BEAM LIFT EXPERT DIAGNOSTIC SYSTEM FOR MULTIPLE PROBLEM IDENTIFICATION

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ABSTRACT

As oil producing companies continue to strive for more efficient and effective operations with reducing manpower levels, new technology and well diagnostic tools are required to meet these demands. This paper outlines and describes the requirements and steps to develop Amoco's Beam Lift Expert System (BLEX) that identifies and evaluates beam lifted well operating problems and suggests corrective courses of action to resolve those problems.

The expert system presented incorporates output data from multiple sources. Amoco's dynamometer diagnostic program (BLAP) for downhole and surface equipment analysis, downhole dynamometer pattern recognition, API RP11L, and production and operating information are all used in the systems extensive rule based logic structure to generate an evaluation and recommendation on all of the main components of a beam pumping system. The expert system output report presents all of the input data, as well as the evaluations and recommendations, in a concise format for easy interpretation.

The paper consists of seven main components. They are: choosing an expert system, defining input and output requirements, operating conditions evaluation, pattern recognition, surface equipment evaluation, rod string evaluation, and pump evaluation. For each of the evaluation sections, a logic structure used in the program is presented. Additionally, a brief discussion on potential benefits and future developments will be presented.

INTRODUCTION

Most all domestic oil production companies are trying to optimize the profitability of mature operations by means of reducing operating costs though reduced work force and improved operations. As a result, a mandate has been made to better utilize the technology and information available to both engineering and operating personnel.

In nearly all mature operations, artificial lift and the associated electrical power consumption comprise the majority of all operating expenses. Consequently, the greatest potential for reduced expenses lies in an operator's ability to optimize the artificial lift operations. Domestically, this means optimizing sucker rod pumped wells since, over 85% of all artificial lift operations are performed by sucker rod pumping.

In recent years, many new technological advances have been made to better understand and monitor rod pump operations. Computer tools have been written to both predict and to diagnose beam pumped wells and to pattern match downhole pump dynamometer cards to problem cards. Supervisory Pump-off Controllers (SPOC's) have been installed to have digital controlled pump-off operations, control from a central location, and generate real time dynamometer information. Additionally, most operators have automation systems that monitor individual well run times, well tests and alarmed conditions.

The one key ingredient required to take advantage of this technology is a knowledgeable operator that can interpret the computer programs'output and other performance information to generate a complete analysis of a well's operation and to provide a recommended course of action if potential problems or inefficiencies exist. Typically, complete well analysis have only been performed by experienced engineers or contract experts. Due to the limited availability of these experts, most wells have not been completely analysis and, therefore a great potential exist to reduce costs by developing a system to evaluate a wells performance and take advantage of an experts knowledge without having the expert.

This paper describes Amoco's Beam Lift Expert (BLEX) program that was developed to utilize existing technology and expert knowledge to perform a quick and easy complete well analysis that can be run by any field level technician. Included in this paper are: the considerations required in choosing an expert system, the input and output requirements, the logic structure for each part of the rod pumping system (surface equipment, rod string, pump), the logic structure for evaluating operating conditions, the potential benefits, and future work that still needs to be done in this field.

CHOOSING AN EXPERT SYSTEM

In choosing an expert system for the BLEX program, several factors had to be considered. They were: the platform requirements, the programming language interaction, ease to use, the sophistication of the knowledge base, the ability for future changes, and the cost of the development shell and runtime versions.

The platform requirements dictated that the expert system be capable of operating in DOS and have the ability to be ported to a UNIX operating system in the future. The DOS requirement was necessary since several of the existing external analysis programs that were to be run in conjunction with the expert system were already on DOS operated platforms. Additionally, operating personnel typically have access to either portable or desktop DOS computers. The ability to operate under a UNIX platform was desired since the existing field automation systems operate under UNIX and future enhancements to BLEX may require that the program be operated in the same computers.

The programming language chosen had to be powerful enough that it could handle some very complicated demands and still be supportable. One of the needs was to loop though commands a variable number of times to determine and obtain needed information. This was especially critical for evaluating differing taper rod strings. Another need was that the language had to be capable of calling (executing) other programs. We also wanted a language that was widely used to ensure that technical support was available and enhancements could be easily made. To meet all of the language requirements, the "C" language was chosen.

