
Complete Oxidation of Benzene over Au-V₂O₅/TiO₂ and Au-V₂O₅/ZrO₂ Catalysts

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A gold promotional effect is reported for the complete oxidation of benzene using Au/V₂O₅ supported on titania or zirconia catalysts.

The complete catalytic oxidation of hydrocarbons has received much attention in connection with enabling increased environmental protection from their emission from motor vehicles and processing plants. The many studies have involved the use of various metals, metal oxides and mixed metal-metal oxide systems as catalysts for these reactions (1-3).

This paper gives a short account of the high catalytic activity found for the complete oxidation of benzene using gold-promoted vanadium pentoxide catalysts supported on titania or zirconia. There are results described in the literature on the promoting effect of Pd and Ag over supported vanadium pentoxide (2, 3) related to the activation of oxygen, and the reversible oxidation of V⁴⁺, thus leading to an equilibrium in the redox process. The promoting effect of gold in catalysts used for the complete oxidation of various saturated and unsaturated aliphatic hydrocarbons and other materials has already been reported (4); but the present results are the first to describe the effects of gold promotion on supported vanadium pentoxide catalysts for the complete oxidation of benzene.

Six catalyst samples were studied: *ie* Au/TiO₂, V₂O₅/TiO₂, Au/V₂O₅/TiO₂, Au/ZrO₂, V₂O₅/ZrO₂, and Au/V₂O₅/ZrO₂. The samples were prepared by deposition-precipitation of gold onto the support and impregnation with (NH₄)₂[VO(C₂H₄)₂]. The precursors were dried under vacuum and calcined at 400°C for 2 h, the atomic Au:V₂O₅:MO₂ (M = Ti, Zr) ratios being 1 : 1.3 : 31. The average particle size of the supported gold clusters was 2 - 3 nm for those on

titania and 3 - 4 nm for those on zirconia, as determined by X-ray diffraction (XRD) and transmission electron microscopy (TEM).

The catalytic activities of the samples were evaluated in a gradientless reactor with external circulation under the following conditions: catalyst volume - 0.2 cm³ (particle size 0.25 - 0.50 mm), inlet benzene concentration - 0.019 mol m⁻³ in oxygen, temperature range 150 - 400°C. Figure 1 illustrates the catalytic activities obtained at 225°C expressed as moles of benzene oxidized per m² of the surface per second (mol m⁻² s⁻¹).

The activities observed demonstrate that there is a synergistic effect giving increased activity in the catalysts when a combination of gold with vanadium oxide is present on both of the oxide supports employed. The increased benzene conversion effect occurs at about 150°C lower than was found previously for promotion of vanadium oxide catalysts by palladium or silver where the 90 - 95% conversion is reached at 400°C (2, 3). At 250°C, the conversion of benzene on Au/V₂O₅/TiO₂ is 98%, compared with 50% for V₂O₅/TiO₂; and for Au/V₂O₅/ZrO₂ 70% compared with 30% for V₂O₅/ZrO₂.

The unusual properties of the gold nanoclusters thus cause a considerable enhancement of the catalytic activity of the supported vanadium oxide for the complete oxidation of benzene. There are data on the formation of low coverage hydroxy species on gold established by optical and electrochemical measurements (5 - 7). Such surface gold atoms with low coordination numbers are more energy-rich and

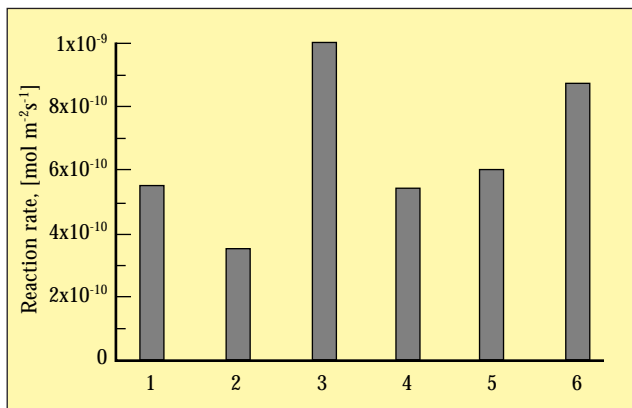


Figure 1 Rates for the complete oxidation of benzene at 225 °C for the catalyst samples: 1 V_2O_5/TiO_2 , 2 Au/TiO_2 , 3 $Au-V_2O_5/TiO_2$, 4 V_2O_5/ZrO_2 , 5 Au/ZrO_2 , 6 $Au-V_2O_5/ZrO_2$.

