Supporting Information

A critical literature review of the kinetics for the oxidative dehydrogenation of propane over well-defined supported vanadium oxide catalysts

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S1. Calculation and assumptions needed to compare the encountered data:

S1.1 Apparent activation energy for propane ODH, Ea (KJ/mol):

The Arrhenius equation is used (equation A) which express the relationship between the reaction rate constant \( k \) and the temperature \( T \), and where \( A \) is the pre-exponential factor (sometimes also called frequency factor), \( R \) is the universal gas constant, 8.31 J/mol*K, \( T \) is the absolute temperature, and \( E_a \) is the apparent activation energy.

\[
k = A e^{-\frac{E_a}{RT}}
\]  
(equation A)

By taking the logarithm of equation A, equation B is obtained:

\[
\ln k = \ln A - \frac{E_a}{RT}
\]  
(equation B)

Measuring the reaction rate at different temperatures and plotting \( \ln(k) \) against \( 1/T \), a straight line is obtained where its slope and intercept represent the apparent activation energy \( (E_a) \) and the pre-exponential factor \( (A) \), respectively. Since the reaction rate \( (r) \) is giving by equation C, and keeping the initial reactant concentration constant, the Arrhenius equation (equation A), by taking its logarithm, may be writing as in equation D:

\[
\text{rate} = r_0 = k \times [\text{reactants}]
\]  
(equation C)

\[
\ln k = \ln r_0 = \ln A - \frac{E_a}{RT}
\]  
(equation D)

At low conversion levels, where the concentrations of reactants and products is roughly the same, the initial reaction rate is approximately proportional to the reactant conversion \( (X_r) \) showed in equation E:
Finally, equation D could be expressed as equation F wherein, as mentioned the slope and intercept from the straight-line represent the activation energy and the pre-exponential factor, respectively.

\[
\ln(X_r) = \ln A \frac{E_a}{RT} \quad \text{(equation F)}
\]

Most of the studies included in this review generally reported the conversion of propane against temperature plot, instead of the propane ODH apparent activation energy. For the cases where the raw data allowed it, the propane ODH activation energy is calculated based on equation F. As mentioned, activation energies obtained from catalysts with either promoters, vanadia loadings above the monolayer coverage or/and experimental “artifacts” are discarded in this review. Merely few studies needed any kind of assumption to re-calculate the apparent propane ODH activation energy. Some assumptions are based on presumably type-mistakes instead of errors associated to the experiments or the calculations per set. The majority of supported vanadium oxide catalysts excluded in this review are because of the presence of V$_2$O$_5$ NPs evidenced by either UV-vis or Raman spectroscopy.

Due to brevity, only selected studies are included in this information support. From the selected studies listed below, it is important to notice the thorough examination of the data used for this review. The cited number references in this supporting information follow the order used in the main manuscript.

**V/SiO$_2$ catalysts:**

*Puglisi et al.* [139] studied the effect of vanadia loading in propane ODH on V$_2$O$_5$/SiO$_2$ catalysts. The catalysts are prepared by incipient wetness impregnation of the support with a basic solution of ammonium metavanadate. Catalytic measurements are performed using a catalytic fixed bed reactor. Mass and heat transfer effects are excluded. Since they reported the initial reaction rate at different temperatures, the apparent propane ODH activation energy for each studied catalyst is re-calculated based on equation F. For the sake of a proper comparison, only kinetic data from catalysts with vanadia dispersion up to 1.3 Vatom/nm$^2$ is considered.

*Karakoulia et al.* [140] studied propane ODH over vanadia catalysts supported on mesoporous silica with varying pore structure and size. The catalysts are prepared by wet impregnation of
the silica supports using ammonium metavanadate (AMV) dissolved in aqueous solution of oxalic acid. Both mass and heat transfer limitation are excluded (pellets between 20 – 100 µm and diluted into quartz). V$_2$O$_5$ NPs are evidenced by Raman spectra for the 8%V/HMS-3 (2.3 V$_{\text{atom}}$/nm$^2$). As a consequence, this catalyst is not included in this review. Propane ODH activation energy is recalculated by using equation F. Despite of the authors reported propane conversions also above 525 °C, where homogeneous gas phase reactions are expected, only data below this temperature is considered for this review.

