Distribution Category
UC-13

LAWRENCE LIVERMORE LABORATORY

University of California/Livermore, California/94550

UCRL-51861

# PERFORMANCE TEST OF A LYSHOLM ENGINE

H. Weiss

R. Steidel

A. Lundberg

MS. date: July 3, 1975

## DISCLAIMER

# DISCLAIMER

# PERFORMANCE TEST OF A LYSHOLM ENGINE


## Abstract

The Geothermal Energy Program at the Lawrence Livermore Laboratory emphasizes energy conversion by means of the Total Flow process. One candidate energy conversion machine is the Lysholm engine or helical rotary screw expander.

Recent performance tests conducted by LLL in its Geothermal Test Facility on a Lysholm engine yielded 49 data test points. Maximum engine efficiencies of 49% at 16 kW for 3000 rpm, 53% at 23 kW for 4000 rpm, and 55% at 30 kW for 5000 rpm, were observed, using steam-water mixtures varying in vapor fraction from 11.6% to 34%.

It is concluded that the Lysholm engine can operate effectively on a two-phase mixture approximating that from a geothermal resource, and that it is a viable candidate machine for the Total Flow energy conversion process.

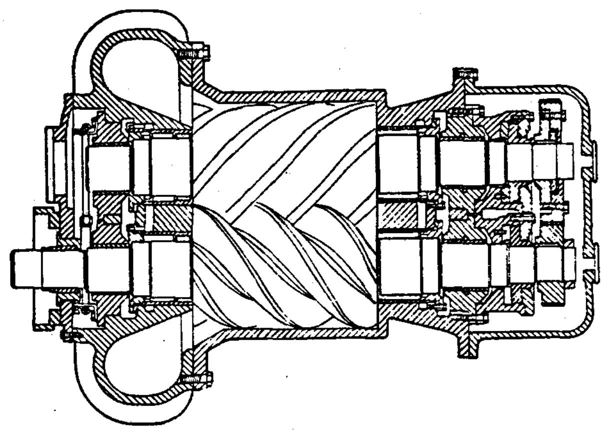

## Introduction

The Geothermal Energy Program at the Lawrence Livermore Laboratory (LLL) emphasizes energy conversion for hydrothermal resources by means of the Total Flow process, which has the potential for the greatest efficiency of utilization of the available energy, i.e., direct expansion of the wellhead fluid in the conversion machine. This contrasts with other processes that either transfer heat energy to a second fluid, or use only the vapor fraction and discard the liquid.[1]

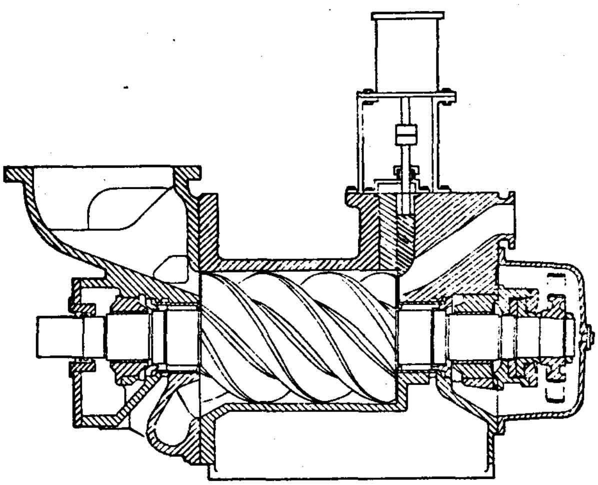
Generally, the wellhead condition of geothermal fluids is a mixture of liquid and vapor, with quality (vapor fraction) up to 40%. Pressure and temperature may be as high as 400 psia (2.75 MPa) and 450°F (505 K), respectively. Dissolved minerals comprise up to 30% by weight, in some cases.

The variety of geothermal resources, with regard to thermodynamic state and chemistry, requires the complete understanding of many different machines and systems. One candidate machine for the Total Flow process is the Lysholm engine, also known as the helical rotary screw expander. It is a positive-displacement machine that takes in a discrete volume of fluid and allows it to expand to do work.

The Lysholm design is perhaps best known as a gas compressor, and is manufactured in a wide range of sizes by a number of companies throughout the world. As an expander, its features are very attractive for hostile environments. The rotors are basically rugged and their action, in the housing and with each other, tends to keep the parts free of scale.



PLAN SECTION VIEW



SIDE SECTION VIEW

Fig. 1. A 4 + 6 lobed Lysholm machine adapted for hot brine expansion. The male rotor drives the output shaft.

Historically, Lysholm's paper of 1966 described the basic expander application.[2] The rugged characteristics of the engine for use in severe environments were recognized by Wells et al.[3] At LLL the Lysholm engine has been studied extensively for high temperature applications[3] and as a topping engine for Rankine cycles.[4]

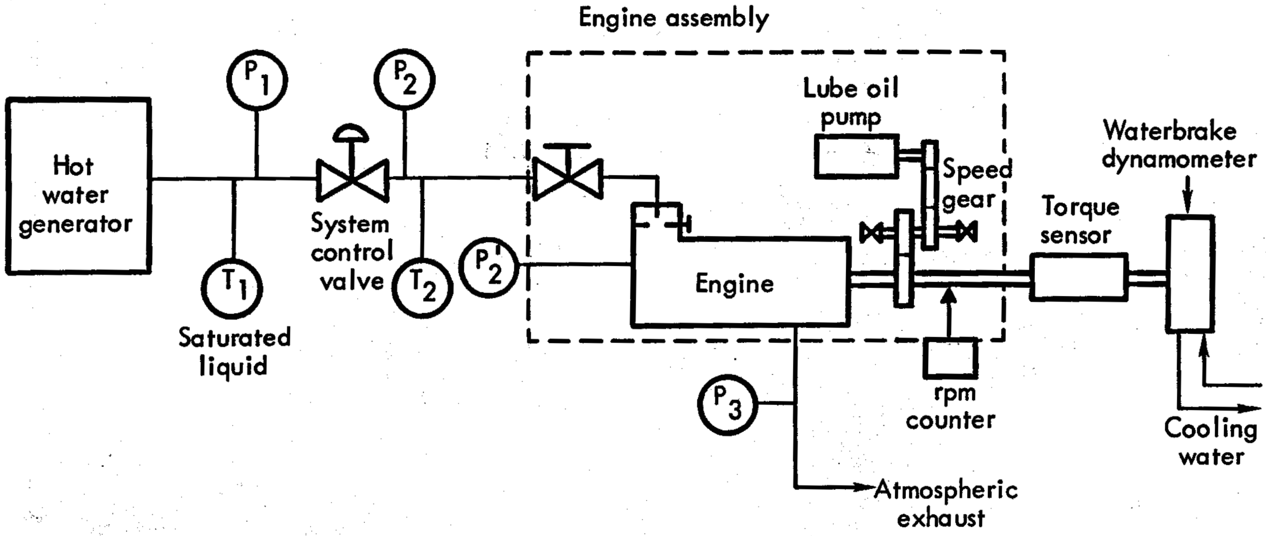
The basic concept of the Lysholm engine for geothermal applications has been demonstrated by field tests of an air compressor unit, with 6-in. rotors, modified by the Hydrothermal Power Company, Ltd. (HPC).[5] Figure 1 is a diagram of the concept. Tests have been conducted by HPC at the Cerro Prieto field in Mexico and at the East Mesa geothermal field in the Imperial Valley of California. In both locations the tests were limited by the available wellhead conditions. The latter tests are reported in Ref. 5.

In order to gain a better understanding of the capabilities of the Lysholm engine over a wider range of inlet conditions, closely controlled tests with more precise measurements were conducted by the Lawrence Livermore Laboratory in its Geothermal Test Facility.[6]

## Test Description

A schematic diagram of the test set-up is shown in Fig. 2. Inlet pressure to the rotors was varied from 24.4 psia (0.17 MPa) to 76.5 psia (0.51 MPa). Vapor fraction (quality) ranged from 11.6% to 33.3%. In all tests the exhaust pressure was one atmosphere. Figure 3 is a temperature-entropy diagram showing the state points of the fluid at various locations. Figure 4 depicts the HPC expander under test.