The ease of use was a necessity. It was desired to have an easy to operate system, the ability to make changes by technicians without the help of programmers and have an easily readable logic base. The program that was used accomplished this by utilizing windowing capabilities, free form input, and by presenting graphical display of the knowledge base.

As with most expert system programs, the sophistication of the knowledge base was the major consideration. We needed the expert system that could work with rules that were either condition driven or hypothesis driven, commonly known as forward or backward chaining. The program, also, was required to import data from a variety of data bases and do syntax checking and validation of that data.

The final two considerations of choosing an expert system were its ability for future changes and its cost. Many expert programs are on the market and are good for specific applications. We wanted one that was widely used and adaptable to a wide range of applications. By having these qualifications it was felt that the expert system could be integrated with other oilfield applications, be assured of product enhancements, have technical shell support, and be low in cost for the short and long term.

OUTPUT REPORT/INPUT REQUIREMENTS

OUTPUT REPORT: For any expert system program to be effective, the output report must be easily readable, concise, and present all of the useful information required for an operator to draw the same conclusions, or refute the conclusions, that are derived. The output report structure and a conceptual idea of desired outcomes should, also, be established prior to developing the program. The most obvious reasons for this are that input requirements can then be determined and logic can be developed to meet the desired result.

The BLEX program output was structured to address five major areas. Three of these areas are evaluations of equipment (surface equipment, rod string, sucker rod pump) , one is an evaluation of operating conditions and the last is a section on downhole dynamometer pattern matching. These areas were chosen to create a complete analysis of the beam pumping operation and to provide important information that is required for an operator to draw conclusions. Each of the five areas will be discussed in detail further in the paper. Figure No.1 is a copy of a typical BLEX output report showing the five main areas and the format.

The same basic format was used for each of the evaluation areas. Each area was designed to, first, present all of the raw input and output data, then, provide a short conclusion and recommendation statement. The pattern matching section of the output report used a different format since no conclusions or recommendations are made. Only the raw data is presented.

INPUT REQUIREMENTS: The input required to achieve the output results were classified into two categories, imported results from other programs and user interfaces. The imported information used in the BLEX program came from primarily two other programs. Amoco's BLAP diagnostic program was used to provide stress and torsional analysis of dynamometer cards for rod string and surface equipment evaluations and to provide pattern matching of generated downhole dynamometer cards to library problem cards. A computer version of the API RP11L program was, also used to provide predictive values of production, stresses, loads and horsepower that could be compared to actual values.

The user interfaces were required to provide site specific default values on a variety of different parameters and to provide production and operating condition information that wasn't available from the external programs.

OPERATING CONDITIONS EVALUATION

The purpose of the this section is to evaluate how effectively the well is being operated and to identify any problems that could be reducing the productivity or efficiency of a rod pumping system and by how much. To accomplish this task, it was determined that seven different variables must be checked and evaluated in combination to completely analyze the wells performance.

The most important variable, which determined the combinations of the remaining variable, was the operating fluid level above the pump (FAP). From this one parameter it can be determined if the well is producing at its full capacity. If the fluid level is higher than a preset fluid level the condition is set to positive and an IPR calculation is made to determine the potential production loss. The remaining support variables that are compared in combination with the FAP include: average runtime, volumetric efficiency, tubing anchor. There are also three variables that are evaluated in combination with the above variables but not with each other these include: gas interference, fluid pound and pump problems. Figure No.2 shows the ladder logic for all of the combinations of these seven variables.

The fluid level and runtime variables are direct user inputs while the remaining variables are based on calculations and pattern matches of the wells downhole dynamometer card to problem cards. The volumetric efficiency is a simple calculation of the wells actual production compared to its theoretical production. The actual production is an input variable and the theoretical production can be either an input variable or a default that was calculated from the API RP 11L. The operator has his choice.

