TITLE PAGE

Report Title: **Using Cable Suspended Submersible Pumps to Reduce Production Costs to Increase Ultimate Recovery in the Red Mountain Field in San Juan Basin Region**

Type of Report: Project Semi-Annual Technical Progress Report

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ABSTRACT:

A joint venture between Enerdyne LLC, a small independent oil and gas producer, and Pumping Solutions Inc., developer of a low volume electric submersible pump, suspended from a cable, both based in Albuquerque, New Mexico, has re-established marginal oil production from the Red Mountain Oil Field, located in the San Juan Basin, New Mexico by working over 17 existing wells and installing submersible pumps.

The project was funded through a cooperative 50% cost sharing agreement between Enerdyne LLC and the National Energy Technology Laboratory (NETL), United States Department of Energy, executed on April 16, 2003. The total estimated cost for this first phase of the agreement was $ 386,385.00 as detailed in Phase I Authorization For Expenditure (AFE).

This report describes the tasks performed, the results, and conclusions for the first phase (Phase I) of the cooperative agreement.

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LIST OF GRAPHIC MATERIALS

INTRODUCTION

Resume marginal oil production operations in the Red Mountain Oil Field, (P1), located in McKinley County, New Mexico by installing a cable suspended electric submersible pumping system (HDESP), determine if this system can reduce lift costs making it a more cost effective production system for similar oil fields within the region, and if warranted, drill additional wells to improved the economics.

Three Phases of work have been defined in the DOE Form 4600.1 Notice of Financial Assistance Award for this project, in which the project objectives are to be attained through a joint venture between Enerdyne LLC (Enerdyne), owner and operator of the fields and Pumping Solutions Inc. (PSI), developer of the submersible pumping system. Upon analysis of the results of each Phase, the DOE will determine if the results justify the continuation of the project and approve the next Phase to proceed or terminate the project and request that the wells be plugged. This technical report shall provide the DOE with Phase I results and conclusions reached by Enerdyne and PSI.

EXECTIVE SUMMARY

In April, 2003 a cooperative 50% cost share agreement between Enerdyne and the DOE was executed to investigate the feasibility of using cable suspended electric submersible pumps to reduce the lift costs and increase the ultimate oil recovery of the Red Mountain

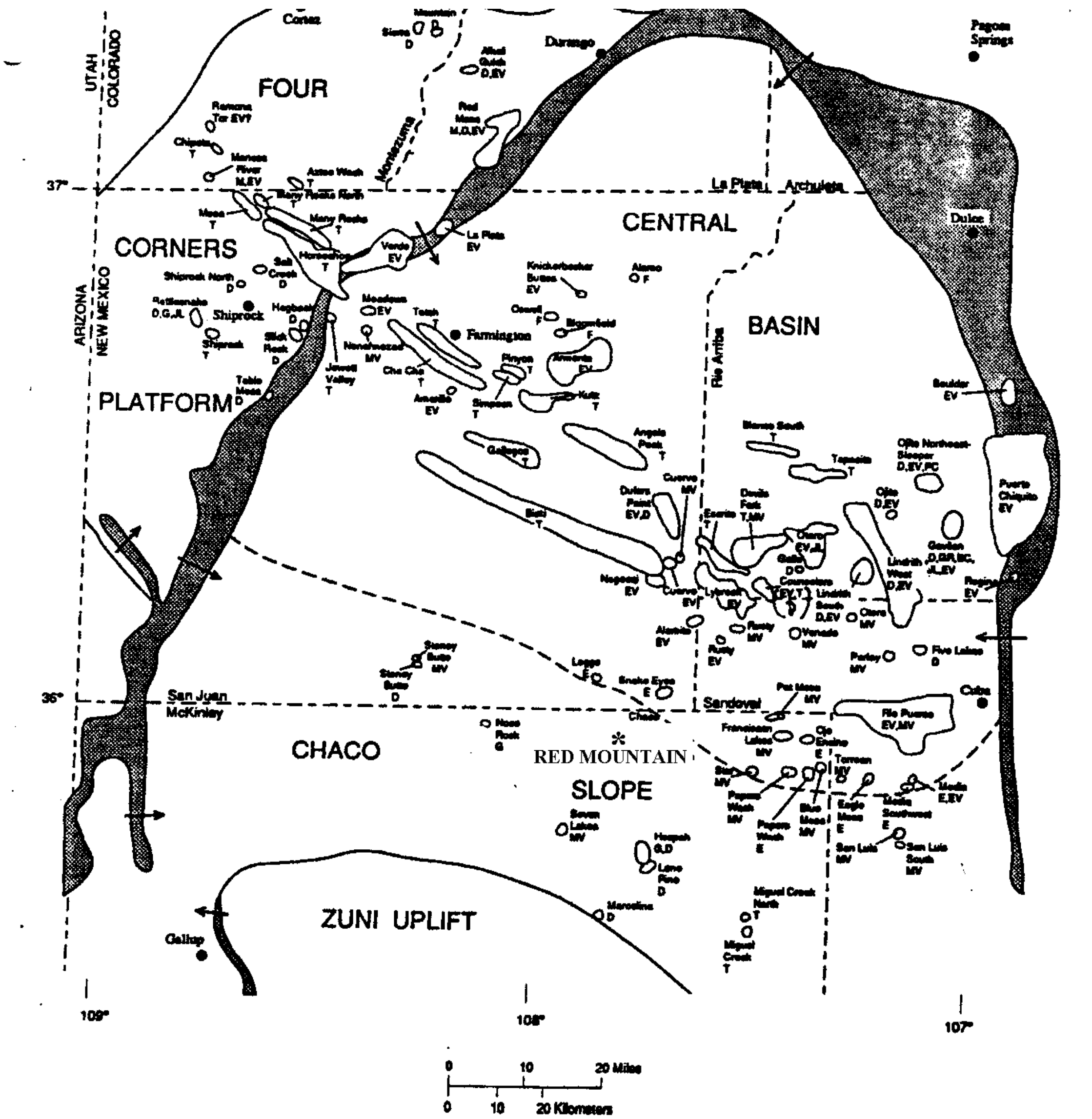
Red Mountain (P1)

Oil Field, located on the Chaco Slope of the San Juan Basin, New Mexico (M1). The Field was discovered in 1934 and has produced approximately 55,650 cubic meters (m^3) (350,000 barrels, bbls., 42 gallons, gals.) of oil. Prior to April, 2003 the field was producing only a few cubic meters of oil each month, however the reservoir characteristics suggest that the field retains ample oil to be economic (M2 & M3). This field is unique, in that, oil accumulations, above fresh water, occur at depths from 88 – 305 meters (m), (290 feet to 1000 feet, ft.), and serves as a relatively good test area for this experiment.

