ELECTRICAL AND MECHANICAL PERFORMANCE OF BEAM PUMPING SYSTEMS IN THE PERMIAN BASIN OF TEXAS

by

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ABSTRACT

An extensive electrical and mechanical testing program has been performed on beam pumping systems in six producing properties in the Permian Basin of Texas. The subject properties are waterflood or carbon dioxide (CO_2) flood projects which produce from the San Andres formation. The effect of motor torque mode setting and direction of rotation was studied in 30 wells. The impact on important operational indicators such as electrical lifting cost, gear box loading, and rod loading are addressed.

It should be noted that much of the data used in this paper was the subject of a paper entitled "Application of Real-Time Measurement of Motor Power to Determination of Beam Pump Efficiency" which was presented at the 1994 Southwestern Petroleum Short Course. Because more data has since been obtained, the conclusions below are more statistically significant.

INTRODUCTION

Electrical efficiency in oil and gas producing operations has become an important issue as energy companies have placed increasing emphasis on expense reduction. Beam pumping systems can be a major contributor to the electrical bill of an oil producing property. In the six properties which were studied in this paper, beam pumping systems account for 50% to 75% of the total electrical consumption.

The properties which are the subject of this paper include:

Mallet Unit (Cochran and Hockley Counties, CO2 flood)
East Mallet Unit (Cochran County, CO2 flood)
Maple Wilson (Hockley County, waterflood)
H.O. Mahoney (Yoakum County, CO2 flood)
East Seminole San Andres Unit (Gaines County, waterflood)
Lindoss Unit (Gaines County, waterflood)

The predominant form of artificial lift is beam pumping systems with pump depths between 4800' and 5400'. Liquid production rates range from <50 BPD to 600 BPD. The majority of the pumping units in these fields are conventional geometry units powered by size C or D ultra high slip (UHS) electric motors. Most rod strings are tapered steel strings; however, some fiberglass strings are installed.

Initially, the primary purpose of this study was to analyze system electrical performance in a variety of operating conditions. As the study progressed, it became obvious that electrical performance could be improved to the detriment of key mechanical parameters. Therefore, the work was expanded to study mechanical performance.

METHODOLOGY

Each of the 30 producing wells was tested in six different operating conditions - three motor torque modes (low, medium, and high) with both directions of rotation (clockwise and counterclockwise). Surface dynamometer data and instantaneous electrical data were obtained for the six test cases for each well.

Time required to obtain data for all six cases for each well was approximately four hours. After each change in torque mode and/or rotation, the well was allowed to stabilize for approximately ten minutes before more data was acquired. Fluid levels and casing pressures were obtained prior to each case to assure that no significant change in producing pump intake pressure had occurred. Instantaneous electrical data was measured at least twice to assure repeatability. The short testing period maximized the chance of comparing "apples to apples" since changes in operating conditions were not allowed to occur.

After the field data was obtained, downhole performance was quantified through computer dynamometer analysis. Two different software programs were utilized. The measured and calculated dynamometer and electrical data was then input into a spreadsheet so that composite operational efficiencies and parameters could be calculated.

DISCUSSION OF RESULTS

Electrical Performance - Motor Torque Modes

Electrical performance was evaluated utilizing three lifting efficiency indicators: kilowatt-hours (KWH) per barrel lifted; KWH per 1000 strokes; and surface efficiency. The denominator of KWH per barrel lifted represents net pump displacement of the system and was determined from downhole dynamometer analysis. Surface efficiency is the ratio of polished rod power to motor input power and is a measure of power losses in the motor, belts, and pumping unit.[1]

Table 1 lists the three lifting efficiency indicators for each motor torque mode/rotation combination. All efficiency indicators are presented as composite numbers for the 30 wells tested. The data indicates that the high torque mode is the most electrically cost-effective mode of operation. The low torque mode is the least cost-effective mode. This result is not surprising since the higher torque mode has a greater motor efficiency than the lower modes for the same motor (see Figure 1). Motor efficiency is defined as the ratio of motor output power to motor input power. The reduced motor efficiency in the lower torque modes is due primarily to higher speed variation. UHS motor manufacturers have advertised that the lower torque mode can overcome lower motor efficiency by lifting more fluid per stroke. This may be true for some installations; however, data from the six subject properties indicates otherwise.

In examining Figure 1, one might be misled into believing that the torque mode with the highest peak motor efficiency is the most efficient mode of operation. This is not necessarily true. Since motor loads are constantly changing throughout a stroke, motor efficiency is also constantly changing. A given torque mode may spend more time in low efficiency operation than another torque mode and still have a higher peak efficiency. The result of more time spent in low efficiency operation may be a lower average motor efficiency through the stroke. Average motor efficiency through a stroke is the stroke average motor output power divided by the stroke average motor input power.