The tubing anchor variable is based on the amount of stretch, or movement, as a percent of tubing length and a positive indication of an anchor problem from pattern matching. The tubing stretch is measured directly off of the downhole dynamometer card. For the expert system to identify a tubing anchor problem, both excessive tubing stretch and a problem tubing card must be present.

The fluid pound condition, like the tubing anchor condition, must have two positive indications before it is determined positive. First, the well must have a low pump fillage. This is calculated by measuring the amount of fluid load from the downhole dynamometer card and then comparing it to a preset default percent fillage. If the actual is lower than the default then low fillage is set to positive. The second positive indication is based on having a positive pattern match that indicates a fluid pound.

The gas interference and pump problem variables are based solely on having a positive pattern match. One of the problems with identifying a gas interference is that it can be vary similar to a fluid pound condition. Both show incomplete pump fillage and often the pattern cards look very much alike. The pump problem condition is really a combination of many possible pump problems that could reduce the lifting capacity of the pump. These conditions will be discussed in the Sucker Rod Pump Evaluation portion of this paper.

A total of 64 different rules were generated to cover all of the possible combinations of problems. However, the logic was structured where only one rule fires per evaluation. An example of one of the rules is shown in Figure No.1.

PATTERN RECOGNITION

The pattern recognition portion of the BLEX program is actually external to the expert system shell program but due to its impact on the results of the BLEX program a few comments are warranted.

The method used is similar to the methods presented by Keating et. al. in Reference No. 2. Each dynamometer card is normalized from 1 to 2 and is then broken into 75 segments of equal length. Then the cosine of the angle between each segment is determined and compared to a set of library pattern cards. The user sees a "trouble rating" with the best match being a minimum value.

One of the problems with this system is that you must pick a staring point. In our model, the starting point for the matching calculations is chosen by picking the vector closest to the origin. Also, cards that have spikes tend to give bad matches. This was minimized by limiting the angle between segments before the cosine was taken. Further, it was also found that if some smoothing with a truncated Fourier series routine was performed on the calculated card before matching with the pattern cards, much better results were obtained.

To accommodate the BLEX program, the library was expanded to cover 99 match pattern cards. This reflected the combinations of potential problems that the BLEX program evaluates. It accounts for up to three potential different problems occurring simultaneously. Realistically, fourth order and fifth order problem cards could be developed to expand the library but at that point the card distortions do to each problem made it virtually unrecognizable and additional cards slow the matching program down.

Because of the relative importance of the pattern matching routine on all of the other sections of the BLEX program, The user must verify the match or chose another match before any of the evaluations or conclusions are completed.
Additionally, every output report shows the top five best pattern matches and the match chosen to be used in all of the other evaluations.

SURFACE EQUIPMENT EVALUATION

The beam unit structure, gear reducer, motor and balance are all evaluated in this segment of the expert program. The beam unit structure loading is calculated in the BLAP program and imported directly into the expert program and doesn't effect any other part of the surface equipment. The remaining loads are all dependent on one main factor, unit balance. It directly effects the loadings of the motor and the gear reducer. The BLAP program calculates the loads on the motor and gear reducer for both the actual counter balance effect and the perfect counterbalance effect. With this information, the logic structure shown in Figure No.3 was developed to evaluate all of the combinations of loadings in the balanced and out of balanced conditions.

Shown in the logic is also a consideration of an acceptable out of balance condition. Arguably, it is impossible to achieve perfect balance of a beam pumped well under all operating conditions (IE: changing fluid levels), so an acceptable degree of out of balance was introduced into the logic structure as an additional variable. This was necessary to avoid having the expert program determine that the gear reducer and or the motor would not be over loaded if the unit were perfectly balanced when in reality any slight degree out of balance could overload either or both. The amount of acceptable out of balance is preset by the operator.

SUCKER ROD EVALUATION

This portion evaluates the well's rod string operation. The purpose of this section is to determine, first, if the rod string is parted, second, if any external factors are effecting the normal operation of the rod string, and finally, if any part of the rod string is overloaded.