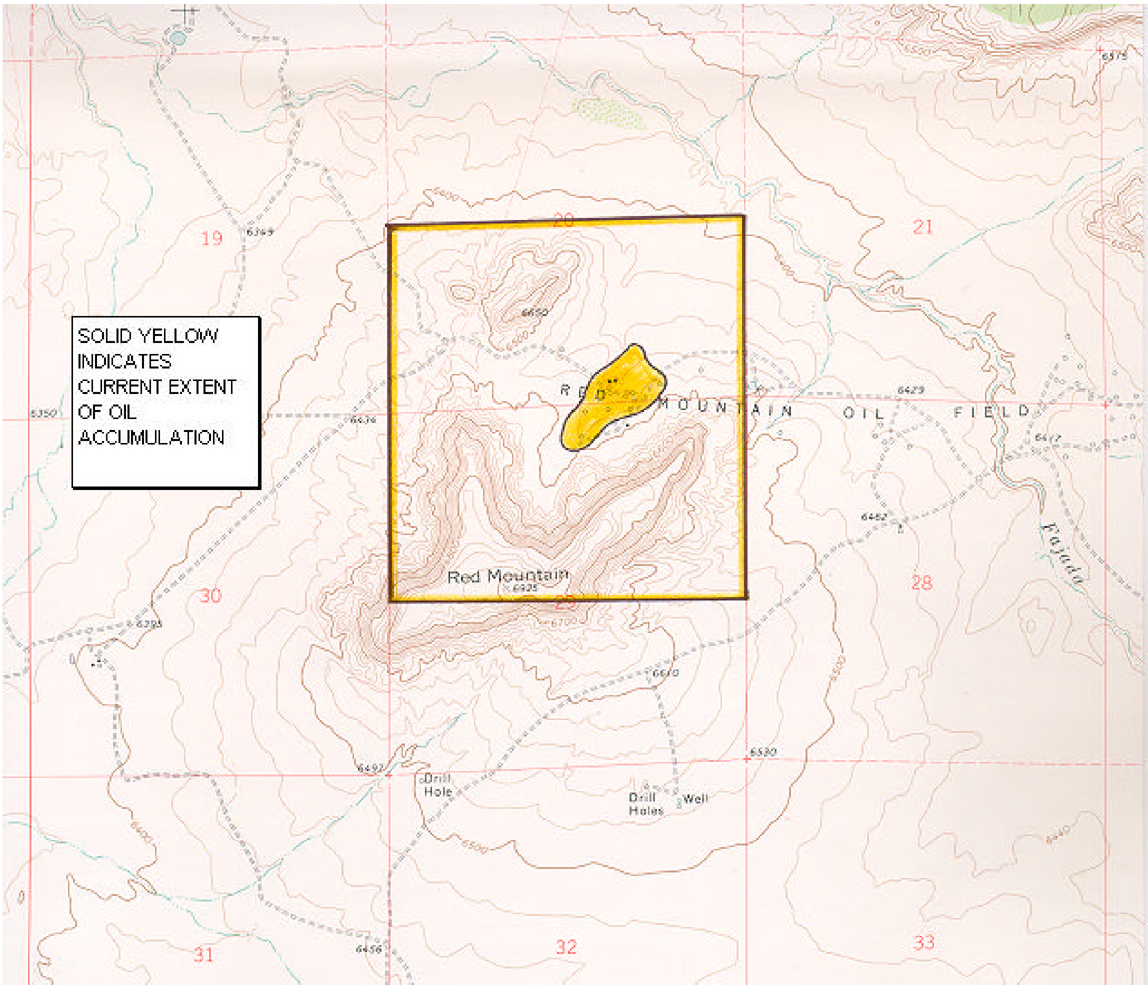
Seventeen well bores were selected by Enerdyne for workover (M4). Wells were selected based on their completed depth, as indicated by existing New Mexico state records, and have, at least, a 101.6 millimeters (mm), (4.0 inches, in.), inside diameter to accommodate the PSI pump.

Using Enerdyne's rig (P2), conventional methods were employed to cleanout all wells of wall buildup and bottom hole sediment accumulation. Each well was then treated for minor skin damage and circulated. No significant problems were experienced during these procedures.

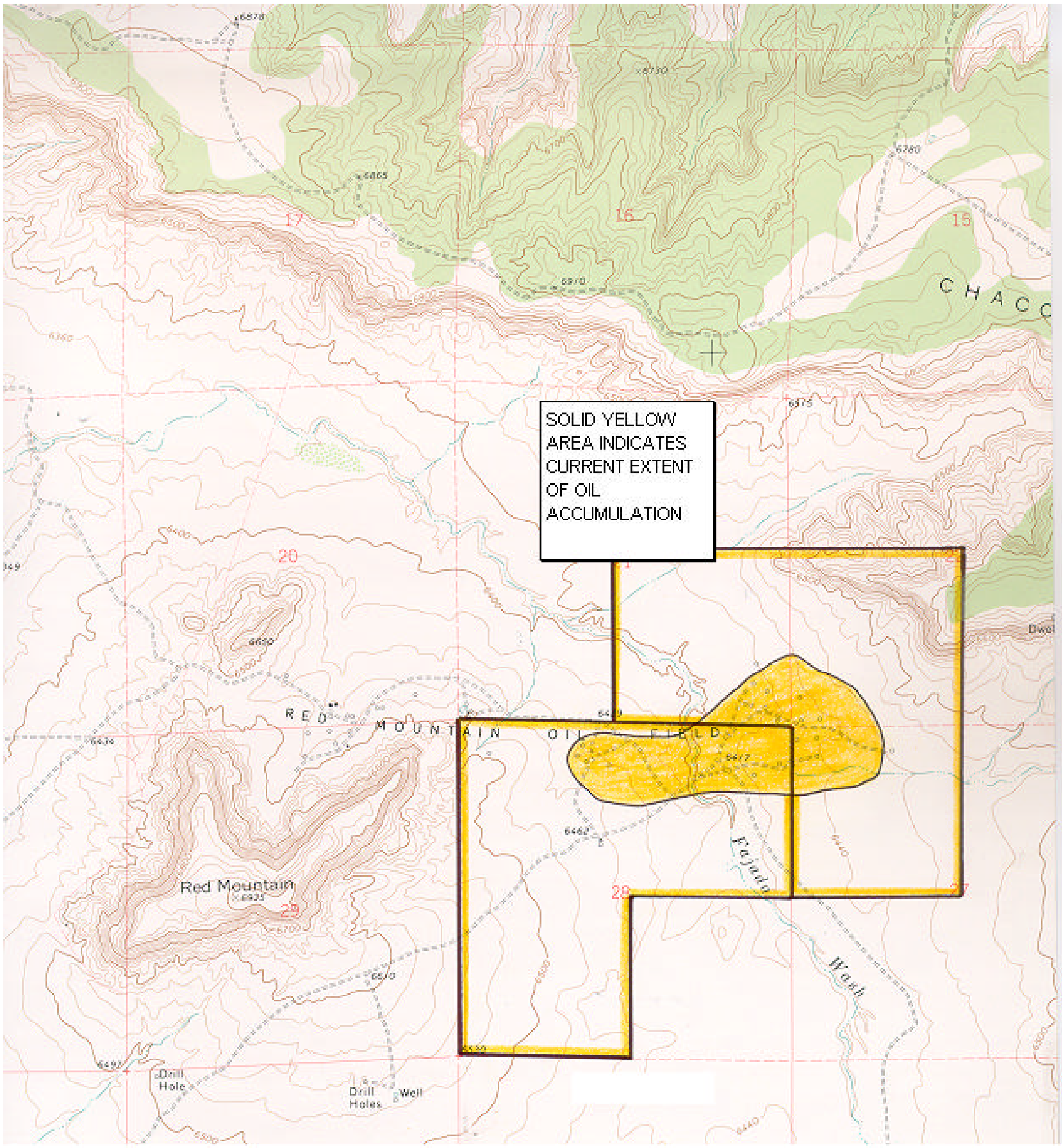
San Juan Basin Oil & Gas Fields (M1)



Red Mountain Topographic Map (M2)



Red Mountain Topographic Map (M3)



After each well was cleaned, PSI began installing it's HDESP system via the CSPS trailer (P8). With the exception of one installation, all pumps were eventually installed, tied-in to a temporary power supply and storage tank (P6). The one installation that was not completed, resulted from an unforeseen down hole condition that caused the pump to become diagonal in the well and irretrievable with the CSPS trailer. It was found, that when using a cable to suspend the pump and flexible production tubing, the maneuverability of the pump is extremely limited. Several other pumps had to be pulled and reinstalled because of electrical and chemical problems.