*Kondratenko et al.* [39] studied propane ODH over V/MCM-41 catalysts comparing O$_2$ and N$_2$O as oxidants. The catalysts are prepared by two different methods. One type of catalysts is prepared by impregnation of the MCM-41 with a predetermined amount of vanadium acetyl acetate (VAc.) in toluene. The second types of catalysts are prepared by mixing both the vanadyl sulfate (VSul) solution with the MCM-41 precursor prior to the calcination. Only the catalyst 20%V$_2$O$_5$/MCM-41 contains three-dimension V$_2$O$_5$ NPs. Apparent propane ODH activation energy is recalculated using equation F. However, as the data is presented, propane consumption TOF rate does not increase with temperature. If the experiments where identically done and simply temperature is varied, it is not reasonable. Precisely, according to the published data, the reaction goes faster at 425°C than 450°C. Assuming that the kinetic data is not distorted by mass transfer limitation effects, and assuming also a simple type-mistake in the labeling of the figure and moreover considering that logically reaction goes faster at 450°C than 425°C, the recalculated activation energy gives an acceptable value of 113.3 kJ*mol$^{-1}$ which is included in our study.

*Gruene et al.* [141] considered the role of dispersion of vanadia supported on the mesoporous silica SBA-15 in propane ODH. The catalysts are prepared by grafting/anion exchange procedure. The catalytic measurements are performed to improve the heat transfer (catalyst diluted in SiC) and avoiding mass transfer limitation (particles sizes between 200-300 µm). Three-dimensional V$_2$O$_5$ NPs in the catalysts with V loadings between 3.1 and 13.6 V$_{\text{atom}}$/nm$^2$ are clearly evidenced by Raman spectroscopy. Due to that, the catalysts above 2.1 V$_{\text{atom}}$/nm$^2$ are not included in this review. Not calculations are needed for determining the apparent propane ODH activation energy.

*Liu et al.* [35] published the structure and catalytic properties of vanadium oxide supported on mesocellulous silica foams (MCF) for propane ODH. The catalysts are prepared by wet impregnation of MCF with an alcoholic solution of ammonium metavanadate. The kinetic experiments are carried out excluding heat and mass transfer effects. The ~5.6%V/MCF
catalyst shows crystallites of V$_2$O$_5$, evidenced by Raman spectroscopy. For this reason, this catalyst is excluded for this review. The propane conversion as a function of temperature plot shows a wide temperature range (450 – 680°C). However, the data shows clearly homogeneous gas phase reactions above 575°C. For this reason, in order to recalculate the activation energy (based on equation F), the maximum propane conversion considered is 550°C.

Heracleous et al. [116] focused on the synthesis, characterization and reactivity in propane ODH of different silicate materials. All supported vanadia catalysts are prepared by the wet impregnation method using aqueous solution of ammonium metavanadate. The catalytic experiments are conducted in a fixed bed quartz reactor excluding heat and mass transfer effects. The structure and porosity characteristics of the studied catalysts are verified by several techniques and no V$_2$O$_5$ NPs are found on the surface of all the mesoporous silica supports for V-loadings as high as 8 wt.%. However, microporous zeolite and non-porous SiO$_2$ show V$_2$O$_5$ NPs. These catalysts are not included in this review. The apparent activation energy is calculated by using equation F.

