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**EFFECT OF GAS RECYCLE RATE ON THE HYDROCRACKING
OF VACUUM BOTTOMS IN A PILOT PLANT**

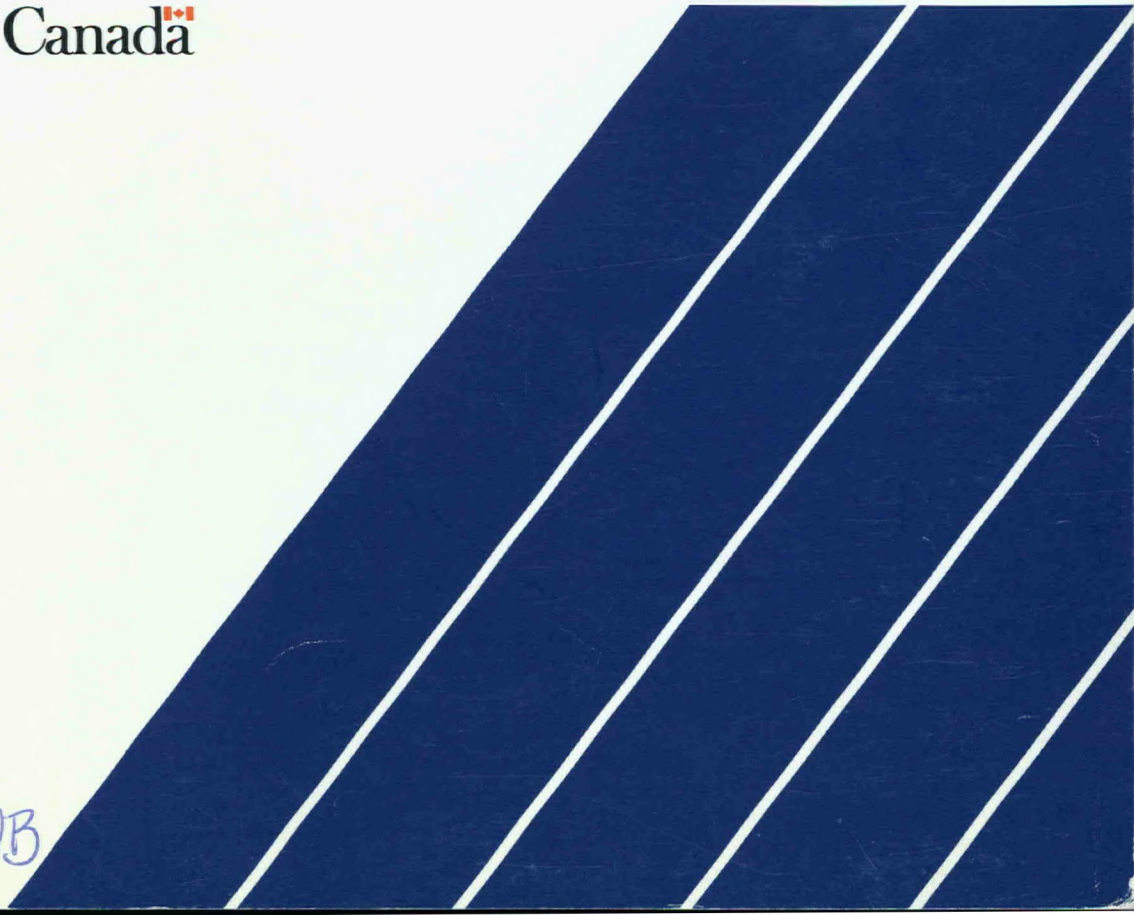
D.D.S. Liu, W.H. Dawson and B.B. Pruden

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by

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ABSTRACT

Hydrocracking runs were carried out in a 1 bbl/d pilot plant using vacuum tower bottoms (VTB) from a blend of Western Canadian heavy crudes. The effect of the superficial gas velocity on the reactor dynamics and on the conversion of VTB to distillate was examined for several sets of superficial gas velocities and various temperatures. A gamma-ray interrogation method was applied to examine the hydrodynamics of multi-phase flows in the bubble column reactor.

Because hydrocracking reactions occur in the liquid phase, the pitch (524°C+) conversion is strongly affected by the liquid holdup which is a function of the superficial gas velocity. In these runs, the effect of gas velocity on pitch conversion was strong enough to offset the normal increase in pitch conversion with temperature so that similar pitch conversion could be obtained for different combinations of temperature and gas velocity. Product distributions were uniquely correlated with the pitch conversion and a first order lumped parameter kinetic model was applicable. Sulphur conversion was also correlated with pitch conversion.

INTRODUCTION

Hydroprocessing is an important approach to upgrade resid. The hydrogen is used to increase the H/C ratio in the products, and to hydrodesulphurize and hydrodenitrogenate the resid. All commercial processes require high temperatures and pressures to achieve high conversions: the temperature is normally chosen to achieve the desired high rate of the chemical reaction, whereas the high pressure enhances the mass transfer of hydrogen into the liquid phase for reaction with the residue. The CANMET hydrocracking process is a typical example. It was developed as part of a continuing program at the Energy Research Laboratories of CANMET to develop hydroprocessing technologies to upgrade the Canadian tar sands bitumen and refinery vacuum tower bottoms (VTB) using bubble column reactors (1).

Careful investigations on the coupling of hydrodynamics and upgrading kinetics are absolutely necessary in the development of hydroprocesses in order to ensure that the fundamental data decoupled from physical factors are obtained for the application to predict the reaction in commercial-scale reactors. Although bubble column reactors have the advantage of being easily constructed, the scaleup rules are not straightforward because of the complexity of the multi-phase flow hydrodynamics (2). This is especially true in the resid upgrading applications, in which additional complexity arises from the lack of knowledge concerning the detailed chemical and physical properties of the reaction medium. In this study, the effect of gas rate on hydrodynamics in a bubble column resid hydrocracker is discussed in relation to the reaction kinetics and the final product yield and distribution.