Following the tie-in procedures, each well was pumped until it was determined that the well was stable and reservoir conditions were normal. The well was then pumped for a period of time to gauge the produced fluid and determine the actual oil cut. It was concluded that, on average, a well would produce approximately .00001472 cubic meters per second (m^3/s), (8 bbls. / day) of fluid with a 15% oil cut. Therefore the field could feasibly produce .00003754 m^3/s of oil (20.4 bbls. / day).

EXPERIMENTAL

PHASE I

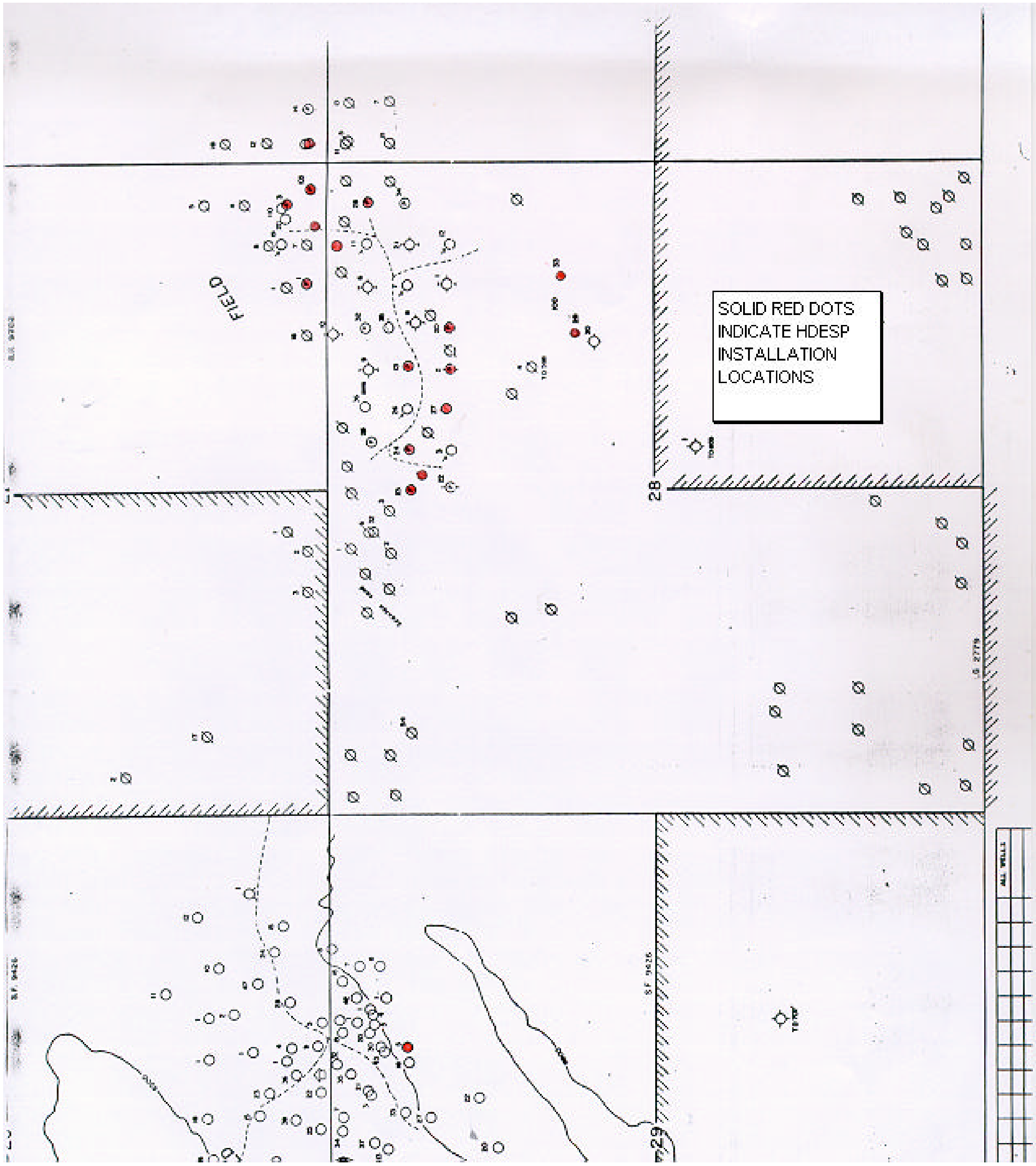
The objective of Phase I was to attempt to establish marginal oil production. This was accomplished by selecting 17 wells within the oil fields, removing existing equipment when necessary, cleaning out each casing, treating the pay zone of each well for minor skin damage, temporarily installing a HDESP in each well, and determining the oil cut of the production.

Well Selection

The Red Mountain Mesaverde is oil productive from at least six shallow lenticular fluvial sandstone channels that pinch out both sides and occur at depths between 88.5 m (290 ft.) and 335.5 m (1100 ft.). These channels average 4.575 m (15 ft.) thick with porosity of 28% and permeability of .3948 μm^3 (400 millidarcies) . Typical of fluvial deposits in this region, they meander in a southwesterly-northeasterly direction and are characterized by upward fining of grain size distribution and have laminated wavy-bedded clay and silt stringer inner beds. These channels drape over two distinct deeper lying structures which have created structural-stratigraphic traps in which migrating 42 API gravity oil has accumulation. The type of drive is fresh water.

Prior to fieldwork commencing, 17 of the 30 wells within the Red Mountain Oil Field were selected for this project. Because there was no question that reservoir characteristics would have the greatest impact on the success of this project, it was Enerdyne's intention

Red Mountain Base Map (M4)



to test each of the productive sands, with the exception of the 335.5 m (1100 ft.) sand, by include at least two wells that were completed in each of the productive sands. And the well casing had to be 101.6 mm (4.0 in.) API inside diameter pipe or greater to accommodate the HDESP.

Well Clean Out

In April 2003, Phase I fieldwork began with the first task being casing clean out. Because most of the subject wells were drilled in the 1960's and 1970's and had been shut-in for several years, it was the concluded by Enerdyne, that in order to give the wells the best chance to produce oil, they should be worked over to improve permeability prior to the HDESP installation. Using Enerdyne's rig and other field equipment, the selected wells, which ranged in depth from 106.75 m (350 ft.) to 175.375 m (575 ft.), were worked over using conventional methods. Typically, once the surface equipment was removed from the location and the rig was setup over the well, the well casing was scraped to remove any large oxidation buildup that could possibly hinder the HDESP installation, by rotating a 95.25 mm (3.75 in.) cone bit, treaded to a .61 m (2 ft.) finned sub on 60.325 mm (2.375 in.) tubing, to total depth (TD). Fresh water treated with an environmentally benign liquid polymer dispersant, to keep clay fines from swelling within the reservoir, was circulated to remove casing debris and other solids from the hole. Samples of formation fluids were taken to determine their compatibility to hydrochloric acid and or wetting agent additives. Confident that no adverse reaction would occur, the well pay zone was then treated with 250.030 liters (L), (55 gals.) of 12% hydrochloric acid with a wetting agent additive to clean out the open hole or perforations of any mineral deposits and that would reduce permeability. After allowing the acid to work for 24 hours, the well was circulated again to remove any spent acid and solids. The well was then treated with 250.03 L (55 gals.) of a .05% polymer dispersant and fresh water mixture to remove any sediment or clay, not reactive to hydrochloric acid, from the producing formation or perforations. The polymer dispersant mixture was agitated repeatedly for at least 24 hours before a submersible pump was installed.

