# AN EXPERIMENTAL STUDY OF THE PHASE CHANGE BY IN-SITU VAPORIZATION IN POROUS MEDIUM

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## Introduction

A natural geothermal reservoir is an aquifer generally in liquid phase confined between two impermeable layers of rock. Drilling of such reservoirs causes a decompression which allows the in-situ vaporization of some water and the development of a dual-phase flow.

Dual-phase flow is directed by the fractures of the reservoir; energy extinction is mainly determined by heat and mass transfers between the rock and the fluids. A large part of the energy stored in the reservoir is the heat of the rock, so the knowledge of these two interconnected mechanisms is very important to appreciate the behavior of geothermal reservoirs.

## Mathematical Model (inspired by Luikov's model)

### ASSUMPTIONS

a. The porous medium is homogeneous and deformable.
b. Fluids and porous medium are supposed to be a fictitious equivalent continuous medium.
c. Viscous works are neglected.
d. Capillarity effects are neglected.

### LOCAL EQUATIONS

With these hypotheses the following equations are available:

Continuity: $$\Phi \frac{\partial}{\partial t} (\rho_i S_i) = - \nabla \cdot (\rho_i \vec{V}_i) + I_i$$

Flow: $$\rho_i \vec{V}_i = - \frac{KK_{ri}}{V_i} \nabla P$$

Enthalpy: $$\frac{\partial}{\partial t} (1-\Phi) \rho_r h_r + \sum_i \rho_i S_i \Phi \left(\frac{\partial h_i}{\partial t}\right) = \nabla \cdot (h^* \nabla T) - \sum_i (\rho_i \vec{V}_i) \cdot \nabla h_i - \sum_i h_i I_i + \frac{dP}{dt}$$

Equations of State: $\rho_i = f(p_i,T)$ ; $V_i = g(p_i T)$ ; $K_{ri} = k(S_i,p,T)$

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A definite fluid heat and mass transfers will depend on:

- porosity,
- nature and granulometry of the porous medium,
- initial thermodynamic conditions,
- liquid saturation,
- exploitation conditions.

## Experimental Apparatus (Fig. 1)

The simulation of auto vaporization phenomena was made on a simple geometrical shape of the porous medium in which heat and mass transfers are mono-directional.

The experimental installation was set up with the following:

1. A cylindrical cell

It allows the average thermodynamic conditions of T = 180°C and P = 10.5 bars. The problem of the conciliation of good performances in pressure and low thermic perturbations caused by the envelope in contact with the porous medium was solved by using two concentric tubes, the internal in epoxy resin and the external in duraluminum. The external tube can be heated by electric resistances controlled by an electronic regulation chain which can work at two levels:

- in relation with a fixed temperature to obtain a regular heating of the porous medium, or
- to minimize the gap of temperature between the axis of the porous medium and the exterior. The heat losses in this position can be assumed to be equal to zero.

2. Fluid alimentation

It is made by a nitrogen-pressurized reservoir containing a deformable envelope. Water goes to the ends of the cylindrical cell through porous plaques. Ends of the cell are kept at: constant temperature by oil circulation.

3. Fluid production

This is initiated by opening a micrometr'ic valve at the end of the condensor. This condensor allows the access to the enthalpy of the produced fluid. The flow rate is determined by weighting the condensed fluids.

4. Measurements

There are 24 thermocouples and 12 pressure gauges distributed along the cell; liquid saturation is measured by Y-ray absorption. The source is 1 $C_i$ of AM241. The accuracy of the method is around 5%.

5. Porous media

At the beginning of experiments glass balls were used. After many problems with the silicate dissolution, a quartz sand was utilized and gave complete satisfaction.

## Experimental Results

### A. Influence of some parameters

#### 1. Porosity

The fraction produced in vapor phase is more important at low porosity (Fig. 2). However, with the horizontal configuration the total massic-produced fraction is not affected by porosfty. The fact that the enthalpy of produced fluids is better at low porosity shows clearly the importance of the solid matrix heat in the vaporization process.