As indicated in test schematic diagram, the performance of the engine was determined by means of speed and torque measurements in conjunction with a waterbrake dynamometer. Water flow




$P_1$ = Control valve upstream pressure (psia).
$T_1$ = Control valve upstream temperature (°F).
$P_2$ = Engine pressure inlet.
$T_2$ = Engine expander inlet temperature.
$P_3$ = Line exhaust pressure
$P_2'$ = Pressure at inlet to rotor.

Fig. 2. Lysholm engine test setup, flow schematic.

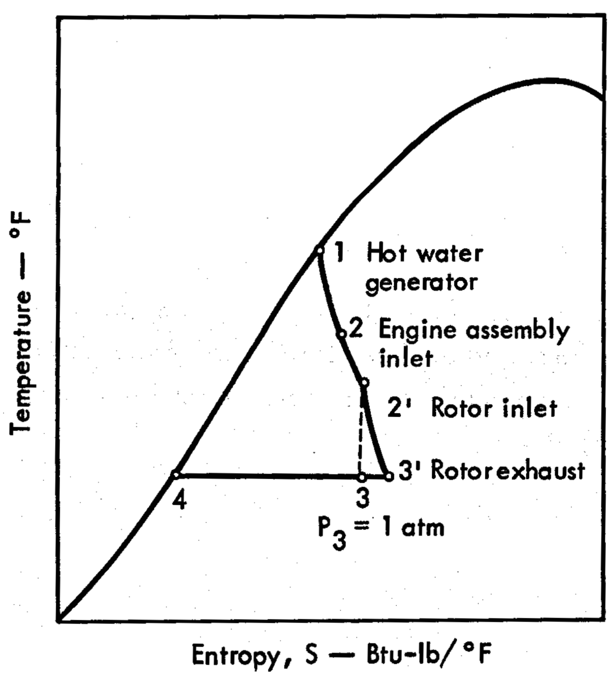



Fig. 3. Temperature-entropy diagram depicting the state points of the fluid at various locations.

rate was measured in the compressed liquid state, just before the system control valve.

The complete engine assembly, as provided by HPC, included a speed reducer and a pump for lubricating oil. The pump power loss was determined from manufacturer's data. The power lost in the speed reducer was measured separately. Both were added to the measured power to give the total output of the engine. See Fig. 5.

In operation, the water heater pressure established state point 1 (Fig. 3), and throttling through the system control valve to a prescribed pressure defined state 2, the inlet to the HPC assembly. Within the HPC assembly, two other valves controlled the flow rate. One was

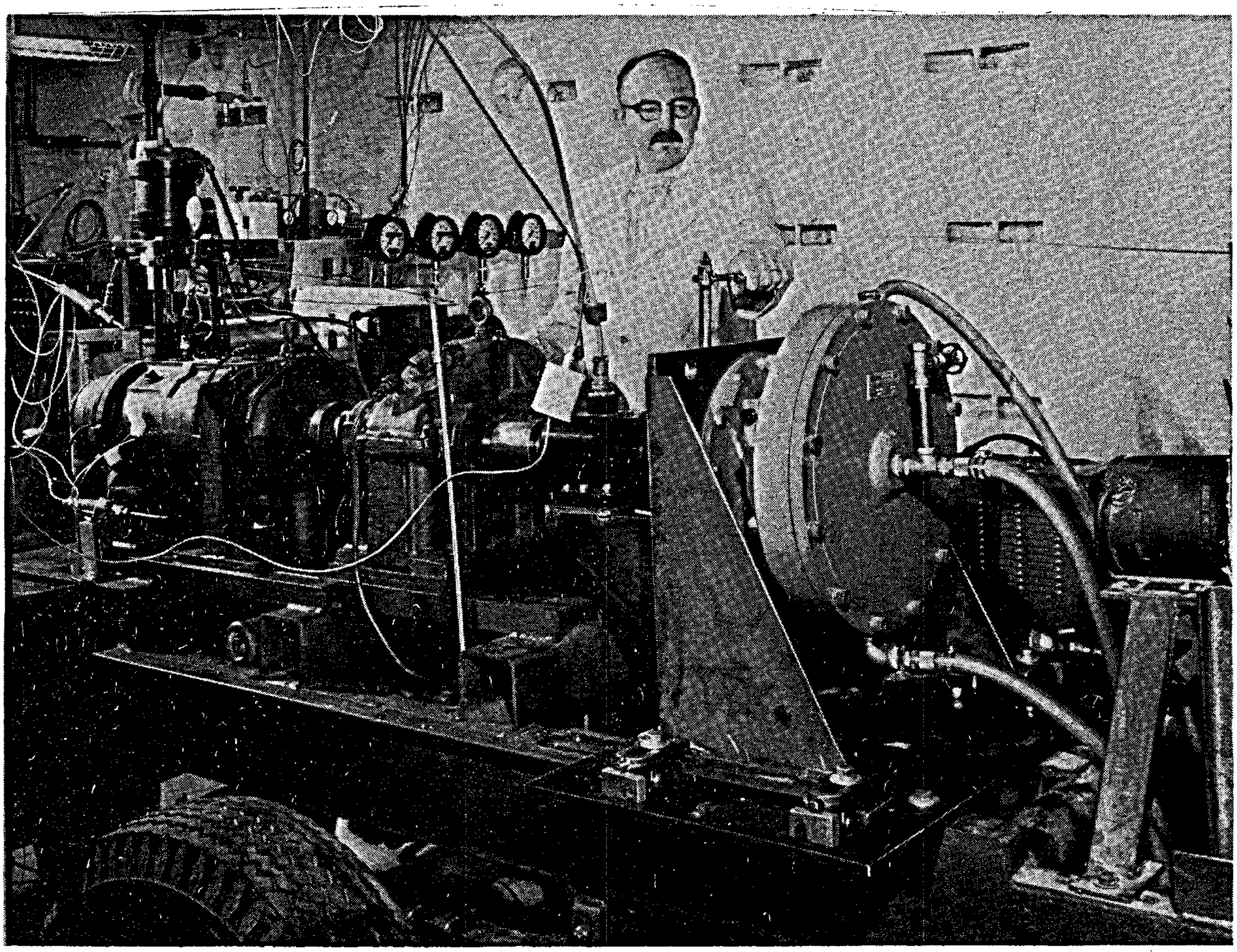


Fig. 4. The HPC brine expander under test.

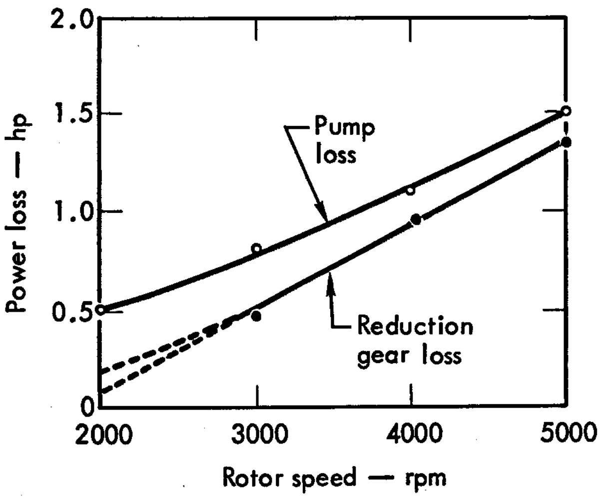



Fig. 5. HPC brine expander power losses as functions of rotor speed.

a gate valve and the other was a governor-controlled orifice plate at the roter inlet. The pressure at the rotor inlet is defined as $P_{2'}$.

# Test Data and Computations

The reduced and calculated values are given in Tables 1, 2, and 3 for 3000, 4000, 5000 rpm respectively. The raw data are given in Tables 4 and 5. Each test point is identified by a test number and date, viz., 3-5/4-10 is for condition 3, run 5 on 10 April. Included in the tables are the efficiencies and power output calculated from the measured values of speed, torque, flow rate, and input enthalpy and the parasitic loads.

In the calculations it was assumed that the inlet enthalpy to the expander is defined by the saturated liquid condition at state point 1, and that pressure drops through the gate valve and the orifice plate are pure throttling processes, i.e., constant enthalpy. In all cases, the exhaust pressure $P_3$, was assumed to be atmospheric pressure.