Schimoeller et al. [50] studied the reactivity of V/SiO$_2$ catalyst in propane ODH prepared by flame spray pyrolysis (FSP) using ammonium metavanadate as precursor. Interestingly, this method proved to be a very versatile method for synthesis of V$_2$O$_5$/SiO$_2$ catalysts with high dispersion of isolated VO$_x$ species at high surface density. Propane ODH rates are performed avoiding mass transfer effects (particle fractioned at 315 – 450 µm) and improving the heat transfer through the catalyst bed by diluting the catalyst with SiC. Since the authors presented the trajectories of propane conversion against reaction temperature, the apparent propane ODH activation energy is recalculated (equation F). Catalysts with V dispersion above 3.3V$_{\text{atom}}$/nm$^2$ are not considered for this review due to the presence of three-dimension V$_2$O$_5$ NPs as is evidenced by Raman spectroscopy.

V/Al$_2$O$_3$ catalysts:

Routary et al. [92] studied the effect of the material support in propane ODH by kinetic parameter estimation based on a Mars-van Kleveland (MVK) model using a generic algorithm. The studied V$_2$O$_5$/Al$_2$O$_3$ catalyst is prepared by incipient-wetness impregnation method using ammonium metavanadate as precursor. Its characterization evidenced that the catalyst lacks of V$_2$O$_5$ particles on the surface. The apparent propane ODH activation energy obtained is 81±6
kJ/mol. Assuming that heat and mass transfer effects are not taking place in the reported kinetic experiments, the obtained apparent activation energy is included in this review.

Argyle et al. [132] studied the effect of catalyst structure on propane ODH on V$_2$O$_5$/Al$_2$O$_3$ catalysts. Different V$_2$O$_5$/Al$_2$O$_3$ catalysts with a wide range of VOx surface density (1.4 – 34.2 V$_{\text{atom/m}}^2$) are synthesized by incipient wetness impregnation method using ammonium methavanadate as precursor. Raman spectroscopy showed that V is dispersed predominately as isolated monovanadate species below ~ 2.3 V$_{\text{atom/m}}^2$. As surface densities increase, two-dimensional polyvanadate appear (2.3 – 7.0 V$_{\text{atom/m}}^2$), along with increasing amounts of V$_2$O$_5$ crystallites at surface densities above 7.0 V$_{\text{atom/m}}^2$. Because three-dimension V$_2$O$_3$ NPs are formed, even at loading below the monolayer, only the catalyst with 1.4 V$_{\text{atom/m}}^2$ is considered.

Cortey et al. [133] studied the role of potassium on the structure and reactivity of V/Al$_2$O$_3$ catalysts in propane ODH. Since doped-catalysts are not considered in this review, only the V/Al$_2$O$_3$ catalyst without potassium is included. This V$_2$O$_5$/Al$_2$O$_3$ catalyst (4 V$_{\text{atoms/m}}^2$) is prepared by impregnation of a commercial γ-Al$_2$O$_3$ support with an aqueous solution of ammonium metavanadate. Vanadium oxide species are highly dispersed on the catalyst surface as is evidenced by Raman spectroscopy. The apparent propane ODH activation energy is calculated by using equation F.

Shee et al. [112] analyzed the effect of surface V loading on the kinetic parameters of propane ODH on several V$_2$O$_5$/Al$_2$O$_3$ catalysts. The catalysts are prepared by the incipient-wetness impregnation technique. Characterization studies reveal that below the monolayer coverage only surface metal oxide species are present. Above the monolayer (~9 V$_{\text{atom/m}}^2$) coverage, both bulk AlVO$_4$ and V$_2$O$_5$ are also observed by Raman spectroscopy. As consequence, the 17.5%V$_2$O$_5$/Al$_2$O$_3$ catalyst is not included in this review.

Yang et al. [41] studied the propane ODH reaction over binary dispersed oxide catalysts using Al$_2$O$_3$ as support material and MoO$_3$ or Cr$_2$O$_3$ as surface modifiers. The catalysts are prepared by incipient-wetness impregnation of Al$_2$O$_3$ with 2-propanol solutions of vanadyl isopropoxide. V$_2$O$_5$ NPs are detected at high VOx surface density (≥ 8.7 V$_{\text{atom/m}}^2$). For this reason, the catalyst 14.8%V$_2$O$_5$/Al$_2$O$_3$ is not included in this review. The kinetic experiments are carried out avoiding mass and heat transfer effects and the activation energy of the 8.3%V$_2$O$_5$/Al$_2$O$_3$ catalyst (~ 5.3 V$_{\text{atom/m}}^2$) is recalculated based on equation F.