Determining if a rod string was parted was one of the more difficult tasks for the expert system. Deep rod parts can often look like a gas lock or in some cases even a full card in the pattern matches. This is due to the normalization that is required in the pattern matching program. Comparing the actual peak and minimum downhole pump loads to predicted API RP 11 L loads and setting allowable deviations was ultimately used to predict a parted rod. Lower than expected pump loads indicate a parted rod.

Two external factors can affect the rod sting, both are checked in the program. First, an evaluation to determine if excessive rod string friction is present is made. This is done by comparing actual peak and minimum polish rod loads to API RP 11 L predicted peak and minimum polish rod loads. If the deviation is higher than the allowable deviation, excessive friction is expected.

The second factor that effects the rod string loads is compression. To evaluate this factor, the rod string was broken down by taper and minimum loads were checked at the top and bottom of each taper. If the minimum load is below a preset minimum load, then compression is assumed. The preset minimums differ for steel and fiberglass rod. For fiberglass rods a value of 200 lbs. is used. For steel rods the minimum is set at -200 lbs. These parameters can be changed by the operator to allow for more or less potential for compression.

The rod string loads are directly imported form the BLAP program and present the percent loading on each taper of the rod string. For the BLEX program, the loads were categorized into three areas, overloaded, heavily loaded, and acceptably loaded. Using a 0.9 service factor, the overload condition is considered at over 100% loaded, the heavily loaded condition is loads between 90% and 100%, and the acceptable loaded condition is rod loads of less than 90%. These three scenarios were chosen primarily because of the different recommendations associated with each. For example, over loaded rods require immediate action while the heavily loaded rods may only require a change the next time the well is pulled.

The logic structure for the rod string evaluations in shown in Figure No.4. The relationships between the rod loadings, compression check and friction check create a total of 49 individual rules.

SUCKER ROD PUMP EVALUATION

A downhole dynamometer analysis and the volumetric efficiency are the only two good indicators an operator has to effectively evaluate the operation of the sucker rod pump. The rod pump evaluation section in the BLEX program uses primarily only the pump dynamometer analysis since the operating conditions section of BLEX considers volumetric efficiency in the logic structure.

For the analysis, the pattern matching of the downhole cards is used to identify combinations of no more than two different pump problems. The combinations include things like leaking standing valve and a bent barrel or sticking plunger and leaky traveling valve, A complete list of all of the pump rules and associated pump problems are presented in Figure No.5.

POTENTIAL PROGRAM BENEFITS

Currently, the BLEX program is being tested in several operating areas within Amoco. Thus far, a few preliminary benefits have been seen. First, the BLEX program has been a tool to teach and educate operators on well analysis. Many operators have learned to use a few tools to analyze a well but only a few have learned how to completely analyze a well and recommend possible solutions. The BLEX program allows an operator to draw his conclusions and make recommendations and then compare them to the computer generated conclusions and recommendations. Often the operators answers will differ from the expert system solutions and he will want to understand why. When this happens, the operator will start asking questions and trying to learn why the BLEX program predicted what it did.

The second benefit that has been experienced is that the BLEX program prepares a much more comprehensive analysis of the wells operation than has typically been performed. Calculations like excessive friction and excessive tubing movement are not made normally when analyzing a well. Often calculations like these can identify problems that have not been identified in the past. Earlier detection will allow for preventive maintenance and reduced costs.

Additionally, it is hopeful that more well analysis will be made and problems identified sooner. Ultimately, benefits of any expert system analysis program are determined on quicker problem identification. For BLEX to be successful, the field technicians that operate and monitor the wells performance on a daily basis, must be able to quickly and easily use the program.

FUTURE DEVELOPMENTS

Since the original BLEX program was developed, several future developments have been identified. First, include economic criteria. Many of the BLEX recommendations are generic in that recommendations to evaluate the economics for making a change are generated. If economics were built into the program, more definitive recommendations could be made and the economic benefits would be clear. The task to include the economics is enormous and must be done in a manor that covers a wide range of conditions and considerations.

Secondly, optimum designs could be incorporated. Currently, the program only evaluates the current design and operating conditions and doesn't check if a better design or a change in the operating conditions could be made to more effectively produce the well. Work is being done in this area to identify a "best design" for a given set of parameters but, nothing has been done to incorporate it into an expert analysis program.

