APPLICATION OF VAPEX (VAPOUR EXTRACTION) PROCESS ON CARBONATE RESERVOIRS

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ABSTRACT

APPLICATION OF VAPEX (VAPOUR EXTRACTION) PROCESS ON CARBONATE RESERVOIRS

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The vapour extraction process, or 'VAPEX' has attracted a great deal of attention in recent years as a new method of heavy oil or bitumen recovery. The VAPEX (vapour extraction) can be visualized as energy efficient recovery process for unlocking the potential of high viscosity resources trapped in bituminous and heavy oil reservoirs.

A total of 20 VAPEX experiments performed with Hele-Shaw cell utilizing three different Turkish crude oils. Two different VAPEX solvents (propane and butane) were used with three different injection rates (20, 40 and 80 ml/min). Garzan, Raman and Batı

Raman crude oils were used as light, medium and heavy oil. Apart from normal Dry VAPEX experiments one experiment was conducted with CO_2 and another one with butane + steam as Wet VAPEX experiment. All experiments were recorded by normal video camera in order to analyze visually also.

For both VAPEX solvents, oil production rates increased with injection rates for all crude oils. Instantaneous asphaltene rate for Garzan oil, showed fluctuated performance with propane solvent. Butane showed almost constant degree of asphaltene precipitation. Instantaneous asphaltene rate for Raman and Batı Raman oils gave straight line results with the injection rate of 20 ml/min for both solvent. When the injection rate increased graphs showed the same performance with Garzan oil and started to fluctuate for both solvent.

For asphaltene precipitation, propane gave better results than butane in almost all injection rates for Garzan and Raman oil. In the experiments with Batı Raman oil, butane made better upgrading than propane with the injection rate 80 ml/min. With the other two rates, both solvents showed almost same performace.

Keywords: VAPEX, vapour extraction, heavy oil, bitumen, asphaltene, Hele-Shaw cell.

ÖZ

KARBONAT REZERVUARLARINDA VAPEX (BUHAR EXTRAKSİYONU) PROSESİNİN UYGULANMASI

Yakut Yıldırım

Yüksek Lisans, Petrol ve Doğalgaz Mühendisliği Bölümü

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Hidrokarbon buharı ile üretim ya da ‘VAPEX’ son yıllarda oldukça ilgi çeken ve üzerinde çalışmalar yapılan ağır petrol ve bitumen rezervleri için yeni bir üretim tekniğidir. Hidrokarbon buharı ile üretim (VAPEX), yüksek akmazlıklı ağır petrol ve bitumen rezervleri için akmazlığını azaltıcı enerji tasarruflu bir üretim tekniği olarak nitelendirilebilir.

Yapılan bu deneysel çalışmada Hele-Shaw hücresi kullanılarak üç değişik Türk ham petrolü iki farklı hidrokarbon gazı (Propan ve Bütan) ve bu gazların üç farklı debisi ile işleme tabi tutulmuştur. Garzan, Raman ve Batı Raman petrolleri hafif, orta ve ağır

petroller olarak kullanılmıştır. Yapılan kuru VAPEX deneylerinin yanı sıra bir deney CO_2 (karbondioksit) ve bir deneyde bütan + buhar (Islak VAPEX) kullanılarak gerçekleştirilmiştir. Yapılan bütün deneyler video kamera aracılığı ile görsel olarak analize imkan tanıması amacıyla kayıt edilmiştir.

Yapılan deneylerde bütün petrol örneklerinin üretim debilerinin VAPEX gazı enjeksiyon debisinin artışı ile arttığı gözlemlenmiştir. Garzan petrolünün anlık asfalt miktarı propan gazı ile yapılan deneylerde dalgalı bir seyir izlemiştir. Bütan gazı ile yapılan deneylerde ise her üç enjeksiyon debisinde ortalama aynı derecede asfalt üretimi gözlemlendi. Raman ve Batı Raman petrollerinin 20 ml/dak gaz enjeksiyon debisiyle yapılan deneylerde her iki gaz ile sabit bir değerde anlık asfalt değerleri verdiği görülmüştür. Gaz enjeksiyon debisi artırıldığında Garzan petrolündeki gibi üretim grafiği dalgalı davranış göstermektedir.

Garzan ve Raman petrollerinden asfalt çökeltilmesi bakımından propan gazı bütan gazına oranla daha iyi sonuçlar vermektedir. Batı Raman petrolü için propan gazının 80 ml/dak. lık enjeksiyon debisi bütana oranla daha iyi sonuç vermiş, diğer iki enjeksiyon debisi aynı performansı sergilemiştir.

Anahtar Kelimeler: VAPEX, buhar ile extraksiyon, ağır petrol, bitumen, Hele-Shaw hücresi

To My Little Sister

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NOMENCLATURE

Roman

Q_o : oil production rate, ml/sec

L : length of the wells, m

K : permeability

g : acceleration of gravity, m/sec^2

ΔS_o : mobile oil saturation

h : height of the reservoir, m

N_s : VAPEX parameter

c_s : concentration of solvent in the mixture, vol. fraction

D_s : dispersion coefficient, m^2/day

Greek

φ : porosity

$\Delta\rho$: difference in density between the solvent/oil mixture and the pure solvent, kg/m^3

μ : viscosity of the mixture, kg/m day

CHAPTER 1

INTRODUCTION

Heavy oil and bitumen represent a huge amount of natural resources; the world's total estimated original OIP in these forms is approximately 6 trillion bbl. A major part of these resources are in Venezuela and Canada. A small fraction of the bitumen (tar sand) at a shallow depth may be produced by surface mining. The size of the estimated heavy oil and tar sand resources in the United States amounts to 100 billion bbl and 62 billion bbl of OIP, respectively. This may be compared to the estimated conventional crude oil reserves of 25 billion bbl in the United States. (1)

In most cases conventional recovery techniques cannot be implemented in the heavy oil and bitumen reservoirs due to the very high viscosity of the oil. In some reservoirs the oil viscosity is in millions of mPa.s at reservoir conditions so that the conventional techniques can recover only 5-6 % of the reserve. Flooding techniques cannot enhance recovery substantially, due to the adverse mobility ratio. However, the viscosities of these crudes are strong function of temperature and decrease drastically with increase in temperature. This is the underlying principle of thermal recovery process that attempt to produce these crudes. Out of these Cyclic Steam Stimulation (CSS) and Steam Assisted Gravity Drainage (SAGD) techniques were successful for these types of crudes. All of these thermal processes suffer from energy inefficiencies due larger to heat losses to the underburden and overburden, especially in thin reservoirs. These energy losses can be avoided if, instead of steam, solvent is used to leach out the heavy oil. [2]

A new idea (VAPEX) is to recover heavy oils using saturated hydrocarbon vapours under carefully controlled conditions which lead to separation of asphaltenes from heavy crude. The asphaltenes thus left behind are deposited on the reservoir matrix while the much lighter oil is recovered. [3]

In this study several VAPEX experiments were performed with three different Turkish crude oils (Garzan, Raman and Batı Raman). Two different VAPEX solvents (propane and butane) were used with three different injection rates (20, 40 and 80 ml/min). Apart from normal Dry VAPEX experiments one experiment was performed with CO_2 and another one with butane + steam (as Wet VAPEX experiment). All experiments were recorded by video camera.

CHAPTER 2

LITERATURE SURVEY

In most of the heavy oil and bitumen reservoirs, the high viscosity of the crude oil limits the primary production and therefore necessitating improved oil recovery (IOR) methods; mostly thermal recovery processes are currently being used. With thermal recovery processes (such as CSS, in-situ combustion, SAGD, etc), the viscosity of the oil is reduced by heating the reservoir. Maximum recovery with CSS process is relatively low and seldom exceeds 20 %. CSS is usually followed by a steam flooding process that may yield a significant additional recovery. For reservoirs with highly viscous oil, this flooding technique may not be suitable. The in-situ combustion technique requires sufficient mobility of the oil and is difficult to control. This process has been investigated and piloted for many years. However, it has met with limited success. Currently, SAGD has become a popular recovery technique for the heavy oil and bitumen. (3)

With SAGD process, steam is injected into the reservoir through a horizontal well, steam condenses at the oil interface and heats the oil in the reservoir. Because of its lower viscosity, hot oil drains to another horizontal well by gravity. There are several field projects in operation using this principle. The SAGD pilot of Alberta Dept. of Energy at Fort McMurry was in its third phase of operation. In the second phase of this pilot, high in-situ viscosity Athabasca bitumen was produced at a rate of

620 B/D from a pair of 500 m long horizontal wells drilled through a tunnel; the cost barrel is $ 7 to $ 9 (Canadian) and the steam oil ratio is about 2.5. In the third phase of this pilot, surface drilled horizontal well pairs were used for injection and production. In the pilot Tangleflags Nort of Scepter resources, steam is injected through a series of vertical wells, and the oil is produced from the chamber to a horizontal production well. In the Esso Cold Lake pilot HWP1, there was a single vertical injector and a deviated well as used as a producer. CS resources have developed a pilot of 5,000 B/D capacity at its Senelac field, and steam is being injected in this twin well with SAGD injectors. Albert Energy Co. is piloting the process at their Primrose lease. At the same time there is a developing interest in the use of a dual-string single horizontal well as both injector and producer; the process is known as single well SAGD. (3)

Despite the apparent success of the steam processes for the recovery of heavy oil and bitumen, they suffer from their inherent disadvantages. Steam process become more difficult to operate in a thin reservoir where heat losses to the base and caprock make the steam / oil ratio prohibitively high. In reservoirs containing swelling clays, in-situ condensation of steam can cause severe permeability damage near the production well. For example, a simulation study using SAGD for the recovery potential of Ugnu Tar sands, North Slope of Alaska showed great promise, but the possibility of formation damage when steam is injected is a great concern. With a steam process, approximately 30 % of the capital investment is used for steam generation facilities. The recycling of produced water requires elaborate processing; disposal of the waste water poses a serous environmental problem. The area requirement and operational hazards may prohibit implementation of a steam project on offshore platform. Thermal well completion and other surface and sub-surface accessories, such as pump, wellhead, cement, tubing, and casing, cost several times more than the normal well completion. Many of these heavy oil and bitumen reservoirs, SAGD may become uneconomic because the thermal energy released by condensation of steam in the water layer ends up heating the aquifer rather than the oil. (3)

Producers in the United States usually rely on thermal enhanced oil recovery techniques, CSS and steam flooding, for the recovery of heavy oil Most of this thermal heavy oil production occurs in California. Although the number of thermal enhanced oil recovery projects declined during the past decade, the fraction of heavy oil in the total crude oil production remained a constant 70 % in California. This implies that, although the marginal projects were terminated because of the declining oil prices, the successful projects expanded to yield higher production. (3)

2.1 The VAPEX Process

Viscosity of heavy oil and bitumen can also be reduced by diluting them with solvent. This is the basic principle behind VAPEX, the vapour extraction process. The concept of the process is shown schematically in Figure 2.1, which shows a vertical cross section of the reservoir. With this process, vapourized hydrocarbon solvents (low molecular weight) are injected into the reservoir through a horizontal injection well (A). The solvents initially dissolve in bitumen around the injection well until the breakthrough of the diluted oil to the horizontal production well (B), placed vertically below the injection well. Solvent vapour rises slowly to form a vapour chamber in the extracted sand matrix above the injection well, dissolves in the bitumen at the solvent bitumen interface, diffuses into the bulk of bitumen, and dilutes it. The diluted oil drains to the production well by gravity. When the chamber reaches the caprock, it spreads sideways until the pattern boundary is reached. The oil-vapour interface then starts falling, and the project is continued until the production rate decreases below the economic limit of operation. (3)

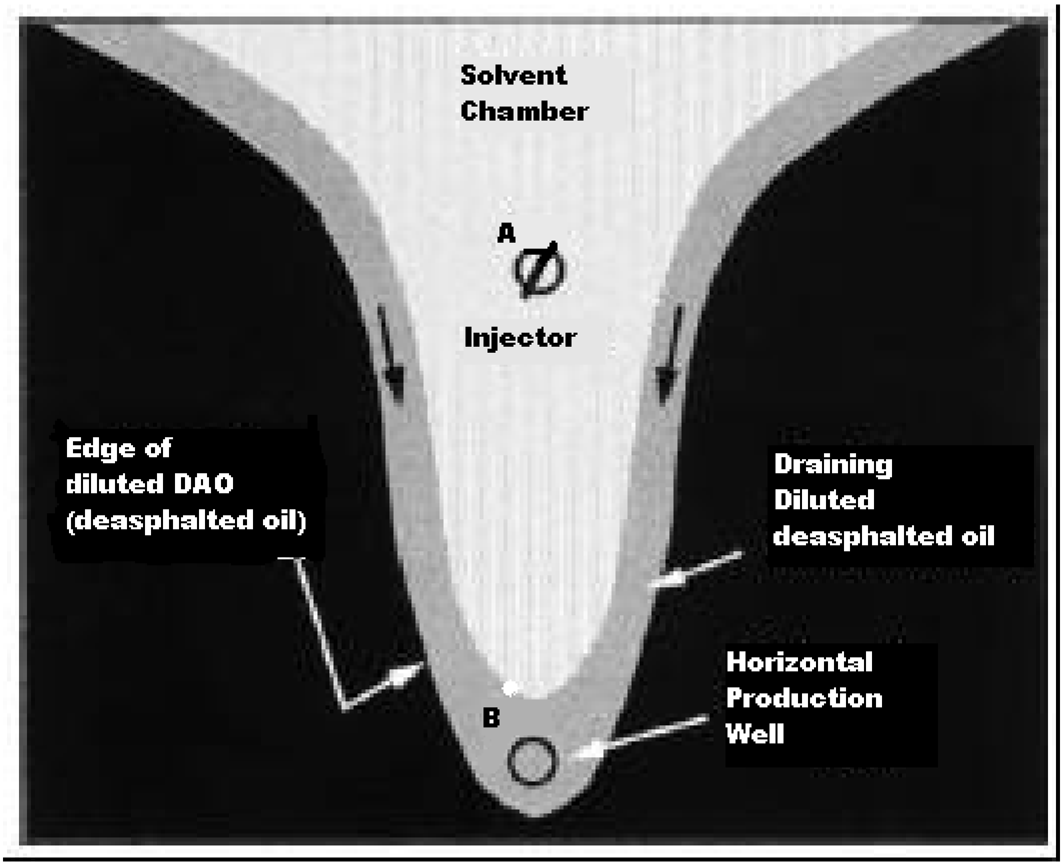


Fig 2.1 The Concept of VAPEX Process (3)

The concept is similar to that of SAGD, except solvent, instead of steam, is used in the VAPEX process. Apart from the configuration of injector and producer wells are also possible. Even a series of existing vertical wells can be used as injection wells. Separation between injector and producer will be dictated by mobility of the oil at reservoir conditions. In a relatively mobile heavy oil reservoir, the injector can be placed near the top of the reservoir, whereas in a bitumen reservoir, the horizontal well pair should be close enough to achieve early communication between them. Injector and producer can be staggered in a heavy oil reservoir with relatively lower oil viscosity. In a reservoir with bottom aquifer, both injector and producer can be placed the water oil contact at opposite ends of the pattern; injected solvent vapour rises, and the diluted oil drains countercurrently by gravity and moves along the water oil contact to the producer. This well configuration results in a higher recovery rate because of the countercurrent nature of extraction process. [(3)]

Most of the heavy oil and bitumen contain a significant amount of asphaltenes, often as high as 22 % by weight. The presence of the asphaltene is the main reason for the high viscosity of these crude oils. If the concentration of the low molecular hydrocarbon solvents in the diluted oil is enough, it may cause de-asphalting and lead to an additional reduction in viscosity. This in-situ upgraded oil is of better quality from a transportation and refining point of view and has a higher market value. However the important concern in the development of the VAPEX process is the possibility of the reduction of permeability (or plugging) of the reservoir matrix because of asphaltene deposition and the consequent hindrance to the flow of oil out of the reservoir. [(3)]

The use of vapourized rather than liquid solvent produces higher driving force for gravity drainage, because of the higher density difference between bitumen and solvent vapour, and also ensures that the residual amount of solvent in the extracted reservoir is less than that with liquid solvents. At a given temperature, the solubility of a vapourized solvent is near maximum its vapour pressure. Hence, the solvent pressure should be as close as possible to its vapour pressure at the reservoir temperature. In field conditions, to avoid liquefaction of solvent at any point in the reservoir, the pressure should be lower than solvent's vapour pressure at the prevailing temperature. Hence, it is clear that the reservoir pressure and temperature play a significant role in the selection of solvent. Because of the low vapour pressure of the possible Vapour extraction solvent, propane and butane, this may impose a serous limitation on the operating pressure and applicability of the process in high-pressure reservoirs. (3)

The process is highly energy efficient. With the VAPEX process and the use of a pure solvent, about 0.5 kg of solvent is injected per 1 kg of oil produced. Of this, only 0.1 kg solvent left behind in the reservoir to fill the extracted sand matrix with vapour. The rest solvent is produced with oil and is recycled. On the contrary, with a steam process in these high viscosity oil reservoirs, usually more than 3 kg of steam is injected per 1 kg of oil produced. This accounts for heating the reservoir rock and fluid and heat losses (4, 5). Similarly, in a study done for the solvent requirements for the process and it has found that the solvent requirements about 2-6 tones per tone (t/t) of produced oil for SAGD and 0.3-0.5 t/t for VAPEX process which is approximately same with the other performed studies. (6)

VAPEX process has several potential advantages and disadvantages for economic scale economic oil production. (2)

The potential advantages are:

- No steam generation
- No water processing / recycling

- Lower fuel costs
- Greater energy efficiency
- Lower carbon dioxide emissions
- May be advantageous in thin reservoirs and with bottom water
- In-situ upgrading

The potential disadvantages are:

- Solvent compression
- Solvent losses
- Untested in field
- Untested well / facilities design

The concept of the VAPEX process, illustrated in Figure 2.1, was developed by Butler at all [8]. Butler and Mokrys [7, 8, 11, 12] have developed an analytic model describing the VAPEX process which is very useful for understanding the key parameters affecting the process. The model predicts that oil production rate, Q_o, will be given by

$$Q_o = 2L\sqrt{2Kg\varphi\Delta S_o h N_s} \quad \text{......1}$$

where L is the length of the wells, K is the permeability, g is the acceleration of gravity, φ is the porosity, ΔS_o is the mobile oil saturation, and the h is the height of the reservoir. N_s is a dimensionless parameter that incorporates the effects of dispersive mixing, to be defined below. [7, 8, 11, 12]

The parameter Ns depends in a complex way on the intrinsic dispersion of the solvent, according to the equation:

$$N_s = \int_{c\,\min}^{1} \frac{\Delta\rho(1-c_s)D_s}{\mu c_s} dC_s \quad \text{......2}$$

In the integral in Equation 2, $\Delta\rho$ is the difference in density between the solvent/oil mixture and the pure solvent, c_s is the concentration of solvent in the mixture, D_s is the dispersion coefficient for the solvent in the mixture and μ is the viscosity of the mixture. All of the quantities $\Delta\rho$, D_s and μ depend on the solvent fraction, c_s. Butler and Mokrys [7, 8] calculated Ns for two systems, toluene/Athabasca bitumen and toluene/Suncor Coker feed, obtaining values 9.44×10^{-7} and 2.5×10^{-6}, respectively. Utilizing these values in the analytic model gave reasonable agreement with the oil production rates observed in their Hele-Shaw cell experiments. [7]

The problem of extraction of heavy oil and sometimes in situ de-asphalting, of oil with solvents can be approached from several directions. There are several laboratory experiments were performed [5, 8, 10, 11, 12] in which VAPEX solvents alone were injected in to the cell, which generally called Dry VAPEX, both under steady state conditions and under pressure cycling regime. In another set of experiments called Wet VAPEX, solvent is injected with steam to study the coexistence of a large, low temperature solvent chamber with a hot steam chamber limited to the proximity of the injector/producer. [9]

Das and Butler [4] performed several experiments to analyze the asphaltene deposition from heavy oils by VAPEX process using a Hele-Shaw cell. They used propane as solvent and three different bitumen samples to investigate the asphaltene deposition in the experimental system and they concluded that asphaltene deposition did not prevent the oil flow and asphaltene precipitation starts if the injected solvent pressure was close to or higher than the solvents vapour pressure.

Butler and Jiang [10] have done experimental study to achieve high oil production rates with economic solvent requirements. During their experiments they investigated the affect of major parameters to the VAPEX performance like temperature, pressure, solvent injection rate, type of solvent etc. at the end of their study they concluded with the practical rates and high oil recovery can be achieved with the solvent injection rate of 0.2 b/b oil. They also expressed that wider lateral well spacings allow higher production rates and made the process more economic.

Butler and Mokrys [11, 12, 13] investigated VAPEX process on crude oil samples in both packed cell and Hele-Shaw cell with two solvent (propane and butane). They observed production rate, recovery percentage, density and viscosity of oil against the solvent rate and temperature. They also conducted series of experiments with solvent and steam as Wet VAPEX process to compare the hot water and hot water + solvent production rates. They found that the injection of propane vapour with hot water results in high oil recovery than hot water alone.

2.2Asphaltenes

2.2.1 Nature and Characteristics of Asphaltenes

Asphaltenes are polyaromatic, high molecular wieght hydrocarbons and are amorphous in nature. Asphaltenes are insoluble in the low molecular weight normal paraffins and are classified by the type of precipitating paraffin since different paraffins precipitate different molecular weight ranges and hence different amounts of asphaltenes. Asphaltenes are commonly defined as n-heptane insoluble and benzene soluble fraction of crude oil following the Institute of Petroleum (IP) Method test 143.

The classical definition of asphaltenes is based on the solution properties of petroleum residuum in various solvents. This generalized concept has been extended to the low molecular weight n-paraffin insoluble and benzene soluble fraction derived from various carbonaceous sources, such as petroleum, coal and shale oil [14]. Asphaltenes must be classified by the particular precipitation solvent since different solvents cause different amounts of precipitation [15]. In general, asphaltenes must be classified as polar, aromatic high molecular weight hydrocarbons of amorphous structure and are believed to exist in crude oils partly in the form of colloidaly dispersed fine particles and partly as dissolved compounds [16]. The exact chemical structures of asphaltenic compounds is known and depend on the type of crude oil; however, asphaltenes are believed to consist of aromatic ring structures with oxygen, nitrogen and sulphur present in heterocyclic side chains and oxygen in alkyl side chains. Long [14] proposed complete characterization of asphaltenes by considering molecular weight and molecular polarity as separate properties of the molecules. He demonstrated that asphaltenes contained a wide distribution of polarities and molecular weights.

Speight [17] shows elemental composition of n-pentane asphaltenes. The elemental compositions of asphaltenes yield H/C ratios of 1.05 ~ 1.15 on a mole basis. The near constancy of this ratio is surprising when the number of possible molecular isomers of massive asphaltene molecules is considered. In contrast are the ratios of hetero atoms in crude oils, for example, oxygen 0.3 ~ 4.9%, nitrogen 0.6 ~ 3.3% and sulphur 0.3 ~ 10.3%.

In the petroleum reservoir, asphaltenes have been observed to occur as dissolved and as micelles or colloidal suspensions in crude oil. Measurement of the surface tension indicates that there exists a critical micelle concentration (CMC) for dilute solutions of asphaltene in toluene. With concentration below the CMC, the asphaltenes in the solution are in a molecular state, while above the CMC, associates and aggregates of asphaltenes may form. When resins and asphaltenes both present as in petroleum, asphaltene molecules are surrounded by resins that act as peptizing agents; that is, the resins maintain the asphaltenes in a colloidal dispersion (as opposed to a solution). The resins are typically composed of a highly polar end group, which often contains hetero atoms such as oxygen, sulphur and nitrogen, as well as, non-polar paraffinic groups. The resins are attracted to the asphaltene micelles through their end group. This attraction is a result of hydrogen bonding through the hetero atoms and dipole-dipole interaction arising from the high polarities of the resin and asphaltene molecules. The paraffinic component of the resin molecule act as a tail making the transition to the relatively non-polar bulk of the oil where individual molecules also exist in true solution. This means when resins and asphaltenes both present as in petroleum asphaltenes tend to associate with resins preferentially over association among themselves. [18]

CHAPTER 3

STATEMENT OF THE PROBLEM

The aim of this study is to investigate the applicability of VAPEX process on different API gravity of Turkish crude oils (Garzan, Raman and Batı Raman) with experimental and visual methods. Experiments were planned to investigate the effects of two different VAPEX solvents (propane and butane) on three different Turkish crude oil samples and the results are discussed.

CHAPTER 4

EXPERIMENTAL SET-UP AND PROCEDURE

In this chapter of the study, experimental method for oil production and the evaluation method are presented.

4.1. Experimental Set-Up

The experimental set-up consists of supply cylinder, mass flow meter and Hele-Shaw cell.

Supply cylinder was used to supply Vapex solvents (propane and butane) to the system. Mass flow meter was used to control and adjust the required solvent rate that goes to the Hele-Shaw cell. The Hele-Shaw cell consist of two closely spaced plates given clearance, which is filled with heavy oil, to a reservoir model with 100% porosity. The front part made from glass to give us a chance to visualize the Vapex process during the experiments. The cell dimensions are 12 cm X 12 cm X 0.15 cm and by including port volumes total cell volume becomes approximately 25 ±1 ml. (Figures 4.1, 4.2)

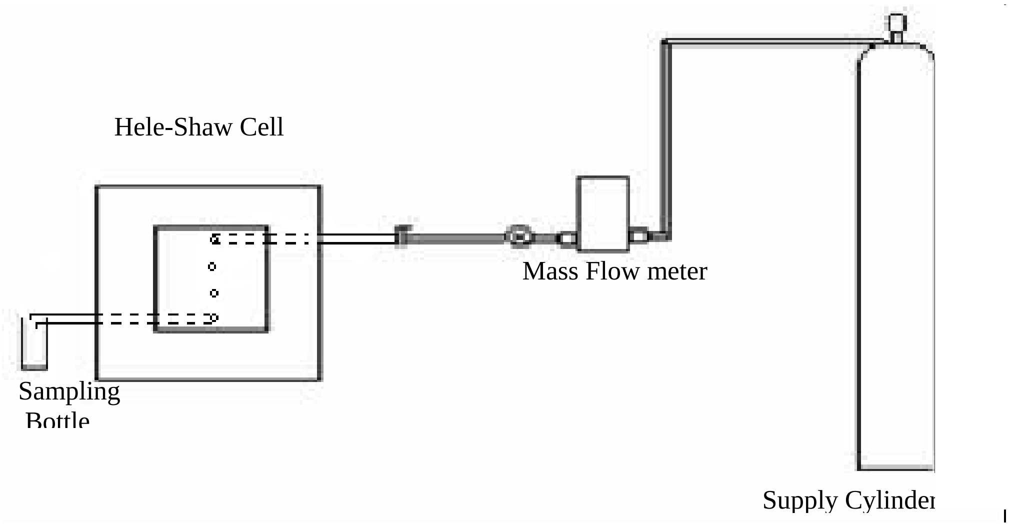


Fig 4.1 Schematic Diagram of the Experimental Set-Up

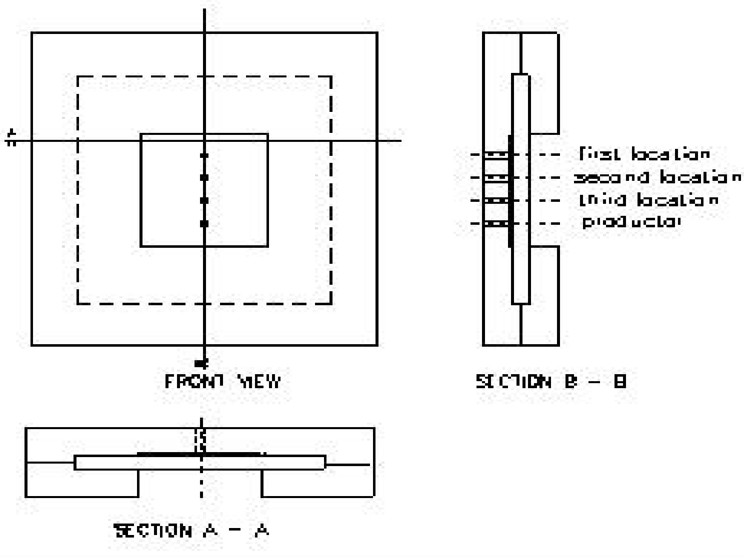


Fig 4.2 Schematic view of Hele-Shaw Cell [19]

4.2 Experimental Procedure

In the experimental setup, the heavy oil was filled manually to the cell due to the high viscosity of the oils. The solvent (propane, butane) was injected from a supply cylinder. The solvent passes from a mass flow meter with a fixed rate (e.g. 20 ml/min) and goes to the Hele-Shaw cell. The produced oil was collected in a graduated cylinder. All the experiments were recorded with video camera in order to analyze the experiments visually.

In the experiments, three different Turkish oils were used (Garzan, Raman, and Batı Raman) with two different hydrocarbon solvents, propane and butane, which are mainly used as Vapex solvents in literature, with three different mass rates of hydrocarbon solvents (20, 40, 80 ml/min). The properties of the Vapex solvent gases and oils used in experiments are given in the Tables 4.1 and 4.2.

Table 4.1 Properties of Vapex Solvents

	Propane	Butane
Formula	C_3H_8	C_4H_{10}
Molecular Weight	44,097	58,124
Boiling Point, ^oF	-43,67	31,1
Vapour Pressure 100 ^oF, psia	190	51,6
Freezing Point ^oF 14,696, psia	-305,84	-217,05
Pressure ,psi	616,3	550,7
Temperature, ^oF	206,01	305,65
Volume, cuft/lb	0,0737	0,0702

Table 4.2 Properties of Crude Oils

	Garzan	Raman	B.Raman
Heavy Fraction %	26	40	51
API	26,12	20,19	14,95

Titration experiments were carried out to determine the amounts of asphaltenes precipitated when the crude oils were titrated with various n-alkanes. In this study hexane was used. A simple gravity filtration was used as most appropriate for routine analysis. The following procedure was used [(20)]:

1. An adequate volume of hexane was added on to the produced oil to give the desired solvent ratio. The solution of hexane and heavy oil was filtered using a Whatman No: 42 filter. The sampling bottle was rinsed with several small volumes of hexane to ensure that all dissolved oil was transferred through the filter.
2. The asphaltenes on the filter paper were washed with several volumes of toluene, until the filtrate was become colourless, on to a pre-weighted beaker.
3. The toluene solution was then allowed to evaporate in the oven (100-120 ^{o}C) for over night and asphaltenes were dried. The beaker was cooled and re-weighted and the result was recorded.

CHAPTER 5

RESULTS AND DISCUSSION

A total of 20 VAPEX experiments were conducted using three different Turkish crude oils. Two different VAPEX solvents were used with three different injection rates (20, 40 and 80 ml/min). Garzan, Raman and Batı Raman crude oils were used as light, medium and heavy oils. Propane and butane were used as VAPEX solvents. Apart from normal dry VAPEX experiments, one experiment was performed with CO_2 and another one with butane + steam as wet VAPEX experiment. All experiments were recorded by video camera.

In the dry VAPEX experiments, firstly propane was used as solvent. With propane totally nine experiments were performed with three different injection rate and three different crude oil samples at the room temperature. Similarly, butane was used as solvent and totally ten experiments (nine + one Wet VAPEX) were conducted at the same experimental conditions. One experiment was performed with CO_2 for comparison purpose. Experimental conditions are given in table 5.1 and the experimental data are given in appendix A.

The results of the experiments are given on dimensionless cumulative oil production and oil rate versus dimensionless time curves and asphaltene rate (instantaneous, cumulative, and produced) versus dimensionless time curves. The experimental graphs are given in appendix B. The dimensionless cumulative oil data were obtained by dividing cumulative oil data to total cell volume. Experimental times were converted to dimensionless time with the help of the formula given below:

$$t_D = t_{exp} \times q \times V^{-1} \quad \text{.......... ....} \quad 3$$

where;

t_D is dimensionless time, t_{exp} is the experimental time, q is the gas injection rate and V is the total cell volume.

Table 5.1 Experimental Conditions

Exp No	**Crude Oil**	**VAPEX Solvent**	**Injection Rate ml/min**
1	Garzan	Propane	20
2	Garzan	Propane	40
3	Garzan	Propane	80
4	Raman	Propane	20
5	Raman	Propane	40
6	Raman	Propane	80
7	Batı Raman	Propane	20
8	Batı Raman	Propane	40
9	Batı Raman	Propane	80
10	Garzan	Butane	20
11	Garzan	Butane	40
12	Garzan	Butane	80
13	Raman	Butane	20
14	Raman	Butane	40
15	Raman	Butane	80

16	Batı Raman	Butane	20
17	Batı Raman	Butane	40
18	Batı Raman	Butane	80
19	Garzan	CO_2	40
20	Garzan	Butane+Steam	40

5.1 Propane Experiments

When propane used as VAPEX solvent in Garzan light oil (Fig B1-B2) the slope of the cumulative produced oil curve increases with the injection rate of solvents and the total production time decreases. Oil rate remains approximately steady with the increase of the injection rate. When theoretical oil rate calculated by using equation 1 and plotted to the same graph with cumulative oil production (Fig 5.1), there was a difference on the slopes of two curves. The difference occurs due to the production with gas push of VAPEX solvent. The differences increased with the solvent injection rate. This means that the oil production is not only due to the gravity drainage but also with solvent gas push. This phenomenon was observed almost same for the all crude oils.

Instantaneous asphaltene rate curves (Fig B5-B7) showed undulate performance for three solvent injection rates. Cumulative asphaltene rate slopes were approximately same but 40 ml/min had the biggest slope. With the rates of 20 ml/min and 40 ml/min almost same asphaltene precipitation were observed. Injection rate of 80 ml/min gave less asphaltene precipitation. This is most probably due to the high injection rate of the solvent.

For Raman oil with propane experiments, when solvent injection rate increased from 20 ml/min to 40 ml/min, slope of the cumulative production rate curve (Fig 5.2) increased also but from 40 ml/min to 80 ml/min, the slope remained almost same. Except the experiment with 40 ml/min injection rate, oil rates (Fig 5.3) remained same. For Raman crude oil with propane experiments; experimental oil rates found from the slope of the curve and calculated oil rates were found as follows:

Table 5.2 Experimental and Calculated Oil Rates for Raman Oil

	Propane Injection Rate (ml/min)		
	20	40	80
Oil Rate Experimental	0,0036457	0,013302	0,023611
Oil Rate Calculated	0,002521	0,002521	0,002521

The calculated oil rates were found with the assumption of Ns value with degree of 2,5 e-07 which was a value of found by Butler and Mokrys in an experimental study [(8)]. When these rates plotted together, the behavior discussed previously could be seen very easily from the graph.

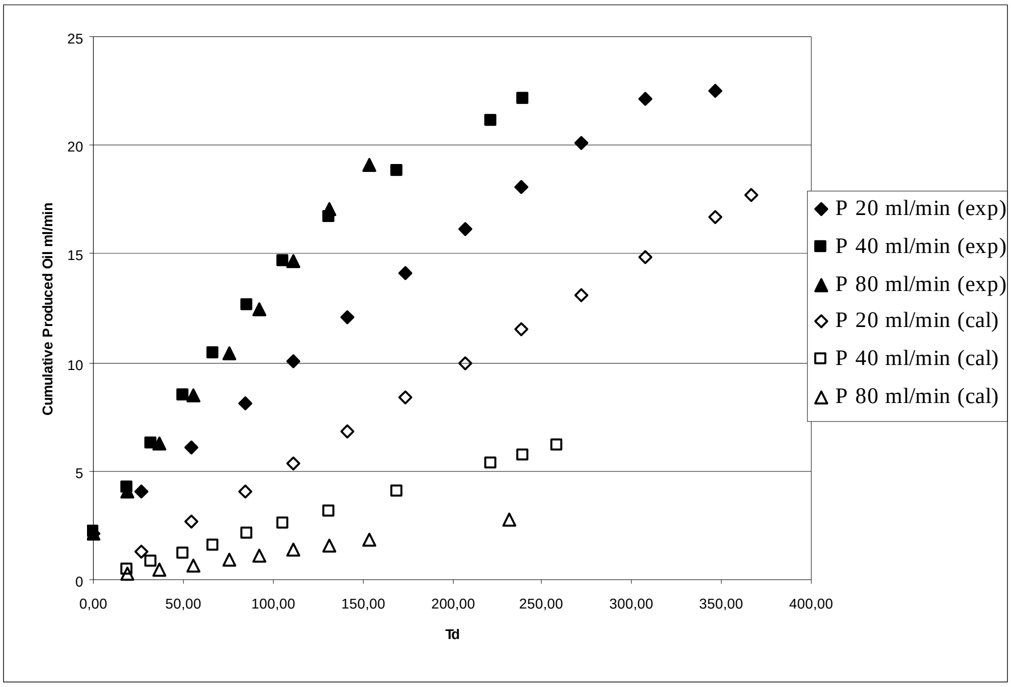


Fig 5.1 Oil Rate (experimental vs calculated) Comparison Graph for Raman Oil with Propane solvent

As mentioned previously, it was observed that when the injection rate increased the gap between two curves were also increased. This means that increase of the injection rate caused as increase of the produced oil with solvent gas push.