KWH per 1000 strokes is a good indicator of lifting efficiency and is very easy to obtain since dynamometer data is not needed. Instantaneous electrical data and pumping speed are the only measurements needed and can be obtained in minutes. This indicator can be very useful in benchmarking beam pumping installations in entire fields. However, one should be cautious when using the KWH per 1000 strokes indicator on installations with fiberglass strings. Increased elasticity of fiberglass strings complicate the problem to the point that dynamometer data and analysis are recommended. Also, installations with different stroke lengths should not be benchmarked together as the longer stroke length wells will usually have a higher KWH per 1000 strokes.

Table 1 also shows the composite thermal current for each torque mode/rotation combination. Thermal current (also referred to as RMS current) is defined as the square root of the average of the squared currents over a pump cycle and is a measure of motor heat losses.[2] For a given motor and load, thermal current increases as torque mode increases. Higher thermal current can be detrimental to electrical performance upstream of the motor due to electrical line losses. The magnitude of line losses is a function of current and size and type of conductor. Line losses can completely offset savings resulting from high motor efficiencies in the higher torque modes. One can get a qualitative indication of line loss magnitude by measuring voltage variation during a pumping stroke. Significant voltage variation is an indication of significant line losses. Voltage variation measurements can easily be taken on each well on a given property to determine potential problem wells. Line losses can also be estimated using computer simulations and/or published data from conductor manufacturers.

It is interesting to note that electrical lifting performance at the motor gets worse as percent motor loading increases. Percent motor loading is the ratio of thermal current to motor nameplate current rating (each torque mode of a motor has a different nameplate current rating). Contrary to this data, conventional wisdom indicates that electrical lifting efficiency should improve as percent motor loading approaches 100%. A possible explanation for this discrepancy is that efficiency improvements resulting from increased percent motor loading in the lower torque modes are offset by lower motor efficiencies.

Comparison of Size C and Size D Motors

The two types of UHS motors tested in this study were 40 HP size C and 75 HP size D motors. Composite analyses were performed for both motors. There were 12 size C motor installations and 17 size D motor installations. Composite data for both motor sizes is found in Tables 2 and 3. It should be noted that this comparison is not "apples to apples" since different wells were involved for each motor type; however, some interesting observations exist.

The size C motors exhibit a wider range of electrical lifting efficiency from low to high torque mode. For example, KWH per barrel lifted in the low torque/counterclockwise (CCW) case is 42% higher than the high torque/CCW case for the size C motors while low torque/CCW is only 15% higher than high torque/CCW for the size D motors. This indicates that the difference in motor efficiency between low and high torque modes is less with the size D motors than the size C motors.

The size D motors required less thermal current per polished rod horsepower than the size C motors. Size D motors averaged 2.2 thermal amps per polished rod horsepower while size C motors required 2.4. The size D motors also exhibited greater surface efficiency. However, higher thermal current with size D motors will increase the magnitude of electric line losses which may offset the benefit of higher surface efficiency.

Electrical Performance - Direction of Rotation

A composite comparison of all clockwise (CW) and counterclockwise (CCW) cases is presented in Table 4.

Composite KWH per barrel lifted, KWH per 1000 strokes, and surface efficiency are essentially identical for both rotations.

The only notable difference in electrical performance is that the CCW rotation required more thermal amps per polished rod horsepower than the CW rotation. This indicates a greater tendency for line losses upstream of the motor in the CCW rotation.

Mechanical Performance - Motor Torque Modes

Mechanical performance was evaluated utilizing two parameters: gear box torque and rod loading.

A key advantage of UHS motors over other types of oil field motors is decreased gear box loading and rod loading. Increased speed variation of UHS motors is the main reason for improved loading characteristics. UHS motor speed will decrease as unit loading increases and will increase as unit loading decreases. Since motor and, therefore, pumping unit speed are decreased during periods of high load, gear box torque peaks are reduced. High speed variation will also decrease peak polished load and increase minimum polished rod load thus improving rod loading characteristics.

Table 1 illustrates that gear box torque generally increases with higher torque modes. This is the expected result since speed variation decreases with higher torque mode. Higher gear box loading in the high torque modes is partially the result of increased pumping speeds.

Percent of allowable rod stress also increases with higher torque modes. Again, higher pumping speed in the higher torque mode is partially responsible for higher rod loading.

