon.

A gas horizon is shown by light fractions in the cuttings, and an oil horizon by increasing light fractions followed by heavier fractions. The hydrocarbon values generally drop off sharply on passing the pay horizon.

Carbonaceous shales give high hydrocarbon values, but give no evidence in the overlying beds. G. D. H.

Drilling.

605.* Horizontal Wells from Shaft to be Used in Pennsylvania. A. C. MacIntyre. *Oil Gas J.*, 9.4.42, **40** (48), 42.—The paper describes what may prove to be the first large-scale test of the horizontal drilling theory in the world. Plans call for the sinking of a circular shaft, 8 ft. in diameter and about 400 ft. deep, into the Venango First sand near Franklin, Venango County, in the Middle district of the Pennsylvania region.

The oil in that sand is known as the Franklin heavy crude, and has an unusually high lubricating content, and less gasoline and other light distillates than any other crude produced in Pennsylvania.

The Middle district seems to be the best testing place for the operation, since the oil-sands are at the shallowest point in the Pennsylvania region. The oil content per acre is not as great as in the Bradford–Allegany fields, where water-drive has proved successful. The Middle district sands do not lend themselves to water-drive, but air- and gas-drives have proved successful. Reserves recoverable by present methods, according to a recent survey, are greater in the Middle district than in any other area of the Pennsylvania region. The properties of the crude are briefly given.

The shaft is dug, not drilled, about 400 ft. deep, which takes it into the sand. It is 8 ft. in diameter. The working chamber at the bottom of the shaft is also circular, and 27 ft. in diameter. Both shaft and chamber are lined with 12 and 18 in. of concrete. The shaft enters the chamber at one side, and not in the centre. No gas, oil, or water is allowed to enter the shaft or work-chamber.

It is anticipated that 3-in. holes will be bored horizontally from the working chamber into the face of the sand, and will extend up to distances of 2000 ft. Under the proposed plan the oil will flow by gravity from the horizontal holes into a pump at the bottom of the working chamber, by which it will be lifted to the surface.

Earlier work by Mr. Ranney, the inventor of the method, is summarized. A. H. N.

606.* Present Position of the Drilling Contractor. B. Mills. *Petrol. Engr*, April 1942, **13** (7), 48.—A brief historical review is given of the contractors' rôle in oil-well drilling, beginning with the Drake well of 1859, which was drilled under contract. Drilling contractors annually complete more than 75% of all wells drilled in the U.S.A. There are approximately 250 such contractors in that country, and this surprising total includes organizations equipped to meet every drilling requirement. They normally employ between 75,000 and 100,000 persons, and actually support several times that number. Between 4000 and 4500 rotary drilling rigs, and between 2800 and 3200 cable-tool drilling rigs are available for immediate use in the U.S.A.; of these totals, drilling contractors own and operate about 75%.

A very light-weight rotary drilling outfit costs about $25,000; a medium-weight rotary drilling outfit approximately $60,000; a very heavy type steam drilling rig as much as $125,000; a gasoline or butane rig about $140,000, and a heavy diesel-electric rig represents an outlay of almost $200,000. Cable-tool drilling rigs cost from $7500 to $25,000, but they are as essential to maintenance of oil reserves as rotary tools. These values represent original cost, and should not be regarded as the present worth. All drilling equipment depreciates rapidly, and replacements are numerous.

The service life of a drilling rig is difficult to determine as a single unit. Many of the major items last several years, whereas other items wear out in a short time. Frequent replacements will obviously be necessary to carry on normal drilling operations in any area. The average service life of a drilling outfit is 4 or 5 years when based on normal rates of depreciation. This means that whereas some of the items must be replaced several times in 4 or 5 years, others will remain serviceable throughout the entire depreciation period. Such items as wire-line, bits, and drill-pipe are not ordinarily depreciated as much on a time basis as on a service basis. Equipment receiving fairly uniform service lasts longest, and is usually depreciated on a time basis. Boilers, derricks, pumps, engines, and draw-works have a comparatively long service life.

The cost of drilling and equipping a well in the U.S.A. varies from $1000 in the very shallow districts to $200,000 in the deepest producing areas. The average drilling cost is about $21,000 per well. The cost/ft. varies from $1.50 to $15.00. The average drilling cost in the U.S.A. is about 7.00 dollars/ft., including materials necessary to place the well on production. A. H. N.

607.* Complete Detonation in Well-Shooting. F. R. Cozzens. *Petrol. Engr*, April 1942, **13** (7), 54.—Solidified nitroglycerin, commonly termed gelatin, is rapidly gaining prominence as a well-torpedo in eastern oil-producing areas. Under certain conditions its results appear to equal, and even to surpass, those of liquid nitroglycerin, as the solidified form, which may be had in various types and strengths, is less sensitive and can be pressed by a qualified shooter into crevices and pockets of a sand-face to give the utmost in blasting efficiency. The correctly loaded shot cracks and crumbles the sand-face, exerting equal force in all directions against it, and following, of course, the lines of least resistance. These lines should be the small cracks and porous structure that are a natural condition in a producing sand, thus such cracks are enlarged and amplified. Certain shooting jobs are, however, ineffective due to partial detonation.

Practically all detonating agents, with the exception of the time-bomb, which is not generally used, expend their force at the extreme top of the explosives pack. This point of detonation gives every opportunity for compression of the centre and lower masses of the charge, where, if detonation dees occur, unexploded particles are almost certain to be blown into the spoil or residue that is being forced from the well. The smaller the diameter of the well, the more likely this is to occur. Tests conducted under actual oilfield conditions have proved conclusively that the most effective results are attained when the detonating agent contacts the centre of the explosive pack, as well as its top and bottom. In wells 4 in. or less in diameter at the bottom, when a torpedo shell is used to house the explosives, electric blasting caps should be attached to the firing wire at intervals of 2 ft. along the entire course of the torpedo.

The method is described in detail. A. H. N.

608.* Mud Programmes Important in Drilling Abell Field Wells. D. H. Stormont. *Oil Gas J.*, 9.4.42, **40** (48), 35.—Drilling in the Abell field is generally considered to be the most difficult in the Permian Basin. The hard formations encountered require rock-bit digging all the way, whilst the faulted conditions of the structure, the variance in depth of markers, and lack of uniformity of saturation in the field's six pay horizons all make for much coring. Sulphur-water flows and high-pressure gas are encountered in varying degrees throughout the field, and at most wells trouble is encountered with lost circulation.

Because of the numerous variations in the formations and in the pressures carried by them, operators have found it impossible to adopt a specific mud programme that can be used for every well. Accordingly, the general practice is to establish a mud programme that has proved satisfactory on the nearest producer, and then make changes to deal with any abnormalities encountered while drilling.

That such a procedure is proving successful is reflected in a comparison of mud costs of the first few wells drilled with those more recently completed. Total mud costs for twelve wells drilled early in the field's life, representing a total of 60,493 ft. of drilling, was $21,487, or 35·5 cents/ft. For five wells completed more recently the total mud cost for 22,410 ft. was $5201, or an average of 23·2 cents/ft. Thus the average mud-cost for a 5500-ft. well has been reduced from $1952 to $1276, or a saving of $676 per well. Furthermore, some wells are now being drilled with a total mud-cost of less than $900, or about half the cost of earlier wells.

In addition to this saving, the frequency of blow-outs has been reduced. One well that got out of control while drilling through a sulphur-water horizon had a total mud-cost of almost $12,000. Careful control of mud properties is therefore paying even greater dividends than the above figures indicate.

The problems encountered in surface and deep drilling are detailed, and a typical table of mud programmes is given in full, with explanations. A. H. N.

609. Deep Rotary Drilling in Michigan. G. C. MacDonald. *Oil Gas J.*, 16.4.42, **40** (49), 39. *Paper Presented before American Petroleum Institute.*—The drilling of the deepest well in Michigan, the Gulf 1 Bateson, was one of the most interesting episodes in that State's oil history. Numerous difficulties were encountered which required application of the most advanced techniques known to drilling. The experience gained and the information accumulated will be of great value in future deep development in the State.

These are given in detail, giving dimensions, properties of fluids, and field information.

Now that the subsurface conditions are known, it should be possible to drill a similar well in the same area with a fraction of the expense and difficulty encountered in 1 Bateson. The greatest drilling difficulties undoubtedly occur above 5000 ft., and if that section were adequately cased off with an intermediate string of pipe, most of the difficulties encountered in drilling 1 Bateson would be eliminated. The lower 5000 ft.

of hole could undoubtedly be drilled more rapidly than the upper 5000 ft. It is true that abnormal gas pressures would probably still be present in the Salina formation, but the very fact that their existence is now known would contribute immeasurably to the successful handling of those pressures.

Certain alterations in the mechanical equipment would further increase the ease and safety of drilling additional wells. A salt-water base mud would reduce enlargement through the extensive salt section. A flooded pump suction is extremely desirable whenever mud of any such weight as 17 lb. to 18 lb./gal. is used. A. H. N.

610.* Cement Slurry to Fit the Job. W. A. Sawdon. *Petrol. Engr*, April 1942, **13** (7), 23–26.—Cementing companies have developed techniques that have insured very high efficiency in the handling of the cement at the surface, providing speed and consistency of mix at whatever pumping pressure may be necessary. The planning of the job, the proper preparation of the hole, the amount of cement to use, the selection of the kind of cement, and the determination of the water–cement ratio are, however, dependent on down-hole conditions known only to the operator. These points are discussed and amplified.

By preparation of the hole is meant not only putting it in the best condition possible to take the cement, but also providing the casing string with equipment that will help ensure a successful job when such equipment is necessary. This applies mainly to casing jobs, as the condition of the hole and the equipment in place are usually fixed quantities when re-completion or repair work is to be done. The selection of the casing point is important, but existing conditions sometimes preclude the use of the most desirable casing point.

When cement is placed against porous formations, the mud-cake formed on those formations during drilling will interfere with the bond of the cement with the formation, and will sometimes start channelling. A study of channelling, the effects of mud-cake on the bond, and the relative value of various mechanical devices and chemical means for the removal of mud-cakes was made about two years ago by one of the major oil companies in California. These studies indicated that the mud-cake formed on formations having appreciable permeability will remain between the set cement and the formation unless specific means are employed to effect its removal; and that whereas the movement of the casing and circulation of water may reduce the thickness of the mud-cake slightly, they will not remove it completely.

The quantity and quality of cement slurries and their dependence on various factors are next discussed in detail. Temperature and pressure effects are studied in particular.

Squeeze-cementing is also discussed. So far as is now known, the effectiveness of squeeze-cementing off water- or gas-bearing sands depends on the permeability of the formations and the ability of this permeability to provide for the formation of a cement filter-cake on the face of the sand. Numerous tests made by various companies indicate that cement applied to water- or gas-sands commonly found in oil-wells does not penetrate beyond the face of the sand, no matter what pressure is applied. These sands, under formation pressure, carry water or gas to the bore of the well, and when a pressure greater than the formation pressure is applies in the well, water or gas will pass from the bore into the formation. While building up this differential pressure during squeeze-cementing operations, some of the water contained in the slurry is squeezed out and forced into the formation. This loss of water causes a cement filter cake to form on the face of the sand. A. H. N.

611.* Wildcat Drilling in 1941 with Some Comments on Discovery Rate. F. H. Lahee. *Oil Wkly*, 20.4.42, 105 (7), 25.—During 1941 11,615,085 ft. of wildcat drilling was done, representing 3264 holes, and, of these, 503 were producers accounting for 2,047,377 ft. of drilling. The southern States had 258 producers out of 1563 wildcats, these amounting to 1,264,774 ft. out of a total of 6,843,749 ft.

