ÅBO AKADEMI UNIVERSITY

AQUEOUS-PHASE REFORMING OF RENEWABLES FOR HYDROGEN PRODUCTION

Laboratory of Industrial Chemistry and Reaction Engineering

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Preface

This thesis is the final work of my Bachelor study at the University of Valladolid, Spain. The work has been carried out at Åbo Akademi University, Turku, Finland, from September 2017 to May 2018 as a part of the Erasmus exchange student program.

This academic year has been a fulfilling experience not only in the academic part but also in a personal way, learning how to live by oneself.

In the first place, I wish to express my sincere thanks to Professor Tapio Salmi, Dean of the Faculty of Science and Engineering, Professor Dmitry Murzin and Professor Henrik Grenman for giving me the opportunity to do this research at Laboratory of Industrial Chemistry and Reaction Engineering and providing me with all the facilities.

I would like also to express my gratitude to Kari Eränen for all help he has offered to me during this year.

I am also extremely thankful and indebt with my supervisor, Atte Aho, for sharing his expertise, guiding me through this valuable year of my life and for every help he has offered to me.

Finally, I also place on record, my sincere thanks to my parents, for the unceasing encouragement, attention and support from home.

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ABSTRACT

The present work studies the feasibility of selective hydrogen production from biomass derived sugar alcohols, through aqueous-phase reforming, in the presence of Pt supported on Al_2O_3 catalysts.

Aqueous-phase reforming (APR) is a catalytic transformation of biomass to produce hydrogen and light hydrocarbons. Carbon dioxide is also produced as a stoichiometric by-product.

The reaction occurs under elevated temperature and high pressure to maintain aqueous-phase conditions.

However, APR can be considered as an energy-efficient process, due to the fact that all reactants remain in the liquid phase during the reaction saving energy required for vaporization.

In order to investigate the main factors that affect conversion and selectivity in APR. Influences of reaction temperature and pressure, flow rates of inert gases, concentration and flow rates of reactants as well as catalysts particle size have been studied.

In the present work, aqueous-phase reforming of xylitol, xylose and formic acid was studied in the presence of platinum supported on alumina in a trickle bed reactor. Influence of the reaction conditions on conversion and selectivity was monitored.

1. INTRODUCTION

Because to the enormous energy consumption globally and recent concerns about fossil fuels, a necessity to develop new energy sources has arisen. Renewable energy sources have experienced a remarkable growth in the recent years. One of these sources is biomass, that is without any doubts one of the most outstanding energy sources.

Traditionally, our society and economy at large have been based on fossil fuels. In 2013, the 84% of the global energy came from such fuels. Due to the increased prices, first, uncommon fossil resources, as shale gas, seemed to be economically viable being however, a limited source and in some cases risky for human health.[1]

In April 2009, the European Union commission for renewables energies required that at least 20% of the total energy is produced with renewable sources by 2020[2, 3].

In November, 2016, a proposal was published by the EU commission in order to make the EU leader in renewable energy by ensuring a 27% renewable energy of the total production by 2030[3].

Biomass has emerged as a potentially renewable energy source with a small impact on the environment[4]. As it can be seen in Fig. 1 biomass is the renewable source with the highest consumption, currently and also in the future. The term "biomass" refers to every organic material that has accumulated energy through photosynthesis. Biomass energy is produced by living or once-living organisms.

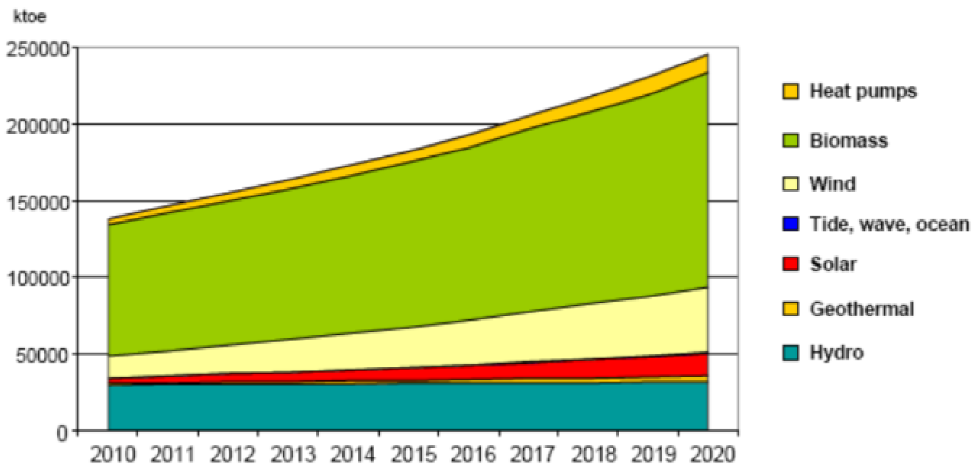


Fig. 1 Sources of renewable energy projected to 2020 in the EU

To the majority of people, the most familiar renewable energy is associated with solar and wind power. However, biomass is the oldest and most often used renewable energy.

This form of energy is considered to be renewable mainly due to two reasons. First, energy in it comes from the solar energy and second, because the time needed to grow biomass is negligible compared it with hundreds of millions of years required for formation of fossil fuels[5].

Because of photosynthesis, plants capture carbon dioxide and with the aid of solar power transform it into carbohydrates. When those carbohydrates are consumed to obtain energy, the carbon dioxide is released again[5].

Development of biomass as an energy reservoir is ecologically friendly and significant when it is related to the environment protection; taking into account that biomass is a carbon dioxide emission neutral fuel[6]. Furthermore, it is also interesting to discover new ways to obtain energy that will occur simultaneously with the ones existing now and in the future will substitute the obsolete ones.

In the recent years, interest in hydrogen has increased. Nowadays, there are many places in the world where this gas is used as a fuel in public transportation. The largest car companies are developing projects in which they include hydrogen as the only or a partial fuel for those cars. Hydrogen that comes from renewable resources is 100% clean fuel that only produces water in combustion, without formation of greenhouse gases[7, 8].

Biomass, as shown in Fig. 2 consist of cellulose, hemicellulose and lignin[9]:

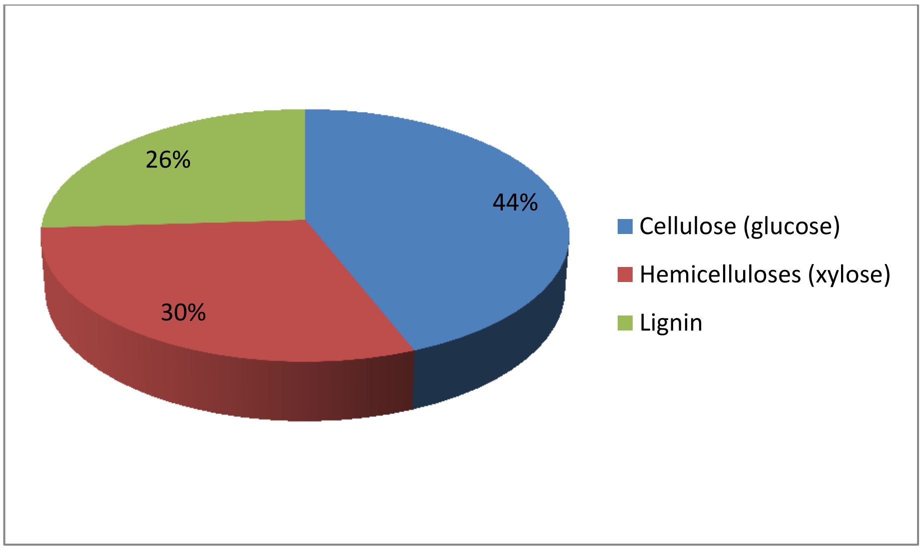


Fig. 2 Biomass composition

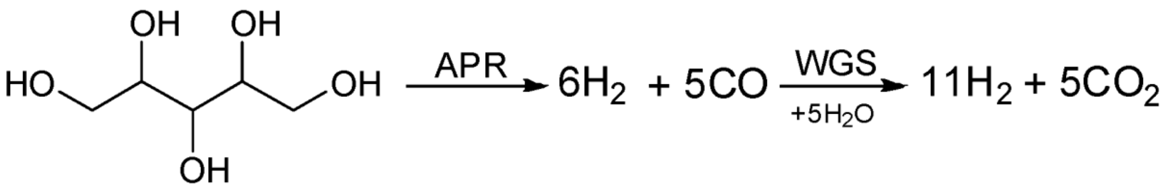
Because biomass can produce not only heat and power by combustion but also liquid and gas fuels it is considered to be one of the most efficient renewable feedstock[10].

The most relevant processes to convert biomass are shortly described below. They can be divided in two groups, thermochemical and biochemical process[11].

Thermochemical processes in term can be subdivided:

- Pyrolysis: thermal decomposition in absence of oxygen resulting in liquid, solid and gaseous products and fuels.
- Combustion: a way to use biomass directly as fuel, burning it in air excess to produce heat and power.
- Gasification: process used to obtain synthesis gas (syngas). The main application of this gas is for electricity generation. Other usage is related to production of synthetic petroleum via the Fischer-Tropsch process.

It is relevant to point out that these processes to treat biomass require a large amount of energy[12]. Aqueous-phase reforming is also a way to manage biomass residues and produce fuels. Glucose can be produce from cellulose (Fig. 2) and subsequently hydrogenated[13]. One type of hemicelluloses are xylans, Which are monomers of xylose. Hydrogenation of xylose gives xylitol with more than 99% of conversion and selectivity[14].



Xylitol

Fig. 3 Aqueous-phase reforming of xylitol

As it can be seen in Fig. 3 one molecule of xylitol gives in the first reaction, six hydrogen and five carbon monoxide molecules. Carbon monoxide reacts further with excess water resulting in additional hydrogen and also carbon dioxide[15]. Besides hydrogen and carbon dioxide as major products, some hydrocarbons are also produced. It has been previously shown that platinum has the highest catalytic activity and selectivity to hydrogen in APR.

The reaction shown in Fig. 3 is performed in a tubular reactor in the presence of acatalyst, e.g. platinum on alumina at different temperatures (170-235 ºC) and pressures (14-30 bar).

2. AIMS OF THIS PROJECT

Industrially, the most important process to produce hydrogen is steam reforming of natural gas or hydrocarbons.

The aims of the present project are to study an alternative to steam reforming, namely aqueous-phase reforming of xylitol.

In particular, the current work comprises:

- Study the reduction temperature
- Determination of the activation energy in xylitol APR.
- Determination of the optimal APR reaction conditions to hydrogen and carbon dioxide production such as:
    - Temperature
    - Pressure
    - Reactant liquid flow
    - Inert gas flow
    - Catalyst properties

3. EXPERIMENTAL PART

4.1 Reaction equipment

In the present study, a fixed-bed tubular reactor (length 50 cm, diameter 4.2 mm) was placed in an oven. The temperature was monitored by two K-type thermocouples, one measuring and controlling the oven and the other one measuring the reactor temperature.

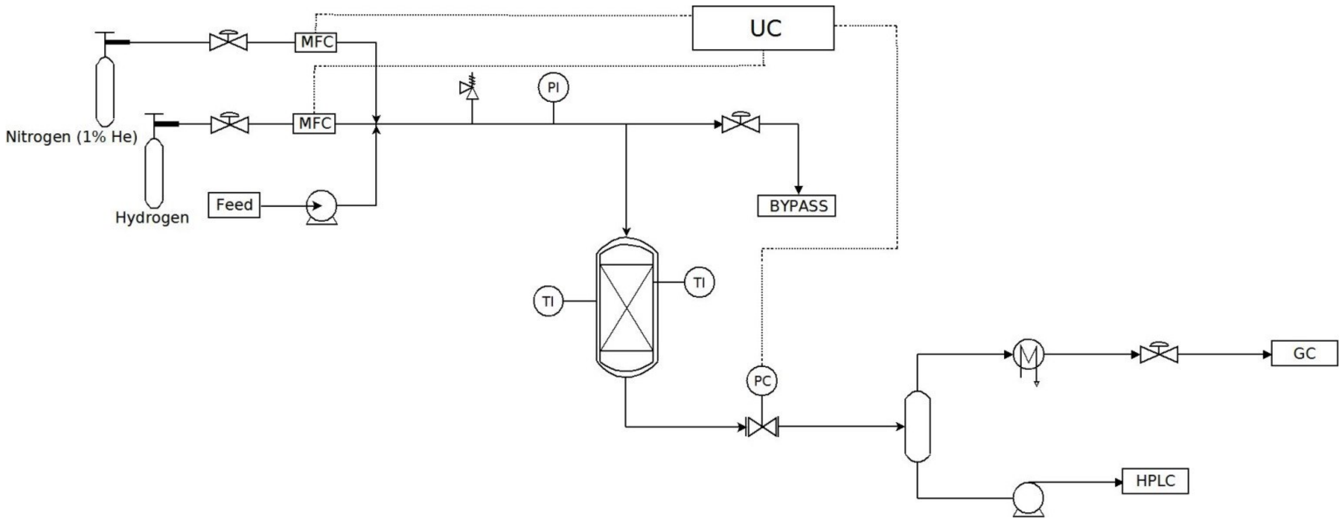


Fig. 4 Reaction set-up

As it can be seen from Fig. 4, two gas lines were connected to the set-up: the inert; 99% of nitrogen and 1% of helium, used as an internal standard and hydrogen for the catalyst reduction. The sugar alcohol solution was fed with an HPLC pump.

The reaction pressure was kept constant by a back membrane pressure regulator (EQUILBAR) placed downstream of the reactor, using argon, to control the pressure. A pressure indicator and a safety valve were placed at the inlet of the reactor.

A mass flow controller (Brooks Instrumental, 5850S) was used to set up the flows for all gases and pressure inside the reactor.

Downstream the pressure controller, a 25 mL liquid-gas phase separator was placed. The gases pass through a cooler to condensate all the vapors that can exist after the reactor and then to micro GC. The liquid phase is periodically collected in 2 mL vials and analyzed by HPLC. Both pieces of equipment are shortly described below.

4.2 Catalyst

The catalyst used was commercial 1% Pt/Al_2O_3 in the form of pellets (Aldrich-Chemistry). Catalyst performance has been studied with or without reduction. Reduction was carried out at 250 ºC for 2h in a flow of hydrogen under atmospheric pressure.

The effect of the catalyst particle size was also studied using particles between 350 and 500 μm and 3.2 mm pellets. Application of pellets is justified by the egg-shell Pt distribution. To complete the filling of the reactor, glass beads of 425-600 μm has been utilized.

4.3 Chemicals

The substrates studied in the present work are xylitol (99,9%), formic acid (98%) and xylose (99%). Supplier for all chemicals is Sigma-Aldrich.

Nitrogen and helium were used as an internal standard, hydrogen was applied for the reduction and argon was used for the pressure controller.

Three different mixtures have been used to calibrate the gas chromatograph. The composition of the calibration gases are:

- Standard 1: methane (1%), ethane (1%), propane (1%), iso-butane (1%) and n-butane (1%). The balance gas helium.
- Standard 3: methane (3%), carbon monoxide (12%), carbon dioxide (15%), hydrogen (12%). The balance gas nitrogen.
- Standard 5: n-heptane (500 ppm), n-hexane (500 ppmm), cyclo-hexane (400 ppmm), 2-methyl pentane (300 ppm), n-pentane (500 ppm), iso-pentane (300 ppm), 2,2-dimethyl propane (400 ppm) and helium as a balance.

4.4 Analysis equipment

The gaseous products were analyzed periodically with a gas chromatograph (Agilent Micro GC 3000A) equipped with four columns: Plot-U, OV-1, alumina and molecular sieve. The method used in GC consisted in an injection at 100 ºC to each column at 2.1, 2.8, 2.8 and 2.765 bar respectively. Each analysis had duration of 2 minutes. The micro GC was calibrated with the gases described above to be able to calculate the production of H_2, N_2, CO, CO_2 and several other hydrocarbons C_1-C_7 using He as internal standard.

Liquid samples were collected in 2mL vials, each hour or half an hour and then analyzed by HPLC. Duration of each analysis was 1h at 75 bar with an eluent of 5mM of sulfuric acid and an injection of 2μL in a Aminex HPX-87H column.

4.5 Calculation

Calculation of conversion was based on the peak area obtained from HPLC. In the cases of xylitol as a feed, this was calculated as follows:

$$\chi(\%) = \left(1 - \frac{A_x}{A_0}\right) * 100\% \ [1]$$

Where A_x is the area for the current sample, A_0 is the area for the zero sample (sample taken from the feeding vessel) and X is conversion-

When xylitol and formic acid were used as a feed, one more equation was needed due to the fact that the areas in HPLC results depend on the concentration. If the amount of formic acid decreases in the reaction, the xylitol peak in a sample could be higher than the zero sample, requiring re-calculation of the percentage for the current sample. For that, the calibration, given in Fig 5 where HPLC results for different formic acid concentrations are presented:

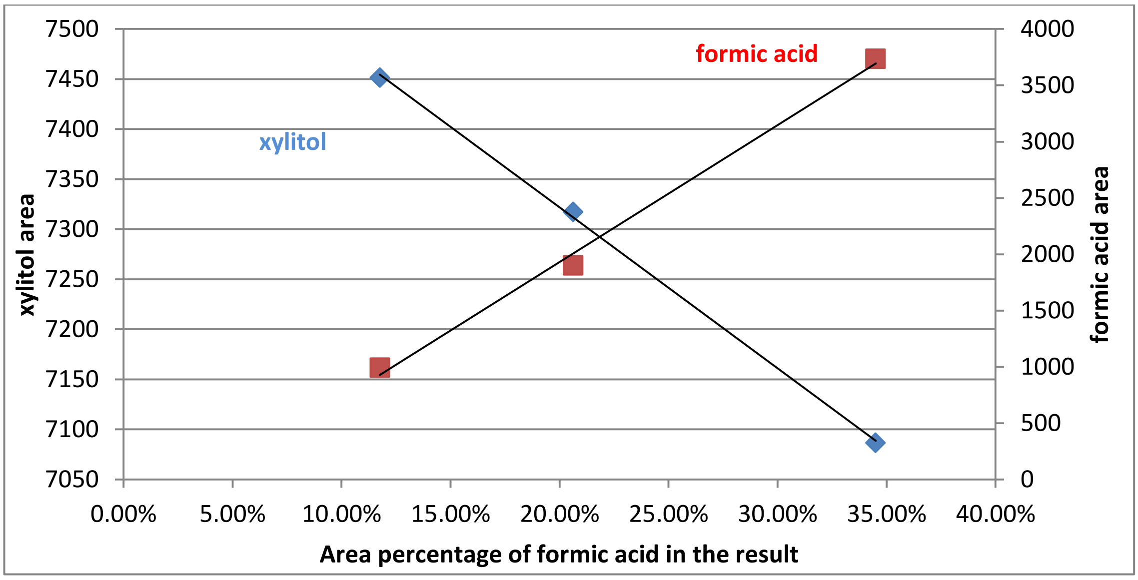


Fig. 5 Calibration for HPLC zero samples

The trendline equations are for xylitol:

$$y = -1609x + 7643.8 \qquad [2]$$

For formic acid:

$$y = 12161x - 501.16 \qquad [3]$$

With the degree of explanation being 0.9993 and 0.9956 respectively.

Thus, the assumed xylitol areas for the zero samples can be calculated with the linear equation as following:

$$A'_0 = -1609 * (\%Area) + 7643.8 \qquad [2']$$

Equation (1) can be then used by substituting A_0 for A'_0.

Selectivity to hydrogen can be calculated with the following formula:

$$S_{H_2}(\%) = \frac{n_{H_2}}{n_C} * \frac{100}{SR} \qquad [4]$$

Where n_{H_2} are moles of hydrogen in the gas, n_C are moles of carbon in the outgoing gas and SR is the reforming ratio H_2/CO_2, which is 11/5 for xylitol as follows from Fig. 3. In the same way, this reforming ratio is 10/5 for xylose and 1/1 for formic acid.

Selectivity to carbon dioxide is calculated as:

$$S_{CO_2}(\%) = \frac{n_{CO_2}}{n_C} * 100 \qquad [5]$$

For the experiments with a mixture of xylose and formic acid, the reforming ratio was calculated as follows in equation (6).

$$RR_{mix} = \frac{C_o X_{xylose} RR_{xylose} + C_o X_{formic\ acid} RR_{formic\ acid}}{C_{o_1} X_{xylose} + C_{o_1} X_{formic\ acid}} \qquad [6]$$

4.6 Catalyst characterization

The equipment used for catalyst characterization namely TPR was Micromeritics AutoChem 2910.

Such characterization allowed to determine the optimal temperature for catalyst reduction.

The first step was heating to 250 °C and holding at this temperature during 60 minutes with 100% argon flow. Then the temperature was decreased to ambient one. The next step was to prepare and displace a cold trap made with iso-propanol and liquid nitrogen. The last step is to heat toi 900 °C with 5% hydrogen and 95% argon flow and observe the hydrogen consumption.

CO chemisorption has been carried out in order to determine the platinum particle dispersion. The method is shortly described below.

First, reduction was carried out under 250 ºC during two hours. Thereafter a sample was cooled to 25 ºC. The final step was to analyze CO chemisorption with pulses of 10% CO in He.

4. RESULTS AND DISCUSSION

5.1 Catalyst characterization

TPR results shown in Fig. 6 can be interpreted as follow.

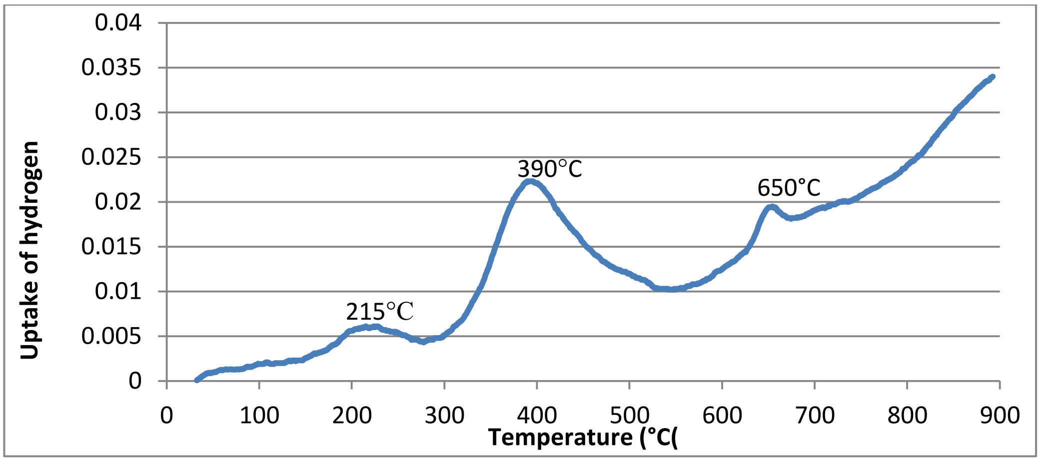


Fig. 6 TPR profile for Pt/Al2O3

The first peak is due to reduction of different PtO_x species while the last two peaks are probably caused by the interaction between platinum and alumina support[15].

CO chemisorption results given in Fig. 7 allowed to calculate metal dispersion, which was 48%, corresponding to the size of Pt of 1.2nm.