Mechanical Performance - Direction of Rotation

Table 4 shows that composite gear box loading and rod loading are higher with the CW direction of rotation. Composite pumping speeds are almost identical for both rotations.

THE BALANCING ACT

When engineering motor torque mode and direction of rotation for a given installation, the operator has many choices. Changing torque mode may improve one operational parameter to the detriment of another. For example, the high torque mode will result in a greater surface efficiency than the low torque mode but electrical line losses and/or gear box loading may increase.

The data presented in this paper provides a guideline for wells with characteristics similar to those analyzed in this study. Unfortunately, there is not a "one size fits all" answer. Each field must be evaluated individually before operational changes can be confidently modified.

CONCLUSIONS

1) The following conclusions should not be used as a "one size fits all" recipe for efficient beam pumping. Many beam pumping installations have characteristics which set them apart from installations studied in this paper. For example, improved geometry units were not tested and the conclusions of this paper should not be applied to improved geometry units. To understand installations on a given property, one should measure and analyze several installations on that property.

2) On a per barrel lifted basis, UHS motors are more electrically efficient in the higher motor torque modes. Thermal current increases in the higher torque modes. Higher thermal current may cause excessive electrical line losses upstream of the motor thereby offsetting the benefits of high motor efficiency.

3) KWH per stroke is a good indicator of beam pumping electrical efficiency and is easy to obtain since dynamometer data is not needed. When benchmarking installations using KWH per stroke, installations with similar stroke lengths should be compared.

4) The difference in electrical lifting efficiency from low to high torque mode was greater on installations with size C motors than those with size D motors. The size D motors had a smaller difference in motor efficiency from low to high torque mode.

5) Direction of rotation had little effect on electrical lifting efficiency.

6) Lower torque mode cases had lower unit gear box and rod loading. Increased speed variation and decreased pumping speed in the lower torque modes influenced this result.

7) The CCW rotation had lower gear box and rod loading than the CW rotation.

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Table 1
Composite Results for all Cases

MOT TORQ MODE	DIR OF ROT	SPM	KWH/ BFL	KWH/ 1000 STR	SURF EFF %	THER CURR AMPS	% MOT LOAD	POL ROD HP	THER AMPS/ PRHP	% GEAR BOX TORQ RTG	MAX % ROD STR RTG
LOW	CCW	8.25	1.58	38.9	62	34	86	15.9	2.2	90	78
LOW	CW	8.31	1.56	38.0	64	31	78	16.2	1.9	95	83
MED	CCW	8.97	1.48	37.3	69	42	77	18.6	2.3	98	83
MED	CW	9.00	1.47	36.5	70	40	72	18.4	2.1	100	87
HIGH	CCW	9.25	1.30	33.7	75	49	68	19.5	2.5	97	83
HIGH	CW	9.25	1.33	34.1	74	47	65	19.5	2.4	100	88

Table 2
Composite Results for Size C UHS Motors

MOT TORQ MODE	DIR OF ROT	SPM	KWH/ BFL	KWH/ 1000 STR	SURF EFF %	THER CURR AMPS	% MOT LOAD	POL ROD HP	THER AMPS/ PRHP	% GEAR BOX TORQ RTG	MAX % ROD STR RTG
LOW	CCW	7.61	1.49	29.4	58	22	82	10.1	2.2	89	70
LOW	CW	7.65	1.46	28.8	61	20	76	10.3	2.0	95	77
MED	CCW	8.58	1.32	26.8	66	29	76	11.8	2.4	99	75
MED	CW	8.59	1.29	25.9	70	27	71	11.8	2.2	101	79
HIGH	CCW	8.93	1.05	21.6	73	33	65	12.4	2.7	99	75
HIGH	CW	8.89	1.06	21.6	73	32	62	12.3	2.6	102	80

Table 3
Composite Results for Size D UHS Motors

MOT TORQ MODE	DIR OF ROT	SPM	KWH/ BFL	KWH/ 1000 STR	SURF EFF %	THER CURR AMPS	% MOT LOAD	POL ROD HP	THER AMPS/ PRHP	% GEAR BOX TORQ RTG	MAX % ROD STR RTG
LOW	CCW	8.74	1.63	45.2	63	43	89	20.1	2.1	91	84
LOW	CW	8.81	1.61	44.2	65	39	80	20.4	1.9	94	87
MED	CCW	9.26	1.56	44.8	70	52	77	23.4	2.2	97	88
MED	CW	9.32	1.56	44.0	70	49	73	23.1	2.1	100	94
HIGH	CCW	9.50	1.42	42.5	76	60	70	24.6	2.4	96	88
HIGH	CW	9.52	1.47	43.0	75	57	66	24.6	2.3	99	95