Of the wildcats drilled on geological or geophysical information, 471 were successful and 1928 dry. Thirty successful holes were drilled out of 801 located on a non-technical basis. Compared with 1940, there was a considerable increase in wildcatting in California, Texas, Kansas, Louisiana, and Illinois, whereas there was a marked fall in Michigan and Mississippi. The percentage success in technically located wells rose from 15·6% in 1940 to 19·5% in 1941, but the successes with wildcats drilled without technical advice fell from 4·2% in 1940 to 3·7% in 1941.

Examination of wildcat and reserve statistics for a group of eleven States shows a falling rate of discovery, which is probably largely due to a growing difficulty of finding new geological traps for oil, and a more vigorous wildcatting campaign both as regards numbers and depths seems to be the only way of maintaining a satisfactory discovery rate. A series of tables and curves summarize data regarding wildcatting and reserves.
G. D. H.

612. Completions Decline in March with Small Rise in Drilling. W. V. Howard. *Oil Gas J.*, 16.4.42, **40** (49), 85.—1473 wells were completed in the U.S.A. during March —less than 50% of the total in the peak month of September 1941. Outside the Appalachian region the March completions were 574, compared with 1704 in September 1941. The relative decline in numbers is, on the whole, greatest among the shallow wells.

A survey of wildcat operations over the entire country shows a fall which is nearly proportional to that for the total wells.

Tables summarize by States the operations in all fields in March, and the drilling activity from September 1941 to March 1942. G. D. H.

613.* Sharp Drilling Decline Begins Levelling Off. Anon. *Oil Wkly*, 13.4.42, **105** (6), 41.—Although U.S.A. well completions fell sharply again in number in March, it seems likely that there will be no further marked decrease in numbers. The March daily average was 36% below that of January, and on 1st April 40% fewer wells were being drilled than in January. 2063 wells were drilling on 1st April, with a further 912 built and shut down. On 1st April drilling had increased in comparison with 1st March in Illinois, Indiana, Kansas, Michigan, Pennsylvania, and West Virginia.

Only 1826 wells were completed in the five weeks ending 28th March. To the end of March 6145 wells had been completed in 1942, and 19,295,141 ft. had been drilled. Tables show by States the rigs in operation on 1st April, 1941, 1st March, and 1st April, 1942, and the status of the wells on the last date; the completions in March 1941, February and March 1942, together with the types of completions in March 1942, and in the first three months of 1942. G. D. H.

614.* Attractive Wildcat Prospects Keeping West Texas Active. T. P. Sanders. *Oil Gas J.*, 9.4.42, **40** (48), 18.—The need of overland pipe-line transportation in place of the combined pipe-line and tanker system for delivering crude to the eastern United States has led to curtailment of production in West Texas and New Mexico. In January about 466,000 brl./day was being run from the area, but in the middle of March the figure was only 264,000 brl./day. This caused the average production per well to be only slightly over 14 brl./day, and some wells were curtailed to 6 brl./day.

During the first week of January seventy wells were completed in the West Texas–New Mexico area—fifty-four oil-wells, one gas-well, and nine dry holes in West Texas, and eight oil-wells, one gas-well and two dry holes in New Mexico. About a month later there were only twenty-nine completions in the same area in one week.

It is possible that a new trend of production may be developed between the two main trends developed during the past fifteen years. The Fullerton 1 Wilson well in Andrews County produces from the Clear Fork (Permian) sand at 7045–7275 ft. A discovery in Reagan County yields oil from the Ordovician.

Recently a new pay was found in the Big Lake field ; this lies at 4200 ft. in the San Angelo (Permian). The other producing sands are at 2400 ft., the San Andres at 3000 ft., and the Ellenburger at 8300 ft. The new pay is not found in wells on top of the structure. G. D. H.

615. Patents on Drilling. A. L. Parker. U.S.P. 2,277,713, 31.3.42. Appl. 8.9.39. Thread protection for an internally threaded outlet.

E. Schulthess. U.S.P. 2,277,786, 31.3.42. Appl. 18.3.40. Pressure hose.

J. W. MacClatchie and J. L. Chrisman. U.S.P. 2,277,925, 31.3.42. Appl. 16.12.39. Weight indicator.

L. P. Kinnear. U.S.P. 2,277,989, 31.3.42. Appl. 12.12.33. Method and apparatus for drilling wells.

A. L. Rodgers. U.S.P. 2,278,022, 31.3.42. Appl. 6.3.39. Cathead and clutching device therefor.

M. R. Overholt. U.S.P. 2,278,137, 31.3.42. Appl. 23.3.40. Cable-drilling tool with helical cutting edges forming water-courses.

S. T. Rowe. U.S.P. 2,278,286, 31.3.42. Appl. 28.6.40. Cathead safety device.

A. Boynton. U.S.P. 2,280,786, 28.4.42. Appl. 17.7.39. Threadless drill-pipe coupling sections.

L. Ranney. U.S.P. 2,280,851, 28.4.42. Appl. 12.1.39. Method of horizontal well drilling.

R. B. Booth. U.S.P. 2,280,994, 28.4.42. Appl. 31.5.40. Mud dispersion and the control of its viscosity.

R. B. Booth. U.S.P. 2,280,995, 28.4.42. Appl. 31.5.40. Mud dispersion and the control of its viscosity.

R. B. Booth. U.S.P. 2,280,996, 28.4.42. Appl. 16.11.40. Treatment of salt- and lime-cut mud.

R. B. Booth. U.S.P. 2,280,997, 28.4.42. Appl. 20.11.40. Treatment of salt-cut and lime-cut mud.

W. Brauer. U.S.P. 2,281,019, 28.4.42. Appl. 4.4.40. Swivel connection for rotary well drilling.

W. W. Wilson. U.S.P. 2,281,128, 28.4.42. Appl. 15.5.40. Elevator for pipes.

E. K. Lane. U.S.P. 2,281,163, 28.4.42. Appl. 19.7.40. Apparatus for determining the degree of fatigue in drill-pipe and the like.

C. P. Walker. U.S.P. 2,281,301, 28.4.42. Appl. 14.11.40. Means for determining the location of obstructions in wells.

D. U. Shaffer. U.S.P. 2,281,389, 28.4.42. Appl. 25.10.41. Rotary releasing fishing tool.

J. M. Clark. U.S.P. 2,281,414, 28.4.42. Appl. 7.11.40. Combined bridge-plug and drillable whipstock. A H. N.

Production.

616. Gas-Cycling Increases Recovery. N. Williams. *Oil Gas J.*, 23.4.42, **40** (50), 61.—Gas cycling has been undertaken by owners of combination oil- and gas-wells in the Otis field, in Rush and Barton counties, Kansas, as a means for attaining maximum oil recovery before reservoir pressures in the field are depleted by gas withdrawals for pipe-line outlets. Production allowables have been predetermined covering a period of 9 years, 1 year less than the estimated economic life of the field's gas resources. The programme calls for the return to the producing horizon of all gas not taken by pipe-line outlets.

In the engineering report on which the allowable order governing the present long-range production programme is formulated, it was estimated that on 1st May, 1941, remaining gas reserves in the reservoir totalled 108,700 million cu. ft. It was shown that 99,200 million cu. ft. of gas had previously been withdrawn from the reservoir, including 64,000 million cu. ft. for pipe-line sales, 6100 million cu. ft. used in operation of gas wells, and 29,100 million cu. ft. vented by combination wells.

Of the remaining 108,700 million cu. ft. of gas it was calculated that 93,700 million cu. ft. should be recovered if no further venting of gas from combination wells occurred. This calculation assumed an abandonment pressure of 50 lb. at the well-head. Estimated original bottom-hole pressure of the reservoir was 1178 lb. In the withdrawal of 99,200 million cu. ft. of gas, together with 1,410,868 brls. of oil, as reported in the engineering survey, the bottom-hole pressure, as of 1st May, 1941, had fallen to 660 lb. Assuming a continuation of the present rate of gas production, it was estimated that the recoverable gas would be depleted and well-abandonment pressure reached in approximately 10 years, the period on which the present production programme is based.

The report estimated that the reservoir originally contained 5,912,500 brls. of stock-tank oil, of which 50%, or 2,956,250 brls., should be recovered. Of this, 1,410,868 brls. had been produced up to the time of the report, leaving 1,545,420 brls. to be recovered, providing gas pressures do not fall below the well-abandonment level before all this oil is produced. While the field-abandonment stage is not expected to be reached in less than 10 years, the specified 9-year allowable period provides leeway to assure the recovery of the oil. The allowable schedule calls for a production of 27,200 brls. monthly the first year, 24,000 brls. monthly the second year, 20,800 brls. monthly the third year, 17,600 brls. monthly the fourth year, and 14,400 brls. monthly the fifth year, 11,200 brls. monthly the sixth year, 8000 brls. monthly the seventh year, and 7200 brls. monthly the eighth and ninth years.

The plant is described. A. H. N.

617.* Economics of Gravel-Packing in Semi-Depleted Loma Novia Field. D. L. Harlan. *Petrol. Engr*, April 1942, **13** (7), 83. *Paper Presented before Petroleum Industries Association.*—A detailed study of gravel-packing is given. The most popular current gravel-packing method is as follows: (1) A cable-tool spudder is moved on location, and rods and tubing pulled. (2) The inside of the liner is bailed clean of mud and sand, using a sand-pump. (3) The top and bottom of the liner are checked with a measuring line to assure correct measurements. (4) The liner is then pulled, using cable-tool stem, jars, and spear (little difficulty has been experienced in pulling liners). (5) The open hole is then bailed clean of sand and mud, using dart-bottom bailer and sand-pump. (6) A 1-ft. length of 1⅛-in. wire line is then threaded through and wedged in a horizontal hole drilled through a cable-tool bit. This device is run to bottom on jars and stem and stroked up and down the entire open hole by rocking the beam and raising and lowering tools. (7) When the open hole has become " logy " with caving, tools are removed and the hole is cleaned out to bottom with a sand-pump. (8) A longer line is then wedged in the bit and the process repeated up to 4 ft. long, until a satisfactory cavity is created. (9) When a sufficiently large cavity has been created and cleaned out, gravel is merely poured into the casing in batches of 5–19 cu. ft. Oil is sometimes allowed to flow into the casing in small quantities while gravel is being poured, to prevent undue breakage of pebbles on casing joints. A measuring line or bailer is run after each batch of gravel, to ascertain the rate of fill and the shape of the cavity. Use of a bailer for this purpose allows some tamping and levelling of gravel in the cavity. The amount of gravel placed varies from 1½ to 5 yds., the average being 3 yds. (10) When the open hole and 2 ft. of casing are filled with gravel, a liner with " orange peel " point, and protecting baffle on bottom, perforated from bottom up high enough to reach within 2 ft. of the casing show, and with drive-head or pin coupling on top, is run-in on cable-tool pin that supports liner driver, jars, and stem. (11) The liner is driven through the gravel to total depth, this operation usually requiring from ½ hr. to 6 hrs.' jarring, depending on the size of the cavity obtained. (12) When the liner is on bottom and checked with a measuring line, the inside of it is bailed clear of broken-up gravel and settled sand and the well put back on the pump in the usual manner.

The results of 199 tests represent an immediate increase of 143% and a settled increase of 93% over the total potential immediately before gravel-packing. Some operators with relatively large numbers of completed jobs show an immediate increase of as much as 230% and a settled increase of 203% over the potential immediately before the work-over.

Costs and other items are discussed. A. H. N.

618.* Bottom-Hole Pressure Conditions Simulated in Flow Valve Test Rack. G. M. Wilson. *Oil Wkly*, 20.4.42, **105** (7), 17.—The paper described a method of determining the exact pressure differential under actual well conditions at which a particular valve will operate. A simple pressure-chamber, in which is placed the flow-valve, was mounted on a heavy steel rack and connected up with high-pressure gas from a field line. By manipulation of several valves and checking pressure gauges and a manometer, actual bottom-hole pressure and flowing conditions may be observed while the valve operates. From the information thus gained, the valve may be adjusted at the surface before the tubing string is lowered in the well, thus obviating the necessity of making several trial-and-error settings before the valves are exactly adjusted to the conditions of a particular well.

