Spe 734

SUCKER ROD PUMPING

The Role of Two-Speed Motors In Lifting Heavy Oil

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Abstract

During the past few years, the use of two-speed electric motors has been applied to sucker-rod pumping for lifting high volumes of heavy, viscous crude in Venezuela's Lake Maracaibo area. The crude involved ranges from 12°-15° API gravity, is very viscous and contains considerable entrained gas that is highly resistant to separation.

Lifting maximum rates (1,500-3,000 BOPD) of this oil presents many and varied problems. The major problems encountered in pumping high volumes of the heavy oil are motor sizing, rod fall and low pumping efficiencies due to the entrained gas. Extensive field studies have shown that under single-speed motor operation, approximately twice the normal operating horsepower is required to provide the necessary start-up torque under dead oil, or start-up conditions. This leads to improper motor utilization, lower efficiencies and lower power factors throughout the entire electrical system.

Pumping speeds are also limited, under single-speed operation, to approximately 75 per cent of normal desired speeds due to rod fall limitations encountered upon start-up under dead oil conditions. This, in turn, aggravates the low efficiency problem of pumping viscous oil containing entrained gas, resulting in an over-all decreased producing rate.

Under two-speed motor operation, constant horsepower, single winding, squirrel cage induction motors have been utilized to overcome or greatly relieve these problems in the Lake Maracaibo operation. These motors have met with very satisfactory results by permitting start up at half speed, thus providing considerably more starting torque when most needed. After displacing the dead, thick oil from the well tubing and flow line, the pumping speed is automatically increased to twice the start-up speed and normal operating speeds are achieved. The utilization of the two-speed pumping motor has resulted in approximately a 50 per cent reduction in motor sizes required, reduced cable sizes necessary for the higher hp motors previously required, and has increased the efficiency of the electrical system since the two-speed motor is essentially fully loaded (85-95 per cent) at all times. These motors have also enabled pumping speeds to be increased approximately 30 per cent with corresponding increases in producing rates.

Introduction

In the Bolivar Coastal fields of Western Venezuela's Lake Maracaibo region, one of the largest producing reservoirs is the Bachaquero-2 heavy oil reservoir. The crude produced from the B-2 reservoir, as it is commonly called, is a low gravity (12°-16° API) asphaltic oil with viscosities ranging from 5,000-15,000 SSU at 85 F. One of the big problems involved in producing this reservoir is that of maintaining high producing rates in areas of declining bottom-hole pressure, by artificial lift methods. Since the wells are located in Lake Maracaibo and the area is completely electrified, the most common method of artificial lift is the use of sucker-rod pumps with pumping units powered by electric motors. To date, rates of 1,300-3,000 BOPD/well have been achieved by this method, utilizing standard equipment. The present average production from 179 pumping wells in the field is 400 BOPD/well with 62 high volume pumping installations averaging 700 BOPD/well.

Due to the physical characteristics of this viscous, low gravity crude, three major problems must be overcome to achieve highpumping rates from the wells: (1) low pump efficiency, (2) rod-fall limitations, and (3) motor utilization and sizing.

Pumping Efficiency

The oil produced from the B-2 reservoir, aside from its low gravity viscous nature, is best described as containing a homogeneous entrainment of gas which results in a low density mixture that is extremely resistant to separation. Extensive studies on pumping wells in the field have shown that due to the effect of the entrained gas, the maximum pump efficiency is 40-50 per cent for wells having a gas-oil ratio above 150 scf/bbl (Fig. 1). This means that to achieve the desired pumping rates from the wells, the pumping installation has to be designed with a 40-50 per cent pump efficiency factor being considered, or approximately twice the size that would normally be required to pump an equivalent volume of fluid having a density similar to water.

Rod Fall Limitations

Since the density of the fluid being pumped changes from start-up conditions to normal operating conditions, varying from "dead" oil conditions (58-61 lb/cu ft) to "live" oil conditions (32-39 lb/cu ft), another

Original manuscript received in Society of Petroleum Engineers office Aug. 5, 1963. Paper presented at the SPE Fall Meeting in New Orleans, Oct. 6-9, 1963.