Instantaneous asphaltene rate curves (Fig 5.4) showed undulate performance with injection rates of 40 ml/min and 80 ml/min. With 20 ml/min, instantaneous asphaltene rate remained steady. The cumulative asphaltene rate curve (Fig 5.5) slopes increased with the injection rates of 20 ml/min and 40 ml/min. Solvent injection rate of 40 ml/min and 80 ml/min gave the same slope. With the rates of 20 ml/min and 40 ml/min, almost same asphaltene precipitation achieved. With the injection rates of 20 and 40 ml/min gave %50 asphaltene production. This value decreased to the %45 with the rate of 80 ml/min. Injection rate of 80 ml/min gave less asphaltene precipitation. Because the injection rate of the VAPEX solvent is too high (mostly in literature injection rates maximum used 20 ml/hr), the VAPEX solvent could not found enough time to contact with oil and therefore most of the oil production occurred with the gas push. Due to this reason, the highest injection rate gave the least asphaltene precipitation.

For the Batı Raman crude oil, different from other two crude oil samples, cumulative produced oil curve (Fig B.3) slopes decreased with the increase of the solvent injection rate. Oil rates (Fig B.4) of this crude for different injection rates firstly increased and after decreased gradually for all. The reason of this observation may be due to the when production port opened and production started; the oil accumulated to the bottom of the cell produced so the oil rates increased. Later with the effect of plugging, oil rate decreased.

Instantaneous asphaltene rates (Fig B.8-B.10) showed three different performances belonging to the injection rates. For the injection rate of 20 ml/min instantaneous asphaltene rate curve increased. In contrast to 20 ml/min, in rate of 40 ml/min instantaneous asphaltene rate decreased sharply. The injection rate of 80 ml/min instantaneous asphaltene rate showed undulate performance. The rate of 20 ml/min gave less asphaltene precipitation degree of %48 and other two rates gave almost same degree of asphaltene precipitation of %55 around. In literature, the researchers conducted their experiments with heavy oils and they controlled the temperature and pressure of solvents instead of injection rate. Due to this reason, very limited results obtained from this study can be compared with literature. In a study one by Butler and Mokrys [11,12] they found the cumulative oil production continued with a steadily declining rate as in our study.

5.2 Butane Experiments

When butane used as VAPEX solvent with Garzan oil the slope of cumulative produced oil decreased, while injection rate increased from 20 ml/min to 40 ml/min. On the other hand, an increase in injection rate from 40 ml/min to 80 ml/min increased and became almost same slope with the rate of 20 ml/min. Oil rates were slightly decreased in all injection rates. When theoretical oil rate calculated and plotted to the same graph with cumulative oil production, there was a difference on the slopes of two curves. This difference occurs due to the production with gas push of VAPEX solvent. The differences increased with the solvent injection rate. This means that the produced oil rate with gas push increases. This phenomenon was found almost same for all three crude oil samples with butane solvent.

The Garzan crude oil instantaneous asphaltene rate curves showed undulate performance. Cumulative asphaltene rate curve slopes were approximately same but 20 ml/min injection rate had the biggest slope. The injection rates of 20 and 80 ml/min gave almost the same asphaltene precipitation degree of %45. 40 ml/min injection rate gave the precipitation value of %40.

For the Raman oil, injection rate of 20 ml/min gave the biggest slope for cumulative produced oil. The rates of 40 ml/min and 80 ml/min slopes were same and lower than 20 ml/min. Like in Garzan oil, the oil rates decreased with the increase of the injection rates. For Raman crude oil with butane experiments; experimental oil rates found from the slope of the curve and calculated oil rates were found as follows:

Table 5.3 Experimental and Calculated Oil Rates for Raman Oil

	Butane Injection Rate (ml/min)		
	20	40	80
Oil Rate Experimental	0,014634	0,012377	0,025227
Oil Rate Calculated	0,002521	0,002521	0,002521

The calculated oil rates were found with the assumption of Ns value with degree of 2,5 e-07 which was a value of found by Butler and Mokrys in an experimental study [13]. The butane solvent showed same behavior with propane solvent which is stated previously.

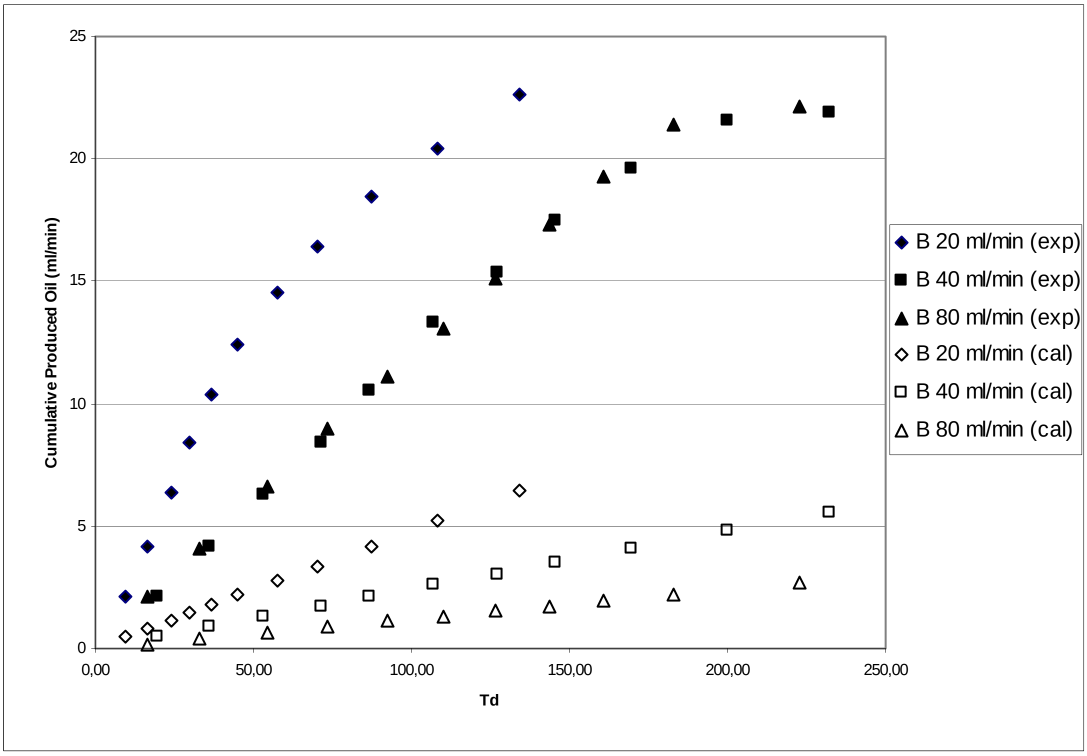


Fig 5.7 Oil Rate (experimental vs calculated) Comparison Graph for Raman Oil with Butane solvent

Raman crude oil instantaneous asphaltene rate curves showed undulate performance. Cumulative asphaltene rate curve slopes were same for 40 ml/min and 80 ml/min injection rates and 20 ml/min injection rate gave the biggest slope. 20 ml/min made better asphaltene precipitation than other two injection rates. This could be happened due to the rates of 40 and 80 ml/min could not find enough time to contact with crude oil.

For the Batı Raman crude oil, slope of cumulative produced oil curve greatly increased when the solvent injection rate increased from 20 ml/min to 40 ml/min but also slope greatly decreased with the injection rate of 80 ml/min. When solvent injected to the system and production started the accumulated oil produced and oil rate increased sharply and later started to fall. For the injection rate of 20 ml/min, oil rate remained same during the whole experiment.

Batı Raman crude oil instantaneous asphaltene rate curves showed undulate performance. 20 ml/min gave the smallest slope and 40 ml/min gave the biggest. Asphaltene precipitation increased with the increase of the rate of the injection. This could be happened due to the rates of 40 and 80 ml/min could not find enough time to contact with crude oil.

5.3 Comparison of the Experiments

For the Garzan crude oil, cumulative produced oil slopes with propane were found much higher than butane experiments. When injection rates increased, oil rates of propane were found also higher than the butane oil rates except 20 ml/min injection rate for both solvent. On this rate both solvent gave almost same oil rate.

The Garzan oil instantaneous asphaltene rate curves for both solvents showed undulate performance. Cumulative asphaltene rate curve slopes for propane found higher than butane except the injection rate of 20 ml/min. in this injection rate cumulative asphaltene rate's curve slope was almost same.

For the Raman crude oil, injection rates of 40 ml/min and 80 ml/min for both solvents gave same slope in cumulative produced oil graph. 20 ml/min butane experiment gave the biggest slope and in contrast to that, 20 ml/min propane gave the smallest slope. Oil rates showed undulate performance except for propane 20 ml/min. in this injection rate, oil rate found almost constant.

The two solvents instantaneous asphaltene rate curves showed undulate performance with Raman oil experiments. The cumulative asphaltene rate curves showed that propane made better upgrading than butane in consideration of asphaltene precipitation. The slopes of the curves of butane were bigger than propane. Injection rate of 80 ml/min with propane made the best in-situ upgrading of all.

For Batı Raman oil all injection rates of both solvents approximately, same with other solvent cumulative produced oil curve slope. The injection rate of 40 ml/min for both solvents gave the highest slope for cumulative produced oil. Oil rate curves showed almost same performance and increased firstly than started to fall. Except the rate of 20 ml/min, other injection rate of propane started with higher oil rate than butane.

Propane had lesser instantaneous asphaltene rate with Batı Raman oil except the solvent rate of 20 ml/min. butane showed slightly decrease and an undulate pattern of instantaneous asphaltene rate with Batı Raman crude oil. As cumulative asphaltene rate, propane 40 ml/min and butane 40 ml/min, gave the same slope and bigger than the other injection rates. Except the injection rate of 80 ml/min for both solvents, the other rates made same asphaltene precipitation. In all of them butane 80 ml/min injection rate made the best upgrading.

As the last work, one experiment conducted with CO_2, with injection rate of 40 ml/min, and another one with butane (40ml/min) + steam (Wet VAPEX). As wet VAPEX only butane + steam system were used because at that time we were lack of propane gases. In these experiments, CO_2 gave the biggest slope on the cumulative produced oil graph. The reason why CO_2 gave better performance than the other systems is that in the equation 1 and equation 2 the parameters depends to the solvent type are higher for CO_2. Propane and butane + steam showed the same slope and bigger then butane curve slope. When oil rates were compared, CO_2 showed undulated performance with highest oil rate of all. Propane and butane + steam oil rate curves showed slightly decrease except at the beginning butane + steam system increased a bit. In experiment which butane used alone as solvent oil rate stayed steady degree.

5.4 Visual Analyses of the Experimental Videos

According to the video images all experiments were analyzed by visually to investigate the process (chamber type, production style etc...) and are given in the table as follows;

Table 5.4 Visual Analyze of the Experiments from Video Images

Exp No	Oil	Solvent	Injection Rate	Observations
1	Garzan	Propane	20ml/min	Vapour chamber was not observed, oil produced with solvent push, asphaltenes stuck to the cell window, no fingering formation observed.
2	Garzan	Propane	40ml/min	Vapour chamber was not observed, oil produced with solvent push, asphaltenes stuck to the cell window but not uniformly, no fingering formation observed.
3	Garzan	Propane	80ml/min	Vapour chamber was not observed, oil produced with solvent push, asphaltenes stuck to the cell window, no fingering formation observed
4	Raman	Propane	20ml/min	Vapour chamber was not observed, oil produced with

				solvent push, asphaltenes stuck to the cell window but not uniformly, highly fingering formation observed.
5	Raman	Propane	40ml/min	Nothing could be seen
6	Raman	Propane	80ml/min	Nothing could be seen
7	Batı Raman	Propane	20ml/min	Nothing could be seen
8	Batı Raman	Propane	40ml/min	Nothing could be seen
9	Batı Raman	Propane	80ml/min	Nothing could be seen
10	Garzan	Butane	20ml/min	Vapour chamber was not observed, oil produced with solvent push, asphaltenes stuck to the cell window but not uniformly, no fingering formation observed.
11	Garzan	Butane	40ml/min	Vapour chamber was not observed, oil produced with solvent push, asphaltenes stuck to the cell window but not uniformly, no fingering formation observed.
12	Garzan	Butane	80ml/min	Vapour chamber was not observed, oil produced with solvent push, asphaltenes stuck to the cell window, no fingering formation observed.
13	Raman	Butane	20ml/min	Vapour chamber was not observed, oil produced with solvent push, asphaltenes stuck to the cell window, no fingering

				formation observed
14	Raman	Butane	40ml/min	Vapour chamber was not observed, oil produced with solvent push, asphaltenes stuck to the cell window, no fingering formation observed
15	Raman	Butane	80ml/min	Nothing could be seen
16	Batı Raman	Butane	20ml/min	Nothing could be seen
17	Batı Raman	Butane	40ml/min	Nothing could be seen
18	Batı Raman	Butane	80ml/min	Nothing could be seen
19	Garzan	CO_2	40ml/min	Nothing could be seen
20	Garzan	Butane+Steam	40ml/min	Vapour chamber was not observed, oil produced with solvent push, asphaltenes stuck to the cell window, no fingering formation observed

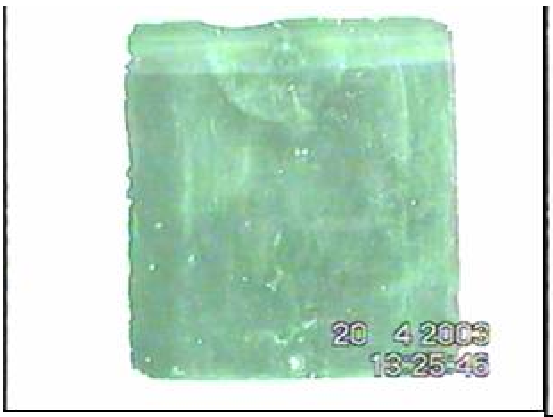
From video images, oil production has been calculated according to the time. Screen shots have been taken on the sampling time and after measured with ruler from the screen. The measured value multiplied by a scaling factor in order to get the correct value. After multiplied by length and width of the cell and produced oil calculated. An example has been given in the below table for experiment 1 (Garzan + Propane 20 ml/min).

Table 5.5 Experimental and Calculated Oil Production Comparisons for Exp. 1.

Graduated Bottle No	Produced Oil, ml (Exp)	Produced Oil, ml (Calculated from images)
1	2,4	2,38
2	2,2	2,13
3	1,9	1,74
4	2	1,94
5	2	1,94
6	2	1,94

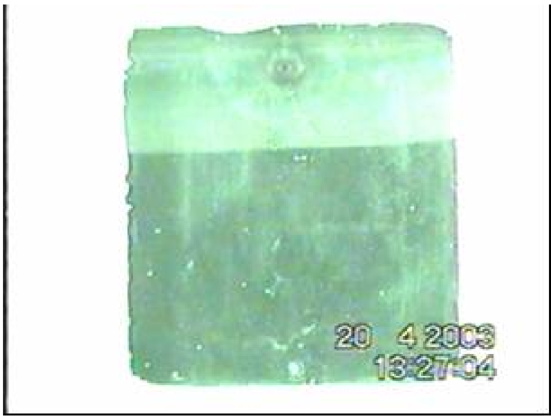
This calculation has been done in order to evaluate the correction of the production rates. According to the results, experimental data and calculated data were almost equal and the difference probably occurred due to the experimental errors and insensitive measurements from the video images. A sample of video images recorded during experiment1 is given below.

1st Bottle

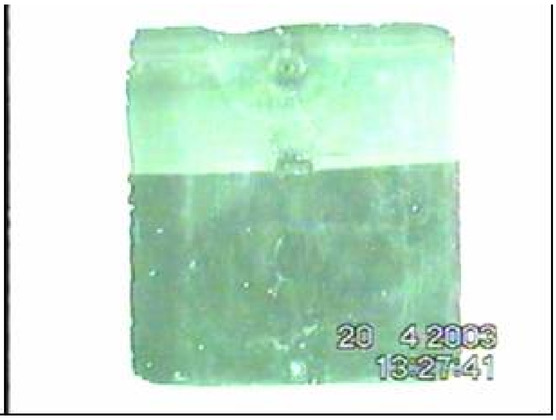


2nd Bottle

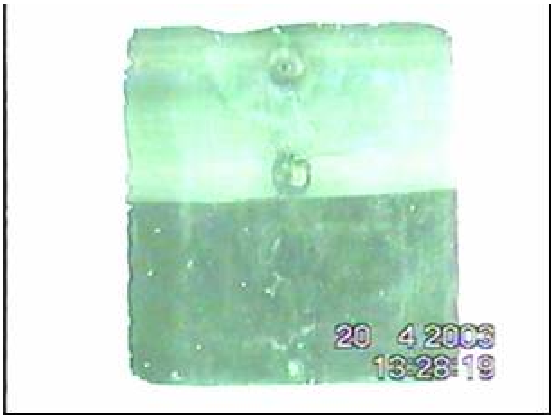
3rd Bottle



4th Bottle



5th Bottle



6th Bottle

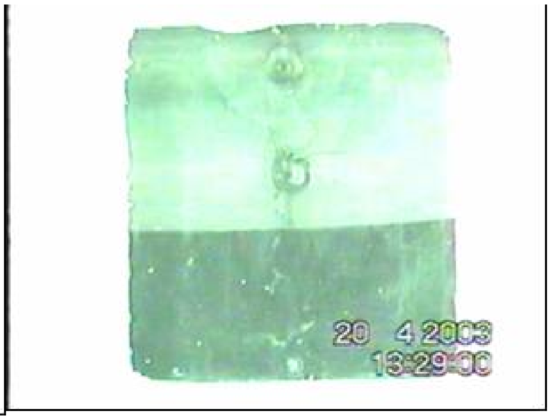


Fig 5.20 Video Images form Experiment 1 (Garzan Oil + Propane 20 ml/min)

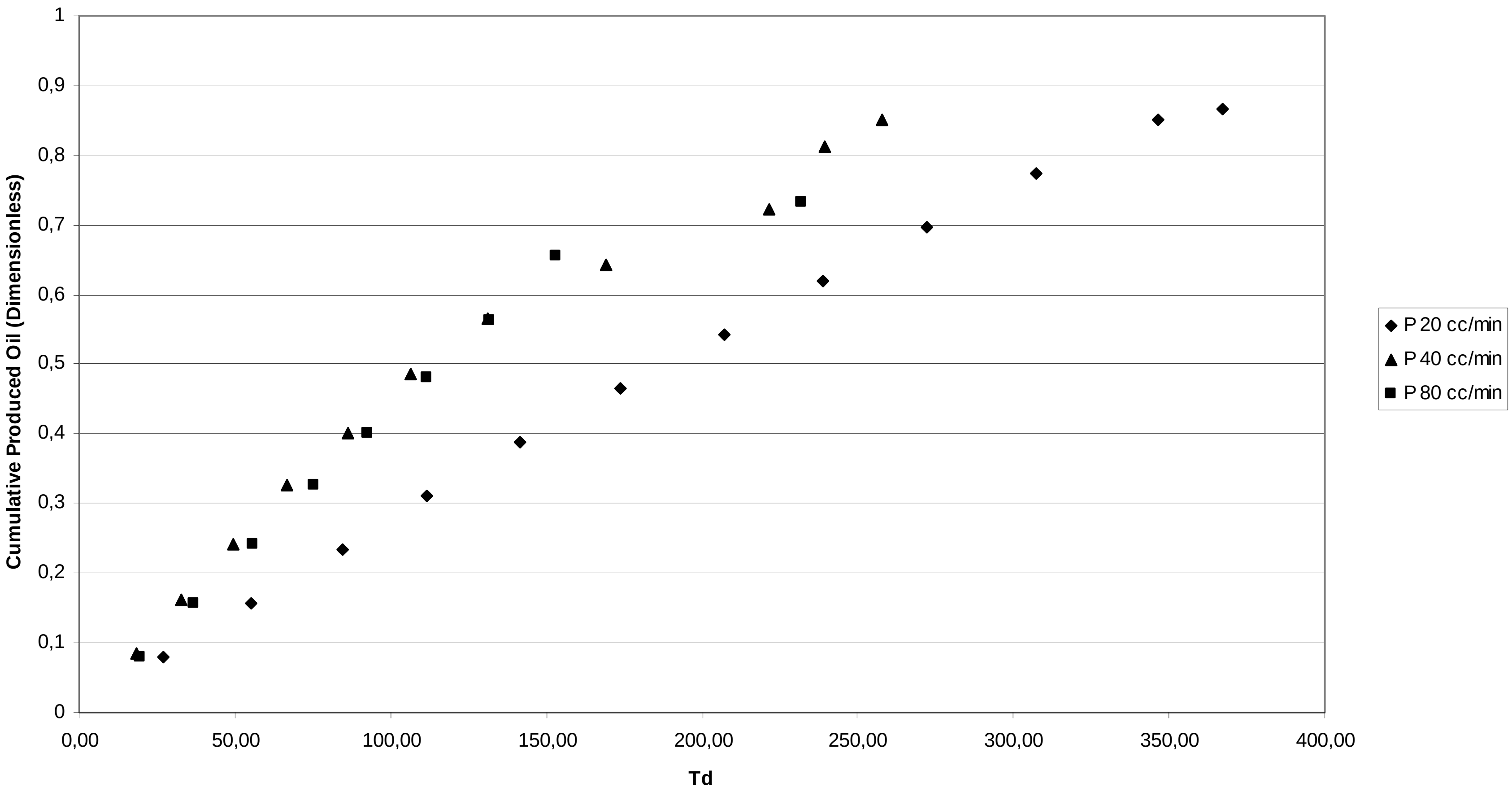


Fig 5.2 Cumulative Produced Oil for Raman Crude with 3 different rates of Propane

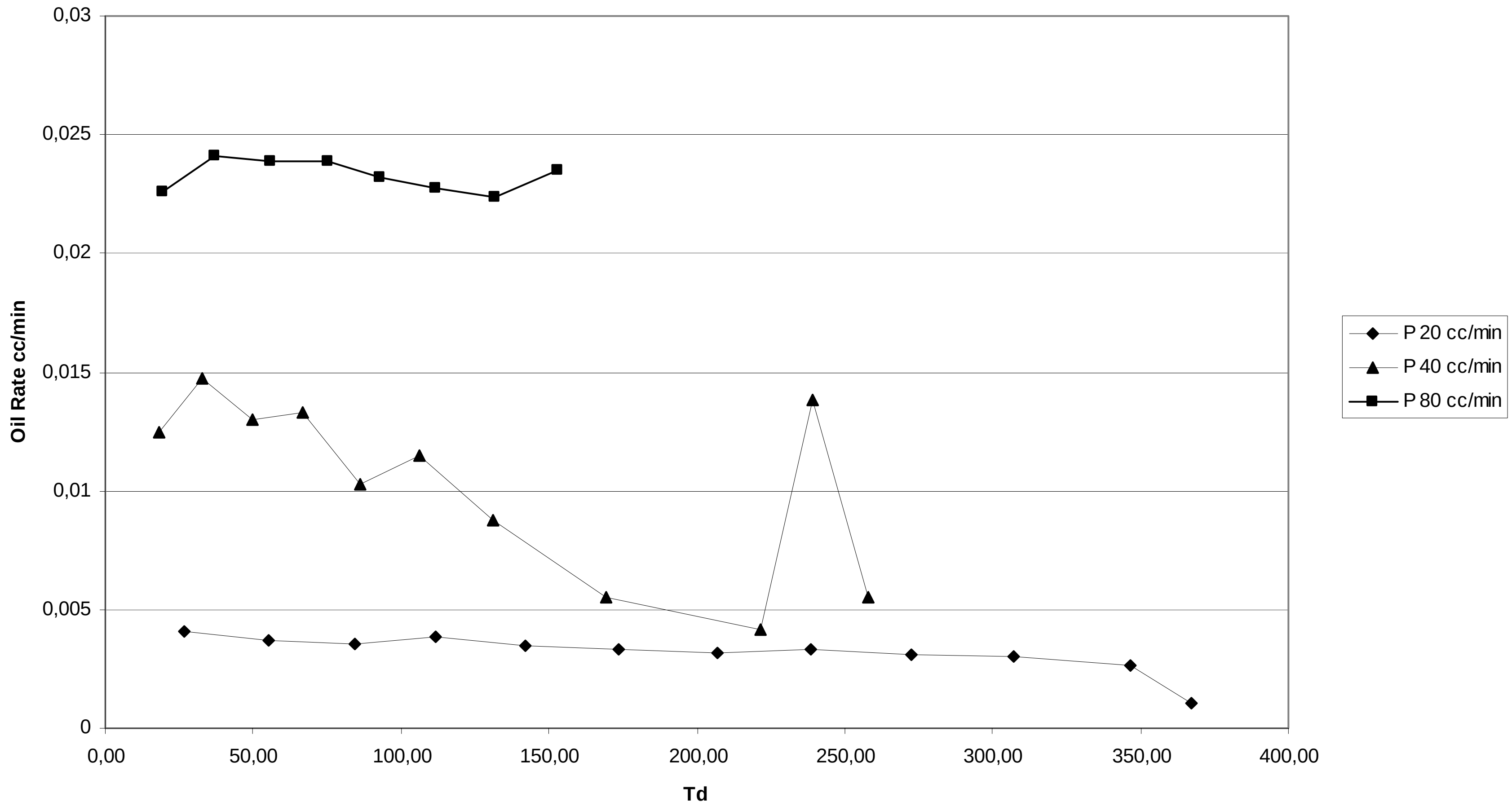


Fig 5.3 Oil Rate for Raman Crude with 3 different rates of Propane

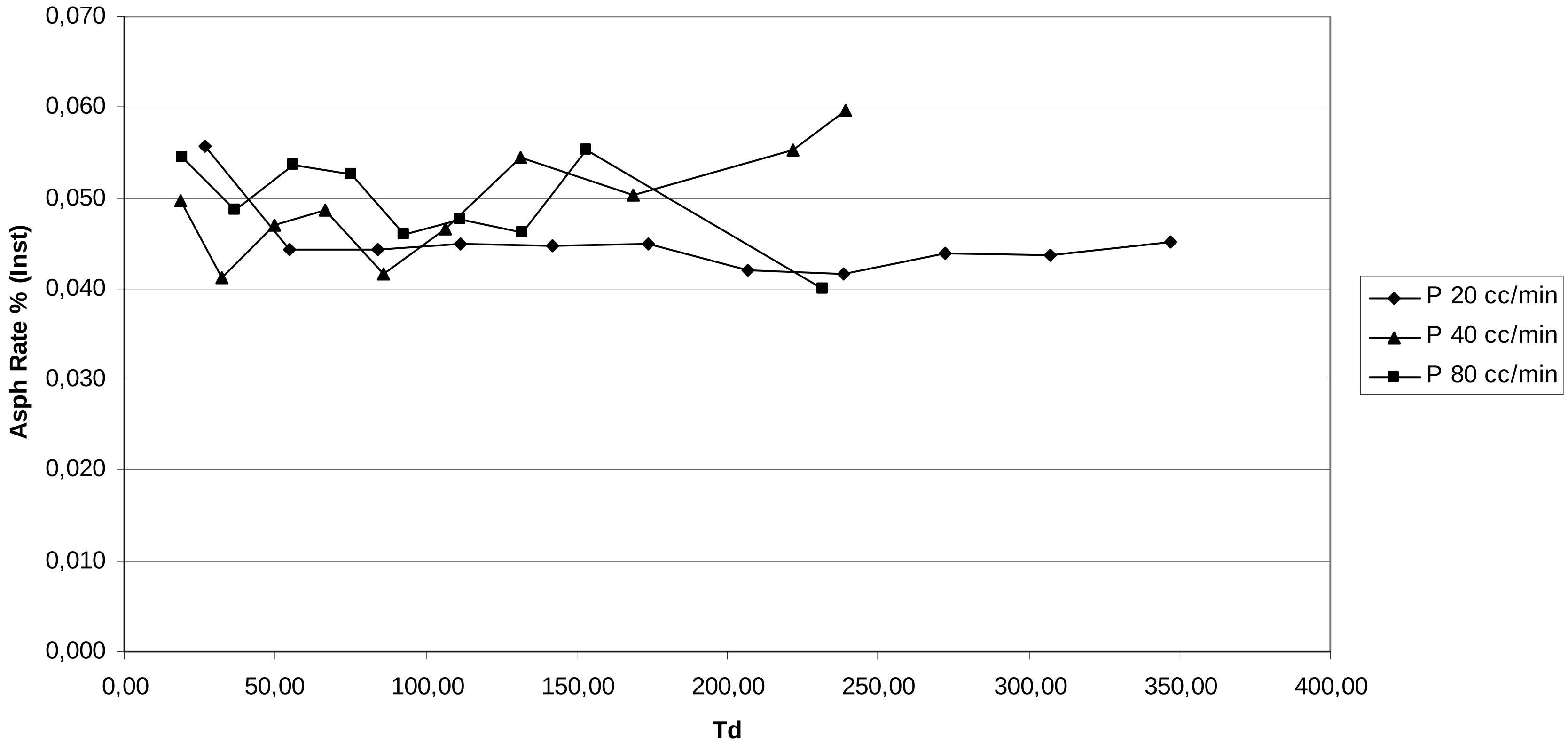


Fig 5.4 Instantaneous Asphaltene rate of Raman Oil with 3 different Propane rates