#### 2. Speed of decompression (Figs. 3 and 4)

If the decompression is too fast, a great quantity of water in liquid phase is expulsed. Then a large fraction of the energy stored in the solid matrix cannot be used for vaporization.

#### 3. Initial liquid saturation

When the initial liquid saturation is low, the produced fraction is low, but the enthalpy and vapor quality of the produced fluids are better. The results agree with the numerical studies of Toronyi and Martin (Figs. 5 and 6).

#### 4. Heat influx or heat losses

Heat influx or heat losses have a strong effect on the behavior of the model; some critical studies were made to estimate the envelope contribution to the phenomena. Such effects must be carefully checked to insure accuracy of the measurements.

### B. Energy extraction efficiency

Energy extraction efficiency is defined by $\eta = E_p/E_i$, where $E_p$ is the produced energy and $E_i$ the initial energy of the reservoir; both of them are calculated from a temperature level of 100°C. We can see in Fig. 7 that:

- All the runs have the same shape of the graphs of $\eta(P/P_o)$
- $\eta$ is maximum for the runs with Sol = 1 and in-situ vaporization (H5, H6). The run H1 (high-speed run) shows an initial expulsion of liquid water producing a large depletion without any energy extraction by in-situ vaporization. Then the behavior of this run is similar to the behavior of low initial liquid saturation runs.
- A large part of the energy remains in the reservoir for the low saturation runs. This result shows clearly the interest of reinjection for vapor-dominated or very low-porosity reservoirs.

### C. "Black box" model based on mass and energy balances

A comparison of numerical and experimental data shows excellent results (Fig. 8). A model similar to those of Whiting and Ramey and of Brigham and Morrow describes an experimental simulation very well.

## Conclusions

This study shows some qualitative results on the problem of in-situ vaporization in porous media; however, these results cannot be applied directly for reservoir exploitation. Among the problems remaining we can show the improvement of some numerical models based on local equations, the determination of the relative permeabilities curves, and the behavior of geothermal reservoirs at very low initial liquid saturation with the influence of capillarity effects.

## References


BORIES, S., and GHALLEB, K. Transferts de chaleur et de masse dans les milieux poreux non saturés. 1972, G.E. I.F.P.-I.M.F., ENSEEIHT, Toulouse.

BORIES, S., CASTANIER, L., KLOCKENBRING, F., and MONFERRAN, L. Transferts de chaleur avec changement de phase en milieu poreux -- Application à la géothermique. Contrat D.G.R.S.T., G.D. 1.F.P.-I.M.F. 1977, ENSEEIHT, Toulouse.

BRIGHAM, E., and MORROW, B. P/Z behavior for geothermal steam reservoirs. 1974, Congrès de l'AIME, SPE Paper No. 4899.

LUIKOV, A.V. Heat and mass transfer in capillary porous bodies. Pergamon Press, 1966.

LUIKOV, A. V., and MIKHAYLOW. Theory of energy and mass transfer. Prentice Hall, Inc., Englewood, 1961.

MARX, J. W., and LANGENKEIM, R. H. Reservoir heating by fluid injection (1959). AIME 216, AIME 312.

PELLERIN, MAUBOURGUET MM. Contribution à l'étude par voie numérique des transferts de chaleur conjugués. Thèse de Spécialité, Université de Toulouse, Novembre, 1977.