EXPERIMENTAL

A CANMET primary upgrading pilot plant equipped with a tubular reactor was used for this study. A schematic of the

pilot plant is shown in Fig. 1. Liquid feed containing fine powdered additive was combined with the hydrogen-rich recycle gas and the mixture was fed through a preheating section into the bottom of the reactor. The reactor was operated in the concurrent bubble column mode. Four electric heaters were used to control the internal temperatures, allowing the fluid to be essentially isothermal along the length of the reactor. The product effluent from the top of the reactor was fed into a hot separator where the heavy liquid product is let down to atmospheric pressure. The vapour in the hot separator was discharged into a cold separator where the C_4+ products were condensed and let down to ambient conditions. The noncondensable gas was then passed through a water scrubber in series with an oil scrubber to control the hydrogen purity. The scrubbed gas was then combined with make-up hydrogen and recirculated to the reactor by a gas pump. The maximum superficial gas velocity through the reactor was 12 cm/s.

The feed used was a blend of Western Canadian heavy crude vacuum tower bottoms (VTB) obtained from Petro-Canada's refinery at Montreal. The properties of the feed are given in Table 1.

Twenty-five steady state hydrocracking runs were carried out at five temperatures. At each temperature, five runs were carried out at different superficial gas velocities. The run lengths ranged from 11 to 34 h. Including the time between runs, the total duration of the experiment was longer than 53 d. The superficial gas velocities were estimated by using van der Waals equation of state based on the compositions of recycle gas at the point of entering the reactor.

The hourly and cumulative volumetric and mass rates for input and output streams were measured during each run. Samples from each stream were taken to measure the properties. The pitch concentration in the feed and in the samples obtained from the

bottom of the hot separator were measured by a Podbielniac distillation apparatus. Distillate fractions were obtained by Hempel distillation.

Reactor fluid densities, which are directly related to hydrodynamic parameters, were measured for each set of temperature/flow rate hydrocracking conditions using a single beam gamma-ray densitometer (Fig. 2)(3).

RESULTS AND DISCUSSION

The pitch conversions are plotted against reactor temperatures in Fig. 3 and against superficial gas velocities in Fig. 4. The conversion is a strong function of temperature and gas velocity. The reaction rate increased as the temperature increased, whereas it decreased as the gas rate increased. The plot of pitch conversion against reactor temperature in Fig. 3 is smoother than the plot against gas velocity in Fig. 4 indicating that the temperature has a stronger effect than the gas rate. A one-dimensional dispersion model (4) using the first order Arrhenius rate expression and taking into account the effects of liquid holdup (Fig. 5) and dispersion, and product vapourization, is capable of describing the observed pitch conversions. Calculated values are shown as dots in Fig. 4.

Note that some experiments gave similar pitch conversions for very different combinations of temperatures and gas velocities. Despite the large difference in operating conditions, both weight and volumetric yields of distillates (C_4+ to $524^\circ C$) were uniquely correlated with pitch conversion (Fig. 6 and 7), consistent with the model predictions.

The boiling point can conveniently be used as the parameter to represent the continuous product distributions (5). The total liquid products were cut into three fractions to examine

the distributions in more detail. Figure 8 shows the yields in wt % of feed for heavy gas oil (HGO 343°C - 524°C), light gas oil (LGO 204°C - 343°C), naphtha (C₄+ - 204°C) and C₁ - C₃ gases as functions of pitch conversion. The product distributions are again similar for runs with similar pitch conversions despite the use of different temperatures and gas velocities.

Figure 9 shows simulated product distributions represented by a modified Gaussian distribution function at 40, 60, 80 and 90 wt % pitch conversions based on the results shown in Fig. 8. The distribution of products progressively shifted to the lower boiling points as the pitch conversion increased. It is also shown clearly in Fig. 9 that the secondary cracking of high boiling point HGO is important at high pitch conversions.

Figure 10 shows sulphur conversion plotted against pitch conversion. Clearly the sulphur conversion, like product yields, depends on pitch conversion regardless of the different combinations of temperatures and pressures. This allows the pitch conversion to be considered as the only effective parameter in the modelling of the kinetics of sulphur conversion.

CONCLUSIONS

Increasing the gas velocity decreases the liquid holdup, which results in a decrease in pitch conversion. This can be modelled using a first order reaction model and a hydraulics model.

Identical pitch conversions can be obtained from combinations of temperatures and gas velocities. Correlations of product yields and sulphur conversion with pitch conversion were obtained.

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Table 1. Feed Properties

Gravity	° API	6.95
Ash,	wt %	0.02
Carbon,	wt %	85.4
Hydrogen,	wt %	10.8
Sulphur,	wt %	2.06
Nitrogen,	wt %	0.46
R.C.R.,	wt %	15.4
Pentane insolubles,	wt %	13.4
Toluene insolubles,	wt %	0.79
Softening point,	° C	37.5
Pour point,	° C	39.0
Vanadium,	ppm	78
Nickel,	ppm	38
Iron,	ppm	72
Sodium,	ppm	24
Potassium,	ppm	10
Aluminum,	ppm	14