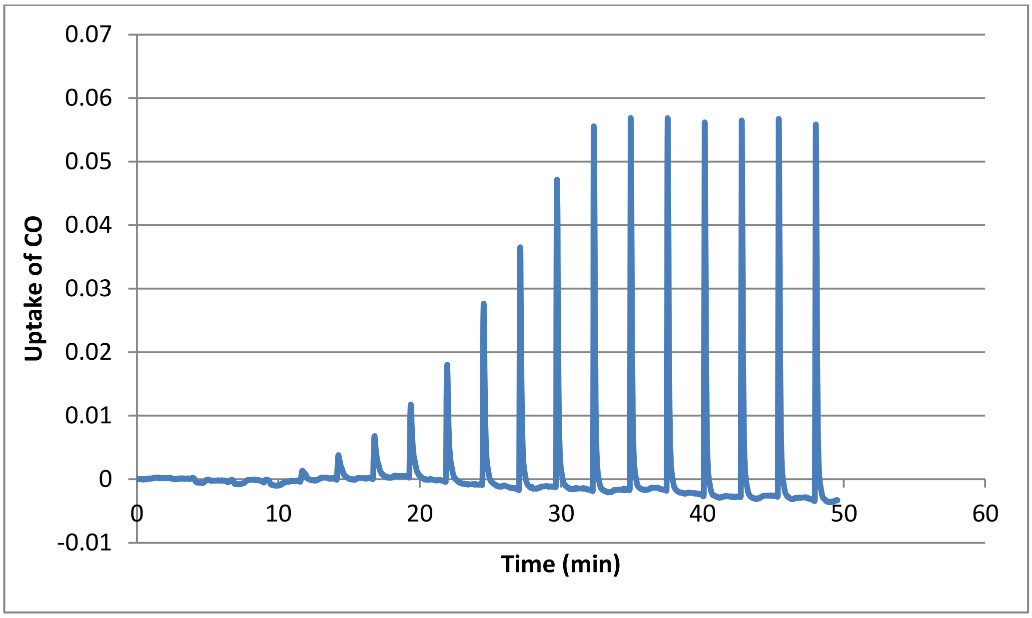


Fig. 7 CO chemisorption results

5.2 Temperature influence

In the experiment shown in Table 1, temperature inside the reactor has been varied from 215 ºC to 225 ºC. The rest of the variables are constant during the experiment.

Condition	Value	Units
Pressure	30	bar
Inert flow	33.9	mL/min
Liquid flow	0.2	mL/min
Catalyst weight	0.5	g
Catalyst size	350-500	µm
Reactant	Xylitol 5%	-
Reduction	Yes	-

Table 1 Experiment 1 conditions. Temperature influence

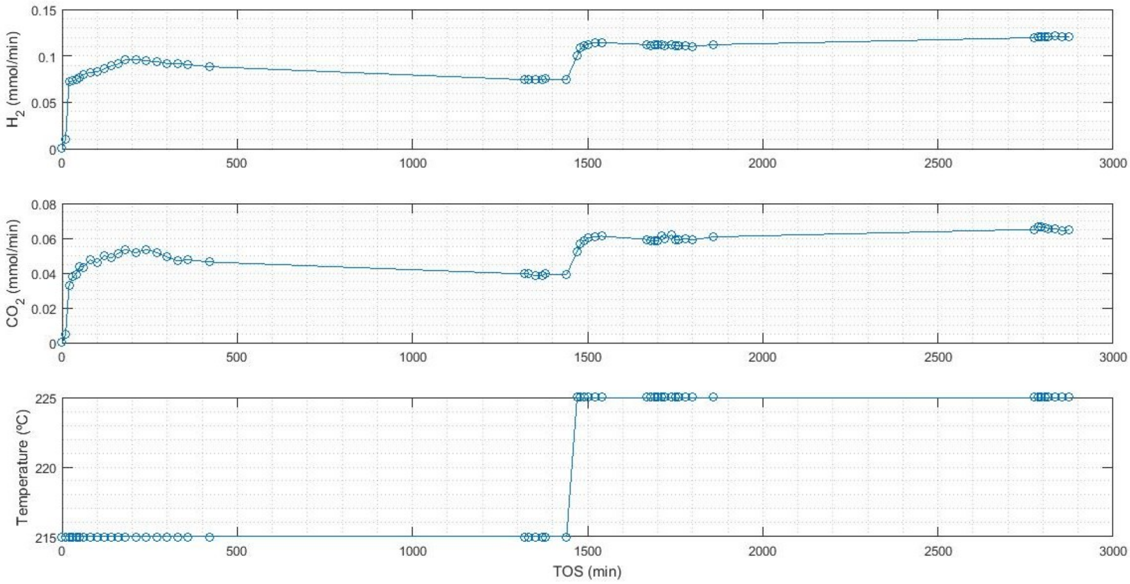


Fig. 8 Temperature influence Micro GC results

As it can be observed in Fig. 8, production of H_2 and CO_2 increased with temperature.

Conversion data obtained with HPLC are given in Fig. 9.

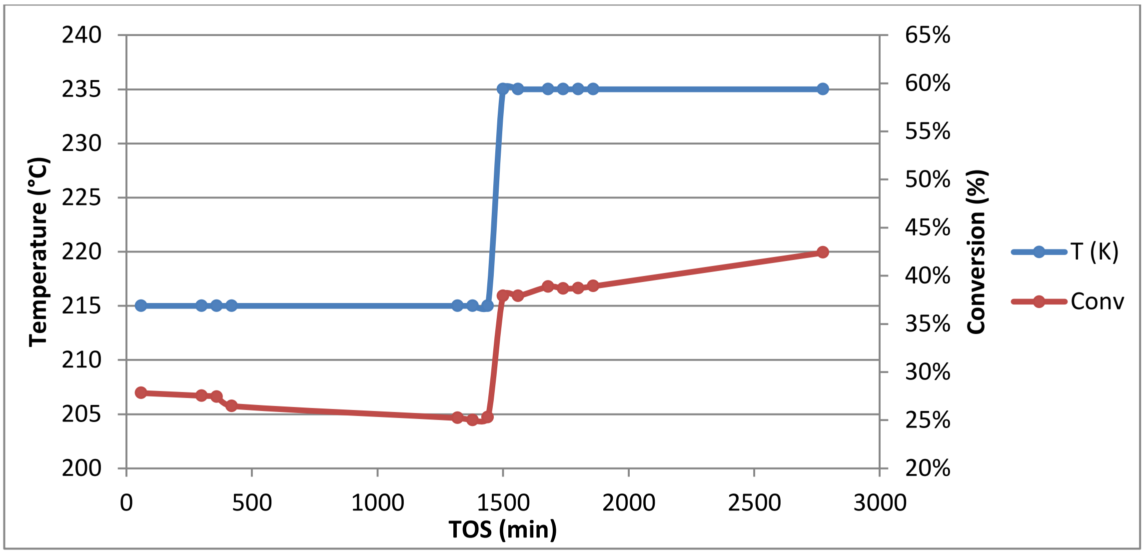


Fig. 9 Temperature influence HPLC results

An increase of H_2 and CO_2 can be related to selectivity or activity increase with temperature

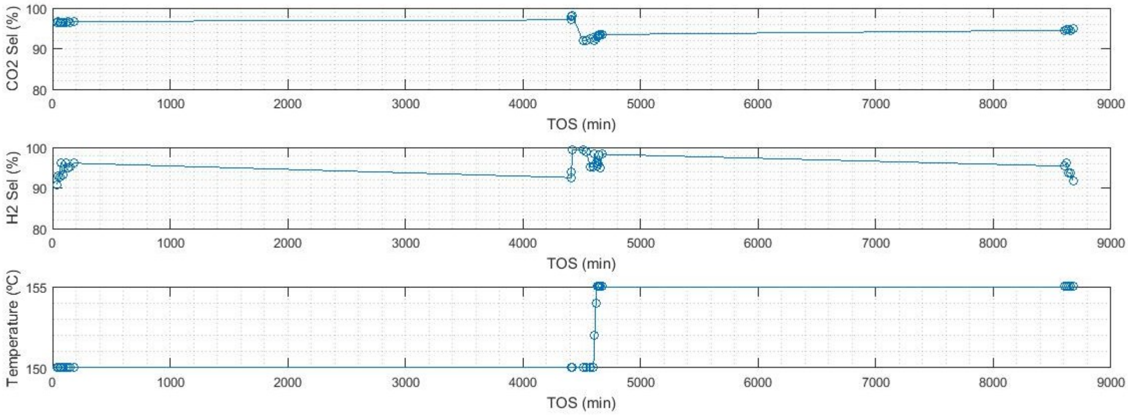


Fig. 10 Temperature influence. Selectivity

Selectivty shown in Fig. 10 barely change with temperature, thus it can concluded that higher yield of gases coming out from the reactor are related only a higher xylitol conversion.

The experiment shown has been carried out under 30 bar. In the experiment that will be shown below, the temperature variation is done from 150 ºC to 155 ºC, under 15 bars. The rest of the conditions (Table 2) are kept constant.

Condition	Value	Units
Pressure	15	bar
Inert flow	33.9	mL/min
Liquid flow	0.05	mL/min
Catalyst weight	1.5	g
Catalyst size	Pellets 3.2	mm
Reactant	3,5% formic acid, 1,5% xylose	-
Reduction	Yes	-

Table 2 Experiment 2 conditions. Temperature influence

The results of the CO_2 and H_2 flow are shown in Fig. 11

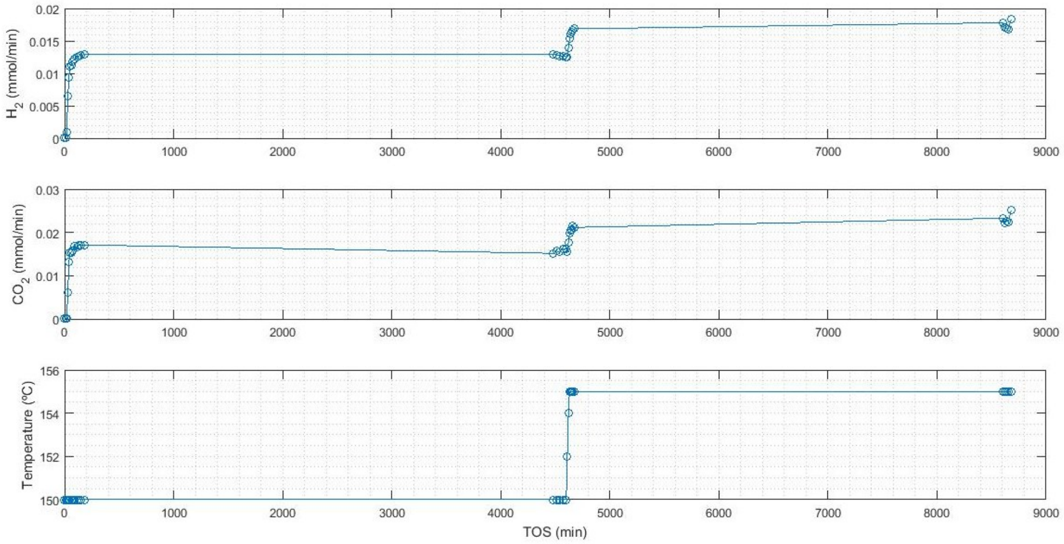


Fig. 11 Temperature influence. Micro GC results for experiment 2

A Increase of temperature gives the same results as in the previous experiment.

Selectivity plot against TOS is presented in Fig. 12.

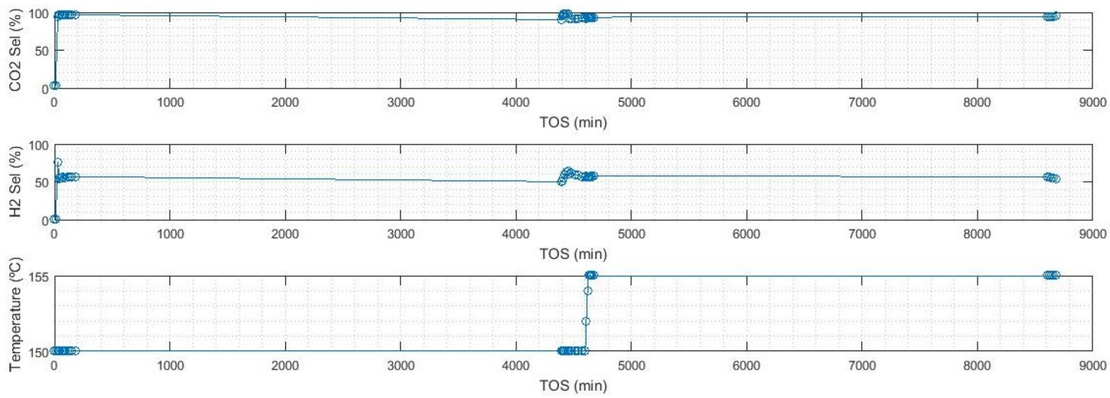


Fig. 12 Temperature influence. Selectivity in experiment 2

It can be seen that selectivity is constant thus higher yields are related to higher conversion.

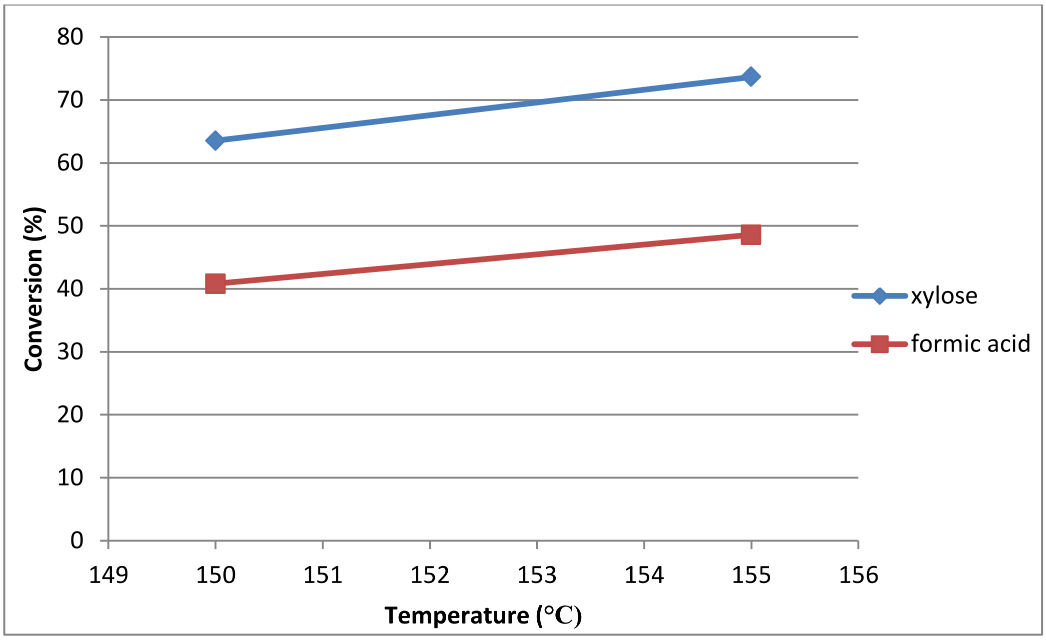


Fig. 13 Temperature influence for experiment 2

An increase of conversion with temperature is shown in Fig. 13

Not surprisingly higher temperatures give higher flows of H_2 and CO_2.

Catalyst activation energy

In order to calculate the activation energy, experiments were carried out at three different temperatures, 215 ºC, 225 ºC and 235 ºC. The data are presented in Fig. 14 and Fig. 15.

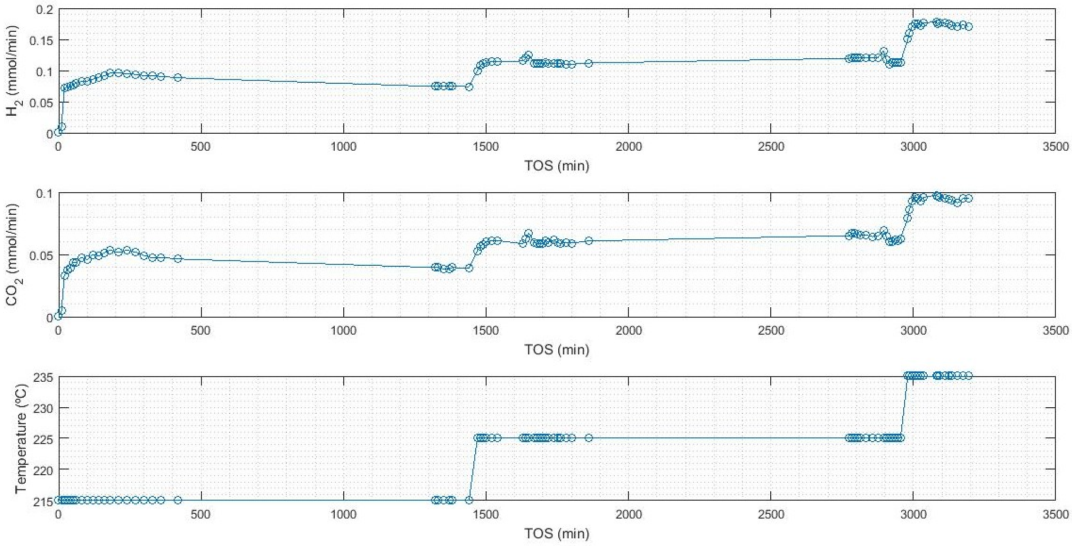


Fig. 14 Catalyst activation energy. Results

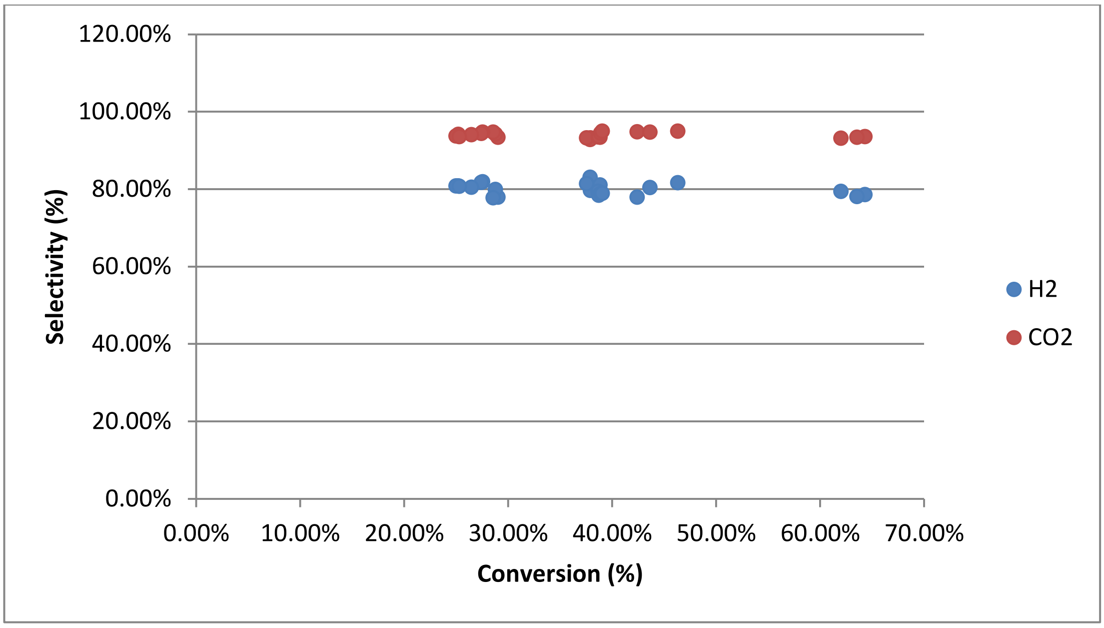


Fig. 15 Activation energy. Selectivity

Calculation of the activation energy according to the Arrhenius equation:

$$K = Ae^{\frac{-Ea}{RT}} \qquad [7]$$

And further linearization.

$$\ln(K) = \ln(A) - \frac{Ea}{RT} \qquad [8]$$

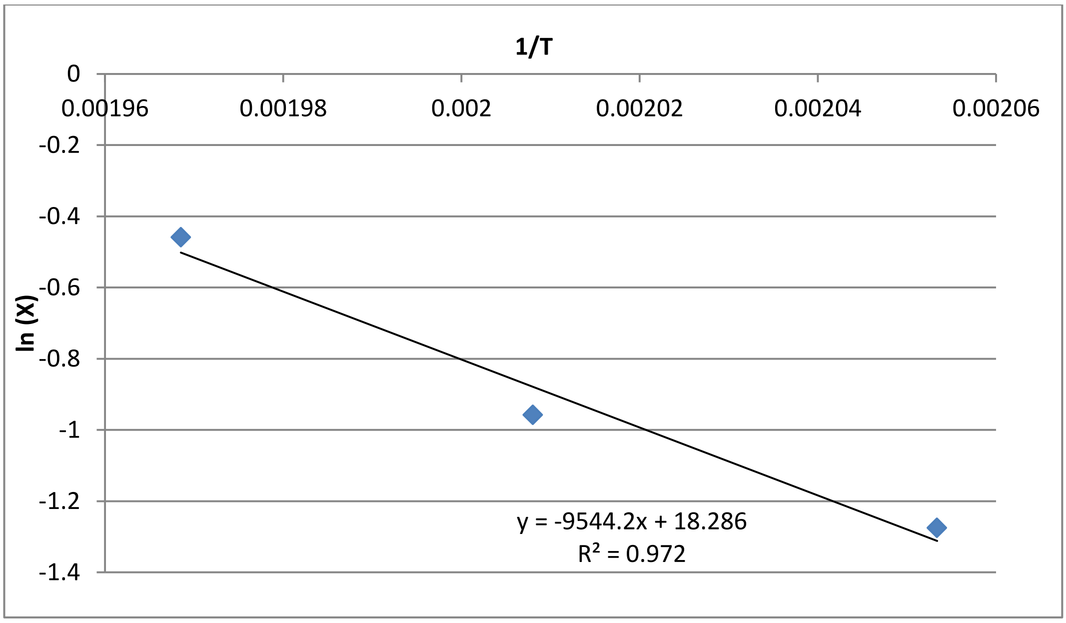


Fig. 16 Arrhenius equation represented

Fig. 16 gives the value of Ea equal to 79.4 kJ/mol.

5.3 Pressure influence

In a series of experiment, the pressure inside the reactor has been changed from 30 bar to 22 bar with the pressure controller located at the exit of the reactor. The rest of the conditions shown in Table 3 were the same.

Condition	Value	Units
Temperature	170	ºC
Inert flow	11.3	mL/min
Liquid flow	0.2	mL/min
Catalyst weight	1.5	g
Catalyst size	350-500	µm
Reactant	Xylitol 5%	-
Reduction	Yes	-

Table 3 Experiment 1 conditions. Pressure influence

The results from the micro GC processed with Matlab are shown in Fig. 17:

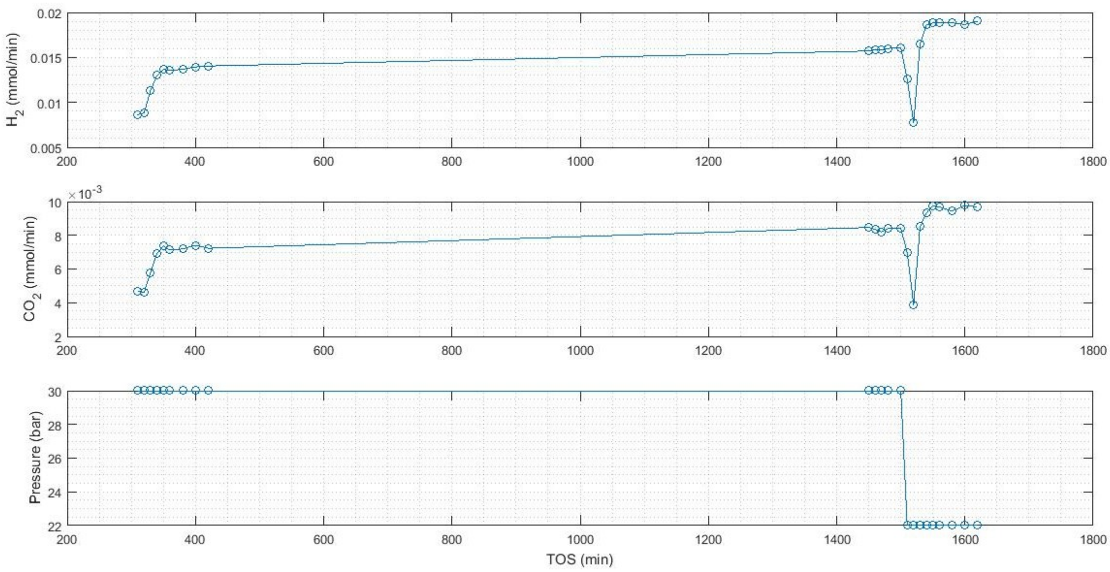


Fig. 17 Pressure influence Micro GC results

A pressure decrease gives an increase in the molar flows of CO_2 and H_2 which is caused by higher conversion and not selectivity as it can be seen in Fig. 18 and Fig. 19.