V/TiO$_2$ catalysts:
**Lemonidou et al.** [115] studied the molecular structure and reactivity of vanadium oxide catalysts for propane ODH. The catalysts are prepared by wet-impregnation of TiO$_2$ anatase using aqueous ammonium methavanadate solution. Raman spectroscopy evidenced that the 9.7%V$_2$O$_5$/TiO$_2$ catalyst has V$_2$O$_5$ NPs. This catalyst is excluded in this review. The authors reported the propane conversion as a function of the reaction temperature from which, based on equation F, the apparent propane ODH activation energy is recalculated.

**V/ZrO$_2$ catalysts:**

**Pieck et. al.** [126] studied the oxidative dehydrogenation of propane on VO$_x$/ZrO$_2$ catalysts. Catalysts are prepared by wet-impregnation of the support with an aqueous solution containing ammonium metavanadate as precursor and nitric acid as a component that improve the precursor solubility. This solvent, differs from the majority of the studies reporting the catalyst preparation. Catalysts containing vanadium oxide surface densities above ~ 9 V$_{\text{atom}}$/nm$^2$ showed the existence of V$_2$O$_5$ NPs whereas bellow such loading the vanadium oxide is highly disperse on the catalyst surface. Regarding to the kinetic measurements, they are carried out avoiding mass transfer effects. However, the catalyst bed preparation is not described. For example, the catalyst dilution in a good thermal conductor as SiO$_2$ or SiC is not mentioned. Propane conversion as a function of reaction temperature is reported from which the propane ODH activation energy is recalculated (equation F).

**S1.2 Propane consumption turnover frequency, TOF (s$^{-1}$):**

TOF is given by:

$$\text{TOF} = \frac{\text{moles of propane}}{\text{moles of active metal} \times \text{time}} = \text{s}^{-1}$$

In order to show the propane consumption rate in s$^{-1}$ units (TOF), recalculations from the original data in several studies are required. In most of the cases, only changes in the rate units are needed. However, some recalculations are based on assumptions that are explained in particular cases. In addition, as it was done for the propane activation energy recalculation, only highly dispersed catalysts and correctly tested are included in the TOFs comparative study.

Among others, reaction rates are influenced by temperature. Therefore, in order to do the comparative study properly, considering the propane consumption TOF rate as the comparative parameter, it should be done at same reaction temperature. The studies in
literature are carried out at different reaction temperatures (~ 333 – 600 °C). So, recalculations were done in order to normalize the propane consumption TOF at the same reaction temperature. We selected both 400 and 500 °C due to the following reasons: (1) the majority of the published studies are carried out employing such reaction conditions, or at least between this temperature range, (2) the highest selected temperature (500°C) is far away enough from the temperature where homogeneous gas phase reactions start to take place (~600 °C). Moreover, above 500 °C aggregation of surface V species could occur resulted in the formation of small V$_2$O$_5$ crystallites or even formation of mix oxide species with the material support. (3) The lowest selected temperature (400 °C) is sufficiently high to work at reasonable residences times avoiding either high mass of catalyst or extremely low flow rates. At the same time, (4) lower temperatures reduce the presence of both heat and mass transfer limitations.

