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Case No: HC10C01570 and HC13B01040

IN THE HIGH COURT OF JUSTICE
CHANCERY DIVISION
PATENTS COURT

Rolls Building
Fetter Lane, London, EC4A 1NL

Date: 22 September 2014

Before :

THE HON MR JUSTICE ARNOLD

Between :

COMPACTGTL LIMITED	<u>Claimant</u>
- and -	
(1) VELOCYS PLC	<u>Defendants</u>
(2) VELOCYS INC	
(3) BATTELLE MEMORIAL INSTITUTE	

And between :

VELOCYS INC	<u>Claimant</u>
- and -	
(1) COMPACTGTL LIMITED	<u>Defendants</u>
(2) BATTELLE MEMORIAL INSTITUTE	

Iain Purvis QC and Henry Ward instructed by **Bird & Bird LLP** for **Velocys**
Andrew Lykiardopoulos QC instructed by, and **Tim Powell** of, **Powell Gilbert LLP** for
CompactGTL

Hearing dates: 22-24, 28 July 2014

Approved Judgment

I direct that pursuant to CPR PD 39A para 6.1 no official shorthand note shall be taken of this Judgment and that copies of this version as handed down may be treated as authentic.

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THE HON MR JUSTICE ARNOLD

MR JUSTICE ARNOLD :

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Introduction

1. In these proceedings Velocys Inc, which is a subsidiary of Velocys plc, alleges that CompactGTL Ltd has infringed European Patents (UK) Nos. 1 206 508 and 1 206 509 (“the Patents”). The Patents are owned by Battelle Memorial Institute and exclusively licensed to Velocys Inc. I shall refer to Battelle Memorial Institute and Velocys Inc collectively as “Velocys”. The specifications of the Patents are almost identical, although neither is a divisional of the other or of a common parent, and they differ mainly in their claims. Both Patents relate to catalysts for use in the Fisher-Tropsch (“FT”) process, which is used for so-called gas-to-liquid (“GTL”) conversion of hydrocarbons. In brief summary, the key feature of the inventions disclosed and claimed is the use for the purposes of FT synthesis of “structured” catalysts of a kind which had previously been used in other fields, and in particular the automotive industry, but not in FT synthesis. CompactGTL denies infringement and contends that the Patents are invalid. There is no challenge to the claimed priority date of 17 August 1999. Velocys has applied to amend both Patents.
2. In general, the legal principles to be applied in this case are well-established principles which I have set out in numerous previous judgments. I shall therefore not repeat them here. The case also raises two legal points which are less familiar, however.

The witnesses

3. Velocys’ expert was Dr John Brophy. He obtained a BSc and a PhD from King’s College London between 1966 and 1972. From 1976 to 1981 he was a Lecturer in Chemistry, first at Leeds University and then at Birmingham University. From 1981 to 1992 he worked for BP successively as Senior Technologist, Project Leader Exploratory Gas Conversions and Corporate Research Coordinator. During this period he was heavily involved in various aspects of BP’s GTL programme, including work on catalysts and on the scaling up and development of catalytic processes. From 1992 to 1997 he was employed by BP Chemicals as Technology General Manager. In that capacity, he was responsible for the research and development of catalytic processes for chemicals production. Since 1997 he had been an independent consultant advising several international oil companies on GTL technology, including methods of manufacturing synthesis gas and FT synthesis as well as other chemicals-related catalyst and reactor technologies. Between 2000 and 2007 one of his clients was Velocys.
4. Counsel for CompactGTL submitted that Dr Brophy had at times found it hard to differentiate what the skilled person would have known in August 1999 and what he had learnt, in particular from Velocys, subsequently. It is always hard for expert witnesses in patent cases to distinguish between what was known at the priority date and what became known subsequently, but Dr Brophy was clear that he had attempted to put himself in the shoes of a skilled person in August 1999 when considering the interpretation and validity of the Patents. I am not persuaded that his evidence on these topics was significantly affected by knowledge he acquired later.
5. For his part, counsel for Velocys submitted that Dr Brophy was a very knowledgeable and practical expert with a great deal of experience in the commercial application of FT reactors. I agree with this.

6. CompactGTL's expert is Dr Charles Mauldin. He obtained a degree in Chemistry from Southern Methodist University in 1972 and a PhD in Organic Chemistry from the University of Texas at Austin in 1976. From 1976 to 2005 he was employed by Exxon (later ExxonMobil) Research & Development Laboratories. From around 1980 until about 1989 or 1990, he was engaged in laboratory research on FT catalysts for fixed bed reactors. From about 1989 or 1990 he was engaged in research on FT catalysts for slurry phase reactors. After an initial focus on catalyst composition, his work expanded to include other aspects of FT catalysts, including preparation, activation and regeneration. He also acquired experience of FT processes in pilot and demonstration units. Since 2005 he has been an independent consultant in relation to FT catalysts and processes.
7. Counsel for Velocys submitted that it was evident from Dr Mauldin's evidence that his background in laboratory research and testing of catalysts meant that he was far more interested in the intrinsic properties of the catalysts themselves than he was in the practical implementation of systems that made use of those catalysts. I agree with this.
8. Counsel for Velocys also submitted that, whether through lack of care and through the adoption of an unduly partisan approach or both, Dr Mauldin's reports had contained a great deal of assertion that was revealed in cross-examination to be little more than speculation, or even to be based on incorrect assumptions. For example, he gave evidence that it would be obvious to choose Fecralloy from Table 1 of Schanke on the basis of its thermal conductivity, but it turned out that he had not checked the thermal conductivity of Fecralloy or compared its thermal conductivity with that of the ceramics used by Schanke and indeed without any firm understanding of how thermal conductivity was even measured. Furthermore, counsel submitted that Dr Mauldin had not approached the Patents in a balanced way, but had read them in a critical spirit. He accepted, however, that Dr Mauldin had mostly been fair in his oral evidence. I accept these submissions.

Technical background

9. The following account of the technical background is based on the primer agreed between the parties, which is in turn a synthesis of the relevant sections of the experts' reports. (It would have been better if the parties had agreed the primer first, before the experts prepared their reports.)

Background to FT synthesis

10. FT synthesis provides a means for producing synthetic hydrocarbons such as oils or fuels from (typically) coal, natural gas or biomass. The process was first developed in Germany in 1923 by Franz Fischer and Hans Tropsch. In response to inadequate supplies of petroleum following World War I, many German chemists researched ways in which hydrocarbons, especially liquid fuels like gasoline and diesel, could be synthesised from smaller building blocks, particularly carbon monoxide and hydrogen derived from coal. Fischer and Tropsch devised the first successful process, which resulted in the first commercial FT plant in Germany in around 1936.
11. After the Second World War, South Africa, faced with embargoes on imports of crude oil, continued development of FT for utilisation of its substantial coal reserves. Later,

it further developed the process for utilising local natural gas. The USA also had development programmes based on its coal reserves, but these were not commercialised due to the availability of relatively cheap crude oil.

12. Many of the world's largest natural gas fields are located far from markets for that gas, which consequently has had low value compared to crude oil which is relatively easily transported. GTL is a process that can potentially add value to this "stranded" gas by converting it to longer-chain premium hydrocarbon products such as diesel, jet fuel, kerosene and lubricating oils that are free of sulphur, aromatics and metals. To date, the only commercial GTL plants have been on a very large scale located close to large fields with security of supply.
13. Other opportunities for GTL include gas produced with crude oil ("associated gas"), which in the past has been flared i.e. the gas is released as a waste product and simply burned off. Associated gas reserves are usually relatively small in volume and the economics of GTL have precluded applications at smaller scales until recently. Environmental constraints on flaring and the recent availability of relatively plentiful, inexpensive and widely distributed shale gas, have made smaller scale GTL plants an option.
14. By 17 August 1999, Sasol and Shell had emerged as operators of commercial FT plants. A number of other companies, including Texaco, Mobil, Exxon, BP, Statoil, Gulf and possibly others, had FT research projects underway.