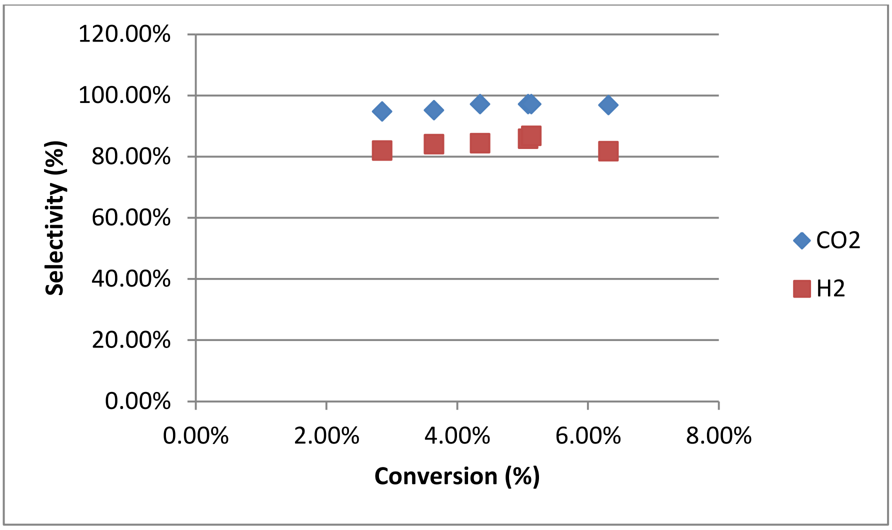


Fig. 18 Pressure influence. Selectivity

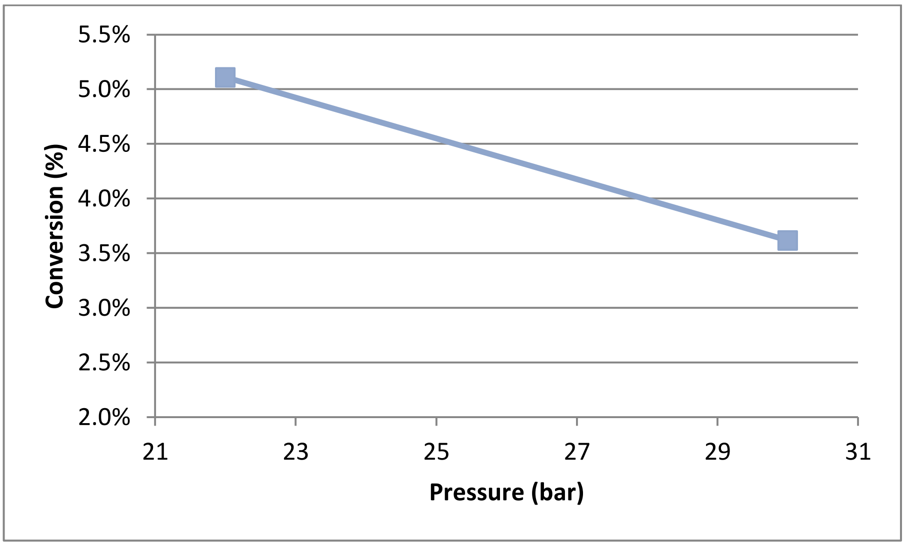


Fig. 19 Pressure influence. HPLC results

As it can be seen, while lower pressure gives higher molar flows of products, all reactants have to be in liquid phase making a limit on how low is the pressure.

Another experiment, studying the effect of pressure was carried out changing the operating pressure twice, from 35 bar to 30 bar and finally to 25 bar. The rest of the conditions are presented in Table 4.

Condition	Value	Units
Temperature	215	ºC
Inert flow	33.9	mL/min
Liquid flow	0.2	mL/min
Catalyst weight	0.5	g
Catalyst size	350-500	µm
Reactant	Xylitol 5%	-
Reduction	Yes	-

Table 4 Experiment 2 conditions. Pressure influence

From Fig. 20 it can be observed that hydrogen and carbon dioxide production is higher for lower pressure.

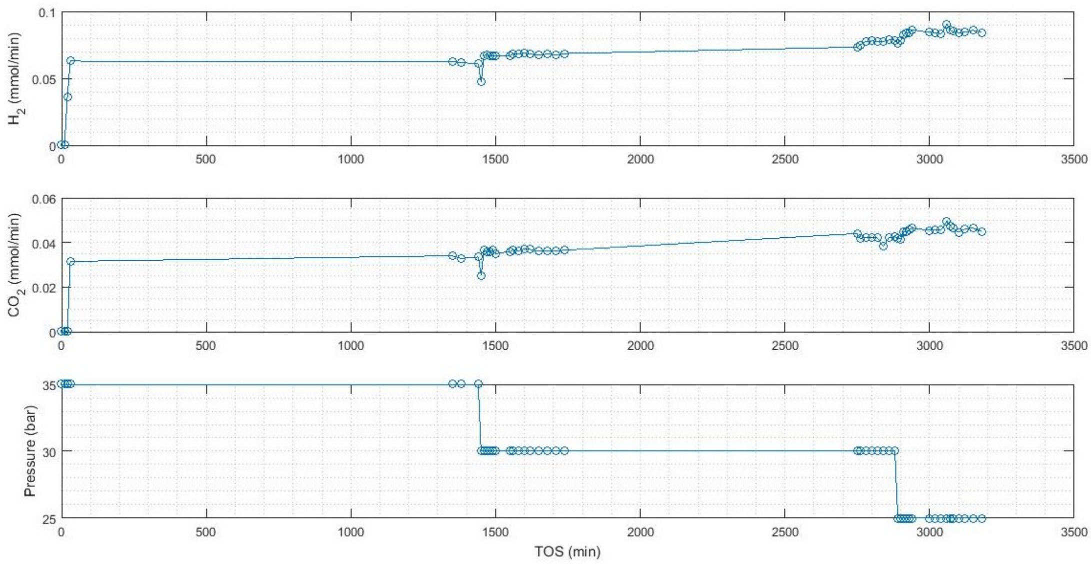


Fig. 20 Pressure influence Micro GC results (2)

Having three different pressures, it can be represented average conversion per each pressure shown in Fig. 22.

In Fig. 21 selectivity is represented against conversion, showing that it remains constant. Higher molar flows of CO_2 and H_2 caused by an increase in conversion.

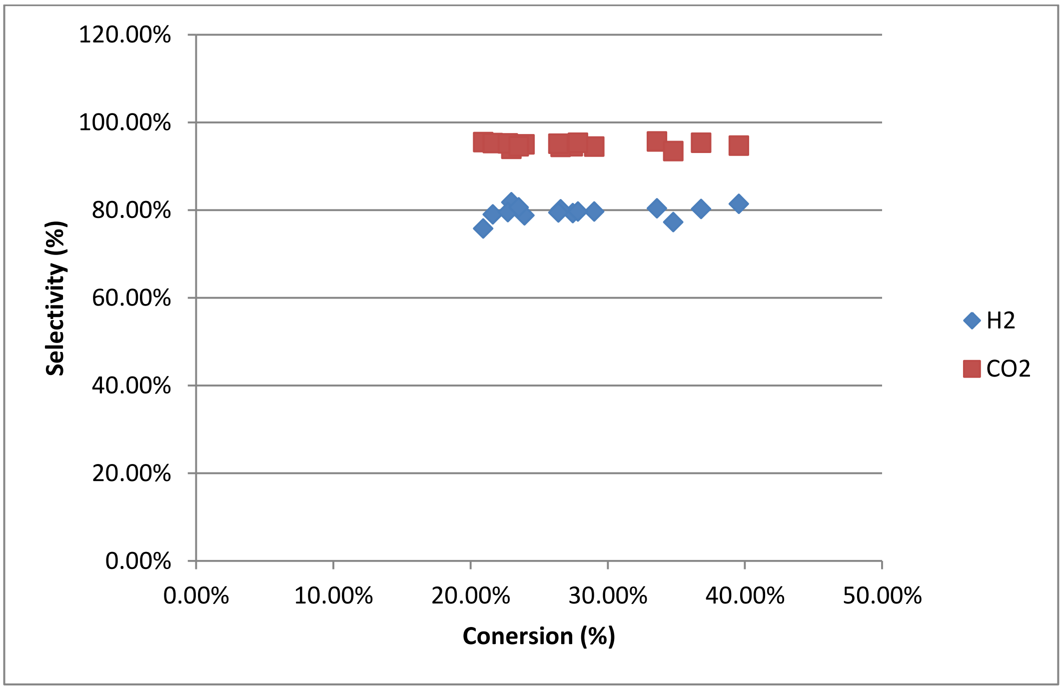


Fig. 21 Pressure influence (2) Selectivity

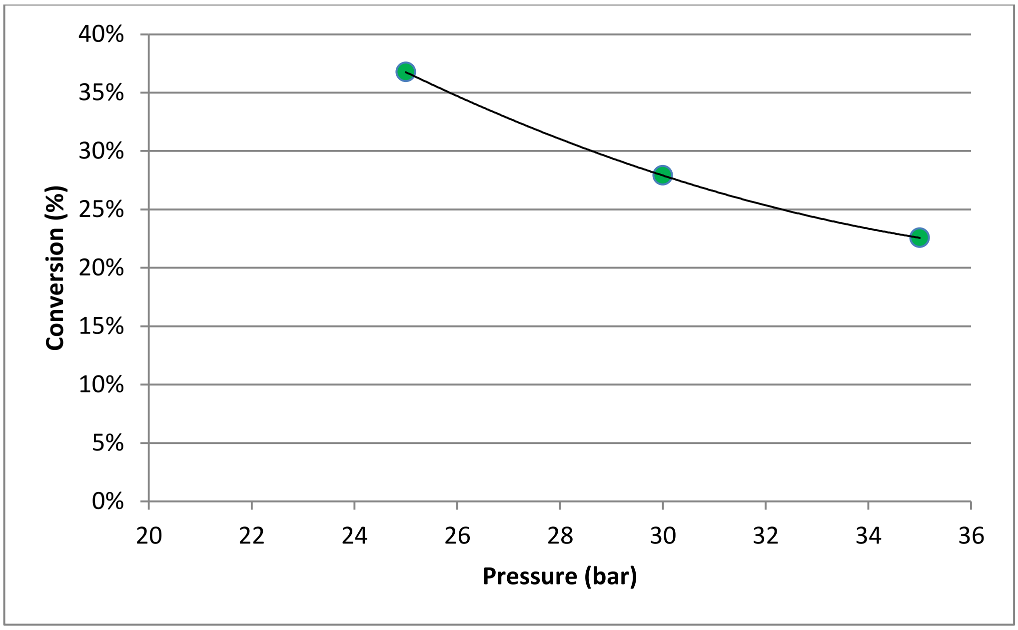


Fig. 22 Pressure influence for experiment 2. Conversion

As it can be seen in both experiments, the gas production is larger at lower pressures, as a result of the fact that in the reaction, gas is produced, so increasing the pressure makes the reaction slower.

Optimal for APR would be the lowest pressure and the highest temperature possible to have all reactants in a liquid phase, taking into account a safety margin.

5.4 Inert flow influence

The next variable studied was the influence of the inert flow. In the experiment shown in Table 5, the inert flow is changed three times. The flows were 33.9 mL/min, 22.6 mL/min and 11.3 mL/min at three different pressures 30 bar, 22 bar and 14 bar.

To calculate the exact value of the inert flow the next formula was applied:

$$Inert\ flow\left(\frac{mL}{min}\right) = Inert\ flow(\%) * 2.8261 \qquad [10]$$

The other conditions are presented in Table 5.

Condition	Value	Units
Temperature	170	ºC
Liquid flow	0.2	mL/min
Catalyst weight	0.5	g
Catalyst size	350-500	µm
Reactant	Xylitol 5%	-
Reduction	Yes	-

Table 5 Experiment 1 conditions. Inert flow influence

The results for the experiment at 30 bar, are given in Fig. 23.

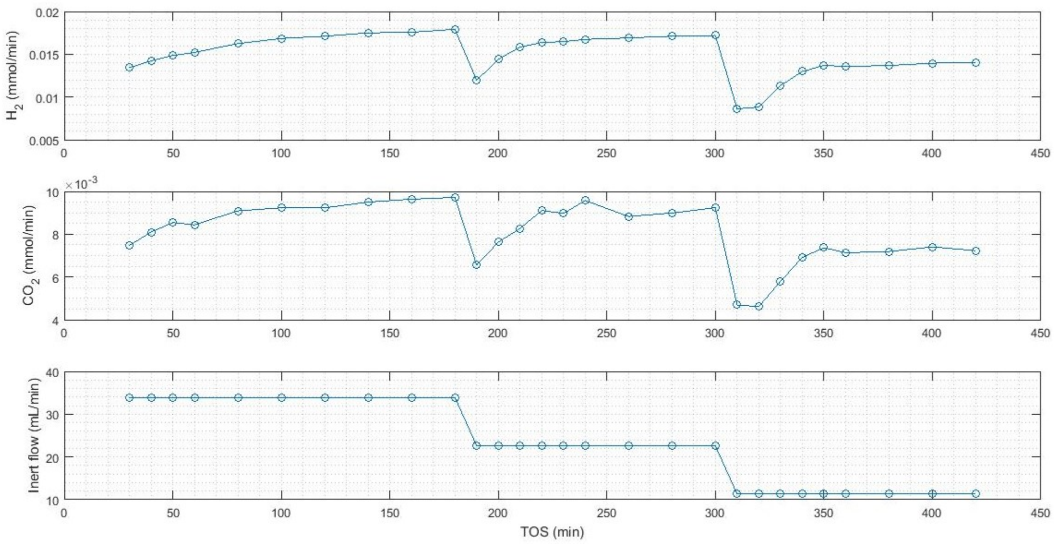


Fig. 23 Inert flow influence. Micro GC results

Fig. 23 shows that the yields of both gases decrease if the inert flow is lower.

In Fig. 24 it can be seen that selectivity for both gases does not change with conversion.

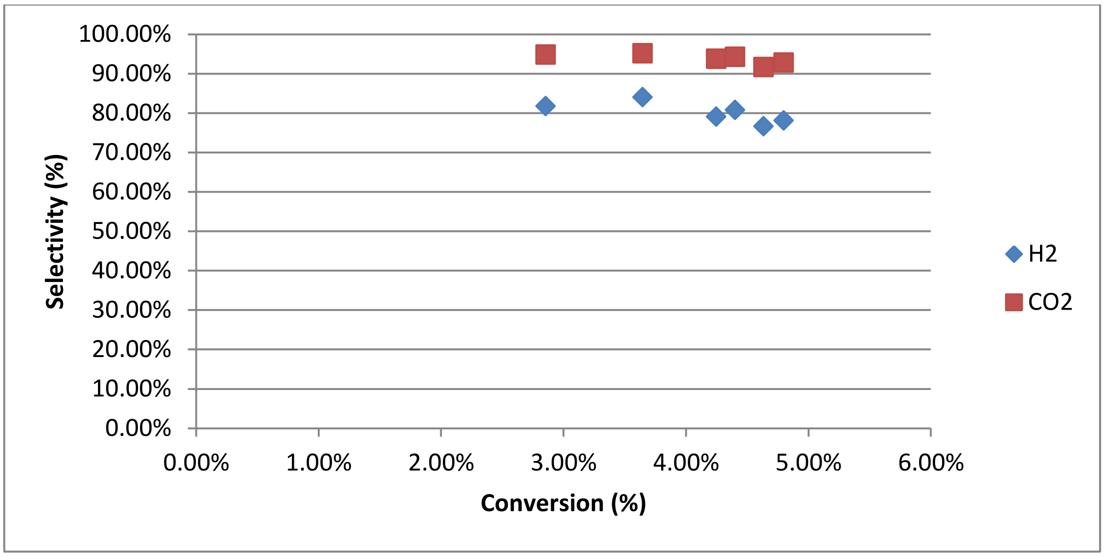


Fig. 24 Inert flow influence. Selectivity (1)

Results from same experiment and different pressure (22 bar) are shown in Fig. 25

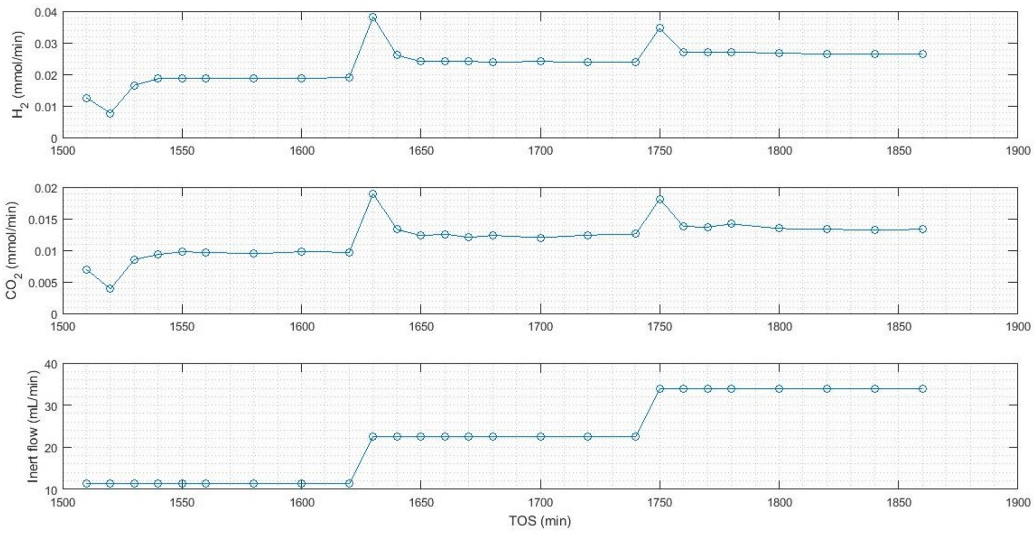


Fig. 25 Inert flow influence. Micro GC results (2)

As it can be seen in Fig. 25, the yields of both gases are higher when pressure was 22 bar compared to 30 bar.

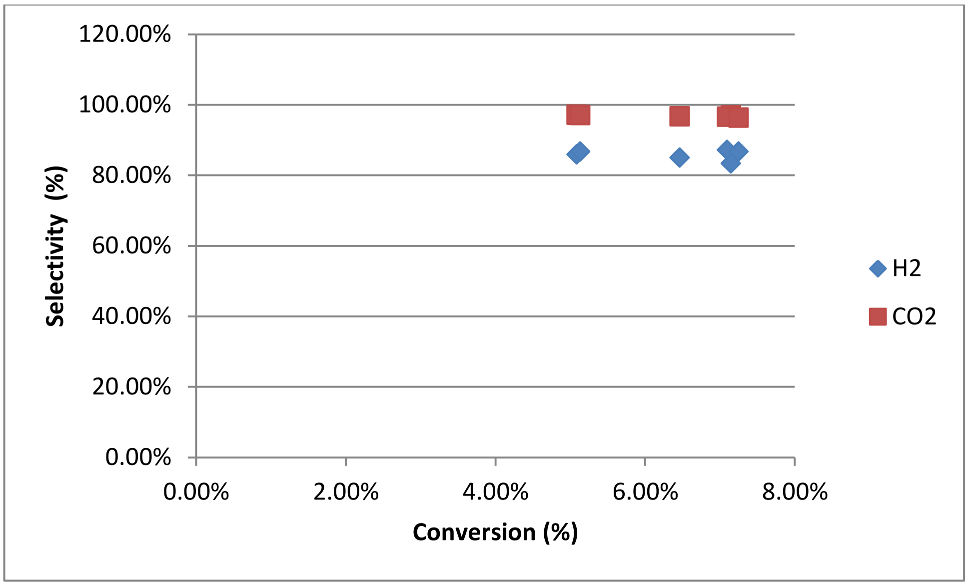


Fig. 26 Inert flow influence. Selectivity (2)

Selectivity results are given in Fig. 26

The next results presented in Fig. 27 which are same conditions as before except from the pressure that is 14 bar, has same performance but with higher yields, due to lower pressure.

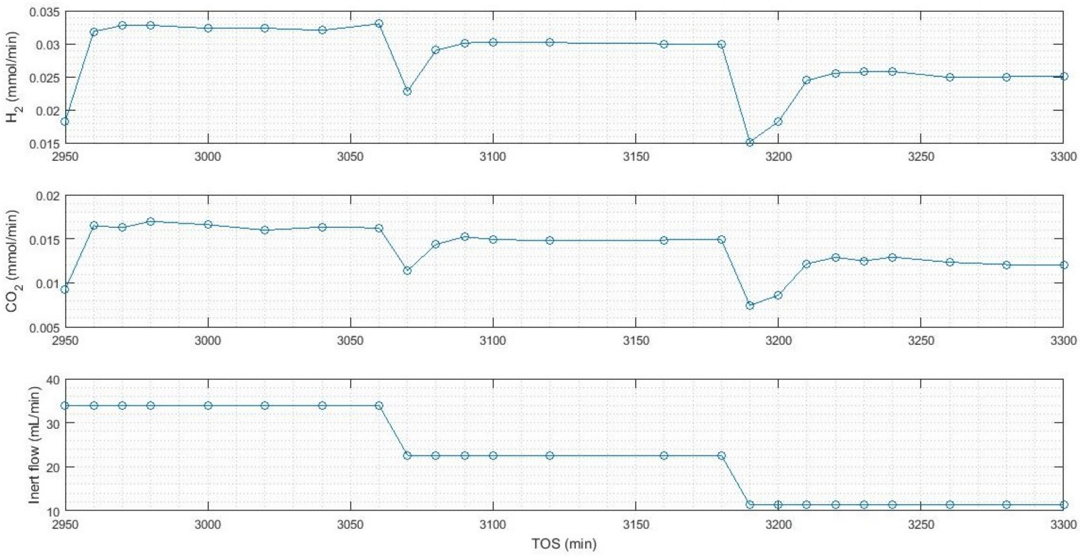


Fig. 27 Inert flow influence. Micro GC results (3)

Fig. 28 illustrates how the average conversion is influenced by pressure and inert flow.

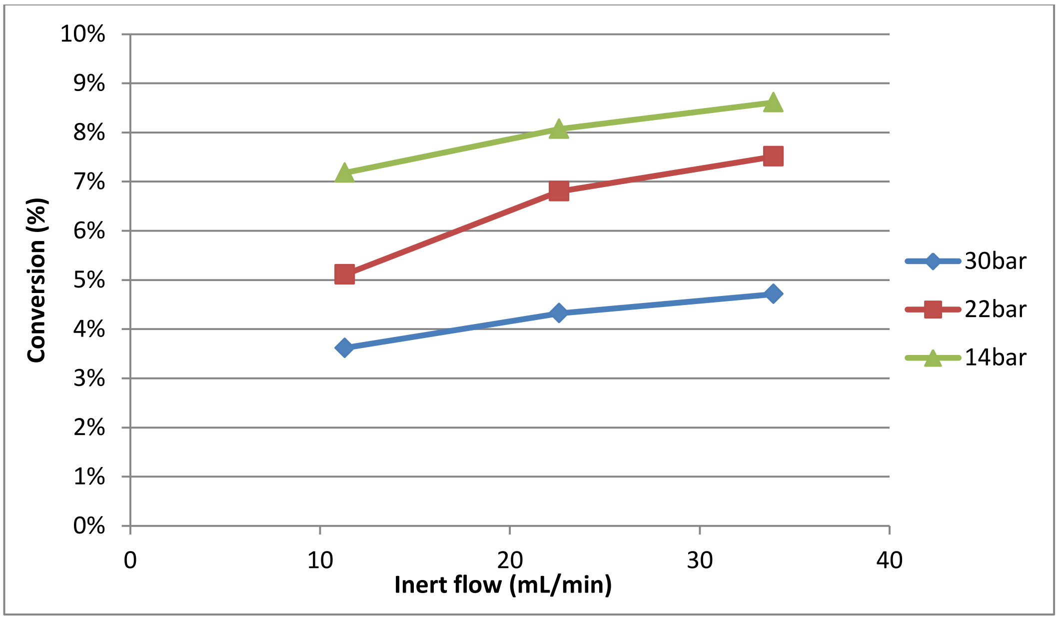


Fig. 28 Inert flow influence. HPLC results

Fig. 28 shows that conversion increases with a higher flow of the inert through the reactor. From Fig. 29 it can be observed that selectivity remains constant with different conversion.