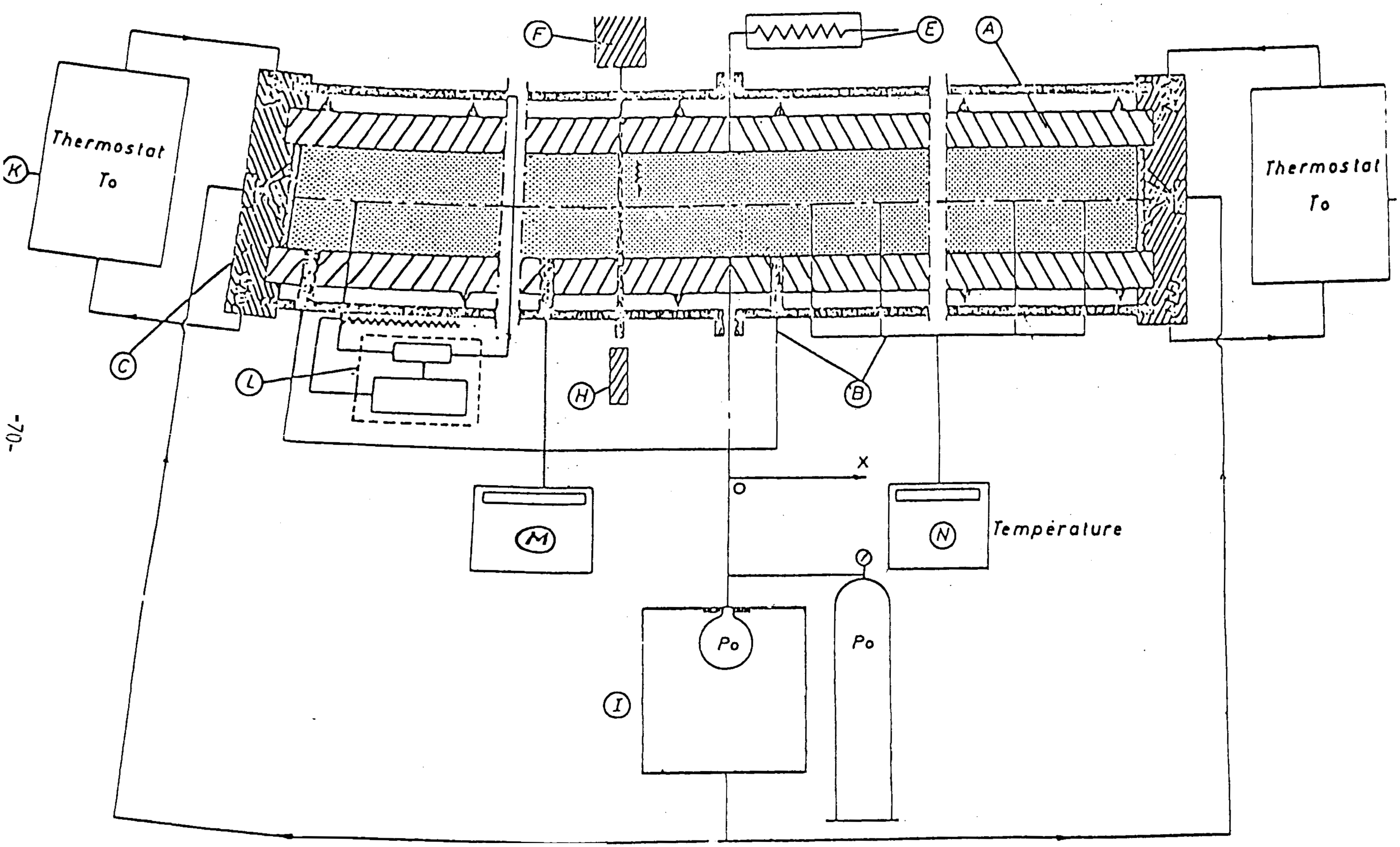
MARTIN, J. C. Analysis of internal steam drive in geothermal reservoirs. 45th Annual California Regional Meeting of the SPE of AIME, Apr. 2, 1975, Ventura, SPE Paper No. 5382.

MERCER, J. W., and FAUST, C. R. Simulation of water and vapor dominated hydrothermal reservoirs. 5th Annual Fall Meeting of the SPE of AIME, Dallas, Sept. 28, 1977, SPR Paper No. 5520.

TORONYI, R. M., and FAROUK ALI, S. M. Two-phase, two-dimensional simulation of a geothermal reservoir and the welbore system. 50th Annual Fall Meeting of the SPE of AIME, Dallas, Sept. 28, 1977, SPE Paper No. 5521.