The FT reaction

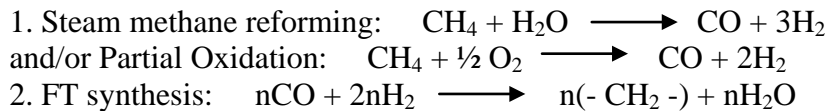
15. The FT reaction consists of passing carbon monoxide (CO) and hydrogen (H₂) gas over a catalyst, which produces a mixture of hydrocarbons. The reaction is normally performed at temperatures between 200 and 350°C and at pressures of 20-60 bar. The reaction may be summarised as follows:



16. The product of the reaction is largely made up of liquid hydrocarbons and paraffin waxes and is widely referred to as synthetic crude oil or "syncrude". Water is also produced as steam in the reactor and condensed downstream as a byproduct. After the FT process, the solid, longer-chain hydrocarbons in the syncrude (i.e. the waxes) can be "cracked" to produce liquid transportation fuels, such as gasoline, diesel and jet fuel.
17. FT synthesis is a heterogeneous reaction, meaning that more than one phase is involved in the reaction. The carbon monoxide and hydrogen starting materials are in the gas phase, while the hydrocarbon products are in a mixture of gases (i.e. short-chain hydrocarbon products and steam) and liquids (longer-chain hydrocarbons including molten paraffin waxes). The FT catalysts used are in the solid phase and are known as heterogeneous catalysts as they are in a different phase from the reactants and products.
18. The FT reaction is highly exothermic. If the heat produced by the reaction is not removed from the catalyst surface, hot spots (localised areas of high temperature) will develop and cause problems. This is explained further below.

Synthesis gas

19. The combination of carbon monoxide and hydrogen is often called “synthesis gas” or “syngas”. Synthesis gas for FT is usually (but not always) generated as a product of another reaction. This is commonly a steam methane reforming reaction (“SMR”), in which natural gas (methane) and steam are converted to a gaseous mixture of carbon monoxide and hydrogen. SMR is an endothermic reaction, normally performed over a nickel-based catalyst at temperatures between 700-1100°C and pressures of 20 bar and higher. Methane may also be converted to synthesis gas by partial oxidation.
20. The ratio of hydrogen to carbon monoxide in the synthesis gas feed to the FT reactor is determined by the nature of the original feedstock. Coal-derived synthesis gas typically has a hydrogen : carbon monoxide ratio of 1 : 1. Synthesis gas obtained from natural gas by SMR contains more hydrogen, typically a ratio of 3:1. In synthesis gas obtained from natural gas by partial oxidation, the ratio is close to 2:1. This is better suited to FT, where the ideal ratio is close to 2.
21. The overall GTL process starting from methane is therefore:



FT terminology

22. Set out below are some of the key terms used in FT:
- i) **Conversion** – conversion is a measure of the amount of a reactant that reacts. In the case of FT, carbon monoxide conversion is often referred to, i.e. the fraction or percentage of the carbon monoxide input gas which reacts. High carbon monoxide conversion is targeted.
- ii) **Selectivity** – selectivity refers to the product of the FT process and is expressed as a percentage of reactant converted. For example, methane (CH₄) selectivity is often referred to in FT. The formation of methane during FT (“methanation”) is unwanted (formation of longer chain hydrocarbons is favoured). Accordingly, low methane selectivity is targeted.
- iii) **Space velocity (SV)** — space velocity is a commonly used measure of reactor throughput. It is defined as:

$$\text{SV} = Q_v/V$$

where Q_v is the volumetric flow rate of the feed and V is the catalyst volume. Space velocity has units of inverse time (t^{-1}). In some cases, the space velocity is based on the reactor inlet conditions (which should be quoted), while in other cases it may be calculated at a reference state (for example, 1 bar pressure and 298 Kelvin temperature), or a standard state of 1 atmosphere pressure and 273 Kelvin.

- iv) **Gas hourly space velocity (GHSV)** – GHSV is a common way of expressing space velocity. It is used for gaseous feed streams with the volumetric flow rate expressed in terms of volume per hour, thus the GHSV has units of h^{-1} . The temperature and pressure of the feed must be stated. A high GHSV, indicating greater throughput, is targeted.
- v) **Heat transfer** – heat transfer is the process whereby heat moves from one substance or body to another. The FT reaction generates a significant amount of heat which needs to be removed to avoid temperature excursions and, ultimately, heat runaway. Therefore, maximising heat transfer from the reaction chamber is a major consideration in FT reactor design.
- vi) **Mass transfer** – mass transfer is the net movement of mass from one location to another. Mass transfer occurs in many processes, such as absorption, evaporation and distillation. In FT, it includes the movement of the hydrogen and carbon monoxide gases to the catalytic surface and the movement of the hydrocarbon and water products away from the surface and eventually out of the reactor.
- vii) **Pressure drop** – pressure drop refers to the decrease in pressure from the inlet zone of a reactor to the outlet zone. This drop in pressure can be significant in fixed bed FT reactors because of the combination of (a) a preferred high feed rate (for good throughput), (b) small diameter tubes (for good heat transfer), and (c) the presence of catalyst particles. Generally speaking, the smaller the catalyst particles, the greater the pressure drop. Pressure drop needs to be minimized so that the entire reactor is functioning under ideal conditions. This is not an issue with slurry reactors.

FT reaction conditions

- 23. As stated above, the FT process is generally operated at temperatures between 200 and 350°C. Higher temperatures will lead to faster reaction time and higher conversion rates, but also tend to favour methane production (i.e. higher methane selectivity) and faster catalyst deactivation.
- 24. As explained above, the FT reaction is highly exothermic. In order to prevent excessive temperature rise within the catalyst bed and unwanted methanation, rapid removal of this heat is a major consideration in the design of suitable reactors. For this reason, FT reactors have heat exchangers which are fed with water or another coolant. A key consideration in reactor design is achieving rapid heat transfer from the catalyst particles to the heat exchanger walls. In practice, this was achieved in fixed bed reactors by having the reaction take place in relatively narrow reaction vessels to minimise the distance to the walls of the reaction chambers and the surrounding coolant.
- 25. Increasing the pressure at which FT synthesis is carried out typically leads to higher CO conversion rates, up to a point. As FT reactions involve a decrease in the number of moles (a unit used to express the amount of a chemical substance), conversions at a given temperature will increase with increase in pressure. Increased pressure also favours formation of long-chain hydrocarbons (i.e. a lower methane selectivity).

26. There are disadvantages to high pressure, however, such as the cost of high-pressure equipment, and the fact that the kinetic response to pressure ceases to increase at some point. FT processes are therefore generally run in a pressure range of about 10 to 40 atm.

FT catalysts

27. FT synthesis is carried out in the presence of an FT catalyst. A catalyst is a substance which serves to increase the rate of reaction (i.e. the rate of production of a desired product or the rate of destruction of an undesired substance). A catalyst participates in the chemical reaction, but is (in the ideal case) not ultimately changed itself, although the catalyst may lose activity over time. The three most important characteristics of a catalyst are its activity, lifetime and product selectivity.
28. Many different issues may impact on the extent of catalytic activity, or even whether a substance has a catalytic effect in a given application. For instance, whether a catalytic metal is present in the form of pure metal particles or as a compound can have a large effect on its ability to catalyse a reaction.
29. Initially, in the majority of FT processes, cobalt was used as the catalyst metal, but iron, nickel, osmium, ruthenium and rhenium are also known to have catalytic activity and have been reported or used in FT. Cobalt is still the most popular catalyst as it provides good catalytic activity and is not as expensive as other metals such as ruthenium where supply is limited. In FT synthesis, it is the metals that are catalytically active, not their compounds.
30. Cobalt FT catalysts operate at relatively low temperatures of 200-250°C and produce a wide range of products from methane up to heavy waxes. This is referred to as “Low Temperature FT” (LTFT). FT synthesis over iron catalysts typically operates at higher temperatures of 300-350°C and is referred to as “High Temperature FT” (HTFT). This produces a lighter range of hydrocarbons with more olefins in the product. Compared to iron, cobalt produces a better quality product at lower pressure and lower operating costs. Cobalt also has a clear cost advantage over ruthenium.
31. The active FT catalyst will often be combined with a promoter, which is a substance which acts to increase the rate of catalytic activity or specificity, although it is not itself a catalyst. The choice of promoter will depend upon the primary metal catalyst being used.
32. Metal catalysts are generally deposited onto a high surface area support material in such a way as to maximise the metal dispersion. This increases the available surface area of catalyst in contact with reactant gases in comparison to using solid metal particles where potentially only the exterior surface of the particles is in contact with reactants and able to act as a catalyst. In order to further increase the available surface area of catalyst, the support material is usually porous, increasing the surface area per unit volume over which the catalyst metal may be dispersed. The support material may be common refractory inorganic oxides (referred to in this context as “ceramics”) like alumina, silica, titania and zeolites.
33. The form of the catalytically inactive support material may range from a fine powder to a structure such as an extrudate, pellet, tablet or pill. It was well known in August

1999 to deposit the active FT catalyst onto a pre-formed support (i.e. a powder, extrudate, pellet, tablet or pill). Alternatively, it was also well known to change the form of the support after deposition of the active FT catalyst. For example, FT catalyst could be deposited onto a powdered form of support and the resulting powder pill, tableted or extruded.