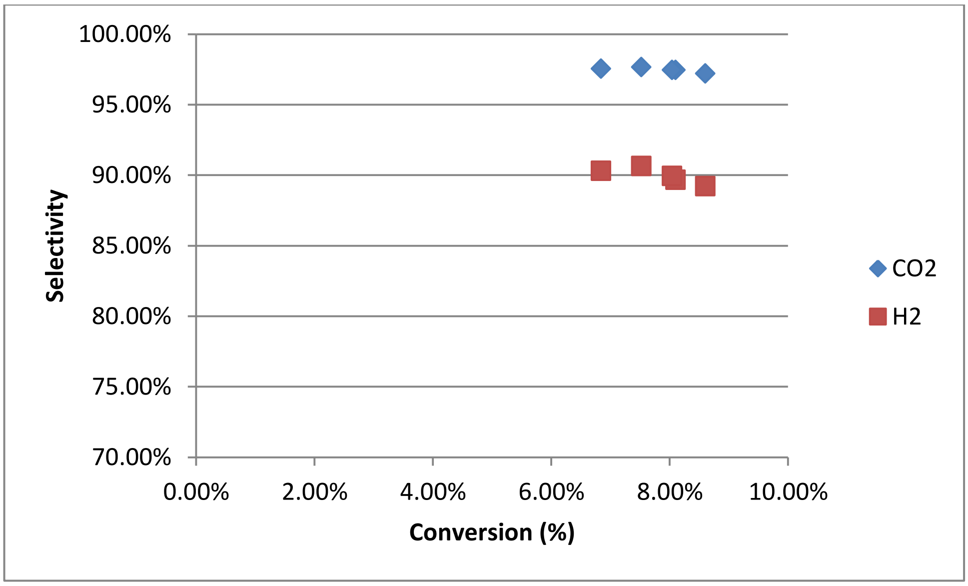


Fig. 29 Inert flow influence. Selectivity (3)

Larger products yields can be explained by removal of hydrogen from the reactor zone facilitating xylitol conversion.

5.5 Influence of reactant conditions

Reactant liquid flow:

The liquid flow of the reactant has been changed maintaining the rest of the conditions in order to study the influence of it. The conditions for this experiment are shown in Table 6.

Condition	Value	Units
Temperature	170	ºC
Pressure	22	bar
Inert flow	33.9	mL/min
Catalyst size	350-500	µm
Reactant	Xylitol 5%	-
Weight of catalyst	1.5	g
Reduction	Yes	-

Table 6 Reactant liquid flow influence. Conditions

Fig. 30 illustrates the yields of products.

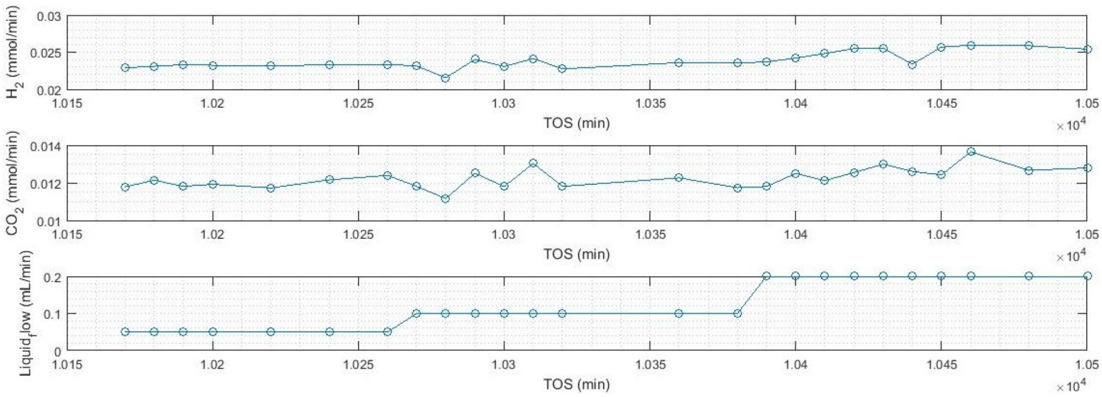


Fig. 30 Reactant liquid flow influence. Micro GC results

As it can be seen in Fig. 30, flows of both gases slightly increase when increasing the reactant flow, not being, owever, proportional.

Liquid flow (mL/min)	Hydrogen flow (mmol/min)	Carbon dioxide flow (mmol/min)
0.05	0.0232	0.0119
0.1	0.0236	0.0123
0.2	0.0256	0.0130

Table 7 Reactant liquid flow. Gases flows results

The molar flows of products are given in Table 7.

Fig. 31 displays conversion for three different pressures.

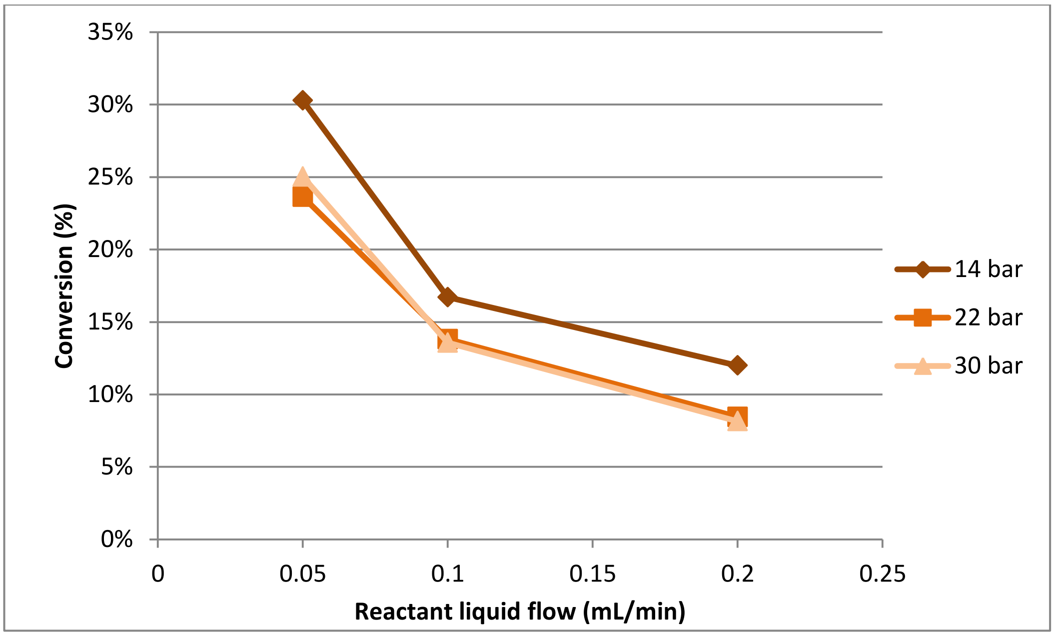


Fig. 31 Reactant liquid flow. Conversion

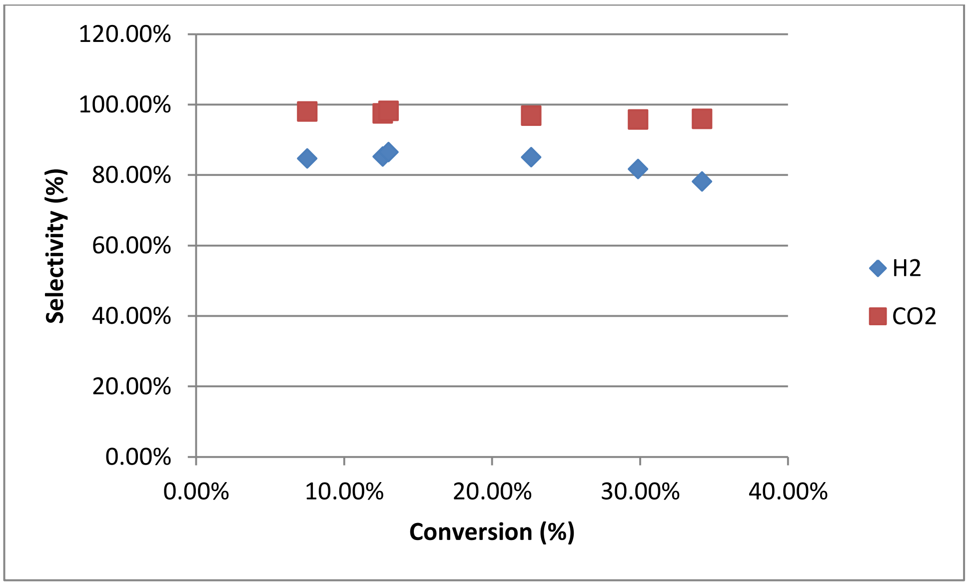


Fig. 32 Reactant liquid flow. Selectivity

It can be observed from Fig. 31 that conversion is higher at lower liquid flow and thus the residence time.

Selectivity was constant as it illustrated in Fig. 32.

Xylitol concentration in the feed

An experiment has been carried out under standard condition of 170 ºC, 14 bar, inert flow of 33,9 mL/min, liquid flow of 0.2 mL/min with 0,5 g f reduced catalyst. The only difference was xylitol concentration, which was varied keeping the liquid flow.

The molar flows of hydrogen and carbon dioxide are shown in Fig. 33.

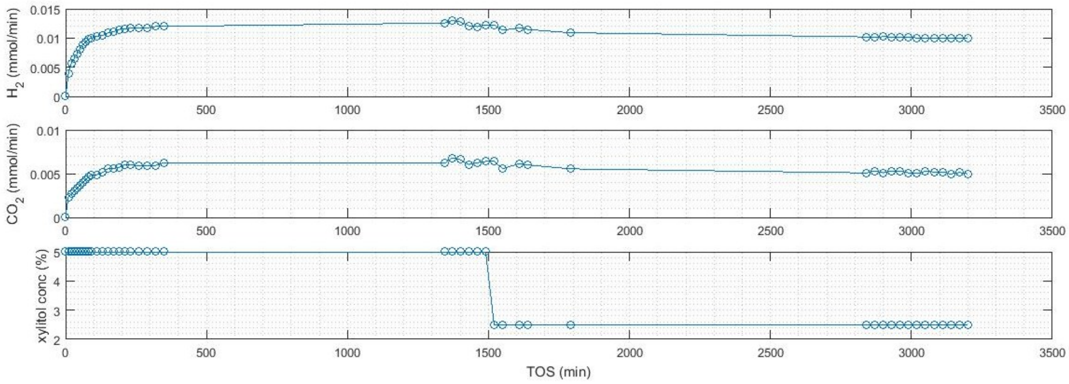


Fig. 33 Reactant liquid concentration influence. Micro GC results

The results show that for a lower concentration of 2,5 wt% of xylitol, the molar flows are slightly lower.

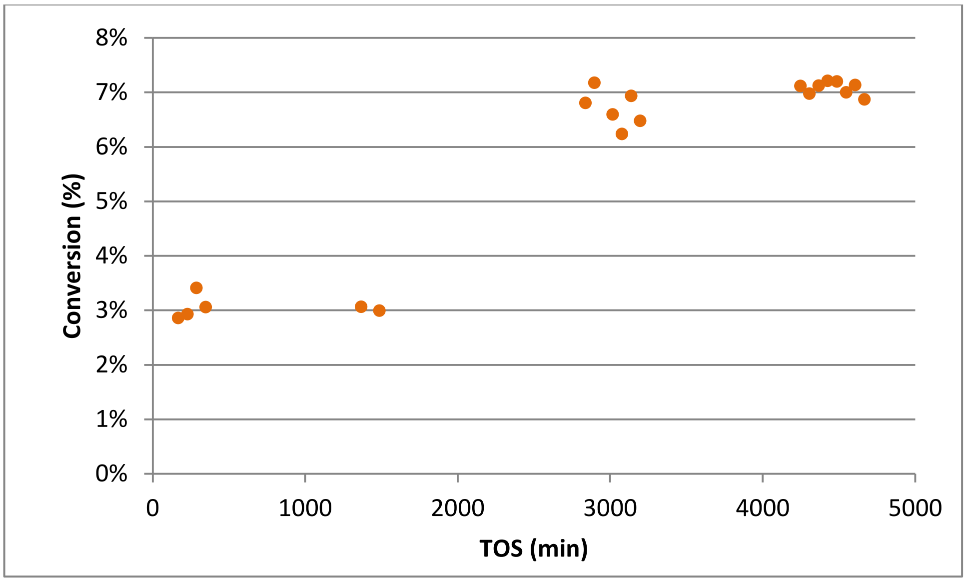


Fig. 34 Reactant liquid concentration influence. HPLC results

Fig. 34 illustrates that conversion is the double for the lower concentration of xylitol.

5.6 Influence of catalyst

Amount of catalyst

Two experiments were carried out under the same conditions shown in Table 8 changing the catalyst amount.

Condition	Value	Units
Temperature	170	ºC
Pressure	14	bar
Liquid flow	0.2	mL/min
Inert flow	33.9	mL/min
Catalyst size	350-500	µm
Reactant	Xylitol 5%	-
Reduction	Yes	-

Table 8 Catalyst influence. Weight of catalyst

The primary results are shown in Fig. 35 for 0,5 g of catalyst.

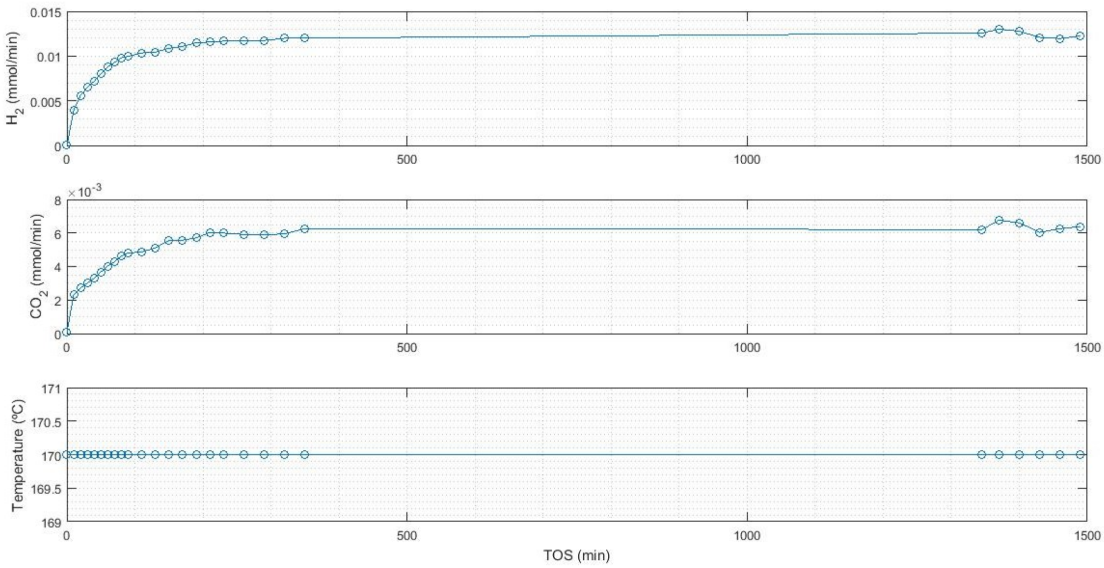


Fig. 35 Catalyst influence. Micro GC results 0.5 g

Results for 1,5 g of catalyst are given in Fig. 36.

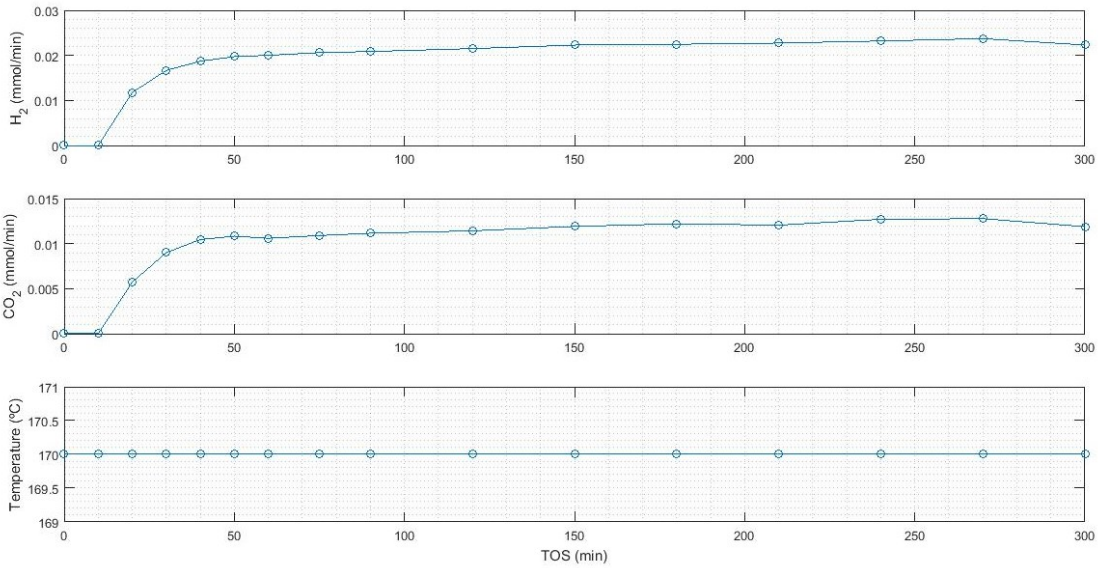


Fig. 36 Catalyst influence. Micro GC results 1.5 g

As we can see in Fig. 35 and Fig. 36, the flows are about the double with 1.5 g of catalyst inside the reactor, so we can affirm that with 1.5 g of catalyst or less, the weight of it is not a restricting factor in the reaction, but the amount of both gases produced and the amount of catalyst are not proportional.

Reduction role

Two experiments were performed apart from the catalyst pretreatment with the same condition shown in Table 9.

Condition	Value	Units
Temperature	170	ºC
Pressure	14	bar
Liquid flow	0.05	mL/min
Inert flow	12	%
Catalyst size	Pellets 3,2	mm
Reactant	Xylitol 5%	-
Weight of catalyst	1.5	g

Table 9 Catalyst influence. Reduction role

Experimental results are presented in Fig. 37, Fig. 38

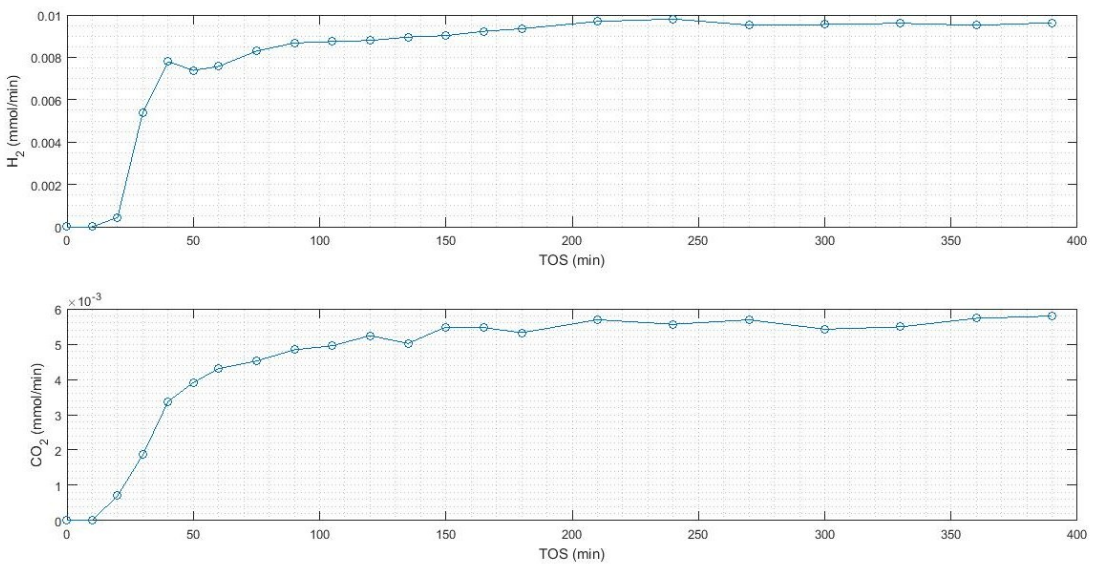


Fig. 37 Reduction role. Catalyst with reduction

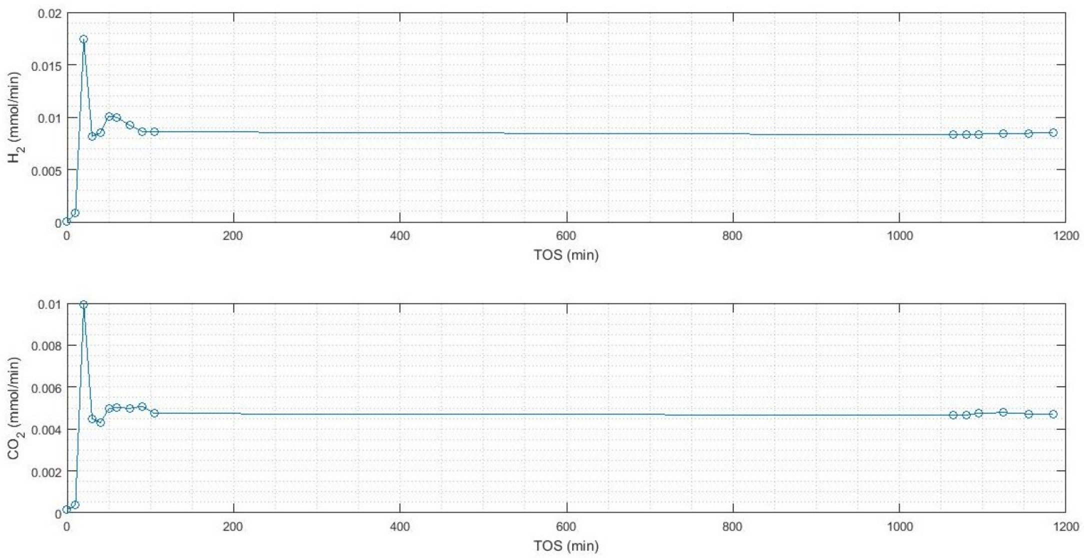


Fig. 38 Reduction role. Catalyst without reduction

Data in Fig. 37 and Fig. 38, summarized in Table 10, illustrate that the products molar flow are just slightly higher for the experiment with the reduced catalyst.

Experiment	Hydrogen flow	Carbon dioxide flow
Reduction	0.095 mmol/min	0.0055 mmol/min
No reduction	0.080 mmol/min	0.0045 mmol/min

Table 10 Catalyst influence. Reduction role results

The largest difference was found in selectivity. Without catalyst reduction, formation of other hydrocarbons compared to the reduced catalyst was favored.