The pressure chamber essentially is a short section of an oil-well, complete with casing and tubing. The lower section of the casing is removable, to allow the flow-valve to be screwed on to the tubing. Through outside controls, high-pressure gas may be injected into or released from the tubing and/or casing, simulating the exact pressure or flow conditions found at depth in a well.

The construction and operation of the apparatus are described and illustrated.

Each flow-valve to be run into a well is tested in this device before being made up in the tubing string. Any necessary adjustments in the kick-off pressure settings can be made with the assurance that they will conform to the conditions that by computation and experience are expected at that depth in the well. Similarly, whenever a string of flow-valves is removed from a well the valves are tested individually to determine if they were operating the same way at the end of the period as when originally run in the hole. This procedure yields a constant check on the performance of each make of valve which may be used. On valves that have been removed due to poor operating results it also indicates whether a valve failure has occurred or changes in well conditions have taken place.

Other principal purposes of the test-rack include detection of valve leaks in new and reconditioned valves, as well as in valves being taken out of service; changing valve differential settings by varying spring tensions; and varying the valve-port diameter in order to permit the passage of optimum volumes for the operating conditions.

A. H. N.

619.* Standardization Tests for Condensate Well-Sampling Devices. E. Sterrett. *Oil Wkly*, 27.4.42, **105** (8), 18.—With a view to establishing basic data on which sampling devices for measuring flow of gas-condensate wells may be rated, the Natural Gasoline Association of America has initiated and is sponsoring a series of tests on condensate wells of varying liquid content and pressure ranges in which the various sampling devices are checked against full, calibrated well-flow.

Testing of condensate wells is done by one or two general methods: (1) Full-scale tests involving measurement and sampling of the entire well production. This is expensive in outlay and personnel required to obtain an accurate measure of well capacity, but serves as guide or master control against which accuracy of all other methods is checked. (2) Small-scale testing, in which a relatively small representative portion of the well affluent is withdrawn from the flow-stream and examined.

Over half a dozen sampling devices are in use in various areas, and in quantities ranging from single units in the hands of their developers to multiple installations with wide distribution. Most of these units are variations on the principle of a small tube inserted into the flow-stream of the well. An equal or even greater number of devices and test methods is being used for evaluating the sample, nearly all of which involve separation at some pressure suitable to the individual operator, with or without examination of the separated gas at the option of the operator.

Gas volumes handled in these tests vary from around 20 cu. ft. up to several hundred feet, depending on the method being employed and the operator's views on the subject.

The flow-stream of practically all condensate wells contains retrograded liquid. The amount varies widely, as it is a function of the reservoir fluid and reservoir temperatures and pressures and surface temperatures and pressures. As surface temperatures can vary widely with changes in flow-rates, the relative amount of retrograded liquid is entrained as a finely divided mist, and a part of this liquid collects and flows along the walls of the tubing as a liquid film, flow being uniform or by heads, depending on the interrelation of wellhead factors. No sampling tube in the centre of the stream is able to sample this film liquid. Several of the devices now in use atomize the entrained liquid into an entrained mist, and then, through a sampling tube located at the optimum point, obtain a representative sample.

A series of tests is described in detail, and the paper is freely illustrated with photographs of a number of different types of apparatus and methods. A. H. N.

620.* A Practical Example in Unitization and Repressuring. J. E. Howell. *Oil Wkly*, 27.4.42, **105** (8), 28. *Paper Presented before Interstate Oil Compact Commission.*—The Shuler field of Union County, Arkansas, is a practical example of the benefits to be derived through the combination of unitization and repressuring. A tremendous gas waste has been eliminated, high gas–oil ratios reduced, sharply declining bottom-hole pressures have been checked, the flowing life of wells extended materially, and an additional recovery of 20 million barrels of oil is anticipated, after which approximately 23 billion cu. ft. of gas will be available for industrial and domestic markets. The field and its development are described.

Immediately upon starting operations as a unit, all wells producing large volumes of gas were shut in, and allowable production obtained only from wells of low gas–oil ratios. The result was a reduction in the average ratio of from more than 3000 cu. ft. to a barrel of oil to approximately 1400 cu. ft. to one barrel. This action alone reduced the decline in bottom-hole pressure from 1·6 lb./day to 0·5 lb./day. This improvement resulted in preventing a tremendous waste of gas and reservoir energy during the period of design and construction of a plant for the reinjection of the gas produced from the Jones sand back into that formation. The compressor plant is described.

The decline in bottom-hole pressure is less than 5 lb./month, and with the addition of gas planned to be collected from other sands producing in the field, and returned to the formation, this decline in pressure will be further retarded or eliminated. The results of the pressure–maintenance programme indicate that an additional recovery of 20 million barrels of oil will be obtained. After the production of oil ceases the reservoir will contain approximately 23 billion cu. ft. of gas available for use in industrial and domestic markets.

In keeping with the sound operating practice of maintaining the producing gas–oil ratio for the pool at a minimum, allowable production is taken from those wells having the lowest gas–oil ratios. This has resulted in the using of no more than fifty of the 146 wells at any one time. This in turn resulted in further agreements to unitize the upper horizons in the area with further success and saving. A. H. N.

621.* Paraffin Clogged Lines and Tanks Kept Open by Portable Boiler. G. M. Wilson. *Oil Wkly*, 27.4.42, **105** (8), 15–16.—Steaming out paraffin-clogged and constricted lead lines, tank batteries, separators, and numerous other important jobs around large leases is being easily and quickly done by one major company operating in West Texas, with the aid of a shop-assembled small portable boiler.

Following the spotting of the boiler at one of the centralized tank batteries in the morning, it is not uncommon to have the lead lines of eight wells cleaned out, the sludge and paraffin melted and drained out of the two tanks, and the header, separator cleaned out, all within an eight-hour tour. In addition, a small all-metal dog-house towed behind the boiler provides heat and shelter to the two men while they are on the job. When the boiler unit is moved, this is converted into a handy tool-house, in which are carried wrenches, fittings, and the flexible hoses that connect the boiler into the gas and water outlets at the tank location. The boiler and method of its use are described.

While the boiler unit was designed primarily for steaming lines and tanks, it has since fitted admirably into several other important jobs around the lease. It often happens, for example, that in bringing in a new well, a tank of dirty oil will be obtained which, unless processed with a chemical treatment, would not be pipe-line oil. With the aid of a heat exchanger and a portable circulating pump used in conjunction with the boiler, the oil can be heated and cleaned up to pipe-line condition. A. H. N.

622. Scale Removed from Pipe by Simple Treatment. H. F. Simons. *Oil Gas J.*, 16.4.42, **40** (49), 29.—The paper deals mainly with the problems met in pipes carrying salt water for disposal purposes. The scale deposition on the inside of pipes and tubing used in the disposal system is often so bad that these lines have to be taken up and the tubular material discarded or milled out. From a cost standpoint this is frequently prohibitive. However, a system designed to carry so many barrels/day will not function properly when the diameter of the pipe and tubing is reduced substantially through an accumulation of scale.

There is also the possibility in some cases, and an actual occurrence in many, that scale will be deposited in the pores of the disposal zone and plug it. The reverse often happens in pumping wells where subsurface pumps frequently become clogged so badly with scale that they will not operate. Examples are quoted in detail.

Scale deposited by salt water in producing wells, lines, and in salt-water disposal systems is due to three general causes. These are (1) calcium supersaturation of the brine due to change in equilibrium and precipitation of the excess material, (2) mixture of brines from different sources, which causes precipitation of previously dissolved components, and (3) the presence of dissolved iron in the brine which will precipitate if it is exposed to the atmosphere.

The mixture of sodium hexametaphosphate and alkaline quebracho tannin will effectively prevent carbonate precipitation and also the deposition of sulphates of calcium, strontium, and barium. It will suspend four parts of iron in solution for each part of sodium hexametaphosphate present. Corrosion is also retarded. The sodium hexametaphosphate–quebracho treatment has been used with much success for preventing scale formation in cooling systems. The sodium hexametaphosphate possesses several properties which make it particularly suited for eliminating scale or preventing its deposition. It has the ability to combine with many multivalent cations, thereby increasing their solubility ; it has definite surface-acting properties, and it is absorbed by metal surfaces. Alkaline quebracho tannin also possesses the property of preventing the deposition of scale.

Cost of the chemical for the treatment is quite low, ranging from 0·3 to 0·6 mills/brl. of salt water. Experimental results are reported. A. H. N.

623. Design of Gun-Barrel Tanks for Oil–Water Separation. F. B. Gordon. *Oil Gas J.*, 23.4.42, **40** (50), 71.—The primary purpose of the gun-barrel is to separate water from oil, hence it is sometimes referred to as a settling tank. The separation is effected by the difference in density and mutual insolubility of water and oil. In nearly all cases the process is continuous. Therefore the accumulating water and oil must be removed. The removal of the water takes place at the water-drain, somewhere near the bottom of the tank. The oil passes out through a fixed overflow connection. For proper operation, the water level in the gun-barrel should remain constant. In practice, the water level is controlled by an adjustable gooseneck overflow or siphon. The water overflow is sometimes called a grasshopper. The dimensions and settling of the grasshopper determine the water level in the gun-barrel.

The principles of design are given briefly, in conjunction with illustrations.

A. H. N.

624.* Salt Water Disposal System Utilizes Non-Corrosive Materials. C. C. Pryor. *Petrol. Engr*, April 1942, **13** (7), 42.—One of the major companies operating in eastern Texas fields has designed and placed in operation a salt-water system that is regarded as being most successful from several standpoints.

As the company decided upon a policy of returning the salt water to a formation approximately 300 ft. below the main producing zones and outside the producing area of the field, it was necessary to adopt a method of gathering the salt water from the various leases throughout the field. To accomplish this purpose, concrete pits were constructed at strategic points, into which the salt water was collected from a certain number of leases. The leases were selected so that their total production of salt water could be easily handled by the pits. The construction and other details of the pits are described.

It had been the practice of the company to purchase large quantities of chlorine for treating the water in these collecting pits before it was conducted by gathering lines to the final treating-pit. In the present emergency War Production Board restrictions have resulted in the manufacturer being unable to deliver the required chlorine. As it was essential that the water be sterilized before entering the pipe-line to the final treating-pit, it was decided to manufacture the required product. The equipment used is described and illustrated.

The special salt-water pumps used are studied. These consist of an 11-stage turbine assembly with approximately 3 ft. of 3-in. discharge column, a surface-type discharge head, and a 5-h.p., 3-phase, vertical hollow-shaft motor. The pumps were designed for a capacity of 60 gal./min. against a head of 185 ft. with an efficiency of about 83%. Construction of these pumps is such that there are no metal-to-metal contacts between the rotating shaft and impellers and the stationary bowls. Similar metals are used in so far as it is practicable.

The gathering system and the treatment of the water to remove iron oxide by aeration are finally discussed, together with filtering arrangements used Leaving the filters, the water is metered, and passes through a regulator that holds back-pressure on the filters, keeping them full of water, as the vacuum on the wellhead would drain the water out and allow them to dry.

There is a vacuum of approximately 30 in. of mercury at the wellhead. The well tubing is 5-in. O.D., cement-lined, with the bottom end opened and a packer set above the formation in the 7-in. casing. A. H. N.

625.* Subsurface Disposal of Oilfield Brines in Oklahoma. S. S. Taylor and E. O. Owens. *U.S. Bur. Mines, Rep. Invest.* 3603, January 1942.—As a method of oilfield brine disposal, subsurface injection has been practised in many oil-producing areas in Oklahoma and elsewhere. The technique, which has been vastly improved since its inception in 1925, offers many advantages over other systems of brine disposal—*e.g.*, impounding and solar evaporation, controlled diversion into surface waters, and recovery of the mineral salts of the brine, and, in fact, eliminates the damaging effects of mineralized water on freshwater supplies, vegetation and aquatic, and other animal life.