Along the same lines as the optimal design, power consumption considerations could be incorporated into the expert system program. It would require a few more inputs, but it could also generate substantial benefits.

Finally, the one future development that could create the greatest improvement of the expert system is to have it automated. Information from supervisory pump-off controllers, field automations computers, and data base systems could be feed into the expert system automatically with analysis being made on a continuous basis. Ideally, each well could be analyzed every day and alarms could be set to notify operators of a problem. Monitoring would be done by the expert system to ensure optimum performance. Much work needs to de done before an automated system could be functional to that level.

CONCLUSIONS

The development of an expert system for a complete sucker rod pumping system analysis requires: that logic structured rules be developed for every aspect of a pumping system; that an expert system shell program be chosen that allows for easy import and export of information and be capable of allowing future expansions;

and that output reports be easily generated, concise and readable to field technicians.

Several benefits of a beam lift expert system have been experienced. A much easier and more complete pumping well analisis can be gernated in a significantly short period of time. Additionally the BLEX program has shown to be a good training tool for operators.

Much more work can be done to fully utilize the abilities of an expert system analysis to optimize beam lifted operations. The inclusion of optimum designs, power consumption considerations and economic criteria is needed to generate a complete profitability analysis of a well. Those changes along with the automation of the expert program could completely change the way beam lifted well operations are monitored and controlled.

ACKNOWLEDGMENTS

We are grateful to Amoco Production Company management for having the vision to allow the develop the BLEX program. Additionally, thanks to all of the operating personnel that provided invaluable input during the development and testing of the program.

REFERENCES

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2) J.F. Keating, R.E. Laine, J.W. Jennings: "Application of a Pattern-Matching Expert System to Sucker-Rod Dynamometer-Card Pattern Recognition" SPE, Oklahoma City, OK 1991 (SPE 21666)

3) W.L. Foley and J.G. Svinos: "Expert Advisor Program for Rod Pumping" SPE, Dallas, TX 1987 (SPE 16920).

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BEAM LIFT EXPERT PROGRAM (BLEX)

Propietary and Confidential

Date: 01/28/92	Version 1.0	Time: 11:57:22
User's Name: OLB		Well Name: 391

Operational Conditions

Input Data

Oil Test Rate:	108.0 bfpd	FAP:	1200.0 ft
Water Test Rate:	345.0 bfpd	Casing Pressure:	50.0 psi
Theoretical Lift Capacity:	600.0 bfpd	Average Runtime:	23.0 hrs
Volumetric Efficiency	90.6 %		

ANALYSIS

RULE 108

This well has a high fluid level of 1200 ft., a long run time of 23.0 hrs, and good volumetric efficiency of 91 %. However, no problems that would affect these operating conditions were indicated from pattern matching techniques. If this well can be pumped down to 500 ft., an incremental production rate of 22.2 BOPD could be obtained. The pumped-off well production is 546 BFPD and 80% of theoretical lift capacity is 480 BFPD.

Recommendations

Evaluate increasing the lift capacity to pump off the well.

PUMP CARD PATTERN MATCHING

	Match Priority	Match Score	Pattern No.	Problem Description
	1	0.143471	221	unanchored tubing-slight travelling valve leak.
	2	0.173107	121	leaking travelling valve or plunger.
s	3	0.177548	127	full pump- pump friction.
	4	0.182913	122	severe travelling valve or plunger leak.
	5	0.185794	227	unanchored tubing-pump friction.

Please note: s => Pump card selected as best match.

Surface Equipment Evaluation

Input Data

Unit Size:	640-365-144	Pumping Speed:	10.9 spm
Unit Manufacturer:	AMERICAN	Operating Stroke Length:	142.0 in
Unit Type:	Conventional	Rotation:	Negative

Structural Analysis

Maximum Loading:	30295.8 lbs.	Percent Loaded:	83.0 %

Gear Box and Motor Analysis

	Existing	In Balance
Peak Torque (M in-lbs)	919.6	874.6
Counterbalance (M in-lbs)	1400.0	1448.2
Gearbox rating (%)	143.7	136.7
Required Horsepower	88.7	87.8

ANALYSIS

RULE 323

The structure is 83 % loaded. This is less than the site specific limit of 100 %. The gearbox is 137 % loaded in the in balance condition. This is more than the site specific limit of 100 %. The motor is 89 % loaded in the existing condition. This is less than the site specific limit of 100 %. Therefore it is not overloaded in the in balance condition. The unit is 5 % out of balance. This is within the acceptable range of 15 %.