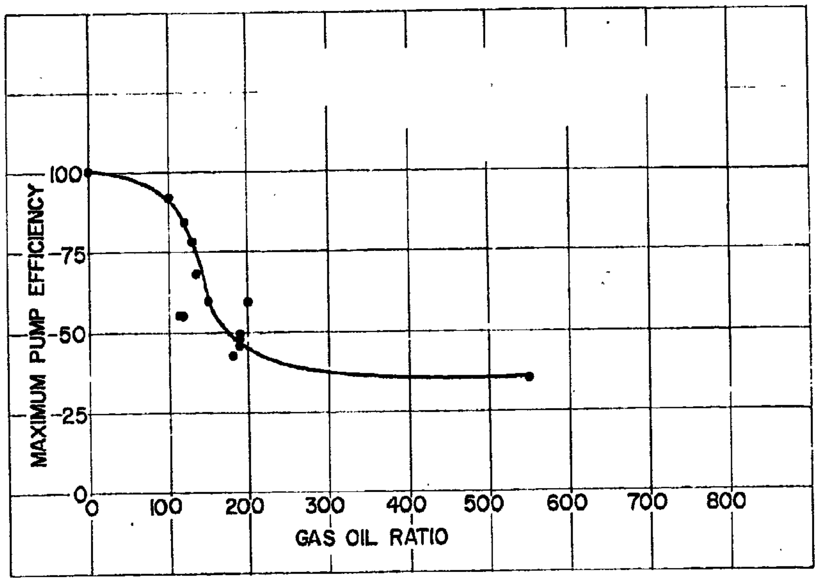

Fig. 1—Maximum possible pump efficiency, effect of GOR on well fluid gradient.

problem is introduced. When the pumping unit is intially started with well control fluid in the tubing, or after a sustained shut-down period during which the gas has been partially released from the live oil, pumping speeds have to be reduced some 30 per cent to avoid rod fall problems while starting the unit. This further reduces the desired producing rates since the well cannot be pumped at design speed until the dead oil is displaced from the tubing by the lighter, live oil containing a higher percentage of entrained gas. The faster pumping speed could, of course, be attained by making a sheave change on the motor after start-up is achieved and live oil pumping conditions are attained. However, changing sheaves has not been a satisfactory answer to the problem due to the difficulties that are encountered in the event of a power failure or other general shutdown, considering a lake operation where a large number of wells is involved.

Theory and Definitions

Prior to 1959, the majority of the pumping installations in the B-2 reservoir were utilizing 25-50 hp electric motors with NEMA C (High Torque-Normal Slip) design standards, giving an available starting torque of 200-250 per cent of full load running torque and less than 5 per cent slip. As bottom-hole pressures declined in the wells, more wells required artificial producing aids to achieve the higher rates expected from the reservoir, and larger pumping installations were required. In the latter part of 1958, field studies were initiated to determine the adequacy of the entire pumping system, i.e., the subsurface pump and rods, the pumping unit, the electric motor and the electrical distribution system. As a result of these studies it was concluded that the motors being used and the electrical distribution system in use at that time would not properly handle the proposed program for lifting high volumes of this viscous crude. The higher horsepower (60-150 hp) motor installations encountered low voltage problems due to long runs of submarine electrical cable, start-up difficulties, and excessive fuse blow-outs due to long acceleration times when starting the pumping units.

The studies pointed out that motors for pumping large volumes of this crude must be designed to provide the required starting torque and pumping horsepower under dead oil conditions. However, once the unit is started and the dead oil is displaced from the well tubing and flow line, the motors are generally only 40-50 per cent loaded in terms of permissible motor current capacity. Basically then, a single speed NEMA C motor generally has to be twice as large as is required to pump the well under normal live oil pumping conditions in order to get the pumping installation started (Table 1). The larger motors also required parallel runs of electric cable, or the use of larger cable to minimize the voltage drop; both of which resulted in increased investment costs. As a result of field measurements, well tests, acoustical well sounder surveys and dynamometer surveys, the problem was found to be a result of improper motor utilization and inadequate electrical distribution facilities, at least in the portion of the reservoir requiring high volume pumping installations. While the need for better voltage controls was indicated, this factor alone could not solve the other problems associated with lifting high volumes of the viscous oil containing entrained gas, i.e., low pump efficiency, rod-fall problems, and high starting torque requirements.