Enerdyne Rig (P2)

A typical water well seal was installed to prevent any debris from entering the well bore prior to the HDESP installation. The clean out process took two men, on average, three days per well with all 17 wells cleaned and ready for pump installation by late August 2003.

HDESP

A newly developed pumping system, the HDESP consists of a 95.25 mm (3.75 in.) diameter light weight low volume electric submersible oil well pump that functions by hydraulically actuating diaphragms with a small hydraulic pump and electric motor. This gives the pump the ability to pump low viscosity fluids as well as abrasives given up by the reservoir. By increasing the length of the diaphragms and or the size of the electric motor, the pumping capacity increases. Its stainless steel construction allows the pump to be deployed in corrosive down hole environments without damage to the components. It is suspended, in the well, using a 6.35 mm (.25 in.) D stainless steel cable to which the electric power cable and 15.875 mm (.625 in.) reinforced polyethylene tubing, with a burst pressure of 17237.5 kilopascals (kPa) (2500 pounds per square inch, psi), are tied. The stainless steel cable is tied off at the wellhead while the power cable and tubing pass through. The entire system can be deployed, continuously, by one man operating the CSPS trailer, a 4.88 m (16 ft.) winch trailer that is equipped with hydraulically actuated spools that feed or gather the cables and tubing simultaneously.

For this project, the HDESP appears to be perfectly suited to handle the field conditions and reservoir characteristics of the Red Mountain: the lack of reservoir pressure that exists due to the shallow nature of the pay requires a pump that can pump off without damaging the pump. Those wells that experience sand entry into the wellbore from the formation require a pump that will not prematurely wear out from sand abrasion to its components. During the winter months it is extremely difficult to prevent low volume wells, that produce fresh water, from freezing and splitting wellhead fittings and valves or metal flow lines, therefore a production system is needed that is not exposed to weather conditions. And, because the field is remote, a production system that has no above ground moving parts that require maintenance or can harm livestock or other native animals is most beneficial.

HDESP Installation

In June 2003, PSI began to installing pumps employing their CSPS trailer. Once on location, the trailer was centered over the well and leveled with its hydraulic out riggers,

Typical HDESP Installation (P9)

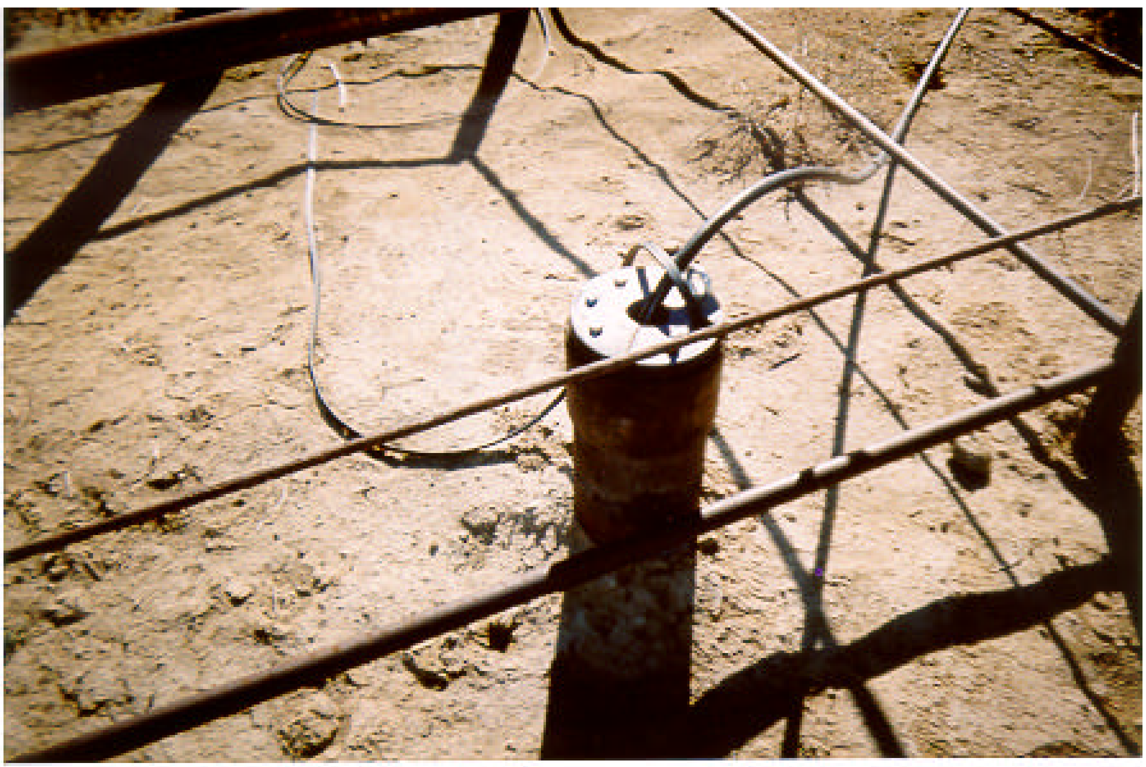
the derrick was raised and the pumping system was prepared for installation. A 60.325 mm (2.375 in.) round bull plug, modified to accept 15.875 mm (.625 in.) polyethylene tubing and also provide a attachment loop for the 6.35 mm (.25 in.) stainless steel cable, was threaded into the top of the pump and tightened. The 6.35 mm (.25 in.) stainless steel suspension cable was then run from its trailer spool, through the derrick pulley and secured to the pump. A threaded 12.75 mm (.5 in.) NTP male flare fitting was threaded into the bull plug and the 15.875 mm (.625 in.) polyethylene tubing was run from its spool on the trailer, through the derrick pulley and secured to the pump with a 12.75 mm (5. in.) female push lock fitting clamped to the end of the tubing. The pump electric submersible motor lead was spliced to No. 3-10 polyethylene jacketed copper power cable after the cable had been run from its trailer spool and through the derrick pulley. The two cables and tubing were clamped together at the end of the pump and lowered into the well. As the pump was lowered, by the CSPS trailer, the tubing and cables were clamped together at 1016 mm (40 in.) intervals to prevent the tubing or electric power cable from stretching as well as to keep the suspension cable from twisting around the tubing which could squeeze the tubing and create a flow restriction. A pressure clamp clamped to an auxiliary line off the derrick was used to hold the system in place during cable-tubing clamping. After the TD was reached, the pump was lifted 1.525 m (5 ft.) off bottom and typical 101.6 mm (4.0 in.) water well seal with 9.525 mm

(.375 in.) stainless steel eye bolts screwed into the bottom and top of the seal were used to tie off the suspension cable and carry the load of the system (P3). Prior to setting the well seal permanently in the well casing, the power cable and tubing were guided through the seal and cut off at appropriate lengths to allow the power cable to be tied into an electric motor starter mounted on a 152.4 mm x 152.4 mm (6in. x 6 in.) wooden post set approximately 127 mm (5 ins.) from the well head and to allow the 15.875 mm (.625 in.) production tubing to be tied into a flow line. The entire installation process for one would typically take two men 8 hours.