Recommendations:

Due to the gearbox in balance being overloaded, an evaluation needs to done on, changing the operating parameters (unit speed, rotation, pump size, stroke length, etc) to reduce the load, or installing a larger pumping unit.

Rod String Evaluation

Input Data

Size (in)	Rod Grade	Segment Length(ft)	Max Stress	Min Stress	Eff Min Load	Percent of Stress Range 1.0	0.9	0.8
1.000	D	2050	38574	11073	5732.1	115.04	134.76	162.63
0.875	D	1875	37050	8506	3808.8	114.04	131.69	155.79
0.750	D	1925	36574	6709	1408.1	115.69	132.36	154.66

ANALYSIS

RULE 422

The steel rods are overloaded. This may be the result of excessive friction or a poor rod design coupled with the operating conditions. A higher than expected peak polish rod load is indicated that there may be excessive friction.

Recommendations:

Due to the overload condition, immediate action should be taken. Evaluate pulling the rods to and checking them for localized wear. Additionally, check the rod design with BLAP predictive to determine if any operational changes or rod string modifications can be made to reduce the rod loadings.

Rod Pump Evaluation

Input Data

Pump Size:	2.000	Percent Pump Fillage:	99.7
Net Pump Stroke:	126.8 in	Volumetric Efficiency:	90.6
Net Pump Displacement:	643.2 bfpd		
(based on 24 hour runtime)			

ANALYSIS

RULE 519

No pump related problems were detected from pattern matching techniques.

Figure 1 - Output report

				ANCHORED RULE NO.	UNANCHORE RULE NO.
HIGH FAP	LONG RUNTIME	LOW EFF.	GAS INTERFERENCE	101	201
			FLUID POUND	102	202
			WORN PUMP	103	203
			NO INDICATIONS	104	204
		NOT LOW EFF.	GAS INTERFERENCE	105	205
			FLUID POUND	106	206
			WORN PUMP	107	207
			NO INDICATIONS	108	208
	O.K. RUNTIME	LOW EFF.	GAS INTERFERENCE	109	209
			FLUID POUND	110	210
			WORN PUMP	111	211
			NO INDICATIONS	112	212
		NOT LOW EFF.	GAS INTERFERENCE	113	213
			FLUID POUND	114	214
			WORN PUMP	115	215
			NO INDICATIONS	116	216
LOW FAP	LONG RUNTIME	LOW EFF.	GAS INTERFERENCE	117	217
			FLUID POUND	118	218
			WORN PUMP	119	219
			NO INDICATIONS	120	220
		NOT LOW EFF.	GAS INTERFERENCE	121	221
			FLUID POUND	122	222
			WORN PUMP	123	223
			NO INDICATIONS	124	224
	O.K. RUNTIME	LOW EFF.	GAS INTERFERENCE	125	225
			FLUID POUND	126	226
			WORN PUMP	127	227
			NO INDICATIONS	128	228
		NOT LOW EFF.	GAS INTERFERENCE	129	229
			FLUID POUND	130	230
			WORN PUMP	131	231
			NO INDICATIONS	132	232