This report embodies the results of a study by the Bureau of Mines of three disposal systems in Oklahoma, designed to take care of brine produced from approximately 1000 oil-wells.

Conclusions reached are that for effective and economic subsurface disposal schemes, deep-seated permeable strata are desirable. Otherwise it becomes necessary to employ relatively high surface pressures. To avoid plugging of the disposal formation, the brine injected should be conditioned so that no suspended solids reach or are precipitated in the disposal formation. If the brine is found to be corrosive to iron or steel, the use of corrosion-resistant equipment between the filters and the disposal formation will facilitate the operation if the brine has been adequately conditioned.

It was found with the particular brines studied in this report that stabilization or removal of the iron compounds was the most important chemical change necessary in preparing the brine for subsurface disposal. Other types, however, may contain unstable bicarbonate compounds or soluble iron compounds requiring special treatment.

In cases where extensive gathering lines are used and the brine flowing through them to the conditioning plant is exposed to and agitated in the presence of atmospheric oxygen, due consideration must be given to the probable change which may occur in chemical characteristics of the brine during transportation before finalizing design and capacity of the brine-treating equipment. H. B. M.

626.* Use of Hot Distillate to Remove Paraffin from Sand Face. T. P. Sanders. *Oil Gas J.*, 9.4.42, **40** (48), 37.—This method supplies both heat and solvent in one operation through a system of washing the bottom of the well with a hot distillate. At present the work employs no special equipment that was not on hand at the leases prior to the first trial, but it is quite likely that the washing treatment could be improved and streamlined through the use of special portable units.

The 100-brl. charge of distillate is heated to about 190° F. before being introduced into the well. Attempts to obtain higher temperatures with low-pressure steam passing through the coils have seldom been successful, because too much time is required, resulting in a correspondingly large loss of vapour from the distillate.

The hot distillate is not dumped down the casing, because heat loss would thereby be too great. Instead, the sucker rods are raised to unseat the plunger and the standing valve so that the hot fluid can be introduced down the tubing. No transfer pump is used, since there is ordinarily very little fluid in this type of well that requires treatment, and the 100-brl. tank is therefore rapidly emptied by gravity flow into the well.

Within about 15 minutes after the hot solvent has been placed, the well is put back on the beam. This requires reseating the standing valve, after which the entire charge of distillate is pumped out of the well and back into the 100-brl. tank. The temperature drop of the solvent is then noted, and steam is again turned into the coil. When the charge has been reheated to 190° it is again sent down the tubing. This washing cycle is repeated three times.

On returning to the surface after the third cycle, the " distillate " is usually about 50% crude oil and paraffin. At this point it is sent through the lead line to the tank battery to be sold with the lease production. Bought as distillate at 4½ cents/gal. ($1·89 per brl.), it is sold as crude oil at $1·20 per brl. so that comparatively little is lost in the exchange. Pampa crude normally averages 42–43° gravity, and since 40-gravity crude brings top price, no monetary benefit is derived from the distillate on the basis of gravity increase. This would not be the case in all fields, however, and in localities where the increase in gravity meant additional revenue from oil sales the added sum would serve to reduce the cost of treatment. A. H. N.

627.* Economic Use of Electric Power in Petroleum Production. W. H. Stueve. *Oil Gas J.*, 9.4.42, **40** (48), 38.—In a relatively small area of some 7 sq. miles surrounding the town of St. Louis, in Pottawatomie County, Oklahoma, the oil producers have been using electric-motor-driven submerged centrifugal pumps for 8 years, from 1934 to date, to produce oil profitably from certain wells which, had it not been possible to secure this type of equipment, would doubtless have been abandoned.

In summarizing the 8-year record of operations of the submerged centrifugal pumps in use in the St. Louis field of Oklahoma, the following conclusions are reached : (1) With an average investment of approximately $340,000 (thirty-four pumps) during the 8 years studied, a gross revenue of about $12 million has been achieved before royalty payments and production taxes. (2) With a net revenue from oil produced of about $10 million during the period studied, after allowances are made for repairs of $1,160,000 and an estimated cost of electric power of $2,085,000, there remains a balance of $6¾ million from which the other costs and the profit on the operations are obtained. (3) With an average lifting depth of 4000 ft. and a composite specific gravity of 1·18 for the total liquid pumped during the period studied, a resultant overall efficiency of 48% is obtained from electric metered energy to fluid delivered at the ground surface tank battery. A. H. N.

628.* Usefulness of Sucker Rods Prolonged by Proper Care at the Well. J. C. Albright. *Petrol. Engr*, April 1942, **13** (7), 72.—In a short paper the extra life imparted to sucker rods by using proper stands on which to lay the rods being pulled from a well is stressed. In recent months many operators have abandoned the use of wooden rod-troughs, and have devised metal stands on which the rods are laid. These stands are generally made of material that permits quick and ready movement from the ground to the pulling machine or truck, and likewise can be strung out at the well with little delay. One set usually suffices for as many wells as one pulling machine can service. These metal stands are portable, are easy to wipe clean when oil drips from the rods, and provide no fire hazard. The older wooden troughs represented a considerable investment, and the material from which they were constructed could not be utilized for another purpose once they were built and had become soaked with oil and crusted with drifting sand and dust.

The method of constructing these stands is discussed. A. H. N.

629. Patents on Production. H. R. Downs. U.S.P. 2,277,746, 31.3.42. Appl. 20.3.39. Fluid regulator for use with a fluid motor adapted to operate against a variable back pressure.

T. A. Andrew. U.S.P. 2,277,898, 31.3.42. Appl. 26.4.40. Means for measuring flow in wells.

R. F. McMurray. U.S.P. 2,277,922, 31.3.42. Appl. 29.7.39. High-pressure slip coupling.

A. S. Parks. U.S.P. 2,278,017, 31.3.42. Appl. 22.5.39. Flow apparatus for wells using tubing.

M. De Groote and B. Keiser. U.S.P. 2,278,164, 31.3.42. Appl. 25.1.41. Process for breaking petroleum emulsions.

M. De Groote and B. Keiser. U.S.P. 2,278,165, 31.3.42. Appl. 25.1.41. Process for breaking petroleum emulsions.

M. De Groote and B. Keiser. U.S.P. 2,278,166, 31.3.42. Appl. 25.1.41. Process for breaking petroleum emulsions.

M. De Groote and B. Keiser. U.S.P. 2,278,167, 31.3.42. Appl. 25.1.41. Process for breaking petroleum emulsions.

M. De Groote and B. Keiser. U.S.P. 2,278,168, 31.3.42. Appl. 25.1.41. Process for breaking petroleum emulsions.

M. De Groote and B. Keiser. U.S.P. 2,278,169, 31.3.42. Appl. 25.1.41. Process for breaking petroleum emulsions.

M. De Groote and B. Keiser. U.S.P. 2,278,170, 31.3.42. Appl. 25.1.41. Process for breaking petroleum emulsions.

M. De Groote and B. Keiser. U.S.P. 2,278,171, 31.3.42. Appl. 25.1.41. Process for breaking petroleum emulsions.

J. H. Wiggins. U.S.P. 2,278,294, 31.3.42. Appl. 11.3.40. Drainage means for tank roofs.

J. O. Wilson. U.S.P. 2,278,296, 31.3.42. Appl. 24.7.41. Rotator attachment for pumping-jacks.

C. E. Bridwell. U.S.P. 2,278,399, 31.3.42. Appl. 2.1.40. Pumping mechanism with stationary tubular plunger and reciprocating barrel.

A. Boynton. U.S.P. 2,280,785, 28.4.42. Appl. 4.10.38. Well-testing tool using packers.

A. Boynton. U.S.P. 2,280,787, 28.4.42. Appl. 8.12.39. Differential stage-lift flow device.

A. Boynton. U.S.P. 2,280,788, 28.4.42. Appl. 8.12.39. Flow device for oil-wells using gas-lift.

W. H. Hazard. U.S.P. 2,280,910, 28.4.42. Appl. 30.10.39. Lubricating means for the power mechanism of a deep-well pump.

G. C. MacDonald. U.S.P. 2,281,103, 28.4.42. Appl. 3.11.39. Apparatus for placing explosives in a well under positive control from the top of the well.

C. E. Records. U.S.P. 2,281,326, 28.4.42. Appl. 15.8.40. Well-screen.

A. H. N.

Transport and Storage.

630.* The Amount and Measurement of Internal Corrosion in Gasoline Pipelines. J. M. Pearson. *Oil Gas J.*, 6.11.41, **40** (26), 169.—The method of inserting steel samples into the line to measure internal corrosion is open to several objections detailed, and fails to evaluate the unknown effect of scraping. Since experience shows the corrosion is general and pitting of the metal presents a relatively low profile, measurement of weight loss directly on the pipe-wall should provide useful data, and two types of experiments with this object in view are in progress. In both cases the weight of pipe is determined from careful measurements of pipe resistance and temperature. The electrical circuits and connections required are described and illustrated. In one experiment quarter sections of pipe joints were cleaned, machined, measured, and weighed, and then welded into a trunk line, the outside being protected by a box filled with asphalt, to obviate external corrosion. For reweighing by electrical methods, pipe had to be removed and re-machined before replacement, and the short lengths necessitated very accurate measurements. In the second experiment a longer section of pipe was used, and electrical connections and a thermometer well were provided to permit measurements to be made *in situ*. The entire section, together with insulating joint to eliminate stray currents which might interfere with readings, is enclosed in a box filled with asphalt, thus extending the insulation provided by the joint to include the entire electrical circuit, as well as eliminating external corrosion. A sample of the actual pipe used is taken, so that variation of resistance with temperature can be measured and the results used as basis for estimating loss in weight of the test pipe in service from the resistance and temperature determinations. Present data are insufficient to enable final conclusions to be reached, but indicate : (1) Rate of corrosion is higher in proportion to the amount of moisture and oxygen introduced. (2) Rate of corrosion is highest at the point of introduction of these elements, falling sharply at more remote points. (3) Depending on pumping rates and location, weight-loss rates of corrosion vary from 0·1% to 2% of the pipe-wall per annum. (4) There is some evidence that scrapers increase the average rate of corrosion. (5) As regards life expectancy of lines, soil corrosion and other external factors deserve first consideration.

R. A. E.

631.* Experience With and the Effect of Use of Scrapers on Internal Corrosion of Gasoline Pipe-lines. D. E. Sullivan. *Oil Gas J.*, 6.11.41, **40** (26), 122.—It has been found by experience that the capacity of a gasoline pipe-line declines unless steps are taken to combat internal corrosion, considered to be due to precipitation of water from the gasoline by reduction in temperature. In some cases the building up of corrosion products in sharp bends or around interior recesses of valves completely plugged the lines, and in others barnacle-like structures adhering to the inside of the pipe increased resistance to flow. It was found that conventional type scrapers as used on crude oil and water lines were not efficient in removing water and corrosion products from gasoline lines, and also gave rise to operational difficulties.