Csps Trailer (P8)

Temporary Well Tie-in

After a HDESP was installed, a 101.6 mm x 457.2 mm x 812.8 mm (4in. x 18 in. x 32 in.) concrete pad, designed with openings to fit around the wellhead and also allow the electric cable and tubing to pass through, was place over the wellhead, production tubing and power cable, and the well was tied-into a power supply and gathering system. A 20 amp disconnect and 240 volt timer were mounted adjacent to the starter on the wooden post and wired together. A power supply cable was run to the well and wired into the disconnect. The production tubing was coupled and run, on the surface, to a production tank, tied-into another nearby flow line or into a portable tank. The wellhead was then covered by bolting a 203.2 mm x 406.4 mm x 558.8 mm (8in. x 16in. x 22 in.) metal box to the concrete base. The location was fenced with pipe panels or t-posts and barbed wire and the well was produced for approximately one hour per day (P4).



Typical Wellhead (P3)

Typical Equipped Well (P4)

RESULSTS

HDESP Installations

Production volumes and the fact that all but two HDESP installations went smoothly indicated that the clean out process was a success. It was estimated that .795 - 1.59 m^3 (5-10 bbls.) of fluid were introduced into the reservoir during the clean out process, however the typical well made .795 – 1.272 m^3 (5-8 bbls.) of fluid in 2 hours of pumping for several pumping cycles.

Field tests taken by completely drawing down the fluid in the casing and then pumping the well so that the reservoir fluid entry could be gauged and the oil cut calculated, indicated that, given the current state of the reservoir, an average well would produce 48+ m^3 (30+ bbls.) of fluid in a 24 hour period with a 18% oil cut. Currently, only two wells are being produced because all tanks are full or close to full and, with winter coming on, all produced water should be removed soon from the tanks.

Oil Production Gauge Tank (P6)

The quantity of fluid that each well made per day upon pumping operations commencing along with the fact that all pumps made it to depth, indicate that the clean out technique, employed for Phase I, was effective. Although three wells did not respond with good fluid entry upon initial production, each well did eventually come around after the three wells were re-acidized by pumping them off and then dumping 113.6 L (30 gals.) of 12% hydrochloric acid down the well bore through a 12.75 mm (.5 in.) polyethylene tube. After allowing the acid to work for 24 hours, the wells were pumped once again and all made 2.385 m^3 (15+ bbls.) of fluid within a few hours of pumping.

As earlier stated, PSI experienced installation problems with two wells: the Santa Fe 106 and the State 2. The Santa Fe 106 is approximately 106.75 m (350 ft.) deep and completed with an open hole. Typically, when installing a HDESP system, the pump is set at five feet above TD. When PSI tagged TD with the pump, the pump became diagonal in the open hole and lodged. Several attempts were made to free the pump, however the pump would not release and the 6.35 mm (.25 in.) suspension cable snapped from the pulling force, leaving the pump and approximately 91.5 m (300 ft.) of cable in the hole. The well seal was installed and the well abandoned to be plugged during Phase II, of this project, if the pump and cable can not be fished from the hole with the Enerdyne drill rig. Another condition was encountered while installing the

HDESP system in the State 2, a 160.13 m (525 ft.) well that was drilled in the 1970's. It was discovered that this well has 139.70 mm (5.5 in.), outside diameter, casing at the surface, but the second joint of casing is reduced to 101.6 mm (4.0 in.); this diameter is too small for the typical pump to pass through. Therefore, in order to over come this condition, PSI had to reduce the diameter of a pump's hydraulic gear housing. After two unsuccessful attempts to install the modified pump in the well, PSI was able to reduce the pump diameter to the point where it would clear the tighter casing and set the modified pump at 1.525 m (5 ft.) above TD.

Three other pumps had to be pulled and replaced, after installation, for various reasons: one of the first pumps installed was returned to the shop for repairs because the pump was assembled with an aluminum component, embedded in an epoxy as a sealant, that reacted with residual hydrochloric acid from the clean out process. When this pump was submerged in the well, the epoxy sealant dissolved, leaving the aluminum component exposed. The aluminum would have corroded and the pump would have failed within a short period of time, therefore PSI replaced the epoxy-aluminum component with a similar part fabricated from stainless steel. The pump was reassembled, returned to the field and installed in the well where it has been operating without a problem. Fortunately, this circumstance was discovered during the second HDESP system installation, therefore, a costly situation was avoided by replacing the epoxy-aluminum components in the remaining pumps to be installed. By going to stainless steel, it also made it possible to re-acidize a well without pulling the system from the well bore. Two other pumps had to be pulled and replaced on account of upstream electrical problems: an electric short circuit that occurred with the power supply cable to a well location, cause one pump's electric motor to short circuit, while another pump was pulled and replaced because the electric motor failed as a result of an assembly error.

Minor problems were also experienced and solved during the installation and pulling of the pumping system. It was found that the production tubing, power cable and stainless steel cable had to be clamped together by weaving the clamp through the stainless steel cable and around the tubing and power cable. This prevented the clamp from slipping up or down during installation or pulling, which, if occurs, could cause the tubing and or power cable to fold within the well bore and tangle making it very difficult tom perform the task.

Production

The original plan for oil production was to allow each well to pump for a couple of days or until the well pumped off and then calculate the oil cut. The results would determine if the well was economic. It was found that the typical well made 1.272 m^3 (8+ bbls.) of fluid per day in the first four weeks of initial production, with the pump operating two hours per day. The average oil cut was calculated at 15%. Within a few weeks of pumping, the production tanks would be full and the produced water would require disposal. Once all wells were online, it was apparent that the volume of produced water was too great to manage. If all wells were allowed to pump for two hours per day, the total fluid produced would be approximately 636 m^3 (4000+ bbls.) per month; although it is doubtful that this production rate would last for more than 90 days.

Typical Producing Well (P5)

Typical Production Tank (P7)

Economics

Phase I was estimated to take 90 days to complete. The actual time it took to complete the tasks described in Phase I was nearly twice as long. HDESP installations were delayed because of pump manufacturing delays. As a result of these delays and unforeseen conditions and tasks, Enerdyne's in-kind contribution exceeded DOE contributions by $44,000.00.

CONCLUSIONS & RECOMMENDATIONS

Oil Production

Marginal oil production has been re-established at the Red Mountain Oil Field using the cable suspended pumping system. However, in order for the field to be economic, produced water must be reintroduced into the reservoir to maintain reservoir pressure and as a method of disposal, as addressed in the AFE's submitted for Phase II & III for this project.

It is recommended that the project continue into Phase II; operating the field for a year to determine the economic benefits of the HDESP system. This would involve acquiring administrative approval from the New Mexico Oil Conservation Department to inject produced water back into the reservoir, converting those wells that do not produce paying quantities of oil to injectors and transfer the HDESP system in those converted wells to other wells within the field.

HDESP System

For any field with similar characteristics as the Red Mountain, the HDESP system will be ideal. However, it does not appear that the pumping system can be installed in a well that produces low viscosity oil or heavy paraffin, a deviated well, or any well with a casing condition that requires the pump to be pushed, pulled or turned. The current design of the pump, with flat ends and sharp edges that can catch on offsets or mineral buildup in the well bore, and cable suspension does not lend itself to any force other than pulling. It is recommended that, if these conditions are encountered, the pump should be installed using 31.75 mm (1.25 in.) steel tubing or schedule 80 PVC for production tubing using a water well winch truck for shallow installations and a small work over rig for deeper wells. Inevitably, a more streamline design, similar to logging tools, will be required.