Under practical field conditions, the polished rod torque requirements were found to be approximately 400-500 per cent (at start-up) of the motor torque actually required under live oil pumping conditions. Utilizing NEMA D single-speed motors with approximately 275 per cent starting torque characteristics and 5-8 per cent slip characteristics relieved the problems somewhat, but the installations still required oversized motors resulting in poor motor utilization. Also, slower

TABLE I—MOTOR SELECTION—B-2 RESERVOIR

Theoretical or Calculated Polished Rod Horsepower (Pumping Water)	Installed Motor Size (Former Practice — NEMA C Motors), Suitable for Dead Oil Start Up	Typical Motor Size (NEMA C) Actually Required — (Live Oil Pumping Only — Not Start up)	Motor Size and Type (Present Practice) Suitable for Dead Oil Start Up	
			NEMA C Single Speed	NEMA D — Two Speed (Start Up at Half Speed)
6 hp	15 hp	7.5 hp	10 hp	7.5 hp
8	20	10	15	10
10	25	15	20	15
12	30	15	25	15
15	40	20	30	20
20	50	25	40	25
25	60	30	50	30
30	75	40	60	40
40	100	50	75	50
50	125	60	100	60
60	150	75	125	75
80	200	100	150	100
100	250	125	200	125

1. Use of NEMA D motors will permit next smaller size motor to be used compared to practice of using NEMA C motors.

2 Use of NEMA D two-speed motors allows a reduction of two motor sizes (45 to 50 per cent smaller) compared to practice of using NEMA C motors.

than desired pumping speeds were ncessary, due to the varying density of the crude from start-up to live oil pumping conditions.

To further explain the improper motor utilization and slower pumping speeds, the normal running torque during the live oil pumping cycle is represented by "T". Our field studies have shown that some 400 per cent of normal running torque, or 4T, is required for start-up. Utilizing a NEMA C design motor with approximately 200 per cent starting torque characteristics at constant speed, it can be seen that a motor with twice the starting torque characteristics or 400 per cent (4T) is required. In former installations, this was achieved by installing a NEMA C motor with approximately twice the horsepower normally required in order to provide minimum starting torque characteristics (4T) as indicated in Table 1. This resulted in a motor utilization, when pumping under normal live oil conditions, of approximately 50 per cent.

Using NEMA D single-speed motors, a motor size of approximately 1.7 times that required for normal live oil pumping was needed to supply the necessary torque characteristics for start-up under dead oil conditions. Utilizing either motor, NEMA C or NEMA D, after the unit is started and the well begins to produce lower density fluid, as flow lines become warmer and pumping oil viscosity is somewhat lower, the oversized motor is no longer required and the installation is therefore essentially overdesigned as to horsepower requirements.

Since the electric induction motor, as used for oil well pumping, is at its peak efficiency and power factor when fully loaded, it may be readily seen that improper motor utilization or, as in the case of the B-2 wells, oversized motors can cause many operating problems. Reduced power factors, poor electrical efficiency, low motor efficiency, high voltage drops in cable runs during start up, which in turn result in motor overheating and losses of starting torque, are only a few of the major problems caused by improper motor selection when pumping heavy, viscous crude such as that produced by the Bachaquero-2 reservoir.

It should also be pointed out that the elapsed time interval from dead oil pumping conditions to live oil conditions varies from 45 minutes to four hours depending on the size of the installation and individual well conditions. It is during this critical period that rod-fall problems, high polished rod loads, and greater torque requirements (up to 200 per cent of normal) are encountered.