Referring to the diagram in Fig. 3, the efficiences are defined as follows;

Table 1. Lysholm engine performance at 3000 rpm nominal speed.

| Test No./date | Speed (rpm) | $P_2'/P_3$ | Flow, (lb/sec) | Power (kW) | Engine efficiency ($\eta_e$) | Thermal efficiency ($\eta_e$) | Water rate (lb/kW-hr) |
|---|---|---|---|---|---|---|---|
| 1—4/4-8 | 3025 | 2.042 | 0.975 | 0.97 | 0.1150 | 0.0055 | 3619 |
| 1—5/4-8 | 3106 | 2.736 | 1.410 | 9.517 | 0.5043 | 0.0332 | 533 |
| 2—1/4-8 | 2975 | 1.903 | 0.651 | 0.970 | 0.1349 | 0.0061 | 2415 |
| 2—2/4-8 | 2975 | 3.083 | 1.187 | 10.477 | 0.4632 | 0.0347 | 408 |
| 2—3/4-8 | 3050 | 2.944 | 1.153 | 9.905 | 0.4673 | 0.0338 | 419 |
| 3—1/4-8 | 3012 | 1.694 | 0.656 | 0.970 | 0.1327 | 0.0050 | 2435 |
| 3—2/4-8 | 2950 | 3.153 | 1.084 | 12.231 | 0.4635 | 0.0362 | 319 |
| 4—2/4-8 | 2975 | 3.292 | 0.940 | 12.326 | 0.4424 | 0.0363 | 275 |
| 4—3/4-8 | 3050 | 4.194 | 1.320 | 21.322 | 0.4503 | 0.0436 | 219 |
| 3—1/4-10 | 3000 | 2.034 | 0.697 | 1.766 | 0.2076 | 0.0103 | 1421 |
| 3—2/4-10 | 2981 | 2.931 | 1.071 | 8.644 | 0.4307 | 0.0311 | 711 |
| 3—3/4-10 | 3018 | 3.621 | 1.289 | 13.294 | 0.4662 | 0.0393 | 349 |
| 4—1/4-10 | 2962 | 2.034 | 0.530 | 1.496 | 0.1825 | 0.0092 | 1275 |
| 4—2/4-10 | 3062 | 3.207 | 0.974 | 11.300 | 0.4690 | 0.0372 | 310 |
| 4—7/4-10 | 3069 | 3.759 | 1.088 | 15.409 | 0.4797 | 0.0429 | 254 |
| 5—2/4-10 | 2981 | 3.897 | 1.071 | 16.054 | 0.4309 | 0.0400 | 240 |
| 5—3/4-10 | 3025 | 5.260 | 1.391 | 25.407 | 0.4363 | 0.0483 | 197 |

Table 2. Lysholm engine performance at 4000 rpm nominal speed.

| Test No./date | Speed (rpm) | $P_{2'}/P_3$ | Flow (lb/sec) | Power (kW) | Engine efficiency ($\eta_e$) | Thermal efficiency ($\eta_t$) | (Water rate (lb/kW-hr) |
|---|---|---|---|---|---|---|---|
| 1—6/4-8 | 4012 | 2.042 | 1.492 | 1.492 | 0.1459 | 0.0071 | 2531 |
| 1—7/4-8 | 4062 | 2.597 | 1.775 | 9.786 | 0.4912 | 0.0304 | 653 |
| 2—4/4-8 | 3918 | 2.042 | 0.812 | 1.492 | 0.1466 | 0.0073 | 1960 |
| 2—5/4-8 | 3975 | 2.667 | 1.187 | 9.255 | 0.4629 | 0.0307 | 462 |
| 2—6/4-8 | 3975 | 3.014 | 1.400 | 13.843 | 0.5274 | 0.0388 | 364 |
| 3—4/4-8 | 3962 | 1.972 | 0.788 | 2.547 | 0.2209 | 0.0106 | 1114 |
| 3—5/4-8 | 3931 | 3.292 | 1.276 | 15.800 | 0.5017 | 0.0404 | 291 |
| 3—6/4-8 | 4100 | 3.639 | 1.549 | 21.146 | 0.5187 | 0.0448 | 264 |
| 3—8/4-8 | 3912 | 4.681 | 1.889 | 30.664 | 0.5160 | 0.0521 | 218 |
| 3—4/4-10 | 3981 | 3.069 | 1.361 | 13.155 | 0.4887 | 0.0367 | 273 |
| 3—9/4-10 | 3956 | 2.034 | 0.853 | 2.546 | 0.2340 | 0.0116 | 1206 |
| 4—3/4-10 | 4018 | 3.069 | 1.097 | 13.263 | 0.5015 | 0.0384 | 298 |
| 4—6/4-10 | 3962 | 4.103 | 1.437 | 22.244 | 0.4979 | 0.0470 | 233 |
| 4—8/4-10 | 3906 | 2.172 | 0.636 | 2.532 | 0.2268 | 0.0124 | 904 |
| 5—4/4-10 | 3981 | 5.000 | 1.306 | 23.403 | 0.4417 | 0.0475 | 201 |
| 5—5/4-10 | 4075 | 5.000 | 1.550 | 30.432 | 0.4827 | 0.0520 | 183 |

Engine efficiency, $\eta_e = \dfrac{h_{2'} - h_{3'}}{h_{2'} - h_3}$

$$= \frac{(3412)\ \text{kW}}{\dot{m}\ (h_{2'} - h_3)} \quad (1)$$

Thermal efficiency, $\eta_t = \dfrac{h_{2'} - h_{3'}}{h_{2'} - h_4}$

$$= \frac{(3412)\ \text{kW}}{\dot{m}\ (h_{2'} - h_4)}. \quad (2)$$

Here:

$h_{2'}$ = enthalpy at expander inlet, Btu/lb,

$h_{3'}$ = enthalpy at expander outlet, Btu/lb,

$h_3$ = enthalpy at expander outlet, assuming an isentropic drop, Btu/lb,

$h_4$ = enthalpy of the feedwater at exhaust pressure $P_3$, Btu/lb,

$\dot{m}$ = flow rate, lb/hr,

kW = power, kilowatts.

With $\eta_e$ known by means of the power output, the actual enthalpy drop can be calculated from Eq. (1)

$$h_{2'} - h_{3'} = \eta_e\ (h_{2'} - h_3) \quad (3)$$

which yields $h_{3'}$,

$$h_{3'} = h_{2'} - \eta_e\ (h_{2'} - h_3). \quad (4)$$

Table 3. Lysholm engine performance at 5000 rpm nominal speed.

| Test No./date | Speed (rpm) | $P_{2'}/P_3$ | Flow (lb/sec) | Power (kW) | Engine efficiency ($\eta_e$) | Thermal efficiency ($\eta_t$) | Water rate (lb/kW-hr) |
|---|---|---|---|---|---|---|---|
| 1—8/4-8 | 4925 | 2.250 | 1.350 | 2.126 | 0.1436 | 0.0078 | 2286 |
| 1—9A/4-8 | 5056 | 2.528 | 1.795 | 9.756 | 0.4583 | 0.0280 | 662 |
| 1—9B/4-8 | 5056 | 2.528 | 1.674 | 7.961 | 0.4144 | 0.0252 | 757 |
| 2—7/4-8 | 5006 | 2.511 | 0.999 | 2.126 | 0.1604 | 0.0083 | 1690 |
| 2—8/4-8 | 4987 | 2.667 | 1.305 | 9.652 | 0.4352 | 0.0289 | 487 |
| 3—9/4-8 | 4918 | 2.042 | 0.904 | 2.999 | 0.2174 | 0.0110 | 1117 |
| 3—10/4-8 | 4987 | 3.222 | 1.438 | 18.064 | 0.5232 | 0.0415 | 262 |
| 3—11/4-8 | 4868 | 4.056 | 1.845 | 29.352 | 0.5529 | 0.0513 | 226 |
| 3—5/4-10 | 4931 | 3.414 | 1.782 | 19.636 | 0.5191 | 0.0421 | 327 |
| 3—6/4-10 | 4956 | 3.414 | 1.507 | 13.565 | 0.4292 | 0.0347 | 400 |
| 3—10/4-10 | 4925 | 2.241 | 1.050 | 3.875 | 0.2573 | 0.0144 | 976 |
| 4—4/4-10 | 4943 | 3.414 | 1.312 | 17.046 | 0.4920 | 0.0409 | 277 |
| 4—5/4-10 | 5018 | 3.897 | 1.570 | 24.845 | 0.5358 | 0.0489 | 228 |
| 4—9/4-10 | 4931 | 2.241 | 0.826 | 3.877 | 0.2578 | 0.0147 | 767 |
| 5—1/4-10 | 4931 | 1.828 | 0.808 | 3.877 | 0.3000 | 0.0131 | 750 |
| 5—6/4-10 | 4906 | 5.000 | 1.695 | 35.226 | 0.5115 | 0.0551 | 173 |