Geothermal Energy
Review of research and development, UNESCO, Paris, 1973.

WHITING, R. L., and RAMEY, H. J., Jr. Application of Material energy balances to geothermal steam production, Journal of Petroleum Technology, 893-900, 1959.




EXPERIMENTAL APPARATUS

FIGURE 1

A - Epoxy tube
B - Thermocouples
C - Oil circulation
E - Condenser
F - γ Ray source

H - γ Ray absorbtion
I - Water injection
K - Thermostats
L - Electric heating regulation
M - Pressure recorder
N - Temperature recorder

FIGURE 2 -

INFLUENCE OF POROSITY

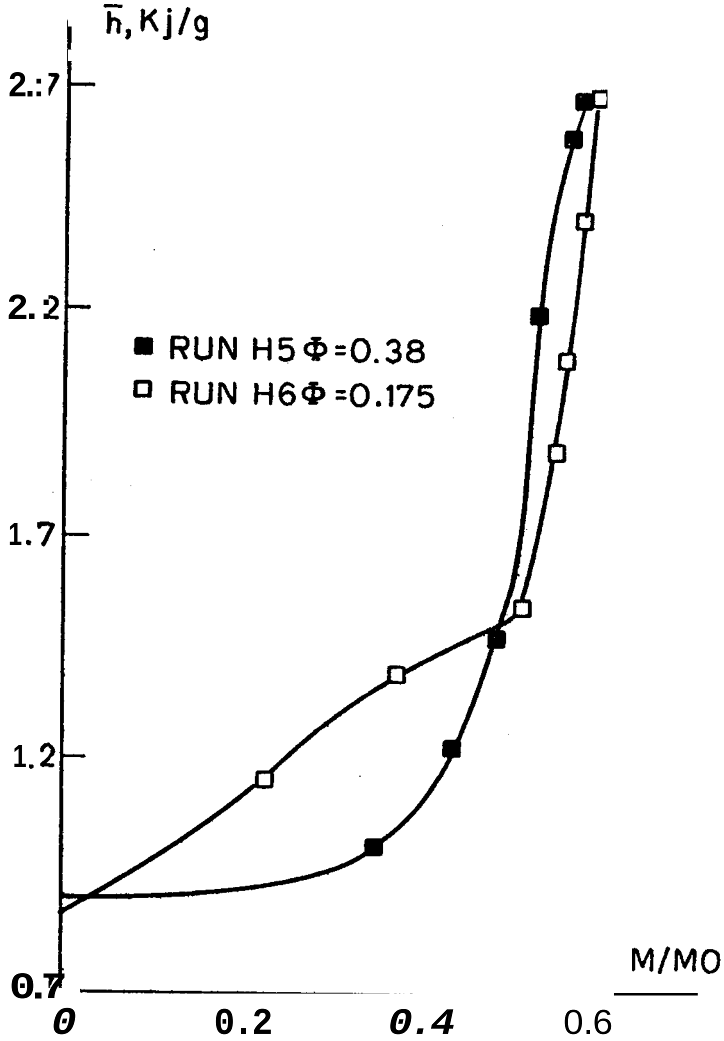


FIGURE 3 -

INFLUENCE OF FLOW RATE

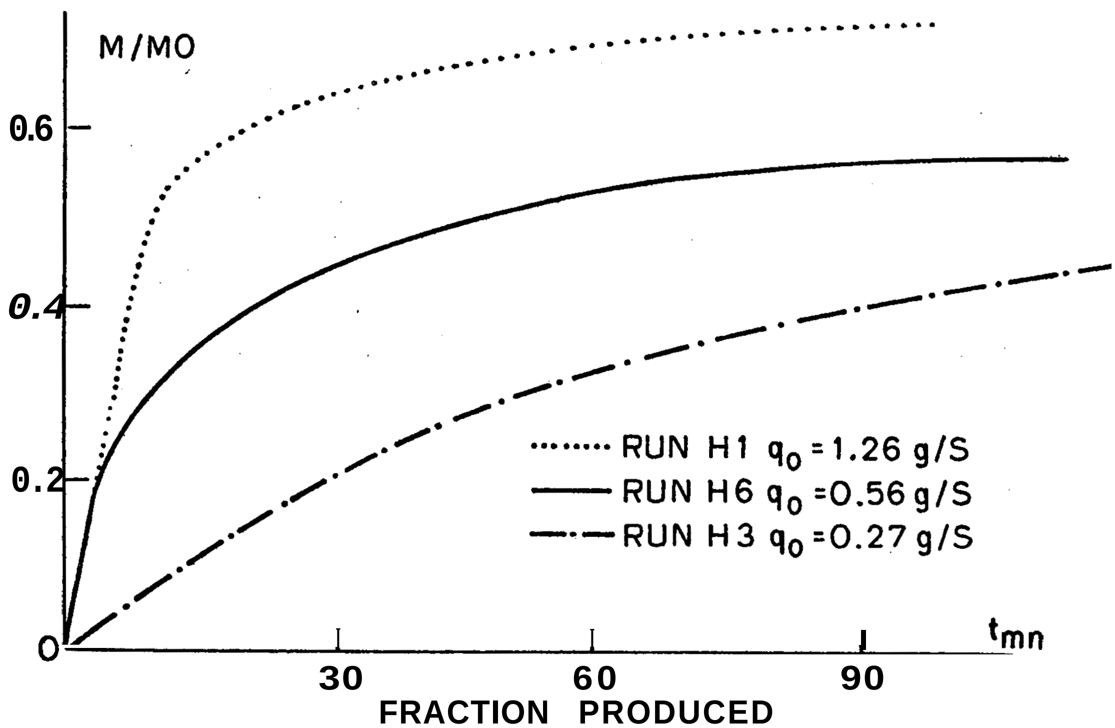