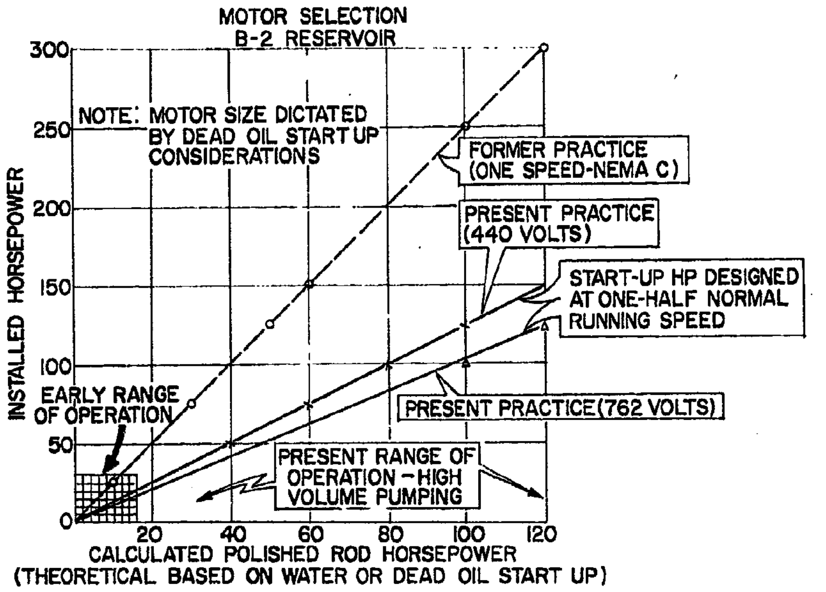

Fig. 2—Motor selection, B2 reservoir.

Based on field studies and corresponding analyses of the various problems, it was concluded that pumping unit motors in the B-2 heavy oil area should be sized under dead oil conditions for start-up at one-half the desired normal running speed based on permissible motor current capacity (Fig. 2). Due to the severe starting torque requirements, it was obvious that the unit could never be started at the higher, desired running speed

TABLE 2—MOTOR SELECTION—HIGH VOLUME AREA

Former Practice	Present Practice
NEMA C motors—Single Speed 440/480—4/0 or equivalent cable.	NEMA D—Two-Speed Motors—440/480v—4/0 or equivalent cable.
Actual installed horsepower per 1000 B/D of gauged oil—90-100 hp.	Actual installed horsepower per 1,000 B/D of gauged oil—35-40 hp.
(This horsepower is generally required for start up and the first 30-45 minutes of dead oil pumping.)	(Start up and dead oil pumping is being done at half speed.)
Required motor size per 1000 B/D or gauged (live oil pumping) 45 to 55 hp.	Required motor size per 1,000 B/D of gauged oil (live oil pumping) 35 to 45 hp.
Average motor utilization based on thermal current (I-thermal/I-rated) is less than 50 per cent.	Estimated average motor utilization based on thermal current is 85 to 95 per cent.
Electric Power Requirements. 50 kva per 1000 B/D 0.5 kva per hp installed	Electric Power Requirements. 45 kva per 1,000 B/D 1 kva per hp installed
Typical Installations. (1) 2,500 to 3,000 ft pump depth (2) 9-12 SPM—120 in. stroke (3) 3 in. pumps (Nominal) (4) 650-750 B/D (gauged oil) (5) 75 hp/well (6) 4600 ft of two 1/0 cables Would require 150 hp for 1,300 to 1,500 B/D.	Present Installations. (1) 3,000 to 3,500 ft (2) 12-14 SPM—144 in. stroke (3) 4 in. pumps (Nominal) (4) 1,500 to 1,650 B/D (gauged oil) (5) 75 hp/well (6) 4,600 ft of two 1/0 cables or one 4/0 cable. Would require 40 hp for 650 to 750 B/D.
Extra High Volume Installations. (Typical) (1) 2600 ft pump depth (2) 5 in. pump (Nominal) (3) 8-10 SPM—192 in. stroke (4) 1,650-2,000 B/D (gauged oil) (5) 150 hp (Would require 250 to 300 hp for 2,500-3,000 B/D)	Extra High Volume Installations. (1) Pump depth 3,000-3,500 ft. (2) 5 in. pump (Nominal) (3) 10-12 SPM—192 in. stroke (4) 2,500 to 3,000 B/D (5) 150 hp (Would require 75 hp for 1,650 to 2,000 B/D)