Table 4. Lysholm engine test data, April 8, 1975.

| Run No. | $P_1$ | $T_1$ | $P_2$ | $P_{2'}$ | $P_3$ | $\dot{m}$ | Torque | Speed | Losses |
|---|---|---|---|---|---|---|---|---|---|
| | (psia) | (°F) | (psia) | (psia) | (psia) | (lb/sec) | (in.-lb) | (rpm) | (hp) |
| 1-1 | 482 | 379 | 126.8 | 24.4 | 14.4 | 0.668 | 1.0 | 2068 | 0.70 |
| 1-2 | 404.3 | 382.6 | 108.0 | 44.4 | 14.4 | 1.42 | 345.0 | 1950 | 0.70 |
| 1-3 | 407.2 | 380.7 | 102.5 | 47.4 | 14.4 | 1.74 | 367.5 | 2425 | 0.70 |
| 1-4 | 453.6 | 375.6 | 118.3 | 29.4 | 14.4 | 0.97 | 1.0 | 3025 | 1.30 |
| 1-5 | 435.4 | 396.7 | 108.7 | 39.4 | 14.4 | 1.41 | 232.5 | 3106 | 1.30 |
| 1-6 | 462.8 | 393.6 | 117.5 | 29.4 | 14.4 | 1.05 | 1.0 | 4012 | 2.00 |
| 1-7 | 370.9 | 377.4 | 99.4 | 37.4 | 14.4 | 1.77 | 172.5 | 4062 | 2.00 |
| 1-8 | 451.4 | 394.5 | 111.3 | 32.4 | 14.4 | 1.35 | 1.0 | 4925 | 2.85 |
| 1-9A | 402.7 | 388.8 | 99.0 | 36.4 | 14.4 | 1.79 | 127.5 | 5056 | 2.85 |
| 1-9B | 402.8 | 383.9 | 100.4 | 36.4 | 14.4 | 1.67 | 97.5 | 5056 | 2.85 |
| 2-1 | 578.4 | 432.7 | 122.8 | 27.4 | 14.4 | 0.65 | 1.0 | 2975 | 1.30 |
| 2-2 | 543.4 | 440.9 | 113.8 | 44.4 | 14.4 | 1.19 | 270.0 | 2975 | 1.30 |
| 2-3 | 541.3 | 440.9 | 113.0 | 42.4 | 14.4 | 1.15 | 247.5 | 3050 | 1.30 |
| 2-4 | 552.0 | 438.0 | 120.0 | 29.4 | 14.4 | 0.81 | 1.0 | 3918 | 2.00 |
| 2-5 | 543.0 | 440.3 | 113.6 | 38.4 | 14.4 | 1.19 | 165.0 | 3975 | 2.00 |
| 2-6 | 516.9 | 441.0 | 108.1 | 43.4 | 14.4 | 1.40 | 262.5 | 3975 | 2.00 |
| 2-7 | 548.5 | 441.5 | 117.2 | 30.4 | 14.4 | 0.99 | 1.0 | 5006 | 2.85 |
| 2-8 | 523.6 | 442.0 | 110.5 | 38.4 | 14.4 | 1.31 | 127.5 | 4987 | 2.85 |
| 3-1 | 801.6 | 474.3 | 122.5 | 24.4 | 14.4 | 0.66 | 1.0 | 3012 | 1.30 |
| 3-2 | 763.9 | 488.3 | 121.5 | 45.4 | 14.4 | 1.08 | 322.5 | 2950 | 1.30 |
| 3-3 | 793.6 | 492.2 | 124.6 | 49.4 | 14.4 | 1.27 | 420.0 | 3162 | 1.30 |
| 3-4 | 800.7 | 481.8 | 129.2 | 28.4 | 14.4 | 0.79 | 22.5 | 3962 | 2.00 |
| 3-5 | 782.7 | 484.2 | 130.2 | 47.4 | 14.4 | 1.28 | 307.5 | 3931 | 2.00 |
| 3-6 | 753.5 | 482.7 | 127.6 | 52.4 | 14.4 | 1.55 | 405 | 4100 | 2.00 |
| 3-8 | 622.9 | 488.7 | 161.68 | 67.4 | 14.4 | 1.89 | 630 | 3912 | 2.00 |
| 3-9 | 800.9 | 480.9 | 168.6 | 29.4 | 14.4 | 0.90 | 15.0 | 4918 | 2.85 |
| 3-10 | 760.9 | 481.5 | 157.8 | 46.4 | 14.4 | 1.44 | 270.0 | 4987 | 2.85 |
| 3-11 | 635.0 | 487.0 | 171.4 | 58.4 | 14.4 | 1.85 | 472.5 | 4868 | 2.85 |
| 4-1 | 1075.8 | 392.4 | 219.0 | 27.4 | 14.4 | 0.59 | 22.5 | 3000 | 1.30 |
| 4-2 | 1029.5 | 527.7 | 193.5 | 47.4 | 14.4 | 0.94 | 322.5 | 2975 | 1.30 |
| 4-3 | 1076.7 | 530.4 | 207.8 | 60.4 | 14.4 | 1.32 | 555.0 | 3050 | 1.30 |
| 4-4 | 992.5 | 536.7 | 202.8 | 64.4 | 14.4 | 1.50 | 630.0 | 3556 | 1.65 |
| 4-5 | 1014.2 | 536.5 | 202.8 | 70.4 | 14.4 | 1.64 | 622.5 | 4212 | 2.00 |
| 4-7 | 1039.5 | 392.2 | 220.6 | 31.4 | 14.4 | 0.84 | 15.0 | 5006 | 2.85 |

Table 5. Lysholm engine test data, April 10, 1975.

| Run No. | $P_1$ | $T_1$ | $P_2$ | $P_{2'}$ | $P_3$ | $\dot{m}$ | Torque | Speed | Losses |
|---|---|---|---|---|---|---|---|---|---|
| | (psia) | (°F) | (psia) | (psia) | (psia) | (lb/sec) | (in.-lb) | (rpm) | (hp) |
| 3-1 | 796.4 | 434.4 | 177.1 | 29.5 | 14.5 | 0.69 | 22.5 | 2988 | 1.30 |
| 3-2 | 814.3 | 445.5 | 207.5 | 42.5 | 14.5 | 1.07 | 217.5 | 2981 | 1.30 |
| 3-3 | 737.3 | 448.0 | 230.9 | 52.5 | 14.5 | 1.29 | 345.0 | 3018 | 1.30 |
| 3-4 | 793.7 | 448.8 | 231.8 | 44.5 | 14.5 | 1.36 | 247.5 | 3981 | 2.00 |
| 3-5 | 619.6 | 447.6 | 206.5 | 49.5 | 14.5 | 1.78 | 300.0 | 4931 | 2.85 |
| 3-6 | 732.4 | 445.3 | 226.4 | 49.5 | 14.5 | 1.51 | 195.0 | 4956 | 2.85 |
| 3-7 | 791.0 | 404.9 | 215.9 | 39.5 | 14.5 | 1.18 | 165.0 | 3988 | 2.00 |
| 3-8 | 778.8 | 406.2 | 220.9 | 36.5 | 14.5 | 0.91 | 150.0 | 3025 | 1.30 |
| 3-9 | 814.3 | 443.1 | 229.2 | 29.5 | 14.5 | 0.85 | 22.5 | 3956 | 2.00 |
| 3-10 | 794.6 | 443.1 | 209.8 | 32.5 | 14.5 | 1.05 | 30.0 | 4925 | 2.85 |
| 4-1 | 925.0 | 485.2 | 219.1 | 29.5 | 14.5 | 0.53 | 15.0 | 2962 | 1.30 |
| 4-2 | 876.5 | 489.2 | 209.8 | 46.5 | 14.5 | 0.97 | 285.0 | 3062 | 1.30 |
| 4-3 | 861.5 | 491.1 | 217.9 | 44.5 | 14.5 | 1.09 | 247.5 | 4018 | 2.00 |
| 4-4 | 862.4 | 493.5 | 220.3 | 49.5 | 14.5 | 1.31 | 255.0 | 4943 | 2.85 |
| 4-5 | 938.5 | 498.7 | 207.9 | 56.5 | 14.5 | 1.57 | 382.5 | 5018 | 2.85 |
| 4-6 | 870.0 | 503.0 | 206.8 | 59.5 | 14.5 | 1.44 | 442.5 | 3962 | 2.00 |
| 4-7 | 875.0 | 503.9 | 210.9 | 54.5 | 14.5 | 1.09 | 397.5 | 3069 | 1.30 |
| 4-8 | 934.3 | 495.9 | 218.2 | 31.5 | 14.5 | 0.64 | 22.5 | 3906 | 2.00 |
| 4-9 | 917.5 | 495.6 | 215.9 | 32.5 | 14.5 | 0.83 | 30.0 | 4931 | 2.85 |
| 5-1 | 1092.7 | 532.9 | 224.7 | 26.5 | 14.5 | 0.81 | 30.0 | 4931 | 2.85 |
| 5-2 | 1070.3 | 538.3 | 212.6 | 56.5 | 14.5 | 1.07 | 427.5 | 2981 | 1.30 |
| 5-3 | 1025.4 | 540.7 | 207.1 | 76.5 | 14.5 | 1.39 | 682.5 | 3025 | 1.30 |
| 5-4 | 1047.5 | 539.9 | 210.5 | 72.5 | 14.5 | 1.31 | 465.0 | 3981 | 2.00 |
| 5-5 | 1029.5 | 540.5 | 205.7 | 72.5 | 14.5 | 1.55 | 600.0 | 4075 | 2.00 |
| 5-6 | 1027.3 | 540.3 | 202.9 | 72.5 | 14.5 | 1.69 | 570.0 | 4906 | 2.85 |
| 5-8 | 1049.9 | 531.3 | 217.9 | 32.5 | 14.5 | 0.69 | 30.0 | 4837 | 2.85 |