Catalyst deactivation

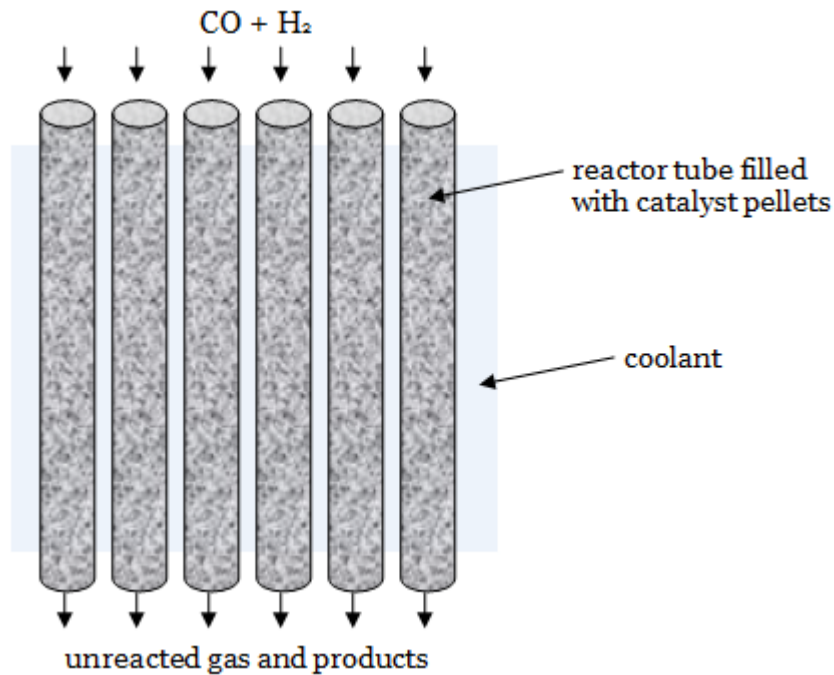
34. Catalyst deactivation in FT synthesis occurs by several mechanisms. At low temperatures, the longer chain, high boiling hydrocarbon products form a liquid coating on the catalyst and prevent access to the active sites. At higher temperatures, the formation of hot spots, increased production of methane and coking occur.
35. Hot spots, which in extreme circumstances could reach up to 1000°C, damage the catalyst. For instance, high temperatures are likely to cause the catalyst to sinter, where the highly dispersed active metal catalyst particles coalesce and present a much lower active surface area for the reactants. In extreme cases, hot spots can cause the catalyst to melt, leading to reactor blockages and damage to the reactor requiring shut down and loss of productivity.
36. Hot spots also can cause coking, i.e. carbon formation on the catalyst surface, which deactivates the catalyst and can cause catalyst fracture. Coking reduces catalyst performance over time by preventing the gaseous reagents from reaching the catalyst surface. Coking increases with time on stream and at higher temperatures.
37. Catalyst activity can be recovered to some extent by raising the reaction temperature. Eventually, activity falls to a point where the catalyst temperature can no longer be raised without producing excessive amounts of methane, and the catalyst has to be regenerated. This can be done in various ways, including burning off the coke with air and/or treating the deactivated catalyst with hydrogen to reduce the catalytic metal to the active form.

Commercial FT reactors

38. Probably the biggest issue for commercial FT reactors is removing the heat generated by the reaction from the catalyst bed and from the reactor. All of the commercial FT reactors described below that were known in August 1999 are designed to manage the heat removal within the limitations of the various reactor systems. Limited heat removal limits reactor productivity (a function of both CO conversion and throughput).
39. Commercial reactors for LTFT produce a mainly liquid product including gasoline (C6-C10 hydrocarbons), diesel (C11-19), and/or paraffin wax (C20+). Typical reaction conditions employed in commercial LTFT reactors are temperatures around 200-250°C and an operating pressure of 10-45 bar. Commercial HTFT reactors produce a lighter olefinic product where all of the products are in the gas phase in the reactors. Temperatures are typically over 300°C and pressure is 20-30 bar.
40. Prior to 17 August 1999, there were three types of FT reactor in commercial use: (1) the fixed bed reactor; (2) the fluidised bed reactor; and (3) the slurry phase reactor.

Fixed bed reactors

41. A fixed bed reactor may be schematically represented as follows:



42. Commercial fixed bed reactors are made up of many thousands of very long (up to ten metres or more), narrow reactor tubes welded onto “tube plates”. The reactor tubes are very long in order to maximise CO conversion by increasing the time over which the reactant gases are in contact with catalyst. Each tube contains a bed of catalyst through which the inlet gases flow. In August 1999, fixed bed reactors commonly operated with catalyst pellets in order to allow for gas flow through the catalyst bed. The catalyst particles did not move and therefore there was no catalyst in the product stream. The reactor tubes were surrounded by water (or other coolant) for heat removal.
43. The catalyst particles used in fixed bed reactors are generally 1 mm to 5 mm in diameter, and the reactor tubes typically have a diameter of 20-50 mm to allow good heat transfer from the catalyst bed to the surrounding coolant. If the tube diameter is too large (for example greater than around 50 mm diameter), then there is a danger that there will be insufficient heat transfer from the centre of the catalyst bed to the tube wall, which can lead to hot spots and temperature runaway as described above. High linear gas velocities through the catalyst bed are required to give turbulent flow and efficient heat transfer. This can lead to low conversion per pass through the reactor, and requires recycling of some of the unconverted gas stream to achieve high conversion of the fresh feed. However, recycling is at the expense of overall reactor throughput and productivity.
44. Catalyst particle diameter is chosen to allow the gas to easily flow between the catalyst particles and minimise pressure drop across the reactor at high linear velocities. The catalyst particles may also be designed to be uneven shapes in order to

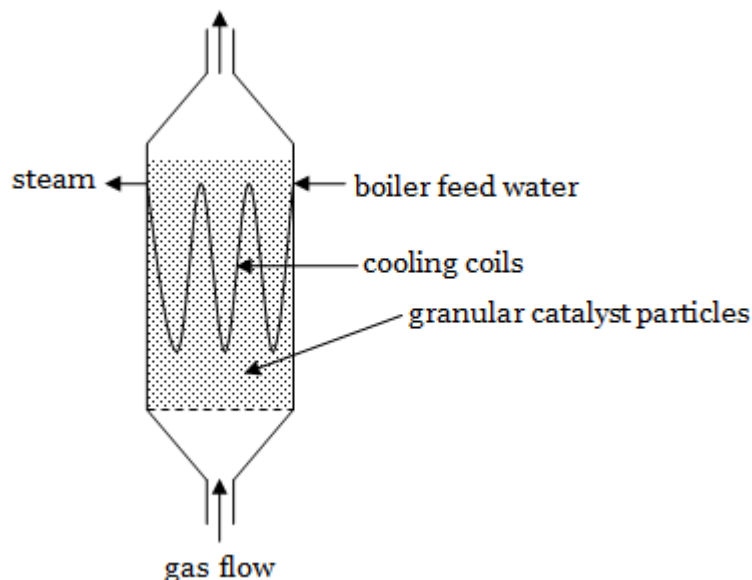
reduce their packing efficiency within the reactor tubes and prevent undue pressure drop.

45. Commercial fixed bed FT reactors have had to be very large in order to produce hydrocarbon products at a commercially viable rate. This in turn has led to GTL plants being very capital intensive (for instance the Shell Middle Distillate plant in Bintulu, Malaysia cost approximately \$850 million) and has limited their use to areas where there is a long term supply of the raw materials needed, in order to recoup the cost of the plants.