For the TOF normalization, apparent propane ODH activation energy is needed. For this, data previously reported from our group is used (Table S1).\[^{37}\]

Table S1. ODP apparent activation energies on differently supported low loading vanadium oxide catalysts

<table>
<thead>
<tr>
<th>Support</th>
<th>V$_2$O$_5$ (% wt.)</th>
<th>$V_{\text{atom}}$/nm$^2$</th>
<th>Ea (kJ/mol)</th>
</tr>
</thead>
<tbody>
<tr>
<td>SiO$_2$</td>
<td>0.6</td>
<td>0.3</td>
<td>146 ± 6</td>
</tr>
<tr>
<td>Al$_2$O$_3$</td>
<td>2.1</td>
<td>2.1</td>
<td>113 ± 6</td>
</tr>
<tr>
<td>TiO$_2$</td>
<td>1.6</td>
<td>1.6</td>
<td>56 ± 5</td>
</tr>
<tr>
<td>ZrO$_2$</td>
<td>1.6</td>
<td>1.6</td>
<td>78 ± 6</td>
</tr>
<tr>
<td>CeO$_2$</td>
<td>1.4</td>
<td>1.4</td>
<td>68 ± 6</td>
</tr>
</tbody>
</table>

However, since the V-loadings showed in Table S1 are considerable low, new vanadium oxide catalysts were synthesized. These new catalysts have V-loadings of approximately 75% of the monolayer coverage. Three-dimension V$_2$O$_5$ NPs are not present on the catalyst surface as it is evidenced by Raman spectroscopy. Details are found elsewhere.\[^{120}\] Table S2 summarized the obtained apparent propane ODH activation energies of high loading vanadium oxide catalysts.

Table S2. ODP apparent activation energies on differently supported high loading vanadium oxide catalysts

<table>
<thead>
<tr>
<th>Support</th>
<th>V$_2$O$_5$ (% wt.)</th>
<th>$V_{\text{atom}}$/nm$^2$</th>
<th>Ea (kJ/mol)</th>
</tr>
</thead>
<tbody>
<tr>
<td>SiO$_2$ *</td>
<td>10.7</td>
<td>1.8</td>
<td>141 ± 8</td>
</tr>
<tr>
<td>Al$_2$O$_3$</td>
<td>8.79</td>
<td>3.1</td>
<td>117 ± 6</td>
</tr>
<tr>
<td>TiO$_2$</td>
<td>1.10</td>
<td>3.5</td>
<td>83 ± 5</td>
</tr>
</tbody>
</table>
The activation energy selected to normalize the TOFs depends on the surface vanadia dispersion (V\text{atom}/nm\textsuperscript{2}) reported for each catalyst. Apparent propane ODH activation energies in Table S1 are used for low V-loading catalysts while data in Table S2 is used for high V-loading catalysts.

The TOF normalization at 400 and 500 °C is based on Arrhenius equations H and I:

\[ \ln \sigma_1 = \ln(A) - \frac{E_a}{RT_1} \]  

(equation H)

\[ \ln \sigma_2 = \ln(A) - \frac{E_a}{RT_2} \]  

(equation I)

Now, combining equation H and equation I and after canceling out the pre-exponential factor (\(\ln(A)\)) because it is not temperature depended, the equation J is obtained:

\[ \ln r_2 - \ln r_1 = \ln \frac{r_2}{r_1} = -\frac{\Delta E_a}{R} \left( \frac{1}{T_2} - \frac{1}{T_1} \right) \]  

(equation J)

where:

\[ r = \text{TOF} = s^{-1} \]  

(equation K)

Solving equation J in terms of \(r_2\) and paying careful attention in the units and using the apparent propane ODH activation energy from either Table S1 or/and Table S2, the propane consumption TOFs at the wish temperature (400 and 500 °C) is obtained.

A can be seen below, few selected studies are listed in order to show some recalculations that are necessary for calculating the propane consumption TOFs.