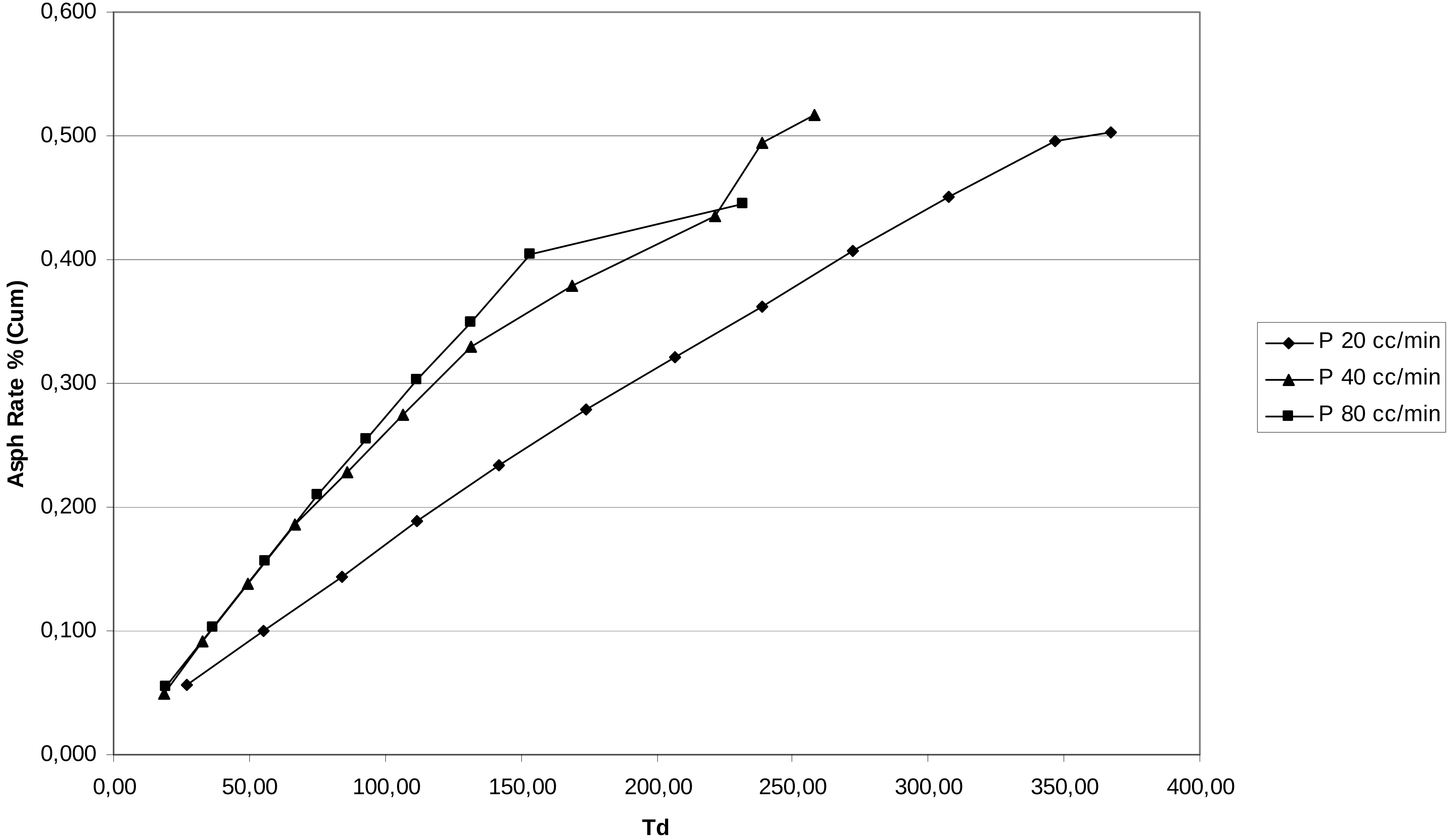


Fig 5.5 Cumulative Asphaltene rate of Raman Oil with 3 different Propane rates

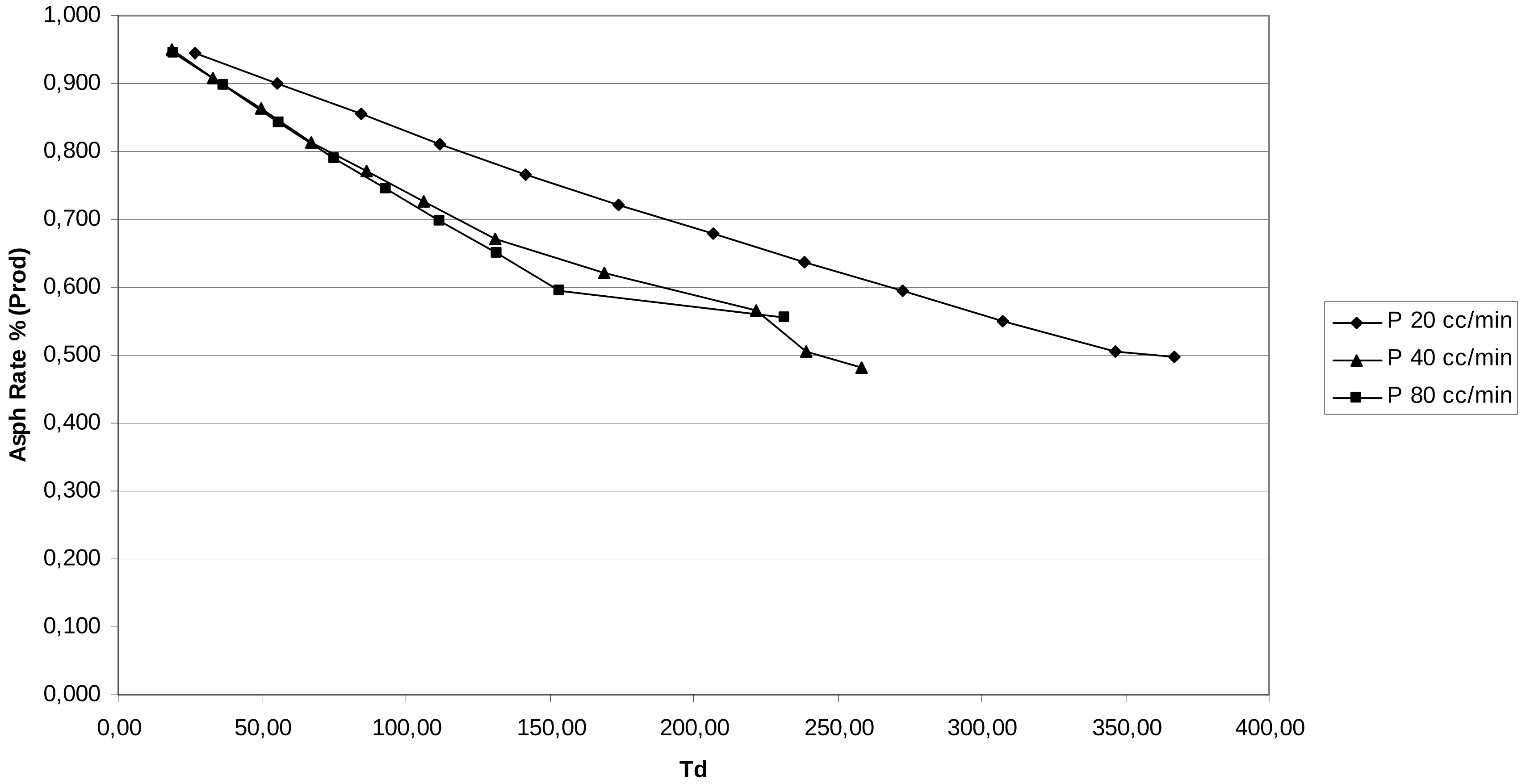


Fig 5.6 Produced Asphaltene rate of Raman Oil with 3 different Propane rates

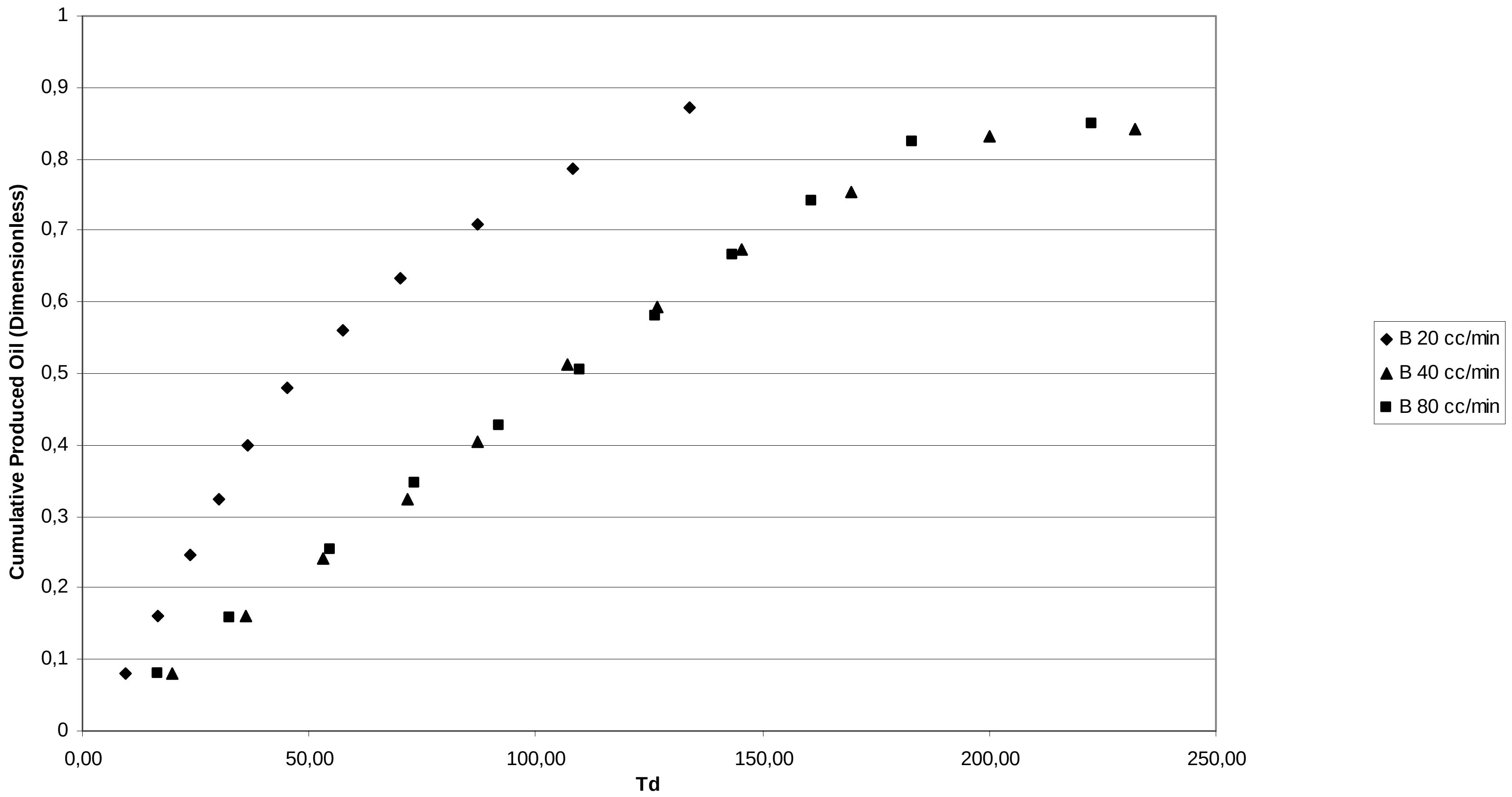


Fig 5.8 Cumulative Produced Oil for Raman Crude with 3 different rates of Butane

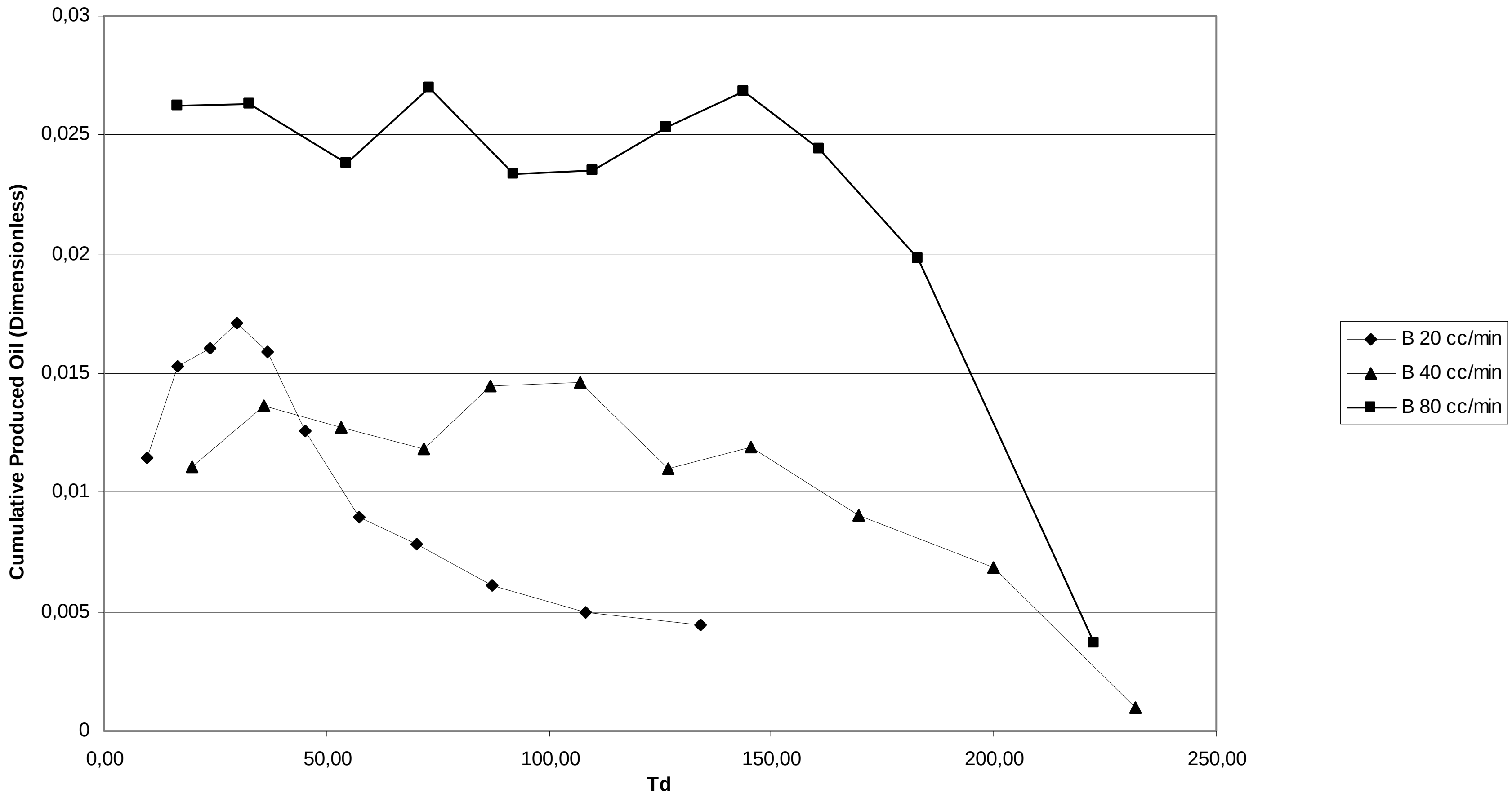


Fig 5.9 Oil Rate for Raman Crude with 3 different rates of Butane

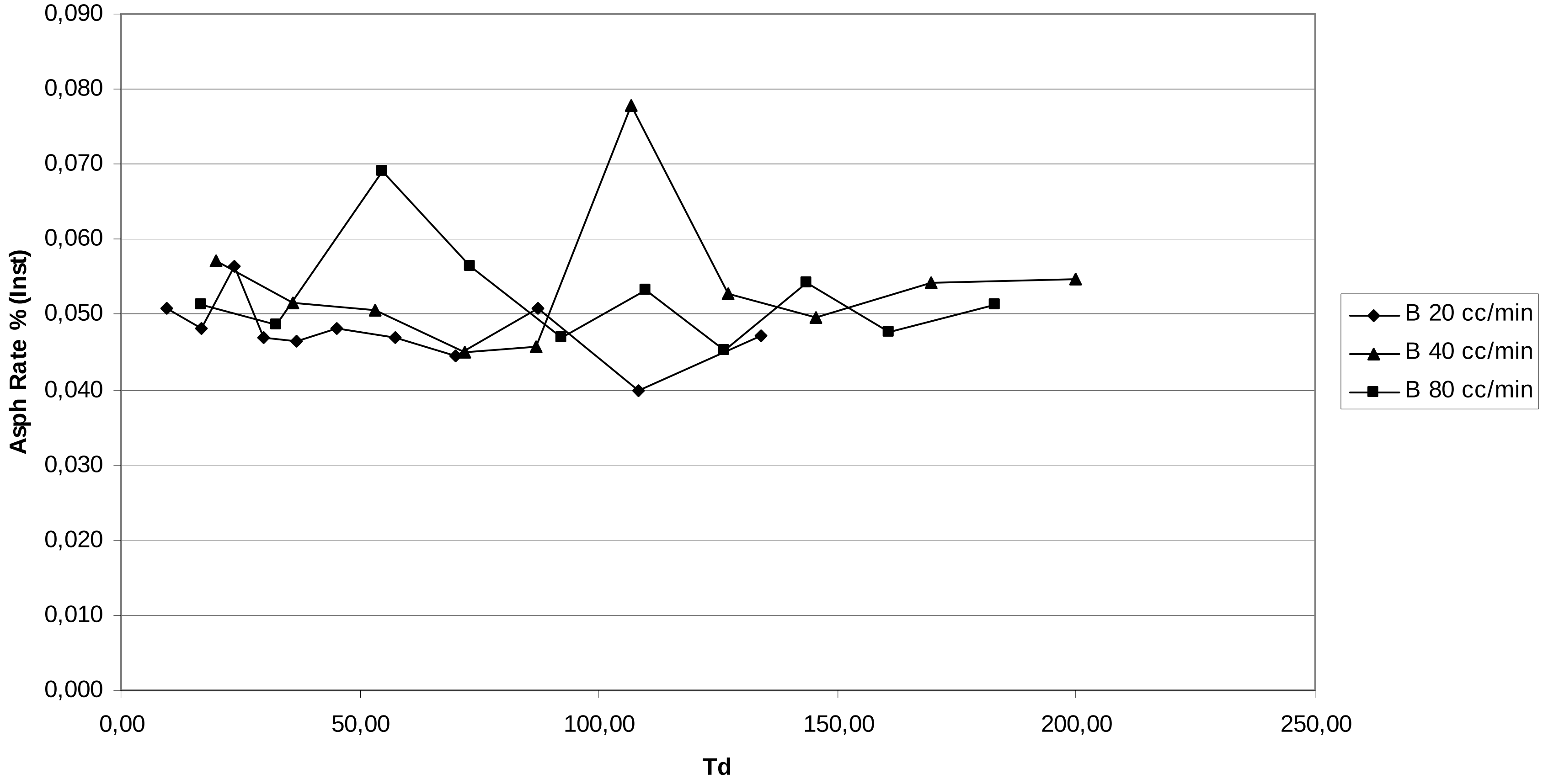


Fig 5.10 Instantaneous Asphaltene rate of Raman Oil with 3 different Butane rates

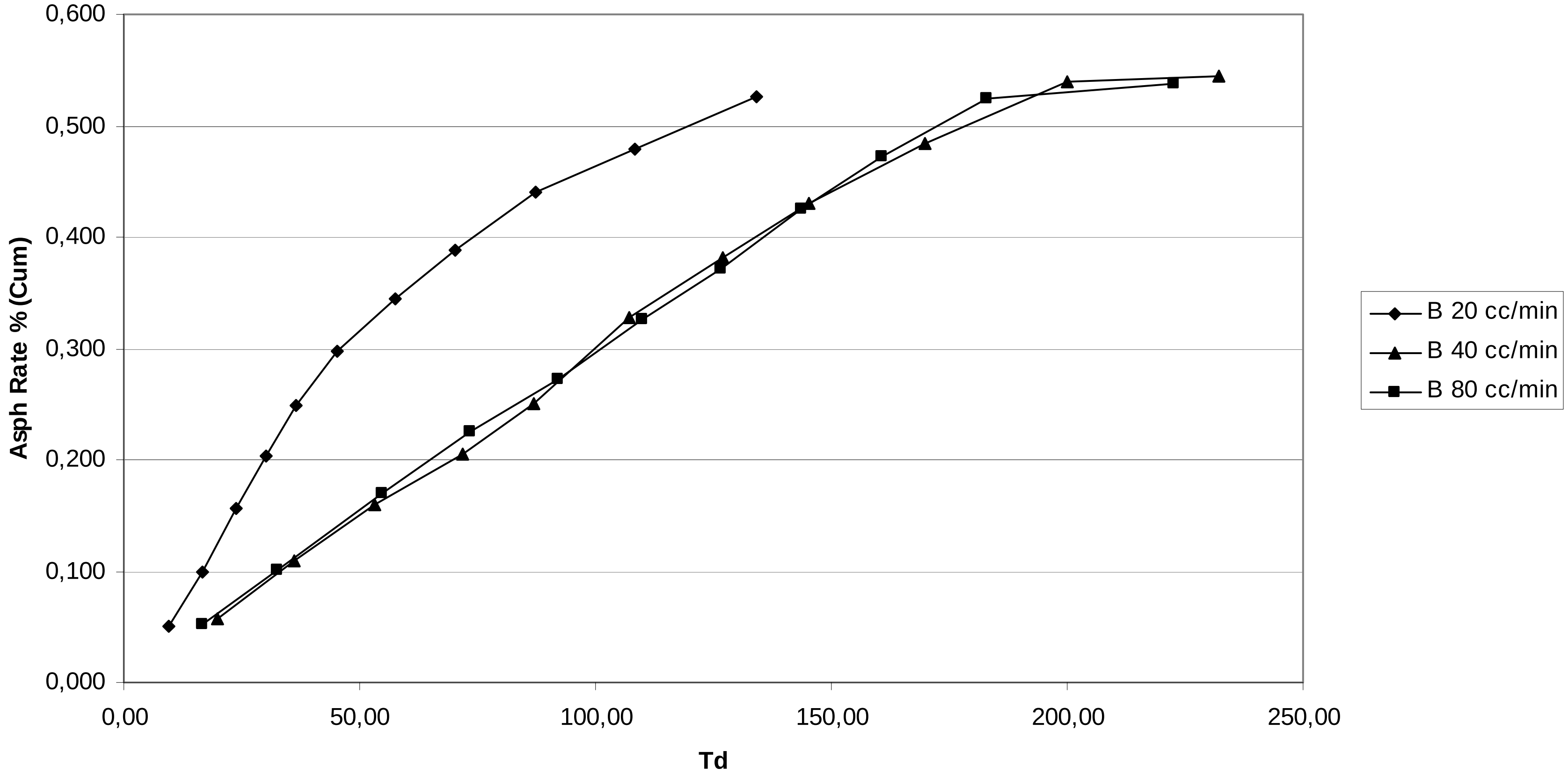


Fig 5.11 Cumulative Asphaltene rate of Raman Oil with 3 different Butane rates

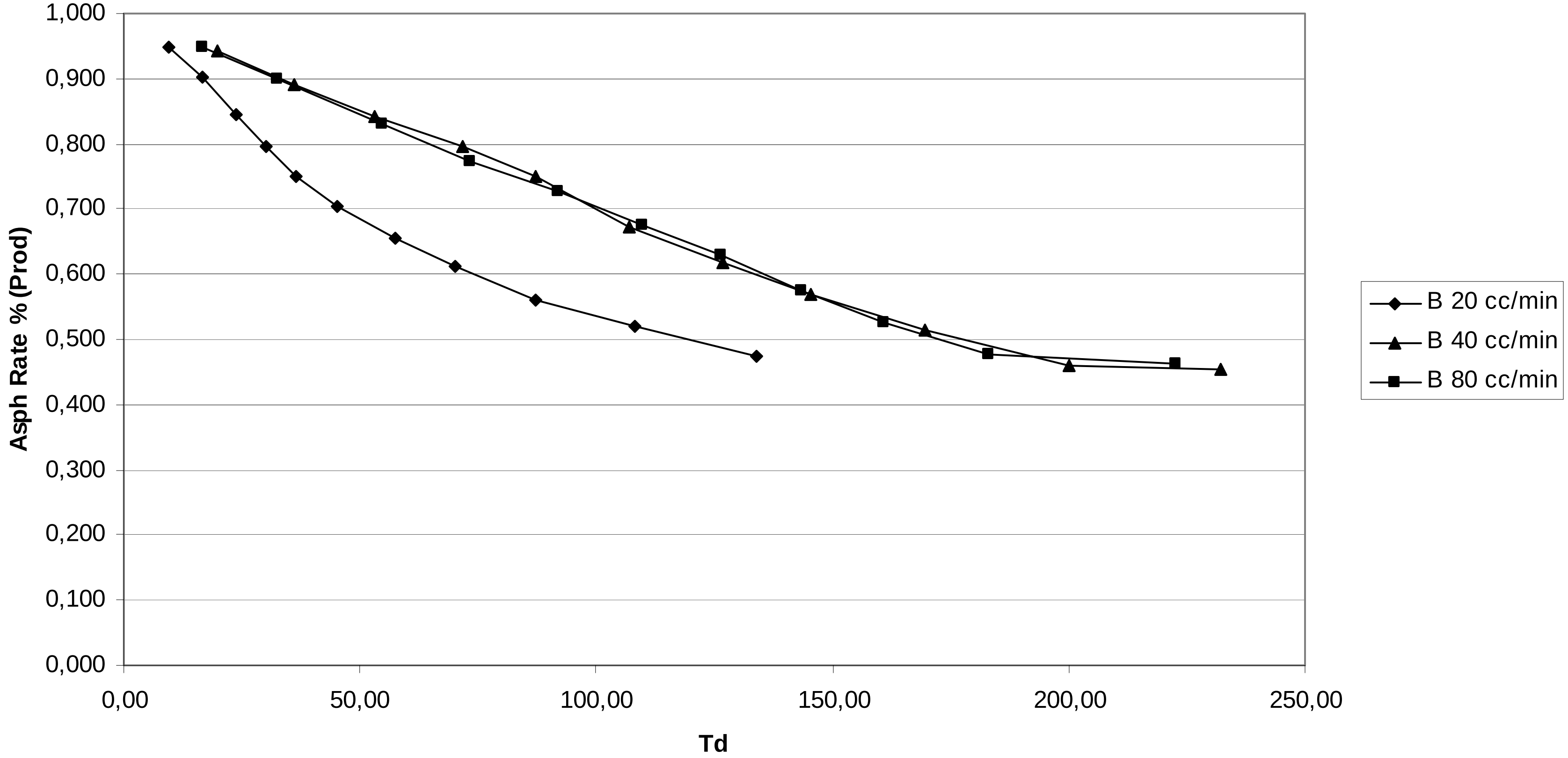


Fig 5.12 Produced Asphaltene rate of Raman Oil with 3 different Butane rates

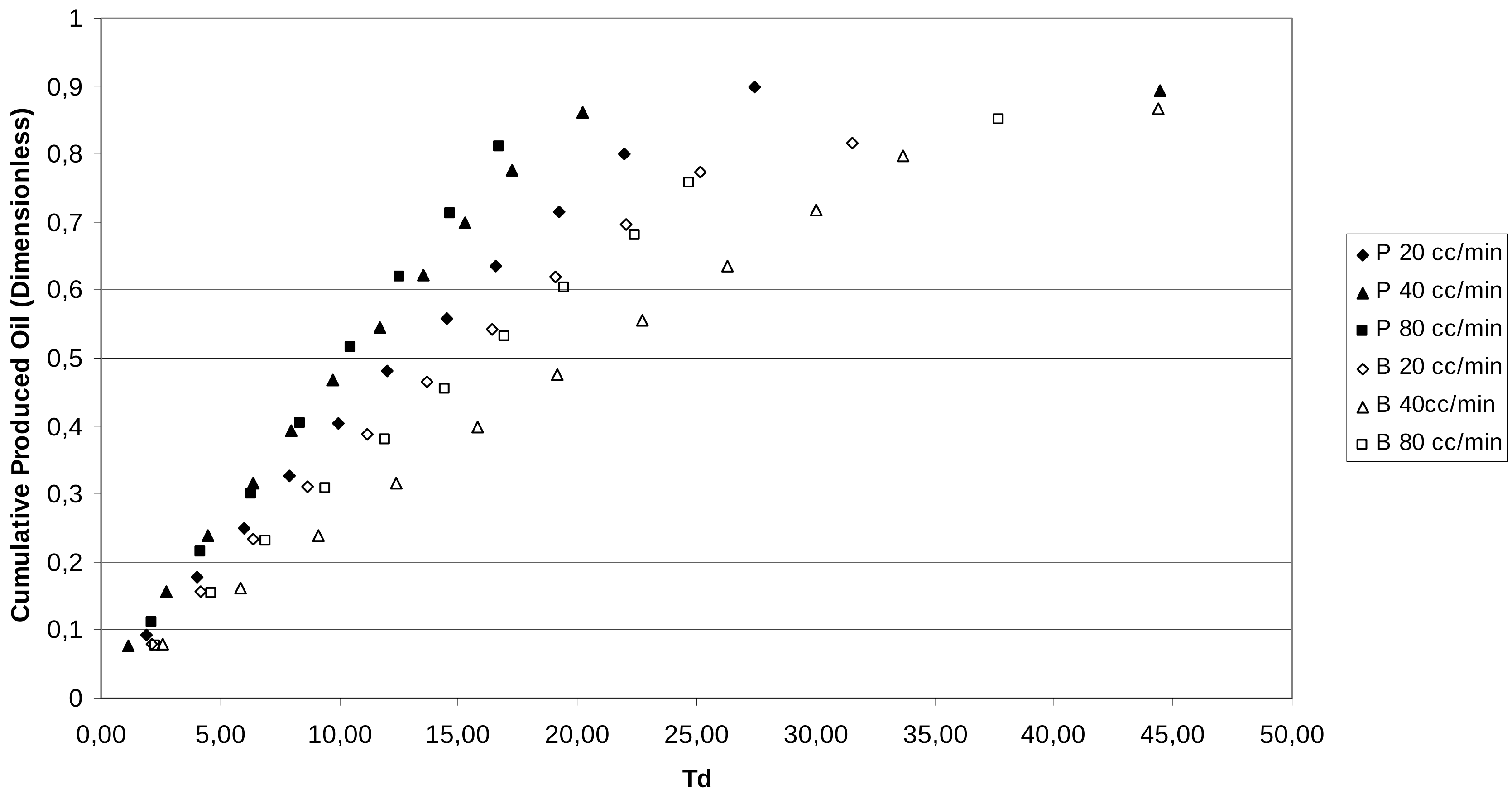


Fig 5.13 Cumulative Produced Oil for Garzan Oil (Propane vs. Butane)

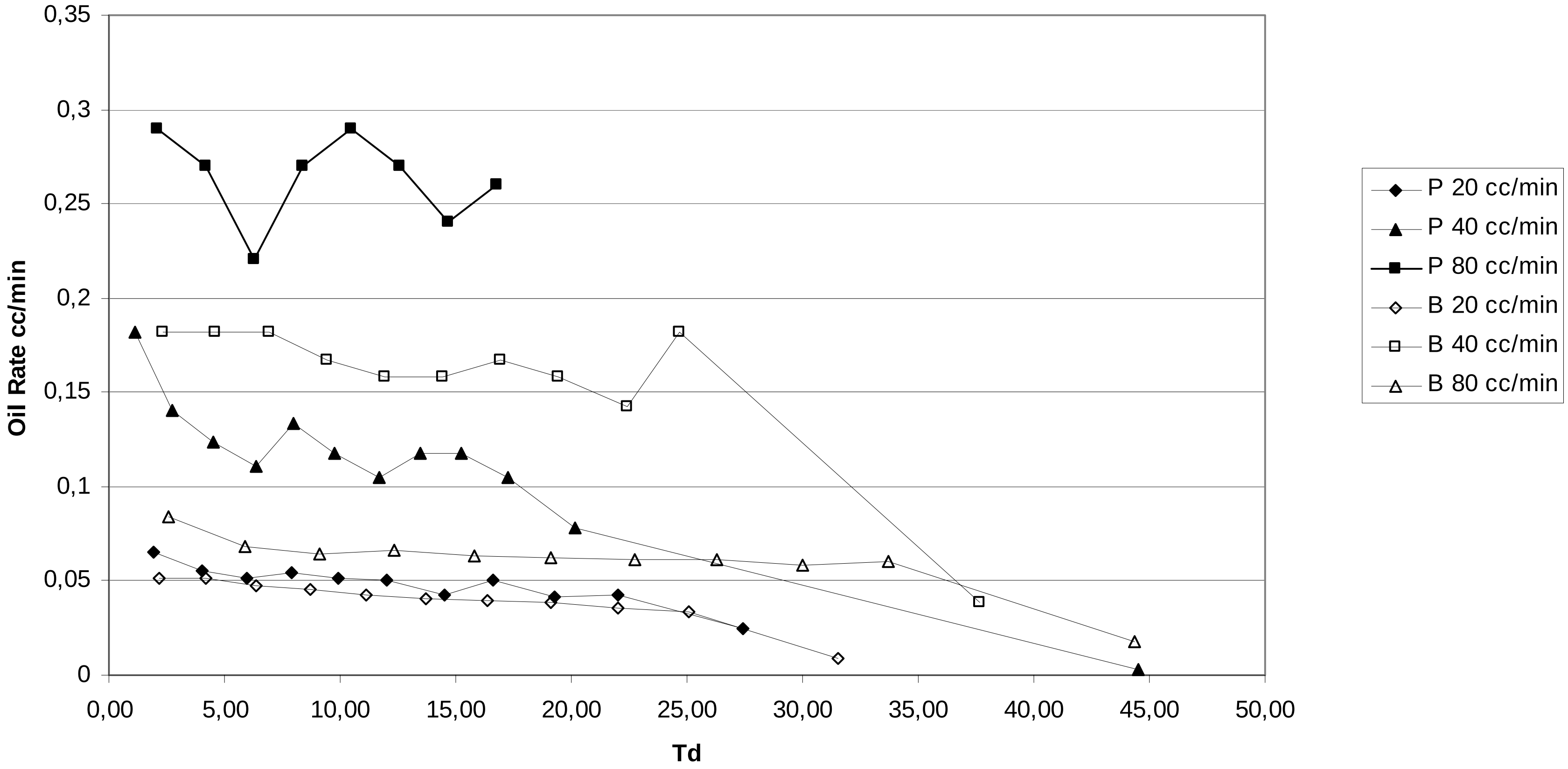


Fig 5.14 Oil Rate for Garzan Oil (Propane vs. Butane)

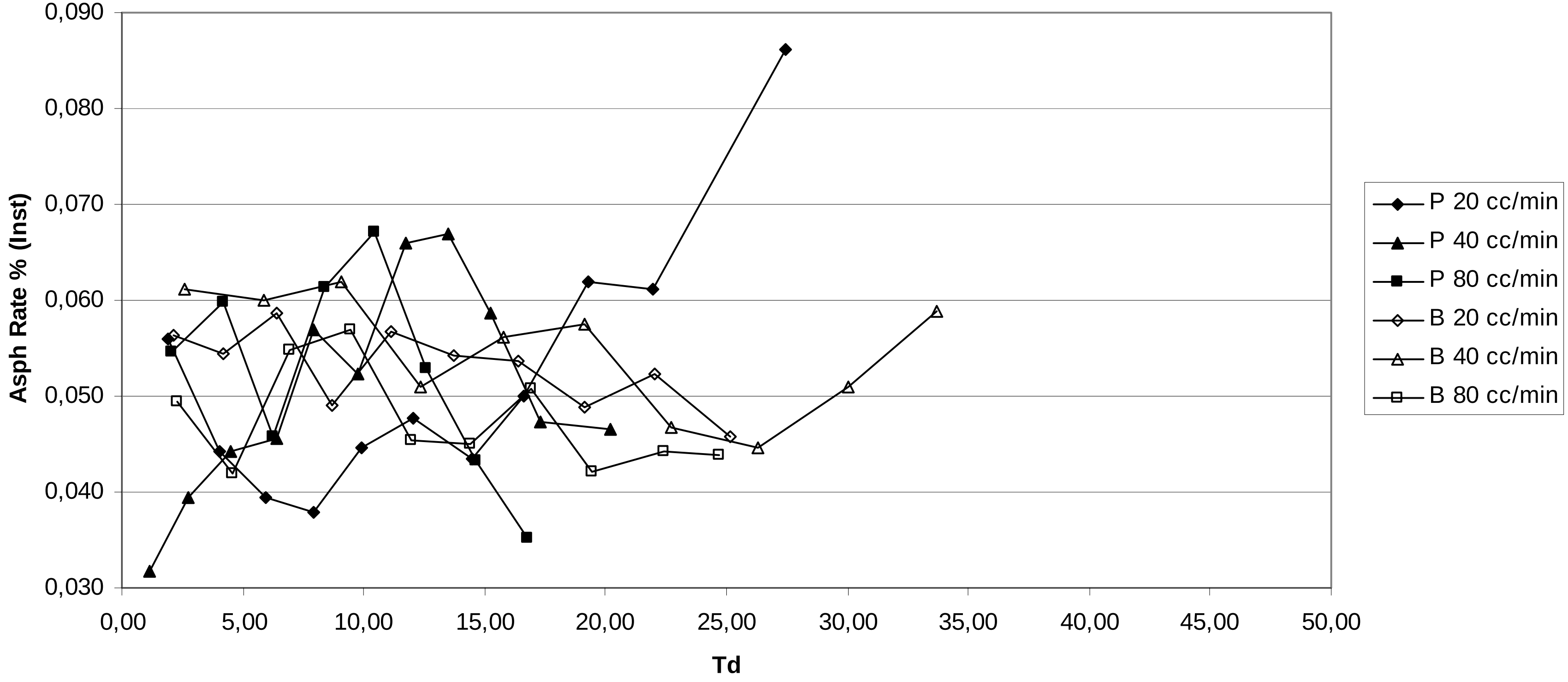


Fig 5.15 Instantaneous Asphaltene rate of Garzan Oil (Propane vs. Butane)

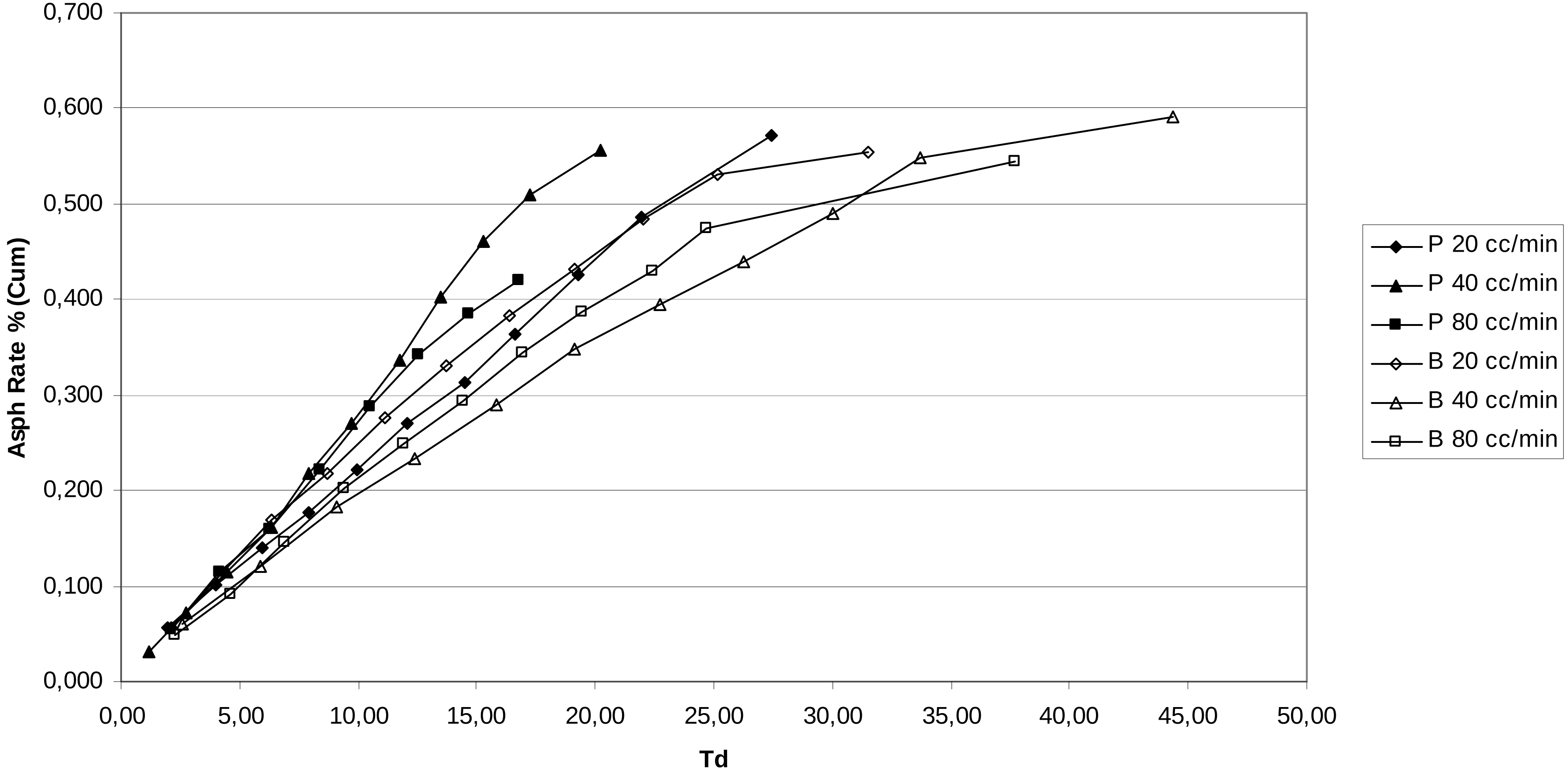


Fig 5.16 Cumulative Asphaltene rate of Garzan Oil (Propane vs. Butane)