## Results

It is essential, in evaluating these results, to remember that they describe the performance characteristics of a Lysholm engine running on a mixture of water and steam. The performance of a Lysholm compressor is well documented. Adiabatic compressor efficiency or engine efficiency, the fundamental measure of performance, has been typically reported as a function of pressure ratio.[7] Similarly, as an expander using a gas, e.g., a argon or helium, as the working fluid, performance has been related to pressure ratio.[3] The same treatment might therefore seem appropriate to characterize the performance of the Lysholm engine using geothermal fluid as a working medium.

In these tests the working fluid is a steam-water mixture with a quality of 15-35%, not a gas. It is not obvious that performance would be clearly related to pressure ratio. No performance characteristics for any engine using a range of low-quality mixtures as working fluids are known. For a steam engine, performance is measured in terms of engine efficiency, thermal efficiency, and water rate, i.e., the flow necessary to generate 1 kW of power, as functions of power output. Measuring these quantities as functions of power output also seems appropriate for the Lysholm engine.

In grouping the data for analysis, what variable should be constant: inlet pressure, inlet enthalpy, speed, or pressure ratio? The speed of the output shaft was selected, and on that basis, seven test points were excluded from the analysis. Only two test points were taken nominally at 2000 rpm, and these were discarded as insufficient data.
The test points at 2425, 3162, 3556, 4212, and 4837 rpm were arbitrarily excluded because they were too far removed from any nominal speed. The largest deviation accepted was 132 rpm for test 3-11/4-8.

Four other tests, 4-1/4-8, 4-7/4-8, 3-7/4-10, and 3-8/4-10 were also discarded. The inlet enthalpy for these runs did not match the inlet enthalpy for other runs at that same heater setting. Evidently, the state conditions were not maintained, since the state temperatures $T_1$ and the mixture quality do not correspond.

This leaves 49 data points that are reported in Tables 1, 2, and 3. Raw data for all 60 runs are included in Tables 4 and 5.

Figures 6-9 show thermal efficiency and engine efficiency vs output power, for output shaft speeds of 3000, 4000 and 5000 rpm, respectively. Figure 9 combines all three speeds and shows that thermal efficiency is, for all practical purposes, independent of speed. These test results show a maximum engine efficiency of 49% at 16 kW for 3000 rpm, 53% at 23 kW for 4000 rpm, and 55% at 30 kW for 5000 rpm.

Figures 10-12 repeat Figures 6-8, but as a function of pressure ratio $P_{2'}/P_3$. Performance over much of the speed range is in excess of 50% for pressure ratios as high as 5:1.

The flatness of the engine efficiency characteristic with respect to speed and

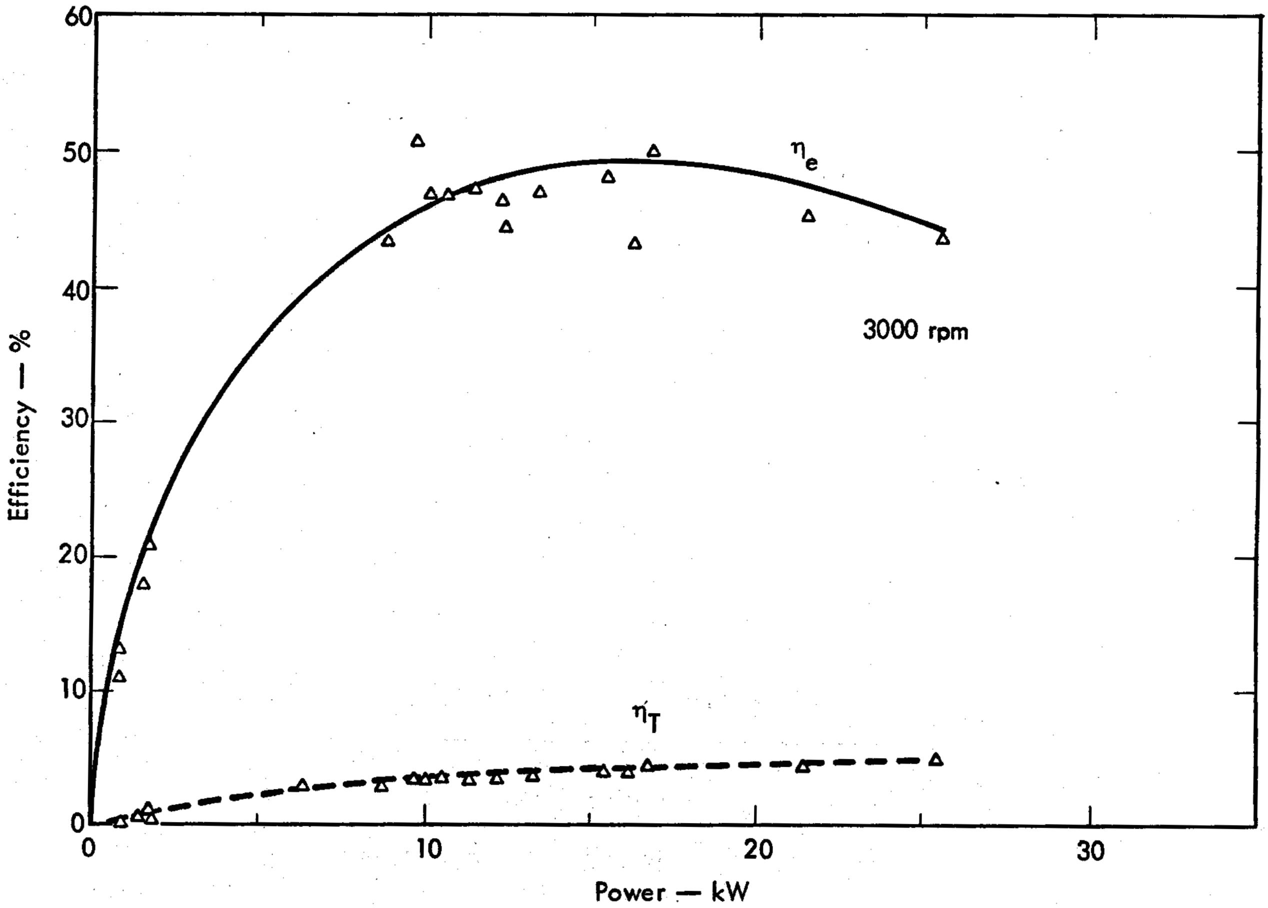



Fig. 6. Thermal and engine efficiencies vs power output at 3000 rpm.

power output and pressure ratio has been exhibited by all Lysholm engines and compressors. This is due to the fact that leakage effects decrease with increased speed, while throttling and other dynamic losses increase with higher speed. These losses counterbalance each other to a certain extent. A flat performance characteristic is advantageous inasmuch as it means that although the engine is designed for optimum performance at one pressure ratio, its behavior under other than design conditions is good.[2,3,7]

Figure 13 shows water rate as a function of power. Note that the performance is a characteristic of the engine and is also, for all practical purposes, independent of speed. The lowest water rate measured was 173 lb/kW-hr, which is entirely reasonable, considering that this is an experimental engine running with a very small enthalpy drop.