Fluidised bed reactors

46. There are two types of fluidised bed reactors, depending on whether the catalyst bed is contained within the reactor vessel (fixed fluidised bed, FFB) or whether the catalyst is entrained in the gas flow and is carried around a loop (circulating fluidised bed, CFB). The CFB type of reactor was only used for HTFT employing iron catalysts. Due to complexity and reactor erosion problems, CFB reactors have been phased out and replaced with fixed fluidised bed reactors.

47. A fixed fluidised bed reactor may be schematically represented as follows:



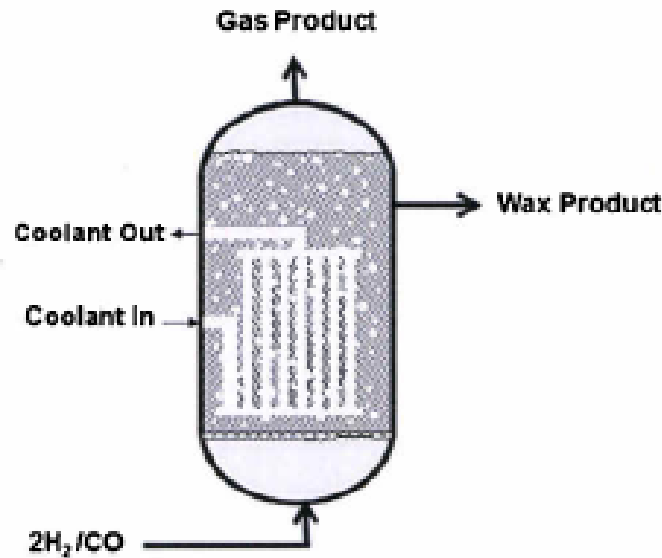
48. In fixed fluidised bed reactors, the reactant gases are passed through the catalyst particles at sufficient velocity to cause the bed to fluidise. Catalyst particles are much smaller than those used in a fixed bed reactor to enable them to be fluidised at reasonable gas velocities. Within the top of the reactor, cyclones disengage the catalyst particles and return them to the bed whilst the product gas stream flows through to the condensing train.

49. Cooling coils are arranged within the reactor to remove heat. The suspended particles are in intimate contact with the gas stream and the cooling coils. This, together with the small particle size, gives excellent heat transfer to the cooling coils. Therefore, heat transfer and removal is much faster than in a fixed bed reactor. As the catalyst

particles are moving at high velocities and experiencing regular collisions, however, they physically break down to a powder and so have to be replaced on a continuous basis.

Slurry phase reactors

50. A slurry phase reactor may be schematically represented as follows:



51. In slurry phase reactors at August 1999, synthesis gas was bubbled through a slurry made up of a powdered supported FT catalyst (small solid catalyst particles of 0.1-0.2mm) suspended in the liquid hydrocarbon products. Internal cooling coils allowed for heat removal. A variety of methods existed for separating the catalyst powder from the product that is liquid under reaction conditions, with some form of internal filtration being most common. Slurry phase reactors where gas is introduced at the bottom of the reactor and rises up through the slurry (obviating the need for any mechanical stirring) were known as bubble column reactors.
52. This type of reactor provides excellent temperature control and close to isothermal operation with no temperature gradients. The reactor can therefore be operated at slightly higher temperatures and higher reaction rates than fixed bed reactors. Pressure drop is low (because the gas is realised as bubbles), control is relatively simple and operating costs are less than a fixed bed reactor. However, liquid products formed in the reactor must be filtered after removal from the slurry bed in order to remove catalyst particles. This requires the use of complicated and expensive filtering systems to recover the (expensive) catalyst from the final product.

The Patents

53. Since the specifications of the Patents are almost identical, I shall refer just to the specification of 508. Under the heading "Background of the invention", the specification discusses some of the limitations of conventional FT reactors employing conventional catalysts. It then sets out in Table 1 data for contact time, conversion and

methane selectivity for a number of catalysts obtained from seven prior references. These data are also plotted graphically in Fig. 1. The specification continues:

“[0004] Literature data (Table 1 and FIG. 1) were obtained at lower H₂/CO ratio (2:1) and longer contact time (3 sec or longer) in a fixed bed type reactor. Low H₂/CO (especially 2-2.5), long contact time, low temperature, and higher pressure favor Fischer-Tropsch synthesis. Selectivity to CH₄ is significantly increased by increasing H₂/CO ratio from 2 to 3. Increasing contact time also has a dramatic favorable effect on the catalyst performance. Although reference 3 in Table 1 shows satisfactory results, the experiment was conducted under the conditions where Fischer-Tropsch synthesis is favored (at least 3 sec residence time, and H₂/CO=2). In addition, the experiment of reference 3 was done using a powdered catalyst on an experimental scale that would be impractical commercially because of the pressure drop penalty imposed by powdered catalyst. Operating at higher temperature will enhance the conversion, however at the much higher expense of selectivity to CH₄. It is also noteworthy that contact time in commercial Fischer-Tropsch units is at least 10 sec.

[0005] Hence, there is a need for a catalyst structure and method of Fischer-Tropsch synthesis that can achieve the same or higher conversion at shorter contact time, and/or at higher H₂/CO.”

54. Under the heading “Summary of the invention”, after a consistory paragraph corresponding to claim 1 of 508, the specification says that catalytic activity is an intrinsic property of a catalyst. It goes on at [0008]:

“This property is defined by various testing conditions. For example, a preferred catalyst has a Fischer-Tropsch catalytic metal supported on a porous support; where the catalyst possesses catalytic activity such that [sic]. If the catalyst is placed in a tube inside an isothermal furnace and exposed to a feed stream consisting of a 3 to 1 ratio of hydrogen gas to carbon monoxide, at 250°C, at 6 atm, at a contact time less than 5 seconds and the product stream is collected and cooled to room temperature, the selectivity to methane is less than 25%, and the carbon monoxide conversion is greater than 25%. To check whether a catalyst meets a claimed activity property requires only a test at the specified conditions.”

55. At [0010] the specification states:

“Advantages that may be provided by the invention include (i) at residence/contact times shorter than the prior art, higher conversions are achieved with no increase to methane selectivity; and (ii) as residence/contact times increase, conversion increases and methane selectivity decreases. Surprisingly, it has been found that carbon monoxide can be

hydrogenated at short contact time to produce liquid fuels at good conversion levels, low methane selectivities and good production rates.”

56. Under the heading “Description of the preferred embodiment(s)”, the specification states at [0013]:

“A catalyst is depicted in FIG. 1 having a porous support 100, a buffer layer 102, an interfacial layer 104, and, optionally, a catalyst layer 106. Any layer may be continuous or discontinuous as in the form of spots or dots, or in the form of a layer with gaps or holes.

As is common ground, the reference to Fig. 1 is clearly erroneous. The correct reference is to Fig. 2, which I reproduce below:

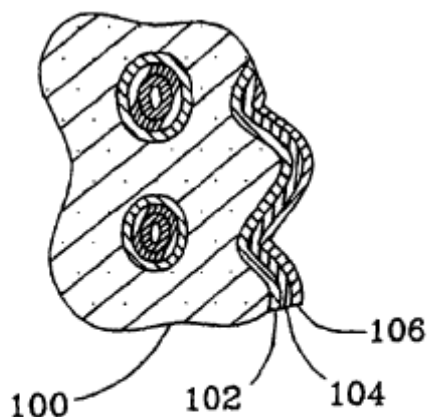


Fig. 2

57. The specification describes the porous support in [0014] as follows:

“The porous support 100 may be a porous ceramic or a porous metal. Porous supports suitable for use in the present invention include carbides, nitrides, and composite materials. Prior to depositing the layers, the porous support preferably has a porosity of 30% to 99%, more preferably 60% to 98%, as measured by mercury porosimetry and an average pore size of from 1µm to 1000 µm as measured by optical and scanning electron microscopy. Preferred forms of porous supports are foams, felts, wads and combination, thereof. Foam is a structure with continuous walls defining pores throughout the structure. Felt is a structure of fibers with interstitial spaces there between. Wad is a structure of tangled strands, like steel wool. Less preferably, porous supports may also include other porous media such as pellets and honeycombs, provided that they have the aforementioned porosity and pore size characteristics. ...”