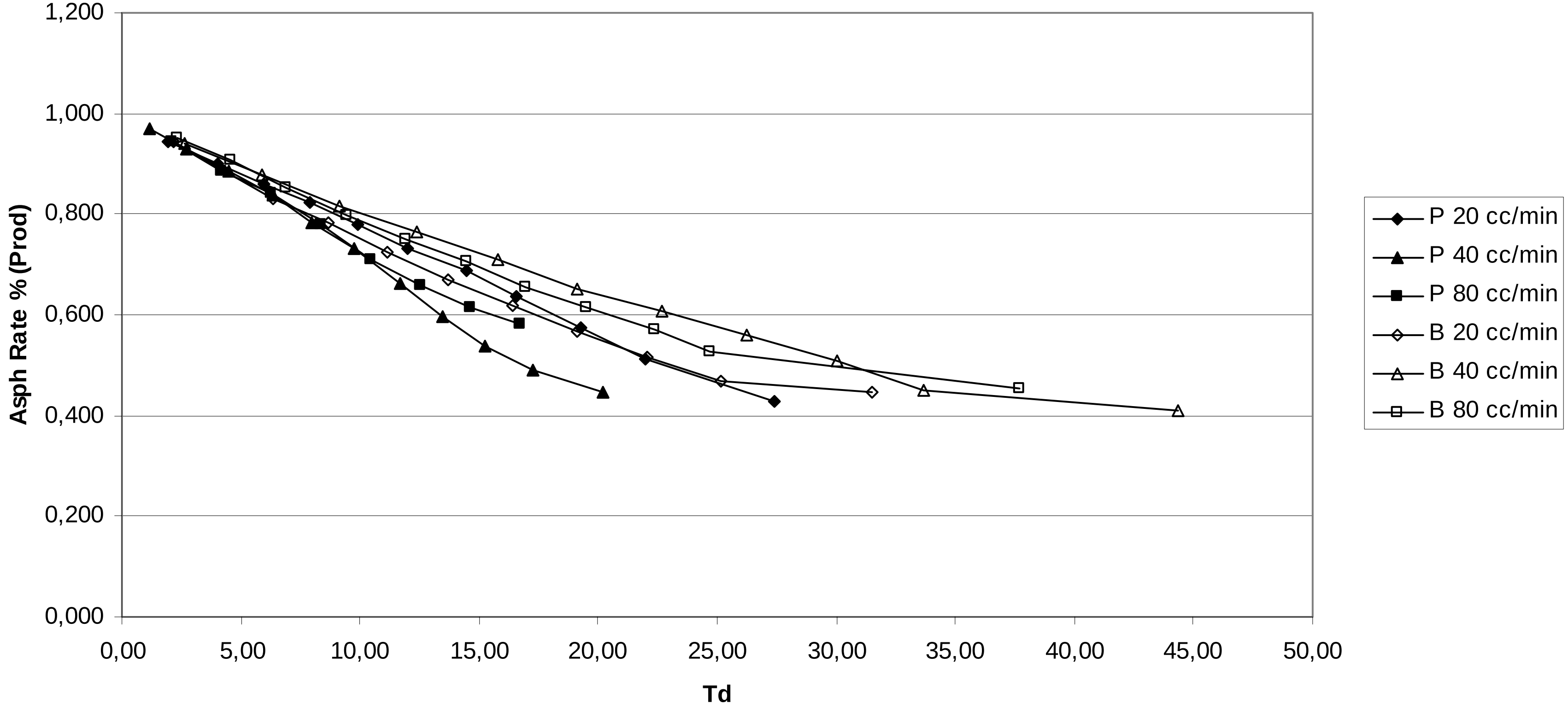


Fig 5.17 Produced Asphaltene rate of Garzan Oil (Propane vs. Butane)

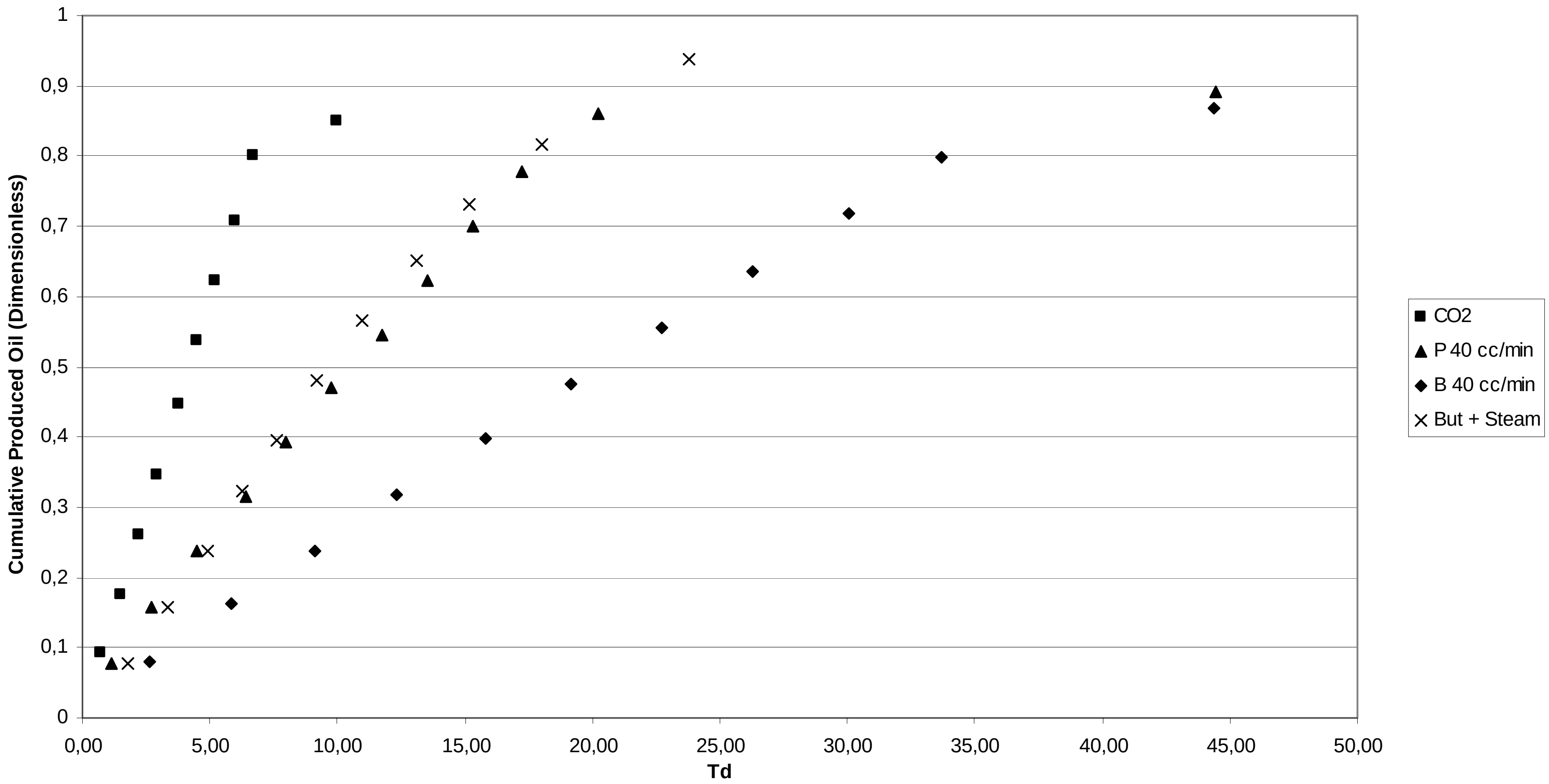


Fig 5.18 Comparison graph for Cumulative Produced Oil of Garzan Oil with two VAPEX solvents +CO2+WetVAPEX

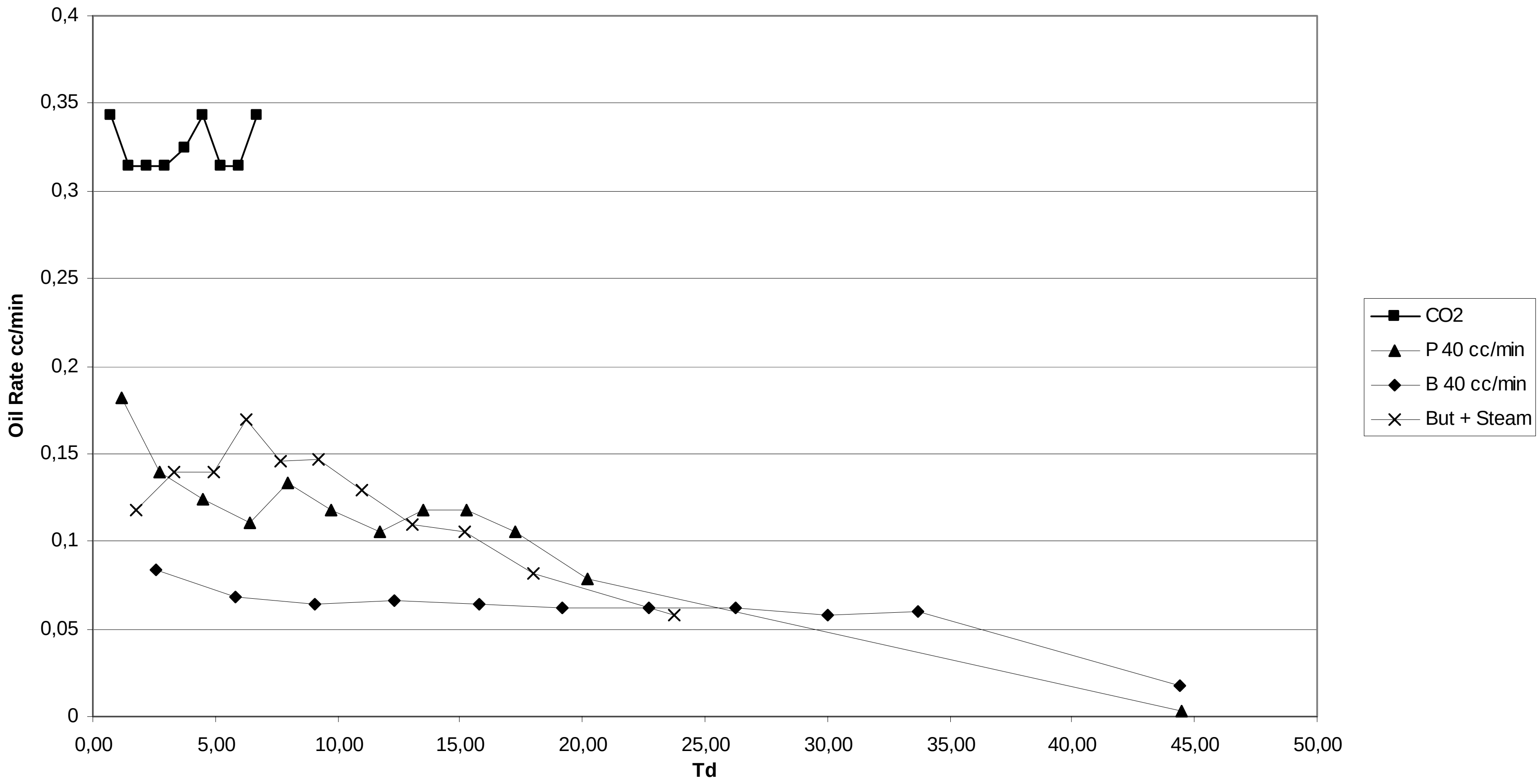


Fig 5.19 Comparison graph for Oil Rate of Garzan Oil with two VAPEX solvents +CO2+WetVAPEX

CHAPTER 6

CONCLUSIONS

As stated before, due to the decline of conventional oil reserves, enhanced oil recovery techniques have been improved or new techniques discovered. In this thesis, VAPEX process has been applied on three different Turkish crude oils and two different solvents, with three different injection rates. According to the experimental results, the following statements can be concluded.

- For both VAPEX solvents, oil rates increased with injection rates for all crude oils. When calculated and experimental oil rates are compared, a big difference on the slopes has been seen. Thus, it was concluded that oil production not only happened with gravity drainage but also with solvent push.
- Instantaneous asphaltene rate for Garzan oil, showed fluctuated performance with propane solvent. This fluctuating happened due to the asphaltene, which adhered to the glass surface, forced to move with gas push. Butane showed almost constant degree of asphaltene precipitation.
- Instantaneous asphaltene rate for Raman oil gave straight line results with the injection rate of 20 ml/min for both solvent. When the injection rate increased graphs gave the same performance with Garzan oil and started to fluctuate for both solvent.

- Instantaneous asphaltene rate for Batı Raman oil gave straight line results with the injection rate of 20 ml/min for both solvent. When the injection rate increased graphs gave the same performance with other two oil samples and started to fluctuate for both solvent. With this oil also plugging of the production line could be another effect of fluctuating.
- For asphaltene precipitation, propane gave better results than butane in almost all injection rates for Garzan and Raman oil. The experiments with Batı Raman oil, butane made better upgrading than propane with the injection rate 80 ml/min. With the other two rates both solvents showed almost same performace.
- From the experimental videos, for Raman and Batı Raman oils nothing seen form the cell window due to the highly adherence of both oil to the glass surface. Only in two experiments fingering formation has been observed for Raman oil. For Garzan oil, vapour chamber was not observed in all experiments.
- The results of the experiments conducted with CO_2 and butane + steam it was observed that CO2 gave better performance than other systems and butane + steam system showed same almost same performance with propane alone system at the same injection rate. It can be proposed that the systems could be comparable in terms of economic point of view, which was not done by this study.

CHAPTER 7

RECOMANDATIONS

In this experimental study applicability of VAPEX process on Turkish crude oils has been investigated. In the future studies, it is recommended to make viscosity measurements at the beginning and at the end of the experiments. Also controlling temperature and pressure during the experiments will give better possibility to analyze the experimental data. For the last word, economical analyses of the VAPEX process could give better opportunity to compare with the other enhanced oil recovery techniques which are already applied all over the world.

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APPENDIX A

EXPERIMENTAL DATA

This appendix will cover the details of the experimental data for the VAPEX experiments. A total of 20 experiment's data including total sampling time, gas correction coefficient, total asphaltane quantity, remaining asphaltane quantity, instantaneous asphaltane rate, cumulative asphaltane rate, system asphaltane rate, cumulative oil, instantaneous oil volume and dimensionless cumulative oil.

Table A.1 Data of Experiment 1

Exp 1											
Garzan + Propan 20 ml/min											
Total Sampling Time (sn)	Gas Correction (q/v)*1/p	T_d	Asp. Qty (gr)	Total Asp. Qty (gr)	Remaining Asp Qty (gr)	Inst Asph Rate	Cum Asph Rate	Sys Asph Rate	Cum Oil	Inst Oil	Dim Cum Oil
0	0,0523286	0,00	0	0	6,760	0,000	0,000	1,000			
37	0,0523286	1,94	0,378	0,378	6,382	0,056	0,056	0,944	2,4	0,0648649	0,0923077
77	0,0523286	4,03	0,299	0,677	6,083	0,044	0,100	0,900	4,6	0,055	0,1769231
114	0,0523286	5,97	0,266	0,943	5,817	0,039	0,139	0,861	6,5	0,0513514	0,25
151	0,0523286	7,90	0,256	1,199	5,561	0,038	0,177	0,823	8,5	0,0540541	0,3269231
190	0,0523286	9,94	0,302	1,501	5,259	0,045	0,222	0,778	10,5	0,0512821	0,4038462
230	0,0523286	12,04	0,323	1,824	4,936	0,048	0,270	0,730	12,5	0,05	0,4807692
277	0,0523286	14,50	0,294	2,118	4,642	0,043	0,313	0,687	14,5	0,0425532	0,5576923
317	0,0523286	16,59	0,338	2,456	4,304	0,050	0,363	0,637	16,5	0,05	0,6346154
368	0,0523286	19,26	0,418	2,874	3,886	0,062	0,425	0,575	18,6	0,0411765	0,7153846
420	0,0523286	21,98	0,414	3,288	3,472	0,061	0,486	0,514	20,8	0,0423077	0,8
524	0,0523286	27,42	0,583	3,871	2,889	0,086	0,573	0,427	23,4	0,025	0,9

Table A.2 Data of Experiment 2

Exp 2											
Garzan + Propan 40 ml/min											
Total Sampling Time (sn)	Gas Correction (q/v)*1/p	T_d	Asp. Qty (gr)	Total Asp. Qty (gr)	Remaining Asp Qty (gr)	Inst Asph Rate	Cum Asph Rate	Sys Asph Rate	Cum Oil	Inst Oil	Dim Cum Oil
0	0,1046572	0	0	0	6,760	0,000	0,000	1,000			
11	0,1046572	1,15	0,214	0,214	6,546	0,032	0,032	0,968	2	0,1818182	0,0769231
26	0,1046572	2,72	0,266	0,480	6,280	0,039	0,071	0,929	4,1	0,14	0,1576923
43	0,1046572	4,50	0,299	0,779	5,981	0,044	0,115	0,885	6,2	0,1235294	0,2384615
61	0,1046572	6,38	0,308	1,087	5,673	0,046	0,161	0,839	8,2	0,1111111	0,3153846
76	0,1046572	7,95	0,385	1,472	5,288	0,057	0,218	0,782	10,2	0,1333333	0,3923077
93	0,1046572	9,73	0,354	1,826	4,934	0,052	0,270	0,730	12,2	0,1176471	0,4692308
112	0,1046572	11,72	0,446	2,272	4,488	0,066	0,336	0,664	14,2	0,1052632	0,5461538
129	0,1046572	13,50	0,452	2,724	4,036	0,067	0,403	0,597	16,2	0,1176471	0,6230769
146	0,1046572	15,28	0,397	3,121	3,639	0,059	0,462	0,538	18,2	0,1176471	0,7
165	0,1046572	17,27	0,320	3,441	3,319	0,047	0,509	0,491	20,2	0,1052632	0,7769231
193	0,1046572	20,20	0,314	3,755	3,005	0,046	0,555	0,445	22,4	0,0785714	0,8615385
425	0,1046572	44,48	0,122	3,877	2,883	0,018	0,574	0,426	23,2	0,0034483	0,8923077

Table A.3 Data of Experiment 3

Exp 3											
Garzan + Propan 80 ml/min											
Total Sampling Time (sn)	Gas Correction (q/v)*1/p	T_d	Asp. Qty (gr)	Total Asp. Qty (gr)	Remaining Asp Qty (gr)	Inst Asph Rate	Cum Asph Rate	Sys Asph Rate	Cum Oil	Inst Oil	Dim Cum Oil
0	0,2093145	0,00	0	0	6,760	0,000	0,000	1,000			
10	0,2093145	2,09	0,369	0,369	6,391	0,055	0,055	0,945	2,9	0,29	0,111538
20	0,2093145	4,19	0,404	0,773	5,987	0,060	0,114	0,886	5,6	0,27	0,215385
30	0,2093145	6,28	0,309	1,082	5,678	0,046	0,160	0,840	7,8	0,22	0,3
40	0,2093145	8,37	0,415	1,497	5,263	0,061	0,221	0,779	10,5	0,27	0,403846
50	0,2093145	10,47	0,454	1,951	4,809	0,067	0,289	0,711	13,4	0,29	0,515385
60	0,2093145	12,56	0,358	2,309	4,451	0,053	0,342	0,658	16,1	0,27	0,619231
70	0,2093145	14,65	0,292	2,601	4,159	0,043	0,385	0,615	18,5	0,24	0,711538
80	0,2093145	16,75	0,238	2,839	3,921	0,035	0,420	0,580	21,1	0,26	0,811538

Table A.4 Data of Experiment 4

Exp 4											
Raman + Propan 20 ml/min											
Total Sampling Time (sn)	Gas Correction (q/v)*1/p	T_d	Asp. Qty (gr)	Total Asp. Qty (gr)	Remaining Asp Qty (gr)	Inst Asph Rate	Cum Asph Rate	Sys Asph Rate	Cum Oil	Inst Oil	Dim Cum Oil
0	0,0523286	0,00	0	0	10,400	0,000	0,000	1,000			
516	0,0523286	27,00	0,579	0,579	9,821	0,056	0,056	0,944	2,1	0,0040698	0,0807692
1053	0,0523286	55,10	0,460	1,039	9,361	0,044	0,100	0,900	4,1	0,0037244	0,1576923
1612	0,0523286	84,35	0,461	1,500	8,900	0,044	0,144	0,856	6,1	0,0035778	0,2346154
2136	0,0523286	111,77	0,467	1,967	8,433	0,045	0,189	0,811	8,1	0,0038168	0,3115385
2711	0,0523286	141,86	0,465	2,432	7,968	0,045	0,234	0,766	10,1	0,0034783	0,3884615
3319	0,0523286	173,68	0,468	2,900	7,500	0,045	0,279	0,721	12,1	0,0032895	0,4653846
3956	0,0523286	207,01	0,438	3,338	7,062	0,042	0,321	0,679	14,1	0,0031397	0,5423077
4563	0,0523286	238,78	0,432	3,770	6,630	0,042	0,362	0,638	16,1	0,0032949	0,6192308
5205	0,0523286	272,37	0,457	4,227	6,173	0,044	0,406	0,594	18,1	0,0031153	0,6961538
5875	0,0523286	307,43	0,454	4,681	5,719	0,044	0,450	0,550	20,1	0,0029851	0,7730769
6626	0,0523286	346,73	0,470	5,151	5,249	0,045	0,495	0,505	22,1	0,0026631	0,85
7013	0,0523286	366,98	0,079	5,230	5,170	0,008	0,503	0,497	22,5	0,0010336	0,8653846

Table A.5 Data of Experiment 5

Exp 5											
Raman + Propan 40 ml/min											
Total Sampling Time (sn)	Gas Correction (q/v)*1/p	T_d	Asp. Qty (gr)	Total Asp. Qty (gr)	Remaining Asp Qty (gr)	Inst Asph Rate	Cum Asph Rate	Sys Asph Rate	Cum Oil	Inst Oil	Dim Cum Oil
0	0,1046572	0,00	0	0	10,400	0,000	0,000	1,000			
176	0,1046572	18,42	0,517	0,517	9,883	0,050	0,050	0,950	2,2	0,0125	0,0846154
312	0,1046572	32,65	0,428	0,945	9,455	0,041	0,091	0,909	4,2	0,0147059	0,1615385
474	0,1046572	49,61	0,488	1,433	8,967	0,047	0,138	0,862	6,3	0,012963	0,2423077
639	0,1046572	66,88	0,506	1,939	8,461	0,049	0,186	0,814	8,5	0,0133333	0,3269231
824	0,1046572	86,24	0,433	2,372	8,028	0,042	0,228	0,772	10,4	0,0102703	0,4
1016	0,1046572	106,33	0,484	2,856	7,544	0,047	0,275	0,725	12,6	0,0114583	0,4846154
1255	0,1046572	131,34	0,566	3,422	6,978	0,054	0,329	0,671	14,7	0,0087866	0,5653846
1616	0,1046572	169,13	0,523	3,945	6,455	0,050	0,379	0,621	16,7	0,0055402	0,6423077
2119	0,1046572	221,77	0,576	4,521	5,879	0,055	0,435	0,565	18,8	0,004175	0,7230769
2285	0,1046572	239,14	0,620	5,141	5,259	0,060	0,494	0,506	21,1	0,0138554	0,8115385
2466	0,1046572	258,08	0,240	5,381	5,019	0,023	0,517	0,483	22,1	0,0055249	0,85

Table A.6 Data of Experiment 6

Exp 6											
Raman + Propan 80 ml/min											
Total Sampling Time (sn)	Gas Correction (q/v)*1/p	T_d	Asp. Qty (gr)	Total Asp. Qty (gr)	Remaining Asp Qty (gr)	Inst Asph Rate	Cum Asph Rate	Sys Asph Rate	Cum Oil	Inst Oil	Dim Cum Oil
0	0,2093145	0,00	0	0	10,400	0,000	0,000	1,000			
93	0,2093145	19,47	0,567	0,567	9,833	0,055	0,055	0,945	2,1	0,022581	0,080769
176	0,2093145	36,84	0,507	1,074	9,326	0,049	0,103	0,897	4,1	0,024096	0,157692
268	0,2093145	56,10	0,558	1,632	8,768	0,054	0,157	0,843	6,3	0,023913	0,242308
360	0,2093145	75,35	0,547	2,179	8,221	0,053	0,210	0,790	8,5	0,023913	0,326923
444	0,2093145	92,94	0,479	2,658	7,742	0,046	0,256	0,744	10,45	0,023214	0,401923
534	0,2093145	111,77	0,495	3,153	7,247	0,048	0,303	0,697	12,5	0,022778	0,480769
630	0,2093145	131,87	0,480	3,633	6,767	0,046	0,349	0,651	14,65	0,022396	0,563462
732	0,2093145	153,22	0,576	4,209	6,191	0,055	0,405	0,595	17,05	0,023529	0,655769
1108	0,2093145	231,92	0,416	4,625	5,775	0,040	0,445	0,555	19,05	0,005319	0,732692

Table A.7 Data of Experiment 7

Exp 7											
B.Raman + Propan 20 ml/min											
Total Sampling Time (sn)	Gas Correction (q/v)*1/p	T_d	Asp. Qty (gr)	Total Asp. Qty (gr)	Remaining Asp Qty (gr)	Inst Asph Rate	Cum Asph Rate	Sys Asph Rate	Cum Oil	Inst Oil	Dim Cum Oil
0	0,0523286	0,00	0	0	13,260	0,000	0,000	1,000			
1504	0,0523286	78,70	0,602	0,602	12,658	0,045	0,045	0,955	2,05	0,001363	0,0788462
2746	0,0523286	143,69	0,951	1,553	11,707	0,072	0,117	0,883	5,05	0,0024155	0,1942308
3384	0,0523286	177,08	1,158	2,711	10,549	0,087	0,204	0,796	8,45	0,0053292	0,325
3782	0,0523286	197,91	1,444	4,155	9,105	0,109	0,313	0,687	11,95	0,008794	0,4596154
4125	0,0523286	215,86	1,198	5,353	7,907	0,090	0,404	0,596	15,25	0,009621	0,5865385
5147	0,0523286	269,34	1,239	6,592	6,668	0,093	0,497	0,503	18,65	0,0033268	0,7173077
6747	0,0523286	353,06	0,372	6,964	6,296	0,028	0,525	0,475	19,55	0,0005625	0,7519231

Table A.8 Data of Experiment 8

Exp 8											
B.Raman + Propan 40 ml/min											
Total Sampling Time (sn)	Gas Correction (q/v)*1/p	T_d	Asp. Qty (gr)	Total Asp. Qty (gr)	Remaining Asp Qty (gr)	Inst Asph Rate	Cum Asph Rate	Sys Asph Rate	Cum Oil	Inst Oil	Dim Cum Oil
0	0,1046572	0,00	0	0	13,260	0,000	0,000	1,000			
291	0,1046572	30,46	1,305	1,305	11,955	0,098	0,098	0,902	3,6	0,0123711	0,1384615
462	0,1046572	48,35	1,037	2,342	10,918	0,078	0,177	0,823	6,6	0,0175439	0,2538462
618	0,1046572	64,68	0,960	3,302	9,958	0,072	0,249	0,751	9,6	0,0192308	0,3692308
846	0,1046572	88,54	0,863	4,165	9,095	0,065	0,314	0,686	12,45	0,0125	0,4788462
1170	0,1046572	122,45	0,788	4,953	8,307	0,059	0,374	0,626	14,95	0,007716	0,575
1630	0,1046572	170,59	0,605	5,558	7,702	0,046	0,419	0,581	17,05	0,0045652	0,6557692
2190	0,1046572	229,20	0,359	5,917	7,343	0,027	0,446	0,554	18,35	0,0023214	0,7057692
3069	0,1046572	321,19	0,243	6,160	7,100	0,018	0,465	0,535	19,25	0,0010239	0,7403846

Table A.9 Data of Experiment 9

Exp 9											
B.Raman + Propan 80 ml/min											
Total Sampling Time (sn)	Gas Correction (q/v)*1/p	T_d	Asp. Qty (gr)	Total Asp. Qty (gr)	Remaining Asp Qty (gr)	Inst Asph Rate	Cum Asph Rate	Sys Asph Rate	Cum Oil	Inst Oil	Dim Cum Oil
0	0,2093145	0,00	0	0	13,260	0,000	0,000	1,000			
128	0,2093145	26,79	0,699	0,699	12,561	0,053	0,053	0,947	1,7	0,013281	0,065385
262	0,2093145	54,84	1,241	1,940	11,320	0,094	0,146	0,854	5	0,024627	0,192308
552	0,2093145	115,54	1,187	3,127	10,133	0,090	0,236	0,764	8	0,010345	0,307692
842	0,2093145	176,24	0,852	3,979	9,281	0,064	0,300	0,700	10,5	0,008621	0,403846
1319	0,2093145	276,09	1,050	5,029	8,231	0,079	0,379	0,621	13,2	0,00566	0,507692
2043	0,2093145	427,63	0,882	5,911	7,349	0,067	0,446	0,554	16	0,003867	0,615385
3216	0,2093145	673,16	0,479	6,390	6,870	0,036	0,482	0,518	17,5	0,001279	0,673077

Table A.10 Data of Experiment 10

Exp 10											
Garzan + Butan 20 ml/min											
Total Sampling Time (sn)	Gas Correction (q/v)*1/p	T_d	Asp. Qty (gr)	Total Asp. Qty (gr)	Remaining Asp Qty (gr)	Inst Asph Rate	Cum Asph Rate	Sys Asph Rate	Cum Oil	Inst Oil	Dim Cum Oil
0	0,0523286	0,00	0	0	6,760	0,000	0,000	1,000			
41	0,0523286	2,15	0,381	0,381	6,379	0,056	0,056	0,944	2,1	0,0512195	0,0807692
80	0,0523286	4,19	0,368	0,749	6,011	0,054	0,111	0,889	4,1	0,0512821	0,1576923
122	0,0523286	6,38	0,396	1,145	5,615	0,059	0,169	0,831	6,1	0,047619	0,2346154
166	0,0523286	8,69	0,332	1,477	5,283	0,049	0,218	0,782	8,1	0,0454545	0,3115385
213	0,0523286	11,15	0,384	1,861	4,899	0,057	0,275	0,725	10,1	0,0425532	0,3884615
262	0,0523286	13,71	0,367	2,228	4,532	0,054	0,330	0,670	12,1	0,0408163	0,4653846
313	0,0523286	16,38	0,363	2,591	4,169	0,054	0,383	0,617	14,1	0,0392157	0,5423077
365	0,0523286	19,10	0,33	2,921	3,839	0,049	0,432	0,568	16,1	0,0384615	0,6192308
421	0,0523286	22,03	0,353	3,274	3,486	0,052	0,484	0,516	18,1	0,0357143	0,6961538
480	0,0523286	25,12	0,309	3,583	3,177	0,046	0,530	0,470	20,1	0,0338983	0,7730769
602	0,0523286	31,50	0,166	3,749	3,011	0,025	0,555	0,445	21,2	0,0090164	0,8153846

Table A.11 Data of Experiment 11

Exp 11											
Garzan + Butan 40 ml/min											
Total Sampling Time (sn)	Gas Correction (q/v)*1/p	T_d	Asp. Qty (gr)	Total Asp. Qty (gr)	Remaining Asp Qty (gr)	Inst Asph Rate	Cum Asph Rate	Sys Asph Rate	Cum Oil	Inst Oil	Dim Cum Oil
0	0,1046572	0,00	0	0	6,760	0,000	0,000	1,000			
25	0,1046572	2,62	0,413	0,413	6,347	0,061	0,061	0,939	2,1	0,084	0,0807692
56	0,1046572	5,86	0,405	0,818	5,942	0,060	0,121	0,879	4,2	0,0677419	0,1615385
87	0,1046572	9,11	0,418	1,236	5,524	0,062	0,183	0,817	6,2	0,0645161	0,2384615
118	0,1046572	12,35	0,345	1,581	5,179	0,051	0,234	0,766	8,25	0,066129	0,3173077
151	0,1046572	15,80	0,380	1,961	4,799	0,056	0,290	0,710	10,35	0,0636364	0,3980769
183	0,1046572	19,15	0,389	2,350	4,410	0,058	0,348	0,652	12,35	0,0625	0,475
217	0,1046572	22,71	0,316	2,666	4,094	0,047	0,394	0,606	14,45	0,0617647	0,5557692
251	0,1046572	26,27	0,301	2,967	3,793	0,045	0,439	0,561	16,55	0,0617647	0,6365385
287	0,1046572	30,04	0,345	3,312	3,448	0,051	0,490	0,510	18,65	0,0583333	0,7173077
322	0,1046572	33,70	0,398	3,710	3,050	0,059	0,549	0,451	20,75	0,06	0,7980769
424	0,1046572	44,37	0,281	3,991	2,769	0,042	0,590	0,410	22,55	0,0176471	0,8673077

Table A.12 Data of Experiment 12

Exp 12											
Garzan + Butan 80 ml/min											
Total Sampling Time (sn)	Gas Correction (q/v)*1/p	T_d	Asp. Qty (gr)	Total Asp. Qty (gr)	Remaining Asp Qty (gr)	Inst Asph Rate	Cum Asph Rate	Sys Asph Rate	Cum Oil	Inst Oil	Dim Cum Oil
0	0,2093145	0,00	0	0	6,760	0,000	0,000	1,000			
11	0,2093145	2,30	0,334	0,334	6,426	0,049	0,049	0,951	2	0,181818	0,076923
22	0,2093145	4,60	0,283	0,617	6,143	0,042	0,091	0,909	4	0,181818	0,153846
33	0,2093145	6,91	0,371	0,988	5,772	0,055	0,146	0,854	6	0,181818	0,230769
45	0,2093145	9,42	0,385	1,373	5,387	0,057	0,203	0,797	8	0,166667	0,307692
57	0,2093145	11,93	0,307	1,68	5,08	0,045	0,249	0,751	9,9	0,158333	0,380769
69	0,2093145	14,44	0,304	1,984	4,776	0,045	0,293	0,707	11,8	0,158333	0,453846
81	0,2093145	16,95	0,343	2,327	4,433	0,051	0,344	0,656	13,8	0,166667	0,530769
93	0,2093145	19,47	0,285	2,612	4,148	0,042	0,386	0,614	15,7	0,158333	0,603846
107	0,2093145	22,40	0,299	2,911	3,849	0,044	0,431	0,569	17,7	0,142857	0,680769
118	0,2093145	24,70	0,297	3,208	3,552	0,044	0,475	0,525	19,7	0,181818	0,757692
180	0,2093145	37,68	0,478	3,686	3,074	0,071	0,545	0,455	22,1	0,03871	0,85

Table A.13 Data of Experiment 13

Exp 13											
Raman + Butan 20 ml/min											
Total Sampling Time (sn)	Gas Correction (q/v)*1/p	T_d	Asp. Qty (gr)	Total Asp. Qty (gr)	Remaining Asp Qty (gr)	Inst Asph Rate	Cum Asph Rate	Sys Asph Rate	Cum Oil	Inst Oil	Dim Cum Oil
0	0,0523286	0,00	0	0	10,400	0,000	0,000	1,000			
183	0,0523286	9,58	0,529	0,529	9,871	0,051	0,051	0,949	2,1	0,0114754	0,0807692
320	0,0523286	16,75	0,501	1,030	9,370	0,048	0,099	0,901	4,2	0,0153285	0,1615385
457	0,0523286	23,91	0,588	1,618	8,782	0,057	0,156	0,844	6,4	0,0160584	0,2461538
574	0,0523286	30,04	0,489	2,107	8,293	0,047	0,203	0,797	8,4	0,017094	0,3230769
700	0,0523286	36,63	0,484	2,591	7,809	0,047	0,249	0,751	10,4	0,015873	0,4
863	0,0523286	45,16	0,502	3,093	7,307	0,048	0,297	0,703	12,45	0,0125767	0,4788462
1098	0,0523286	57,46	0,488	3,581	6,819	0,047	0,344	0,656	14,55	0,0089362	0,5596154
1340	0,0523286	70,12	0,463	4,044	6,356	0,045	0,389	0,611	16,45	0,0078512	0,6326923
1668	0,0523286	87,28	0,528	4,572	5,828	0,051	0,440	0,560	18,45	0,0060976	0,7096154
2069	0,0523286	108,27	0,414	4,986	5,414	0,040	0,479	0,521	20,45	0,0049875	0,7865385
2560	0,0523286	133,96	0,491	5,477	4,923	0,047	0,527	0,473	22,65	0,0044807	0,8711538