A scraper which has been found satisfactory for the purpose consists of a short, plug-like scraper made up of a series of six natural rubber discs and five circular wire brushes suitably mounted on a 14-in. length of extra strong pipe, plugged at both ends. The brushes are double-knot wire brush-wheels 1 in. thick, made of 0·014-in. piano wire, and having a diameter of 6¼ in. for use on a 6-in. line. They scrape the products of corrosion free from the walls of the pipe. The rubber discs are prepared from a natural rubber compound partly soluble in gasoline and expanding 25–50% in volume when immersed in gasoline for 12 hrs. The squeegee effect of the discs tends to wipe off water which adheres to the pipe walls, and the swelling of the rubber in contact with gasoline helps to counteract the effects of wear in use, so that the scraper can be used for about 120 miles of line before becoming unserviceable. Recommendations for use as a result of experience are : (1) Use scrapers in pairs with a 15–20 min. interval between. (2) Instal at each pit where scrapers are removed from the line a slop-tank of sufficient capacity to deal with discharge from the line during a period 5 mins. before arrival of scraper and 10 mins. afterwards. Most of the debris and water are collected during this period, and the use of the slop-tank avoids deposition in strainers or delivery tanks. (3) The use of scrapers at uniform intervals of 3–4 days will avoid risk of line-plugging due to piling up of debris ahead of the scraper. Experience on a 6-in. line 80 miles in length showed a decline in line capacity to 74% of the original over a period of 2½ years' operation. The relationship between scraper usage and capacity during the succeeding 5 years is illustrated graphically, and at the end of the period usage at the recommended rate had restored capacity to slightly over 100%. The effect of the scrapers on the actual rate of interior corrosion of the line is not known. Methods of insertion and removal are described and illustrated.

R. A. E.

Crude Petroleum.

632.* Characteristics of California Crude Oils. R. C. Mithoff, G. R. MacPherson, and F. Sipos. *Oil Gas J.*, 6.11.41, **40** (26), 81. (*Paper presented before American Petroleum Institute.*)—Owing to the wide variations in properties of crude oils produced in California, the Standard of California has developed special methods of analysis, which are described and illustrated. Three analytical distillation methods which are used as required are :—

(1) Yields of gasoline, kerosine, gas oil, and residue of defined qualities are obtained by distillation from a 5-litre flask of stainless steel equipped with a 29-in. column of special design and conventional analyses of the products made to ascertain their principal properties. (2) True boiling-point distillations are carried out in an apparatus of special design, and 4% cuts obtained by successive distillation to 635° F., (*a*) under atmospheric pressure, (*b*) under pressure of 10 mm., (*c*) under pressure of 1 mm. The cuts are examined for gravity, sulphur content, viscosity, neutralization number, pour point, aniline point, and mol. wt., and a measure of paraffinicity is obtained by determination of characterization gravity, the arithmetic average of instantaneous gravities of distillates boiling at 350° F., 450° F., and 550° F. vapour line temperature at 25 mm. pressure. (3) Analyses are carried out on heart-cuts prepared by blending fractions of narrow boiling range obtained by distillation of 15 gals. of crude in a 20-gal. still fitted with an efficient column, and with provision for applying steam and vacuum. Results may be plotted on charts which show the particular quality as a function of percentage distillate from the crude oil at the start and end of the desired distillate, and yield/quality curves may also be obtained.

No truly satisfactory method is available for grouping or classifying California crude oils among themselves. However, broadly speaking: (1) Most of the more naphthenic oils (characterization grav. 23° or lower) are of 27° A.P.I. grav. or heavier, whereas oils of 28° A.P.I. grav. or lighter (characterization grav. 26–30°) are relatively paraffinic. (2) Most oils of high sulphur content are heavier than 20° A.P.I. grav., but sulphur content bears little relationship to paraffinicity, as many relatively heavy oils are of low sulphur content. (3) Relation to geological age appears general, deep wells from geologically older strata usually yielding lighter, more paraffinic oils of lower sulphur content than shallower wells in the same field.

From the results of numerous analyses of California crude oils the following conclusions are reached: (1) A.P.I. grav. range is from about 6° to 60°. (2) Gasoline yield nil to 85% (390° F. E.P.). (3) General trend for gasoline content to increase with rising A.P.I. grav., but yield variation for given A.P.I. grav. is great. (4) Sulphur contents range from 0·1% to 6·0% (normally 0·3–1·5%), but the oils are relatively free of H_2S and mercaptans. The sulphur compounds are more stable to heat than those present in most crude oils, and tend to produce less H_2S on distillation at low pressures. Distillates are, however, relatively high in total sulphur content, and on cracking residuum the sulphur compounds tend to split into compounds of intermediate boiling range which appear in the naphtha. Cracking of Californian stocks also results in considerable H_2S and mercaptan formation, and gives rise to considerable corrosion of equipment, necessitating the use of special steels for tubes, lines, and vessels. (5) The naphthenic character of the oils is reflected in the relatively high octane ratings of the straight-run, cracked, and reformed gasolines obtained. (6) Wax contents of the relatively paraffinic types normally range from 2% to 4%, and the wax is concentrated in the heavy gas oil and lubricating oil distillates. (7) Naphthenic acids occur throughout the boiling range from kerosine to asphalt, and considerable amounts are recovered from the distillates. (8) Cracked naphthas contain considerable amounts of nitrogen bases and phenolic compounds which can be recovered.

As regards straight-run products from Californian crudes, gasolines usually require acid treatment to meet colour requirements, and sometimes to lower sulphur content and pass the doctor test; kerosines require SO_2 treatment to produce high-grade burning oils; high-grade lubricants are normally prepared by solvent treatment and dewaxing of distillates from waxy crudes; the heavy fuels produced by straight distillation or cracking usually require blending with 10–20% of light gas oil to meet viscosity and gravity requirements.

Good yields of high-octane-rating gasolines are obtained by reforming Californian naphthas, but treatment is needed to meet colour and colour stability requirements. Residue is usually employed as cracking stock, and results show that yields of gasoline obtainable can be satisfactorily related to viscosity of stock for Californian oils, and a viscosity/yield chart is presented. Other charts relate sulphur content of cracked naphtha to that of charging stock and octane number of cracked gasoline to characterization gravity of charging stock for single-coil units equipped with reaction chambers.

Comparison is made with Eastern and other crude oils as regards characteristics, refinery treatment, and yields. R. A. E.

Cracking.

633. Patents on Cracking. G. C. Connolly. U.S.P. 2,275,176, 3.3.42. Appl. 6.12.38. Method of cracking hydrocarbon oils which involves subjecting the oil at cracking temperature to the action of a synthetic silica–alumina gel catalyst containing a minor portion of alumina and not more than 1% of tin oxide.

E. H. McGrew. U.S.P. 2,276,081, 10.3.42. Appl. 12.8.39. Method of combining hydrocarbon oil heavier than gasoline with hydrocarbons in the gasoline boiling range. The resultant mixture is subjected to the action of a cracking catalyst at a temperature between 600° and 900° F. Gasoline is separated from insufficiently converted oil, and at least a portion of the latter catalytically cracked at a higher temperature to convert a substantial portion into gasoline. The heavier fractions of the gasoline are combined with the hydrocarbon oil.

N. K. Chaney. U.S.P. 2,276,288, 17.3.42. Appl. 19.10.38. Production of manufactured gas and valuable hydrocarbons by the thermal cracking of fluid hydrocarbons in vapour phase. Firstly, a heated path is established, and the fluid hydrocarbons passed along it and cracked. A portion of the moderately cracked products is then withdrawn and exposed to severe cracking conditions to form reactive radicals. Afterwards the products are returned to the path for reaction with the unwithdrawn products.

K. M. Watson. U.S.P. 2,278,228, 31.3.42. Appl. 13.5.40. Conversion of hydrocarbon oil into substantial yields of high anti-knock gasoline by adding to the oil a powdered cracking catalyst in amount substantially less than that maintained in a subsequent reaction. The mixture is subjected to catalytic cracking conditions of temperature, and at a pressure adequate to maintain a substantial portion of oil boiling above the gasoline range in liquid phase. The vaporous fraction is removed, and gasoline and gas are recovered. A portion of liquid reactants is withdrawn from the reaction zone to a separating zone and subjected to gravity settling. In this way the catalyst is substantially removed from a part of the reactants. A portion of the remaining oil from the settling zone is returned to the reaction zone to build up and maintain a higher concentration of catalyst in the zone than is added to the hydrocarbon oil. H. B. M.

Hydrogenation.

634. Patents on Hydrogenation. Universal Oil Products Co. E.P. 544,127, 30.3.42. Appl. 3.4.40. A two-stage process for the production of butadiene from normal butane. The first stage involves the dehydrogenation of butane to normal butenes, and the second a further dehydrogenation of separated butenes to butadienes under altered and optimum conditions.

E. N. Hague. U.S.P. 2,275,178, 3.3.42. Appl. 11.5.39. Process for recovering *iso*-octane from excess hydrogen-containing gas used in the hydrogenation of *iso*-octenes to *iso*-octanes. The excess gas containing *iso*-octane vapours is contacted with an absorption oil comprising polymers boiling in the range 300–400° F. Thereafter the used absorption oil is distilled to separate from it the absorbed *iso*-octane.

V. N. Ipatieff and B. B. Corson. U.S.P. 2,275,181, 3.3.42. Appl. 3.4.39. Conversion of olefinic and aromatic hydrocarbons into more saturated hydrocarbons by subjecting the initial material to hydrogenation in the presence of metallic copper and iron oxide. H. B. M.

Polymerization and Alkylation.

635. Patents on Polymerization and Alkylation. Standard Oil Development Co. E.P. 543,420, 25.2.42. Appl. 11.12.39. Improved method of preparing non-asphaltic linear type polymers of high molecular weight by polymerization of *iso*-olefins with a metallic halide Friedel–Crafts catalyst at a temperature below −10° F. When the desired viscosity has been reached an alkaline substance is added to the reaction mass, and improved polymerization products are obtained by contacting the products of this process with the alkaline substance before the temperature is allowed to rise above −10° F.

W. M. Smyers. U.S.P. 2,274,749, 3.3.42. Appl. 17.7.37. Preparation of a copolymer having a molecular weight above 1500 by polymerizing at a temperature below 0° C. in the presence of an active halide catalyst a mixture of an aliphatic olefine having more than two carbon atoms, and a different reactive mono-olefinic hydrocarbon capable of polymerization and containing a cyclic nucleus. These materials are the only reactants.

J. C. Morrell. U.S.P. 2,276,250, 10.3.42. Appl. 29.2.40. Production of hydrocarbons boiling within the gasoline range from *iso*paraffin and olefin hydrocarbons by simultaneously contacting an *iso*paraffin and an olefin at an alkylating temperature with sulphuric acid to which has been added an inorganic, oxygen-containing boron compound. The amount and concentration of the acid, the reaction temperature, and the proportion of olefin to *iso*paraffin are correlated to effect alkylation of the *iso*paraffin, with minimum olefin polymerization. In this way the *iso*paraffin and olefin hydrocarbons are chemically combined to form a heavier hydrocarbon boiling in the gasoline range.

J. C. Morrell. U.S.P. 2,276,251, 10.3.42. Appl. 29.2.40. Production of hydrocarbons boiling within the gasoline boiling range in a manner similar to that described in U.S.P. 2,276,250 above, except that an organic base is added to the sulphuric acid instead of an inorganic oxygen-containing boron compound.

P. Subkow. U.S.P. 2,277,938, 31.3.42. Appl. 12.7.38. Production of reformed and polymer gasoline by heating at a gasoline reforming temperature in a series of coils in a restricted stream and without separation of vapours, a slurry of comminuted catalyst and petroleum hydrocarbons having an end-point not exceeding 650° F., and containing gasoline fractions. H. B. M.

Refining and Refinery Plant.

636.* World-Oil-Refineries Survey. Anon. *Oil Gas J.*, 25.12.41, **40** (33), 107.—A list of refineries outside U.S.A. is given, and is arranged alphabetically according to country and name of operating company. Details include plant location, name of superintendent, crude capacity, type of refinery, cracking capacity and type of plant, and operating status.

Pre-war totals only are shown in the case of countries which have been at war since the latter part of 1939. R. A. E.