An attempt was made to characterize the leakage through the engine by measuring flow rates at various angular positions of the locked rotors. No conclusions about the effect of leakage on performance could be drawn.

The tests in the laboratory were performed with clean water. Inspection of the rotors after testing indicated that much of the scale built up during the earlier operation of the engine at Cerro Prieto and East Mesa had been removed,

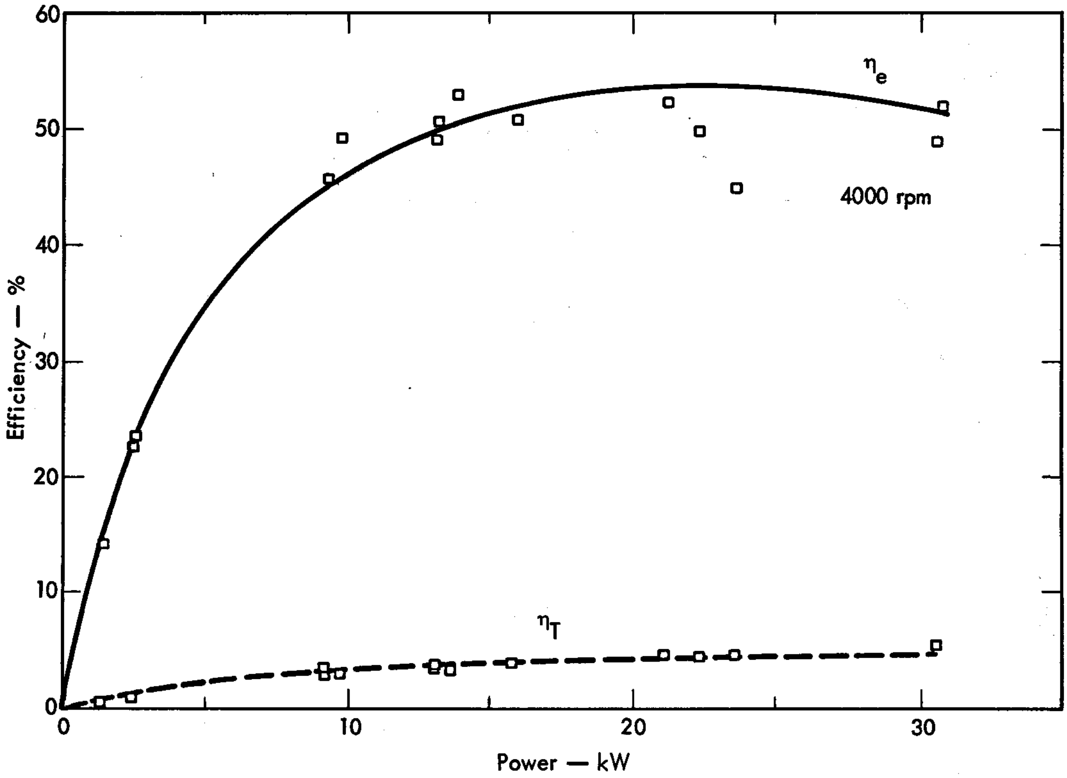



Fig. 7. Thermal and engine efficiencies vs power output at 4000 rpm.

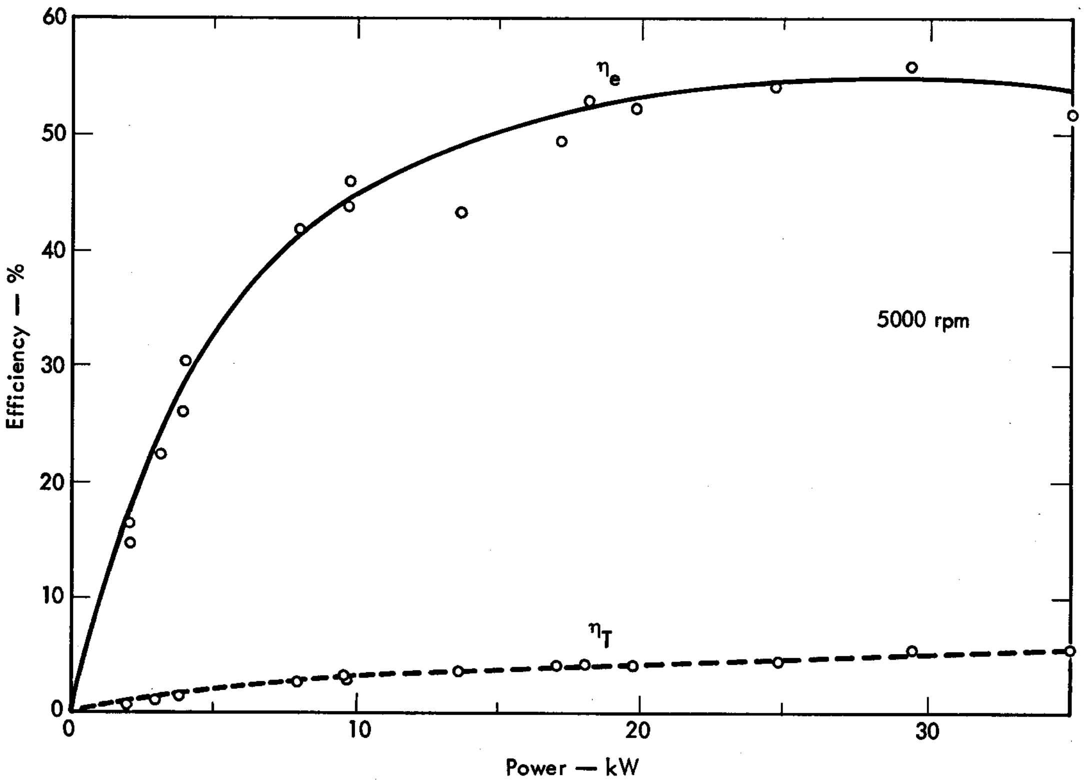



Fig. 8. Thermal and engine efficiencies vs power output at 5000 rpm.

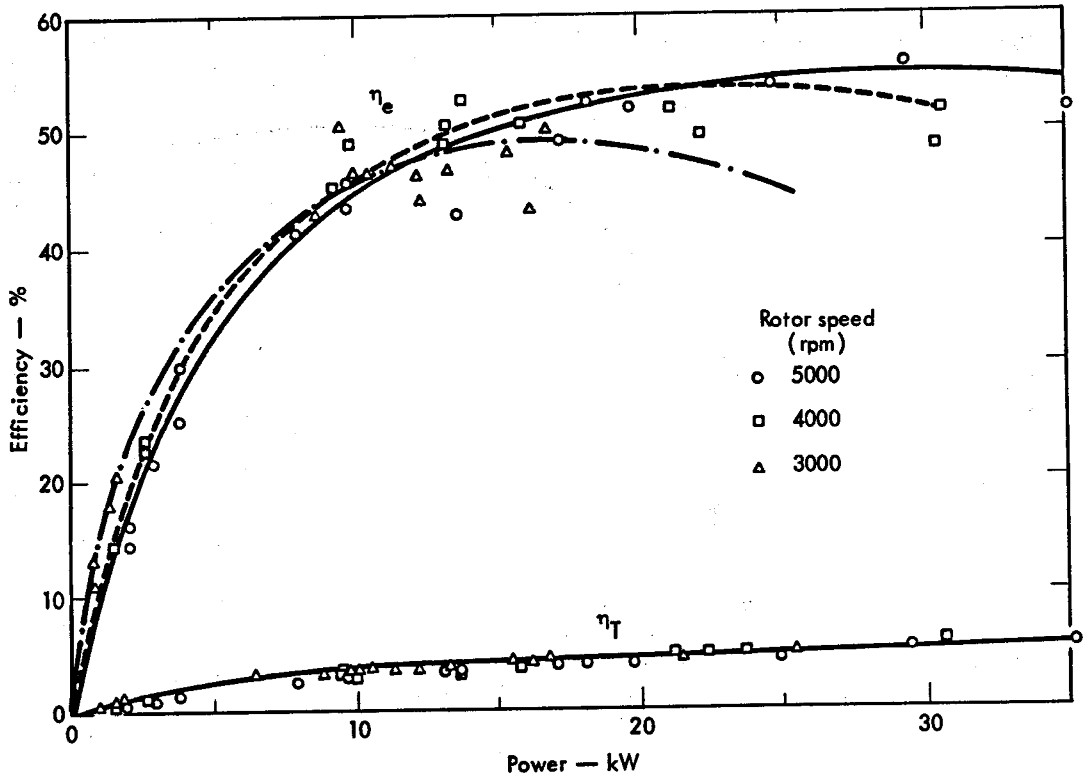



Fig. 9. Thermal and engine efficiencies vs power output at 3000, 4000, and 5000 rpm. A composite of Figs. 6-8.