Table A.14 Data of Experiment 14

Exp 14											
Raman + Butan 40 ml/min											
Total Sampling Time (sn)	Gas Correction (q/v)*1/p	T_d	Asp. Qty (gr)	Total Asp. Qty (gr)	Remaining Asp Qty (gr)	Inst Asph Rate	Cum Asph Rate	Sys Asph Rate	Cum Oil	Inst Oil	Dim Cum Oil
0	0,1046572	0,00	0	0	10,400	0,000	0,000	1,000			
190	0,1046572	19,88	0,595	0,595	9,805	0,057	0,057	0,943	2,1	0,0110526	0,0807692
344	0,1046572	36,00	0,537	1,132	9,268	0,052	0,109	0,891	4,2	0,0136364	0,1615385
509	0,1046572	53,27	0,526	1,658	8,742	0,051	0,159	0,841	6,3	0,0127273	0,2423077
686	0,1046572	71,79	0,467	2,125	8,275	0,045	0,204	0,796	8,4	0,0118644	0,3230769
831	0,1046572	86,97	0,475	2,600	7,800	0,046	0,250	0,750	10,5	0,0144828	0,4038462
1022	0,1046572	106,96	0,810	3,410	6,990	0,078	0,328	0,672	13,3	0,0146597	0,5115385
1213	0,1046572	126,95	0,550	3,960	6,440	0,053	0,381	0,619	15,4	0,0109948	0,5923077
1389	0,1046572	145,37	0,515	4,475	5,925	0,050	0,430	0,570	17,5	0,0119318	0,6730769
1621	0,1046572	169,65	0,563	5,038	5,362	0,054	0,484	0,516	19,6	0,0090517	0,7538462
1911	0,1046572	200,00	0,570	5,608	4,792	0,055	0,539	0,461	21,6	0,0068966	0,8307692
2217	0,1046572	232,03	0,060	5,668	4,732	0,006	0,545	0,455	21,9	0,0009804	0,8423077

Table A.15 Data of Experiment 15

Exp 15											
Raman + Butan 80 ml/min											
Total Sampling Time (sn)	Gas Correction (q/v)*1/p	T_d	Asp. Qty (gr)	Total Asp. Qty (gr)	Remaining Asp Qty (gr)	Inst Asph Rate	Cum Asph Rate	Sys Asph Rate	Cum Oil	Inst Oil	Dim Cum Oil
0	0,2093145	0,00	0	0	10,400	0,000	0,000	1,000			
80	0,2093145	16,75	0,534	0,534	9,866	0,051	0,051	0,949	2,1	0,02625	0,080769
156	0,2093145	32,65	0,507	1,041	9,359	0,049	0,100	0,900	4,1	0,026316	0,157692
261	0,2093145	54,63	0,719	1,760	8,640	0,069	0,169	0,831	6,6	0,02381	0,253846
350	0,2093145	73,26	0,586	2,346	8,054	0,056	0,226	0,774	9	0,026966	0,346154
440	0,2093145	92,10	0,489	2,835	7,565	0,047	0,273	0,727	11,1	0,023333	0,426923
525	0,2093145	109,89	0,553	3,388	7,012	0,053	0,326	0,674	13,1	0,023529	0,503846
604	0,2093145	126,43	0,470	3,858	6,542	0,045	0,371	0,629	15,1	0,025316	0,580769
686	0,2093145	143,59	0,565	4,423	5,977	0,054	0,425	0,575	17,3	0,026829	0,665385
768	0,2093145	160,75	0,497	4,920	5,480	0,048	0,473	0,527	19,3	0,02439	0,742308
874	0,2093145	182,94	0,533	5,453	4,947	0,051	0,524	0,476	21,4	0,019811	0,823077
1064	0,2093145	222,71	0,145	5,598	4,802	0,014	0,538	0,462	22,1	0,003684	0,85

Table A.16 Data of Experiment 16

Exp 16											
B.Raman + Butan 20 ml/min											
Total Sampling Time (sn)	Gas Correction (q/v)*1/p	T_d	Asp. Qty (gr)	Total Asp. Qty (gr)	Remaining Asp Qty (gr)	Inst Asph Rate	Cum Asph Rate	Sys Asph Rate	Cum Oil	Inst Oil	Dim Cum Oil
0	0,0523286	0,00	0	0	13,260	0,000	0,000	1,000			
788	0,0523286	41,23	0,775	0,775	12,485	0,058	0,058	0,942	2,15	0,0027284	0,0826923
1419	0,0523286	74,25	0,781	1,556	11,704	0,059	0,117	0,883	4,35	0,0034865	0,1673077
2412	0,0523286	126,22	0,706	2,262	10,998	0,053	0,171	0,829	6,45	0,0021148	0,2480769
3171	0,0523286	165,93	0,671	2,933	10,327	0,051	0,221	0,779	8,45	0,002635	0,325
3833	0,0523286	200,58	0,628	3,561	9,699	0,047	0,269	0,731	10,45	0,0030211	0,4019231
5264	0,0523286	275,46	0,790	4,351	8,909	0,060	0,328	0,672	12,55	0,0014675	0,4826923
6516	0,0523286	340,97	0,725	5,076	8,184	0,055	0,383	0,617	14,65	0,0016773	0,5634615
8475	0,0523286	443,49	0,851	5,927	7,333	0,064	0,447	0,553	16,9	0,0011485	0,65
9830	0,0523286	514,39	0,746	6,673	6,587	0,056	0,503	0,497	19,15	0,0016605	0,7365385

Table A.17 Data of Experiment 17

Exp 17											
B.Raman + Butan 40 ml/min											
Total Sampling Time (sn)	Gas Correction (q/v)*1/p	T_d	Asp. Qty (gr)	Total Asp. Qty (gr)	Remaining Asp Qty (gr)	Inst Asph Rate	Cum Asph Rate	Sys Asph Rate	Cum Oil	Inst Oil	Dim Cum Oil
0	0,1046572	0,00	0	0	13,260	0,000	0,000	1,000			
382	0,1046572	39,98	0,764	0,764	12,496	0,058	0,058	0,942	2,3	0,0060209	0,0884615
507	0,1046572	53,06	0,925	1,689	11,571	0,070	0,127	0,873	5,4	0,0248	0,2076923
619	0,1046572	64,78	1,036	2,725	10,535	0,078	0,206	0,794	8,6	0,0285714	0,3307692
768	0,1046572	80,38	0,921	3,646	9,614	0,069	0,275	0,725	11,4	0,0187919	0,4384615
937	0,1046572	98,06	0,933	4,579	8,681	0,070	0,345	0,655	14,4	0,0177515	0,5538462
1282	0,1046572	134,17	0,812	5,391	7,869	0,061	0,407	0,593	17,1	0,0078261	0,6576923
3403	0,1046572	356,15	0,423	5,814	7,446	0,032	0,438	0,562	18,5	0,0006601	0,7115385

Table A.18 Data of Experiment 18

Exp 18											
B.Raman + Butan 80 ml/min											
Total Sampling Time (sn)	Gas Correction (q/v)*1/p	T_d	Asp. Qty (gr)	Total Asp. Qty (gr)	Remaining Asp Qty (gr)	Inst Asph Rate	Cum Asph Rate	Sys Asph Rate	Cum Oil	Inst Oil	Dim Cum Oil
0	0,2093145	0,00	0	0	13,260	0,000	0,000	1,000			
324	0,2093145	67,82	0,631	0,631	12,629	0,048	0,048	0,952	1,9	0,005864	0,073077
442	0,2093145	92,52	0,792	1,423	11,837	0,060	0,107	0,893	4,5	0,022034	0,173077
572	0,2093145	119,73	0,787	2,210	11,050	0,059	0,167	0,833	7,05	0,019615	0,271154
713	0,2093145	149,24	0,928	3,138	10,122	0,070	0,237	0,763	9,75	0,019149	0,375
950	0,2093145	198,85	0,760	3,898	9,362	0,057	0,294	0,706	12,05	0,009705	0,463462
1227	0,2093145	256,83	0,804	4,702	8,558	0,061	0,355	0,645	14,15	0,007581	0,544231
2030	0,2093145	424,91	0,601	5,303	7,957	0,045	0,400	0,600	16	0,002304	0,615385

Table A.19 Data of Experiment 19

Exp 19											
Garzan + CO2 40 ml/min											
Total Sampling Time (sn)	Gas Correction (q/v)*1/p	T_d	Asp. Qty (gr)	Total Asp. Qty (gr)	Remaining Asp Qty (gr)	Inst Asph Rate	Cum Asph Rate	Sys Asph Rate	Cum Oil	Inst Oil	Dim Cum Oil
0	0,1046572	0,00	0	0	6,760	0,000	0,000	1,000			
7	0,1046572	0,73	0,466	0,466	6,294	0,069	0,069	0,931	2,4	0,3428571	0,0923077
14	0,1046572	1,47	0,385	0,851	5,909	0,057	0,126	0,874	4,6	0,3142857	0,1769231
21	0,1046572	2,20	0,330	1,181	5,579	0,049	0,175	0,825	6,8	0,3142857	0,2615385
28	0,1046572	2,93	0,414	1,595	5,165	0,061	0,236	0,764	9	0,3142857	0,3461538
36	0,1046572	3,77	0,502	2,097	4,663	0,074	0,310	0,690	11,6	0,325	0,4461538
43	0,1046572	4,50	0,368	2,465	4,295	0,054	0,365	0,635	14	0,3428571	0,5384615
50	0,1046572	5,23	0,407	2,872	3,888	0,060	0,425	0,575	16,2	0,3142857	0,6230769
57	0,1046572	5,97	0,326	3,198	3,562	0,048	0,473	0,527	18,4	0,3142857	0,7076923
64	0,1046572	6,70	0,418	3,616	3,144	0,062	0,535	0,465	20,8	0,3428571	0,8
267	0,1046572	27,94	0,186	3,802	2,958	0,028	0,562	0,438	22,1	0,0064039	0,85

Table A.20 Data of Experiment 20

Exp 20 (Wet Vapex)											
Garzan + Butan 40 ml/min + Steam											
Total Sampling Time (sn)	Gas Correction (q/v)*1/p	T_d	Asp. Qty (gr)	Total Asp. Qty (gr)	Remaining Asp Qty (gr)	Inst Asph Rate	Cum Asph Rate	Sys Asph Rate	Cum Oil	Inst Oil	Dim Cum Oil
0	0,1046572	0,00	0	0	6,760	0,000	0,000	1,000			
17	0,1046572	1,78	0,277	0,277	6,483	0,041	0,041	0,959	2	0,1176471	0,0769231
32	0,1046572	3,35	0,375	0,652	6,108	0,055	0,096	0,904	4,1	0,14	0,1576923
47	0,1046572	4,92	0,288	0,940	5,820	0,043	0,139	0,861	6,2	0,14	0,2384615
60	0,1046572	6,28	0,336	1,276	5,484	0,050	0,189	0,811	8,4	0,1692308	0,3230769
73	0,1046572	7,64	0,233	1,509	5,251	0,034	0,223	0,777	10,3	0,1461538	0,3961538
88	0,1046572	9,21	0,407	1,916	4,844	0,060	0,283	0,717	12,5	0,1466667	0,4807692
105	0,1046572	10,99	0,377	2,293	4,467	0,056	0,339	0,661	14,7	0,1294118	0,5653846
125	0,1046572	13,08	0,400	2,693	4,067	0,059	0,398	0,602	16,9	0,11	0,65
145	0,1046572	15,18	0,412	3,105	3,655	0,061	0,459	0,541	19	0,105	0,7307692
172	0,1046572	18,00	0,409	3,514	3,246	0,061	0,520	0,480	21,2	0,0814815	0,8153846
227	0,1046572	23,76	0,735	4,249	2,511	0,109	0,629	0,371	24,4	0,0581818	0,9384615

APPENDIX B

GRAPHS OF THE VAPEX EXPERIMENTS

This appendix will cover the rest of the experimental graphs for the VAPEX experiments including cumulative produced oil and oil rates for Garzan and B. Raman crude oils with the different injection rates of the VAPEX solvents, instantaneous, cumulative and produced asphaltane rates of Garzan and B. Raman crude oils.

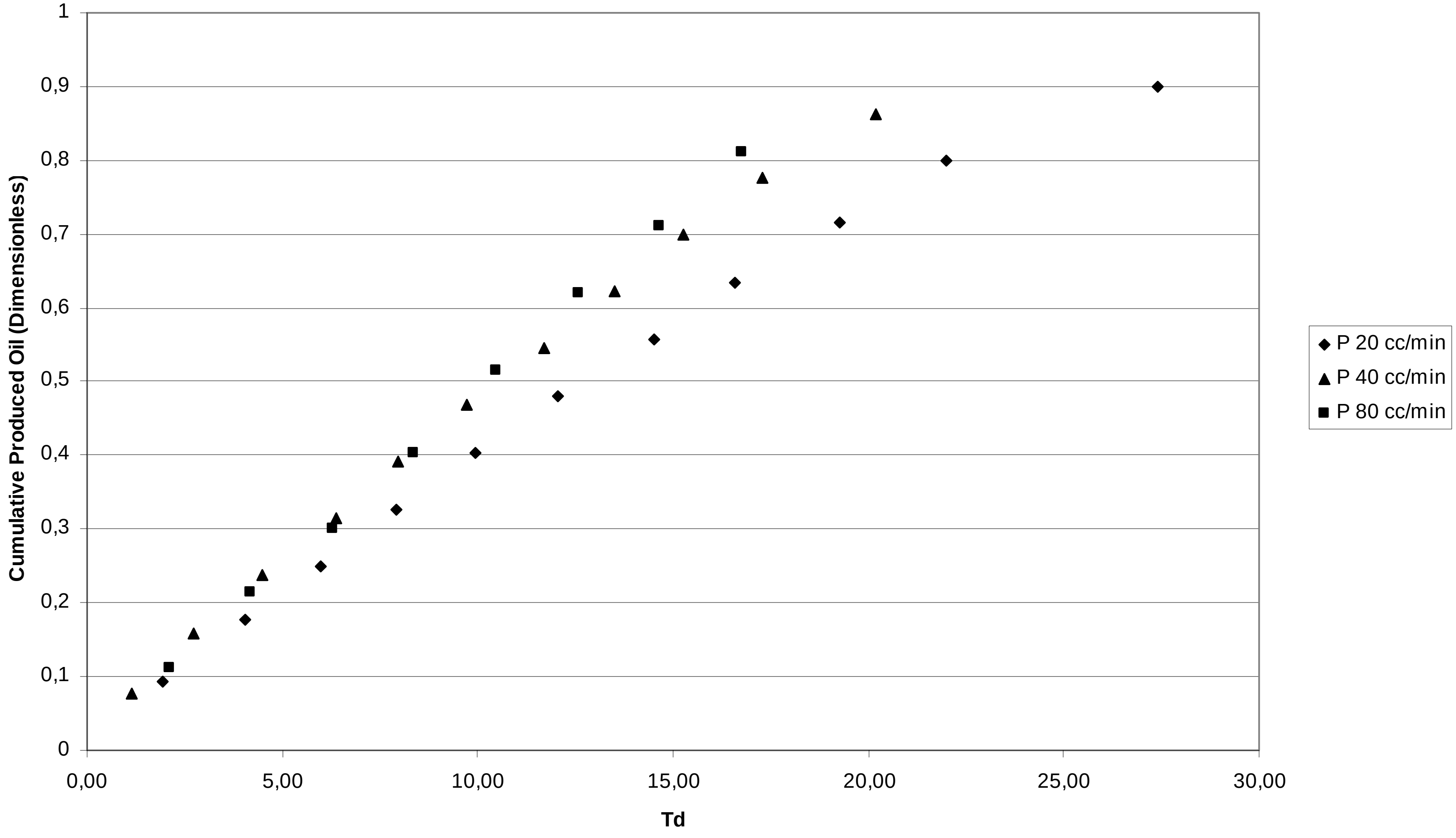


Fig B.1 Cumulative Produced Oil for Garzan Crude with 3 different rates of Propane

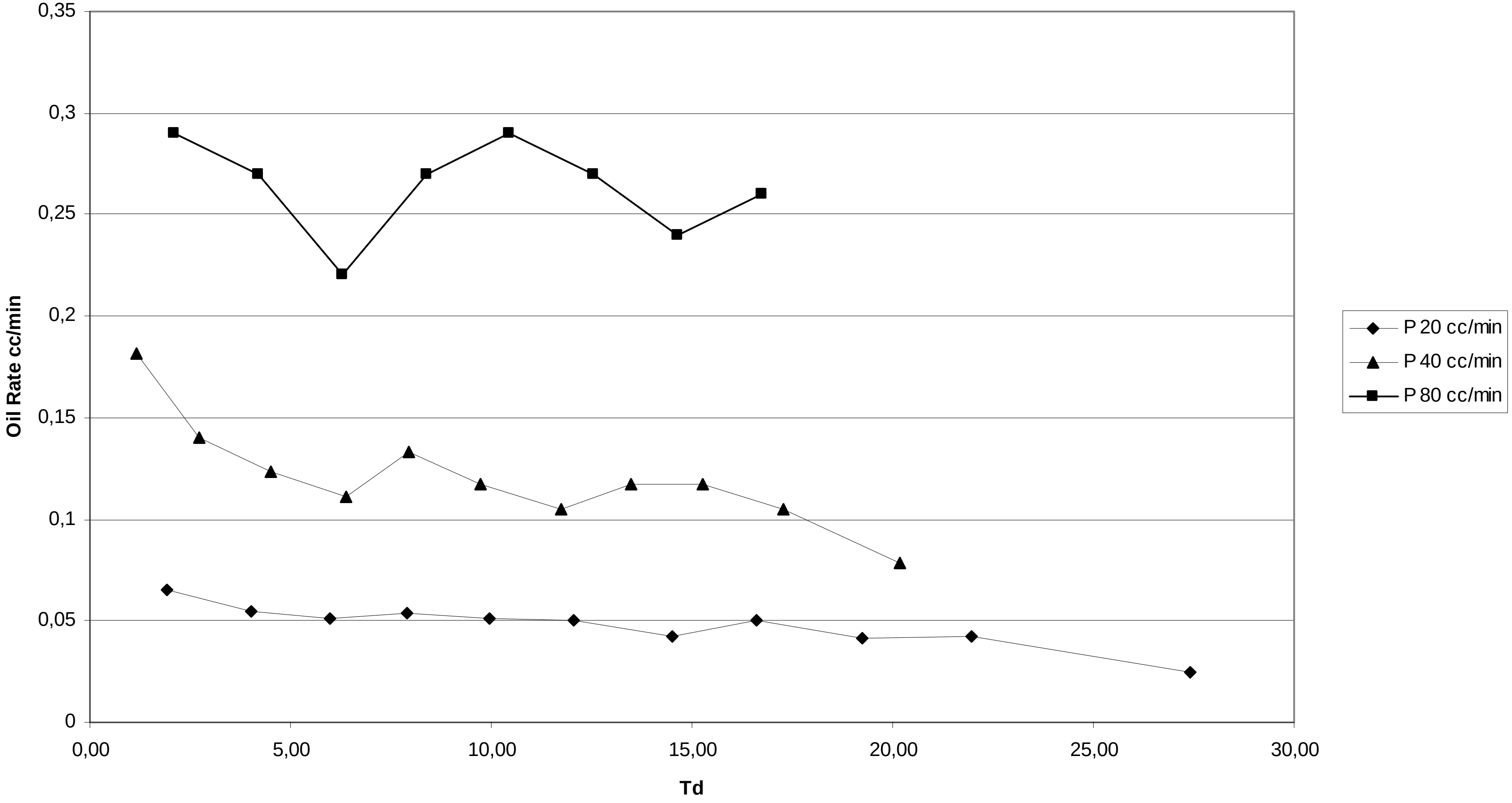


Fig B.2 Oil Rate for Garzan Crude with 3 different rates of Propane

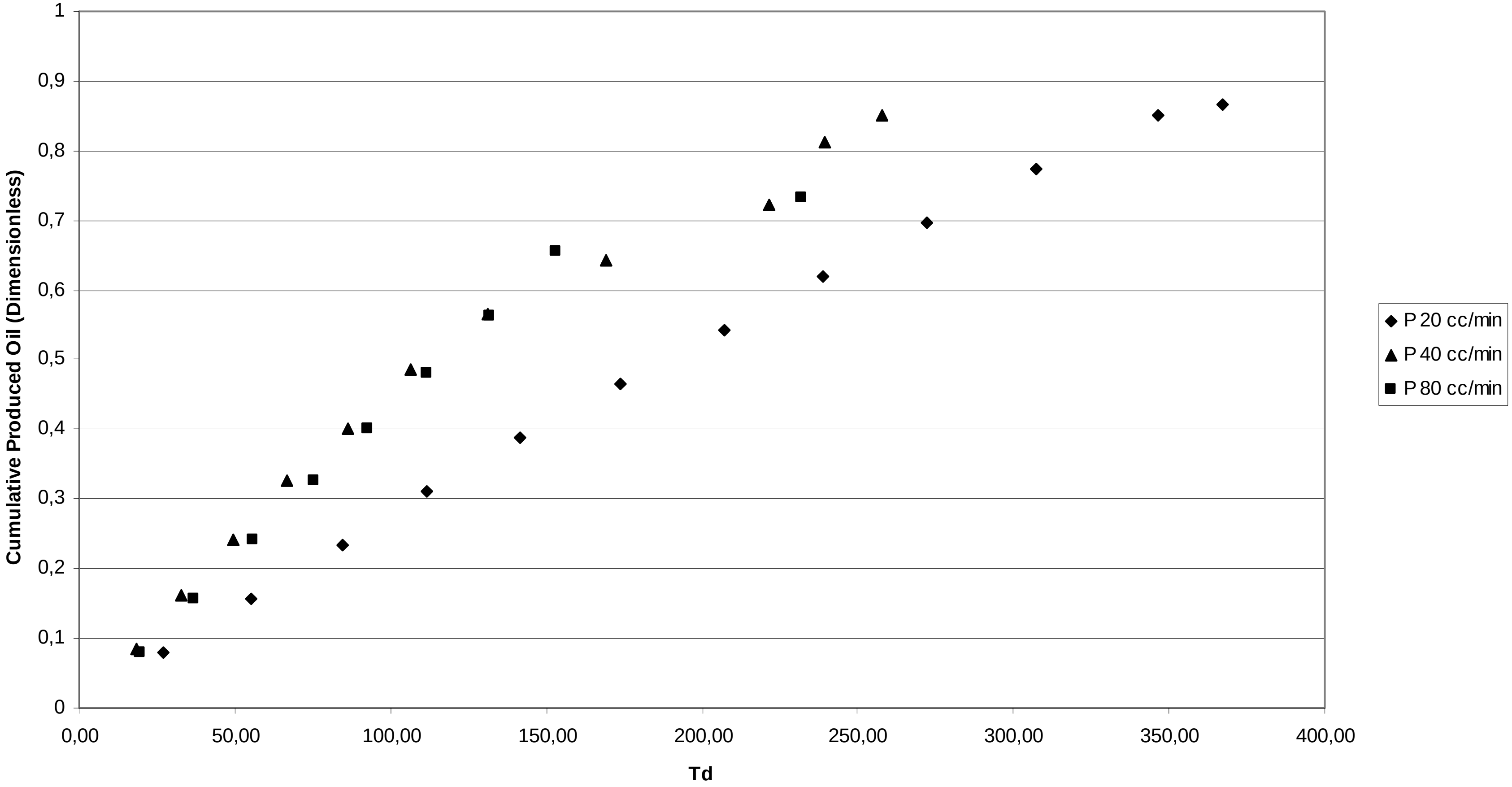


Fig B.3 Cumulative Produced Oil for B.Raman Crude with 3 different rates of Propane

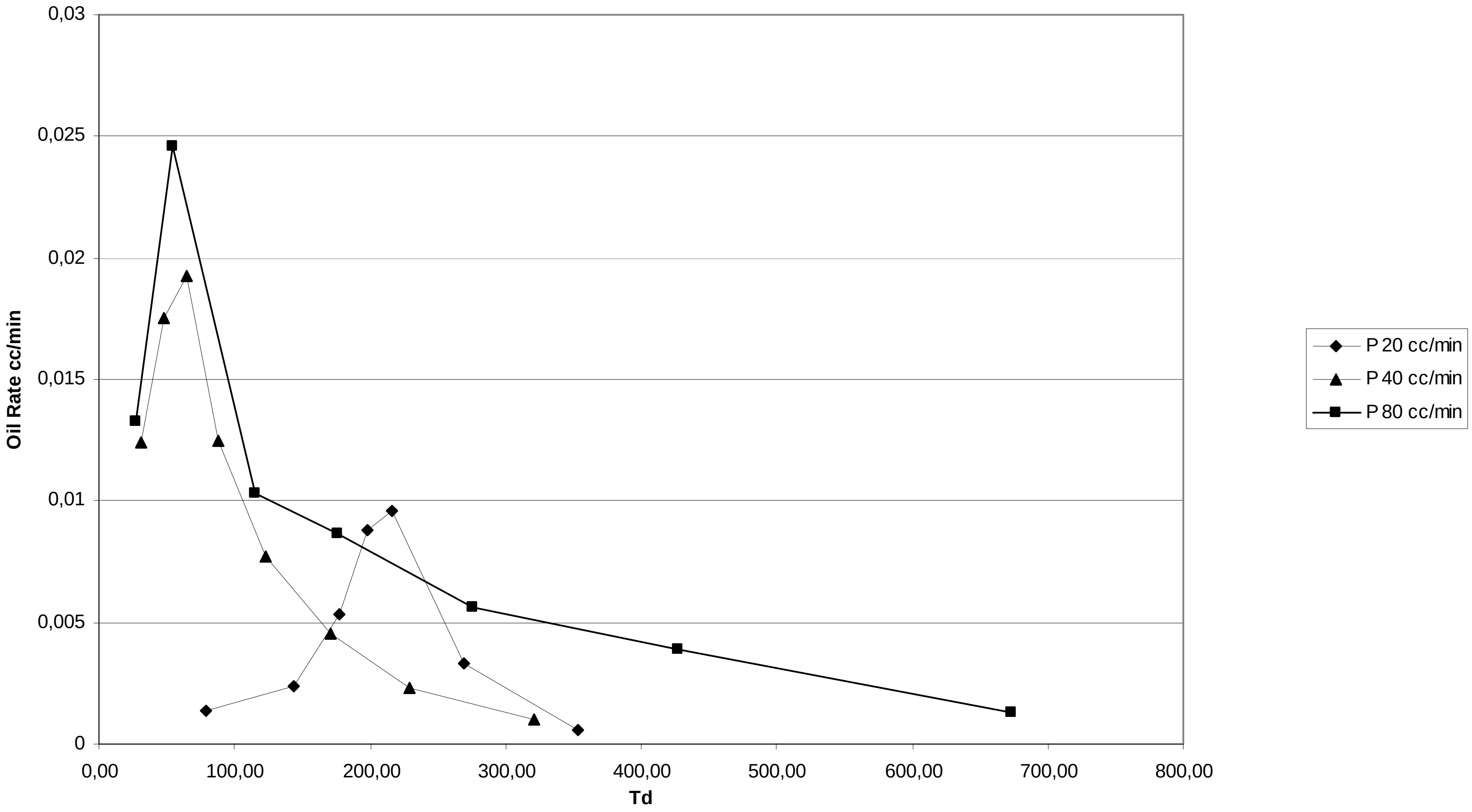


Fig B.4 Oil Rate for B.Raman Crude with 3 different rates of Propane

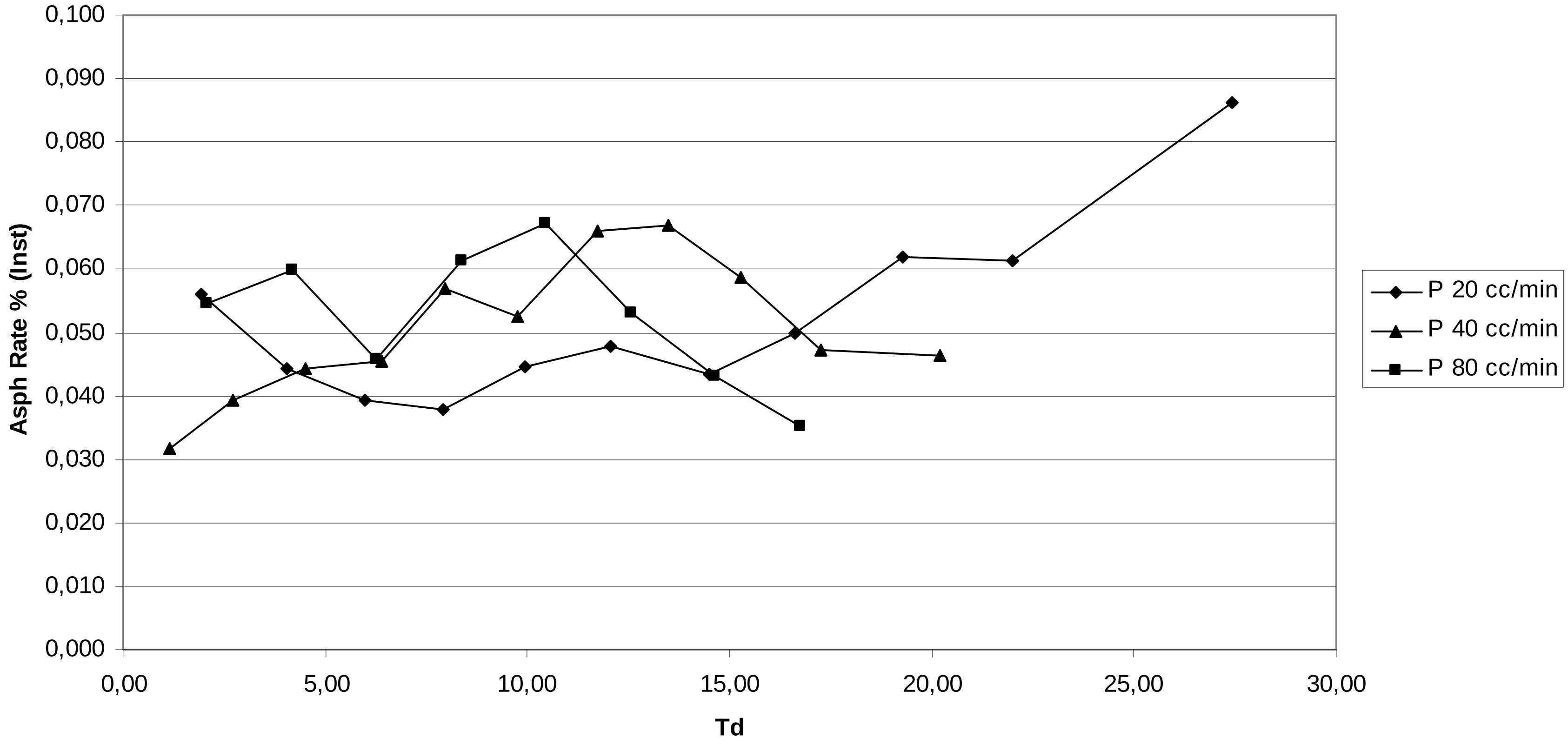


Fig B.5 Garzan Instantaneous Asphaltene rate of Garzan Oil with 3 different Propane rates