unusually reactive. Upon oxidation or contact with water these atoms can coordinate more oxygen or hydroxide species and are able to participate actively in redox reactions on the surface. It could be suggested that the activation of oxygen takes place on the finely divided gold particles on the surface while the benzene is adsorbed on vanadium oxide, via a similar mechanism to that proposed by Andreev *et al* (2, 3) for the complete oxidation of benzene on $Pd/V_2O_5/Al_2O_3$ and $Ag/V_2O_5/Al_2O_3$.

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BOOK REVIEWS

The Gold Explorer's Handbook

by James Regan, Published by Rosendale Press (London, UK) 1997, 224 pages, ISBN 1 872803 32 6, Price £25.00

In his foreword, James Regan gives his personal view of gold exploration, which he describes as a colourful and exciting part of human history. The language style in the foreword and elsewhere reflects the fact that James is the son of a professional soldier. The practical details provided throughout the chapters provide ample evidence that he has a valuable working knowledge gained from over thirty years working at the 'front line' of gold exploration in various parts of the world from Australia to Zimbabwe. He is full of praise for field workers and scientists working in gold exploration and emphasizes

the importance of teamwork, careful planning, attention to detail and the value of local knowledge for trouble-free expeditions.

What makes this book a good read as well as a valuable handbook, is the nice combination of real occurrences and stories with thorough, stepwise and practical guidelines to gold exploration provided in the individual chapters. It is written with enthusiasm and style. Since first receiving this book for review some time ago, I have undertaken my own first guided 'expedition' down an abandoned gold mine in Wales and again experienced first-hand the excitement of panning for gold!

The book is divided into two parts, both well presented, with helpful checklists and tables included throughout. In Part 1 (chapters one to seven), important practical guidelines are presented, with Part 2 focusing on more

specialist techniques from chapters eight to ten. Where appropriate, useful literature and book sources for further reading are given at the bottom of the individual pages. Valuable appendices on the properties of gold, a glossary of scientific terms, a bibliography and up-to-date details on key suppliers, and information sources including computer software and web sites are provided at the back of the book. In Chapter 1, the author describes the first steps in the exploration for gold, discussing in particular the budget, potential difficulties with exploration licences, political factors, gaining the co-operation and respecting the customs of the local community, and environmental protection. The required traits of an explorer are emphasized, in such lines as "anyone... who cannot exist without a regular newspaper, hot bath and an air-conditioned room plus liberal

doses of flattery and gratitude, should never consider a career move to the front line of a mineral exploration project". Under the Chapter 2 heading 'the essential field inventory', portable equipment needs are itemized and discussed in Chapter 2, including field testing equipment and less obvious items such as snake-bite serums (although in one account of a real event, a can of beer sufficed and saved the day!). In Chapter 3, the important roles of aerial photography, topographical maps, surveying and the future use of computers and digitized maps are well highlighted. A comprehensive account of the primary gold deposits from Archaean greenstone and gold-quartz conglomerates, to epithermal, porphyry, Carlin-type and volcanic massive sulfide (VMS) deposits is provided in Chapter 4. The author ascertains that gold grains are rarely seen by miners, geologists or surveyors, as the vast majority of the gold particles are tiny and the characteristics of minerals most commonly mistaken for gold by the inexperienced are given. This is followed appropriately by a chapter on the testing and evaluation of such primary deposits. It is another valuable contribution covering visual surveys, pitting and trenching, use of explosives, mineral identification, field testing and rock staining, sampling, drilling systems and even useful computer simulations and software. On the other hand, some geologists claim to recognise distinctive sounds under their feet when strolling across a silicified zone associated with a disseminated gold deposit - life just isn't fair! In a similar manner, secondary gold deposits and their testing are covered in Chapters 6 and 7, including gold panning and the test mining of placer deposits.