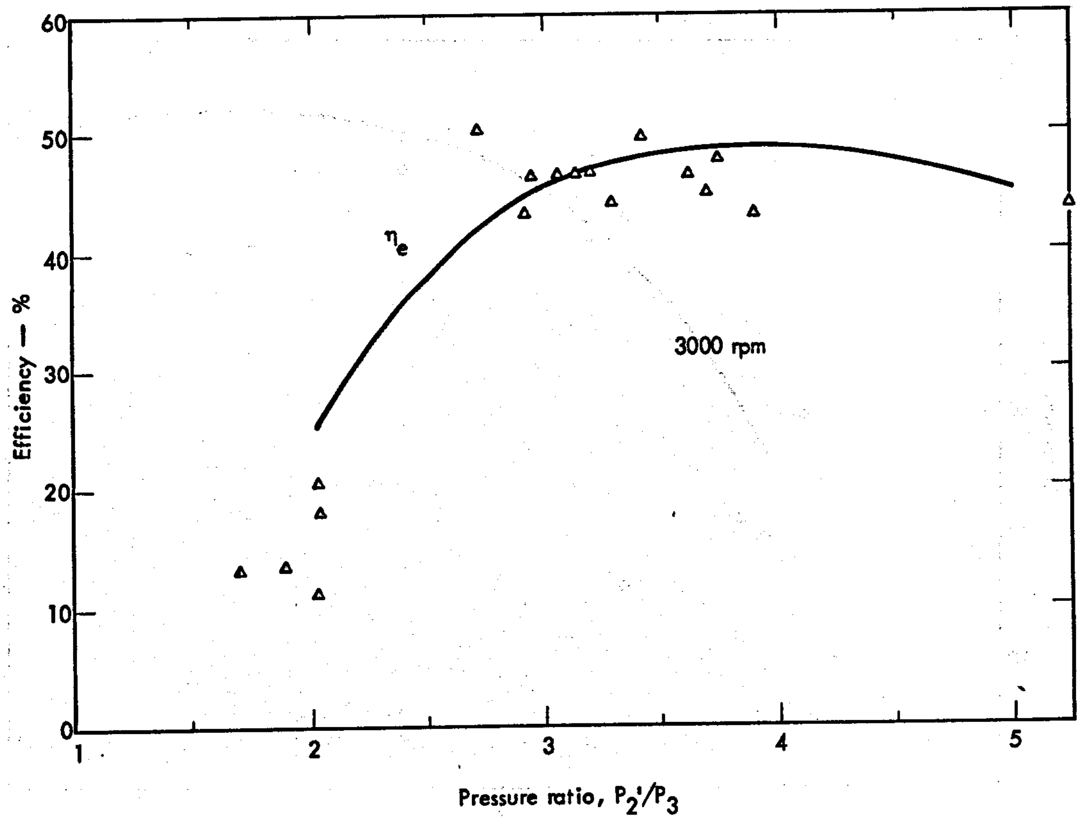



Fig. 10. Engine efficiency at 3000 rpm vs pressure ratio.

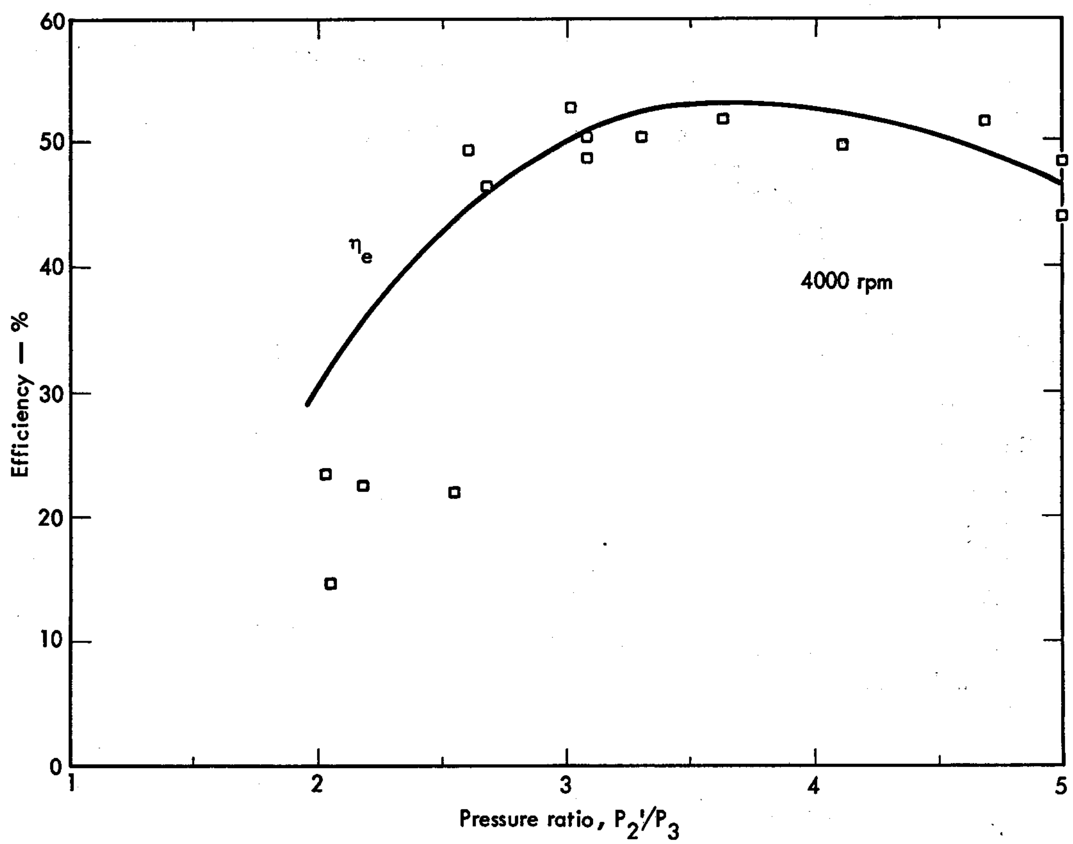



Fig. 11. Engine efficiency at 4000 rpm vs pressure ratio.