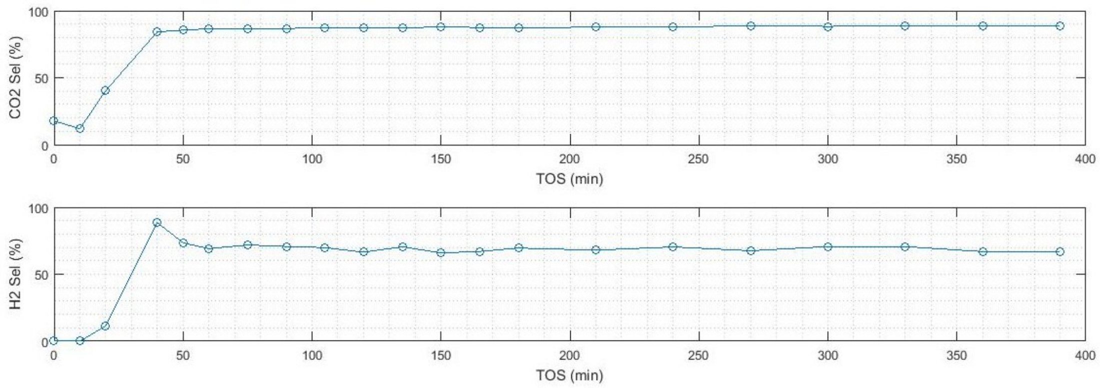


Fig. 39 Reduction role. Selectivity. With reduction

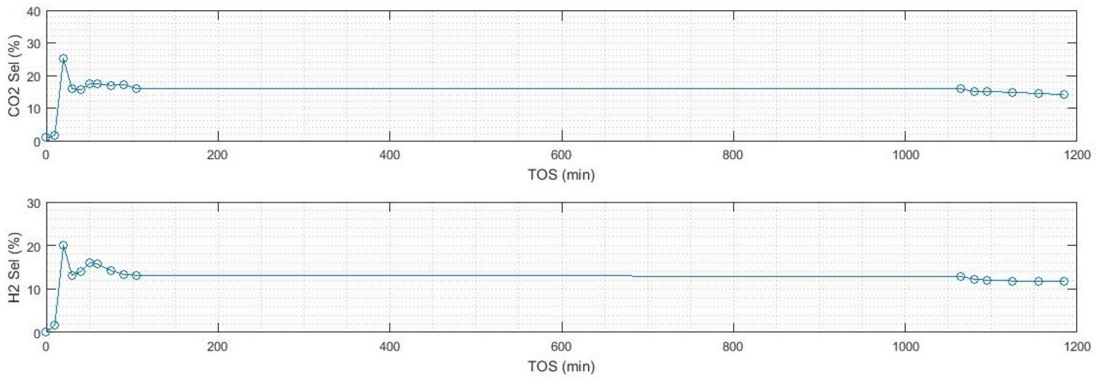


Fig. 40 Reduction role. Selectivity. Without reduction

Selectivity for H_2 and CO_2, as it can be observed in Fig. 39 and Fig. 40, is more than 50% when the catalyst has been pre-reduced.

5. CONCLUSIONS

In the present work, certain conditions have been changed, showing that some of them were favorable for hydrogen and carbon dioxide.

- **Temperature and pressure**
  To conclude it can be affirmed that higher temperature and lower pressure resulted in higher production of hydrogen and carbon dioxide.
  Because higher temperature inevitably results in higher vapor pressure, a balance between those two conditions is required also ensuring that all reactants are in the liquid phase.
- **Inert flow**
  Inert flow affects the gas production, with a larger flow through the reactor flushing away hydrogen from the reactor zone.
- **Amount of catalyst**
  The gas production was not proportional to the catalyst weight because higher catalyst weight promotes higher reactant conversion but it also reduces the residence time.
- **Catalyst reduction**
  Catalyst reduction increased selectivity for carbon dioxide and hydrogen. A non-reduced catalyst exhibited better selectivity for light alkanes and other gases is much higher which can be related to a higher metal oxidation state.
- **Reactant flow**
  A higher gas production was related to a smaller reactant flow caused by a higher conversion due to the residence time.
- **Reactant concentration**
  A higher concentration promotes lower conversions and lower carbon dioxide and hydrogen production.

6. REFERENCES

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7. APPENDIX

Gascalibration file for Matlab	Gasconcentration file for Matlab
1	1.000000
1	1.000000
838580.9	0.150000
66378.0	0.010000
79338.4	0.010000
36101.3	0.010000
39256.9	0.010000
1511.7	0.000378
1227	0.000303
2168.5	0.000502
1365.1	0.000299
2242.1	0.000495
1444.5	0.000399
1556.8	0.000511
5492.8	0.010000
143767.7	0.120000
86007.4	0.990000
3433.5	0.010000
17285.5	0.120000
1	1
1	1
1	1
1	1
1	1

Matlab code for graphs

```
subplot(3,1,1);
plot(TOS,H2_flow,'-o')
grid minor
ylabel('H_2 (mmol/min)')

subplot(3,1,2);
plot(TOS, CO2_flow,'-o')
grid minor
ylabel('CO_2 (mmol/min)')

subplot (3,1,3)
plot(TOS,Temperature,'-o')
grid minor
ylabel ('Temperature (°C)')
xlabel ('TOS (min)')

subplot (3,1,3)
plot(TOS,Pressure,'-o')
grid minor
ylabel ('Pressure (bar)')
xlabel ('TOS (min)')

subplot(3,1,1)
plot(TOS,CO2_sel,'-o')
grid minor
ylabel('CO2_Sel (%)')
xlabel('TOS (min)')

subplot (3,1,2)
plot(TOS,H2_sel,'-o')
grid minor
ylabel ('H2_Sel (%)')
xlabel ('TOS (min)')

subplot (3,1,3)
plot(TOS,Liquid,'-o')
grid minor
ylabel ('Liquid_flow (mL/min)')
xlabel ('TOS (min)')

subplot (3,1,3)
plot(TOS,In_flow,'-o')
grid minor
ylabel ('Inert flow (mL/min)')
xlabel ('TOS (min)')

subplot (3,1,3)
plot(TOS,xy_c,'-o')
grid minor
ylabel ('xylitol_conc (%)')
xlabel ('TOS (min)')
```

Matlab code

```
%   Gas composition, flow and selectivities in APR

load ('APRdatatest.txt');
load ('Gascalibration.txt');
load ('Gasconcentrations.txt');

GCdata=APRdatatest;
```

```
GCresponse=Gascalibration';
Concentrations=Gasconcentrations';

Gas=bsxfun(@rdivide,GCdata,GCresponse);
Gasconc=bsxfun(@times,Gas,Concentrations);

TOS=APRdatatest(:,1);
Sample=APRdatatest(:,2);
He=Gasconc(:,15);
In_flow=APRdatatest(:,22)*282.61;
He_in=In_flow*0.01;
Inert_flow=APRdatatest(:,22);
Xy_c=APRdatatest(:,24)*100;

Tot_flow=He_in./He;
Liquid=APRdatatest(:,23);

Temperature=APRdatatest(:,20);
Pressure=APRdatatest(:,21);

Gas_flow=bsxfun(@times,Gasconc,Tot_flow);
Molar_flow=Gas_flow/22.41;

C=[0 0 1 2 3 4 4 5 5 5 6 6 6 7 0 0 0 1 1 0 0 0 0
0];
Carbon_flow=bsxfun(@times,Molar_flow,C);
Carbon_flow_out=sum(Carbon_flow,2);

CO2_flow=Molar_flow(:,3);
H2_flow=Molar_flow(:,16);

CO2_sel=bsxfun(@rdivide,CO2_flow,Carbon_flow_out)*
100;
H2_sel=bsxfun(@rdivide,H2_flow,Carbon_flow_out)*5/
11*100;

Results=[TOS CO2_sel H2_sel H2_flow];

figure
/Add matlab code for graphs
```

APRdatatest for Fig. 8 and Fig. 10

%TOS	Sample	CO2	C2H6	C3H8	i-C4	n-C4	neo-C5	i-C5	n-C5	i-C6	n-C6	c-C6	n-C7	He	H2	N2	CH4	CO	Temp	Pressure	Gas	Liquid	xylitol
0	2	0	0	0	0	0	0	0	0	0	0	0	5883	0	0	0	0	215	30	0.12	0.2	0.05	
10	3	18110	362	64	22	0	0	12	0	9	2	4	0	5637	8018	0	128	0	215	30	0.12	0.2	0.05
20	4	117611	1676	297	30	0	0	15	0	9	2	3	0	5340	55416	0	694	0	215	30	0.12	0.2	0.05
30	5	133871	1904	414	85	0	0	44	0	12	2	2	0	5257	55363	0	610	11	215	30	0.12	0.2	0.05
40	6	138660	2093	486	130	0	0	68	0	15	2	6	0	5258	56270	0	584	0	215	30	0.12	0.2	0.05
50	7	154533	2333	650	151	0	0	82	0	19	5	3	0	5241	57927	0	546	0	215	30	0.12	0.2	0.05
60	8	149458	2192	607	151	0	0	89	0	22	4	4	0	5117	58821	0	507	0	215	30	0.12	0.2	0.05
80	9	164778	2221	654	133	0	0	90	0	25	4	6	0	5146	60891	0	453	0	215	30	0.12	0.2	0.05

100	10	159627		2014	587	127	0	0	85	0	27	5	4	0	5174	61690	0	398	0
	215	30	0.12	0.2	0.05														
120	11	172419		2077	624	118	0	0	82	0	27	6	7	0	5128	63371	0	380	0
	215	30	0.12	0.2	0.05														
140	12	167517		1908	615	114	0	0	80	0	31	4	10	0	5118	65894	0	352	0
	215	30	0.12	0.2	0.05														
160	13	176655		1941	693	105	0	0	79	0	31	6	3	0	5115	67241	0	327	0
	215	30	0.12	0.2	0.05														
180	14	183426		1979	705	94	0	0	77	0	32	6	5	0	5096	70361	0	326	0
	215	30	0.12	0.2	0.05														
210	15	176070		1852	709	78	0	0	73	0	32	7	5	0	5068	70378	0	305	0
	215	30	0.12	0.2	0.05														
240	16	183908		1871	731	65	0	0	68	0	33	7	3	0	5113	69803	0	291	0
	215	30	0.12	0.2	0.05														
270	17	177933		1761	694	58	0	0	63	0	31	7	2	0	5100	68911	0	278	0
	215	30	0.12	0.2	0.05														
300	18	169882		1674	690	57	0	0	60	0	33	8	7	0	5139	68039	0	266	0
	215	30	0.12	0.2	0.05														
330	19	161496		1579	697	48	0	0	57	0	33	7	4	0	5103	67457	0	260	0
	215	30	0.12	0.2	0.05														

360	20	164152		1587	702	46	0	0	56	0	33	8	5	0	5124	66895	0	248	0
	215	30	0.12	0.2	0.05														
420	21	160431		1552	733	77	0	0	87	0	55	7	7	0	5145	65484	0	233	0
	215	30	0.12	0.2	0.05														
1320	24	139184		1500	956	66	0	0	64	0	55	8	8	0	5241	56152	0	180	0
	215	30	0.12	0.2	0.05														
1330	25	138802		1504	958	62	0	0	59	0	54	7	9	0	5226	56201	0	176	0
	215	30	0.12	0.2	0.05														
1350	26	135513		1476	978	53	0	0	56	0	51	9	8	0	5233	56182	0	179	0
	215	30	0.12	0.2	0.05														
1370	27	134889		1464	948	54	0	0	55	0	55	8	11	0	5202	55823	0	173	0
	215	30	0.12	0.2	0.05														
1380	28	137593		1519	976	49	0	0	55	0	48	7	10	0	5173	55956	0	180	0
	215	30	0.12	0.2	0.05														
1440	33	138026		1502	986	0	0	0	181	0	51	9	14	0	5262	56123	0	178	0
	215	30	0.12	0.2	0.05														
1470	34	179391		2137	1486	0	0	0	126	0	50	9	10	0	5079	72997	0	264	0
	225	30	0.12	0.2	0.05														
1480	35	190984		2303	1639	21	0	0	112	0	63	10	13	0	5001	78099	0	290	11
	225	30	0.12	0.2	0.05														

1490	36	196289		2408	1726	39	0	0	107	0	71	12	11	0	5004	79937	0	298	0
	225	30	0.12	0.2	0.05														
1500	37	202616		2470	1746	53	0	0	111	0	81	14	11	0	5016	81236	0	301	15
	225	30	0.12	0.2	0.05														
1520	38	203902		2500	1826	65	0	0	119	0	63	15	11	0	4978	82084	0	299	0
	225	30	0.12	0.2	0.05														
1540	39	204793		2504	1829	82	0	0	123	0	97	13	14	0	4977	82035	0	302	11
	225	30	0.12	0.2	0.05														
1670	48	207761		2484	1877	96	0	0	124	0	125	14	22	0	5205	84110	0	227	0
	225	30	0.12	0.2	0.05														
1680	49	205241		2462	1840	106	0	0	131	0	130	17	16	0	5222	83679	0	237	0
	225	30	0.12	0.2	0.05														
1690	50	205728		2474	1870	114	0	0	126	0	131	19	24	0	5227	84159	0	222	0
	225	30	0.12	0.2	0.05														
1700	51	205795		2449	1844	109	0	0	128	0	130	16	25	0	5233	84272	0	223	0
	225	30	0.12	0.2	0.05														
1710	52	215301		2579	1986	116	0	0	130	0	131	16	19	0	5226	84505	0	222	0
	225	30	0.12	0.2	0.05														
1720	53	211876		2543	1960	106	0	0	129	0	130	20	22	0	5267	84504	0	235	0
	225	30	0.12	0.2	0.05														

1740	54	216521		2586	1998	97	0	0	114	0	125	15	23	0	5212	84102	0	220	0
	225	30	0.12	0.2	0.05														
1750	55	210271		2512	1899	102	0	0	123	0	128	18	20	0	5270	84182	0	231	0
	225	30	0.12	0.2	0.05														
1760	56	208575		2472	1812	107	0	0	127	0	129	18	18	0	5253	83946	0	223	0
	225	30	0.12	0.2	0.05														
1780	57	211647		2480	1852	104	0	0	130	0	133	16	21	0	5270	83973	0	214	0
	225	30	0.12	0.2	0.05														
1800	58	209636		2472	1888	114	0	0	135	0	141	19	21	0	5275	83798	0	213	0
	225	30	0.12	0.2	0.05														
1860	59	214200		2512	1912	141	0	0	144	0	120	14	15	0	5237	84600	0	219	0
	225	30	0.12	0.2	0.05														
2775	61	228806		1996	1467	146	0	0	151	0	131	22	21	0	5226	90012	0	199	11
	225	30	0.12	0.2	0.05														
2785	62	233099		2029	1473	151	0	0	143	0	134	22	18	0	5195	90388	0	194	0
	225	30	0.12	0.2	0.05														
2795	63	233460		2060	1483	156	0	0	145	0	136	22	20	0	5194	90295	0	192	0
	225	30	0.12	0.2	0.05														
2805	64	231016		2048	1485	161	0	0	149	0	140	24	16	0	5187	90504	0	201	0
	225	30	0.12	0.2	0.05														

2815	65	229967	1984	1455	172	0	0	152	0	147	22	18	0	5221	90554	0	184	10	225	30	0.12	0.2	0.05
2835	66	229556	1929	1457	163	0	0	147	0	146	25	17	0	5203	90874	0	191	0	225	30	0.12	0.2	0.05
2855	67	226536	1912	1456	156	0	0	150	0	143	25	20	0	5238	90665	0	188	0	225	30	0.12	0.2	0.05
2875	68	227847	1885	1387	155	0	0	145	0	142	22	15	0	5239	90929	0	188	0	225	30	0.12	0.2	0.05

Excel data for Fig. 9

Liq sample	Time (min)	T (°C)	Area	Conv
APR-12-1	60	215		27.82%
APR-12-5	300	215	5309.8	27.54%
APR-12-6	360	215	5317.2	27.44%
APR-12-7	420	215	5387.7	26.47%
APR-12-8	1320	215	5479.8	25.22%
APR-12-9	1380	215	5496.4	24.99%
APR-12-10	1440	215	5473.7	25.30%
APR-12-11	1500	235	4549.6	37.91%
APR-12-12	1560	235	4550.5	37.90%
APR-12-14	1680	235	4480.3	38.86%
APR-12-15	1740	235	4494.1	38.67%
APR-12-16	1800	235	4491.4	38.71%
APR-12-17	1860	235	4476.3	38.91%
APR-12-18	2775	235	4220.5	42.40%

APRdatatest for Fig. 11 and Fig. 12

0	1	58	0	0	0	0	229	0	12	0	4	0	0	5295	0	142262	0	0	150	14.2	0.12	0.05	0.05
10	2	48	0	0	0	0	187	0	9	0	3	0	0	5248	0	141901	0	0	150	14.3	0.12	0.05	0.05
20	3	129	0	0	0	0	164	0	8	0	2	0	0	5219	704	141605	26	0	150	14.2	0.12	0.05	0.05
30	4	21825	0	0	0	0	153	0	10	0	0	0	0	5222	4839	140552	14	0	150	14.2	0.12	0.05	0.05
40	5	45796	0	0	0	0	144	0	13	0	0	0	0	5162	7000	139482	36	0	150	14.2	0.12	0.05	0.05
50	6	52935	0	0	0	0	137	0	11	0	11	0	0	5153	8270	139203	44	0	150	15.3	0.12	0.05	0.05
60	7	53544	0	0	0	0	131	0	12	0	13	0	0	5165	8352	139117	51	0	150	14.9	0.12	0.05	0.05
70	8	53926	0	0	0	0	126	0	12	0	18	0	0	5125	8741	138837	55	0	150	14.9	0.12	0.05	0.05
90	9	58098	0	0	0	0	119	0	12	0	20	0	0	5149	9112	138731	68	0	150	14.9	0.12	0.05	0.05

112	10	57351	0	0	0	0	119	0	17	0	33	0	0	5157	9294	138777	62	0
	150	14.9	0.12	0.05	0.05													
130	11	59372	0	0	0	0	111	0	18	0	21	0	0	5184	9484	139127	65	0
	150	14.9	0.12	0.05	0.05													
150	12	59364	0	0	0	0	107	0	17	0	23	0	0	5153	9516	138917	70	0
	150	14.9	0.12	0.05	0.05													
181	13	59289	0	0	0	0	101	0	16	0	23	0	0	5154	9566	139087	64	0
	150	14.9	0.12	0.05	0.05													
4360	19	1513	0	0	0	0	0	34	0	21	65	134	411	5650	180	153934	0	0
	150	14.9	0.12	0.05	0.05													
4370	20	1314	0	0	0	0	0	17	0	10	40	87	305	5439	55	149279	0	0
	150	14.9	0.12	0.05	0.05													
4380	21	6154	0	0	0	0	0	11	0	7	23	60	229	5541	1057	146213	29	0
	150	14.9	0.12	0.05	0.05													
4390	22	26522	0	0	0	0	0	8	0	4	16	43	174	5476	4048	143652	0	0
	150	14.9	0.12	0.05	0.05													
4400	23	50303	0	0	0	0	0	4	0	3	13	25	131	5351	7338	141531	0	0
	150	14.9	0.12	0.05	0.05													
4410	24	55864	0	0	0	0	0	4	0	6	13	21	103	5315	8647	140479	0	0
	150	14.9	0.12	0.05	0.05													

4413	25	56404	0	0	0	0	0	2	0	4	13	12	77	5259	8798	140216	0	0
	150	14.9	0.12	0.05	0.05													
4420	26	55473	0	0	0	0	0	5	0	3	16	10	63	5203	9121	139750	0	0
	150	14.9	0.12	0.05	0.05													
4435	27	55382	0	0	0	0	0	3	0	0	22	12	55	5254	9845	139315	0	0
	150	14.9	0.12	0.05	0.05													
4450	28	54642	0	0	0	0	0	4	0	0	25	8	40	5218	9780	138928	0	0
	150	14.9	0.12	0.05	0.05													
4465	29	53744	0	0	0	0	0	2	0	4	24	6	34	5211	9717	138601	0	111
	150	14.9	0.12	0.05	0.05													
4480	30	53008	0	0	0	0	0	2	0	2	27	3	29	5195	9733	138650	0	106
	150	14.9	0.12	0.05	0.05													
4510	31	55189	0	0	0	0	0	3	0	0	24	5	23	5233	9678	138612	0	111
	150	14.9	0.12	0.05	0.05													
4540	32	54570	0	0	0	0	0	3	0	0	24	5	22	5216	9533	138717	0	110
	150	14.9	0.12	0.05	0.05													
4570	33	56663	0	0	0	0	0	3	0	0	23	2	19	5191	9474	138782	0	106
	150	14.9	0.12	0.05	0.05													
4600	34	56294	0	0	0	0	0	3	0	0	23	6	19	5189	9376	138696	0	102
	150	15	0.12	0.05	0.05													

4610	35	53856	0	0	0	0	0	3	0	0	27	1	17	5182	9349	138433	0	108
	152	15	0.12	0.05	0.05													
4620	36	61851	0	0	0	0	0	2	0	1	23	3	15	5190	10437	138232	0	117
	154	15	0.12	0.05	0.05													
4630	37	69053	0	0	0	0	0	0	0	0	27	0	11	5195	11502	137858	0	124
	155	15	0.12	0.05	0.05													
4640	38	71790	0	0	0	0	0	0	0	0	27	0	11	5195	12008	137846	0	126
	155	15	0.12	0.05	0.05													
4650	39	71786	0	0	0	0	0	0	0	0	27	0	0	5179	12232	137847	0	125
	155	15	0.12	0.05	0.05													
4660	40	75136	0	0	0	0	0	0	0	0	28	0	0	5169	12393	137482	0	130
	155	15	0.12	0.05	0.05													
4675	41	71979	0	0	0	0	0	0	0	0	29	0	0	5057	12289	137493	0	124
	155	15	0.12	0.05	0.05													
8605	42	80169	0	0	0	0	0	13	5	0	43	0	0	5117	13131	137889	0	108
	155	15.1	0.12	0.05	0.05													
8620	43	76084	0	0	0	0	0	11	5	0	42	0	0	5122	12564	137613	0	100
	155	15	0.12	0.05	0.05													
8635	44	78226	0	0	0	0	0	7	3	0	41	0	0	5144	12553	137249	0	103
	155	15	0.12	0.05	0.05													

8654	45	76382	0	0	0	0	0	6	3	0	39	0	0	5062	12298	137070	0	107
	155	15	0.12	0.05	0.05													
8680	46	85210	0	0	0	0	0	4	3	0	43	0	0	5048	13346	136430	0	106
	155	15	0.12	0.05	0.05													

Excel data for Fig. 13

		Xylose				Formic acid
	25-0	2216.7				1851.6
Time		Area	Conv	Area	Conv	
150	25-3	630.2	71.57%	1029.1	44.42%	
210	25-4	668.3	69.85%	1057.4	42.89%	
270	25-5	698.7	68.48%	1072.6	42.07%	
330	25-6	725.4	67.28%	1080.4	41.65%	
460	25-7	725.4	67.28%	1080.4	41.65%	
1420	25-8	851.9	61.57%	1126.4	39.17%	
1480	25-9	862.3	61.10%	1134.4	38.73%	
1540	25-10	872.1	60.66%	1141.8	38.33%	
1600	25-11	876.5	60.46%	1145.1	38.16%	
1660	25-12	886	60.03%	1147.7	38.02%	
1720	25-13	890	59.85%	1149.8	37.90%	
1780	25-14	890.4	59.83%	1146.3	38.09%	
4550	25-17	773.8	65.09%	996.8	46.17%	
4610	25-18	788.6	64.42%	1039.5	43.86%	
4640	25-19	800.6	63.88%	1061.2	42.69%	
4670	25-20	711.8	67.89%	1000.7	45.95%	
8620	25-21	429.4	80.63%	894.2	51.71%	
8680	25-22	393.1	82.27%	853.1	53.93%	

APRdata for Fig. 14

0	2	0	0	0	0	0	0	0	0	0	0	0	0	5883	0	0	0	0	215	30	0.12	0.2	0.05
10	3	18110	362	64	22	0	0	12	0	9	2	4	0	5637	8018	0	128	0	215	30	0.12	0.2	0.05
20	4	117611	1676	297	30	0	0	15	0	9	2	3	0	5340	55416	0	694	0	215	30	0.12	0.2	0.05
30	5	133871	1904	414	85	0	0	44	0	12	2	2	0	5257	55363	0	610	11	215	30	0.12	0.2	0.05
40	6	138660	2093	486	130	0	0	68	0	15	2	6	0	5258	56270	0	584	0	215	30	0.12	0.2	0.05
50	7	154533	2333	650	151	0	0	82	0	19	5	3	0	5241	57927	0	546	0	215	30	0.12	0.2	0.05
60	8	149458	2192	607	151	0	0	89	0	22	4	4	0	5117	58821	0	507	0	215	30	0.12	0.2	0.05
80	9	164778	2221	654	133	0	0	90	0	25	4	6	0	5146	60891	0	453	0	215	30	0.12	0.2	0.05
100	10	159627	2014	587	127	0	0	85	0	27	5	4	0	5174	61690	0	398	0	215	30	0.12	0.2	0.05