58. The specification describes the buffer layer in [0016] as follows

“The buffer layer 102, if present, has different composition and/or density than both the support and the interfacial layers, and preferably has a coefficient of thermal expansion that is intermediate to the thermal expansion coefficients of the porous support and the interfacial layer. Preferably, the buffer layer is a metal oxide or metal carbide. ...”

59. The specification describes the interfacial layer in [0019] as follows:

“The interfacial layer 104 can be comprised of nitrides, carbides, sulfides, halides, metal oxides, carbon and combinations thereof. The interfacial layer provides high surface area and/or provides a desirable catalyst-support interaction for supported catalysts. The interfacial layer can be comprised of any material that is conventionally used as a catalyst support. Preferably, the interfacial layer is a metal oxide. The interfacial layer 104 may serve as a catalytically active layer without any further catalytically active material deposited thereon. Usually, however, the interfacial layer 104 is used in combination with catalytically active layer 106. ...”

60. The specification describes the catalyst layer in [0020] as follows:

“The catalytically active material 106 (when present) can be deposited on the interfacial layer 104. Alternatively, a catalytically active material can be simultaneously deposited with the interfacial layer. The catalytically active layer (when present) is typically intimately dispersed on the interfacial layer. That the catalytically active layer is ‘disposed on’ or ‘deposited on’ the interfacial layer includes the conventional understanding that microscopic catalytically active particles are dispersed: on the support layer (i.e., interfacial layer) surface, in crevices in the support layer, and in open pores in the support layer. The present invention employs a Fischer-Tropsch catalytic metal in the catalytically active layer. ... Catalytic metals in the present invention are preferably iron, cobalt, ruthenium, rhenium, osmium and combinations thereof. In addition to these catalyst metals, a promoter may be added. ...”

61. An important passage in the specification states:

“[0031] According to the present invention, a residence time less than 5 seconds can be achieved by: (a) providing a catalyst structure of a metal foam having a catalyst thereon; and (b) passing a feed stream having a mixture of hydrogen gas with carbon monoxide gas through the catalyst structure and heating the catalyst structure to at least 200°C, thereby obtaining a product stream of at least 25% conversion of carbon monoxide, and at

most 25% selectivity toward methane. In another preferred method, the catalyst structure includes a buffer layer.

...

[0033] Residence and contact times have well-defined meanings in the art. Contact time is the total volume of the catalyst chambers divided by the total flowrate of inlet reactants assuming they are an ideal gas corrected to standard conditions (i.e., the volume of the catalyst chamber / F-total at STP where STP is 273K and 1 atm). The volume of the catalyst chambers includes the volume in immediate proximity and surrounding the catalyst zone. As an example, if one were to pack one quarter of the channels with powders, then the volume of the catalyst chamber would only include that region where gas can flow and where it can contact the catalyst, i.e. only one quarter of the total channel volume would be included in this calculation. The volume of dead space i.e., headers, footers, etc. is ignored in this calculation. Average residence time (also referred to as residence time) is the total volume of the catalyst chambers divided by the total flowrate of inlet reactants, corrected to the actual temperature and pressure of the reactants in the reactor (i.e., the volume of the catalyst chamber / F-total corrected to actual conditions). F-total at STP is the total volumetric flowrate of reactants (includes all reactants, and diluents if present). Inlet gases are typically metered with mass flow controllers set to standard conditions, i.e. the user presets the desired STP flowrate. F-total corrected to actual conditions = F-total-STP x (Temperature in K)/273 x 1 atm/(P actual in atm); this value is used to calculate the residence time or the 'true time' within a reactor. Most practitioners prefer to use contact time, because it is a convenient method to keep the time variable fixed while stepping through 10 degree C increments in reaction temperature etc.

[0034] Contact times less than 5 seconds may be accomplished with standard equipment but at the expense of significant energy to raise the space velocity of the reactants to overcome the pressure drop and poorer heat transfer leading to higher methane formation. Thus, the inventive method is preferably carried out in a reaction chamber in which the catalyst has a thickness of 1.5 cm or less and is touching or in close proximity (within 1 mm) of a reaction chamber wall, where the reaction chamber wall is in thermal contact with a heat exchanger. Heat transfer from the reaction chamber is preferably enhanced by addition of microchannels on at least one reaction chamber wall on the side of the reaction chamber wall opposite the catalyst structure. The catalyst preferably has contiguous and relatively large pores, such as in a foam, to

avoid large pressure drops. Preferably the pore size of the large pores in the catalyst is between 10 μm and 300 μm .

[0035] According to the present invention, carbon monoxide hydrogenation is conducted at a contact time of less than 5 seconds, more preferably, less than about 2 seconds and still more preferably between 0.1 and 1 seconds. At these contact times, good CO conversion and low methane selectivity can be obtained. Preferably, CO conversion is at least 25%, more preferably, at least 50%, and still more preferably, greater than 80%. Methane selectivity is preferably less than 25%, more preferably less than 20%, and still more preferably, between 15% and 5%. Additionally, these properties can be achieved with low pressure drops across the reaction chamber. ...”

62. The specification includes four examples. It is only necessary for present purposes to refer to the first two. The specification states at [0041] that, in Example 1, “The effect of residence time and reaction temperature on the catalytic conversion of CO with H was examined in a constant flow reactor”. In the example, the performance of a monolithic catalyst in accordance with the invention was compared with the same catalyst in powder form at varying contact times and temperatures. The results are set out in Table E1-1, which I reproduce below:

TABLE E1-1

Fischer-Tropsch Catalyst Performance				
Catalyst	Conditions	Contact time	Conversion	CH ₄ selectivity
Co-Ru/Al ₂ O ₃ /foam	231°C, 24-atm, H ₂ /CO=3	1-sec	17 %	9.6 %
"	247°C, 24-atm, H ₂ /CO=3	1-sec	29 %	15 %
"	264°C, 24-atm, H ₂ /CO=3	1-sec	50 %	22 %
"	264°C, 24-atm, H ₂ /CO=3	1-sec	49 %	22 %
"	275°C, 24-atm, H ₂ /CO=3	1-sec	69 %	24 %
"	275°C, 24-atm, H ₂ /CO=3	2-sec	84 %	9.0 %
"	245°C, 24 atm, H ₂ /CO=3	1-sec	33%	12%
Co-Ru/Al ₂ O ₃ / powder	245°C, 24 atm, H ₂ /CO=3	1-sec	99.6%	36%

63. The specification comments on these results as follows:

“[0044] Table E1-1 shows the results of these experiments. In general, the powder form of the catalyst produced greater conversions at a given temperature than the monolithic form. However, at a given temperature, the monolith catalyst produced less methane. In conventional Fischer-Tropsch reactors, methane formation is predominately affected by reactor temperature and feed composition, although it is also affected to a lesser extent by other parameters, such as contact time. The fact that the monolithic catalyst yields lower methane selectivity at a given temperature suggests that the monolith is better able to conduct heat away from the inner part of the reactor, and thus avoid higher local temperatures, which are often present in the inner sections of packed or powder beds. For the monolithic catalyst, conversion is a strong function of both temperature and contact

time, and conversion will increase with increasing temperature and/or time. Decreasing the contact time from 2-seconds to 1-sec at 275°C for the monolithic catalysts resulted in lower conversion and higher methane selectivity.

[0045] When compared to the results of previous studies in Table 1, several characteristics are apparent:

- compared to all of these references, sufficient catalyst performance (conversion greater than about 50% and methane selectivity below about 25%) can be achieved at a contact time that is about three- to twelve-times shorter
- formation of methane, which is highly favored at high reactor temperatures and the hydrogen-to-carbon feed ratios, is intermediate to references 1 and 3, which utilize the most similar contact times; however, the monolithic catalyst produces comparable methane selectivities under conditions which are much more unfavorable than used in these references. The monolith form was able to produce this amount of methane at temperatures up to 260°C (compared to 240°C in reference 1) and a H₂-to CO feed ratio of 3 (compared to 2 for references 1 and 3). This further shows that the monolithic form removes heat more effectively than powder or pellet forms, and that methane formation can be suppressed, even under undesirable conditions.
- at a comparable H₂-to-CO feed ratio of 3 and CO conversion (about 80%), the powdered catalyst in reference 7 produces much higher selectivity to methane than the inventive catalyst even at lower temperatures and longer contact times, where methane formation is unfavored. Note that in reference 7, a change in H₂-to-CO feed ratio of from 2 to 3 nearly tripled methane selectivity.”

