MECHANISTIC STUDIES ON THE MODE OF ACTION OF METHANE MONOOXYGENASE

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ABSTRACT. Consideration is given here to our current understanding of how the enzyme methane monooxygenase effects the O₂- and NADH-dependent oxidation of methane. Physico-chemical analysis of the soluble three-protein enzyme complex from Methylococcus capsulatus (Bath) has indicated that protein C (an iron-sulphur-flavoprotein) passes reducing equivalents from NADH to protein A which then binds the substrate molecule methane. Oxidation of the methane proceeds in the presence of protein B to produce methanol. Kinetic measurements suggest that the rate limiting step in the oxidation is oxidation of the bound substrate rather than the supply of electrons to the enzyme-bound substrate. E.S.R. measurements also suggest that the active site protein of A is, by analogy with ribonucleotide reductase and methaemerythrin, an antiferromagnetically coupled pair of high spin Fe(III) atoms with a bridging oxo-group. Mechanistic studies have indicated that oxidation of aromatic compounds proceeds via arene oxide intermediates implying direct oxygen insertion into the substrate. However the mechanism of oxidation of aliphatic hydrocarbons is still unclear, with evidence for both concerted and two step reactions, although the rate limiting step appears to be C-H bond breakage. Following the recent demonstration that some methanotrophs can express two forms of monooxygenase, substrate specificity data from a variety of sources has been reassessed, enabling comparison of the two enzyme systems and proposals concerning the topography of the active site of the soluble enzyme.

1. INTRODUCTION

The worldwide supply and demand for methanol are currently in balance at around 12 m tonnes per annum, however estimates by the international consulting and research group, Chem Systems Inc. have indicated that the demand for methanol may increase by around 30% by 1990 (see Cameron, 1982). Of the existing feedstock sources for methanol production, the largest, by far, is methane (Fig. 1). Steam reforming of methane at around 800°C in the presence of a nickel...
Catalyst is used to produce synthesis gas, a mixture of carbon monoxide and hydrogen (reaction 1; Fig. 2) (Ghisalba & Heinzer, 1982). The synthesis gas thus produced is too rich in hydrogen for the optimal synthesis of methanol so addition of CO₂ into the reformer shifts the CO:H₂ ratio from 1:3 to the required 1:2 value (reaction 2). This mixture is then catalytically converted to methanol at 250-280°C and 70-110 bar in the presence of a proprietary ICI copper-based catalyst (reaction 3). Because of the overall endothermic nature of the process the conversion efficiency, expressed as the energy available from methanol on combustion compared with the energy input from the feedstock and processing components, is about 60%, or higher (Foo & Heden, 1977). At present there is no direct chemical process for the synthesis of methanol from methane; all processes operating today involve at least two stages with synthesis gas as the intermediate.

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\begin{align*}
\text{15-20\% Ni catalyst on Al}_2\text{O}_3 \text{ or SiO}_2 & \quad \text{CH}_4 + \text{H}_2\text{O} \xrightarrow{700-900^\circ\text{C} \ 1-25 \text{ bar}} \text{CO} + 3\text{H}_2 \\
\text{Ni catalyst} & \quad \text{CO}_2 + \text{H}_2 \xrightarrow{\text{Cu/Zn catalyst}} \text{CO} + \text{H}_2\text{O} \\
\text{Cu/Zn catalyst} & \quad \text{CO} + 2\text{H}_2 \xrightarrow{250-280^\circ\text{C} \ 70-110 \text{ bar}} \text{CH}_3\text{OH}
\end{align*}
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Figure 2. The catalytic synthesis of methanol from methane using the ICI copper-based process.