The economic benefits of the HDESP system during installation have been established; the average well installation took approximately 1/3 the time with the ESPS trailer when compared to a similar installation of pump, rods, and tubing with a small work over rig.

REFERENCES

Phase I Authority For Expenditure (attached)

AUTHORIZATION FOR EXPENDITURE RED MOUNTAIN WORKOVER - PHASE 1	DATE 12/01/02	RED MOUNTAIN 290-450 SAND	LEASE NAME RED MOUNTAIN
LOCATION RED MOUNTAIN	WELL NOS. TYPICAL	TD 500 FT.	FORMATION MENEFEE
OPERATOR ENERDYNE LLC	COUNTY MCKINLEY	STATE NEW MEXICO	AFE NO. TYPICAL
PURPOSE FOR EXPENDITURE TEST 450 MENEFEE SAND FOR OIL PRODUCTIVITY	TYPE OF WELL OIL	LEASE NO.	WORK DATE 2/15/03

INTANGIBLE COSTS	DRILLING	COMPLETION	COMPLETED COST
COMPLIANCE	$500.00	$0.00	$500.00
LEGAL FEES & TITLE OPINIONS	0.00	0.00	0.00
SURVEY & STAKING	0.00	0.00	0.00
SURFACE DAMAGES	0.00	0.00	0.00
ADMINISTRATIVE OVERHEAD	500.00	0.00	500.00
PLUGGING BOND	0.00	0.00	0.00
MOVE IN & OUT, RIG UP	500.00	0.00	500.00
FOOTAGE 0 FT. @ $0/FT.	0.00	0.00	0.00
DAY RATE 1 DAYS @ $2,000.00/ DAY	2,000.00	0.00	2,000.00
BITS, REAMERS, DRILL PIPE	0.00	0.00	0.00
ELECTRICAL SURVEY, OPEN HOLE LOG	0.00	0.00	0.00
DRILL STEM TESTS	0.00	0.00	0.00
CORING, SWS, ANALYSIS	0.00	0.00	0.00
MUD, ADDITIVES, DIESEL & PKR FLUID	100.00	0.00	100.00
CEMENTING: SURFACE 0 FT.-	0.00	0.00	0.00
INTERMEDIATE	0.00	0.00	0.00
INJECTION STRING 3"	0.00	0.00	0.00
FLOAT EQUIP, CENTRALIZER	0.00	0.00	0.00
PERFORATING AND RADIO ACTIVE LOG	0.00	0.00	0.00
SWAB, BAILING, W.O. & COMPLETION CSPS UNIT	750.00	750.00	1,500.00
FRAC OR ACID-STIMULATION	250.00	0.00	250.00
STIMULATION TANK RENTAL	450.00	0.00	450.00
MISCELLANEOUS LABOR	750.00	0.00	750.00
ROADS, FENCING, LOCATION & PITS	70.00	0.00	70.00
WELL SITE GEOLOGIST	500.00	0.00	500.00
PETROLEUM ENGINEER	0.00	0.00	0.00
MUD LOGGING	0.00	0.00	0.00
COMMUNICATIONS	100.00	0.00	100.00
TRANSPORTATION & EQUIPMENT HAULING	500.00	0.00	500.00
ABANDONMENT, PLUGGING, & RESTORATION	1,500.00	0.00	1,500.00
FUEL, POWER, & WATER	250.00	0.00	250.00
SPECIAL SERVICES & RENTALS	250.00	0.00	250.00
WORKOVER OVERHEAD	500.00	0.00	500.00
CONTINGENCY	500.00	0.00	500.00
SUB-TOTAL	$9,970.00	$750.00	$10,720.00
TAX	579.51	43.59	623.10
TOTAL INTANGIBLE COSTS	$10,549.51	$793.59	$11,343.10

TANGIBLE COSTS	DRILLING	COMPLETION	COMPLETED COST
CASING: COND FT. OD @	$0.00	$0.00	$0.00
SURF 0 FT. 9.625" @ $/FT.	0.00	0.00	0.00
INTER FT. OD @	0.00	0.00	0.00
PROD 0 FT. 3" @ $/FT.	0.00	0.00	0.00
LINER	0.00	0.00	0.00
TUBING FT. @ $/FT.	0.00	0.00	0.00
RODS 0 FT. 3/4" @ $/FT.	0.00	0.00	0.00
WELL HEAD & SURFACE	0.00	200.00	200.00
SURFACE FLOAT EQUIPMENT	0.00	0.00	0.00
POLISH ROD ASSEMBLY	0.00	0.00	0.00
PRODUCTION PACKER	0.00	0.00	0.00
DOWN HOLE PUMP	0.00	10,150.00	10,150.00
SEPARATOR	0.00	0.00	0.00
TREATER	0.00	0.00	0.00
VALVES, FITTINGS, CHOKES AND GAUGES	0.00	0.00	0.00
PRODUCTION TANKS	0.00	0.00	0.00
WATER DISPOSAL TANK	0.00	0.00	0.00
GATES, FENCES AND SIGNS	0.00	260.00	260.00
TRIPLEX PUMP	0.00	0.00	0.00
POWER MOVER (SIZE AND TYPE)	0.00	0.00	0.00
ELECTRICAL EQUIPMENT	0.00	0.00	0.00
LINE PIPE & CONNECTIONS	0.00	0.00	0.00
ANCHORS	0.00	0.00	0.00
INSURANCE	50.00	0.00	50.00
CONTINGENCY	0.00	100.00	100.00
SUB-TOTAL	$50.00	$10,710.00	$10,760.00
TAX	2.91	622.52	625.43
TOTAL TANGIBLE COSTS	$52.91	$11,332.62	$11,385.43
TOTAL WELL COST	$10,602.41	$12,126.11	$22,728.53
Total for 17 wells		X 17	386,384.93

BIBIOGRAPHY

LIST OF ACRONYMS AND ABBREVIATIONS

English / Metric Units, Standards for Metric Conversion Factors (attached)

English/Metric Units
Standards for Metric Conversion Factors

The following conversion factors are those published by the American Society for Testing and Materials (ASTM) in E380-76. These same units may be found in literature published by all U. S. Technical Societies, i.e., API Bulletin 2563, American National Standards Institute ANSIZ 210.1, Society of Petroleum Engineers, The Canadian Petroleum Association (CPA) and others.

The metric units and conversion factors adopted by the ASTM are based on the "International System of Units" (designated SI for Systeme International d'Unites), fixed by the International Committee for Weights and Measures. This system has been adopted by the International Organization for Standardization in ISO Recommendation R-31.