64. In Example 2, operation at different pressures was investigated. The results are set out in Table E2-1, which I reproduce below:

Table E2-1 -

Engineered catalyst performance for Fischer-Tropsch synthesis at about 250°C under a constant residence time (i.e., temperature and pressure corrected contact time) of 12.5 seconds. The contact time at 24 atm (absolute) is 1 sec.		
Pressure, atm	Conversion, %	Selectivity to CH ₄ , % (absolute)
6	63	18
7	41	22
11	34	19
24	24	26

65. The specification comments in [0048] that these results show that “with the catalyst structure of the present invention, catalyst activity was unexpectedly enhanced as the pressure was decreased under the same residence time”.

The claims

66. The claims in issue, as proposed to be amended, are as follows. In the case of 508:

“1. A method of Fischer-Tropsch reaction, comprising the steps of:

- (a) providing a catalyst structure having a first porous structure with a first pore surface area and a first pore size of at least 0.1 μm ;

a porous interfacial layer with a second pore surface area and a second pore size less than said first pore size, said porous interfacial layer disposed upon said first pore surface area; and

a Fischer-Tropsch catalyst selected from the group consisting of cobalt, ruthenium, iron, nickel, rhenium, osmium and combinations thereof placed upon said second pore surface area; and

- (b) passing a feed stream having a mixture of hydrogen gas with carbon monoxide gas through said catalyst structure and heating said catalyst structure to at least 200°C at an operating pressure, said feed stream having a residence contact time within said catalyst structure less than 5 seconds, thereby obtaining a product stream of at least 25% conversion of carbon monoxide, and at most 25% selectivity toward methane.

2. The method as claimed in claim 1, wherein the contact time is less than about 2 seconds.

3. The method as claimed in claim 1, wherein the contact time is between 0.1 and 1 seconds.

4-6. The method of any of claims 1-~~3~~5 carried out in a reaction chamber in which the catalyst has a thickness of 1.5 cm or less and is touching or in close proximity of a reaction chamber wall.”

67. In the case of 509:

“1. A catalyst structure for Fischer-Tropsch, comprising

said catalyst structure comprising a first porous structure with a first pore surface area and a first pore size of at least 0.1 μm ;

a buffer layer disposed on said porous structure;

a porous interfacial layer with a second pore surface area and a second pore size less than said first pore size, said porous interfacial layer disposed upon buffer layer; and

a Fischer-Tropsch catalyst selected from the group consisting of cobalt, ruthenium, iron, nickel, rhenium, osmium and combinations thereof placed upon said second pore surface area.

7. The catalyst structure as recited in claim 1, wherein said buffer layer is selected from the group consisting of Al₂O₃, TiO₂, SiO₂ and ZrO₂ and combinations thereof.

9. A method of Fischer-Tropsch reaction, comprising the steps of:

(a) providing a catalyst structure comprising a porous support with a first pore surface area and a first pore size of at least 0.1 μm;

a buffer layer disposed on said porous support

a porous interfacial layer with a second pore surface area and a second pore size less than said first pore size, said porous interfacial layer disposed upon said buffer layer; and

a Fischer-Tropsch catalyst selected from the group consisting of cobalt, ruthenium, iron, nickel, rhenium, osmium and combinations thereof placed upon said second pore surface area; and

(b) passing a feed stream having a mixture of hydrogen gas with carbon monoxide gas through said catalyst structure and heating said catalyst structure to at least 200°C at an operating pressure, said feed stream having a ~~residence~~ contact time within said catalyst structure less than 5 seconds, thereby obtaining a product stream of at least 25% conversion of carbon monoxide, and at most 25% selectivity toward methane.

10. The method as claimed in claim 9, wherein the contact time is less than about 2 seconds.

11. The method as claimed in claim 9, wherein the contact time is between 0.1 and 1 seconds.

~~14-16.~~ A method of making a Fischer-Tropsch catalyst structure, comprising the steps of:

providing a catalyst structure comprising a porous support with a first pore surface area and a first pore size of at least 0.1 μm;

depositing a buffer layer on said porous support,

depositing a porous interfacial layer with a second pore surface area and a second pore size less than said first pore size, upon said buffer layer,

placing a Fischer-Tropsch catalyst selected from the group consisting of cobalt ruthenium, iron, rhenium, osmium and combinations thereof upon said second pore surface area.”

The skilled team

68. There is no dispute about the identity of the skilled team to whom the Patents are addressed. The skilled team is a team interested in methods for utilising natural gas resources via FT synthesis/ GTL technology typically comprising: PhD chemists specialising in design and preparation of catalysts; chemical engineers specialising in reactor design; and process engineers (at both graduate and postgraduate levels). Those individuals would have had substantial experience in industry. This last aspect is important, since the team would involve individuals with the necessary experience to distinguish between theoretically attractive, but unfeasible, proposals, and proposals that take account of, and address, practical problems of implementation.
69. Although it is common ground that in practice there would be a small team of people with different backgrounds, both sides were able to address the issues in this case by calling a single expert. Accordingly, I shall refer for convenience to the skilled person rather than the skilled team.

Common general knowledge

70. There is little, if any, dispute that all the matters I have set out in the technical background section were common general knowledge.
71. Counsel for CompactGTL appeared to suggest in his cross-examination of Dr Brophy that the contents of various literature references were common general knowledge. In his closing submissions, the only matter that he suggested that this evidence established was common general knowledge was that the skilled person would know that, if one is trying to washcoat a metal with another layer, then keying the surface is a good idea to obtain a good bond and one way to key the surface is to oxidise it. I do not accept that this was shown to be common general knowledge, however. Counsel relied upon a paragraph from Dr Mauldin’s first report, but I do not read that paragraph as saying that this was common general knowledge. Nor do I consider that Dr Brophy accepted this. Furthermore, as counsel for Velocys submitted, the principal literature references which were put to Dr Brophy in support of the proposition are ones from outside the field of FT.
72. Counsel for CompactGTL also made two other submissions about the common general knowledge. First, he submitted that the evidence established that it was routine by 1999 to undertake laboratory tests to ascertain the inherent properties of catalysts in terms of CO conversion and methane selectivity. For this purpose, it was routine to combine a range of temperatures, pressures and contact times. Other things being equal, the skilled person would want to target as low a contact time as possible. In a laboratory, it was possible to use an isothermal reactor which prevented hotspots occurring. Accordingly, there was nothing unusual in 1999 in carrying out laboratory

tests using such a reactor at contact times as low as 1 or 2 seconds. I accept this submission.

73. Secondly, he submitted that contact times actually achieved by commercial plants were not generally known. This I accept, but subject to the qualification that it was Dr Brophy's evidence, which I also accept, that people in the field had a general feeling for the sorts of contact times which were being employed and that the Patents were correct to say that such times were at least 10 seconds.

Amendment

74. Velocys' application to amend the Patents divides into two parts which it is convenient to treat as if they were separate applications. The first application, which is relatively unusual, is an application to amend both the main claims and certain passages in the specification on the ground that they contain an obvious mistake. Subject to a point which I shall explain, the second application is a conventional application to introduce more restricted claims.

The first application

75. By the first application, Velocys seeks to change the references to "residence time" in claim 1 of 508 and claim 9 of 509 Patent to "contact time", and to make corresponding amendments to the description. Velocys contends that the references to "residence time" rather than "contact times" are an obvious mistake. CompactGTL disputes this. It is common ground that these amendments are not allowable if the references to "residence time" are not an obvious mistake. It is also common ground that, if the amendments are not allowed, claim 1 of 508 and claim 9 of 509, and claims dependent on those claims, are invalid on the ground of insufficiency. This is because the specifications of the Patents do not teach the skilled person, and the skilled person would not know from his common general knowledge, how to achieve a residence time of less than 5 seconds (at least across the breadth of the claims). On the other hand, CompactGTL does not contend that the amended claims would be invalid on this ground.
76. *The law.* There is no dispute as to the applicable principles. No amendment to a patent may be allowed if it either (a) results in the specification disclosing additional matter or (b) extends the protection conferred by the patent: section 76(3) of the Patents Act 1977 corresponding to Article 123(2) and (3) of the European Patent Convention. As is common ground, the proposed amendments would violate both of these prohibitions unless the references to "residence time" are an obvious mistake. If they are an obvious mistake, however, then the amendments are not prohibited because they simply bring the wording of the claims into line with the meaning which the skilled person would understand them to bear anyway. Thus the court should approach the application in accordance with the principles applicable to requests to correct errors under Rule 139 of the EPC Implementing Regulations (previously Rule 88): see *Mölnlycke Health Care AB v Wake Forest University Health Sciences* [2009] EWHC 2204 (Pat) at [137]-[150] (Kitchin J, as he then was)
77. Rule 139 provides:

“Linguistic errors, errors of transcription and mistakes in any document filed with the European Patent Office may be corrected on request. However, if the request for such correction concerns a description, claims or drawings, the correction must be obvious in the sense that it is immediately evident that nothing else would have been intended than what is offered by the correction.”