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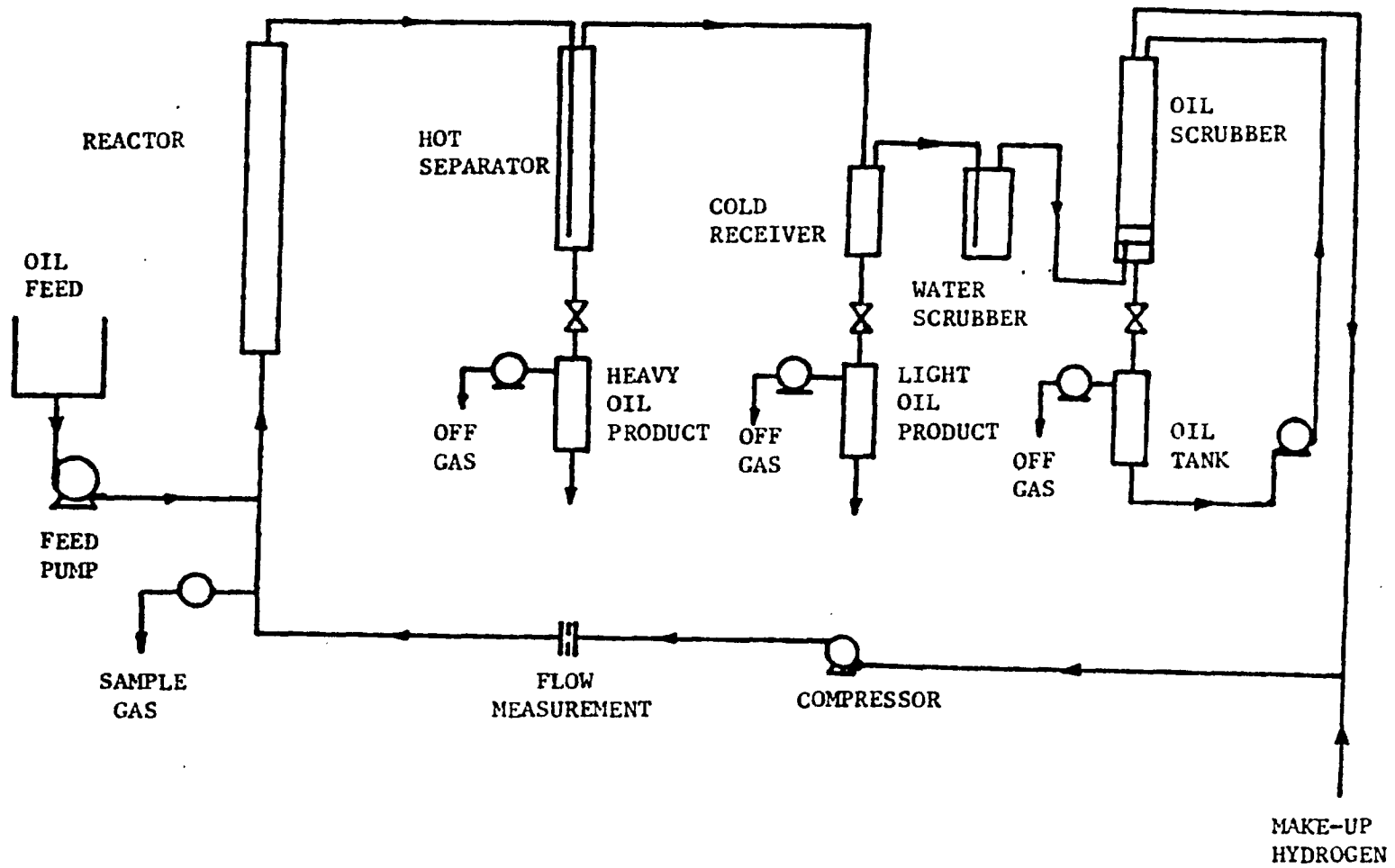