637.* Argentina Expands Refining Facilities. Anon. *Oil Gas J.*, 25.12.41, **40** (33), 96.—Two new refineries have been erected near producing centres with the main objective of supplying surrounding territories and reducing long transportation previously needed. One refinery situated at Lujan de Cuyo in the Province of Mendoza has a daily crude capacity of 3150 brls., is equipped for primary distillation, viscosity reduction, and selective cracking of gas oil, and operates on Tupungato crude. Estimated annual output in brls. is : motor fuel 598,500, kerosine 81,900, fuel and diesel 314,000. The other refinery is at Salta City, and has a daily crude capacity of 1890 brls. Estimated annual output in brls. is : motor fuel 441,000, kerosine 18,900, fuel and diesel 132,000.

In addition, a viscosity-breaking unit was placed in operation at La Plata refinery during the year. This can handle 5000 brls. a day of heavy fuel viscosity S.F. at 122° F. 700–800 secs., producing fuel of viscosity S.F. at 122° F., about 200 secs., meeting Argentine Republic specification in this respect.

Crude runs to refineries in Argentine in 1941 are expected to amount to 27 million brls., whilst imports of petroleum products will be reduced to 10–12 million brls., 95% of which will be fuel oil and crude required to balance home production and consumption. R. A. E.

638.* Capacity of Uruguayan Refinery Increased 25 per cent. E. S. Pelufo. *Oil Gas J.*, 25.12.41, **40** (33), 89.—The capacity of the Ancap refinery has been increased from 5000 to 6300 brls. a day by installation of fuel to crude-heat exchangers and changes in the pumping arrangements. The octane rating of the motor gasoline has been improved slightly by installation of a catalytic-polymerization plant operating on gases from the cracking plant.

Crude charged to the plant during the past 12 months totalled 2,046,000 brls., about 75% of which was Peruvian and Ecuadorian paraffin-base type, and 25%

Temblador (Venezuelan) crude. The latter was treated in the topping plant only, but 40% bottoms from the former are charged to the cracking unit, which handled 650,000 brls. in the same period, and produced 50% gasoline and 42% fuel from the charging stock.

Quantities of the various grades of finished products produced are given. R. A. E.

639. Patents on Refining and Refinery Plant. J. C. Morrell. U.S.P. 2,276,249, 10.3.42. Appl. 19.1.35. A process which involves topping crude petroleum containing straight-run gasoline to separate therefrom a light fraction containing gasoline boiling hydrocarbons. The topped crude is distilled to coke, and high-boiling products are separated from overhead products of the coking operation. The lighter components of the overhead products are combined with the light fraction from the crude petroleum, and the resultant mixture is passed through a heating coil and subjected to cracking conditions of temperature and pressure to increase the anti-knock value of the gasoline hydrocarbons. The resultant conversion products are cooled by indirect heat exchange, with crude oil being supplied to the topping operation in order to preheat the crude and separate heavy constituents of the conversion products. The separated heavy constituents are passed to the coking operation while the cooled conversion products are fractionated and condensed.

G. H. Von Fuchs and H. H. Zuidema. U.S.P. 2,276,526, 17.3.42. Appl. 3.4.39. Method of refining a hydrocarbon oil selected from the group consisting of lubricating and electrical oils free from asphalt containing harmful sulphur in the form of mercaptan sulphur. The oil is heated in liquid state at a temperature between 400° and 700° F., with at least 1 mol. of cuprous oxide per molecule of said mercaptans under non-oxidizing conditions, to convert mercaptan sulphur into cuprous sulphide and substantially to prevent conversion of mercaptans into disulphides. H. B. M.

Chemistry and Physics of Hydrocarbons.

640. Inflammability of Ether–Oxygen–Helium Mixtures: Their Application in Anæsthesia. G. W. Jones, R. E. Kennedy, and G. J. Thomas. *U.S. Bur. Mines, Rep. Invest.* 3589, October 1941.—It is pointed out in this report that helium adds certain very desirable characteristics to anæsthetic mixtures. It is one of the lightest gases known and, because of its low density, its addition to such mixtures enables them to permeate the spaces in the lungs at a higher rate and, therefore, more completely than other mixtures having a higher density. Owing to its almost perfect inertness and very low solubility in water and body-fluids, it exerts little, if any, physiological effect on the patient breathing it.

Its most outstanding advantage over other inert gases is the high rate at which it conducts heat and electricity, and for this reason it is considered to offer remarkable potentialities in the prevention of static ignition of inflammable anæsthetic mixtures.

In April 1939 a Sub-committee, including representatives of the Bureau of Mines, the University of Pittsburg School of Medicine, the American Society of Heating and Ventilating Engineers, etc., was appointed to study the hazards of gases and vapours used in anæsthesia, and this report represents the findings of that Committee. It was found that the oxygen content of ether–oxygen–helium mixtures must be kept below about 16% to eliminate explosion hazards. If strictly non-inflammable mixtures are demanded, the addition of helium to ether–oxygen mixtures presents certain difficulties. Nevertheless, under certain conditions it may be permissible to administer mixtures in which the inflammability is of a mild order, and such mixtures are considered far safer from the explosive point of view than those containing high percentages of oxygen.

Both *cyclo*propane and ether are often used together with oxygen in anæsthesia. The joint effect of two combustible anæsthetics having markedly different oxygen requirements and flame characteristics in combustion with helium is not at present known, but clinical experiments are now being investigated by the authors of this report. Although these experiments are not as yet complete, results so far have been very satisfactory, and indicate that the addition of 5% or more of ether to non-inflammable mixtures of *cyclo*propane–oxygen–helium mixtures in the upper limit range does not bring the mixtures back into the inflammable range. H. B. M.

Motor Fuels.

641. Patents on Motor Fuels. Kodak Ltd. E.P. 543,544, 3.3.42. Appl. 27.5.40. Stabilization of a liquid hydrocarbon motor fuel with N_1N^1-di-(secondary-alkyl)-*p*-phenylenediamine obtained by condensing a *p*-dihydric phenol of the benzene series with a secondary alkyl primary amine containing at least four carbon atoms, and separating from the product a fraction consisting essentially of N_1N^1-di-(secondary-alkyl)-*p*-phenylenediamine.

Standard Oil Development Co. E.P. 543,968, 23.3.42. Appl. 23.2.40. Process for increasing the octane number of a hydrocarbon oil. The oil is subjected to a temperature between 800° and 1100° F. under pressure in the presence of a catalyst and in the presence of a gas containing free hydrogen. The time of treatment is so adjusted in conjunction with temperature, pressure, and partial pressure of the hydrogen that there is no net consumption of free hydrogen. The reaction gases, including the normally gaseous products of the reaction, are recycled in whole or in part to supply the necessary hydrogen-containing gas.

Standard Oil Development Co. E.P. 543,970, 23.3.42. Appl. 13.6.40. Preparation of a motor fuel having an improved road octane rating by catalytically reforming the fractions of a cracked fuel boiling substantially between 192° and 325° F., or the fractions of a virgin naphtha boiling up to 325° F., in the absence of other fractions. The reformed fractions are blended with lighter and/or heavier hydrocarbons to produce a motor fuel having an end-point of about 425° F.

M. W. Kellogg Co. E.P. 544,155, 30.3.42. Appl. 27.9.40. Production of motor fuel having a high anti-knock value, a high percentage of naphthenic compounds, and substantially free of deleterious olefinic compounds from a naphtha fraction boiling within the gasoline range and consisting predominantly of aliphatic hydrocarbons.

Universal Oil Products Co. E.P. 544,336, 9.4.42. Appl. 27.10.39. Conversion of hydrocarbon oils of end boiling point higher than gasoline into large yields of motor fuel of high anti-knock value and substantial yields of normally gaseous, readily polymerizable olefins. The hydrocarbon oils are subjected at a temperature between 425° and 650° C. to contact with a catalytic material consisting of hydrated silica and hydrated zirconia substantially free from alkali metal compounds.

Standard Oil Company. E.P. 544,642, 22.4.42. Appl. 11.9.40. Method of converting a low-knock-rating naphtha into a high-knock-rating motor fuel by passing the former over a non-siliceous catalyst having dehydrogenation and ring-closing properties, in the presence of hydrogen at a temperature between 850° and 1075° F., and a pressure between atmospheric and 450 lb./sq. in., at a space velocity of 0·04–5 vol. of liquid naphtha per volume of catalyst per hour.

D. M. Clark. E.P. 544,729, 24.4.42. Appl. 11.2.41. Method of preparing a fuel composition consisting predominantly of normally fluid, readily inflammable hydrocarbons by adding to the hydrocarbons a sodium soap, not more than limitedly soluble therein, and adapted to congeal the same. Afterwards an organic solvent for the soap and the hydrocarbons is added in amount sufficient to bring them into solution. The solvent boils substantially below the major part of the hydrocarbons. The organic solvent is subsequently removed by distillation and the residual hydrocarbon soap mixture allowed to solidify.

G. H. Cloud. U.S.P. 2,275,175, 3.3.42. Appl. 30.11.39. Preparation of a high-compression spark-ignition motor fuel which consists of gasoline hydrocarbons blended with an octane-number improving amount of 2–15% by volume of a dialkyl phenol wherein a methyl group is one of the positions *ortho* and *meta* to the hydroxy group, and a branched-chain alkyl group containing 3–5 carbon atoms *para* to the hydroxy-group. The dialkyl phenol has a melting point below 40° F. and a boiling point within the range 395–475° F.

F. E. Frey. U.S.P. 2,275,377, 3.3.42. Appl. 2.4.40. Production of motor fuel having a low volatility and a high octane number by reacting alkylation paraffin hydrocarbons of from 3 to 6 carbon atoms per molecule, with olefin hydrocarbons to form paraffin hydrocarbons of a higher number of carbon atoms per molecule than the initial hydrocarbons and in the motor-fuel range. At least part of the effluent of this reaction is passed to the action of a dehydrogenation catalyst to improve the octane number of motor-fuel hydrocarbons, and at the same time to produce olefins lower boiling than motor fuel. From the dehydrogenation effluent a fraction is separated which contains olefins lower boiling than motor fuel. The latter fraction is passed to the alkylation operation.

E. R. Kanhofer. U.S.P. 2,275,441, 10.3.42. Appl. 30.6.39. Production of motor fuel of high anti-knock value and relatively low olefin content by combining olefinic gasoline with a hydrocarbon oil heavier than gasoline and containing a substantial proportion of saturated hydrocarbons. The resultant mixture is subjected to the action of a calcined mixture of precipitated hydrogels of silica, alumina, and zirconia at a temperature between 500° and 800° F. for a sufficiently long time to convert a substantial portion of the heavier oil into gasoline and to effect substantial saturation of gasoline boiling olefins.

J. D. Seguy. U.S.P. 2,276,103, 10.3.42. Appl. 13.9.39. Production of motor and aviation gasolines by subjecting a hydrocarbon oil to thermal cracking treatment in substantially the vapour phase to effect conversion thereof into gas, gasoline, and intermediate products. The intermediate conversion products are returned to the thermal cracking operation; the gasoline is recovered; and the gas separated into a hydrogen methane fraction, a 2- and 3-carbon-atom fraction, and a 4-carbon-atom fraction. The 2- and 3-carbon-atom fraction is subjected, together with residual 4-carbon atom hydrocarbons separated at a later stage, to pyrolytic treatment, and the pyrolytic polymers and gases produced therein are combined with the products of the cracking treatment. The 4-carbon-atom fraction is polymerized to effect substantial polymerization of the olefins to *iso*-octenes and the residual 4-carbon-atom fraction from the polymerization mixed with the 2- and 3-carbon-atom fraction. *iso*-Octenes from the polymerization treatment are hydrogenated with hydrogen from the hydrogen methane fraction and *iso*-octane recovered therefrom.

R. B. Ewell. U.S.P. 2,276,171, 10.3.42. Appl. 30.4.40. Production of more valuable products from volatile-saturated gasoline by fractionating the gasoline to form a light fraction containing normal butane and a heavier fraction containing hexane and higher-boiling hydrocarbons. The light fraction is subjected to dehydrogenation to produce olefins, and the heavier fraction to aromatization to form aromatics. The latter fraction is mixed with at least part of the olefins, and the resultant mixture subjected to alkylation to react olefins with aromatics. Finally the alkylated aromatics are recovered.