120	11	172419	2077	624	118	0	0	82	0	27	6	7	0	5128	63371	0	380	0	215	30	0.12	0.2	0.05
140	12	167517	1908	615	114	0	0	80	0	31	4	10	0	5118	65894	0	352	0	215	30	0.12	0.2	0.05
160	13	176655	1941	693	105	0	0	79	0	31	6	3	0	5115	67241	0	327	0	215	30	0.12	0.2	0.05
180	14	183426	1979	705	94	0	0	77	0	32	6	5	0	5096	70361	0	326	0	215	30	0.12	0.2	0.05
210	15	176070	1852	709	78	0	0	73	0	32	7	5	0	5068	70378	0	305	0	215	30	0.12	0.2	0.05
240	16	183908	1871	731	65	0	0	68	0	33	7	3	0	5113	69803	0	291	0	215	30	0.12	0.2	0.05
270	17	177933	1761	694	58	0	0	63	0	31	7	2	0	5100	68911	0	278	0	215	30	0.12	0.2	0.05
300	18	169882	1674	690	57	0	0	60	0	33	8	7	0	5139	68039	0	266	0	215	30	0.12	0.2	0.05
330	19	161496	1579	697	48	0	0	57	0	33	7	4	0	5103	67457	0	260	0	215	30	0.12	0.2	0.05
360	20	164152	1587	702	46	0	0	56	0	33	8	5	0	5124	66895	0	248	0	215	30	0.12	0.2	0.05

420	21	160431		1552	733	77	0	0	87	0	55	7	7	0	5145	65484	0	233	0
	215	30	0.12	0.2	0.05														
1320	24	139184		1500	956	66	0	0	64	0	55	8	8	0	5241	56152	0	180	0
	215	30	0.12	0.2	0.05														
1330	25	138802		1504	958	62	0	0	59	0	54	7	9	0	5226	56201	0	176	0
	215	30	0.12	0.2	0.05														
1350	26	135513		1476	978	53	0	0	56	0	51	9	8	0	5233	56182	0	179	0
	215	30	0.12	0.2	0.05														
1370	27	134889		1464	948	54	0	0	55	0	55	8	11	0	5202	55823	0	173	0
	215	30	0.12	0.2	0.05														
1380	28	137593		1519	976	49	0	0	55	0	48	7	10	0	5173	55956	0	180	0
	215	30	0.12	0.2	0.05														
1440	33	138026		1502	986	0	0	0	181	0	51	9	14	0	5262	56123	0	178	0
	215	30	0.12	0.2	0.05														
1470	34	179391		2137	1486	0	0	0	126	0	50	9	10	0	5079	72997	0	264	0
	225	30	0.12	0.2	0.05														
1480	35	190984		2303	1639	21	0	0	112	0	63	10	13	0	5001	78099	0	290	11
	225	30	0.12	0.2	0.05														
1490	36	196289		2408	1726	39	0	0	107	0	71	12	11	0	5004	79937	0	298	0
	225	30	0.12	0.2	0.05														

1500	37	202616		2470	1746	53	0	0	111	0	81	14	11	0	5016	81236	0	301	15
	225	30	0.12	0.2	0.05														
1520	38	203902		2500	1826	65	0	0	119	0	63	15	11	0	4978	82084	0	299	0
	225	30	0.12	0.2	0.05														
1540	39	204793		2504	1829	82	0	0	123	0	97	13	14	0	4977	82035	0	302	11
	225	30	0.12	0.2	0.05														
1630	43	182858		2229	1688	93	0	0	115	0	107	15	14	0	4644	77159	0	249	12
	225	30	0.12	0.2	0.05														
1640	44	186969		2255	1652	92	0	0	116	0	116	17	16	0	4444	76895	0	233	0
	225	30	0.12	0.2	0.05														
1650	45	191792		2290	1711	98	0	0	116	0	115	15	14	0	4239	76421	0	215	0
	225	30	0.12	0.2	0.05														
1670	48	207761		2484	1877	96	0	0	124	0	125	14	22	0	5205	84110	0	227	0
	225	30	0.12	0.2	0.05														
1680	49	205241		2462	1840	106	0	0	131	0	130	17	16	0	5222	83679	0	237	0
	225	30	0.12	0.2	0.05														
1690	50	205728		2474	1870	114	0	0	126	0	131	19	24	0	5227	84159	0	222	0
	225	30	0.12	0.2	0.05														
1700	51	205795		2449	1844	109	0	0	128	0	130	16	25	0	5233	84272	0	223	0
	225	30	0.12	0.2	0.05														

1710	52	215301		2579	1986	116	0	0	130	0	131	16	19	0	5226	84505	0	222	0
	225	30	0.12	0.2	0.05														
1720	53	211876		2543	1960	106	0	0	129	0	130	20	22	0	5267	84504	0	235	0
	225	30	0.12	0.2	0.05														
1740	54	216521		2586	1998	97	0	0	114	0	125	15	23	0	5212	84102	0	220	0
	225	30	0.12	0.2	0.05														
1750	55	210271		2512	1899	102	0	0	123	0	128	18	20	0	5270	84182	0	231	0
	225	30	0.12	0.2	0.05														
1760	56	208575		2472	1812	107	0	0	127	0	129	18	18	0	5253	83946	0	223	0
	225	30	0.12	0.2	0.05														
1780	57	211647		2480	1852	104	0	0	130	0	133	16	21	0	5270	83973	0	214	0
	225	30	0.12	0.2	0.05														
1800	58	209636		2472	1888	114	0	0	135	0	141	19	21	0	5275	83798	0	213	0
	225	30	0.12	0.2	0.05														
1860	59	214200		2512	1912	141	0	0	144	0	120	14	15	0	5237	84600	0	219	0
	225	30	0.12	0.2	0.05														
2775	61	228806		1996	1467	146	0	0	151	0	131	22	21	0	5226	90012	0	199	11
	225	30	0.12	0.2	0.05														
2785	62	233099		2029	1473	151	0	0	143	0	134	22	18	0	5195	90388	0	194	0
	225	30	0.12	0.2	0.05														

2795	63	233460		2060	1483	156	0	0	145	0	136	22	20	0	5194	90295	0	192	0
	225	30	0.12	0.2	0.05														
2805	64	231016		2048	1485	161	0	0	149	0	140	24	16	0	5187	90504	0	201	0
	225	30	0.12	0.2	0.05														
2815	65	229967		1984	1455	172	0	0	152	0	147	22	18	0	5221	90554	0	184	10
	225	30	0.12	0.2	0.05														
2835	66	229556		1929	1457	163	0	0	147	0	146	25	17	0	5203	90874	0	191	0
	225	30	0.12	0.2	0.05														
2855	67	226536		1912	1456	156	0	0	150	0	143	25	20	0	5238	90665	0	188	0
	225	30	0.12	0.2	0.05														
2875	68	227847		1885	1387	155	0	0	145	0	142	22	15	0	5239	90929	0	188	0
	225	30	0.12	0.2	0.05														
2895	69	241412		2036	1483	168	0	0	154	0	145	27	20	0	5175	98320	0	202	0
	225	36.5	0.12	0.2	0.05														
2905	70	226216		1864	1256	127	0	0	129	0	133	25	18	0	5213	88634	0	181	11
	225	36.5	0.12	0.2	0.05														
2915	71	211998		1756	1132	99	0	0	114	0	117	21	20	0	5261	83334	0	168	19
	225	37	0.12	0.2	0.05														
2925	72	214403		1811	1209	92	0	0	107	0	109	21	21	0	5260	85421	0	180	0
	225	37	0.12	0.2	0.05														

2935	73	216778		1777	1189	87	0	0	108	0	106	22	20	0	5241	85765	0	180	0
	225	37	0.12	0.2	0.05														
2945	74	213896		1746	1138	87	0	0	107	0	108	23	16	0	5235	85711	0	188	0
	225	37	0.12	0.2	0.05														
2955	75	220875		1838	1207	85	0	0	106	0	101	20	15	0	5255	85877	0	189	0
	225	37	0.12	0.2	0.05														
2980	76	270603		2460	1670	89	0	0	122	0	112	23	15	0	5072	109720		0	263
	0	235	37	0.12	0.2	0.05													
2985	77	290230		2740	1913	127	0	0	143	0	125	27	14	0	5024	115541		0	284
	11	235	37	0.12	0.2	0.05													
2995	78	308393		2920	2023	260	0	0	211	0	164	32	17	0	4941	121662		0	309
	19	235	37	0.12	0.2	0.05													
3005	79	317912		2970	2036	323	0	0	244	0	189	32	16	0	4926	124181		0	319
	19	235	37	0.12	0.2	0.05													
3015	80	315728		2940	2042	373	0	0	273	0	212	34	20	0	4920	123812		0	321
	23	235	37	0.12	0.2	0.05													
3025	81	306980		2801	2031	414	0	0	291	0	229	37	20	0	4904	121583		0	316
	13	235	37	0.12	0.2	0.05													
3035	82	310294		2874	2047	397	0	0	287	0	230	38	19	0	4813	122316		0	339
	21	235	37	0.12	0.2	0.05													

3080	83	303704		2753	2018	437	0	0	301	0	245	37	23	0	4625	118787	0	336
	21	235	37	0.12	0.2	0.05												
3085	84	304516		2753	2018	426	0	0	305	0	248	39	19	0	4674	117725	0	335
	24	235	37	0.12	0.2	0.05												
3090	85	299795		2735	2028	414	0	0	294	0	244	38	23	0	4634	118000	0	336
	22	235	37	0.12	0.2	0.05												
3110	86	295031		2710	2088	395	0	0	284	0	239	37	21	0	4620	117120	0	327
	21	235	37	0.12	0.2	0.05												
3125	87	294536		2679	2033	376	0	0	275	0	239	36	24	0	4632	116510	0	332
	23	235	37	0.12	0.2	0.05												
3135	88	295590		2690	2055	372	0	0	273	0	238	38	25	0	4681	116467	0	322
	25	235	37	0.12	0.2	0.05												
3155	89	288239		2673	2050	364	0	0	268	0	237	38	22	0	4699	115812	0	320
	24	235	37	0.12	0.2	0.05												
3175	90	295584		2671	2104	383	0	0	288	0	251	40	26	0	4624	115449	0	313
	25	235	37	0.12	0.2	0.05												
3195	91	298027		2698	2142	373	0	0	279	0	243	39	26	0	4677	115024	0	312
	26	235	37	0.12	0.2	0.05												

Excel data for Fig. 15

TOS	H2 sel	CO2 sel	Conv	1440	80.71%	93.52%	25.30%	2815	79.51%	94.69%	
				1470	80.79%	93.15%		2835	80.36%	94.66%	43.63%
10	88.54%	88.59%		1480	80.53%	93.23%		2855	80.25%	94.81%	
20	78.67%	89.69%		1490	79.10%	93.01%		2875	81.84%	94.74%	
30	77.41%	89.94%		1500	79.59%	93.22%	37.91%	2895	78.86%	94.89%	39.07%
40	72.09%	90.67%		1520	78.91%	92.87%		2905	79.11%	94.89%	
50	75.86%	90.87%		1540	83.03%	92.78%	37.90%	2915	80.38%	95.12%	
60	72.16%	92.06%		1630	81.33%	93.23%	37.55%	2925	79.92%	95.23%	
80	75.90%	92.60%		1640	78.97%	93.44%		2935	80.91%	95.19%	
100	72.64%	93.19%		1650	80.26%	93.47%		2945	78.55%	95.25%	
120	77.92%	93.39%	29.04%	1670	80.70%	93.32%		2955	81.63%	94.92%	46.32%
140	75.78%	93.86%		1680	81.00%	93.36%	38.86%	2980	79.84%	94.55%	
160	76.53%	94.07%		1690	81.13%	93.41%		2985	78.67%	94.02%	
180	79.84%	94.17%	28.77%	1700	77.82%	93.47%		2995	77.79%	93.89%	
210	76.11%	94.54%		1710	78.96%	93.34%		3005	77.86%	93.60%	
240	77.75%	94.65%	28.56%	1720	77.12%	93.61%		3015	78.54%	93.49%	64.31%
270	80.34%	94.58%		1740	79.35%	93.45%	38.67%	3025	78.05%	93.35%	63.54%
300	83.73%	94.51%		1750	79.85%	93.54%		3035	77.29%	93.17%	
330	81.84%	94.68%	27.54%	1760	78.79%	93.63%		3080	76.40%	93.17%	
360	81.71%	94.38%	27.44%	1780	79.25%	93.48%		3085	77.75%	93.13%	
420	80.45%	94.01%	26.47%	1800	78.35%	93.52%	38.71%	3090	78.42%	93.13%	
1320	80.79%	94.07%	25.22%	1860	78.83%	94.47%	38.91%	3110	78.17%	93.17%	
1330	82.63%	93.97%		2775	77.93%	94.75%	42.40%	3125	77.90%	93.21%	
1350	82.54%	94.03%		2785	77.69%	94.71%		3135	79.36%	93.12%	62.00%
1370	81.11%	94.03%		2795	78.59%	94.58%		3155	77.16%	93.14%	
1380	80.78%	93.67%	24.99%	2805	78.95%	94.52%		3175	76.30%	93.21%	

Excel data for Fig. 16

T(K)	X	1/T	ln(X)
487	0.2795	0.00205	-1.274805
498	0.3836	0.00201	-0.958213
508	0.6318	0.00197	-0.459207

APRdatatest for Fig. 17

%TOS	Sample		CO2	C2H6	C3H8	i-C4	n-C4	neo-C5	i-C5	n-C5	i-C6	n-C6	c-C6	n-C7	He	H2	N2	CH4	CO
	Temp	Pressure		Gas	Liquid	xylitol													
310	23	49819	368	106	0	0	0	17	0	4	3	11	0	5263	19610	0	123	0	170
	30	0.04	0.2	0.05															
320	24	48480	351	110	0	0	0	17	0	5	2	4	0	5208	19859	0	122	0	170
	30	0.04	0.2	0.05															
330	25	59814	447	142	0	0	0	19	0	4	4	2	0	5118	25071	0	147	0	170
	30	0.04	0.2	0.05															
340	26	71528	513	162	0	0	0	22	0	4	2	15	0	5129	28804	0	163	0	170
	30	0.04	0.2	0.05															

350	27 30	75368 0.04	523 0.2	177 0.05	0	0	0	26	0	4	2	3	0	5069	30010	0	164	0	170
360	28 30	73745 0.04	515 0.2	171 0.05	0	0	0	26	0	3	1	5	0	5124	30051	0	161	0	170
380	29 30	74213 0.04	497 0.2	189 0.05	0	0	0	25	0	5	0	10	0	5116	30268	0	155	0	170
400	30 30	75983 0.04	493 0.2	180 0.05	0	0	0	26	0	4	2	13	0	5085	30666	0	154	0	170
420	31 30	74173 0.04	474 0.2	157 0.05	0	0	0	23	0	4	3	16	0	5085	30885	0	142	0	170
1450	33 30	84210 0.04	334 0.2	138 0.05	0	0	0	42	0	10	3	4	0	4930	33494	0	92	0	170
1460	34 30	85650 0.04	336 0.2	142 0.05	0	0	0	35	0	9	0	2	0	5086	34924	0	90	0	170
1470	35 30	85165 0.04	339 0.2	132 0.05	0	0	0	0	0	0	0	0	0	5144	35125	0	84	0	170
1480	36 30	86783 0.04	331 0.2	172 0.05	0	0	0	26	0	6	0	15	0	5111	35351	0	79	0	170
1500	37 30	87089 0.04	333 0.2	141 0.05	0	0	0	22	0	4	1	12	0	5129	35649	0	87	0	170

1510	38	72613	263	122	0	0	0	16	0	2	0	5	0	5161	28018	0	70	0	170	22	0.04	0.2	0.05
1520	39	40848	150	74	0	0	0	17	0	2	4	2	0	5232	17440	0	44	0	170	22	0.04	0.2	0.05
1530	40	87196	363	157	0	0	0	16	0	4	13	0	0	5078	36242	0	96	0	170	22	0.04	0.2	0.05
1540	41	95173	384	136	0	0	0	16	0	2	18	3	0	5053	40661	0	106	0	170	22	0.04	0.2	0.05
1550	42	99122	396	156	0	0	0	17	0	3	3	19	0	5041	41020	0	105	0	170	22	0.04	0.2	0.05
1560	43	98979	389	160	0	0	0	18	0	3	2	12	0	5069	41246	0	103	0	170	22	0.04	0.2	0.05
1580	44	96038	384	165	0	0	0	16	0	5	2	7	0	5043	41093	0	107	0	170	22	0.04	0.2	0.05
1600	45	100500	396	209	0	0	0	26	0	2	4	2	0	5098	41138	0	105	0	170	22	0.04	0.2	0.05
1620	46	99520	389	170	0	0	0	16	0	2	1	14	0	5094	41916	0	106	0	170	22	0.04	0.2	0.05

Excel data for Fig. 18

TOS	H2 sel	CO2 sel	Conv
310	78.57%	94.11%	
320	81.80%	94.14%	
330	83.78%	94.24%	4.40%
340	80.68%	94.46%	
350	80.02%	94.75%	
360	81.87%	94.73%	
380	82.02%	94.81%	2.85%
400	81.26%	94.92%	
420	84.01%	95.13%	3.65%
1450	81.67%	96.81%	6.32%
1460	83.88%	96.99%	
1470	85.26%	97.46%	
1480	83.92%	97.12%	
1500	84.33%	97.13%	
1510	79.63%	97.30%	
1520	87.75%	96.90%	4.35%
1530	85.47%	96.95%	
1540	87.90%	97.00%	
1550	85.16%	97.02%	
1560	85.84%	97.11%	
1580	88.04%	97.01%	5.09%
1600	84.26%	97.04%	
1620	86.72%	97.07%	5.13%

Excel data for Fig. 19

				Averg conv (%)
APR 19-6	360	30	2.85%	
APR 19-7	420	30	3.65%	3.62%
APR 19-9	1560	30	4.35%	
APR 19-10	1560	22	5.09%	5.11%
APR 19-11	1620	22	5.13%	

APR Datatest for Fig. 20

%TOS	Sample		CO2	C2H6	C3H8	i-C4	n-C4	neo-C5	i-C5	n-C5	i-C6	n-C6	c-C6	n-C7	He	H2	N2	CH4	CO
	Temp	Pressure		Gas	Liquid xylitol														
0	1	0	0	0	0	0	13	0	0	21	4	9	0	5643	0	0	0	0	215
	35	0.12	0.2	0.05															
10	2	0	0	0	0	0	0	10	0	13	3	5	0	5633	0	0	0	0	215
	35	0.12	0.2	0.05															
20	3	897	896	172	0	0	0	8	0	7	5	4	0	5409	28253	0	460	0	215
	35	0.12	0.2	0.05															
30	4	110099		1223	274	0	0	0	22	0	8	3	5	0	5192	47045	0	598	0
	215	35	0.12	0.2	0.05														
40	5	113924		1280	343	0	0	0	42	0	11	2	6	0	5179	46985	0	548	0
	215	35	0.12	0.2	0.05														
50	6	117525		1330	405	0	0	0	62	0	14	3	5	0	5212	47313	0	520	0
	215	35	0.12	0.2	0.05														
60	7	122306		1359	445	0	0	0	71	0	16	3	5	0	5202	48360	0	482	0
	215	35	0.12	0.2	0.05														
70	8	126476		1371	458	0	0	0	74	0	20	4	1	0	5202	49118	0	461	0
	215	35	0.12	0.2	0.05														

80	9	128362		1354	474	0	0	0	79	0	23	2	2	0	5182	50399	0	439	0
	215	35	0.12	0.2	0.05														
90	10	130511		1340	526	0	0	0	82	0	24	4	0	0	5155	51465	0	421	0
	215	35	0.12	0.2	0.05														
100	11	136224		1337	498	0	0	0	84	0	27	4	5	0	5238	52608	0	399	0
	215	35	0.12	0.2	0.05														
110	12	135180		1286	499	0	0	0	86	0	28	4	2	0	5187	53328	0	386	0
	215	35	0.12	0.2	0.05														
120	13	135635		1255	513	0	0	0	88	0	30	4	2	0	5232	53876	0	369	0
	215	35	0.12	0.2	0.05														
140	14	139673		1203	506	0	0	0	85	0	30	4	4	0	5252	54278	0	329	0
	215	35	0.12	0.2	0.05														
160	15	140599		1253	552	0	0	0	80	0	32	5	2	0	5238	55494	0	328	0
	215	35	0.12	0.2	0.05														
180	16	135091		1106	548	0	0	0	80	0	30	3	2	0	5248	55399	0	297	0
	215	35	0.12	0.2	0.05														
210	17	134923		1077	552	0	0	0	73	0	31	4	4	0	5248	55311	0	276	0
	215	35	0.12	0.2	0.05														
240	18	136985		1037	576	0	0	0	68	0	34	3	5	0	5205	55349	0	262	0
	215	35	0.12	0.2	0.05														

270	19	140238	1067	615	0	0	0	65	0	32	5	2	0	5196	55733	0	266	0	215	35	0.12	0.2	0.05
300	20	134093	995	560	0	0	0	63	0	35	4	2	0	5275	54889	0	251	0	215	35	0.12	0.2	0.05
1310	21	127301	859	805	0	0	0	53	0	40	6	5	0	4739	47604	0	128	0	215	35	0.12	0.2	0.05
1320	22	123119	817	795	0	0	0	52	0	39	9	2	0	5158	47476	0	132	0	215	35	0.12	0.2	0.05
1330	23	122187	797	765	0	0	0	50	0	42	7	7	0	5312	47751	0	144	0	215	35	0.12	0.2	0.05
1340	24	120553	790	759	0	0	0	48	0	41	7	9	0	5325	47787	0	144	0	215	35	0.12	0.2	0.05
1350	25	121491	799	774	0	0	0	48	0	43	9	12	0	5307	47852	0	145	0	215	35	0.12	0.2	0.05
1380	26	117745	803	747	0	0	0	48	0	40	9	6	0	5335	47517	0	151	0	215	35	0.12	0.2	0.05
1440	27	120431	854	853	0	0	0	48	0	44	8	8	0	5346	46867	0	159	0	215	35	0.12	0.2	0.05
1450	28	91496	666	710	0	0	0	48	0	41	10	5	0	5387	36609	0	110	0	215	30	0.12	0.2	0.05

1460	29	129169	892	951	0	0	0	51	0	47	10	9	0	5233	50542	0	154	0	215	30	0.12	0.2	0.05
1470	30	126780	866	900	0	0	0	58	0	55	12	5	0	5260	51111	0	158	0	215	30	0.12	0.2	0.05
1480	31	128011	874	948	0	0	0	60	0	57	10	10	0	5289	50720	0	149	0	215	30	0.12	0.2	0.05
1490	32	129147	870	961	0	0	0	60	0	58	11	8	0	5261	50770	0	150	0	215	30	0.12	0.2	0.05
1500	33	124385	844	959	0	0	0	60	0	60	9	14	0	5290	50760	0	150	0	215	30	0.12	0.2	0.05
1550	34	128816	916	1029	0	0	0	67	0	68	9	9	0	5322	51261	0	152	0	215	30	0.12	0.2	0.05
1560	35	128362	909	1026	0	0	0	68	0	70	12	11	0	5219	51376	0	150	0	215	30	0.12	0.2	0.05
1580	36	128563	923	1032	0	0	0	67	0	69	7	16	0	5264	51712	0	158	0	215	30	0.12	0.2	0.05
1600	37	130093	938	1062	0	0	0	70	0	73	32	8	0	5215	51655	0	153	0	215	30	0.12	0.2	0.05
1620	38	130027	932	1042	0	0	0	70	0	74	11	13	0	5245	51388	0	153	0	215	30	0.12	0.2	0.05