Fig. 1 - Schematic of CANMET primary upgrading pilot plant

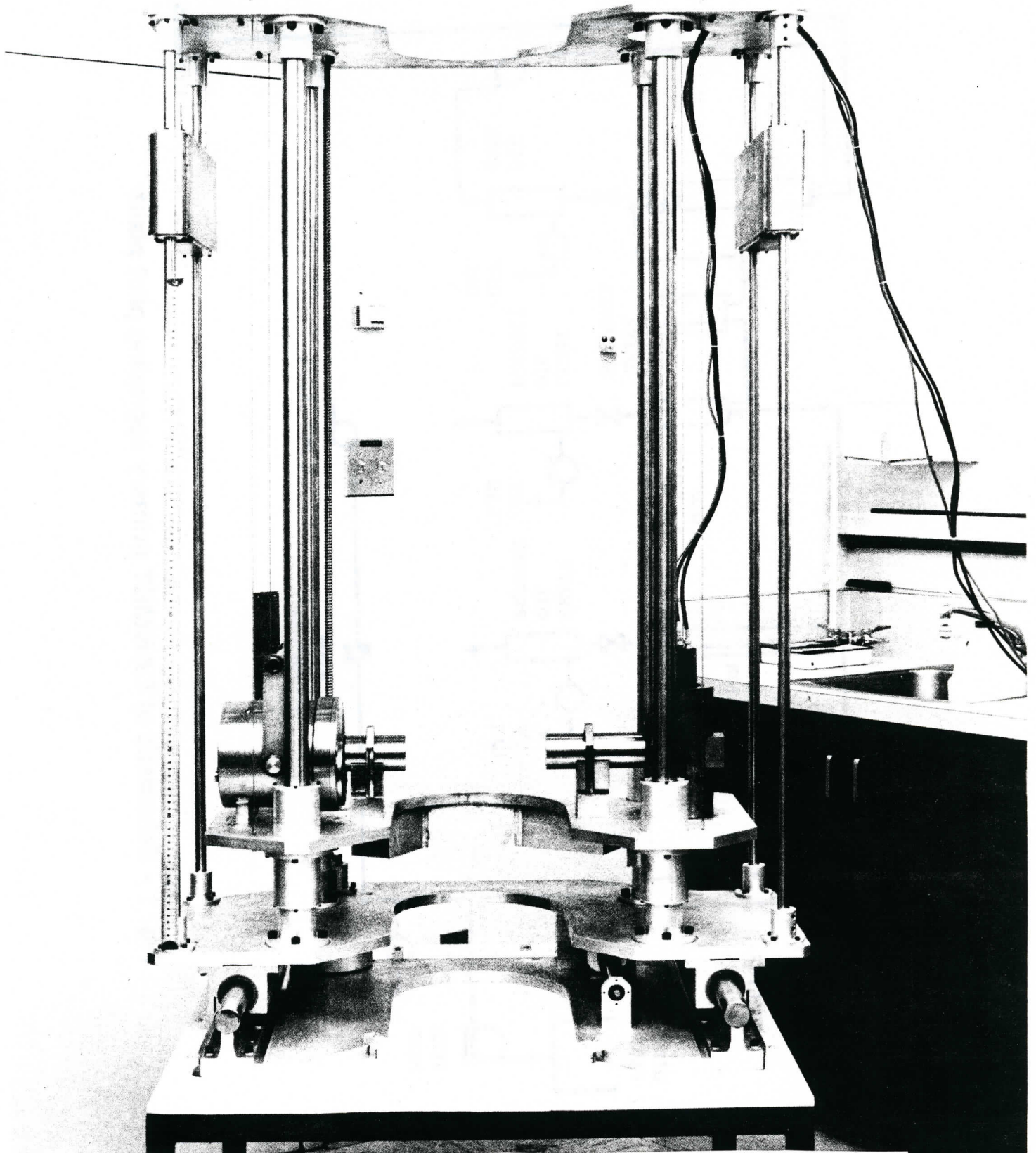


Fig. 2 - CANMET two-dimensional gamma-ray scanner for hydrodynamic studies

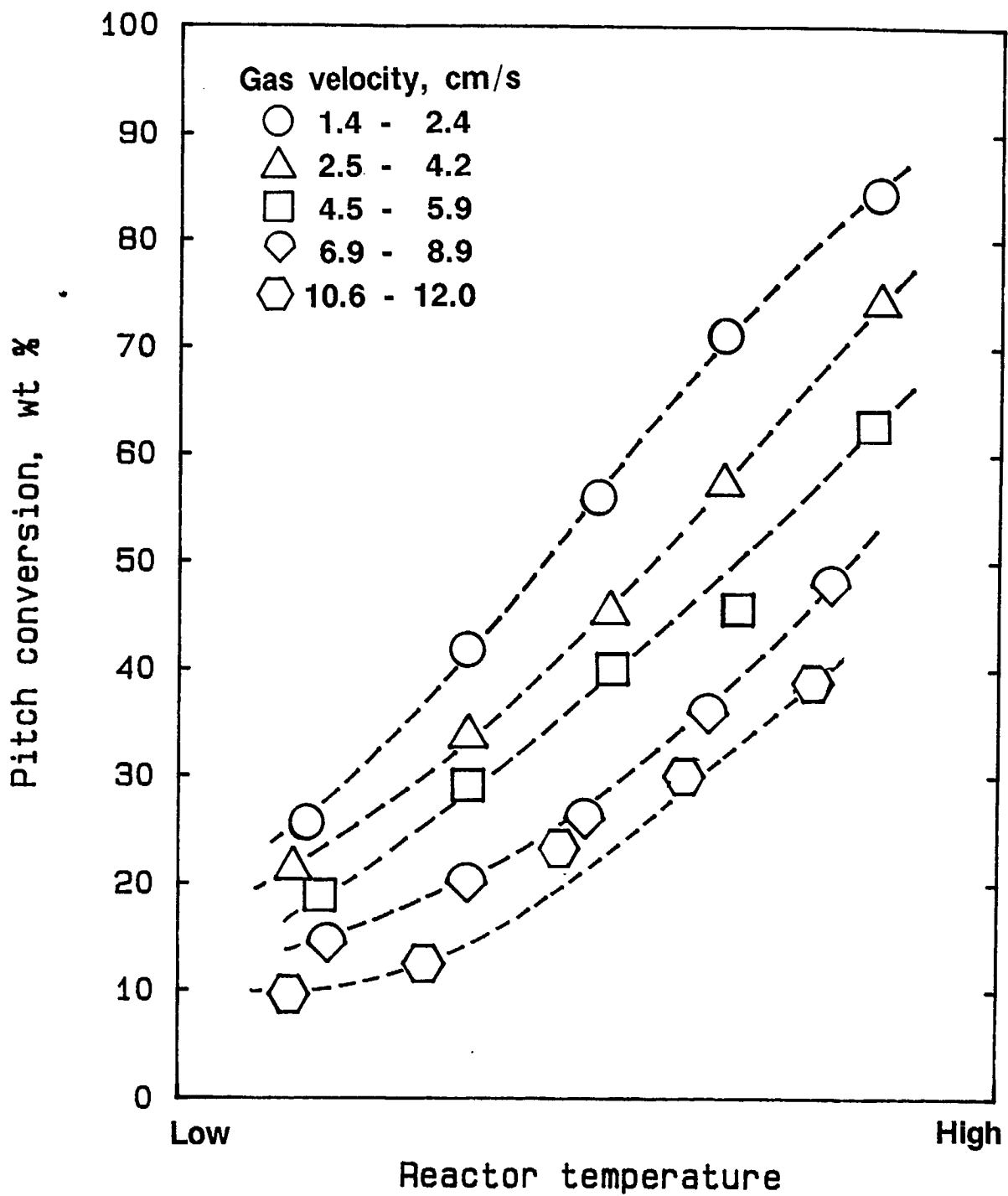


Fig. 3 - Pitch conversion versus reactor temperature as functions of superficial gas velocity