A. V. Grosse and C. B. Linn. U.S.P. 2,276,189, 10.3.42. Appl. 31.3.39. Production of hydrocarbons in the gasoline range by reacting a butane with acetylene in the presence of aluminium chloride and hydrogen chloride at a temperature between 0° and 50° C., and under sufficient pressure to maintain a substantial portion of the butane in liquid phase.

H. B. M.

Gas, Diesel and Fuel Oils.

642. Patents on Gas, Diesel and Fuel Oils. Standard Oil Development Co. E.P. 543,669, 9.3.42. Appl. 12.2.40. Method of improving the combustion characteristics of hydrocarbon fuels in high speed compression-ignition engines. An improved diesel fuel is obtained by adding a small proportion of a nitroalkyl nitrate to a hydrocarbon fuel.

Standard Oil Development Co. E.P. 544,417, 13.4.42. Appl. 8.10.40. Preparation of a compression-ignition engine fuel consisting of a hydrocarbon oil boiling above the gasoline range and 0·2–3% of an organic compound containing a five-membered heterocyclic ring containing nitrogen and sulphur.

Standard Oil Development Co. E.P. 544,492, 15.4.42. Appl. 15.10.40. Process for increasing the stability and reducing the tendency to increase in knocking characteristics during storage of compression-ignition fuels consisting of mixtures of hydrocarbons boiling above the gasoline range and ignition promoters. From 0·01 to 0·1% by weight of a stabilizing agent comprising thiazole or thiazoline is incorporated in the fuel.

L. A. Clarke. U.S.P. 2,274,665, 3.3.42. Appl. 11.10.38. Manufacture of a liquid diesel fuel for compression-ignition engines. The fuel contains a small quantity of trichloronitro-methane.

L. A. Clarke, E. F. Pevere and W. N. Meyer. U.S.P. 2,274,666, 3.3.42. Appl. 5.10.40. Preparation of an improved diesel fuel consisting of a hydrocarbon fuel oil and a minor proportion of a compound selected from the group consisting of dichloro-dinitro-methane, dichloro-tetranitro-ethane, and tetrachloro-dinitro-ethane. The addition compound is present in sufficient amount to decrease the ignition delay period of the fuel, improve its cold starting ability, and decrease its tendency to deposit carbon and carbonaceous materials in the motor combustion chamber.
H. B. M.

Lubricants and Lubrication.

643. Patents on Lubricants and Lubrication. P. G. Colin. U.S.P. 2,276,162, 10.3.42. Appl. 17.12.40. Preparation of a mineral lubricating oil consisting of a viscous hydrocarbon oil normally tending to deteriorate in service and a small amount of di-α-naphthylamine to prevent such deterioration.

C. F. Prutton. U.S.P. 2,276,341, 17.3.42. Appl. 21.12.38. Preparation of a lubricating composition consisting of a hydrocarbon oil, 0·1–5% of naphthenate, and a separate halogenated organic compound.

S. E. Jolly and J. H. Perrine. U.S.P. 2,276,492, 17.3.42. Appl. 16.2.40. Preparation of an extreme-pressure lubricant consisting of a lubricating oil and a minor percentage of amyl benzene dichlor phosphine.

A. H. Gleason and W. J. Sparkes. U.S.P. 2,276,956, 17.3.42. Appl. 22.6.40. Preparation of a lubricant consisting of a hydrocarbon oil blended with a minor proportion of a chemically combined addition product of a high-molecular-weight unsaturated polymeric hydrocarbon and an alkyl hypochlorite. H. B. M.

Asphalt and Bitumen.

644. Patents on Asphalt and Bitumen. Standard Oil Development Co. E.P. 543,625, 5.3.42. Appl. 9.10.40. Method of preparation of a cold-laid paving mixture which involves the incorporation of a wetting agent in a mineral flux oil and the addition of powdered brittle asphalt to the flux oil. Thereafter the whole mass is mixed with mineral aggregates.

D. E. Carr. U.S.P. 2,276,155, 10.3.42. Appl. 7.2.39. Production of asphalts having air-blown characteristics by separating an asphalt residuum into an asphaltine fraction, a resin fraction, and an oil fraction. The oil fraction is blended with the asphaltine fraction to produce a composited asphalt which is substantially free from resins. Finally the blend is oxidized.

U. B. Bray. U.S.P. 2,277,842, 31.3.42. Appl. 5.3.38. Production of oxidized asphalt by blending an oil which will oxidize into asphalt with an oil which has been extracted from an asphalt containing oil by means of a solvent capable of dissolving oil, but not substantial quantities of asphalt. The blend of oils is then oxidized at high temperature with an oxygen-containing gas to produce an oxidized asphalt having a higher weather-ometer test than can be produced by oxidation of the original oil.
H. B. M.

Special Products.

645.* Petroleum Rubber. O. W. Wilcox. *World Petroleum*, February 1942, **13** (2), 26.—The history of the developments which have taken place in synthetic rubber production in Germany, Russia, and the U.S.A. is traced, and differences in the methods of approach to the problem are pointed out. Present production in Germany is thought to be about 100,000 tons a year, mainly of Buna S type, the butadiene required being produced via acetylene from carbide. Russian annual production is also reported to be about 100,000 tons, the butadiene being produced from alcohol by passing the vapours over a catalyst of mixed aluminium and zinc oxides at 400° C. With the loss of sugar-beet areas, the Russians may be forced to use carbide or petroleum hydrocarbons as their source of supply in the future. Up to the present, American policy has been to produce synthetic rubbers of special character to meet requirements for which natural rubber was unsuitable, but the present programme involving the manufacture of 400,000 tons a year is expected to be met mainly by production of Buna S. The necessity for increasing recovery of butane from petroleum sources as raw material for butadiene manufacture is therefore stressed. R. A. E.

646. Patents on Special Products. British Thomson-Houston Co., Ltd. E.P. 543,552, 3.3.42. Appl. 5.11.40. Preparation of a mineral electrical insulating oil to which has been added a small quantity of a derivative of the piperazine group in order to improve the non-sludging quality of the oil.

Standard Oil Development Co. E.P. 544,776, 27.4.42. Appl. 22.10.40. Improved process for the catalytic reforming of hydrocarbon oils in the presence of hydrogen and a finely divided catalyst. After separation from the products of the reaction and the hydrogen, part of the catalyst is subjected to regeneration and recycled to the reaction chamber, together with the remainder of unregenerated catalyst.

E. C. Pitzer and L. Heard. U.S.P. 2,274,633, 3.3.42. Appl. 21.2.40. Method of preparing a hydrocarbon conversion catalyst which involves treating amalgamated aluminium with a dilute solution of acetic acid containing chromic acid, and heating the resultant solution. Finally, the product is dried.

F. O. Rice. U.S.P. 2,275,232, 3.3.42. Appl. 1.6.39. Treatment of hydrocarbons capable of thermal decomposition to form olefin hydrocarbons of lower molecular weight. A small proportion of oxygen is mixed with the hydrocarbons at a temperature insufficiently high to effect any reaction of the oxygen with the hydrocarbons. The resultant mixture is heated rapidly in the absence of halogen and halogen compounds to a temperature sufficient to promote decomposition of the hydrocarbons. The oxygen present in the mixture accelerates decomposition. H. B. M.

Detonation and Engines.

647.* Performance of a Converted Petrol Engine on Producer Gas. J. Spiers. *Inst. Aut. Engrs J.*, 1942, **10** (5), 105–128.—A 6-cyl. petrol engine was converted to operate on gas generated in an "Emergency" type producer using anthracite. With the standard 6 : 1 compression ratio the maximum power under the best possible conditions was only 53% of that obtained with petrol; further reduction, which occurred as the charge of fuel was consumed, was not entirely compensated by advancing the ignition. For mechancial reasons the compression ratio could only be increased to 7 : 1; this raised the maximum power to 61% of the original maximum on petrol. At the higher compression the original power could be recovered by using 72–84% of the original consumption of petrol. It appears that high compression ratio, with petrol assistance when maximum power is needed, offers the best solution to the problem of power recovery. Cylinder wear was high, and it is concluded that gas filtration will have to be much improved. Lubricating oil viscosity showed a marked tendency to increase with use. K. A.

Coal and Shale.

648. Patent on Coal and Shale. E. H. Records and J. E. Louttit. U.S.P. 2,276,342, 17.3.42. Appl. 18.10.37. Process of recovering hydrocarbon oils and gases from oil-shale by enclosing a mass of shale in a reaction retort upon a base of coal, then passing steam through the coal and oil shale to effect decomposition. The operation is carried out in such a manner that decomposition products from the coal pass through the mass of oil-shale. H. B. M.

Statistics.

649.* World Production for 1941 up by 4·68%. Anon. *World Petrol.*, February 1942, **13** (2), 37.—In 1941 the U.S.A. oil production was 1,405,830,000 brl., 3·89% above the 1940 figure. Oklahoma the Eastern area, and Illinois showed declines in output, while Texas, Kansas, and Louisiana showed increases. The South American production of 304,918,000 brl. was 38,092,000 brl. higher than in 1940. Venezuela alone accounted for this rise. There were declines in production in Peru and Colombia in 1941, whereas Argentina had a slight rise. Official figures are lacking for Trinidad.

For the rest of the world estimates alone are available, and Zavoico is of the opinion that Russia showed an increase in output in 1941, while all the other European countries experienced decreases. A decrease of 5·72% is estimated for the Middle and Far East. G. D. H.

INSTITUTE NOTES.

JULY, 1942.

CHANGE OF THE INSTITUTE'S ADDRESS.

The offices of the Institute have been transferred from the University of Birmingham to the Imperial College of Science and Technology, London, S.W.7.

All communications should be addressed to :

THE SECRETARY, THE INSTITUTE OF PETROLEUM,
c/o The Imperial College of Science and Technology,
Prince Consort Road, LONDON, S.W.7.

Telephone: Kensington 9572.

BACK ISSUES OF JOURNAL.

In view of the scarcity of many back issues of the *Journal*, the Council feels that it would be advantageous to have on record details of complete sets from 1914 onwards. It would be helpful, therefore, if members possessing such sets would send particulars to the Secretary, for private record purposes only. Similarly, it would be appreciated if members who are considering the disposal of back volumes or separate parts of the *Journal*, either for sale or salvage, would first send details to the Secretary.

HONOURS.

FREDERICK GODBER, ESQ. (Fellow), was created a Knight Bachelor in the Birthday Honours List of June 11th, 1942. Sir Frederick Godber is Chairman of the Overseas Supply Committee of the Petroleum Board.

PERSONAL

Dr. F. H. GARNER (Vice-President), has been appointed Professor of Petroleum Technology of the University of Birmingham, in succession to the late Prof. A. W. Nash.

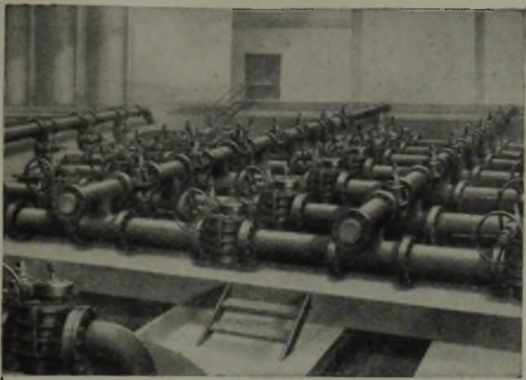
Mr. JAMES KEWLEY (Past-President) has been awarded the Silver Medal of the Royal Society of Arts for his recent paper on "The Evolution in the Petroleum Industry."

Dr. A. E. DUNSTAN (Past President) is President of the British Association of Chemists.