without oversizing the motors to approximately twice the size required at that speed. It was therefore indicated that some type of two-speed operation would be required to provide the necessary 400-500 per cent starting torque, maintain a running torque of 200 per cent of the final desired running torque for periods up to four hours, and provide a slower speed during this period to eliminate rod-fall problems, while maintaining a constant horsepower at both speeds.

These characteristics are all available with two-speed, constant horsepower electric motors. If the pumping installation is started at one-half normal operating speed with a two-speed NEMA D constant horsepower motor, approximately twice the motor starting torque is available, or some 500 per cent of normal running torque at the higher speed. After start-up and during the critical "warm-up" period, the available running torque is twice (200 per cent) that of the higher speed running torque. Also, by starting the units at one-half the normal running speed, rod-fall problems in the heavy oil have been virtually eliminated. Normal running speeds are increased some 25-30 per cent over single speed operation, thus increasing producing rates by a corresponding amount (Table 2).

Description of Equipment

To date, forty-three 900/1,800 rpm, constant horsepower, single winding, squirrel cage, two-speed induction motors have been installed in the Bachaquero-2 heavy oil reservoir in Creole's Western Division Lake Maracaibo area of Venezuela. Controls and cabinets for these installations are so designed that they will start up automatically on low speed after being shut down either manually or from a power failure on the lake. Time controllers then automatically change the unit to high speed operation after one to four hours, depending on individual

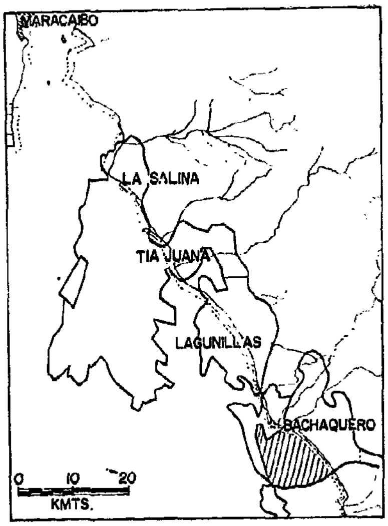

Fig. 3—Map of Bolivar Coastal field.

well conditions and controller settings. These installations have been very satisfactory thus far and have greatly reduced operating problems previously encountered in pumping high volumes of heavy oil.

Installation of these two-speed motors coupled with higher voltage (831v) distribution substations, which have been installed in areas where the higher volume pumping installations are located, have greatly increased the electrical distribution coverage, reduced the size of cable runs, eliminated the necessity of double runs of smaller submarine cable, and eliminated the need for individual 440v transformers on well platforms that previously handled only a few wells in a small area.

The cost of the two-speed motors and controls is approximately twice that of equivalent size single-speed motors and controls. However, since the motor size requirement is essentially cut in half through the use of the two-speed motor, the net motor investment is approximately the same. The improved motor efficiency, reduced electrical distribution costs, and increased production rates, however, have made the application very attractive from an economic standpoint as well as improving the efficiency of the pumping operations in the entire heavy oil area.

Conclusions

1. The use of two-speed motors for pumping heavy, viscous oil containing entrained gas can improve pumping rates and efficiencies some 30 per cent, if properly applied.

2. Substantial capital investment and operating expense reductions have been realized through the application of two-speed motors in pumping heavy oil.

3. Rod-fall problems have been virtually eliminated by starting the heavy oil pump installations at one-half normal operating speeds.

4. Electrical distribution efficiency has been increased through proper motor utilization and reduced voltage drop in distribution lines.

5. The use of two-speed pumping motors in other producing regions may be applicable where severe start-up problems exist such as, (a) pumping through long flow lines, (b) pumping viscous oil, and (c) in colder climates where units are hard to start after prolonged shut-down.

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