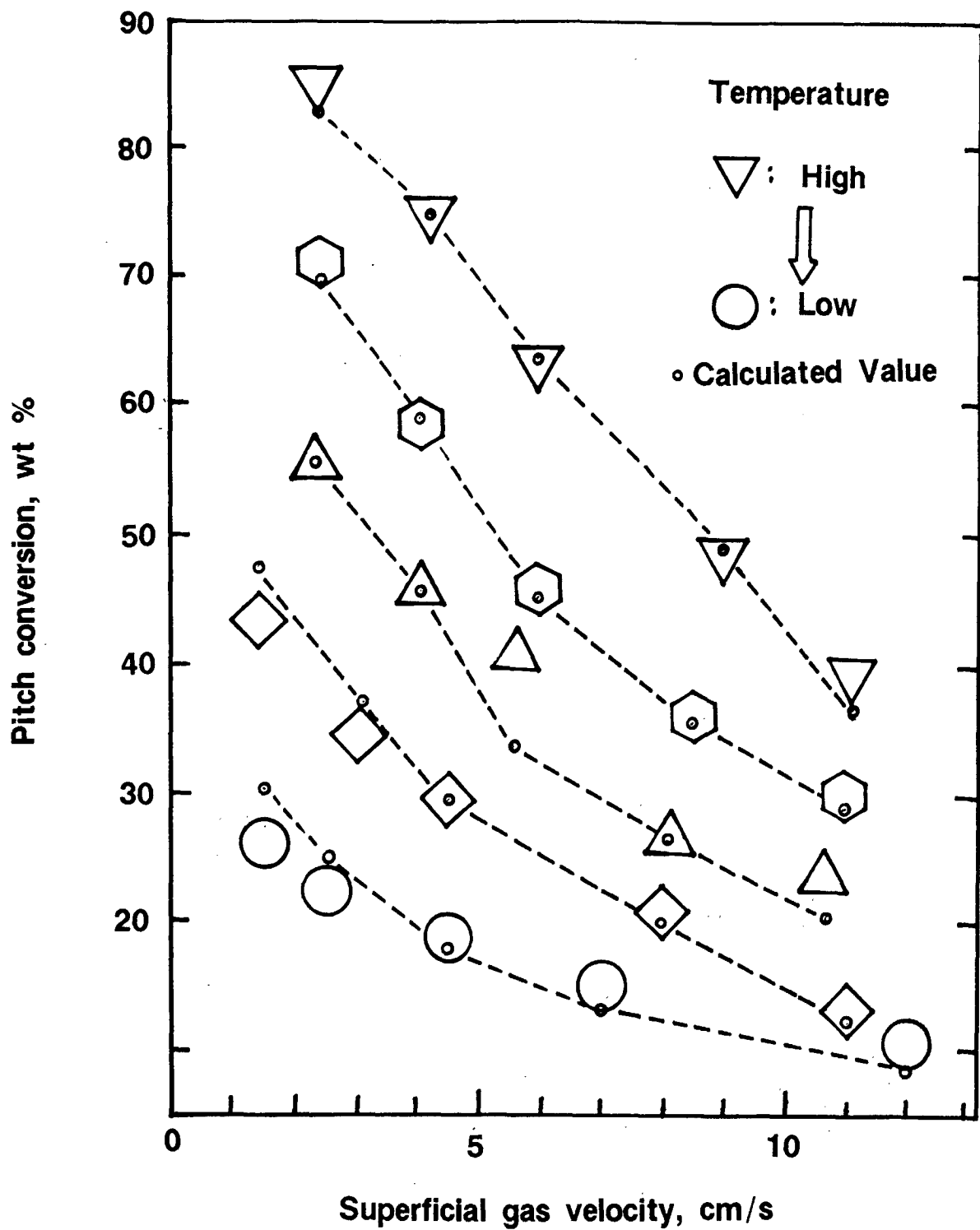


Fig. 4 - Pitch conversion versus superficial gas velocity as functions of reactor temperature

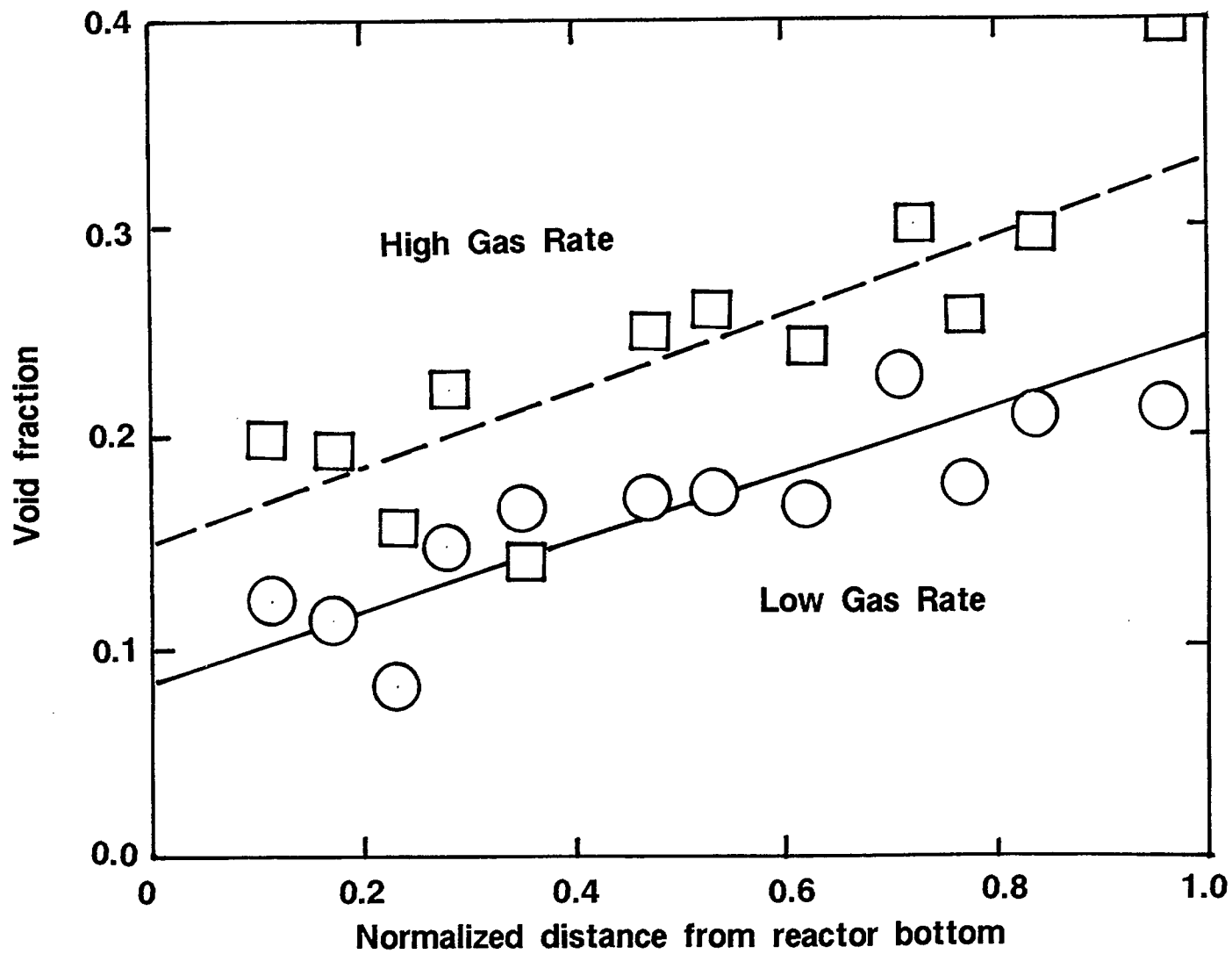


Fig. 5 - Examples of temporal mean void fraction as function of reactor coordinates at elevated temperatures