1650	39	128926	911	1015	0	0	0	69	0	73	12	11	0	5299	51510	0	149	0	215	30	0.12	0.2	0.05
1680	40	128338	888	988	0	0	0	66	0	74	14	14	0	5253	51520	0	146	0	215	30	0.12	0.2	0.05
1710	41	129064	949	1069	0	0	0	67	0	74	14	11	0	5311	51653	0	159	0	215	30	0.12	0.2	0.05
1740	42	128577	904	1065	0	0	0	69	0	74	12	13	0	5229	51634	0	145	0	215	30	0.12	0.2	0.05
2750	43	167031	1131	1068	0	0	0	68	0	77	11	16	0	5646	59684	0	138	0	215	30	0.12	0.2	0.05
2760	44	154063	1102	1203	0	0	0	70	0	74	14	14	0	5470	58964	0	106	0	215	30	0.12	0.2	0.05
2780	45	147922	1040	1190	0	0	0	78	0	80	17	9	0	5206	58215	0	120	0	215	30	0.12	0.2	0.05
2800	46	147250	963	1070	0	0	0	81	0	84	15	12	0	5177	58124	0	116	0	215	30	0.12	0.2	0.05
2820	47	146521	978	1017	0	0	0	79	0	85	19	16	0	5186	58152	0	120	0	215	30	0.12	0.2	0.05
2840	48	134084	964	989	0	0	0	83	0	88	14	15	0	5216	58301	0	119	0	215	30	0.12	0.2	0.05

2860	49	147020		1015	1104	0	0	0	80	0	88	18	12	0	5166	58656	0	126	0
	215	30	0.12	0.2	0.05														
2880	50	147380		900	937	0	0	0	79	0	92	16	16	0	5158	58402	0	107	0
	215	30	0.12	0.2	0.05														
2890	51	145724		876	955	0	0	0	75	0	86	17	16	0	5168	56496	0	106	0
	215	25	0.12	0.2	0.05														
2900	52	144666		918	1139	0	0	0	73	0	81	18	12	0	5175	58355	0	106	0
	215	25	0.12	0.2	0.05														
2910	53	156710		992	1279	0	0	0	84	0	93	22	14	0	5181	61762	0	109	0
	215	25	0.12	0.2	0.05														
2920	54	155995		960	1269	0	0	0	97	0	102	24	14	0	5174	62400	0	106	0
	215	25	0.12	0.2	0.05														
2930	55	157471		1013	1352	0	0	0	108	0	119	26	15	0	5122	62122	0	113	0
	215	25	0.12	0.2	0.05														
2940	56	160670		1144	1548	0	0	0	118	0	132	24	16	0	5148	63977	0	119	0
	215	25	0.12	0.2	0.05														
3000	57	157227		997	1386	0	0	0	195	0	189	27	16	0	5146	62555	0	101	0
	215	25	0.12	0.2	0.05														
3020	58	159020		992	1374	0	0	0	181	0	195	26	18	0	5158	62624	0	100	0
	215	25	0.12	0.2	0.05														

3040	59	158849	1073	1632	0	0	0	171	0	198	28	21	0	5169	62078	0	100	0	215	25	0.12	0.2	0.05
3060	60	171989	1490	2016	0	0	0	181	0	211	30	20	0	5144	67022	0	125	0	215	25	0.12	0.2	0.05
3070	61	162882	1126	1681	0	0	0	193	0	223	34	20	0	5096	63388	0	106	0	215	25	0.12	0.2	0.05
3080	62	160217	989	1463	0	0	0	196	0	236	33	24	0	5132	62883	0	92	0	215	25	0.12	0.2	0.05
3100	63	154055	871	1223	0	0	0	171	0	220	29	22	0	5150	62452	0	87	0	215	25	0.12	0.2	0.05
3120	64	160038	929	1346	0	0	0	148	0	202	32	25	0	5173	62873	0	89	0	215	25	0.12	0.2	0.05
3150	65	160157	1047	1654	0	0	0	144	0	199	29	26	0	5126	63460	0	97	0	215	25	0.12	0.2	0.05
3180	66	155292	877	1320	0	0	0	163	0	216	29	28	0	5146	62471	0	84	0	215	25	0.12	0.2	0.05

Excel data for Fig. 21

TOS	H2 sel	CO2 sel	Conv
10	77.38%	90.62%	23.21%
20	76.51%	91.23%	
30	75.52%	91.68%	
40	76.61%	91.99%	
50	77.14%	92.23%	
60	75.97%	92.75%	
70	77.72%	92.89%	
80	78.42%	93.08%	
90	77.27%	93.74%	
100	78.44%	93.70%	
110	81.74%	93.97%	
120	81.93%	94.22%	22.99%
140	80.96%	94.47%	
160	79.65%	94.50%	
180	82.11%	94.58%	29.02%
210	75.76%	95.51%	
240	78.03%	95.40%	20.93%
270	78.97%	95.26%	
300	80.06%	95.22%	21.63%
1310	79.51%	95.17%	
1320	81.36%	95.05%	22.72%
1330	78.24%	94.79%	
1340	80.33%	94.65%	
1350	78.80%	94.95%	
1380	81.11%	94.86%	23.94%
1440	79.74%	94.88%	
1450	79.13%	94.90%	
1460	81.98%	94.71%	
1470	79.88%	94.63%	
1480	80.32%	94.61%	
1490	80.63%	94.50%	
1500	79.54%	94.45%	23.52%
1550	79.26%	94.55%	
1560	80.20%	94.63%	27.45%
1580	80.63%	94.69%	
1600	80.13%	94.40%	
1620	80.56%	94.58%	26.57%

Excel data for Fig. 22

Sample	Time	Conv	Pressure	AV conv
APR 13-1	60	23.21%	35	
APR 13-2	120	22.99%	35	
APR 13-3	180	29.02%	35	
APR 13-4b	240	20.93%	35	22.57%
APR 13-5	300	21.63%	35	
APR 13-6	1320	22.72%	35	
APR 13-7	1380	23.94%	35	
APR 13-9	1500	23.52%	30	
APR 13-10	1560	27.45%	30	27.91%
APR 13-11	1620	26.57%	30	
APR 13-12	1680	25.66%	30	
APR 13-13	1740	26.40%	30	
APR 13-14	2760	36.80%	30	
APR 13-15	2820	33.58%	30	
APR 13-16	2880	27.83%	30	
APR 13-18	3000	34.79%	25	
APR 13-19	3060	39.55%	25	
APR 13-20	3120	36.09%	25	36.76%
APR 13-21	3180	30.46%	25	
APR 13-22	4200	36.60%	25	

APRdatatest for Fig. 23

%TOS	Sample		CO2	C2H6	C3H8	i-C4	n-C4	neo-C5	i-C5	n-C5	i-C6	n-C6	c-C6	n-C7	He	H2	N2	CH4	CO
	Temp	Pressure		Gas	Liquid	xylitol													
30	4	26899	336	110	0	0	0	456	0	9	8	8	39	5352	10359	0	142	0	170
	30	0.12	0.2	0.05															
40	5	29071	338	134	0	0	0	219	0	7	6	11	27	5337	10939	0	124	0	170
	30	0.12	0.2	0.05															
50	6	30563	342	125	0	0	0	116	0	4	5	9	28	5319	11386	0	132	0	170
	30	0.12	0.2	0.05															

60	7	30023	325	110	0	0	0	73	0	4	4	8	0	5290	11600	0	133	0	170
	30	0.12	0.2	0.05															
80	8	32364	347	106	0	0	0	52	0	3	2	11	0	5293	12396	0	129	0	170
	30	0.12	0.2	0.05															
100	9	32660	334	127	0	0	0	38	0	2	4	5	10	5258	12767	0	128	0	170
	30	0.12	0.2	0.05															
120	10	32655	322	89	0	0	0	32	0	2	4	11	0	5259	12969	0	127	0	170
	30	0.12	0.2	0.05															
140	11	33674	318	112	0	0	0	26	0	5	1	3	0	5269	13291	0	120	0	170
	30	0.12	0.2	0.05															
160	12	34094	326	122	0	0	0	26	0	6	3	5	0	5260	13316	0	120	0	170
	30	0.12	0.2	0.05															
180	13	34343	317	110	0	0	0	22	0	4	1	11	0	5252	13565	0	117	0	170
	30	0.12	0.2	0.05															
190	14	34722	317	121	0	0	0	22	0	3	0	2	0	5252	13576	0	105	0	170
	30	0.08	0.2	0.05															
200	15	40179	362	145	0	0	0	19	0	2	3	3	0	5220	16264	0	132	0	170
	30	0.08	0.2	0.05															
210	16	43754	379	134	0	0	0	19	0	4	5	9	0	5244	17965	0	141	0	170
	30	0.08	0.2	0.05															

220	17	47885	408	143	0	0	0	19	0	5	0	4	0	5210	18444	0	136	0	170
	30	0.08	0.2	0.05															
230	18	47126	396	128	0	0	0	19	0	2	3	2	0	5207	18551	0	132	0	170
	30	0.08	0.2	0.05															
240	19	49955	410	119	0	0	0	17	0	3	3	4	0	5171	18716	0	135	0	170
	30	0.08	0.2	0.05															
260	20	46556	375	100	0	0	0	17	0	4	3	4	0	5227	19102	0	128	0	170
	30	0.08	0.2	0.05															
280	21	47168	369	87	0	0	0	20	0	0	4	2	0	5200	19236	0	127	0	170
	30	0.08	0.2	0.05															
300	22	48714	365	137	0	0	0	19	0	4	0	15	0	5227	19433	0	119	0	170
	30	0.08	0.2	0.05															
310	23	49819	368	106	0	0	0	17	0	4	3	11	0	5263	19610	0	123	0	170
	30	0.04	0.2	0.05															
320	24	48480	351	110	0	0	0	17	0	5	2	4	0	5208	19859	0	122	0	170
	30	0.04	0.2	0.05															
330	25	59814	447	142	0	0	0	19	0	4	4	2	0	5118	25071	0	147	0	170
	30	0.04	0.2	0.05															
340	26	71528	513	162	0	0	0	22	0	4	2	15	0	5129	28804	0	163	0	170
	30	0.04	0.2	0.05															

350	27	75368	523	177	0	0	0	26	0	4	2	3	0	5069	30010	0	164	0	170
	30	0.04	0.2	0.05															
360	28	73745	515	171	0	0	0	26	0	3	1	5	0	5124	30051	0	161	0	170
	30	0.04	0.2	0.05															
380	29	74213	497	189	0	0	0	25	0	5	0	10	0	5116	30268	0	155	0	170
	30	0.04	0.2	0.05															
400	30	75983	493	180	0	0	0	26	0	4	2	13	0	5085	30666	0	154	0	170
	30	0.04	0.2	0.05															
420	31	74173	474	157	0	0	0	23	0	4	3	16	0	5085	30885	0	142	0	170
	30	0.04	0.2	0.05															

Excel data for Fig. 24

TOS	H2 sel	CO2 sel	Conv
30	64.90%	79.45%	
40	68.24%	85.51%	
50	69.27%	87.67%	
60	73.21%	89.34%	
80	73.50%	90.48%	
100	75.10%	90.58%	
120	76.79%	91.16%	
140	76.92%	91.88%	4.63%
160	76.03%	91.78%	
180	77.13%	92.06%	4.80%
190	76.96%	92.81%	
200	79.41%	92.49%	
210	80.64%	92.60%	
220	76.27%	93.35%	
230	78.07%	93.50%	
240	74.49%	93.73%	
260	81.54%	93.69%	4.25%
280	81.23%	93.91%	
300	79.49%	93.94%	
310	78.57%	94.11%	4.40%
320	81.80%	94.14%	

330	83.78%	94.24%		380	82.02%	94.81%	
340	80.68%	94.46%		400	81.26%	94.92%	
350	80.02%	94.75%		420	84.01%	95.13%	3.65%
360	81.87%	94.73%	2.85%				

APRdatatest for Fig. 25

%TOS	Sample		CO2	C2H6	C3H8	i-C4	n-C4	neo-C5	i-C5	n-C5	i-C6	n-C6	c-C6	n-C7	He	H2	N2	CH4	CO
	Temp	Pressure		Gas	Liquid	xylitol													
1510	38	72613	263	122	0	0	0	16	0	2	0	5	0	5161	28018	0	70	0	170
	22	0.04	0.2	0.05															
1520	39	40848	150	74	0	0	0	17	0	2	4	2	0	5232	17440	0	44	0	170
	22	0.04	0.2	0.05															
1530	40	87196	363	157	0	0	0	16	0	4	13	0	0	5078	36242	0	96	0	170
	22	0.04	0.2	0.05															
1540	41	95173	384	136	0	0	0	16	0	2	18	3	0	5053	40661	0	106	0	170
	22	0.04	0.2	0.05															
1550	42	99122	396	156	0	0	0	17	0	3	3	19	0	5041	41020	0	105	0	170
	22	0.04	0.2	0.05															
1560	43	98979	389	160	0	0	0	18	0	3	2	12	0	5069	41246	0	103	0	170
	22	0.04	0.2	0.05															

1580	44	96038	384	165	0	0	0	16	0	5	2	7	0	5043	41093	0	107	0	170	22	0.04	0.2	0.05
1600	45	100500	396	209	0	0	0	26	0	2	4	2	0	5098	41138	0	105	0	170	22	0.04	0.2	0.05
1620	46	99520	389	170	0	0	0	16	0	2	1	14	0	5094	41916	0	106	0	170	22	0.04	0.2	0.05
1630	47	95836	371	169	0	0	0	14	0	3	2	14	0	5011	41291	0	105	0	170	22	0.08	0.2	0.05
1640	48	69147	266	128	0	0	0	14	0	3	3	1	0	5155	29032	0	78	0	170	22	0.08	0.2	0.05
1650	49	64466	268	146	0	0	0	14	0	3	2	3	0	5196	26993	0	67	0	170	22	0.08	0.2	0.05
1660	50	65497	283	125	0	0	0	14	0	3	2	10	0	5168	26912	0	75	0	170	22	0.08	0.2	0.05
1670	51	62512	265	106	0	0	0	14	0	2	2	15	0	5154	26849	0	79	0	170	22	0.08	0.2	0.05
1680	52	64745	276	108	0	0	0	14	0	3	3	14	0	5197	26812	0	76	0	170	22	0.08	0.2	0.05
1700	53	62685	269	133	0	0	0	15	0	4	2	14	0	5179	26969	0	76	0	170	22	0.08	0.2	0.05

1720	54 22	64392 0.08	276 0.2	138 0.05	0	0	0	14	0	2	7	3	0	5150	26468	0	78	0	170
1740	55 22	65176 0.08	286 0.2	131 0.05	0	0	0	15	0	2	3	4	0	5137	26424	0	70	0	170
1750	56 22	62692 0.12	269 0.2	142 0.05	0	0	0	13	0	5	3	2	0	5145	25677	0	67	0	170
1760	57 22	48226 0.12	218 0.2	108 0.05	0	0	0	13	0	4	2	5	0	5217	20311	0	58	0	170
1770	58 22	47858 0.12	221 0.2	108 0.05	0	0	0	13	0	5	0	3	0	5201	20184	0	58	0	170
1780	59 22	49272 0.12	229 0.2	153 0.05	0	0	0	13	0	4	0	2	0	5175	20167	0	56	0	170
1800	60 22	47092 0.12	220 0.2	109 0.05	0	0	0	12	0	3	2	0	0	5209	20040	0	58	0	170
1820	61 22	47063 0.12	217 0.2	100 0.05	0	0	0	14	0	5	4	3	0	5243	19979	0	54	0	170
1840	62 22	46664 0.12	215 0.2	123 0.05	0	0	0	12	0	4	0	2	0	5270	19979	0	57	0	170
1860	63 22	47070 0.12	216 0.2	129 0.05	0	0	0	13	0	4	3	5	0	5249	19973	0	60	0	170

Excel data for Fig. 26

TOS	H2 sel	CO2 sel	Conv
1510	79.63%	97.30%	4.35%
1520	87.75%	96.90%	
1530	85.47%	96.95%	
1540	87.90%	97.00%	
1550	85.16%	97.02%	
1560	85.84%	97.11%	5.09%
1580	88.04%	97.01%	
1600	84.26%	97.04%	
1620	86.72%	97.07%	5.13%
1630	88.65%	97.01%	
1640	86.38%	97.00%	
1650	86.12%	96.97%	
1660	84.33%	96.77%	
1670	87.97%	96.57%	
1680	84.95%	96.71%	6.46%
1700	88.09%	96.54%	
1720	84.28%	96.67%	
1740	83.34%	96.91%	7.15%
1750	84.17%	96.89%	
1760	86.25%	96.56%	
1770	86.39%	96.57%	
1780	83.82%	96.55%	
1800	87.18%	96.58%	7.10%
1820	87.00%	96.62%	
1840	87.65%	96.52%	
1860	86.68%	96.31%	7.25%

APRdatatest for Fig. 27

%TOS	Sample	CO2	C2H6	C3H8	i-C4	n-C4	neo-C5	i-C5	n-C5	i-C6	n-C6	c-C6	n-C7	He	H2	N2	CH4	CO	Temp	Pressure	Gas	Liquid	xylitol
2950	69	32670	106	88	0	0	0	13	0	2	6	0	0	5252	13810	0	26	0	170	14	0.12	0.2	0.05
2960	70	57580	192	89	0	0	0	15	0	5	4	4	0	5198	23866	0	48	0	170	14	0.12	0.2	0.05
2970	71	56565	185	88	0	0	0	15	0	3	1	3	0	5173	24417	0	61	0	170	14	0.12	0.2	0.05
2980	72	58980	203	94	0	0	0	15	0	5	3	0	0	5166	24408	0	54	0	170	14	0.12	0.2	0.05
3000	73	57820	197	98	0	0	0	16	0	5	1	2	0	5182	24152	0	51	0	170	14	0.12	0.2	0.05
3020	74	56054	195	88	0	0	0	16	0	7	5	3	0	5217	24329	0	64	0	170	14	0.12	0.2	0.05
3040	75	57595	202	109	0	0	0	17	0	5	1	5	0	5245	24212	0	47	0	170	14	0.12	0.2	0.05
3060	76	56740	208	112	0	0	0	15	0	6	1	0	0	5200	24740	0	54	0	170	14	0.12	0.2	0.05

3070	77	59469	212	97	0	0	0	16	0	5	3	2	0	5178	25515	0	56	0	170	14	0.08	0.2	0.05
3080	78	74186	261	96	0	0	0	16	0	7	2	3	0	5121	32109	0	75	0	170	14	0.08	0.2	0.05
3090	79	78428	275	104	0	0	0	15	0	5	4	1	0	5108	33241	0	69	0	170	14	0.08	0.2	0.05
3100	80	76653	260	75	0	0	0	16	0	6	1	2	0	5094	33352	0	71	0	170	14	0.08	0.2	0.05
3120	81	76500	265	99	0	0	0	17	0	4	3	3	0	5134	33489	0	69	0	170	14	0.08	0.2	0.05
3160	82	76890	260	101	0	0	0	15	0	6	5	3	0	5130	33261	0	72	0	170	14	0.08	0.2	0.05
3180	83	76586	257	132	0	0	0	17	0	4	2	4	0	5101	33036	0	70	0	170	14	0.08	0.2	0.05
3190	84	76775	264	125	0	0	0	15	0	5	3	0	0	5119	33503	0	74	0	170	14	0.04	0.2	0.05
3200	85	87928	300	90	0	0	0	19	0	5	3	2	0	5076	39953	0	83	0	170	14	0.04	0.2	0.05
3210	86	121319	391	171	0	0	0	15	0	4	3	4	0	4943	52233	0	114	0	170	14	0.04	0.2	0.05

3220	87	127280	406	148	0	0	0	14	0	4	3	4	0	4900	54114	0	103	0
	170	14	0.04	0.2	0.05													
3230	88	124275	401	140	0	0	0	16	0	4	3	0	0	4931	54847	0	113	0
	170	14	0.04	0.2	0.05													
3240	89	128322	409	169	0	0	0	15	0	6	2	0	0	4926	54950	0	110	0
	170	14	0.04	0.2	0.05													
3260	90	127291	406	130	0	0	0	17	0	5	2	0	0	5118	55074	0	114	0
	170	14	0.04	0.2	0.05													
3280	91	124225	402	143	0	0	0	16	0	6	2	4	0	5101	55131	0	111	0
	170	14	0.04	0.2	0.05													
3300	92	123682	398	151	0	0	0	15	0	5	4	1	0	5081	55140	0	117	0
	170	14	0.04	0.2	0.05													

Excel data for Fig. 28

Name	Time(min)	Area	Convers
APR 19-0	0	7509.5	
APR 19-1	60	6746.5	10.16%
APR 19-2	120	7161.6	4.63%
APR 19-3	180	7149.2	4.80%
APR 19-4	240	7190.5	4.25%
APR 19-5	300	7178.9	4.40%
APR 19-6	360	7295.2	2.85%
APR 19-7	420	7235.7	3.65%
APR 19-8	1440	7035.2	6.32%
APR 19-9	1500	7182.7	4.35%
APR 19-10	1560	7127.6	5.09%
APR 19-11	1620	7124	5.13%
APR 19-12	1680	7024.2	6.46%
APR 19-13	1740	6972.9	7.15%
APR 19-14	1800	6976.6	7.10%
APR 19-15	1860	6965.3	7.25%
APR 19-16	2880	6899.2	8.13%
APR 19-17	2940	6940	7.58%
APR 19-18	3000	6861.8	8.63%
APR 19-19	3060	6863.8	8.60%
APR 19-20	3120	6901.3	8.10%
APR 19-21	3180	6905.5	8.04%
APR 19-22	3240	6995.9	6.84%
APR 19-23	3300	6944.5	7.52%

Excel data for Fig. 29

97.21%		87.16%		
97.46%		85.68%		
97.16%	97.33%	88.96%	86.72%	8.63%
97.39%		85.48%		
97.40%		86.30%		
96.92%		89.22%		
97.39%	97.20%	86.84%	89.22%	8.60%
97.22%		89.91%		

97.28%		88.53%		
97.29%		89.31%		
97.53%	97.45%	87.68%	89.67%	8.10%
97.54%		90.02%		
97.48%	97.45%	90.51%	89.95%	8.04%
97.42%		89.39%		
97.39%	97.54%	89.11%	90.31%	6.84%
97.37%		90.12%		

97.50%	93.97%	97.72%	97.66%	88.75%	90.65%	7.52%
97.53%	89.07%	97.71%		89.67%		
97.80%	88.20%	97.65%		91.92%		
97.66%	91.42%	97.58%		92.27%		

APRdatatest for Fig. 30

%TOS	Sample		CO2	C2H6	C3H8	i-C4	n-C4	neo-C5	i-C5	n-C5	i-C6	n-C6	c-C6	n-C7	He	H2	N2	CH4	CO
	Temp	Pressure		Gas	Liquid	xylitol													
10170	141	41667	170	218	0	0	0	35	0	31	3	6	0	5256	17347	0	26	0	170
	22	0.12	0.05	0.05															
10180	142	42569	176	232	0	0	0	29	0	29	2	5	0	5216	17374	0	19	0	170
	22	0.12	0.05	0.05															
10190	143	41606	182	211	0	0	0	27	0	23	3	8	0	5236	17605	0	26	0	170
	22	0.12	0.05	0.05															
10200	144	42050	174	236	0	0	0	24	0	19	2	6	0	5245	17571	0	22	0	170
	22	0.12	0.05	0.05															
10220	145	41622	172	231	0	0	0	21	0	18	5	8	0	5276	17601	0	23	0	170
	22	0.12	0.05	0.05															
10240	146	42767	180	206	0	0	0	23	0	16	4	10	0	5231	17587	0	19	0	170
	22	0.12	0.05	0.05															

10260	147 22	43701 0.12	194 0.05	193 0.05	0	0	0	24	0	14	5	7	0	5241	17656	0	24	0	170
10270	148 22	41792 0.12	182 0.1	167 0.05	0	0	0	24	0	14	33	10	0	5262	17546	0	25	0	170
10280	149 22	39312 0.12	137 0.1	159 0.05	0	0	0	24	0	16	4	6	0	5236	16267	0	20	0	170
10290	150 22	44204 0.12	138 0.1	179 0.05	0	0	0	23	0	15	3	6	0	5252	18189	0	18	0	170
10300	151 22	41442 0.12	136 0.1	155 0.05	0	0	0	22	0	14	4	6	0	5222	17362	0	22	0	170
10310	152 22	45902 0.12	156 0.1	172 0.05	0	0	0	19	0	12	0	7	0	5237	18227	0	18	0	170
10320	153 22	41950 0.12	139 0.1	146 0.05	0	0	0	19	0	12	3	5	0	5280	17313	0	16	0	170
10360	154 22	43078 0.12	150 0.1	143 0.05	0	0	0	18	0	9	3	5	0	5223	17763	0	18	0	170
10380	155 22	41491 0.12	137 0.1	163 0.05	0	0	0	16	0	11	2	5	0	5254	17806	0	14	0	170
10390	156 22	41661 0.12	135 0.2	140 0.05	0	0	0	16	0	8	2	4	0	5249	17938	0	20	0	170