Puglisi et al. \cite{139} shows the activity of V\textsubscript{2}O\textsubscript{5}/SiO\textsubscript{2} catalysts in the oxidative dehydrogenation of propane at different temperatures. The propane consumption rate is expressed in \(10^{6}\text{molC}_3\text{H}_8\text{g}_{\text{cat}}^{-1}\text{s}^{-1}\) and \(10^{6}\text{molC}_3\text{H}_8\text{g}_{\text{V2O5}}^{-1}\text{s}^{-1}\). These rate units are converted into s\textsuperscript{-1} by using the equation C. For this, the V\textsubscript{2}O\textsubscript{5} concentration (denoted by [\#] symbol in equation L),

<table>
<thead>
<tr>
<th>Catalyst</th>
<th>V\text{atom}/nm\textsuperscript{2}</th>
<th>V\text{atom}/nm\textsuperscript{2}</th>
<th>TOF ± Error</th>
</tr>
</thead>
<tbody>
<tr>
<td>ZrO\textsubscript{2}</td>
<td>2.58</td>
<td>3.1</td>
<td>102 ± 5</td>
</tr>
<tr>
<td>CeO\textsubscript{2}</td>
<td>1.26</td>
<td>3.9</td>
<td>90 ± 4</td>
</tr>
</tbody>
</table>

\*details about this catalyst are found elsewhere.\textsuperscript{34}
the V₂O₅ molecular weight (which is PMV₂O₅ = 181.9 g·mol⁻¹), and the vanadium atomic weigh (PAV = 50.94 g·mol⁻¹) are needed.

\[ r_{c_3H_8} = \frac{molC_3H_8}{g_{cat} \times s} \times \frac{1g\text{ cat}}{10^{-2} g V} \times \frac{PAV}{molV} \times \frac{1 molV}{molV \times s} = s^{-1} \]  

(equation L)

Pena et al. \[142\] studied the selective oxidation of propane over well-organized V/MCM-41 and V/MCM-48 catalysts. Propane consumption rate, is expressed in \(10^6\) molC₃H₈·gcat⁻¹·h⁻¹. Equation M is applied to obtain the propane consumption TOF. The symbol [#] denotes the V₂O₅ concentration given by the authors.

\[ r_{c_3H_8} = \frac{molC_3H_8}{g_{cat} \times h} \times \frac{1g\text{ cat}}{10^{-2} g V} \times \frac{PAV}{molV} \times \frac{1 h}{3600 s} \times \frac{molC_3H_8}{molV \times s} = s^{-1} \]  

(equation M)

Liu et al. \[35\] studied the structure and catalytic properties of V₂O₅/MCF catalysts for propane ODH. The authors reported the TOFs in \(10^{20}\) µmolC₃H₆·Vatom⁻¹·s⁻¹ units. Beside this, the authors presented the TOFs for propene formation instead of propane consumption. In order to calculate the TOFs, the Avogadro’s number (6.024 x 10²³ Vatom/mol) is needed to resolve the equation N.

\[ r_{c_6H_{12}} = \frac{\mu molC_3H_6}{V_{atom} \times s} \times \frac{6.024 \times 10^{23} V_{atom}}{1 molV} \times \frac{1 molC_3H_6}{10^6 \mu molC_3H_6} = \frac{molC_3H_6}{molV \times s} = s^{-1} \]  

(equation N)

Notice that the recalculated rate reflects the propene formation. The propane consumption TOF is obtained by interpretation of the propane ODH reaction network and applying equation O.

The selectivity of propene needed to solving the equation O is acquired from the experimental data reported by the authors. Thus, the propane consumption TOF is recalculated by using the propene formation rate obtained from equation N and solving equation O. Similarly, both equation N and equation O are used for data reported by e.g. Liu et al., \[36\] Zhou et al., \[145\] and Schimoeller et al. \[50\]

Martra et al. \[114\] reported the propen consumption TOFs in nmolC₃H₆·m⁻²·s⁻¹ units for different V₂O₅-supported catalysts. Equation P is used to recalculate propane consumption TOF, in which [BET] represents the catalyst surface area.
S2. Parameters used for the comparative study

1) Reaction Temperature:

Temperature significantly influences reaction kinetics since reaction rates tend to increase with increasing temperature and its quantification is given by the activation energy. Knowledge of the activation energy allows comparison of kinetic data (reaction rates) at the same reaction temperature. Also important to be considered is that reaction temperature should be high enough to get the highest possible selectivity toward propene but without overcome the temperature needed to initiate homogeneous gas-phase reactions (above 550°C). Thus, fixing the kinetic parameters at the same reaction temperature allows minimizing discrepancies due to different reaction conditions and increasing the accuracy in comparisons.