In Part 2, the importance of geochemistry in targeting economic

auriferous deposits is described in Chapter 8. Pathfinder minerals are tabulated, with the assertion that the best pathfinder mineral for gold is gold itself. Sections are devoted to sampling in temperate and glaciated terrains, rain forests, stream and lake sediments and the seabed. Methods of trace level gold analysis used in the analytical laboratories are tabulated alongside limit of detection values. Geophysical prospecting and remote sensing techniques are covered in Chapters 9 and 10 respectively. Finally, in an interesting conclusion section entitled 'gold exploration - a growth profession', the impact of new technologies such as bio-leaching and the potential for future technological developments are explored. Such developments should ensure that the recent upsurge in interest and activity in gold exploration will continue.

Books such as this promote the profession and the science admirably.

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The Industry Catalogue of Gold Bars Worldwide

*by Nigel Desebrock, Published by
Grendon International Research Pty
Ltd (Fremantle, Australia) 1998,
344 pages, 950 colour photographs
and illustrations ISBN 0 646 34491
9, Price \$(US)275 (including courier
delivery)*

This catalogue is the outcome of four years' original research into the gold bar markets of 28 countries spread around the world. There is a wealth of valuable information on the enormous range of standard,

innovative and unusual gold bars available worldwide, and this is accompanied by 950 colour photographs and illustrations, including some bars of 100 g and less in actual size. In addition, this authoritative publication provides comprehensive background details on the world's accredited refiners and bar manufacturers, including who they are, where they operate, who owns them, and the company objectives. This catalogue breaks new ground for the gold industry, providing its first definitive reference work on gold bars grouped under major bar categories.

Gold bars are grouped by category, and the book includes comprehensive coverage of the following topics: *Accreditation* - the 61 gold bar manufacturers accredited to the world's major gold associations in London (LBMA), New York (COMEX Division of NYMEX), Tokyo (TOCOM) and Zurich, including listings, ownership and accreditation dates; *Important Standard Bars* - the



Figure Kilobars (100 g) – the world's most widely manufactured bar

world's most widely traded bars: London 'Good Delivery' (400 oz), 1000 g and 10 tola bars; *Other Standard Bars*- all other cast and minted bars issued by accredited manufacturers, in gramme, ounce, tola, tael, baht, chi and don weights; *Innovative and Unusual Bars*- including hologram, kinegram, pendant, decorative, commemorative, gold leaf and yin-yang bars etc; *Technical Descriptions*- by which the weights, dimensions, purities, official stamps and dates are recorded for 750 bars when first issued; *Bulk Packaging*- quantities per box of important gold bars and the materials used; *Gold Bar Manufacture*- how cast and minted gold bars are made; *Gold Refining Services*- covering 53 gold refiners and manufacturers, and including the gold-bearing minerals treated and gold refining methods used; and *Gold Bullion Coins*- an extensive supplement on the world's leading bullion coins.

The catalogue also features *The Industry Collection of Gold Bars Worldwide*. This is the largest collection of gold bars (700) and is the outcome of a collaborative effort among more than 100 bar manufacturers and issuing entities. The sponsor is the World Gold Council. The Custodian and Owner, on behalf of the industry, is N M Rothschild and Sons. The

Curator is Grendon International Research.

The gold industry's reactions to this useful publication have been very positive. For example, Stewart Murray, Chief Executive, Gold Fields Mineral Services Ltd said that "I am tremendously impressed with the scope and quality of information in *The Industry Catalogue of Gold Bars Worldwide*. With its comprehensive treatment and elegant photographs, this volume should find a place on the bookshelf of anyone interested in the gold business." The comments from E M Hood, Chief Executive Officer, World Gold Council, were

"*The Industry Catalogue of Gold Bars Worldwide* provides an authoritative source of knowledge on the surprisingly diverse and fascinating array of gold bars produced around the world. Grendon International Research can be commended for compiling what will become a standard reference work for the industry itself and all who have an interest in gold."

An order form can be obtained from Nigel Desebrock, Grendon International Research Pty Ltd, 33 Alexandra Road, East Fremantle, WA 6158, Australia, Tel: 61 8 9319 2171; Fax: 61 8 9319 2171 E-mail: grendon@global.net.au