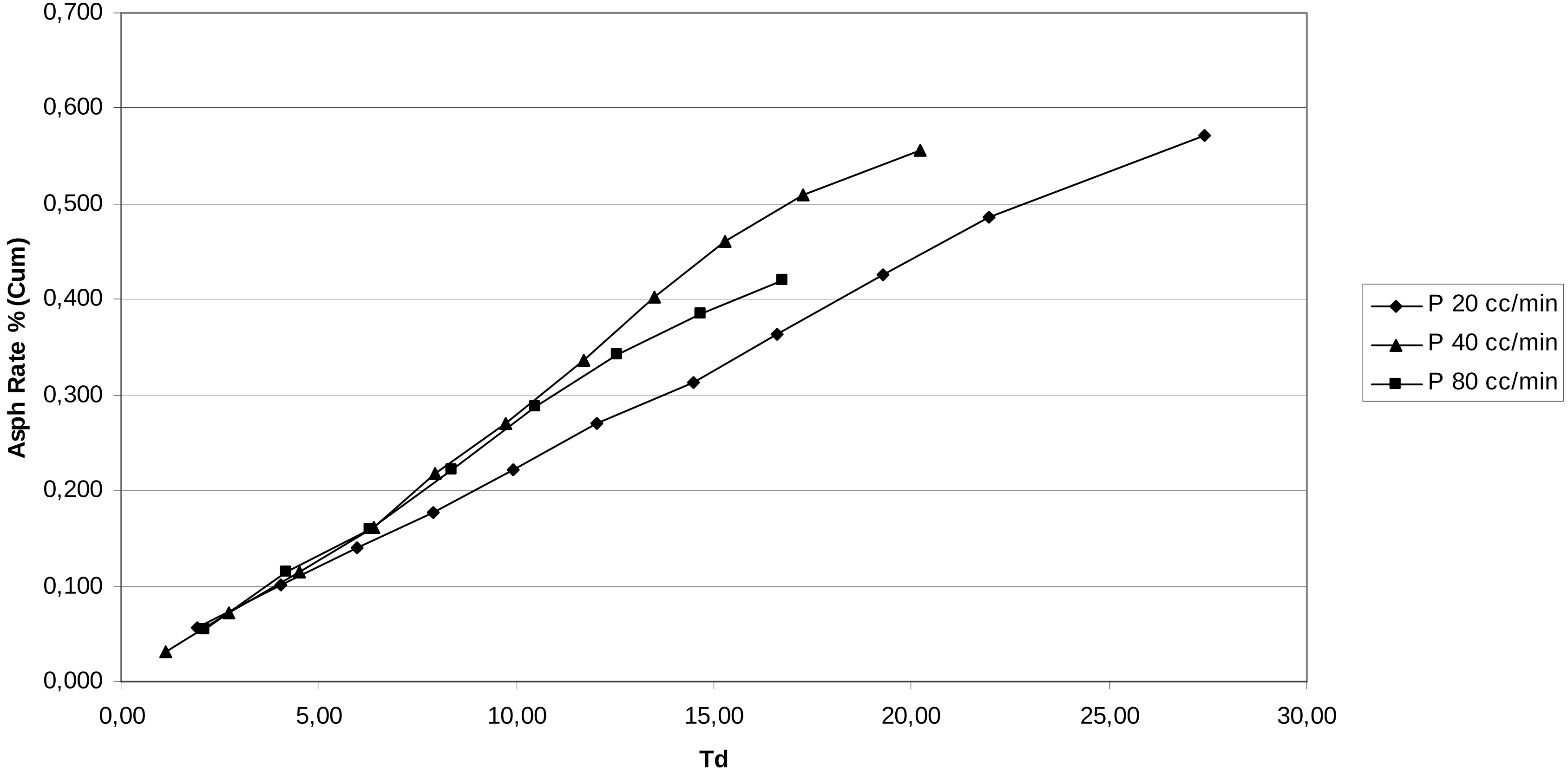


Fig B.6 Cumulative Asphaltene rate of Garzan Oil with 3 different Propane rates

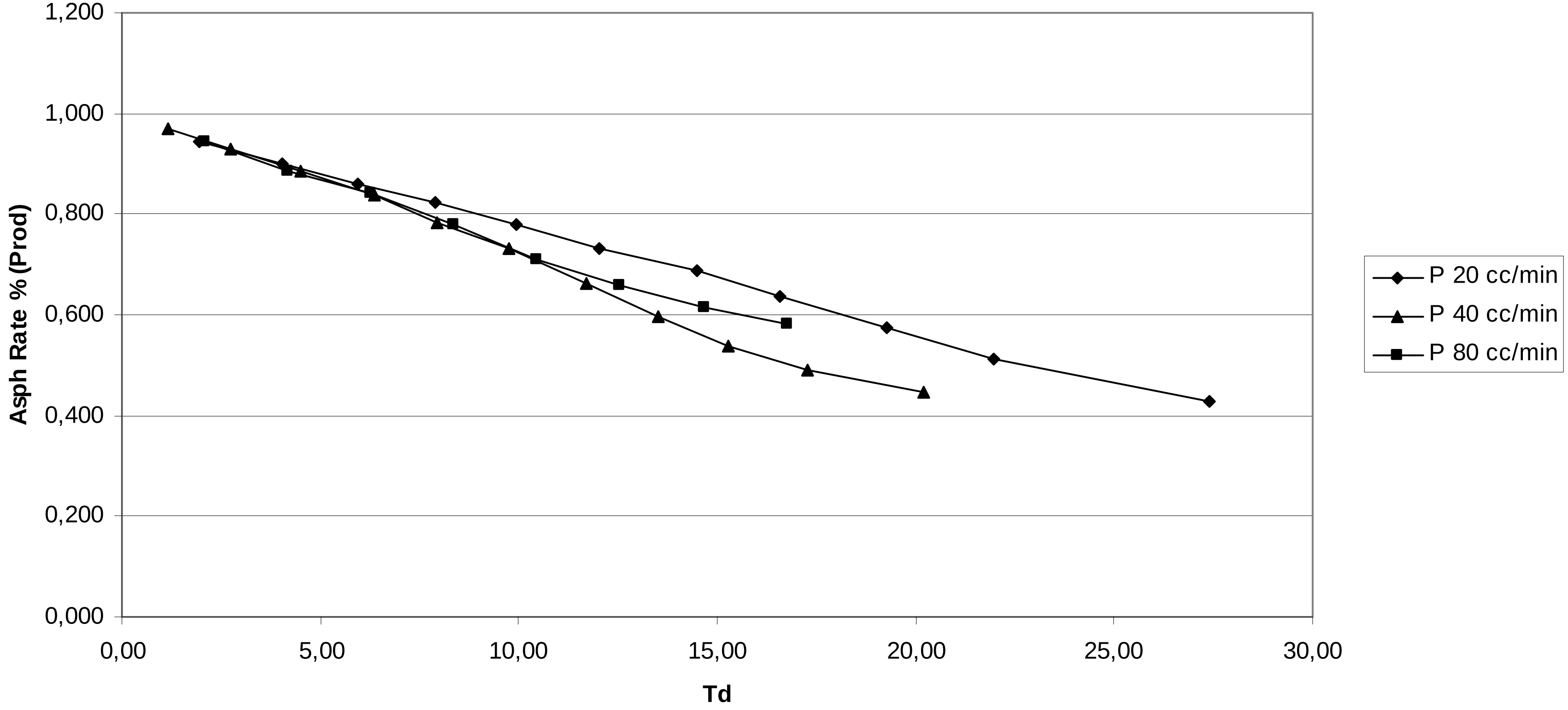


Fig B.7 Produced Asphaltene rate of Garzan Oil with 3 different Propane rates

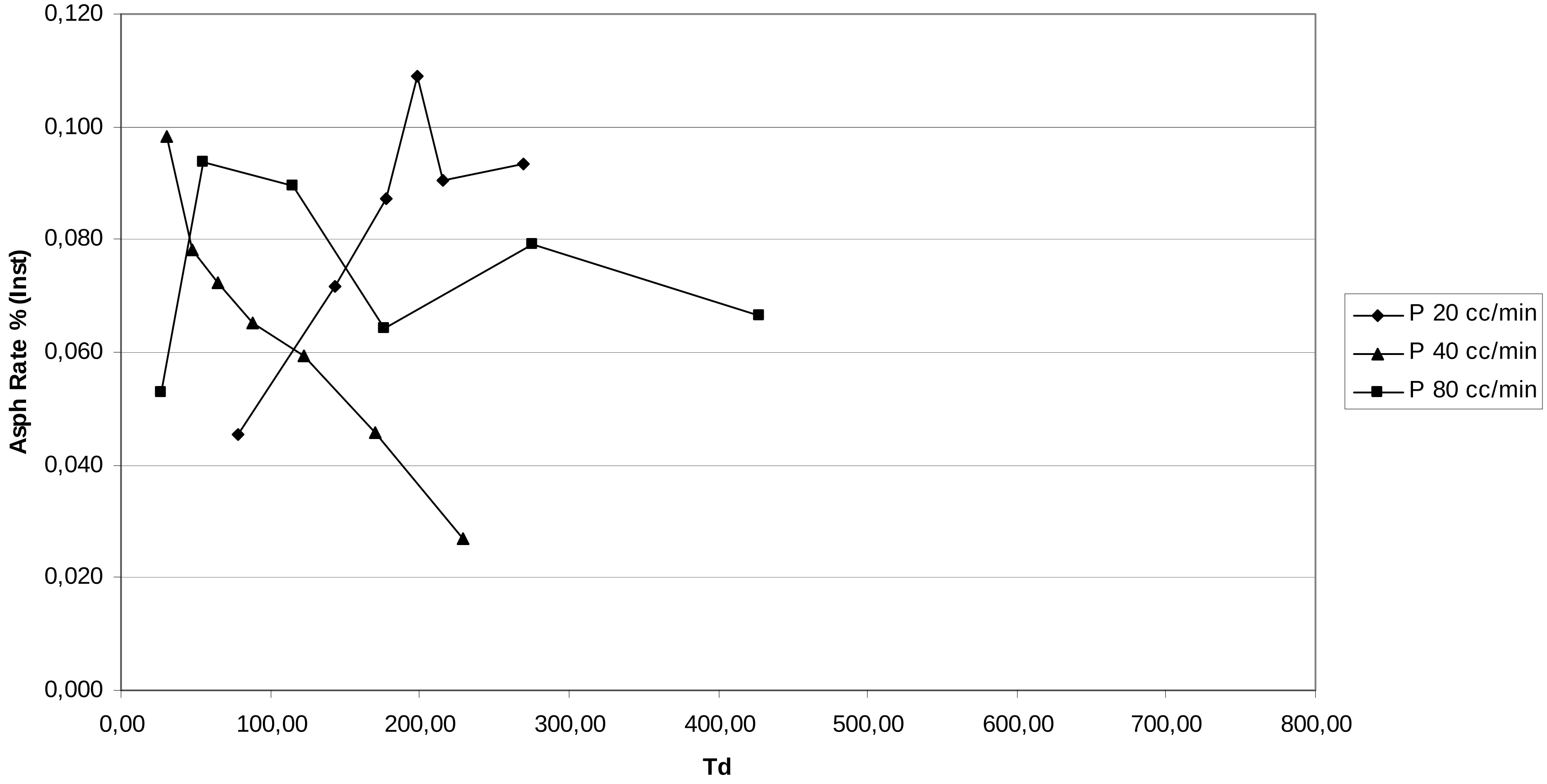


Fig B.8 Instantaneous Asphaltene rate of B.Raman Oil with 3 different Propane rates

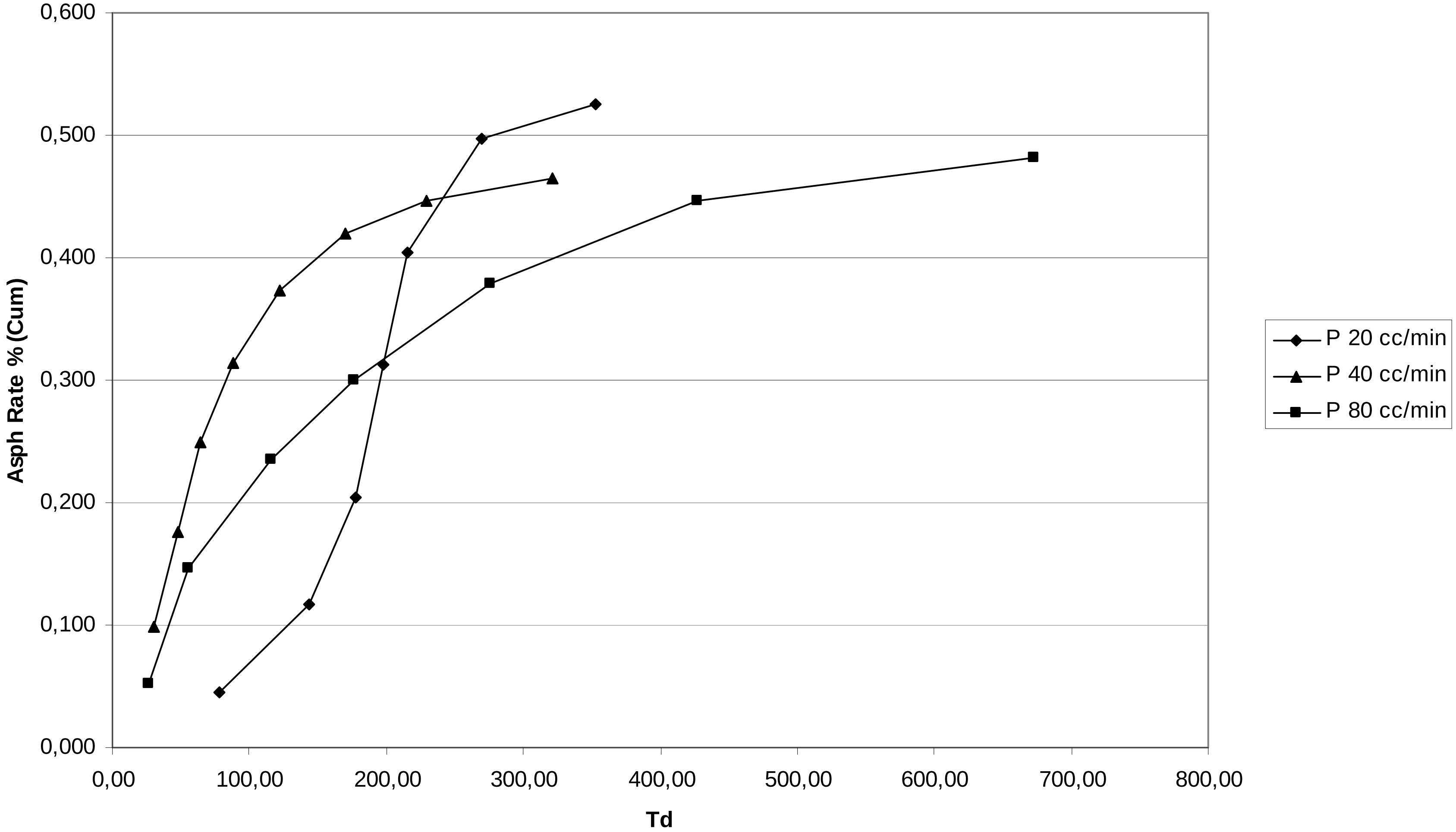


Fig B.9 Cumulative Asphaltene rate of B.Raman Oil with 3 different Propane rates

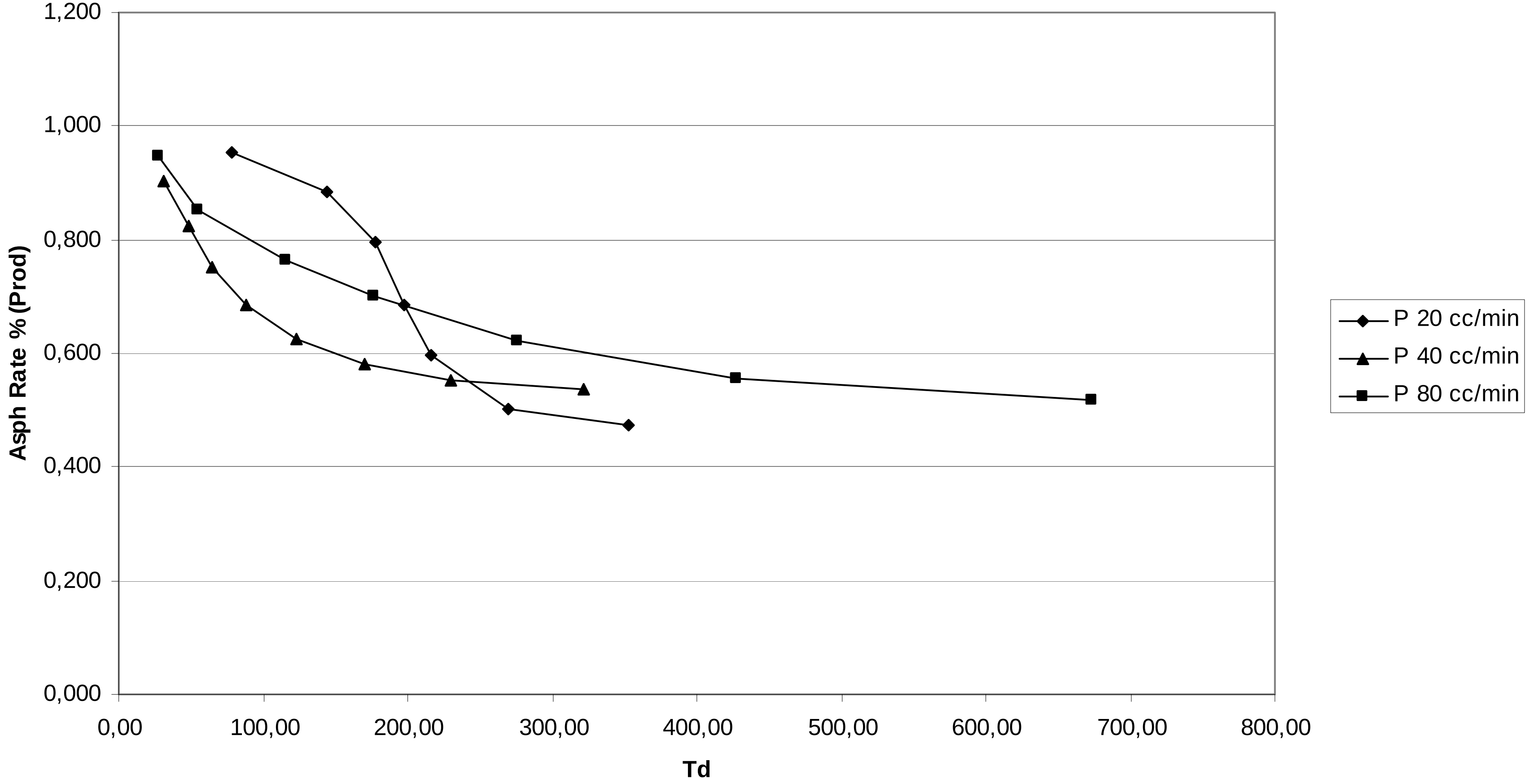


Fig B.10 Produced Asphaltene rate of B.Raman Oil with 3 different Propane rates

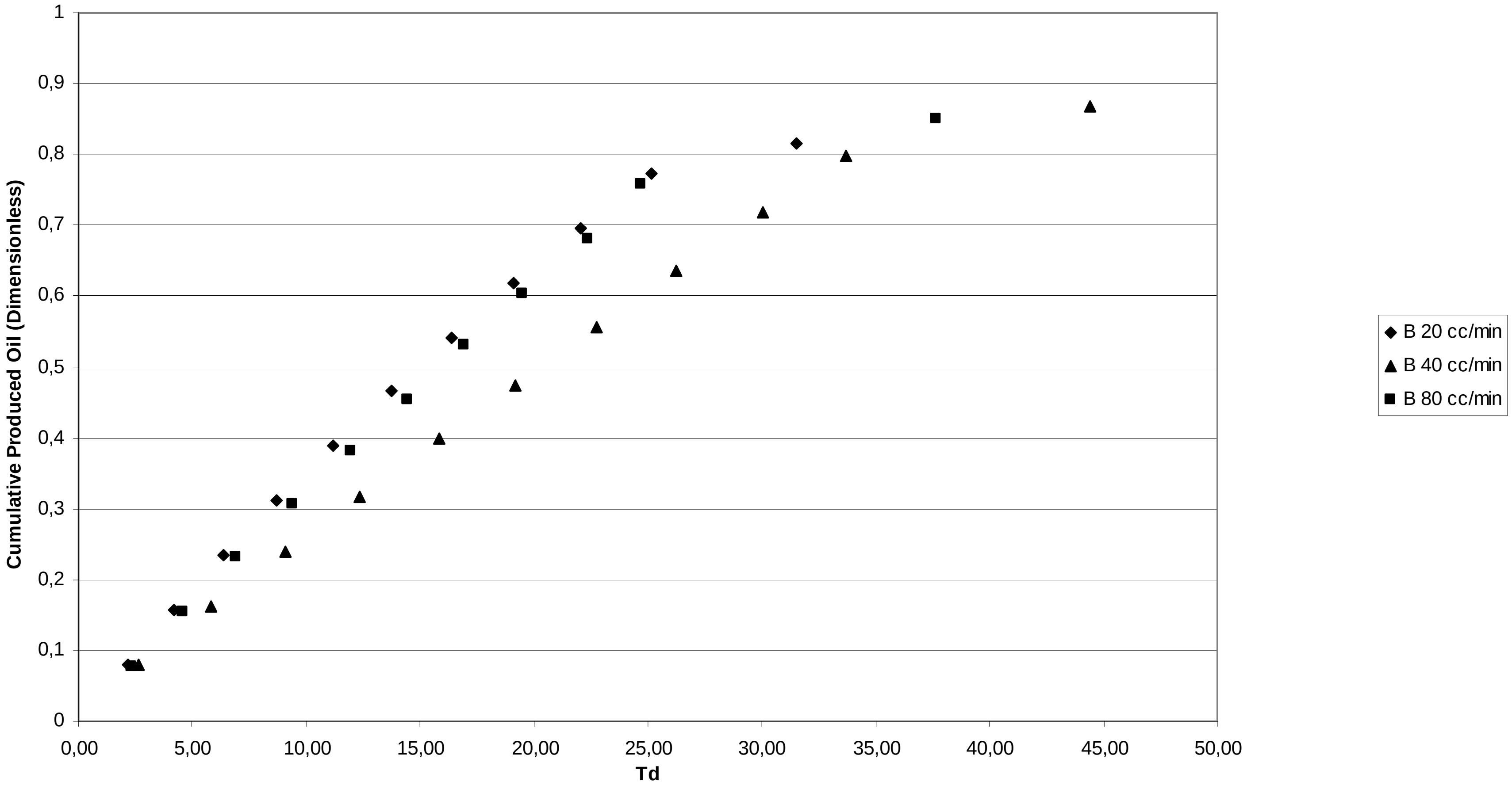


Fig B.11 Cumulative Produced Oil for Garzan Crude with 3 different rates of Butane

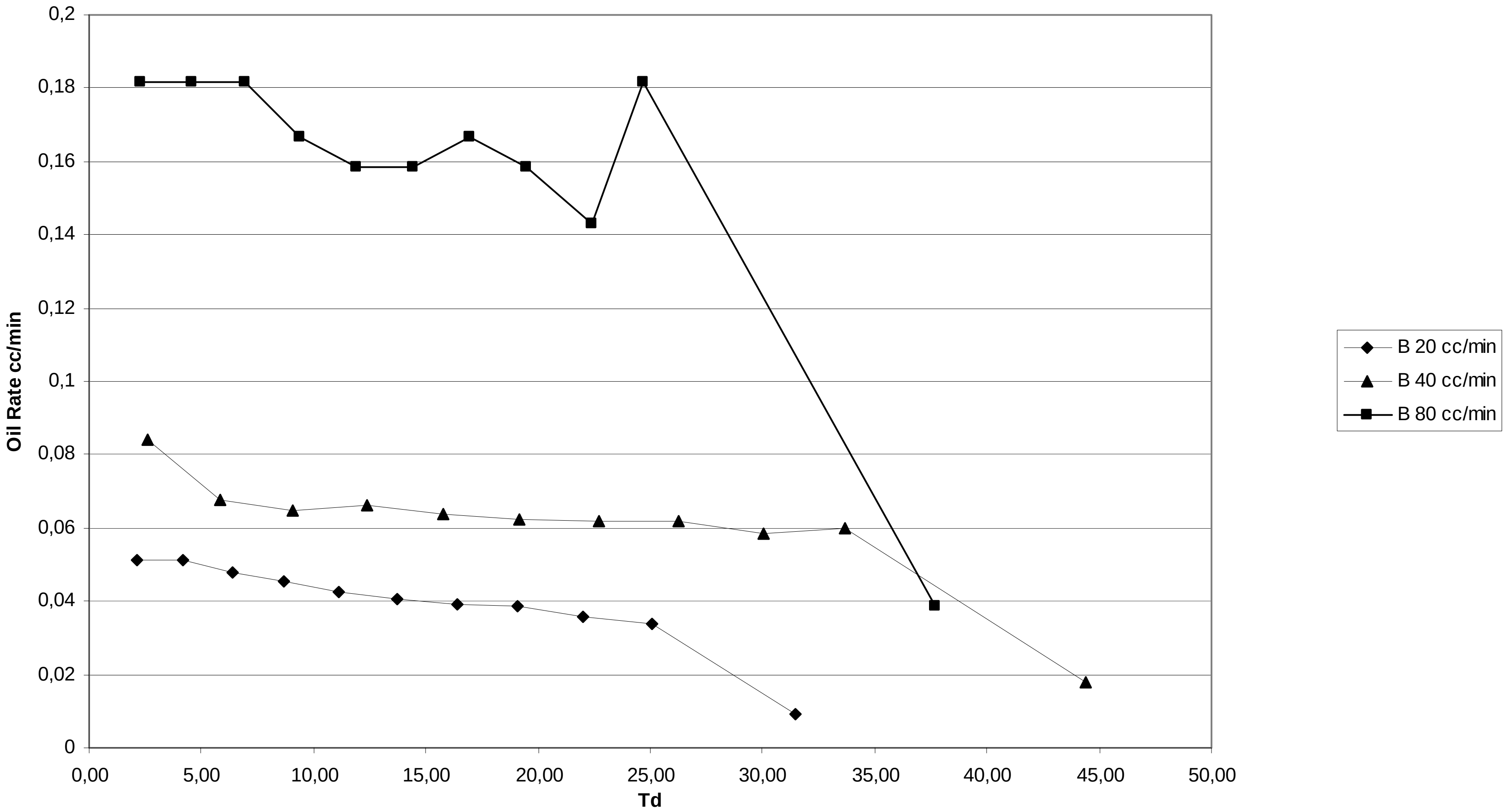


Fig B.12 Oil Rate for Garzan Crude with 3 different rates of Butane

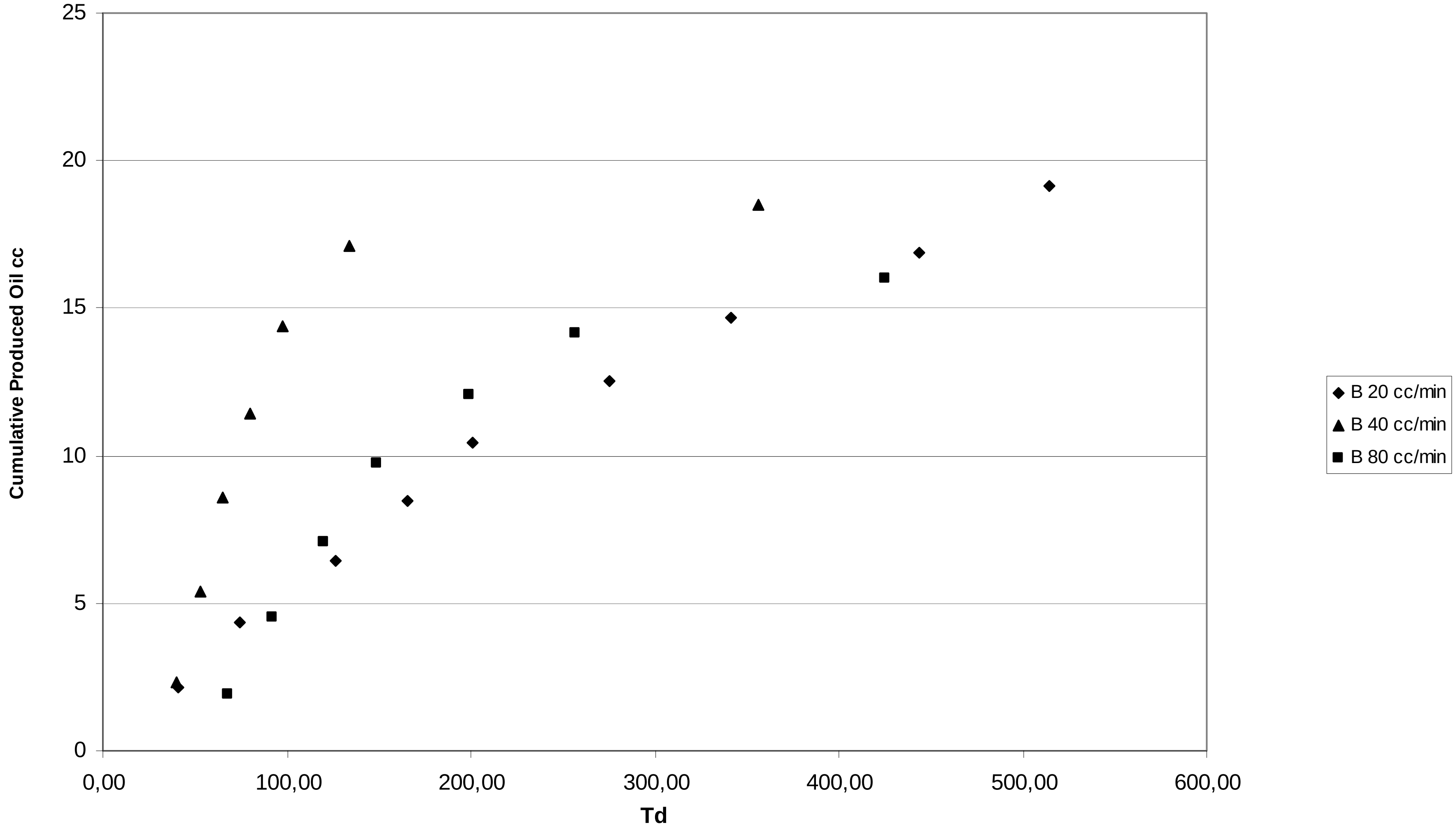


Fig B.13 Cumulative Oil Production for B.Raman Crude with 3 different rates of Butane

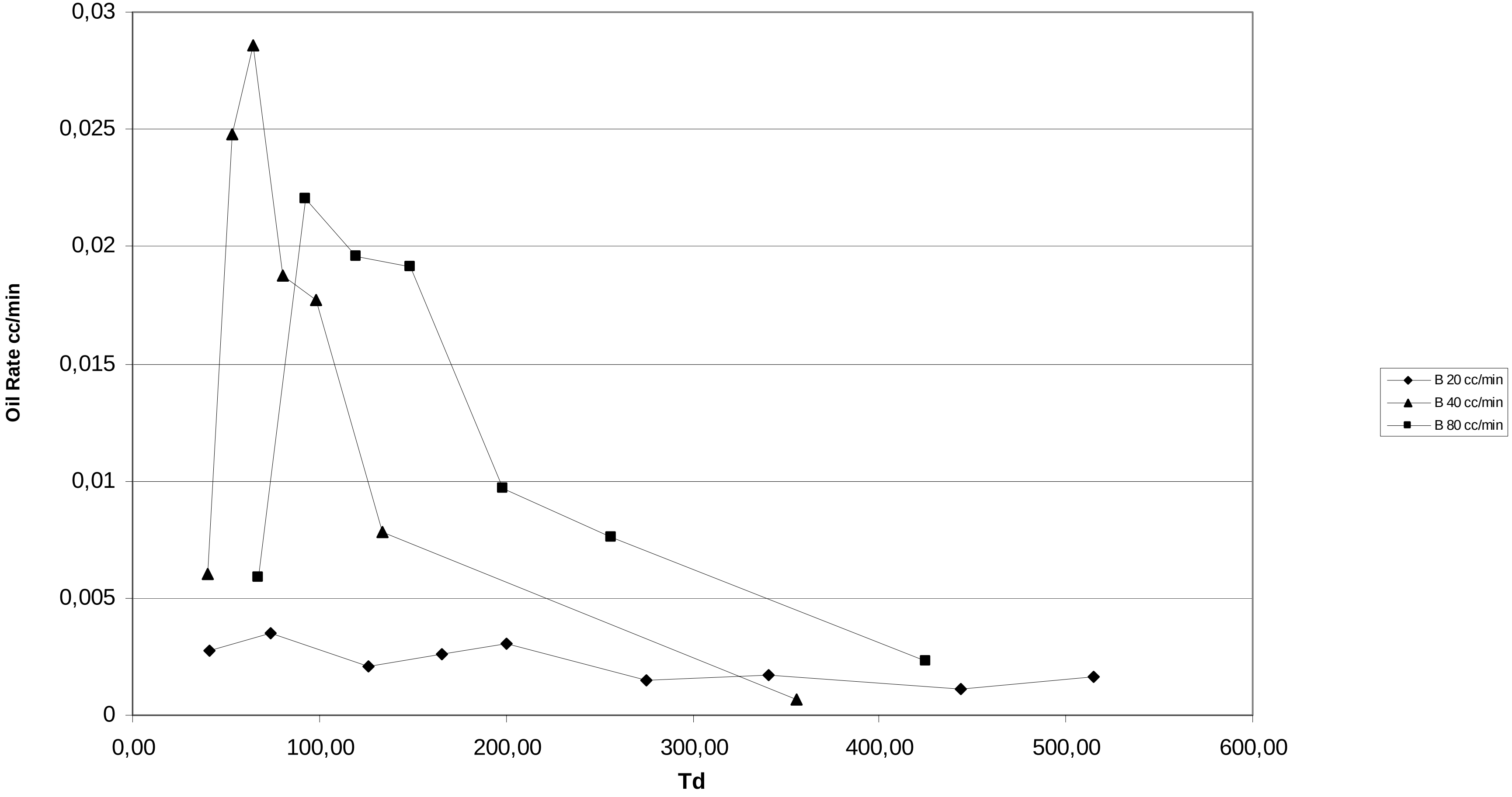


Fig B.14 Oil Rate for B.Raman Crude with 3 different rates of Butane

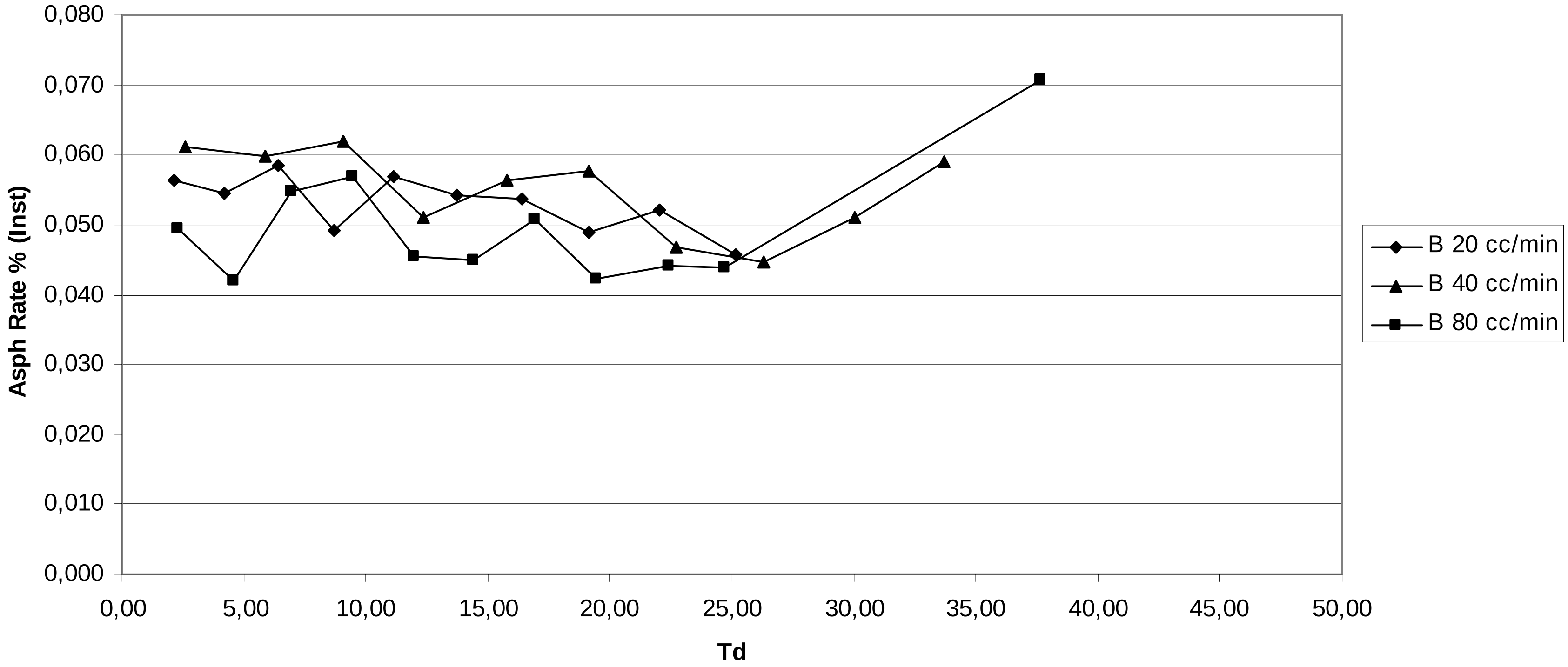


Fig B.15 Instantaneous Asphaltene rate of Garzan Oil with 3 different Butane rates