78. In G11/91 *CELTRIX/Correction of errors* [1993] EPOR 245 the Enlarged Board of Appeal interpreted this provision as follows:

“With regard to a correction under Rule 88, second sentence, EPC it follows that the parts of a European patent application or of a European patent relating to the disclosure must, either on the date of filing or following an amendment under Article 123 EPC, contain such an obvious error that a skilled person is in no doubt that this information is not correct and—considered objectively—cannot be meant to read as such. If, on the other hand, it is doubtful whether any information at all is incorrect, then a correction is ruled out. The same applies if incorrect information only becomes apparent in the light of the proposed correction.

The parts of a European patent application as filed which relate to the disclosure must further allow a skilled person—using the common general knowledge on the date of filing—directly and unequivocally to ascertain the precise content of the information the person making the request actually meant to give, instead of the incorrect particulars, on the date of filing or when making an amendment under Article 123 EPC, so that, for said skilled person, ‘it is immediately evident that nothing else would have been intended than what is offered as the correction’ (Rule 88, second sentence, EPC). However, if there is any doubt that nothing else would have been intended than what is offered as the correction, a correction cannot be made.”

79. The Enlarged Board went on to hold that, although Article 123 applied to requests for corrections under Rule 88, a correction which was permissible under that rule was incapable of extending the subject matter or scope of protection, since:

“The corrected information merely expresses what a skilled person, using common general knowledge, would already derive on the date of filing from the parts of a European patent application, seen as a whole, relating to the disclosure.”

80. It follows that it is necessary for Velocys to demonstrate that:

- i) the reference to “residence time” in the claims is such an obvious error that a skilled person would immediately appreciate that it could not be meant to read as such; and

- ii) the skilled person can unequivocally ascertain that the patentee meant to refer to “contact time”.

81. *Assessment.* Dr Brophy’s evidence was that he had immediately concluded when he first read the Patents that the references to “residence time” in question must be mistaken and that the patentee must have meant to refer to “contact time”. He gave cogent reasons for this conclusion in his reports, and he convincingly defended those reasons in cross-examination. Counsel for CompactGTL suggested that Dr Brophy’s reading of the Patents had been influenced by his knowledge of Velocys’ technology, but I am not persuaded of this. Dr Mauldin rather grudgingly accepted in cross-examination that there was the “possibility” of a mistake, although he had not done so in his reports. The fact that he said that he had not spotted the mistake when reading the Patents is of little significance given the manner in which he approached them. What is more telling is that Dr Mauldin was unable convincingly to explain how the existing wording could be correct, nor did he suggest any alternative correction that might be made. Accordingly, to the extent that the issue is one for expert evidence, I have no hesitation in preferring Dr Brophy’s evidence. It seems to me, however, that it is a question of interpretation for the court reading the specifications through the eyes of the skilled person. In my judgment the skilled person reading the specification would immediately appreciate that the references to “residence time” in question were mistaken and that the patentee had meant to refer to “contact time”. My reasons are as follows.
82. The starting point is that, as is common ground, contact time and residence time are distinct concepts which the skilled person would be familiar with and which are accurately defined in the specifications at [0033]. As the Patents correctly state in [0033], “most practitioners prefer to use contact time” (or its reciprocal, GHSV). The contact time represents the time that a volume of gas spends in the reactor at a given standard temperature and pressure, usually 273 K and 1 atm. This provides a convenient and simple representation of the rate at which feed gas can be processed and therefore the productivity of the plant. Residence time is a measure of the *actual* time that a quantity of gas spends in the reactor, based on the temperature and pressure in the reactor. The true residence time must also account for any volume increase or decrease during the reaction and is difficult to calculate at all easily or accurately. It is therefore of more interest to academics who are measuring the detailed kinetics of reactions.
83. Reading the specifications as a whole, it is plain that the Patents are primarily concerned with reductions in contact time. Table 1 underneath [0003] is headed “Comparison of *Contact Times* effects in Fischer-Tropsch Experimentation” [emphasis added]. The table sets out contact times which have been (correctly) calculated from figures contained in the references given (which do not themselves include contact time figures). The contact times quoted range from 0.72 seconds to 14 seconds, and most are over 5 seconds. At the foot of the table, the specification states:
- “For references that contained results for multiple experimental conditions, the run which best matched our conversion, selectivity and/or conditions was chosen for comparison of contact time”.

It is therefore clear that the patentee is interested in comparing contact times. This is in line with what the skilled person would expect, since it is more usual to use contact time when comparing the performance of different catalysts and experimental conditions.

84. The same message is conveyed by the specifications at [0004] (quoted in paragraph 53 above), where repeated references are made to “contact time”, consistently both with the contents of Table 1 and with what the skilled person would expect. At line 23, however, the specification suddenly refers to “at least 3 secs residence time” while discussing reference 3 in Table 1. As Dr Brophy explained, the skilled person would immediately appreciate that this must be a mistake for the following reasons:
- i) all the discussion up to this point has been of contact times;
 - ii) contact times and residence times are not directly comparable with each other (although it is possible to convert one to the other);
 - iii) the figure of 3 seconds is the contact time which has been calculated from reference 3 and is set out in Table 1 (whereas the corresponding residence time would in fact be about 35 seconds).
85. The same message is conveyed at [0005] (also quoted in paragraph 53 above), where the object of the invention is expressed in terms of “shorter contact time”. In context, it is clear that what the patentee means by this is a shorter contact time than the 10 seconds or more achieved by conventional commercial units. Similarly, at [0008] of 508 (quoted in paragraph 54 above), and [0010] of 509 the specifications refer to “a contact time less than 5 seconds”.
86. It is fair to say that in [0010] of 508 (quoted in paragraph 55 above) and [0013] of 509 the specifications say that advantages provided by the invention include “residence/contact times shorter than the prior art”. This is neutral, however, because if contact time is shorter, then residence time will almost inevitably be shorter as well. But the Patents only state the contact times of the prior art, not the residence times. The rest of the paragraph emphasises that it is contact time with which the Patents are concerned.
87. It is also fair to say that in [0009] of 509 there is a reference to “a residence time of 12.5 seconds”. Read in context, however, it can be seen that this is referring to Example 2, which does indeed use a constant residence time of 12.5 seconds.
88. In the important passage at [0031]-[0035] (quoted in paragraph 61 above), the specifications begin at [0031] by saying that a residence time less than 5 seconds can be achieved, but in [0034] and [0035] they revert to referring to contact times of less than 5 seconds. It is notable that [0034] discusses how to achieve a contact time of less than 5 seconds, but says nothing about how to achieve a residence time of less than 5 seconds. Even more strikingly, [0035] says that “According to the present invention” FT synthesis is carried out “at a contact time of less than 5 seconds, more preferably less than about 2 seconds and still more preferably between 0.1 and 1 seconds”. Thus it would be clear to the skilled person that the reference to “residence time” at the beginning of [0031] was another mistake.