Table 4
Composite Results for CCW and CW Rotations

MOT TORQ MODE	DIR OF ROT	SPM	KWH/ BFL	KWH/ 1000 STR	SURF EFF %	THER CURR AMPS	% MOT LOAD	POL ROD HP	THER AMPS/ PRHP	% GEAR BOX TORQ RTG	MAX % ROD STR RTG
NA	CCW	8.82	1.45	36.7	69	42	77	18.0	2.3	95	81
NA	CW	8.85	1.45	36.2	69	39	72	18.0	2.2	98	86

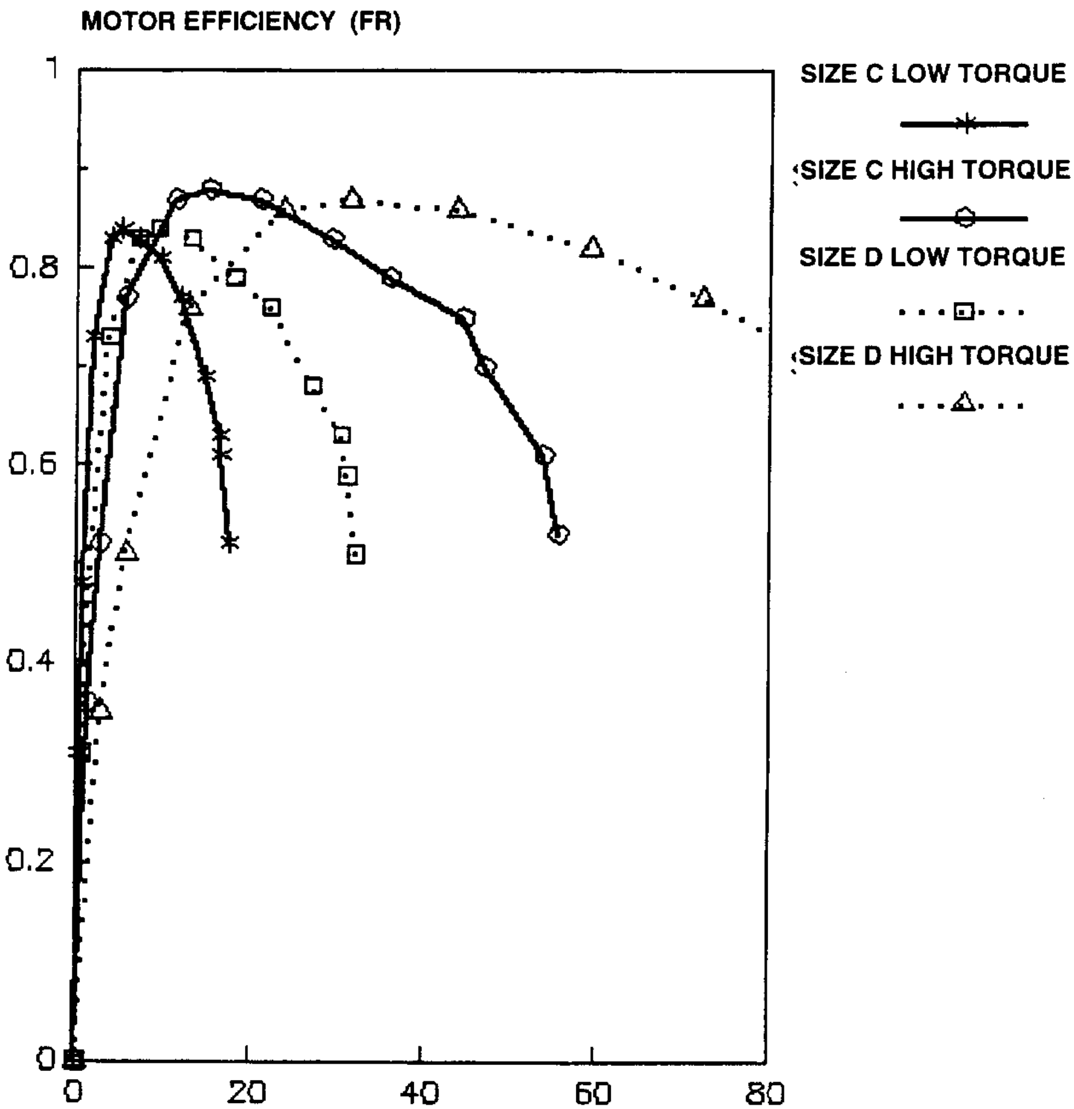

Figure 1 - Motor Output Horsepower