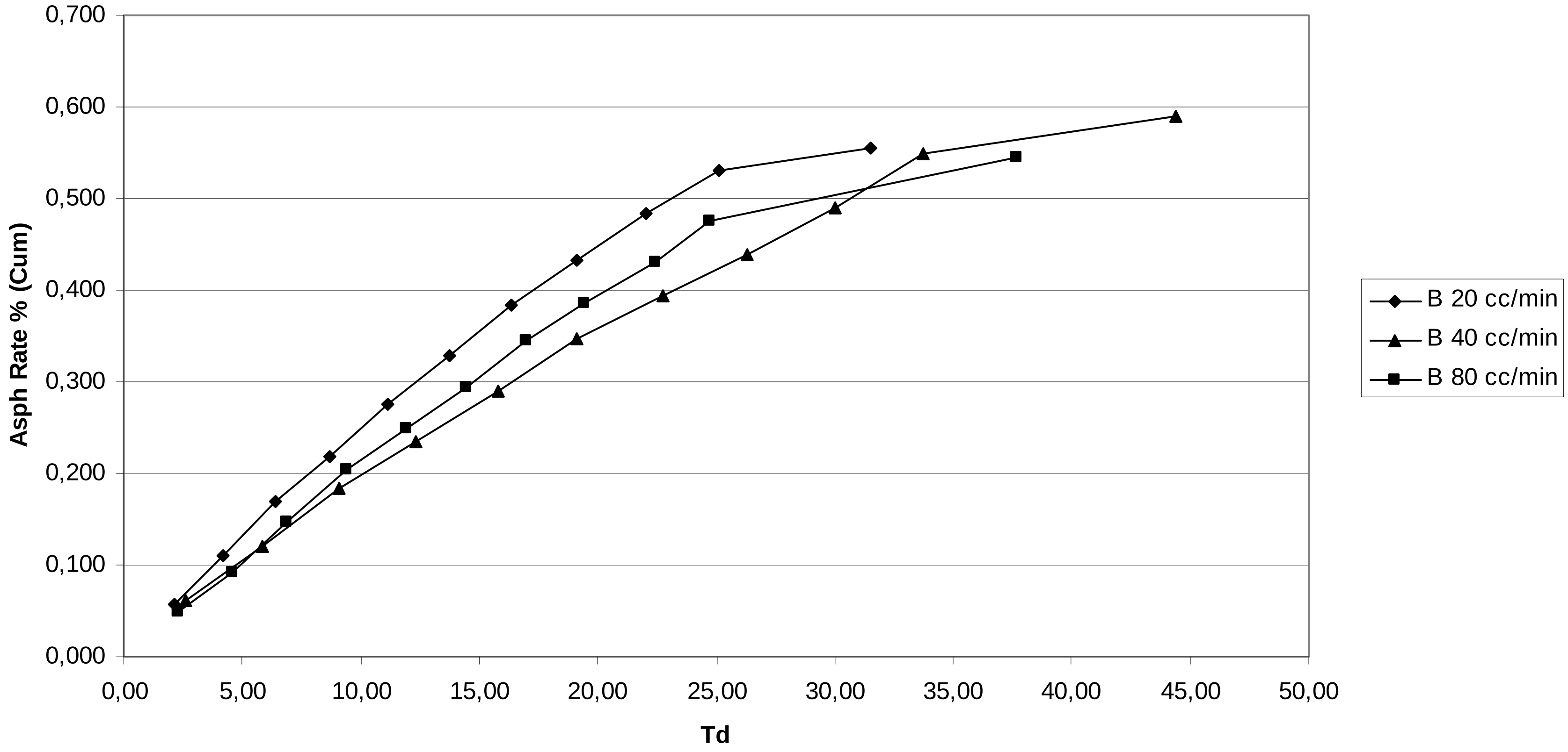


Fig B.16 Cumulative Asphaltene rate of Garzan Oil with 3 different Butane rates

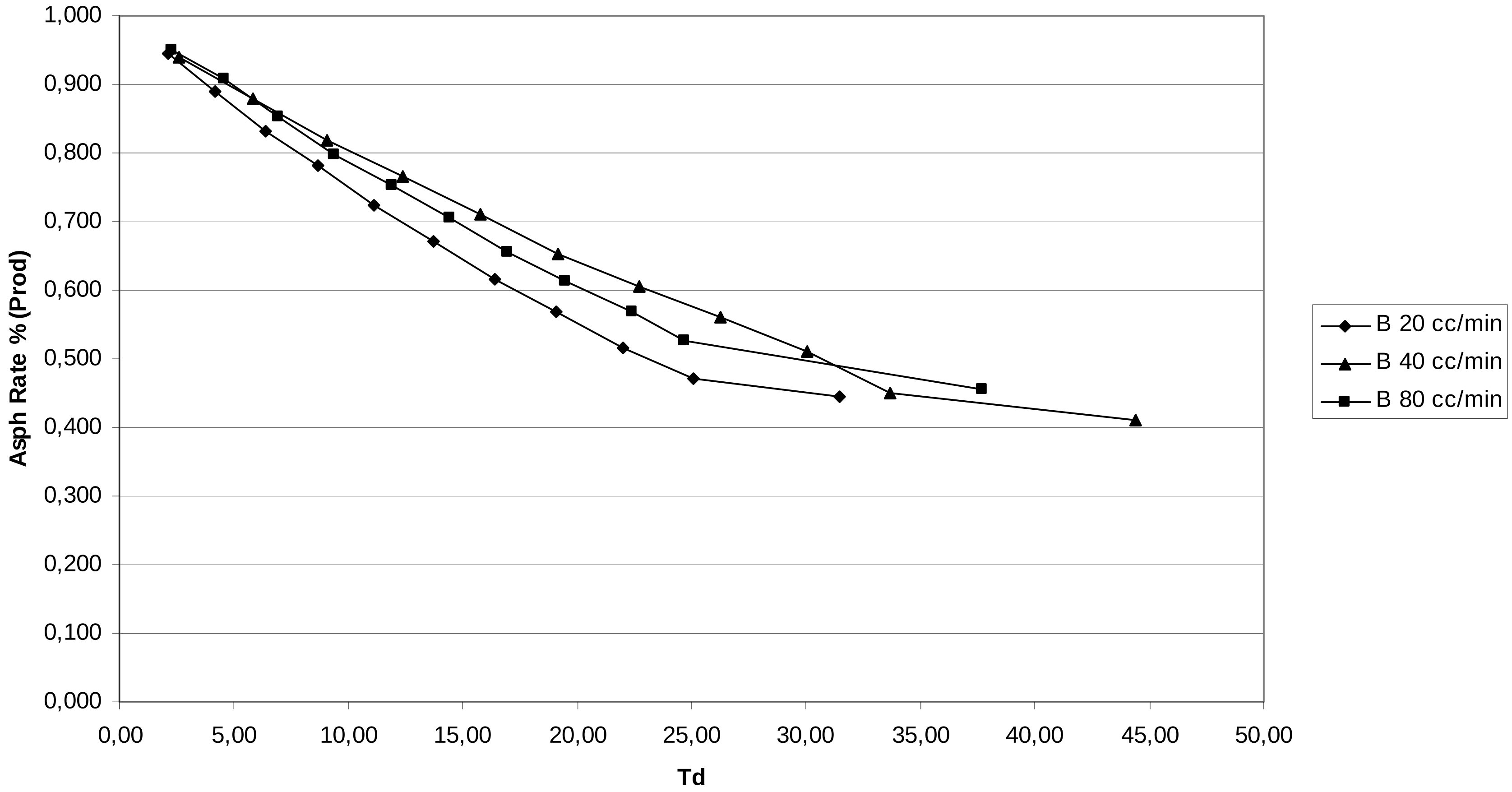


Fig B.17 Produced Asphaltene rate of Garzan Oil with 3 different Butane rates

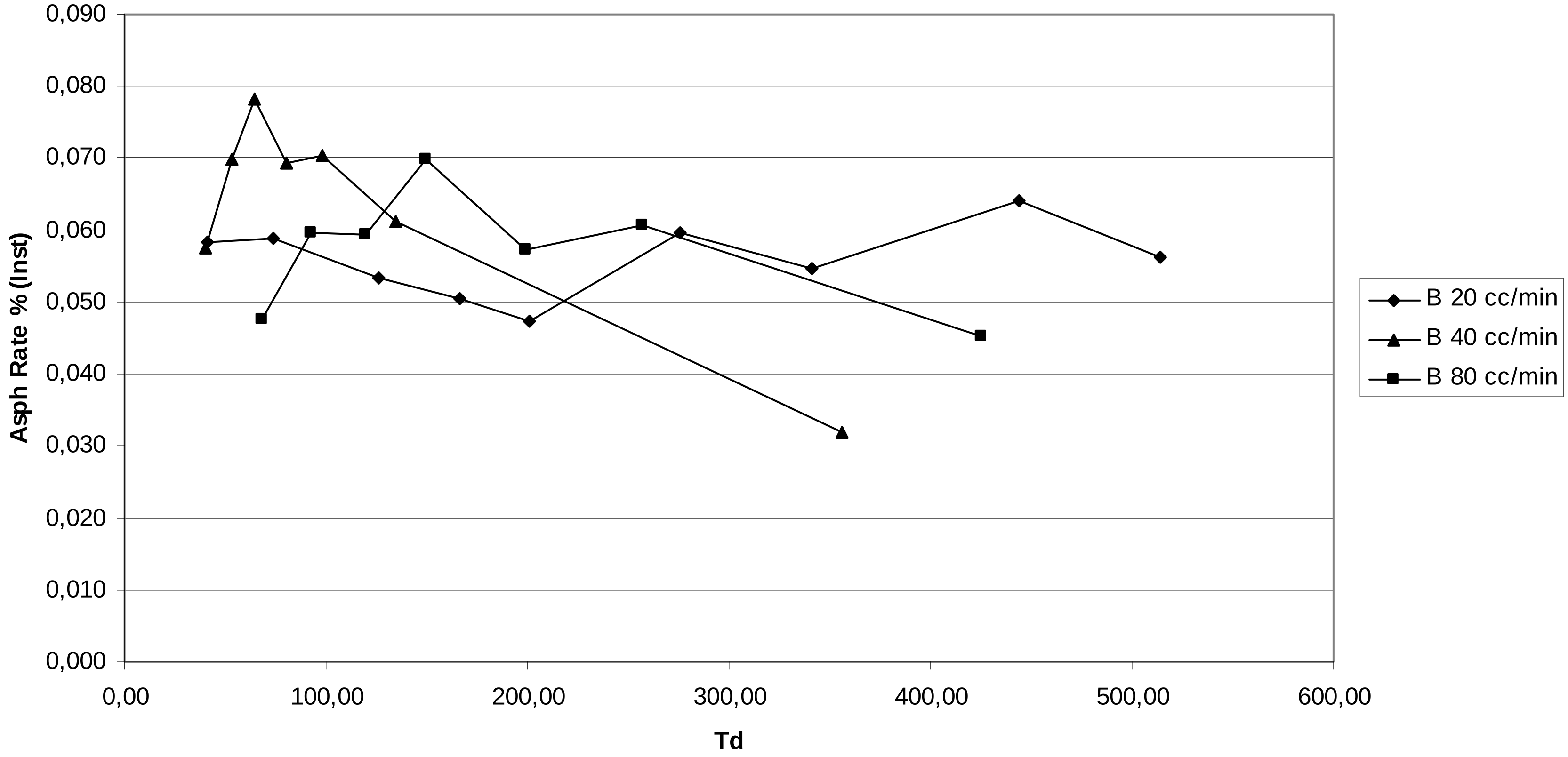


Fig B.18 Instantaneous Asphaltene rate of B.Raman Oil with 3 different Butane rates

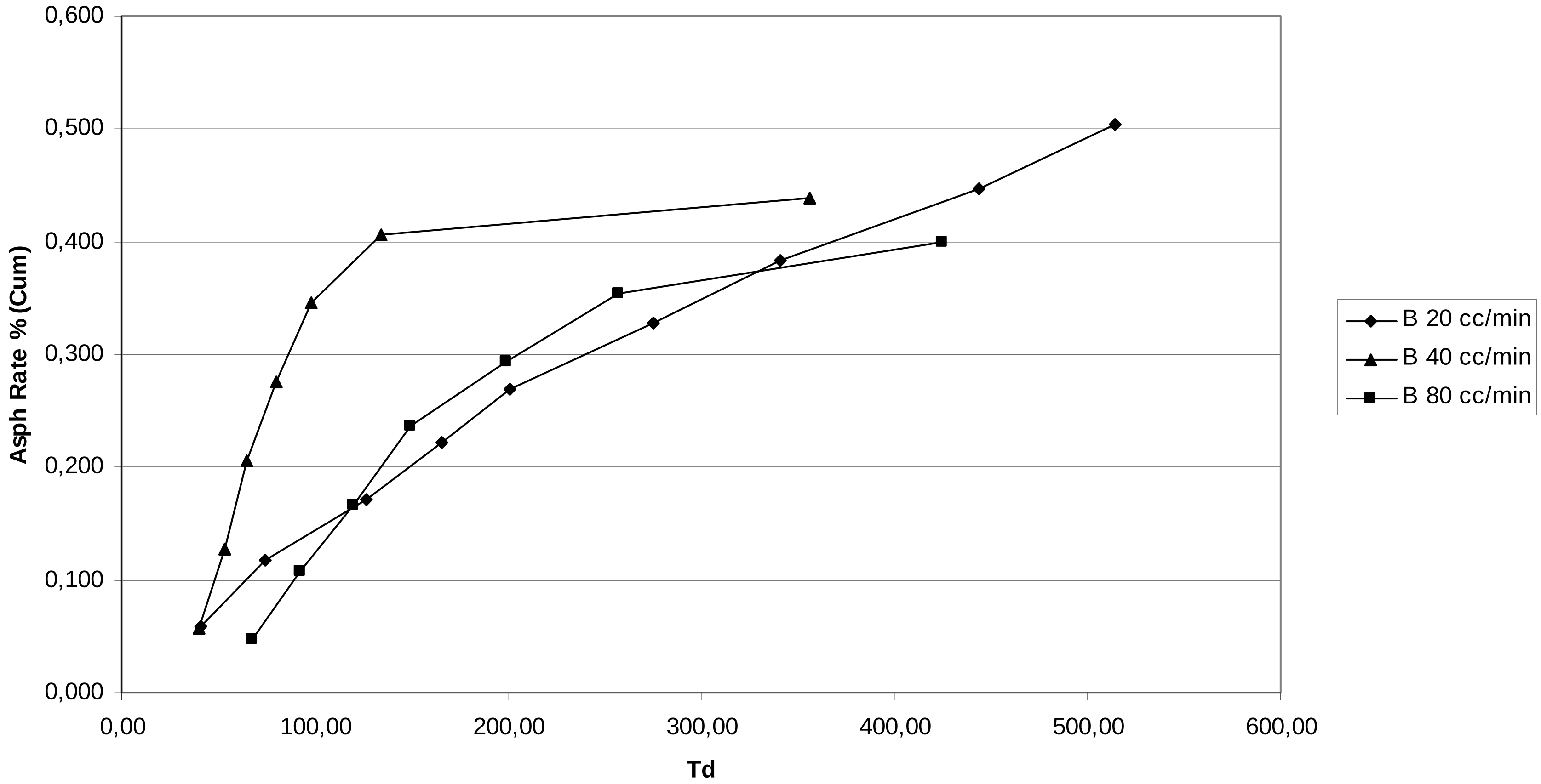


Fig B.19 Cumulative Asphaltene rate of B.Raman Oil with 3 different Butane rates

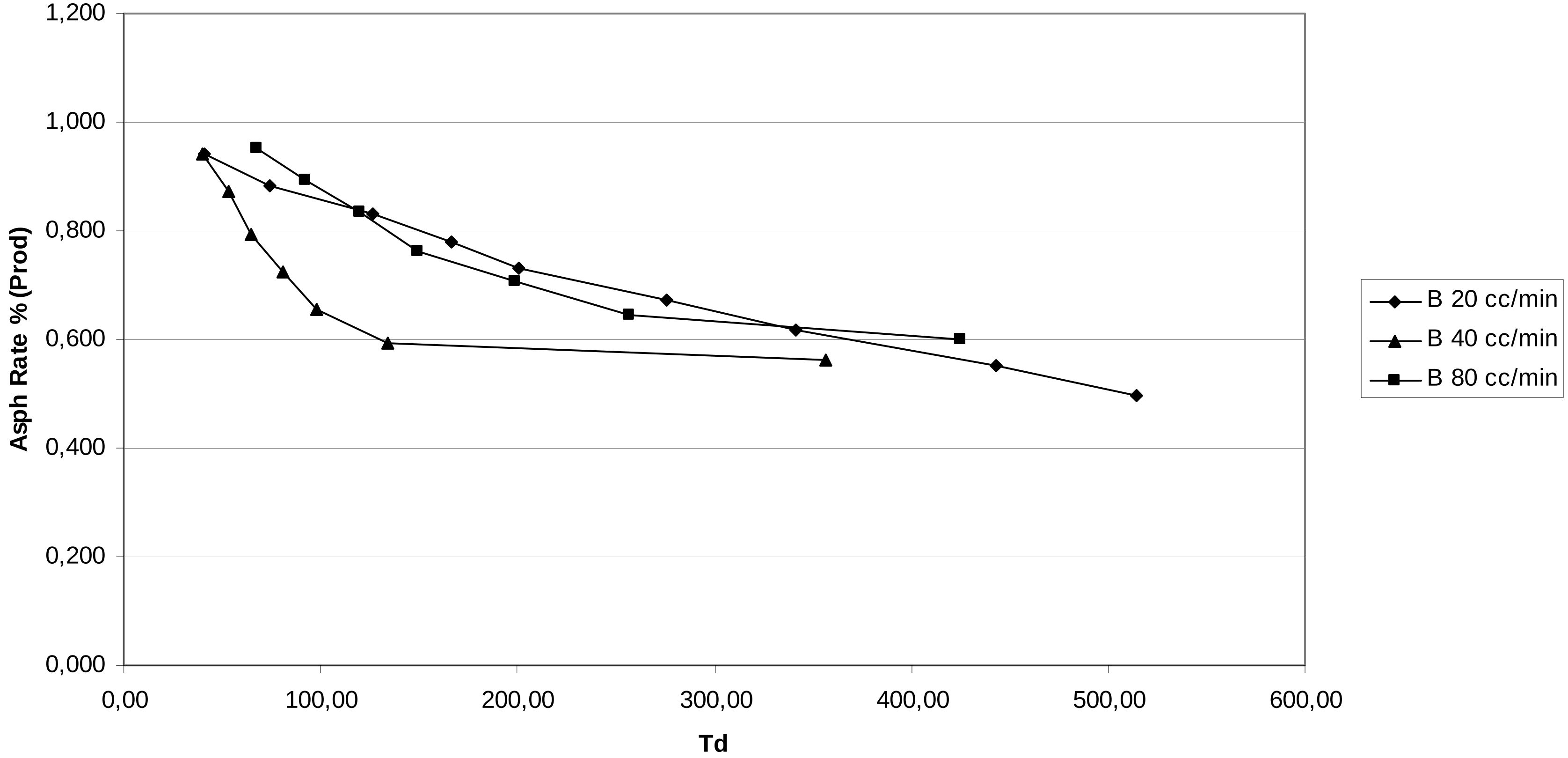


Fig B.20 Produced Asphaltene rate of B.Raman Oil with 3 different Butane rates

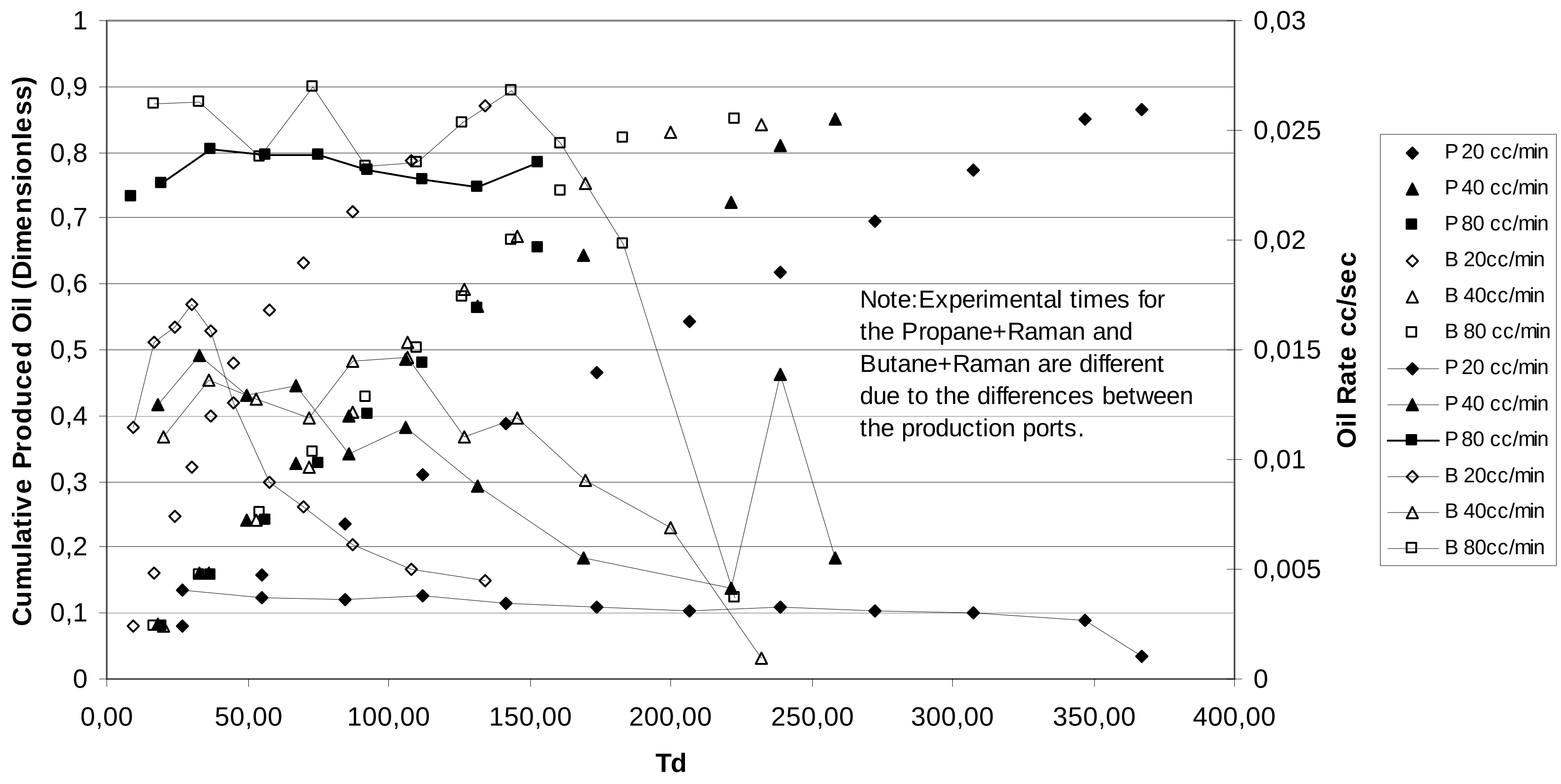


Fig B.21 Cumulative Produced Oil + Oil Rate for Raman Oil (Propane vs. Butane)

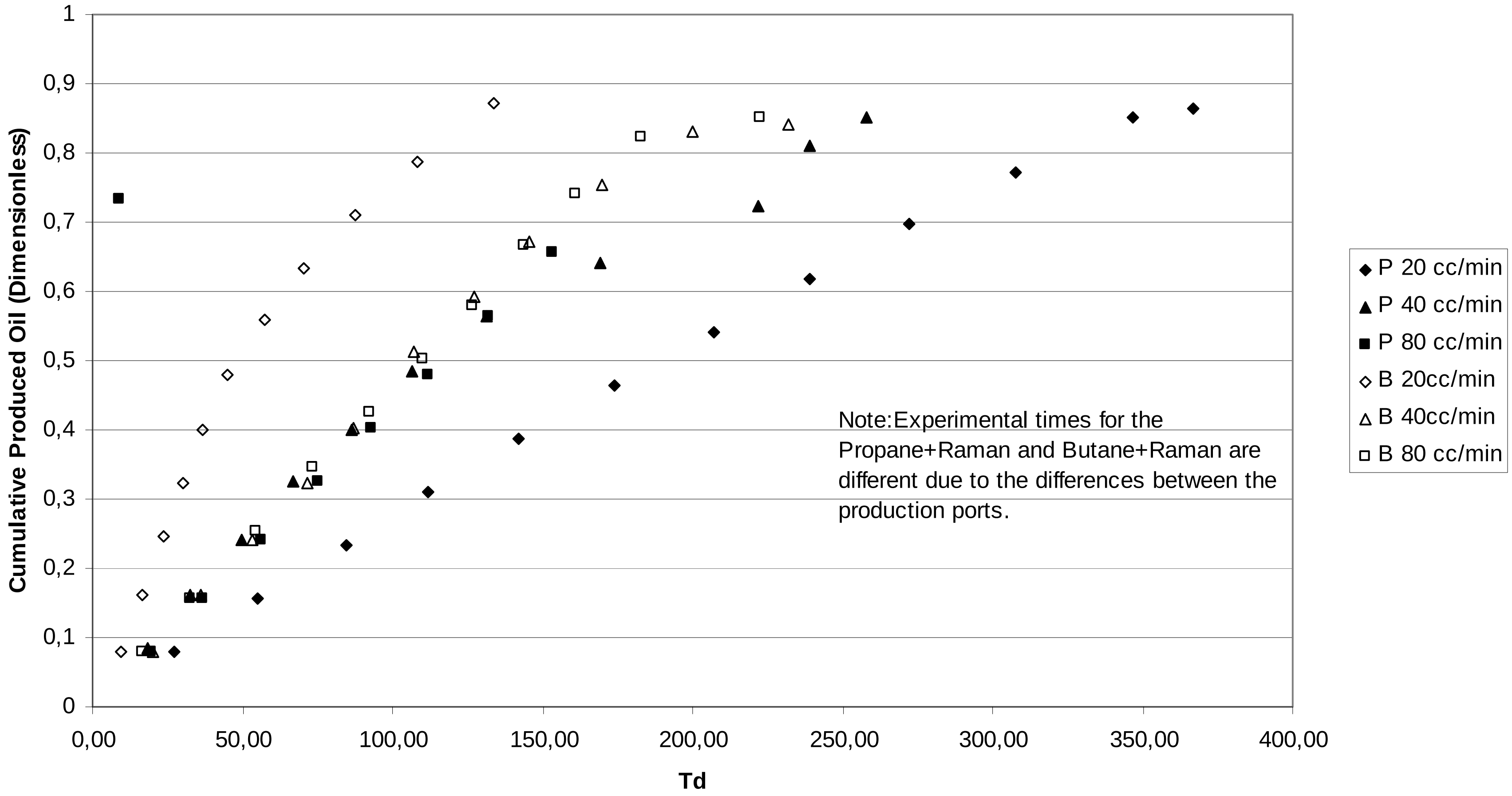


Fig B.22 Cumulative Produced Oil for Raman Oil (Propane vs. Butane)

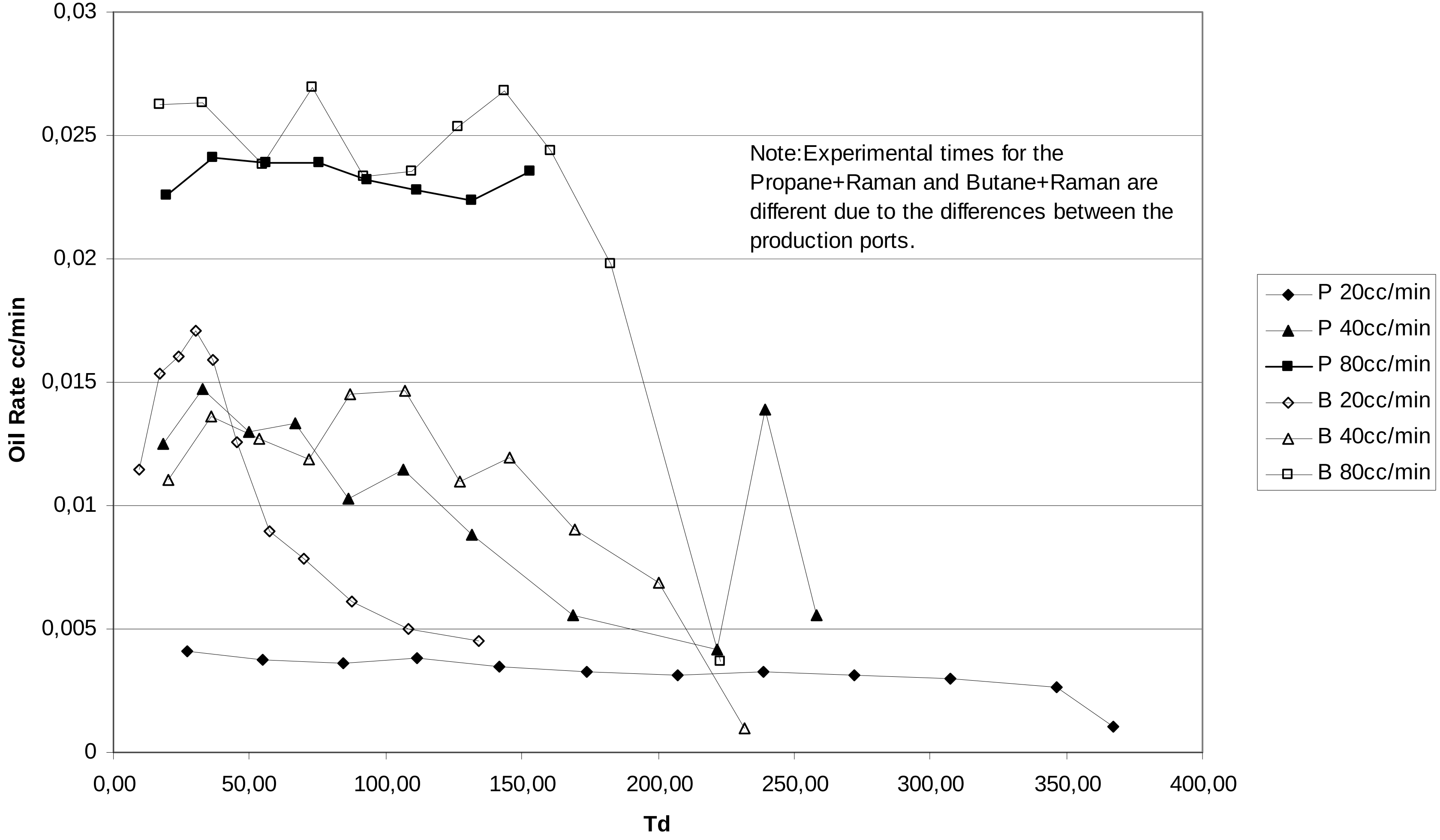


Fig B.23 Oil Rate for Raman Oil (Propane vs. Butane)

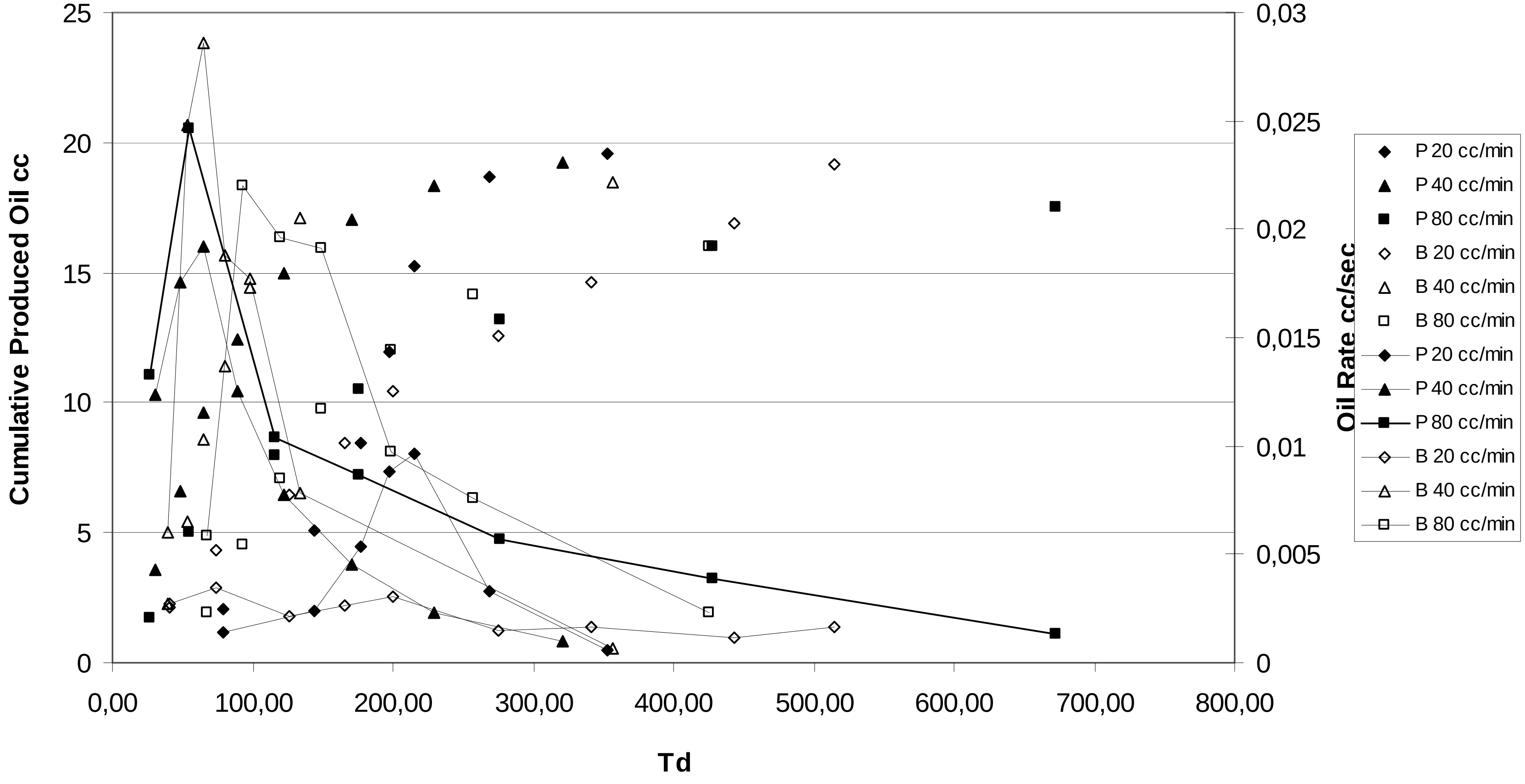


Fig B.24 Cumulative Produced Oil + Oil Rate for B.Raman Oil (Propane vs. Butane)

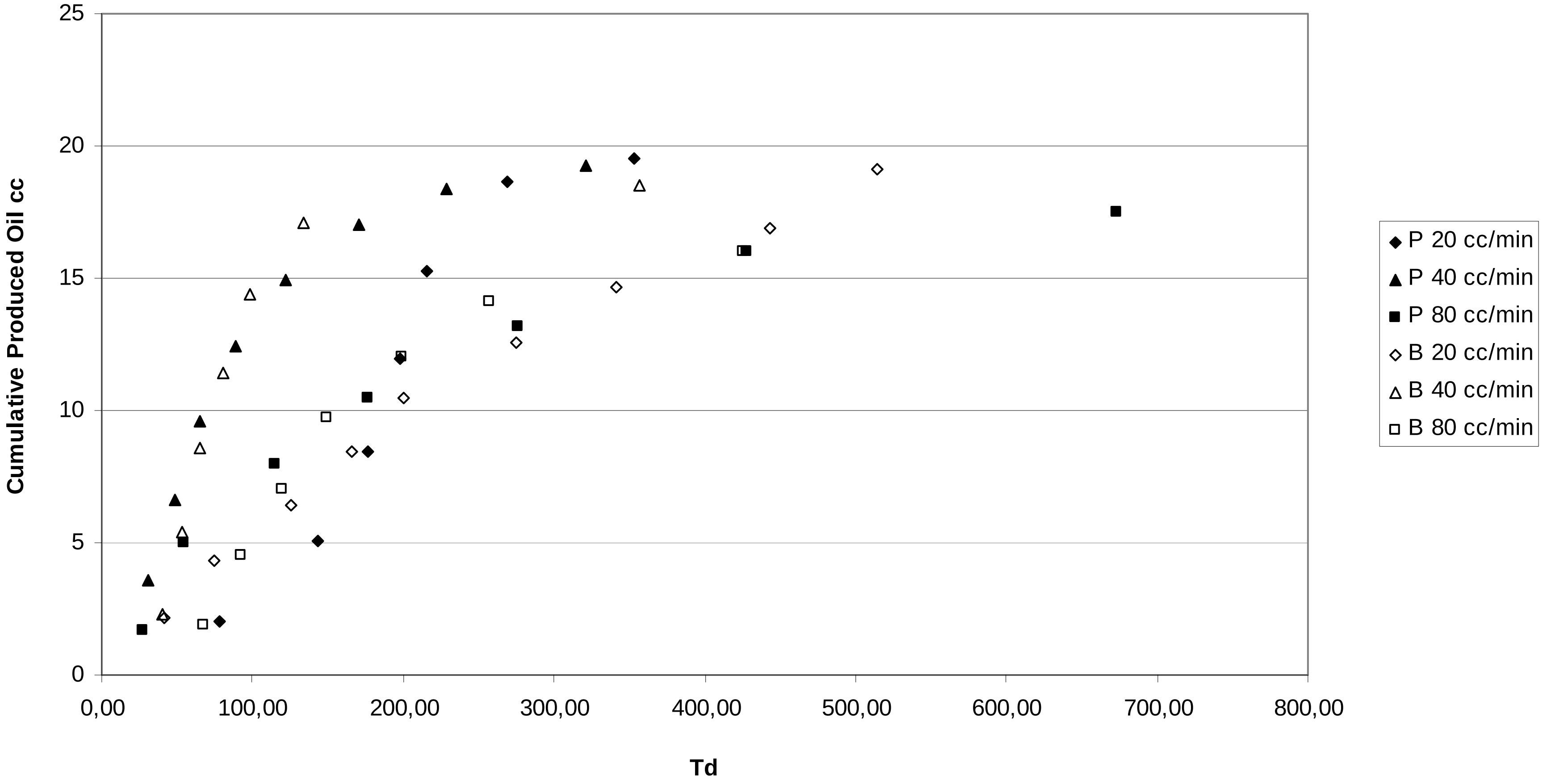


Fig B.25 Cumulative Produced Oil for B.Raman Oil (Propane vs. Butane)