Conversion factors herein are written as a number equal to or greater than one and less than ten with six or less decimal places. This number is followed by the letter E (for exponent), a plus or minus symbol, and two digits which indicate the power of 10 by which the number must be multiplied to obtain the correct value. For example:

(1) 3.523.907 E − 02 is $3.523.907 \times 10^{-2}$

or

0.035 239.07

(2) 3.386.389 E + 03 is $3.386.389 \times 10^{-3}$

or

3 386.389

(3) Further examples of conversion are:

To convert from:	*To:*	*Multiply by:*		
pound-force per square foot	Pa	4.788 026 E + 01	means -	1 lbf/ft^2 = 47.880 26 Pa
inch	m	2.540 000 E - 02		1 inch = 0.0254 m (exactly)

To convert from	*To*	*Multiply by*
	ANGLE	
degree (angle)	radian (rad)	1.745 329 E - 02
minute (angle)	radian (rad)	2.908 882 E - 04
second (angle)	radian (rad)	4.848 137 E - 06
	AREA	
acre (U.S. survey)	meter^2 (m^2)	4.046 873 E + 03
ft^2	meter^2 (m^2)	9.290 304 E - 02
hectar	meter^2 (m^2)	1.000 000 E + 04
in^2	meter^2 (m^2)	6.451 600 E - 04
mi^2 (U.S. survey)	meter^2 (m^2)	2.589 988 E + 06
yd^2	meter^2 (m^2)	8.361 274 E - 01
	CAPACITY (See Volume)	

To convert from:	*To:*	*Multiply by:*
	DENSITY	
	(See Mass Per Unit Volume)	
	ELECTRICITY AND MAGNETISM	
abampere	ampere (A)	1.000 000 E + 01
abohm	ohm (Ω)	1.000 000 E - 09
abvolt	volt (V)	1.000 000 E - 08
ampere hour	coulomb (C)	3.600 000 E + 03
ohm centimeter	ohm meter (Ωm)	1.000 000 E - 02
statampere	ampere (A)	3.335 640 E - 10
statohm	ohm (Ω)	8.987 554 E + 11
statvolt	volt (V)	2.997 925 E + 02
	ENERGY	
British thermal unit (International Table)	joule (J)	1.055 056 E + 03
British thermal unit (mean)	joule (J)	1.055 87 E + 03
British thermal unit (thermochemical)	joule (J)	1.054 350 E + 03
British thermal unit (39°F)	joule (J)	1.059 67 E + 03
British thermal unit (59°F)	joule (J)	1.054 80 E + 03
British thermal unit (60°F)	joule (J)	1.054 68 E + 03
calorie (International Table)	joule (J)	4.186 800 E + 00
calorie (mean)	joule (J)	4.190 02 E + 00
calorie (thermochemical)	joule (J)	4.184 000 E + 00
calorie (15°C)	joule (J)	4.185 80 E + 00
calorie (20°C)	joule (J)	4.181 90 E + 00
calorie (kilogram, International Table)	joule (J)	4.186 800 E + 03
calorie (kilogram, mean)	joule (J)	4.190 02 E + 03
calorie (kilogram, thermochemical)	joule (J)	4.184 000 E + 03
erg	joule (J)	1.000 000 E - 07
ft · lbf	joule (J)	1.355 818 E + 00
ft · poundal	joule (J)	4.214 011 E - 02
kilocalorie (International Table)	joule (J)	4.186 800 E + 03
kilocalorie (mean)	joule (J)	4.190 02 E + 03
kilocalorie (thermochemical)	joule (J)	4.184 000 E + 03
kW · h	joule (J)	3.600 000 E + 06
therm	joule (J)	1.055 056 E + 08
	ENERGY PER UNIT AREA TIME	
Btu (thermochemical) / $ft^2 \cdot s$	watt per meter^2 (W/m^2)	1.134 893 E + 04
Btu (thermochemical) / $ft^2 \cdot min$	watt per meter^2 (W/m^2)	1.891 489 E + 02
Btu (thermochemical) / $ft^2 \cdot h$	watt per meter^2 (W/m^2)	3.152 481 E + 00
Btu (thermochemical) / $in.^2 \cdot s$	watt per meter^2 (W/m^2)	1.634 246 E + 06
Btu (thermochemical) / $cm^2 \cdot min$	watt per meter^2 (W/m^2)	6.973 333 E + 02

To convert from:	*To:*	*Multiply by:*
	FLOW	
	(See Mass Per Unit Time or Volume Per Unit Time)	
	FORCE	
dyne	newton (N)	1.000 000 E - 05
kilogram-force	newton (N)	9.806 650 E + 00
ounce-force	newton (N)	2.780 139 E - 01
pound-force (lbf)	newton (N)	4.488 222 E + 00
poundal	newton (N)	1.382 550 E - 01
	FORCE PER UNIT AREA	
	(See Pressure)	
	HEAT	
Btu (International Table) ·ft / h · ft^2 · °F (k, thermal conductivity)	watt per meter kelvin (W / m · K)	1.730 735 E + 00
Btu (International Table) / ft^2	joule per meter ^{2} (J / m^2)	1.350 653 E + 04
cal (thermochemical)/ cm · s · °C	watt per meter kelvin (W / m · K)	4.184 000 E + 02
cal (thermochemical)/ cm^2	joule per meter ^{2} (J / m^2)	4.184 000 E + 04
	LENGTH	
angstrom	meter (m)	1.000 000 E - 10
foot	meter (m)	3.048 000 E - 01
foot (U.S. survey)	meter (m)	3.048 006 E - 01
inch	meter (m)	2.540 000 E - 02
micron	meter (m)	1.000 000 E - 06
mil	meter (m)	2.540 000 E - 05
mile (international nautical)	meter (m)	1.852 000 E + 03
mile (U.K. nautical)	meter (m)	1.853 184 E + 03
mile (U.S. nautical)	meter (m)	1.852 000 E + 03
mile (international)	meter (m)	1.609 344 E + 03
mile (statute)	meter (m)	1.609 3 E + 03
mile (U.S. survey)	meter (m)	1.609 347 E + 03
parsec	meter (m)	3.085 678 E + 16
yard	meter (m)	9.144 000 E + 01
	MASS	
grain	kilogram (kg)	6.479 891 E - 05
gram	kilogram (kg)	1.000 000 E - 03
hundredweight (long)	kilogram (kg)	5.080 235 E + 01
hundredweight (short)	kilogram (kg)	4.535 924 E + 01
ounce (avoirdupois)	kilogram (kg)	2.834 952 E - 02
ounce (troy or apothecary)	kilogram (kg)	3.110 348 E - 02
pennyweight	kilogram (kg)	1.555 174 E - 03