2) Temperature dependency of the oxidative dehydrogenation of propane:

Apparent activation energy (Ea) is an important parameter to consider which can facilitate the explication for agreements or/and disagreements commonly encountered in literature. Especially data with substantial mass transfer limitation can be identified from Ea that are strongly decreased in comparison to kinetically control reaction. Also, the Ea provides a quantitative way to measure the support effect in propane ODH. Moreover, propane ODH activation energy provides the basis to extrapolate propane consumption reaction rates at different reaction temperatures.

3) Propane consumption turnover frequency, TOF:

The TOF is the number of times that the catalytic reaction in question takes place per catalytic site per unit time for a fixed set of reaction conditions (temperature, pressure or concentration, reactants ratio, extent of reaction). In the 1960s, Boudart proposed the concept of the turnover frequency \(^{[109,110]}\). Boudart denoted the turnover frequency (dimension s\(^{-1}\)) as the reaction rate
with respect to the number of catalytic active sites, which was typically measured in a separate chemisorption experiment prior to investigating the reaction rate. This concept became extremely popular in the area of heterogeneous catalysis, both theoretical and applied. However, the TOF is commonly either criticized or object of discussion in heterogeneous catalysis mainly due to the unknown real number of catalytic active sites participating in the reaction. Normally in propane ODH, in order to calculate the TOF over supported vanadium oxide catalysts, it is assumed that vanadium oxide is highly dispersed on the catalyst surfaces and each V atom is involved in the reaction. This assumption, however, is sometimes only based on the vanadium oxide loadings that are below the theoretical monolayer loading instead of being supported by characterization of the catalysts (e.g., Raman or UV-vis spectroscopy). Such an approach leads to doubts about the interpretation of the reported TOF data since the synthesis method may form V$_2$O$_5$ nanoparticles at loadings below theoretical monolayer coverage. Besides, the situation becomes more complicated if the catalysts contain promoters or three-dimensional NPs. Although TOF is extensively used in catalysis literature to express how fast a reaction takes place it is only valid when employing well-characterized model catalysts where vanadium oxide dispersion is 100%. Only such studies reporting TOFs provide us with realistic information to propose unquestionable conclusions regarding the influence of vanadium oxide loadings, support effect, and reaction conditions for the oxidative dehydrogenation of propane.

4) Catalysts surface area, 5) V$_2$O$_5$ loading and 6) vanadia surface density:

Given that TOF is strongly linked to the vanadium oxide dispersion, the three features together, surface area, vanadium oxide loading, and vanadia surface density play an important role to analyze kinetic data properly. Varying one of these three parameters, the vanadium oxide surface specie or/and species involved in the ODP reaction would not be the same anymore. The reaction kinetic parameters obtained from different vanadium oxide species express different catalytic activity. It is much more remarkable if the vanadium loadings overcome the monolayer coverage. The monolayer concept $^{[111]}$, which considers the vanadium oxide loading as well as type of support oxide, plays an important role that should be considered to establish solid conclusions when different kinetic data are compared.

(7) The synthesis method.

As mentioned in the synthesis chapter, the employed catalyst synthesis method strongly influences the final vanadium oxide surface species. Supported vanadium oxide catalysts are
commonly prepared by incipient wetness impregnation using NH$_4$VO$_3$ as precursor. Due to its low solubility in water, oxalic acid is normally used to improve such solubility. The synthesis methods together with the other aspects mentioned above, are used as comparative parameters, which clearly show that the synthesis method plays an important role.