Dr. G. EGLOFF is President of the American Institute of Chemists.

ARTHUR W. EASTLAKE,
ASHLEY CARTER,
Joint Honorary Secretaries.

NEWMAN-MILLIKEN GLANDLESS LUBRICATED PLUG VALVES ON AN OIL DISTRIBUTION MANIFOLD



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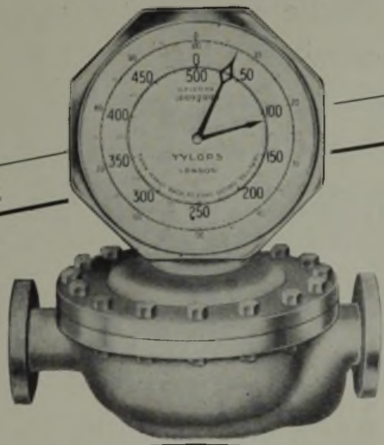

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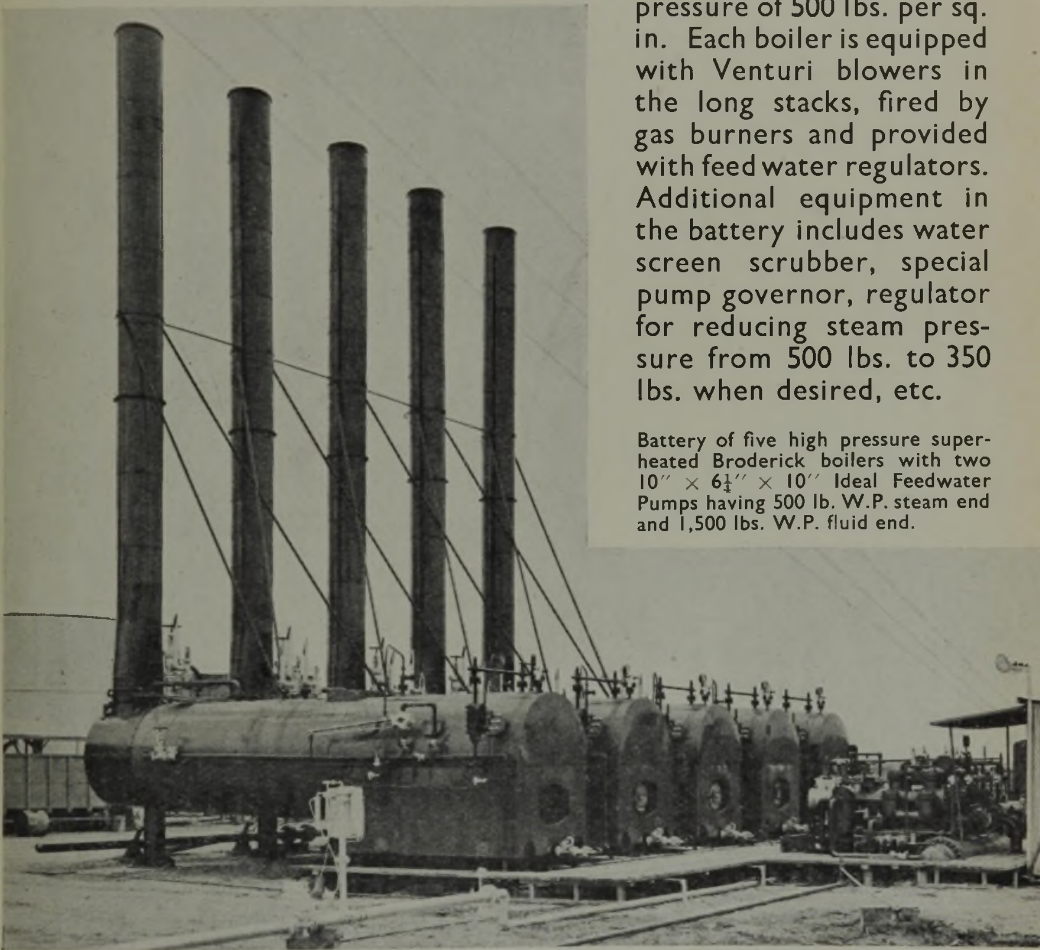
NATIONAL DRILLING BOILERS

The heaviest rotary rig ever constructed, and now being used by the Superior Oil Co. at Rio Bravo, California, is operated by an exceptional boiler installation.

These are National Broderick Boilers, superheated, of 130 h.p. each and for a steam working pressure of 500 lbs. per sq. in. Each boiler is equipped with Venturi blowers in the long stacks, fired by gas burners and provided with feed water regulators. Additional equipment in the battery includes water screen scrubber, special pump governor, regulator for reducing steam pressure from 500 lbs. to 350 lbs. when desired, etc.



Battery of five high pressure superheated Broderick boilers with two 10″ × 6¼″ × 10″ Ideal Feedwater Pumps having 500 lb. W.P. steam end and 1,500 lbs. W.P. fluid end.

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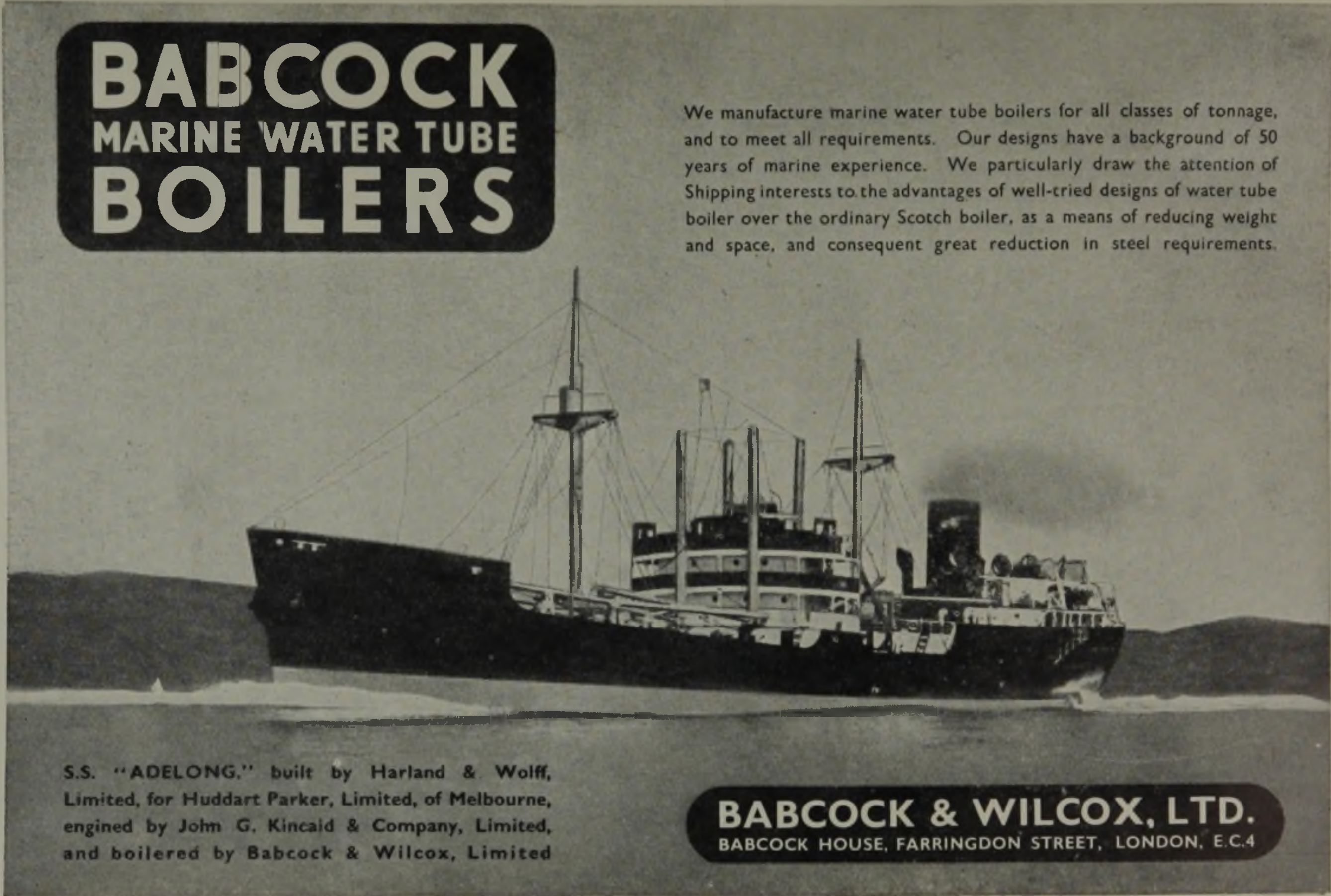
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You can save valuable time coming out of the hole with drill pipe, tubing or casing, when your rig is equipped with a "Cardwell" five-speed, even-ratio transmission. The even-ratio gear changes permit quicker step-up to a faster gear as the load lightens. It is possible to shift into second and third while the ordinary four-speed, truck-type transmission is "lugging" in low.

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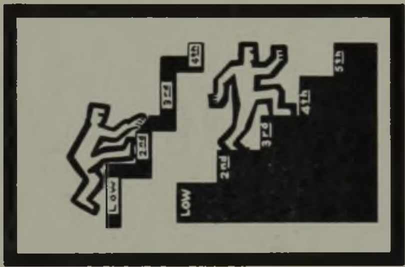
When running the drill pipe or tubing back into the hole, a single lever shift into low enables the load to be quickly picked up off the slips for lowering in. Another quick single lever shift from low to high "runs-up" the empty block after setting the slips.

RESULT — more time saved

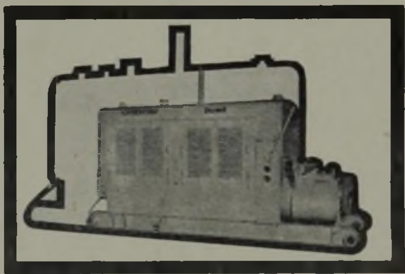


EVEN STEPS REDUCE PULLING TIME

SMALL ENGINE GIVES THE SAME SPEED AS A LARGER ENGINE

A 250 HP engine equipped with a "Cardwell" five-speed, even-ratio transmission will give the same operating speed as a 300 HP engine equipped with the usual transmission arrangement.

RESULTS — the smaller engine saves on first cost, maintenance expense and transportation costs



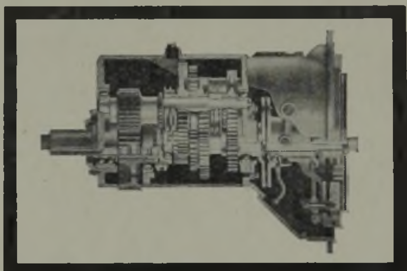
YOUR OPERATING SPEED IS AUTOMATICALLY 20% FASTER

THE VALUE OF A CONSTANT GEAR MESH TRANSMISSION

How much has transmission breakage cost you during the past two years? A major oil company operating in West Texas reports no repairs or trouble of any kind with the "Cardwell" five-speed, even-ratio transmission mounted on their "Cardwell" spudder rig, after two years constant operation.

This transmission is designed so that all gears are in constant mesh and are selected by sliding gear tooth collars, eliminating the partial gear tooth engagement that causes so many breakdowns. Stub tooth spur gears are used to give heavy load-carrying and shock-resisting capacities

RESULTS — the hazard of a lost string of tools, stuck drill pipe or a fishing job due to transmission breakage is greatly reduced



1,400 FOOT-POUND TORQUE CAPACITY

Only "Cardwell" builds a five-speed and reverse, even-ratio gear type transmission with a torque capacity of 1,400 foot-pounds at 1,000 RPM, or the equivalent of 265 HP

CARDWELL ALL STEEL — THIS TRADE MARK INSURES HIGHEST QUALITY AT LOWEST PRICE

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