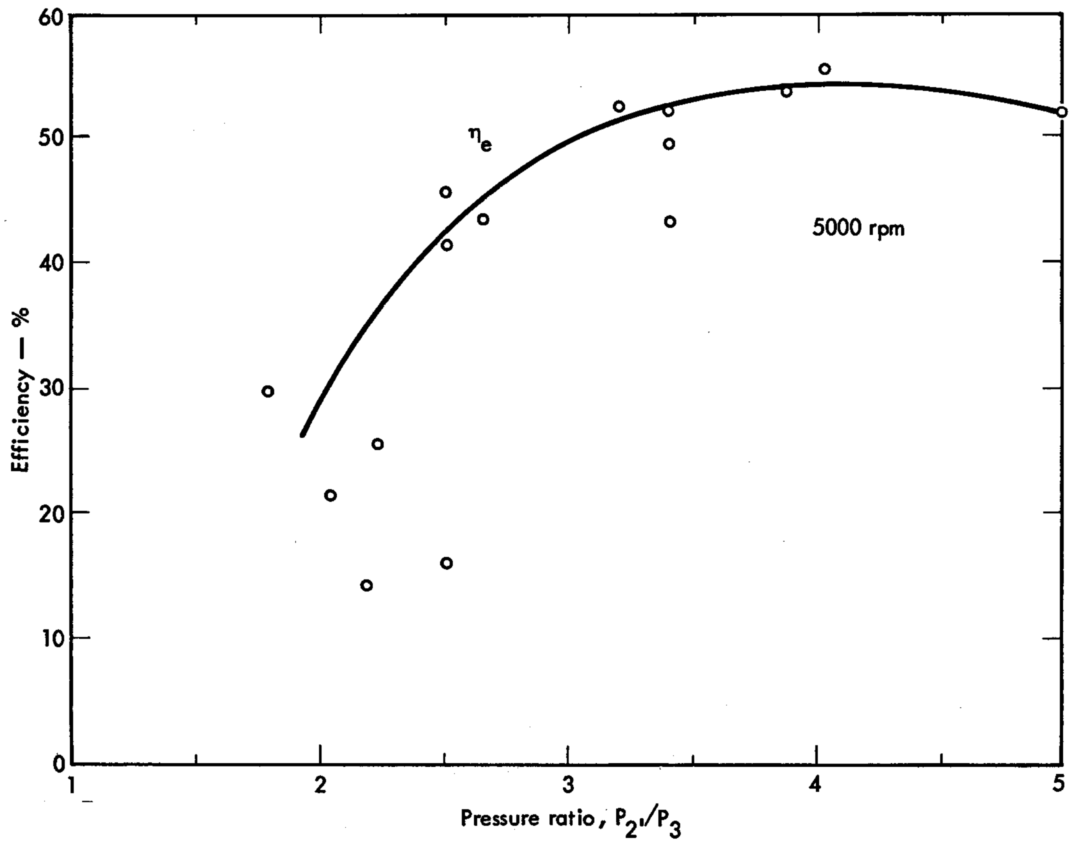



Fig. 12. Engine efficiency at 5000 rpm vs pressure ratio.

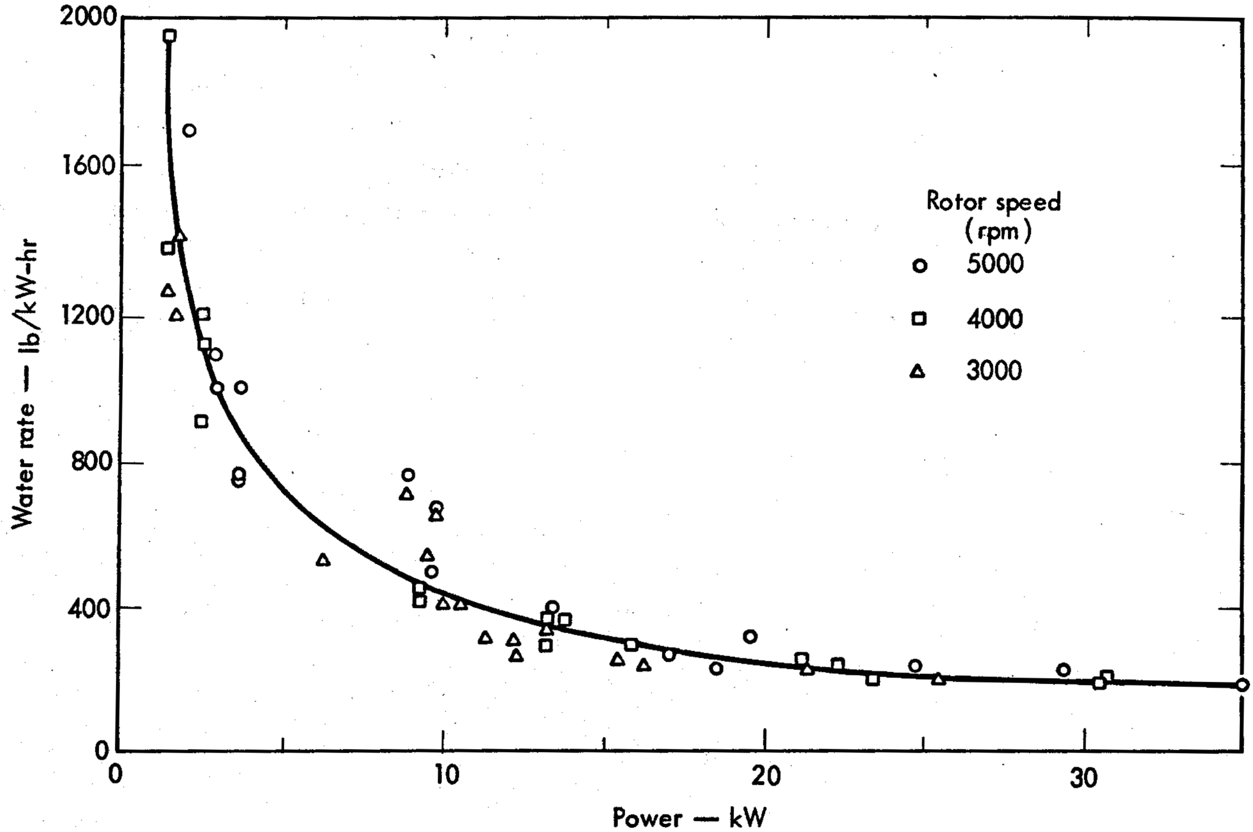



Fig. 13. Water flow rate as a function of power output, for rotor speeds of 3000, 4000, and 5000 rpm.

thereby increasing the leakage. The known effect of leakage on performance of similar engines[8] indicates that a reduction of leakage improves performance. However, the net improvement cannot be estimated easily.

## Conclusions

Several specific conclusions can be drawn from these test results.

1. The Lysholm engine can operate with a two-phase mixture as the working fluid.
2. The Lysholm engine is a viable candidate machine for the conversion of energy from geothermal fluids by the Total Flow process.
3. The results for 3000 and 4000 rpm show that an optimum performance was observed for those speeds, but it is not clear that an optimum was observed for 5000 rpm. There is an indication that higher speed would show improvement in performance.
4. The characteristics of engine efficiency, thermal efficiency and water rate (lb/kW-hr), described as functions of power output, with speed held constant, are effective

measures of the performance of the Lysholm engine.

5. Further testing of the Lysholm engine is warranted. The performance characteristics over a broader range of inlet and exhaust conditions should be determined, including both higher and lower back pressures and higher operating speeds. The effect of changing geometric parameters, e.g., the rotor length-to-diameter ratio, rotor helix angle, and porting, should be studied.

# References


1. A. L. Austin, Prospects for Advances in Energy Conversion Technologies for Geothermal Energy Development, Lawrence Livermore Laboratory, Rept. UCRL-76532 (1975). Presented at U. N. Symp. Devel. Use Geothermal Resources, 2nd, San Francisco, 1975. (To be published in the proceedings.)
2. A. Lysholm, "The Fundamentals of a New Screw Engine," ASME paper 66-GT-67 (1966), unpublished.
3. W. M. Wells, D. W. Hanner, J. L. McElroy, and E. Robinson, High Temperature Testing and Evaluation of Graphite Helical-Screw Expander and Compressors, Lawrence Livermore Laboratory, Rept. UCRL-14660 (1966).
4. W. M. Wells, On Central Station Application of Graphite Helical-Rotor Expanders, Lawrence Livermore Laboratory, Rept. UCRL-70258 (1967).
5. R. A. McKay and R. S. Sprankle, "Helical Rotary Screw Expander Power System," in Proc. Conf. Res. Devel. Geothermal Resources, Pasadena, 1974 (Jet Propulsion Laboratory, Pasadena, 1974) p. 301.
6. H. Weiss and G. Shaw, "Geothermal Two-Phase-Flow Test Facility," U. N. Symp. Devel. Use Geothermal Resources, 2nd, San Francisco, 1975. (To be published in the proceedings.) Paper VII-26.
7. A. Lysholm, "A New Rotary Compressor," Proc. Inst. Mech. Engrs. 150, 11 (July-December 1943).
8. O. E. Baljé, "A Study on Design Criteria and Matching Turbomachines, Part A—Similarity and Design Criteria of Turbines," ASME Trans., J. Engin. Power 84, 83 (1962).


RBC/bl/la