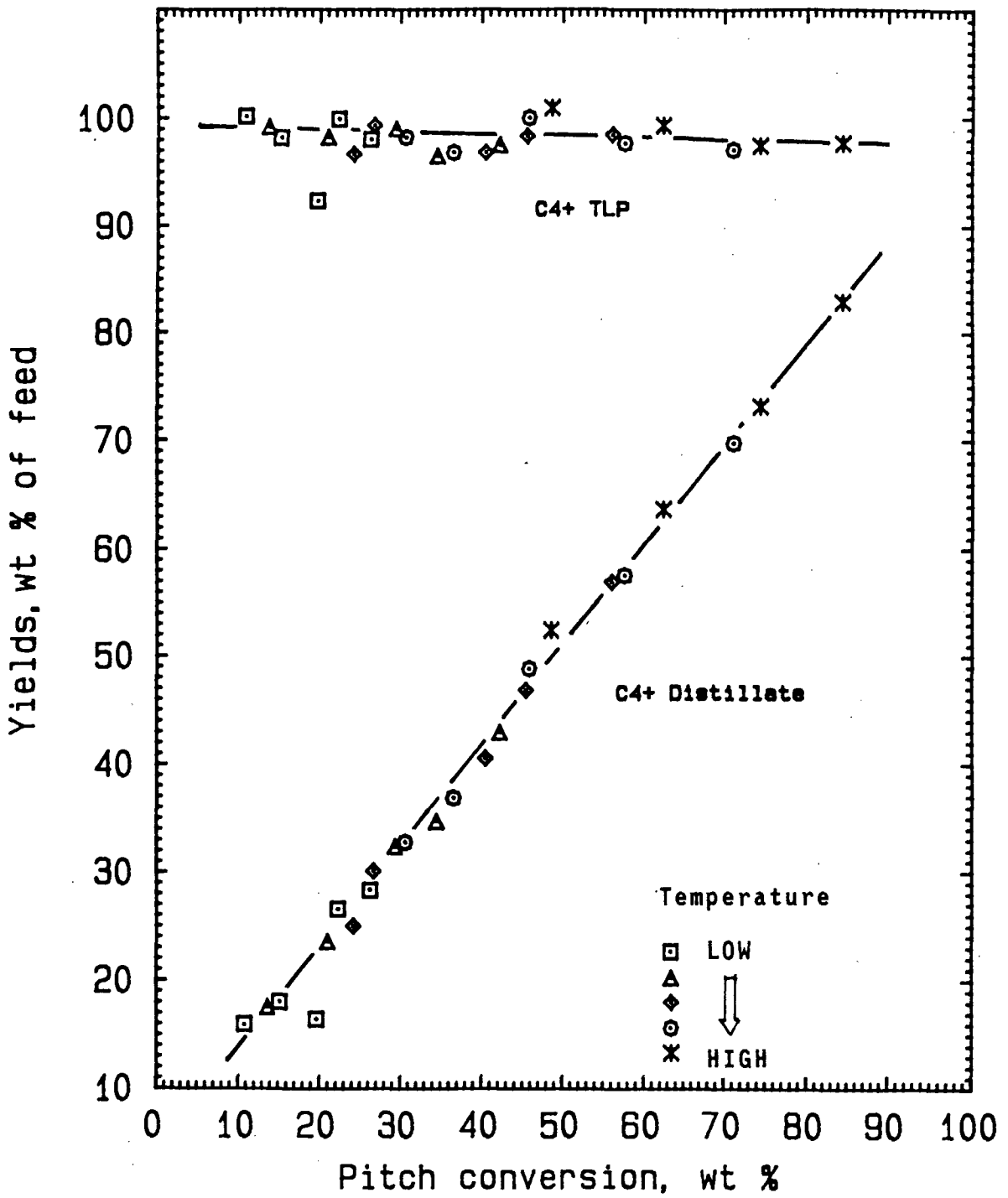


Fig. 6 - Weight yields as a function of pitch conversion

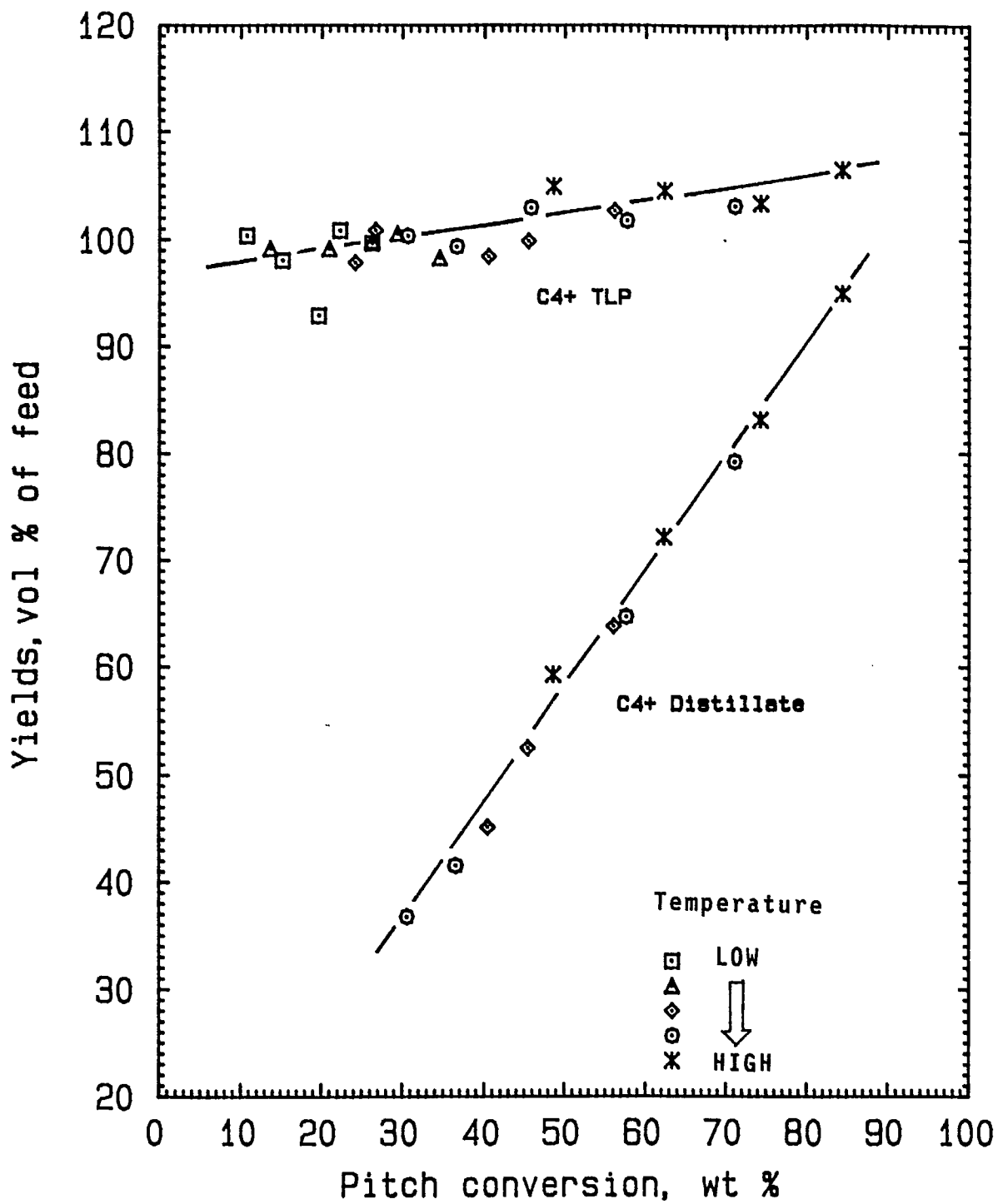