To convert from:	*To:*	*Multiply by:*
pound (lb avoirdupois)	kilogram (kg)	4.535 924 E - 01
pound (troy or apothecary)	kilogram (kg)	3.732 417 E - 01
slug	kilogram (kg)	1.459 390 E + 01
ton (assay)	kilogram (kg)	2.916 667 E - 02
ton (long, 2240 lb)	kilogram (kg)	1.016 047 E + 03
ton (metric)	kilogram (kg)	1.000 000 E + 03
ton (short, 2000 lb)	kilogram (kg)	9.071 847 E + 02
	MASS PER UNIT AREA	
oz/ft^2	kilogram per meter ^{2} (kg/m^2)	3.051 517 E - 01
lb/ft^2	kilogram per meter ^{2} (kg/m^2)	4.882 428 E + 00
	MASS PER UNIT CAPACITY **(See Mass Per Unit Volume)**	
	MASS PER UNIT TIME **(Includes Flow)**	
lb/h	kilogram per second (kg/s)	1.259 979 E - 04
lb/min	kilogram per second (kg/s)	7.559 873 E - 03
lb/s	kilogram per second (kg/s)	4.535 924 E - 01
	MASS PER UNIT VOLUME **(includes Density and Mass Capacity)**	
grain (lb avoirdupois/7000)/gal (U.S. liquid)	kilogram per meter^3 (kg/m^3)	1.711 806 E - 02
g/cm^3	kilogram per meter^3 (kg/m^3)	1.000 000 E + 03
oz (avoirdupois)/gal (U.K. liquid)	kilogram per meter^3 (kg/m^3)	6.236 021 E + 00
oz (avoirdupois)/gal (U.S. liquid)	kilogram per meter^3 (kg/m^3)	7.489 152 E + 00
oz (avoirdupois)/$in.^3$	kilogram per meter^3 (kg/m^3)	1.729 994 E + 03
lb/ft^3	kilogram per meter^3 (kg/m^3)	1.601 846 E + 01
$lb/in.^3$	kilogram per meter^3 (kg/m^3)	2.767 990 E + 04
lb/gal (U.K. liquid)	kilogram per meter^3 (kg/m^3)	9.977 633 E + 01
lb/gal (U.S. liquid)	kilogram per meter^3 (kg/m^3)	1.198 264 E + 02
lb/yd^3	kilogram per meter^3 (kg/m^3)	5.932 764 E - 01
$slug/ft^3$	kilogram per meter^3 (kg/m^3)	5.153 788 E + 02
	PERMEABILITY	
darcy	μm^3	9.869 233 E - 01
millidarcy	μm^3	9.869 233 E - 04
	POWER	
Btu (International Table)/h	watt (W)	2.930 711 E - 01
Btu (International Table)/s	watt (W)	1.055 056 E + 03
Btu (thermochemical)/h	watt (W)	2.928 751 E - 01
Btu (thermochemical)/min	watt (W)	1.757 250 E + 01
Btu (thermochemical)/s	watt (W)	1.054 350 E + 03
cal (thermochemical)/min	watt (W)	6.973 333 E - 02

To convert from:	*To:*	*Multiply by:*
cal (thermochemical)/s	watt (W)	4.184 000 E + 00
erg/s	watt (W)	1.000 000 E - 07
ft · lbf / h	watt (W)	3.766 161 E - 04
ft · lbf / min	watt (W)	2.259 697 E - 02
ft · lbf / s	watt (W)	1.355 818 E + 00
horsepower (550 ft · lbf / s)	watt (W)	7.456 999 E + 02
horsepower (boiler)	watt (W)	9.809 50 E + 03
horsepower (electric)	watt (W)	7.460 000 E + 02
horsepower (metric)	watt (W)	7.354 99 E + 02
horsepower (water)	watt (W)	7.450 43 E + 02
horsepower (U.K.)	watt (W)	7.457 0 E + 02
kilocaloric (thermochemical)/min	watt (W)	6.973 333 E + 01
kilocaloric (thermochemical)/s	watt (W)	4.184 000 E + 03
	PRESSURE OR STRESS (Force Per Unit Area)	
atmosphere (standard)	pascal (Pa)	1.013 250 E + 05
atmosphere (technical = 1 kgf/cm^2)	pascal (Pa)	9.806 650 E + 04
bar	pascal (Pa)	1.000 000 E + 05
centimeter of mercury (0°C)	pascal (Pa)	1.333 22 E + 03
centimeter of water (4°C)	pascal (Pa)	9.806 38 E + 01
dyne/cm^2	pascal (Pa)	1.000 000 E - 01
foot of water (39.2°F)	pascal (Pa)	2.988 98 E + 03
gram-force/cm^2	pascal (Pa)	9.806 650 E + 01
inch of mercury (32°F)	pascal (Pa)	3.386 38 E + 03
inch of mercury (60°F)	pascal (Pa)	3.376 85 E + 03
inch of water (39.2°F)	pascal (Pa)	2.490 82 E + 02
inch of water (60°F)	pascal (Pa)	2.488 4 E + 02
millibar	pascal (Pa)	1.000 000 E + 02
millimeter of mercury (0°C)	pascal (Pa)	1.333 22 E + 02
poundal/ft^2	pascal (Pa)	1.488 164 E + 00
lbf/ft^2	pascal (Pa)	4.788 026 E + 01
lbf/in^2	pascal (Pa)	6.894 757 E + 03
psi	pascal (Pa)	6.894 757 E + 03
	STRESS (See Pressure)	
	TEMPERATURE	
degree Celsius	kelvin (K)	$T_{°K} = T_{°C} + 273.15$
degree Fahrenheit	degree Celsius	$T_{°C} = (T_{°F} - 32)/1.8$
degree Fahrenheit	kelvin (K)	$T_{°K} = (T_{°F} + 459.67)/1.8$
degree Rankine	kelvin (K)	$T_{°K} = T_{°R}/1.8$
kelvin	degree Celsius	$T_{°C} = T_{°R} - 273.15$

To convert from:	*To:*	*Multiply by:*
	VISCOSITY	
Centipoise	pascal second (Pa · s)	1.000 000 E - 03
centistokes	$meter^2$ per second (m^2/s)	1.000 000 E - 06
poise	pascal second (Pa · s)	1.000 000 E - 01
poundal · s / ft^2	pascal second (Pa · s)	1.488 164 E + 00
stokes	$meter^2$ per second (m^2/s)	1.000 000 E - 04
	VOLUME **(Includes Capacity)**	
acre-foot (U.S. survey)	$meter^3$ (m^3)	1.233 489 E + 03
barrel (oil, 42 gal)	$meter^3$ (m^3)	1.589 873 E - 01
fluid ounce (U.S.)	$meter^3$ (m^3)	2.957 353 E - 05
ft^3	$meter^3$ (m^3)	2.831 685 E - 02
gallon (Canadian liquid)	$meter^3$ (m^3)	4.546 090 E -03
gal (U.K. liquid)	$meter^3$ (m^3)	4.546 092 E - 03
gallon (U.S. dry)	$meter^3$ (m^3)	4.404 884 E - 03
gallon (U.S. liquid	$meter^3$ (m^3)	3.785 412 E - 03
$in.^3$	$meter^3$ (m^3)	1.638 706 E - 05
liter	$meter^3$ (m^3)	1.000 000 E - 03
ounce (U.K. fluid)	$meter^3$ (m^3)	2.841 307 E - 05
ounce (U.S. fluid)	$meter^3$ (m^3)	2.957 353 E - 05
pint (U.S. dry)	$meter^3$ (m^3)	5.506 105 E - 04
pint (U.S. liquid)	$meter^3$ (m^3)	4.731 765 E - 04
quart (U.S. dry)	$meter^3$ (m^3)	1.101 221 E - 03
quart (U.S. liquid)	$meter^3$ (m^3)	9.463 529 E - 04
ton (register	$meter^3$ (m^3)	2.831 685 E + 00
yd^3	$meter^3$ (m^3)	7.645 549 E - 01
	VOLUME PER UNIT TIME **(Includes Flow)**	
ft^3/min	$meter^3$ per second (m^3/s)	4.719 474 E - 04
gallon (U.S. liquid)/hp · h (SFC, specific fuel consumption)	$meter^3$ per joule (m^3/s)	1.410 089 E - 09
$in.^3$/min	$meter^3$ per second (m^3/s)	2.731 177 E - 07
yd^3/min	$meter^3$ per second (m^3/s)	1.274 258 E - 02
gallon (U.S. liquid) per day	$meter^3$ per second (m^3/s)	4.381 264 E - 08
gallon (U.S. liquid) per minute	$meter^3$ per second (m^3/s)	6.309 020 E - 05
	WORK **(See Energy)**	

APPENDIX

NETL F 510.1-5 (attached)