Figure 2 - BLEX operating condition rules

STRUCTURE	GEARBOX INBALANCE	GEARBOX EXISTING	MOTOR INBALANCE	MOTOR EXISITNG	UNIT BALANCE	RULE NO.
OVER	OVER		OVER		IN	301
					OUT	302
			OK	OVER	IN	303
					OUT	304
				OK	IN	305
					OUT	306
	OK	OVER	OVER		IN	307
					OUT	308
			OK	OVER	IN	309
					OUT	310
				OK	IN	311
					OUT	312
		OK	OVER		IN	313
					OUT	314
			OK	OVER	IN	315
					OUT	316
				OK	IN	317
					OUT	318
OK	OVER		OVER		IN	319
					OUT	320
			OK	OVER	IN	321
					OUT	322
				OK	IN	323
					OUT	324
	OK	OVER	OVER		IN	325
					OUT	326
			OK	OVER	IN	327
					OUT	328
				OK	IN	329
					OUT	330
		OK	OVER		IN	331
					OUT	332
			OK	OVER	IN	333
					OUT	334
				OK	IN	335
					OUT	336

Figure 3 - Surface equipment rules

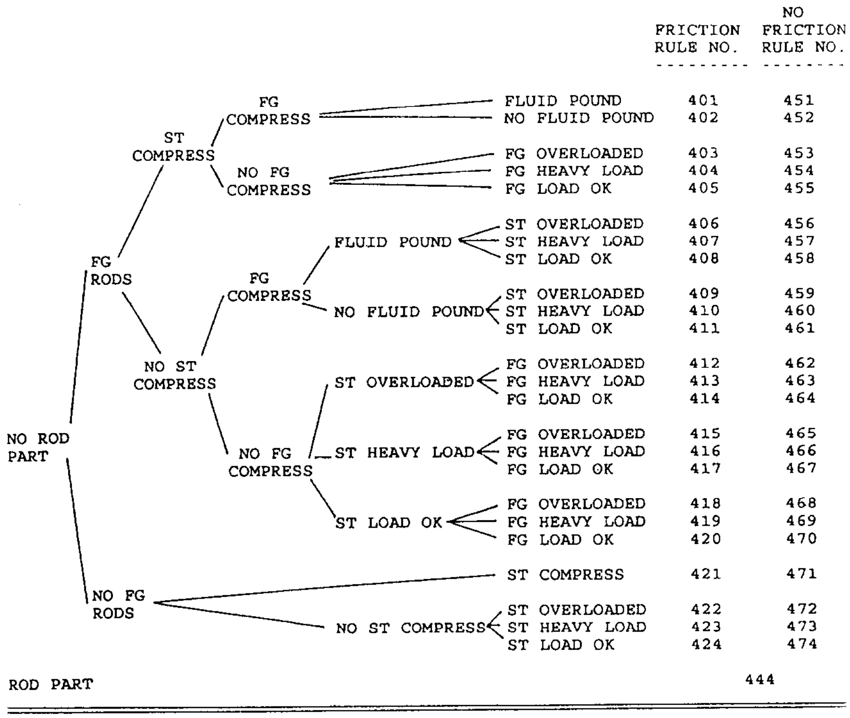

Figure 4 - Rod rules

DESCRIPTION	MATCH PATTERN	RULE NO.
FULL PUMP	101,201	501
WORN OR SPLIT BARREL	109,110,111 209,210,211	502
STICKING BARREL	112,113,114 212,213,214	503
STICKING PLUNGER	115,116,117 215,216,217	504
LEAKING STANDING VALVE	118,119,120 218,219,220	505
LEAKING TRAVELING VALVE OR PLUNGER	121,122,123 221,222,223	506
PUMP TAGGING TOP	124,224	507
PUMP TAGGING DOWN	125,225	508
WORN BARREL & LEAKING STANDING VALVE	139,239	509
WORN BARREL & LEAKING TRAVELING VALVE	140,240	510
STICKING BARREL & LEAKING STANDING VALVE	141,241	511
STICKING BARREL & LEAKING TRAVELING VALVE	142,242	512
STICKING PLUNGER & LEAKING STANDING VALVE	143,243	513
STICKING PLUNGER & LEAKING TRAVELING VALVE	144,244	514
LEAKING STANDING AND TRAVELING VALVES	145,245	515
STUCK PLUNGER	4	516
GAS LOCKED PUMP (ACTUAL PARTED ROD RULE 417)	5	517
GAS LOCKED PUMP	5	518
NO PUMP PROBLEMS	(NO MATCH)	519

Figure 5 - Pump rules