Fig. 7 - Volumetric yields as a function of pitch conversion

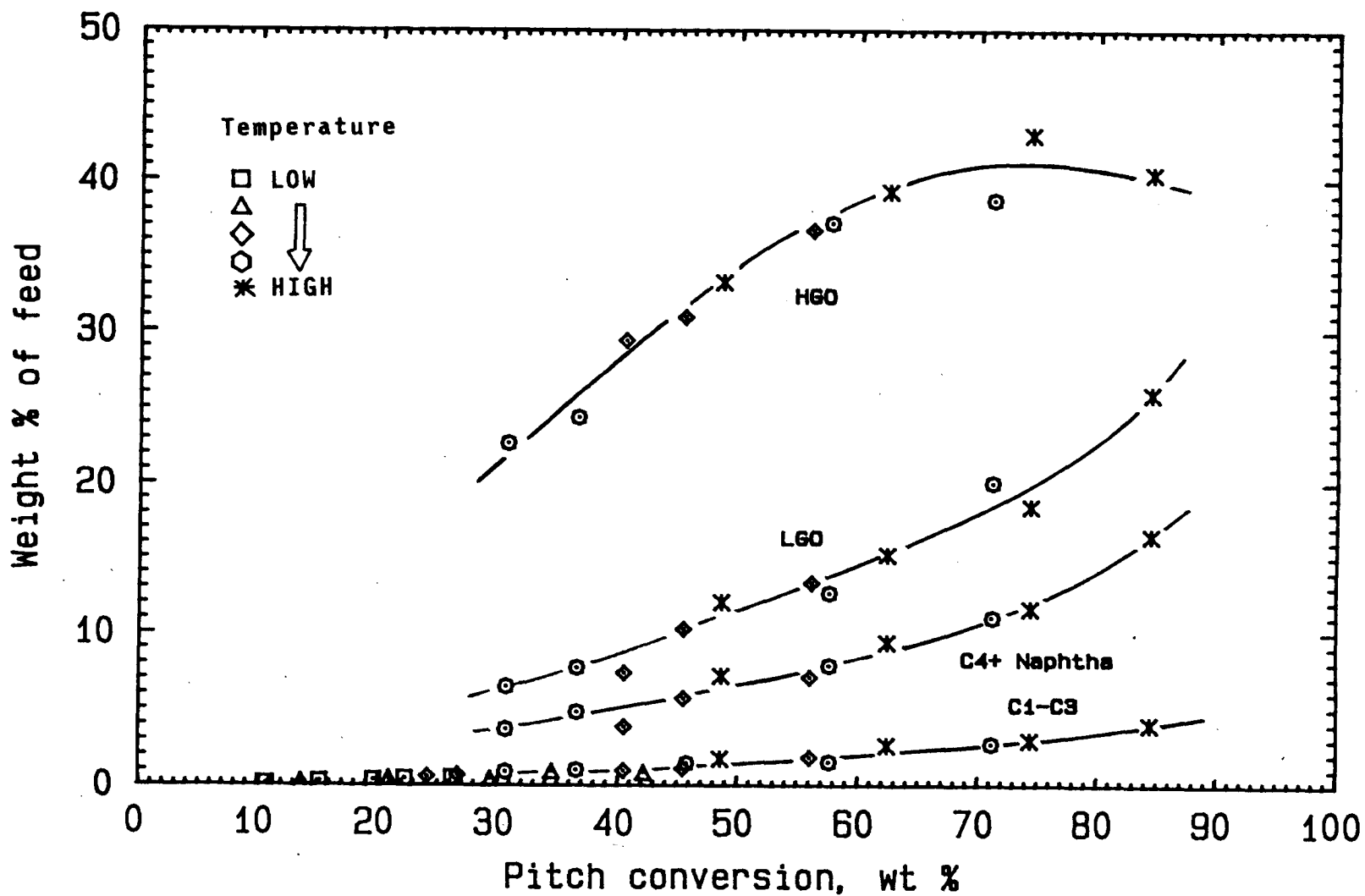


Fig. 8 - Yields of C₁ - C₃, naphtha, LGO and HGO as functions of pitch conversion