FIGURE 4 -

## INFLUENCE OF FLOW RATE

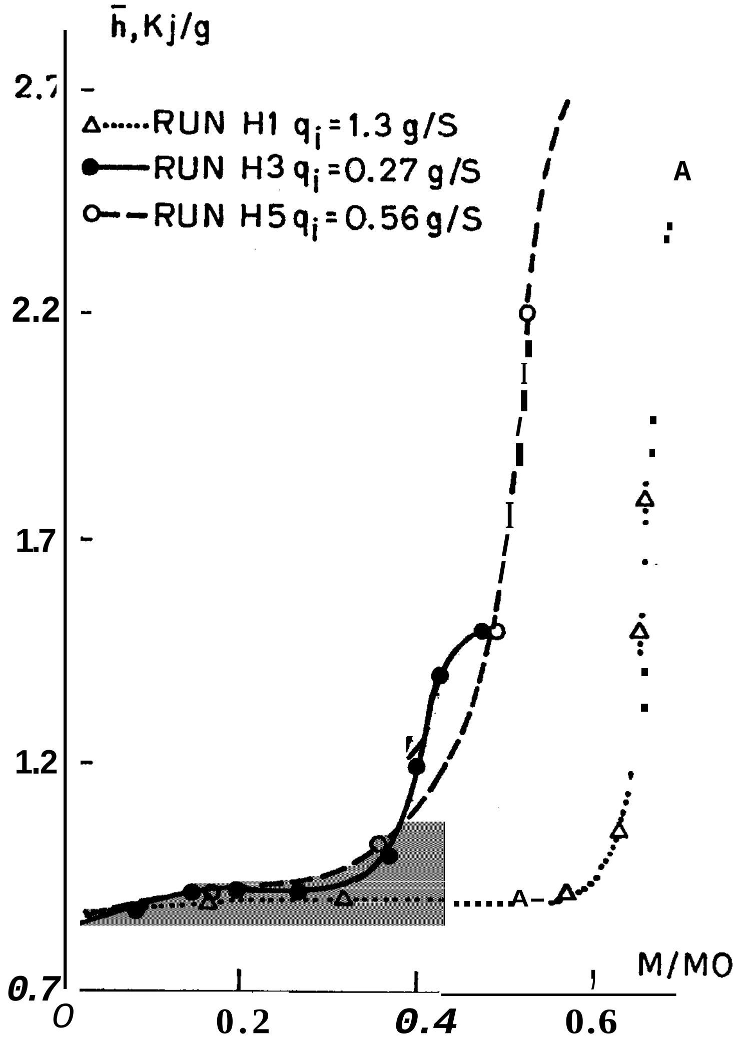


FIGURE 5 -

**INFUENCE OF INITIAL LIQUID SATURATION**

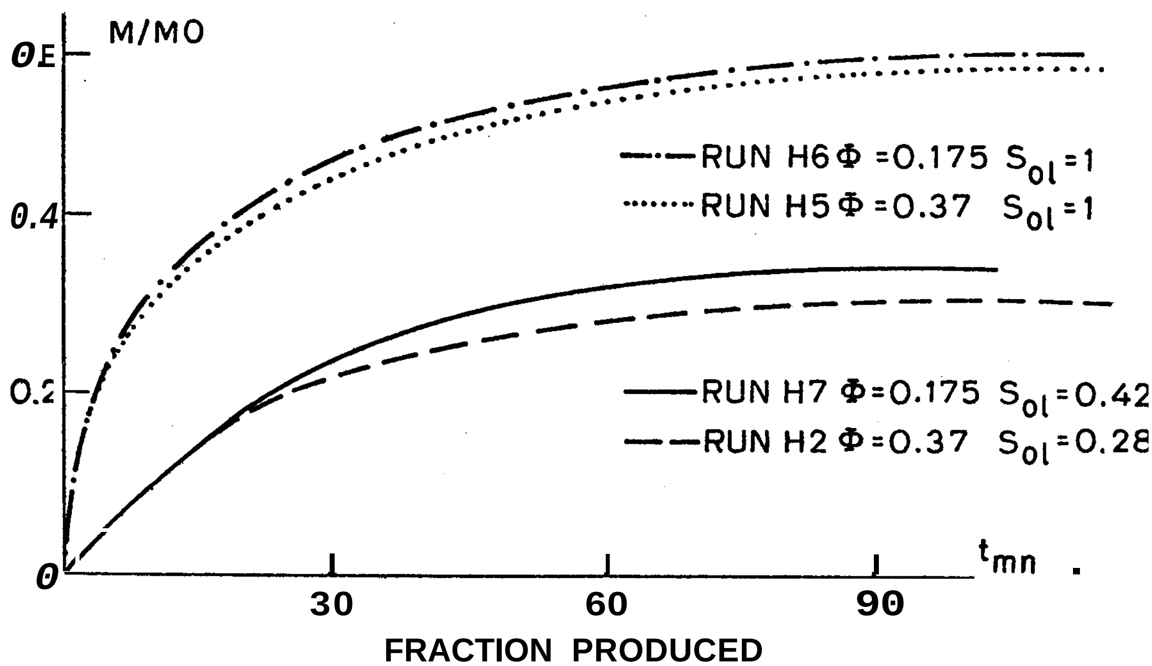


FIGURE 6 -

INFLUENCE OF 'SATURATION