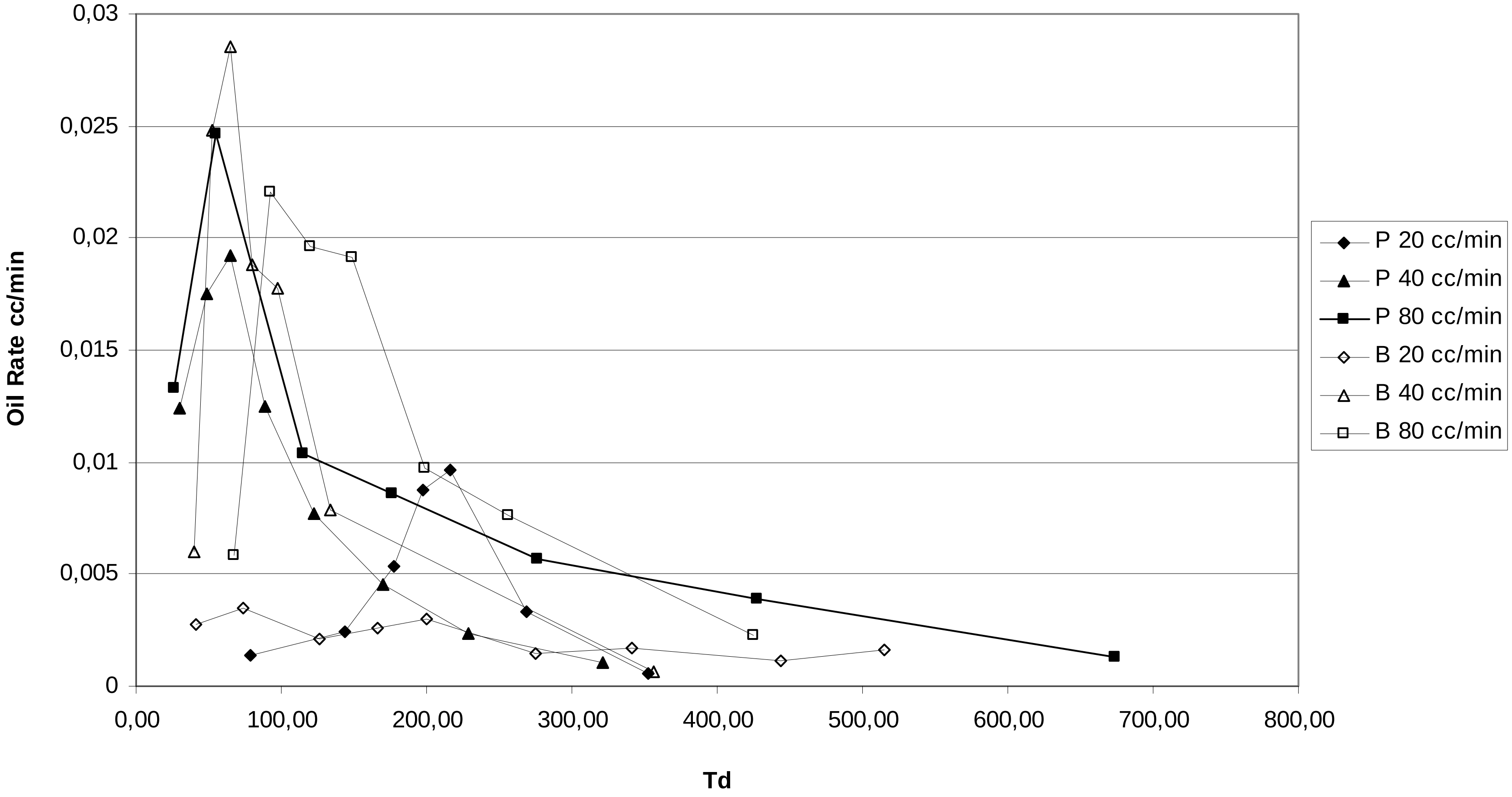


Fig B.26 Oil Rate for B.Raman Oil (Propane vs. Butane)

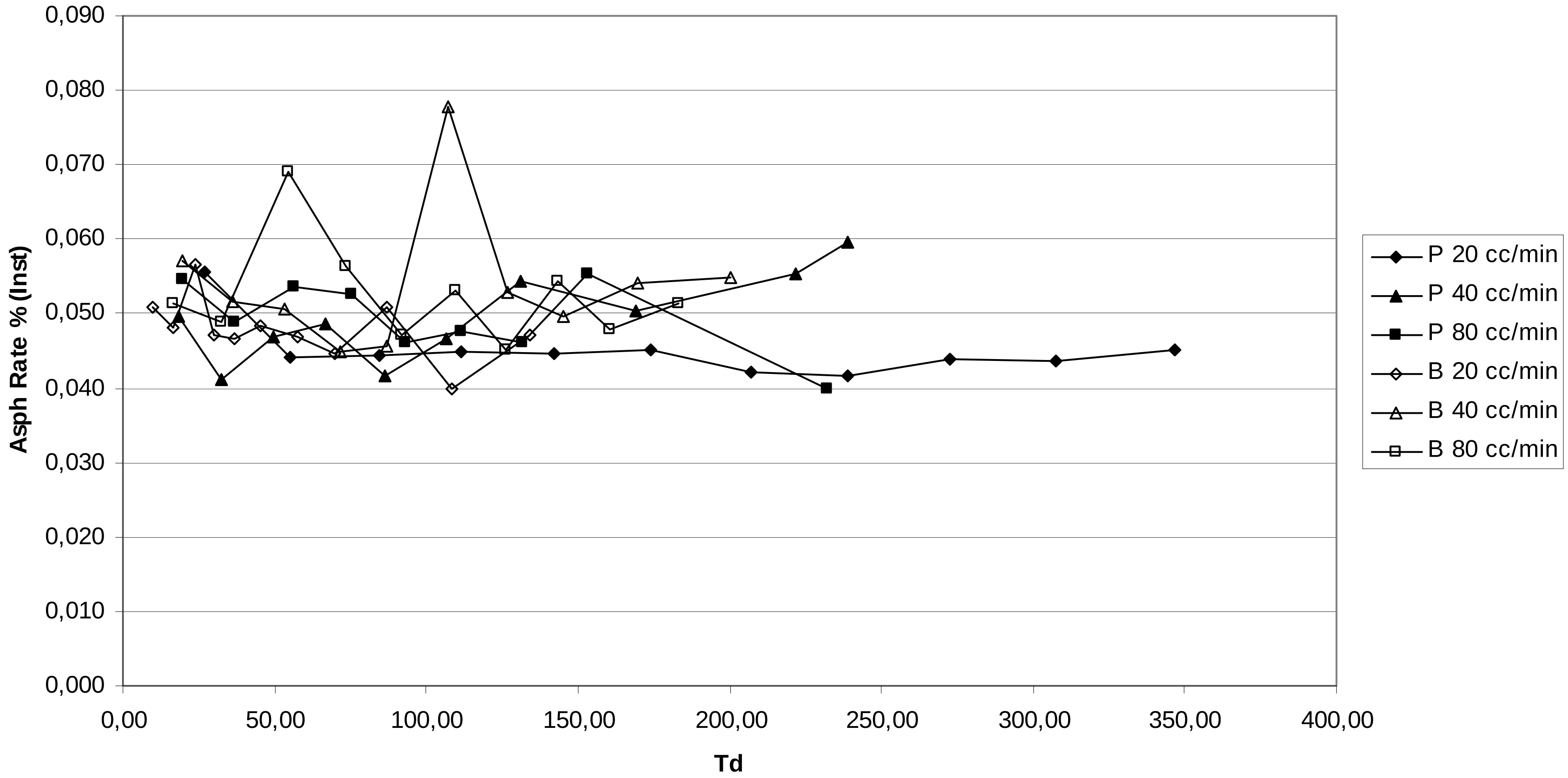


Fig B.27 Instantaneous Asphaltene rate of Raman Oil (Propane vs. Butane)

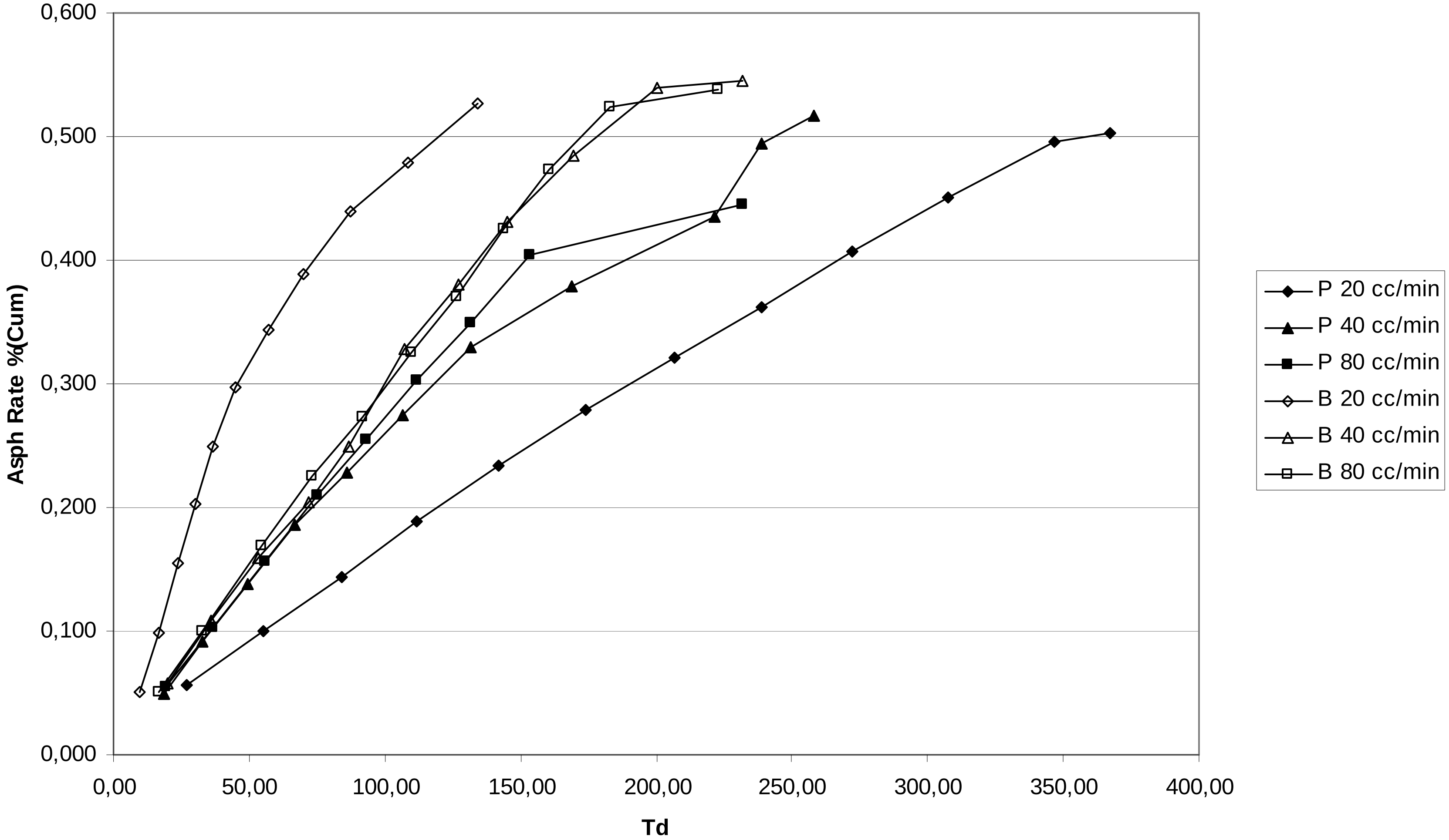


Fig B.28 Cumulative Asphaltene rate of Raman Oil (Propane vs. Butane)

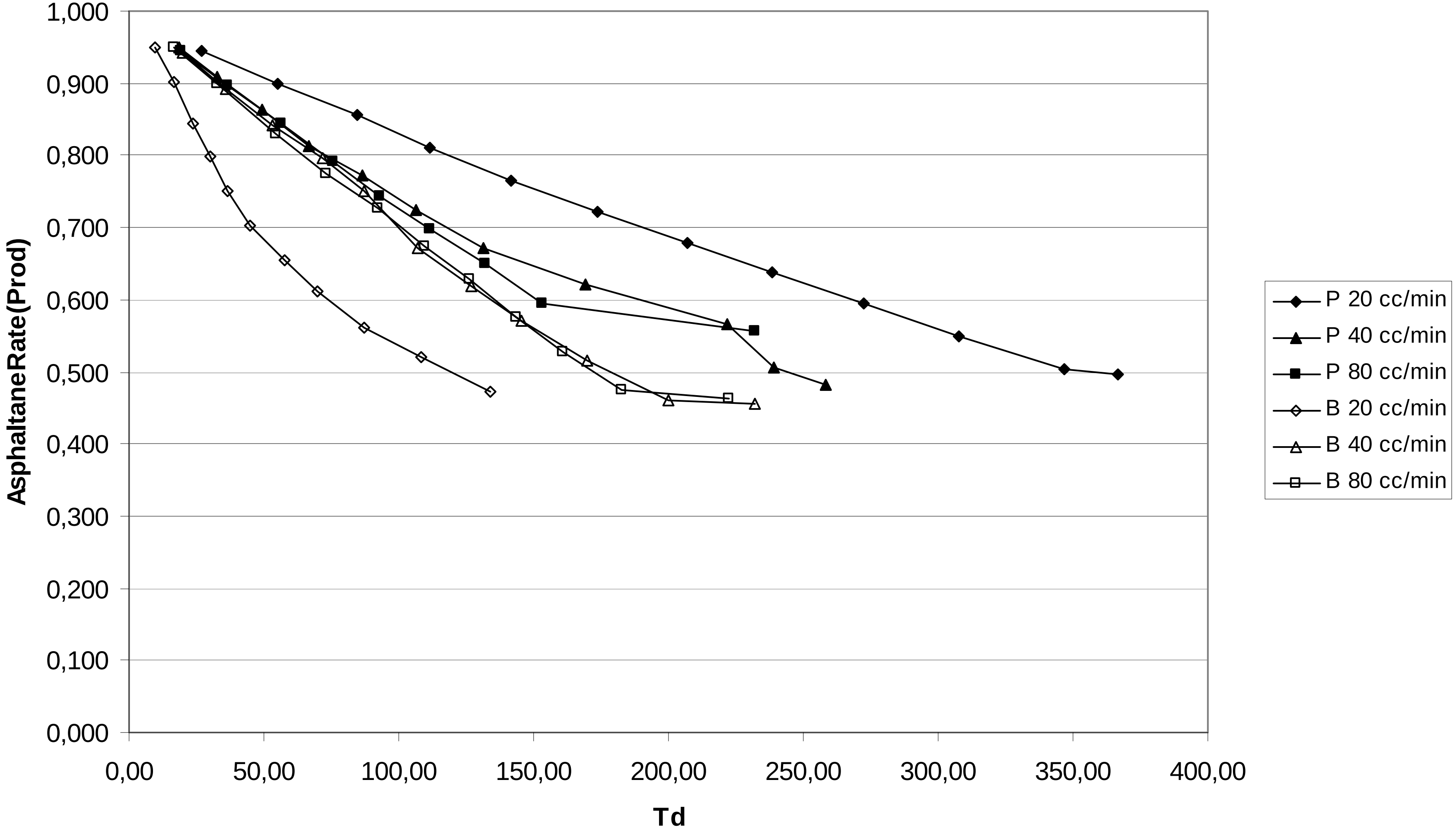


Fig B.29 Produced Asphaltene rate of Raman Oil (Propane vs. Butane)

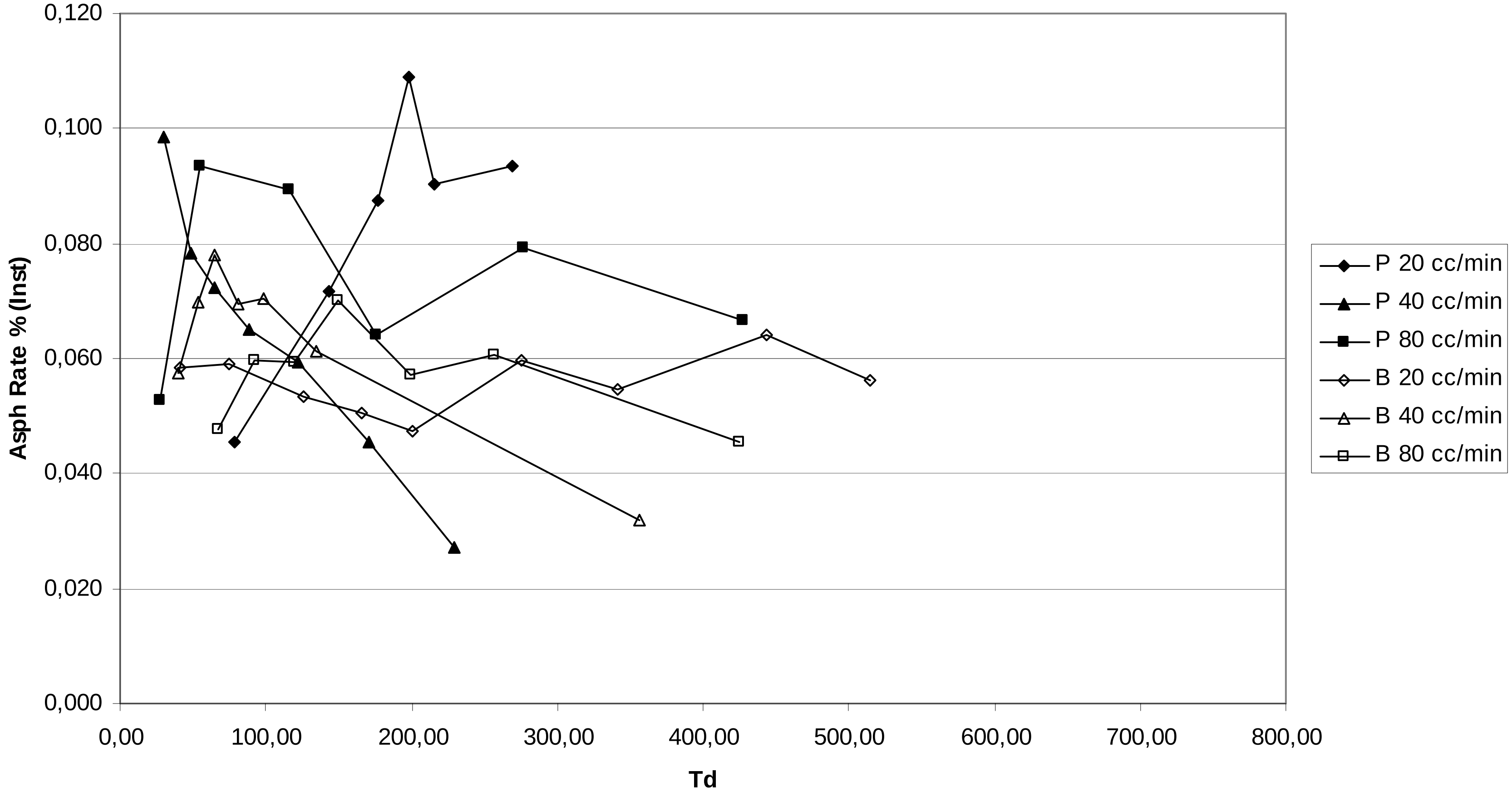


Fig B.30 Instantaneous Asphaltene rate of B.Raman Oil (Propane vs. Butane)

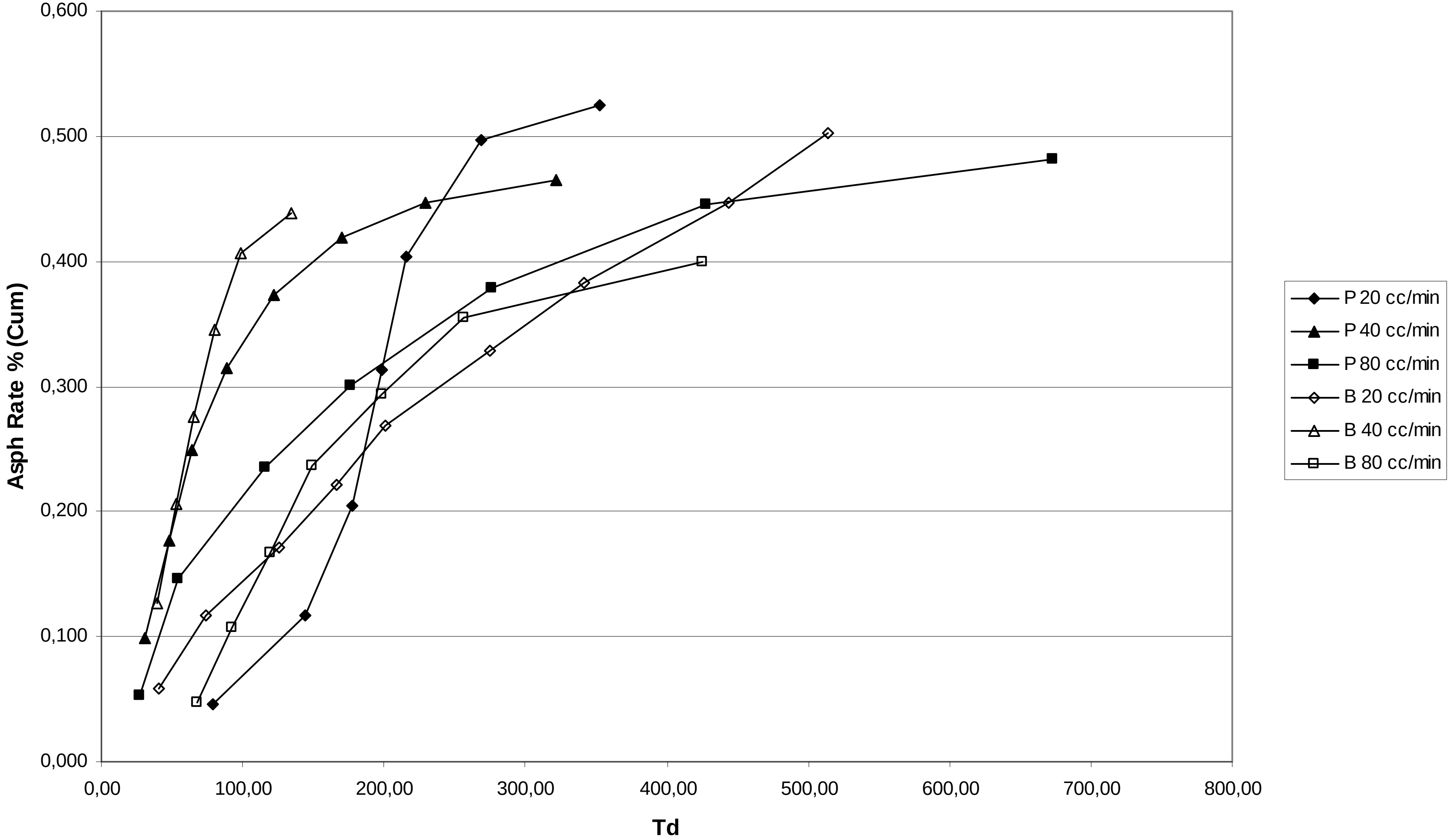


Fig B.31 Cumulative Asphaltene rate of B.Raman Oil (Propane vs. Butane)

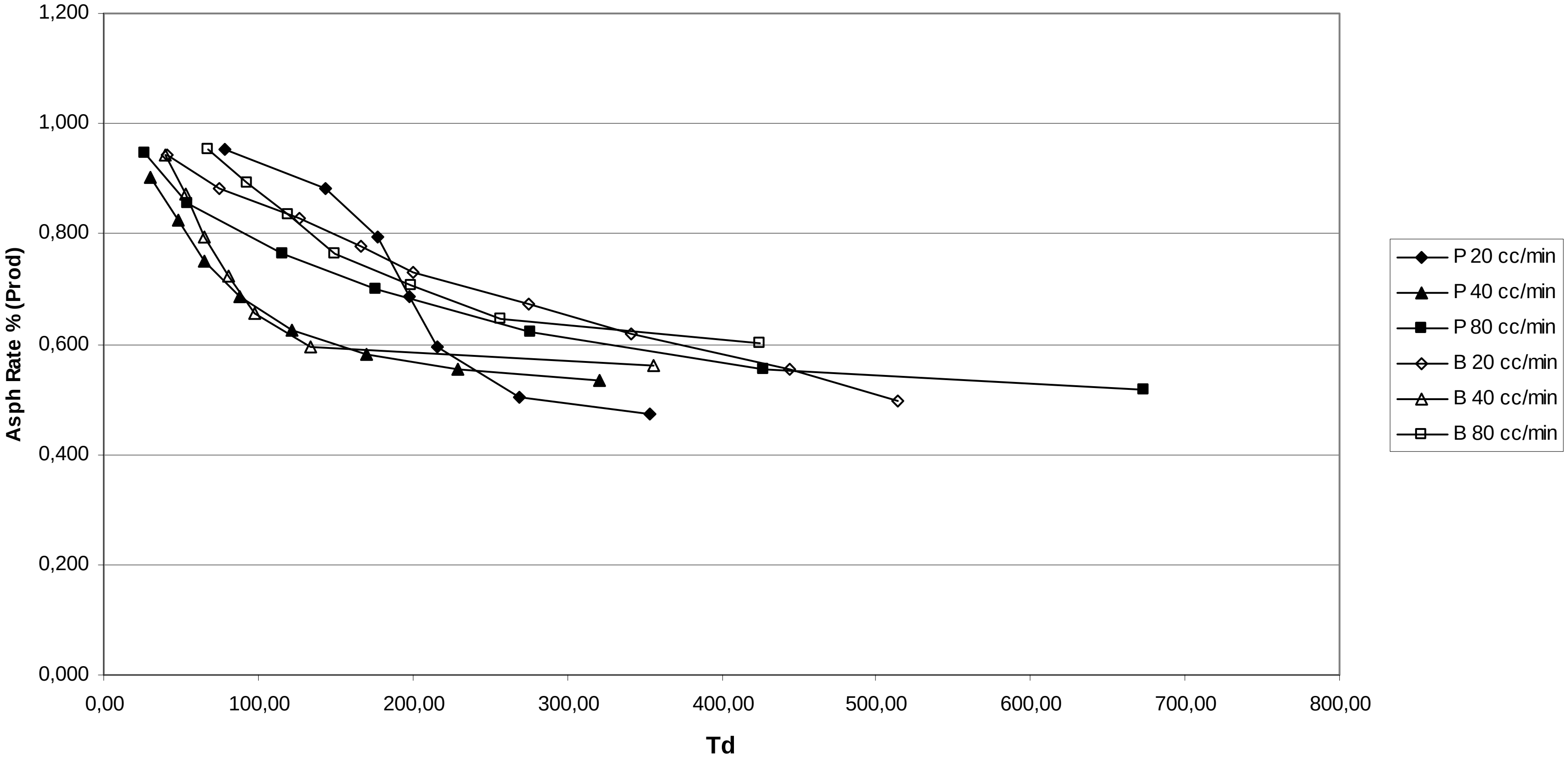


Fig B.32 Produced Asphaltene rate of B.Raman Oil (Propane vs. Butane)

APPENDIX C

EXPERIMENTAL VIDEO IMAGES

This appendix will cover the some other experimental video screen shots taken during the experiments.

1st bottle

2nd bottle

3rd bottle

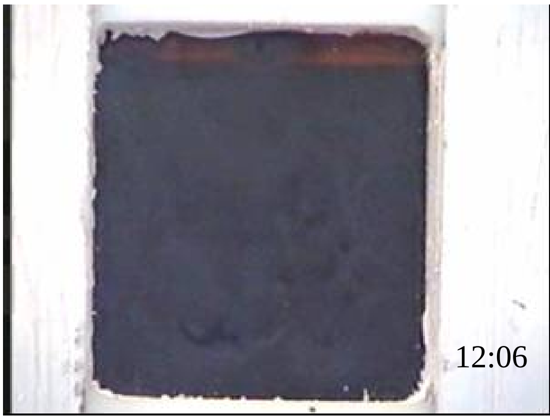
4th bottle

5th bottle

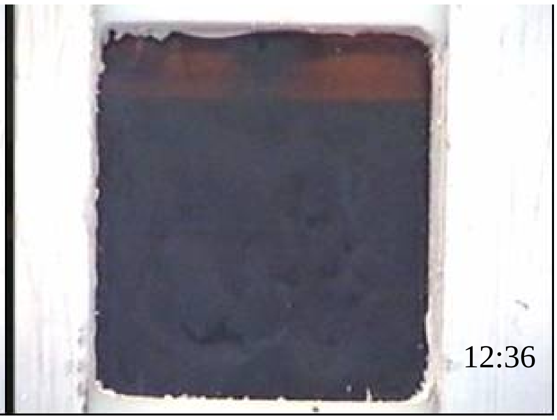
6th bottle

Fig C.1 Video Images form Experiment 10 (Garzan Oil + Butane 20 ml/min)

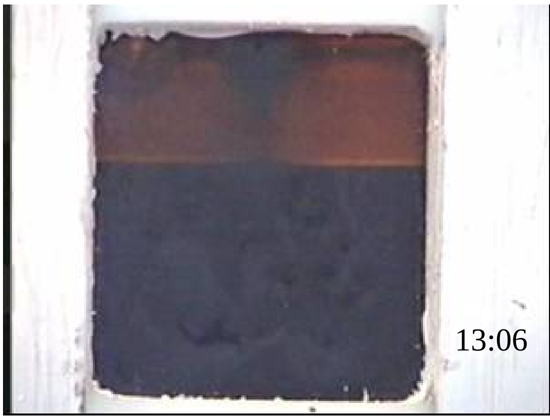
1st.bottle



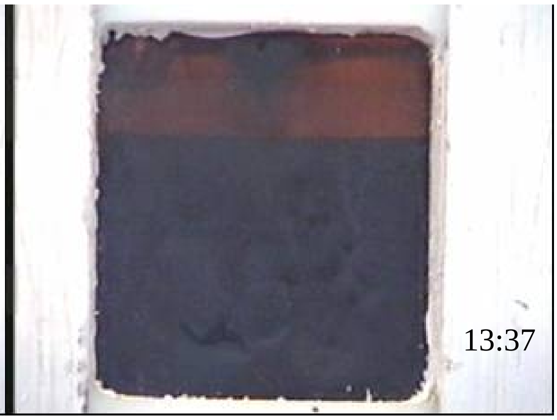
2nd bottle



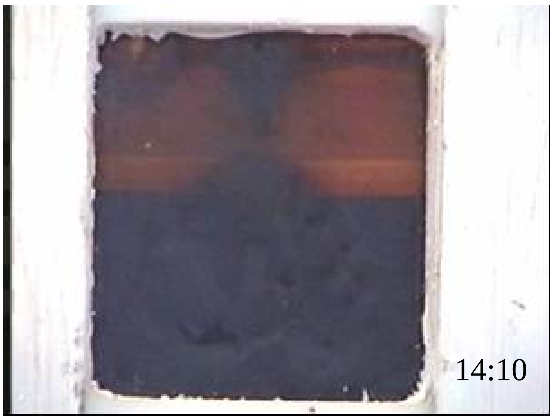
3rd bottle



4th bottle



5th bottle



6th bottle

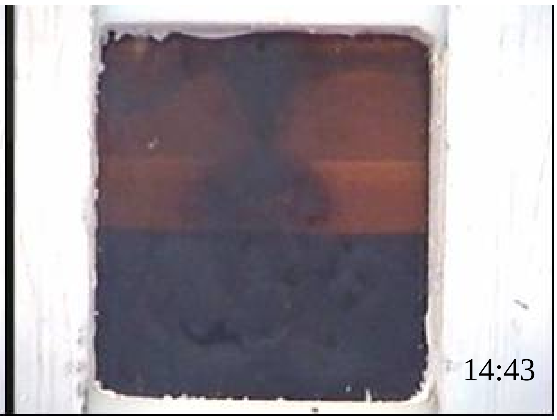


Fig C.2 Video Images form Experiment 11 (Garzan Oil + Butane 40 ml/min)

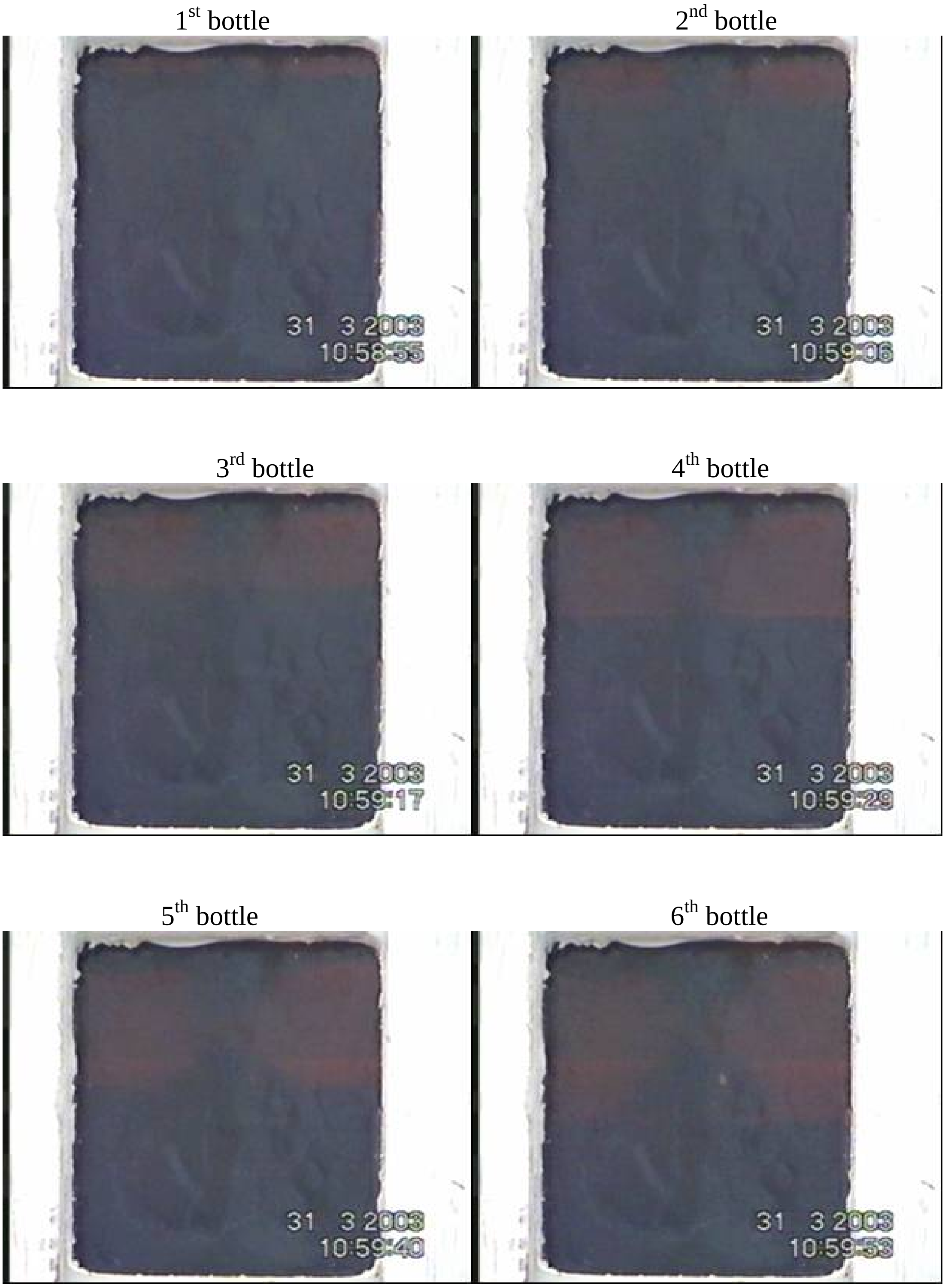


Fig C.3 Video Images form Experiment 12 (Garzan Oil + Butane 80 ml/min)

1st bottle

2nd bottle

3rd bottle

4th bottle

5th bottle

6th bottle

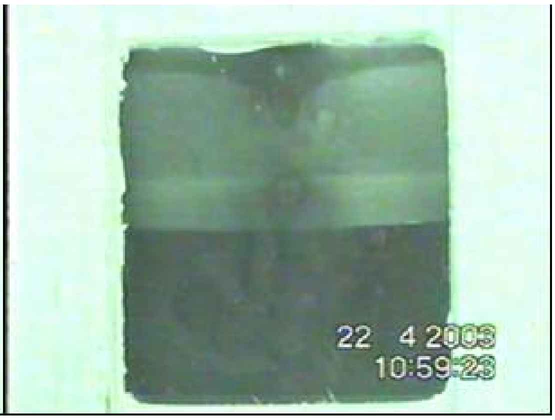


Fig C.4 Video Images form Experiment 20 (Garzan Oil + Butane 40 ml/min + steam)