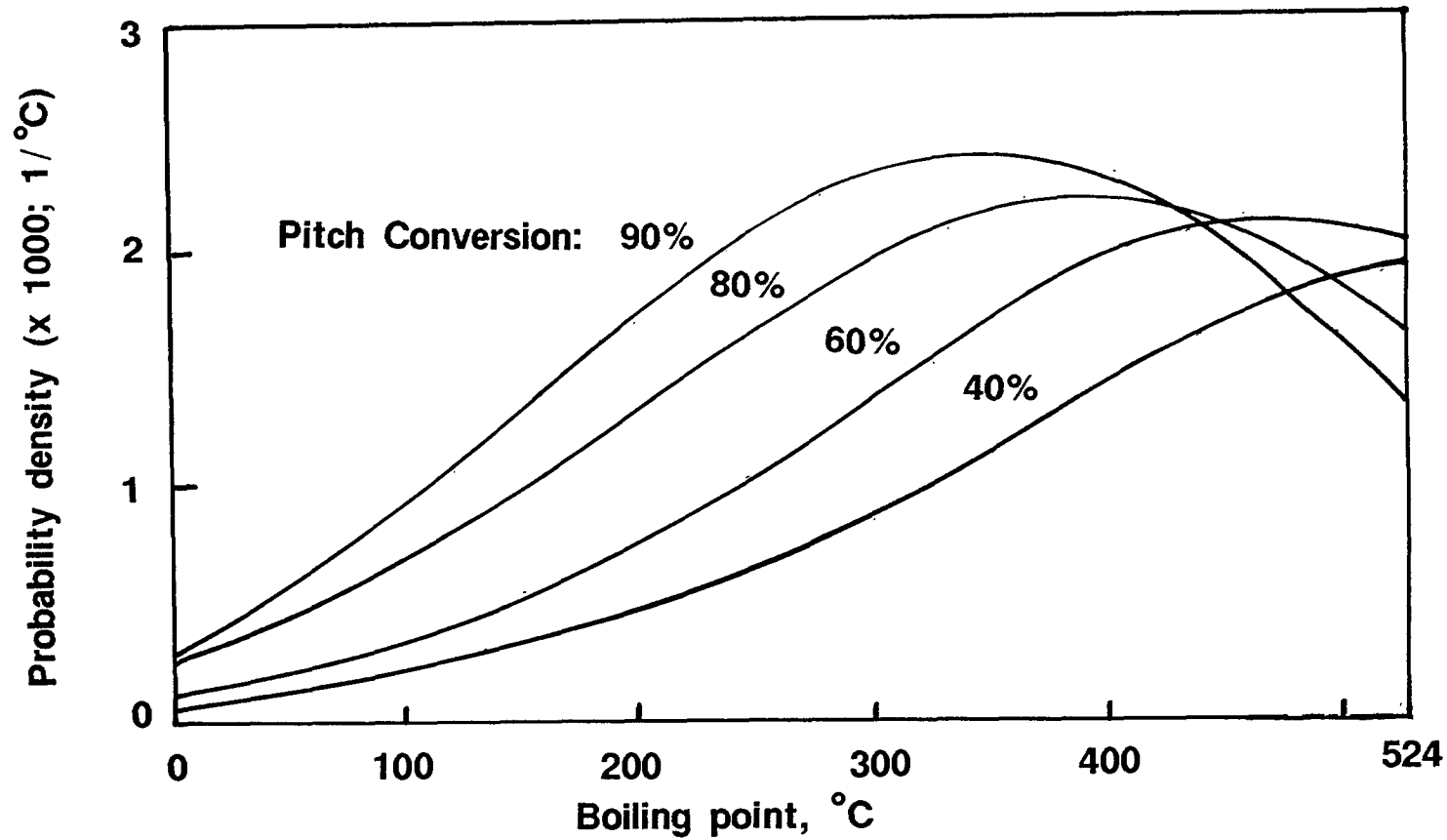


Fig. 9 - Simulated product distributions as functions of reactor temperature

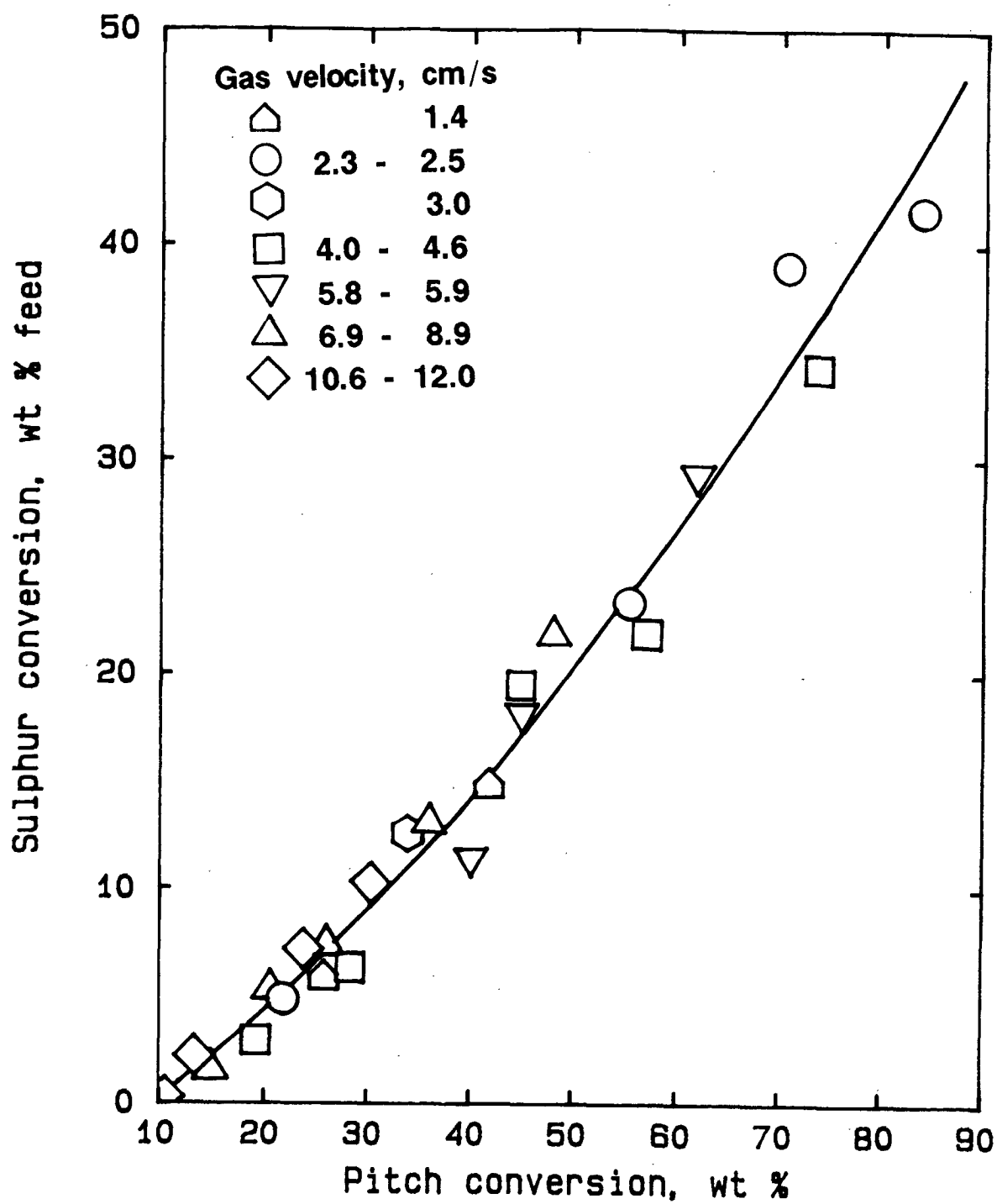


Fig. 10 - Correlation of sulphur conversions with pitch conversions