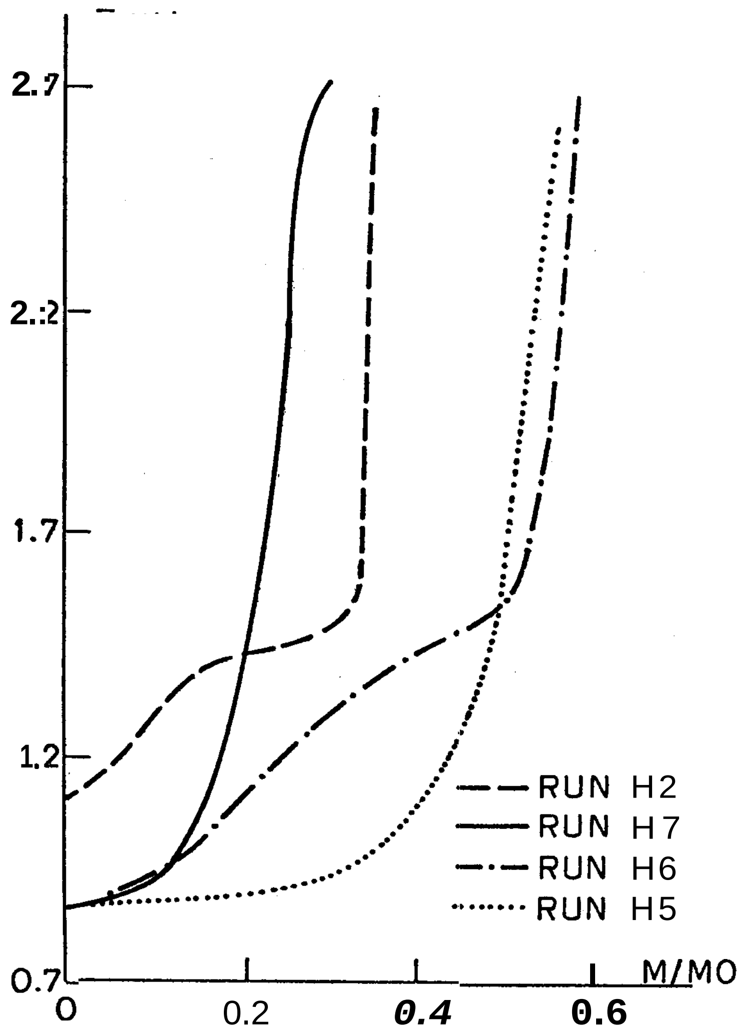


FIGURE 7 -

## ENERGY EFFICIENCY

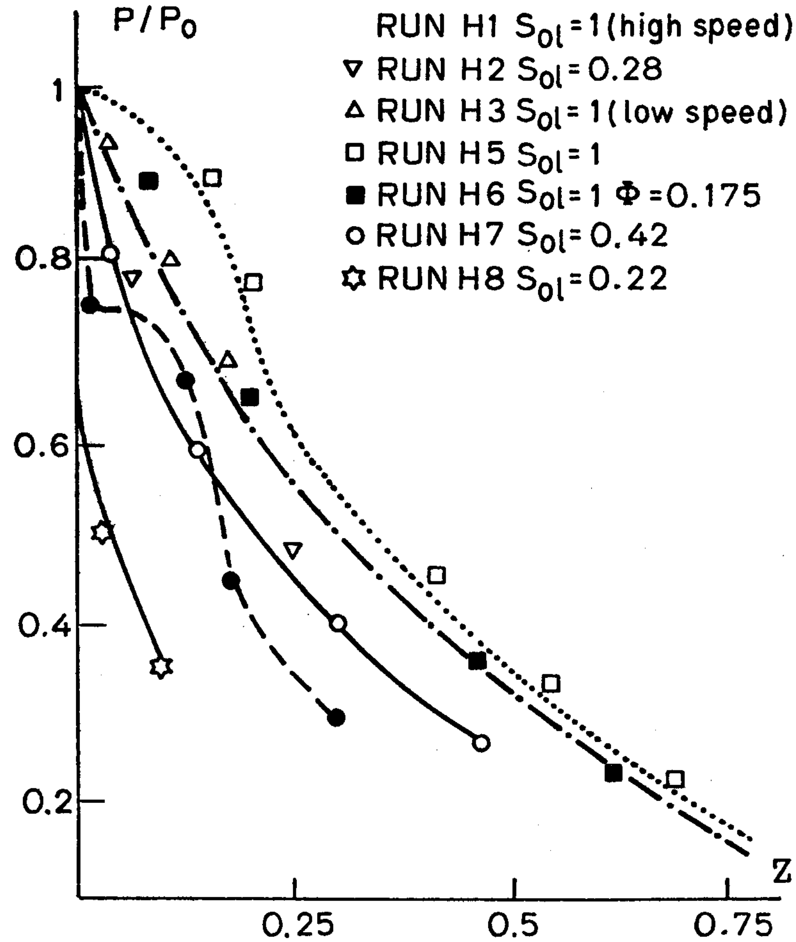
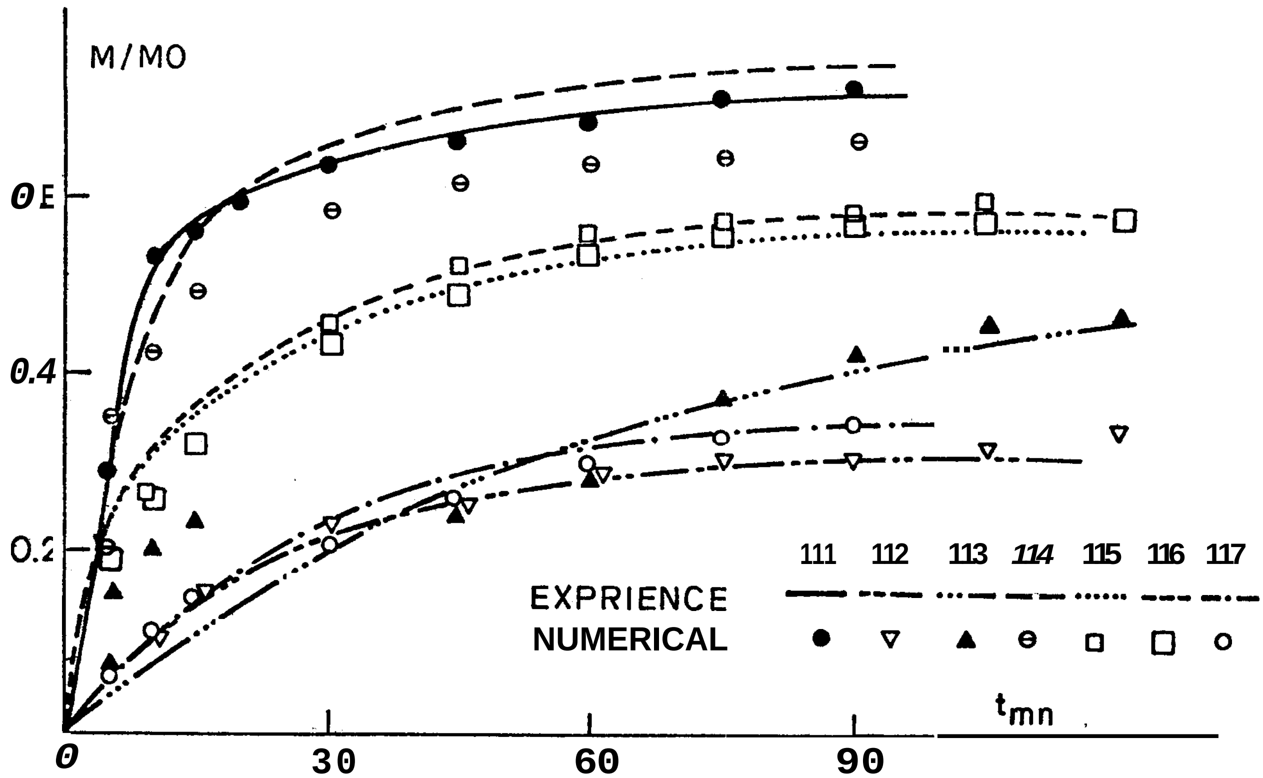


FIGURE 8.




FRACTION PRODUCED (NUMERICAL & EXPERIMENTAL DATA)