10400	157 22	43749 0.12	123 0.2	135 0.05	0	0	0	15	0	9	4	10	0	5205	18159	0	0	0	170
10410	158 22	42769 0.12	125 0.2	138 0.05	0	0	0	13	0	7	4	3	0	5246	18771	0	13	0	170
10420	159 22	44102 0.12	123 0.2	113 0.05	0	0	0	14	0	9	2	5	0	5225	19190	0	16	0	170
10430	160 22	45791 0.12	126 0.2	143 0.05	0	0	0	15	0	8	3	9	0	5240	19294	0	13	0	170
10440	161 22	44440 0.12	121 0.2	138 0.05	0	0	0	13	0	7	4	4	0	5242	17658	0	12	0	170
10450	162 22	44196 0.12	121 0.2	165 0.05	0	0	0	11	0	6	2	4	0	5288	19581	0	14	0	170
10460	163 22	48074 0.12	137 0.2	145 0.05	0	0	0	12	0	6	2	5	0	5237	19575	0	15	0	170
10480	164 22	44582 0.12	129 0.2	156 0.05	0	0	0	11	0	7	3	3	0	5234	19511	0	22	0	170
10500	165 22	45114 0.12	130 0.2	123 0.05	0	0	0	11	0	7	3	3	0	5243	19200	0	15	0	170

Excel data for Fig. 31

Name	Time(min)	P(bar)	Convers	Liq flow
APR 19-1	60	30	10.16%	0.2
APR 19-2	120	30	4.63%	0.2
APR 19-3	180	30	4.80%	0.2
APR 19-4	240	30	4.25%	0.2
APR 19-5	300	30	4.40%	0.2
APR 19-6	360	30	2.85%	0.2
APR 19-7	420	30	3.65%	0.2
APR 19-8	1440	30	6.32%	0.2
APR 19-9	1500	30	4.35%	0.2
APR 19-10	1560	22	5.09%	0.2
APR 19-11	1620	22	5.13%	0.2
APR 19-12	1680	22	6.46%	0.2
APR 19-13	1740	22	7.15%	0.2
APR 19-14	1800	22	7.10%	0.2
APR 19-15	1860	22	7.25%	0.2
APR 19-16	2880	22	8.13%	0.2
APR 19-17	2940	22	7.58%	0.2
APR 19-18	3000	14	8.63%	0.2
APR 19-19	3060	14	8.60%	0.2
APR 19-20	3120	14	8.10%	0.2
APR 19-21	3180	14	8.04%	0.2
APR 19-22	3240	14	6.84%	0.2
APR 19-23	3300	14	7.52%	0.2
APR 19-24	7380	14	13.18%	0.2
APR 19-25	7440	14	10.80%	0.2
APR 19-26	7500	14	17.36%	0.1
APR 19-27	7560	14	16.73%	0.1
APR 19-28	7620	14	17.40%	0.1
APR 19-29	8730	14	16.14%	0.1
APR 19-30	8790	14	15.90%	0.1
APR 19-31	8850	14	51.55%	0.05
APR 19-32	8910	14	35.38%	0.05
APR-19-33	8970	14	29.30%	0.05
APR 19-34	9030	14	29.29%	0.05
APR 19-35	9090	14	32.65%	0.05
APR 19-36	10100	14	29.88%	0.05
APR 19-37	10160	14	34.20%	0.05
APR 19-38	10220	22	100.00%	0.05
APR 19-39	10280	22	22.64%	0.05
APR 19-40	10340	22	12.61%	0.1
APR 19-41	10400	22	13.00%	0.1
APR 19-42	10460	22	7.50%	0.2
APR 19-43	10520	22	7.38%	0.2
APR 19-44	11520	22	9.04%	0.2
APR 19-45	11700	30	8.22%	0.2
APR 19-46	11760	30	8.21%	0.2
APR 19-47	11820	30	8.00%	0.2
APR 19-48	12960	30	14.16%	0.1
APR 19-49	13020	30	13.30%	0.1
APR 19-50	13080	30	13.26%	0.1
APR 19-51	13140	30	20.70%	0.05

APR 19-52	13200	30	24.90%	0.05
APR 19-53	13260	30	25.05%	0.05
APR 19-54	13320	30	25.16%	0.05

Excel data for Fig. 32

TOS	H2 sel	CO2	Conv
10150	81.68%	95.74%	29.88%
10160	78.20%	95.97%	34.20%
10170	84.81%	96.04%	
10180	83.49%	96.44%	
10190	86.37%	96.24%	
10200	85.53%	96.50%	
10220	86.49%	96.43%	
10240	84.37%	96.73%	
10260	82.86%	96.69%	
10270	85.62%	96.15%	
10280	85.04%	96.89%	22.64%
10290	84.88%	97.25%	
10300	86.25%	97.06%	
10310	82.07%	97.44%	
10320	85.32%	97.46%	
10360	85.27%	97.49%	12.61%
10380	88.77%	97.52%	
10390	89.04%	97.50%	
10400	86.49%	98.24%	13.00%
10410	91.15%	97.91%	
10420	90.39%	97.93%	
10430	87.47%	97.88%	
10440	82.61%	98.02%	
10450	91.99%	97.89%	
10460	84.66%	98.02%	7.50%
10480	90.63%	97.63%	
10500	88.50%	98.04%	

APRdatatest for Fig. 33

%TOS	Sample		CO2	C2H6	C3H8	i-C4	n-C4	neo-C5i-C5		n-C5	i-C6	n-C6	c-C6	n-C7	He	H2	N2	CH4	CO
	Temp	Pressure		Gas	Liquid xylitol														
0	1	288	14	39	0	0	0	6	0	0	0	0	0	5511	0	0	0	0	170
	14	0.12	0.2	0.05															
10	2	8538	139	99	0	0	12190	5	0	0	0	0	0	5438	3088	0	62	0	170
	14	0.12	0.2	0.05															
20	3	9798	145	86	0	0	12451	6	0	0	0	0	0	5382	4333	0	71	0	170
	14	0.12	0.2	0.05															
30	4	10734	144	51	0	0	13708	6	0	0	0	0	0	5309	4956	0	94	0	170
	14	0.12	0.2	0.05															
40	5	11818	146	70	0	0	13804	4	0	0	0	0	0	5310	5502	0	109	0	170
	14	0.12	0.2	0.05															
50	6	13125	151	69	0	0	13891	2	0	0	0	0	0	5313	6151	0	125	0	170
	14	0.12	0.2	0.05															
60	7	14487	170	60	0	0	13945	4	0	0	0	0	0	5353	6782	0	134	0	170
	14	0.12	0.2	0.05															
70	8	15289	165	71	0	0	14036	3	0	0	0	0	0	5307	7108	0	139	0	170
	14	0.12	0.2	0.05															

80	9	16478	169	69	0	0	14133	5	0	0	0	0	0	5299	7497	0	148	0	170
	14	0.12	0.2	0.05															
90	10	17264	179	67	0	0	14205	3	0	0	0	0	0	5334	7665	0	149	0	170
	14	0.12	0.2	0.05															
110	11	17322	163	62	0	0	14256	4	0	0	0	0	0	5295	7897	0	116	0	170
	14	0.12	0.2	0.05															
130	12	18249	152	70	0	0	14315	4	0	0	0	0	0	5308	7988	0	60	0	170
	14	0.12	0.2	0.05															
150	13	19777	160	66	0	0	14435	5	0	0	0	0	0	5282	8276	0	57	0	170
	14	0.12	0.2	0.05															
170	14	19851	157	67	0	0	14528	7	0	0	0	0	0	5301	8463	0	53	0	170
	14	0.12	0.2	0.05															
190	15	20251	149	75	0	0	14555	7	0	0	0	0	0	5275	8734	0	51	0	170
	14	0.12	0.2	0.05															
210	16	21519	155	71	0	0	14548	8	0	0	0	0	0	5302	8844	0	49	0	170
	14	0.12	0.2	0.05															
230	17	21377	152	49	0	0	14371	8	0	0	0	0	0	5303	8917	0	47	0	170
	14	0.12	0.2	0.05															
260	18	21002	137	66	0	0	12583	8	0	0	0	0	0	5285	8951	0	48	0	170
	14	0.12	0.2	0.05															

290	19	20934	141	79	0	0	9493	10	0	0	0	0	0	5294	8958	0	46	0	170
	14	0.12	0.2	0.05															
320	20	21204	134	87	0	0	8006	12	0	0	0	0	0	5295	9152	0	39	0	170
	14	0.12	0.2	0.05															
350	21	22399	136	56	0	0	7140	12	0	0	0	0	0	5319	9205	0	40	0	170
	14	0.12	0.2	0.05															
1345	22	21988	74	54	0	0	5184	13	0	0	0	0	0	5273	9555	0	18	0	170
	14	0.12	0.2	0.05															
1370	23	23917	76	39	0	0	4811	13	0	0	0	0	0	5258	9860	0	26	0	170
	14	0.12	0.2	0.05															
1400	24	23413	72	59	0	0	4351	11	0	0	0	0	0	5270	9708	0	19	0	170
	14	0.12	0.2	0.05															
1430	25	22379	74	43	0	0	3947	13	0	0	0	0	0	5511	9600	0	19	0	170
	14	0.12	0.2	0.05															
1460	26	22899	70	40	0	0	3602	8	0	0	0	0	0	5438	9375	0	22	0	170
	14	0.12	0.2	0.05															
1490	27	23109	73	31	0	0	2990	11	0	0	0	0	0	5382	9511	0	17	0	170
	14	0.12	0.2	0.05															
1520	28	22853	68	58	0	0	2300	9	0	0	0	0	0	5309	9385	0	19	0	170
	14	0.12	0.2	0.025															

1550	29	19839	67	64	0	0	1500	8	0	0	0	0	0	5310	8674	0	18	0	170
	14	0.12	0.2	0.025															
1610	30	22019	59	46	0	0	1000	8	0	0	0	0	0	5313	8997	0	12	0	170
	14	0.12	0.2	0.025															
1640	31	21570	66	49	0	0	850	8	0	0	0	0	0	5353	8844	0	21	0	170
	14	0.12	0.2	0.025															
1790	32	19799	62	60	0	0	600	9	0	0	0	0	0	5307	8348	0	20	0	170
	14	0.12	0.2	0.025															
2840	33	18109	46	37	0	0	400	9	0	0	0	0	0	5299	7784	0	16	0	170
	14	0.12	0.2	0.025															
2870	34	19012	53	35	0	0	431	8	0	0	0	0	0	5334	7768	0	11	0	170
	14	0.12	0.2	0.025															
2900	35	18130	63	38	0	0	343	6	0	0	0	0	0	5295	7814	0	12	0	170
	14	0.12	0.2	0.025															
2930	36	18948	53	74	0	0	728	9	0	0	0	0	0	5308	7797	0	14	0	170
	14	0.12	0.2	0.025															
2960	37	18836	62	48	0	0	699	8	0	0	0	0	0	5282	7762	0	13	0	170
	14	0.12	0.2	0.025															
2990	38	18138	56	38	0	0	646	6	0	0	0	0	0	5301	7796	0	12	0	170
	14	0.12	0.2	0.025															

3020	39	17771	50	52	0	0	646	6	0	0	0	0	0	5275	7616	0	10	0	170
	14	0.12	0.2	0.025															
3050	40	18762	51	54	0	0	601	6	0	0	0	0	0	5302	7643	0	12	0	170
	14	0.12	0.2	0.025															
3080	41	18553	57	31	0	0	522	7	0	0	0	0	0	5303	7672	0	0	0	170
	14	0.12	0.2	0.025															
3110	42	18521	53	46	0	0	450	7	0	0	0	0	0	5285	7609	0	14	0	170
	14	0.12	0.2	0.025															
3140	43	17629	59	34	0	0	380	7	0	0	0	0	0	5294	7628	0	15	0	170
	14	0.12	0.2	0.025															
3170	44	18314	56	49	0	0	296	5	0	0	0	0	0	5295	7654	0	16	0	170
	14	0.12	0.2	0.025															
3200	45	17799	54	42	0	0	228	6	0	0	0	0	0	5319	7606	0	11	0	170
	14	0.12	0.2	0.025															

Excel data for Fig. 34

Sample	Time	Area	Conver	AV conv
APR 20-1	50	7203.2	4.34%	
APR 20-2	110	7139.9	5.18%	
APR 20-3	170	7314.9	2.85%	3.23%
APR 20-4	230	7309.8	2.92%	
APR 20-5	290	7273.3	3.41%	
APR 20-6	350	7300	3.05%	
APR 20-7	1370	7299.7	3.06%	
APR 20-9	1490	7305	2.99%	
APR 20-13	2840	3465.3	6.80%	
APR 20-14	2900	3451.5	7.17%	6.91%
APR 20-16	3020	3473.2	6.59%	

APR 20-17	3080	3486.5	6.23%
APR 20-18	3140	3460.4	6.93%
APR 20-19	3200	3477.6	6.47%
APR 20-20	4250	3453.6	7.11%
APR 20-21	4310	3459	6.97%
APR 20-22	4370	3453.4	7.12%
APR 20-23	4430	3450.1	7.21%
APR 20-24	4490	3450.6	7.19%
APR 20-25	4550	3458	7.00%
APR 20-26	4610	3453	7.13%
APR 20-27	4670	3462.8	6.87%

APRdatatest for Fig. 35

%TOS	Sample		CO2	C2H6	C3H8	i-C4	n-C4	neo-C5i-C5		n-C5	i-C6	n-C6	c-C6	n-C7	He	H2	N2	CH4	CO
	Temp	Pressure		Gas	Liquid	xylitol													
0	1	288	14	39	0	0	0	6	0	0	0	0	0	5511	0	0	0	0	170
	14	0.12	0.2	0.05															
10	2	8538	139	99	0	0	12190	5	0	0	0	0	0	5438	3088	0	62	0	170
	14	0.12	0.2	0.05															
20	3	9798	145	86	0	0	12451	6	0	0	0	0	0	5382	4333	0	71	0	170
	14	0.12	0.2	0.05															
30	4	10734	144	51	0	0	13708	6	0	0	0	0	0	5309	4956	0	94	0	170
	14	0.12	0.2	0.05															
40	5	11818	146	70	0	0	13804	4	0	0	0	0	0	5310	5502	0	109	0	170
	14	0.12	0.2	0.05															

50	6	13125	151	69	0	0	13891	2	0	0	0	0	0	5313	6151	0	125	0	170
	14	0.12	0.2	0.05															
60	7	14487	170	60	0	0	13945	4	0	0	0	0	0	5353	6782	0	134	0	170
	14	0.12	0.2	0.05															
70	8	15289	165	71	0	0	14036	3	0	0	0	0	0	5307	7108	0	139	0	170
	14	0.12	0.2	0.05															
80	9	16478	169	69	0	0	14133	5	0	0	0	0	0	5299	7497	0	148	0	170
	14	0.12	0.2	0.05															
90	10	17264	179	67	0	0	14205	3	0	0	0	0	0	5334	7665	0	149	0	170
	14	0.12	0.2	0.05															
110	11	17322	163	62	0	0	14256	4	0	0	0	0	0	5295	7897	0	116	0	170
	14	0.12	0.2	0.05															
130	12	18249	152	70	0	0	14315	4	0	0	0	0	0	5308	7988	0	60	0	170
	14	0.12	0.2	0.05															
150	13	19777	160	66	0	0	14435	5	0	0	0	0	0	5282	8276	0	57	0	170
	14	0.12	0.2	0.05															
170	14	19851	157	67	0	0	14528	7	0	0	0	0	0	5301	8463	0	53	0	170
	14	0.12	0.2	0.05															
190	15	20251	149	75	0	0	14555	7	0	0	0	0	0	5275	8734	0	51	0	170
	14	0.12	0.2	0.05															

210	16	21519	155	71	0	0	14548	8	0	0	0	0	0	5302	8844	0	49	0	170
	14	0.12	0.2	0.05															
230	17	21377	152	49	0	0	14371	8	0	0	0	0	0	5303	8917	0	47	0	170
	14	0.12	0.2	0.05															
260	18	21002	137	66	0	0	12583	8	0	0	0	0	0	5285	8951	0	48	0	170
	14	0.12	0.2	0.05															
290	19	20934	141	79	0	0	9493	10	0	0	0	0	0	5294	8958	0	46	0	170
	14	0.12	0.2	0.05															
320	20	21204	134	87	0	0	8006	12	0	0	0	0	0	5295	9152	0	39	0	170
	14	0.12	0.2	0.05															
350	21	22399	136	56	0	0	7140	12	0	0	0	0	0	5319	9205	0	40	0	170
	14	0.12	0.2	0.05															
1345	22	21988	74	54	0	0	5184	13	0	0	0	0	0	5273	9555	0	18	0	170
	14	0.12	0.2	0.05															
1370	23	23917	76	39	0	0	4811	13	0	0	0	0	0	5258	9860	0	26	0	170
	14	0.12	0.2	0.05															
1400	24	23413	72	59	0	0	4351	11	0	0	0	0	0	5270	9708	0	19	0	170
	14	0.12	0.2	0.05															
1430	25	22379	74	43	0	0	3947	13	0	0	0	0	0	5511	9600	0	19	0	170
	14	0.12	0.2	0.05															

1460	26	22899	70	40	0	0	3602	8	0	0	0	0	0	5438	9375	0	22	0	170
	14	0.12	0.2	0.05															
1490	27	23109	73	31	0	0	2990	11	0	0	0	0	0	5382	9511	0	17	0	170
	14	0.12	0.2	0.05															

APRdatatest for Fig. 37 and Fig. 39

%TOS	Sample		CO2	C2H6	C3H8	i-C4	n-C4	neo-C5i-C5		n-C5	i-C6	n-C6	c-C6	n-C7	He	H2	N2	CH4	CO
	Temp	Pressure		Gas	Liquid	xylitol													
0	1	79	0	4	0	0	24	3	0	9	0	0	8	5482	0	144616		0	0
	170	14.2	0.12	0.05															
10	2	40	0	17	0	0	13	0	0	7	0	0	9	5419	0	143976		0	0
	170	14.2	0.12	0.05															
20	3	2559	35	14	0	0	8	1	0	0	0	0	8	5408	342	143824		217	0
	170	14.2	0.12	0.05															
30	4	6740	190	53	0	0	6	1	0	5	0	0	9	5372	4178	143055		78	0
	170	14.1	0.12	0.05															
40	5	12180	224	62	0	0	6	1	0	6	0	0	9	5373	6039	142552		96	0
	170	14.1	0.12	0.05															
50	6	14127	257	63	0	0	4	0	0	3	0	0	9	5374	5720	142747		102	0
	170	14.1	0.12	0.05															

60	7	15573	266	63	0	0	3	0	0	5	0	0	7	5375	5864	142507	104	0	170	14.1	0.12	0.05
75	8	16239	267	68	0	0	4	2	0	9	0	0	6	5339	6384	142348	112	0	170	14.1	0.12	0.05
90	9	17423	279	75	0	0	4	3	0	6	0	0	8	5352	6694	142465	112	0	170	14.1	0.12	0.05
105	10	17960	276	77	0	0	5	6	0	6	0	0	5	5392	6796	142281	114	0	170	14.1	0.12	0.05
120	11	18847	294	82	0	0	3	6	0	5	0	0	9	5348	6780	142377	117	0	170	14.1	0.12	0.05
135	12	18044	288	78	0	0	0	8	0	7	1	0	8	5345	6899	142486	113	0	170	14.1	0.12	0.05
150	13	19950	309	61	0	0	5	11	0	8	0	0	6	5408	7034	142397	110	0	170	14.1	0.12	0.05
165	14	19843	300	69	0	0	5	11	0	7	2	0	5	5396	7178	142324	121	0	170	14.1	0.12	0.05
180	15	19314	285	101	0	0	5	14	0	5	3	0	7	5395	7271	142099	116	0	170	14.1	0.12	0.05
210	16	20458	293	75	0	0	4	15	0	9	0	0	5	5345	7466	142167	118	0	170	14.1	0.12	0.05

240	17	20038	323	78	0	0	5	17	0	9	0	0	0	5357	7574	142200		114	0
	170	14.1	0.12	0.05															
270	18	20380	272	55	0	0	5	18	0	8	2	0	8	5326	7308	142208		102	0
	170	14.1	0.12	0.05															
300	19	19479	261	75	0	0	5	20	0	8	0	0	6	5341	7352	142345		103	0
	170	14.1	0.12	0.05															
330	20	19771	259	75	0	0	7	20	0	9	0	0	4	5355	7416	142266		98	0
	170	14.1	0.12	0.05															
360	21	20748	267	83	0	0	6	23	0	11	1	0	6	5384	7381	142122		102	0
	170	14.1	0.12	0.05															
390	22	20830	265	68	0	0	8	24	0	10	0	0	7	5344	7419	141995		102	0
	170	14.1	0.12	0.05															

APRdatatest for Fig. 38 and Fig. 40

%TOS	Sample		CO2	C2H6	C3H8	i-C4	n-C4	neo-C5i-C5		n-C5	i-C6	n-C6	c-C6	n-C7	He	H2	N2	CH4	CO
	Temp	Pressure		Gas	Liquid	xylitol													
0	1	589	0	0	0	0	9237	0	0	5	0	0	7	5517	0	145125		18	0
	168	13.8	0.12	0.05	0.05														
10	2	1352	0	1431	0	0	10196	0	0	4	0	0	0	5437	651	144232		278	0
	174	13.8	0.12	0.05	0.05														

20	3	35728	0	694	0	0	10743	0	40	12	3	0	0	5337	13391	141154		1814	0
	175	13.8	0.12	0.05	0.05														
30	4	16395	0	76	0	0	11061	0	0	8	0	0	0	5433	6411	142885		564	0
	175	13.9	0.12	0.05	0.05														
40	5	15609	0	66	0	0	11346	0	0	8	0	0	0	5399	6596	143261		318	0
	175	13.9	0.12	0.05	0.05														
50	6	18050	0	76	0	0	11630	0	0	6	0	0	9	5405	7852	142747		263	0
	173	14	0.12	0.05	0.05														
60	7	18246	0	70	0	0	11841	0	0	0	0	0	10	5401	7771	142691		229	0
	172	14	0.12	0.05	0.05														
75	8	17990	0	70	0	0	12083	0	0	7	0	0	8	5367	7122	142732		195	0
	171	14	0.12	0.05	0.05														
90	9	18610	0	77	0	0	12321	0	0	6	0	0	0	5440	6772	142945		170	0
	171	14	0.12	0.05	0.05														
105	10	17153	0	61	0	0	12518	0	0	8	0	0	0	5382	6669	142763		157	0
	171	14	0.12	0.05	0.05														
1065	11	16890	0	70	0	0	12601	0	0	6	0	0	0	5396	6458	143291		83	0
	170	14.1	0.12	0.05	0.05														
1080	12	16850	0	59	0	0	13346	0	0	9	0	0	0	5365	6461	142849		85	0
	170	14.1	0.12	0.05	0.05														

1095	13	17161	0	62	0	0	13721	0	0	8	0	0	0	5370	6484	142523	77	0
	170	14.1	0.12	0.05	0.05													
1125	14	17349	0	76	0	0	13969	0	0	9	0	0	0	5392	6516	142629	84	0
	170	14.1	0.12	0.05	0.05													
1155	15	17056	0	72	0	0	14255	0	0	10	0	0	0	5373	6558	142571	77	0
	170	14.1	0.12	0.05	0.05													
1185	16	16959	0	74	0	0	14446	0	0	9	0	0	0	5356	6577	142801	78	0
	170	14.1	0.12	0.05	0.05													