89. In 509, but not in 508, the first sentence of [0033] states that “Certain embodiments of the present invention can be characterized in terms of residence or contact time”. This again is neutral, since it is a true statement either way. What matters is whether the characterisation based on a time of less than 5 seconds contained in the claims refers to contact time or residence time.
90. Most tellingly, the only actual examples of the invention given by the patentee are completely inconsistent with a claim to residence times of less than 5 seconds. In Example 1, the specification refers at [0043] to the feed gas flow rate being “controllable to allow for precise generation of a desired contact time, usually about 1-second”. The data in Table E1-1 (set out in paragraph 62 above) are expressed in terms of contact times, and all but one of the runs do indeed have a contact time of 1 second. This would correspond to a residence time of approximately 12.5 seconds. This is consistent with a patent which is concerned with contact times of less than 5 seconds, but wholly inconsistent with a patent concerned with residence times of less than 5 seconds. Indeed, if the patentee had meant to say “residence time” in the claims, it would not have come close to providing any examples of his invention which satisfied the claims, or even achieved the objective of a shorter contact time than 10 seconds. As one would expect, however, the specifications indicate that the examples *do* satisfy the claims, as can be seen from [0044]-[0045] (quoted in paragraph 63 above).
91. The same conclusion is supported by Example 2. Table E2-1 (set out in paragraph 64 above) presents data for the foam catalyst at 250°C and various pressures as the residence time is held constant at 12.5 seconds. The 12.5 second residence time is the only reference to residence time in the data in the Patents, and it is obviously considerably more than 5 seconds. By contrast, the contact time at 24 atm pressure is given as 1 second and the skilled person would appreciate that the contact time at the lowest pressure used was approximately 4 seconds. Again, it is plain that Example 2 is being put forward as an example of the invention described in the Patents.
92. A final small point is that, as noted in paragraph 56 above, it is common ground that the specifications do contain a different obvious mistake, namely the erroneous reference to Fig.1 instead to Fig. 2. In my view this would confirm to the skilled reader that the specifications had not been drafted with the utmost care, and thus encourage him to conclude that the references to a residence time of less than 5 seconds were also mistaken.
93. Accordingly, if the specifications are read with a view to making sense of them, it would be immediately clear to the skilled person first that the various references to “residence time less than 5 seconds” and “contact time less than 5 seconds” were inconsistent with each other and could not be reconciled. A mistake must have been made. The patentee must have meant one or the other, but not both. Secondly, a moment’s consideration by the skilled person would lead to the conclusion that the patentee must have intended to refer throughout to, and certainly to have claimed, a “contact time less than 5 seconds”. The patentee plainly did not intend to set the reader of the patent an ambitious target of 25% CO conversion and less than 25% methane selectivity at less than 5 seconds residence time, without having shown that his invention could achieve this result. Rather, he must have intended to set a target which he had shown could be achieved using his invention, namely those conversion

and selectivity rates at less than 5 seconds contact time. The mistake in the claims is therefore obvious, and the correction is equally obvious.

94. It remains for me to address a number of points which were relied on by counsel for CompactGTL as undermining this conclusion. First, he pointed out that it was possible to characterise an invention directed to achieving shorter gas throughput times using either residence time or contact time. This I accept, but it does not detract from the conclusion that the patentee intended to use contact time for this purpose.
95. Secondly, counsel for CompactGTL submitted that there was nothing inherently implausible about a claim to a residence time of less than 5 seconds. In support of this submission he relied on evidence given by Dr Mauldin in cross-examination. Dr Mauldin began by accepting that the skilled person would regard a claim to a residence time of less than 5 seconds as an astonishing claim, would be sceptical of such a claim and would check the examples to see if it had been achieved. On further questioning, however, Dr Mauldin said that the parameters for CO conversion and methane selectivity required by the claims were not very stringent, and given that leeway a residence time of less than 5 seconds would not be difficult to achieve. In my view Dr Mauldin's initial answers on this point are a more accurate reflection of the skilled person's initial response to the unamended claim than his further thoughts. In any event, however, even if the skilled person considered that the leeway given by the other process conditions meant that a residence time of less than 5 seconds could be achieved, he would still see from the examples that the patentee had not in fact achieved this. Still less had the patentee achieved a residence time of less than about 2 seconds or between 0.1 and 1 seconds, whereas he had achieved a contact time of 1 second.
96. Thirdly, counsel for CompactGTL pointed out that a claim to a contact time of less than 5 seconds would not distinguish references 1 and 3 in Table 1. (Reference 2 and one of the results given for reference 4 also have contact times of less than 5 seconds, but do not meet other requirements of the claim.) The specifications explain reference 3 away at [0004], but not reference 1. On the other hand, much of what is said about reference 3 is also applicable to reference 1, and also reference 1 has higher methane selectivity. Furthermore, for the reasons given above, I think it would be clear to the skilled person that what the patentee was aiming for was a catalyst and a process which enabled a contact time shorter than the 10 seconds or more typical for commercial units, and hence a catalyst and a process which would enable this to be achieved on a commercial scale and not merely under laboratory conditions, although the skilled person would appreciate that the claims are not limited to commercial scale operation. In any event, the key point is the message which this part of the specification would convey to the skilled reader, which I have considered above.
97. Fourthly, counsel for CompactGTL argued that the data in the Examples did not support the full breadth of the claims whether as granted or as proposed to be amended. In my view, however, the fact that the claims involve an extrapolation from the experimental data in the Examples is immaterial. What matters is that, taken at face value, the Examples do not support a claim to a residence time of less than 5 seconds, but do support one to a contact time of less than 5 seconds.
98. Fifthly, counsel for CompactGTL pointed out that Velocys was not seeking to change all references to "residence time" in the specifications to "contact time". He argued

that, if one looked at the references which were sought to be changed, they were not mistakes. I disagree for the reasons given above.

99. Sixthly, counsel for CompactGTL argued that the applications for the Patents as filed showed that the references to a residence time of less than 5 seconds were not a mistake, but rather the result of a deliberate choice by the patentee. Precisely because I am satisfied that the skilled reader would conclude that the specifications contain an obvious mistake, I doubt whether the skilled person would consult the applications for this purpose. But assuming that the skilled person would do so, I do not accept that this would cause the skilled person to reach a different conclusion. In the case of the application for 509 (WO 01/12753), there is no material difference between the application and the granted Patent. In the case of the application for 508 (WO 01/12323), there are certain differences. In particular, the application contains claims characterised both in terms of residence time (claim 1 – “average residence time of 12.5 seconds”, claim 17 – “residence time ... less 5 seconds” and claim 20 – “residence time ... less 5 seconds”) and contact time (claim 4 – “contact time of less than 5 seconds”, claim 5 - “contact time of less than 2 seconds”, claim 6 - “contact time of less than 1 seconds”, claim 8 “contact time of less than about 2 seconds”). I think that the skilled reader would conclude from this that the patentee had chosen to characterise the granted claims by reference to just one kind of time, but it would not alter his conclusion that the choice the patentee had made was mistakenly expressed. (Indeed, he might conclude that claims 17 and 20 of the application were where the mistake had originated. Claim 1 is different, because it is a claim to an average residence time of 12.5 seconds, based on Example 2.)
100. Seventhly, counsel for CompactGTL relied upon the fact that it was not until the proceedings were relatively well advanced that Velocys had applied to amend the claims. He argued that it was to be inferred that the mistake had not been obvious even to Velocys and its advisors. I do not accept that it is legitimate to draw this inference. In any event, the question is whether the mistake would be obvious to the skilled person, not whether it was obvious to Velocys or its advisors.
101. Lastly, counsel for CompactGTL submitted that, even if the skilled person concluded that it was obvious that there was a mistake in the granted claims, it would not be immediately apparent to him how it should be corrected. In particular, he suggested that the skilled reader might consider that the claims should refer to a residence time of less than 12.5 seconds. I do not accept this. As discussed above, Example 2 uses a constant residence time of 12.5 seconds. Thus it makes sense for the Patents to refer to a residence time of 12.5 seconds (as in [0009] of 509). It would also make sense for there to be claim to a residence time of 12.5 seconds (as in claim 1 of the application for 509). It does not follow that references to a residence time of less than 5 seconds would be taken to mean a residence time of less than 12.5 seconds.
102. For these reasons I shall accede to Velocys’ first application.

The second application

103. By the second application, Velocys seeks to introduce new claims 2 and 3 into 508 and new claims 10 and 11 into 509. The primary purpose of this application is to provide Velocys with alternative fall-back positions if it is not successful in defending CompactGTL’s attacks on the validity of claim 1 of 508 and claim 9 of 509, that is to

say, to use the terminology of the European Patent Office, they are auxiliary requests. There is no objection to Velocys making a conditional application to amend for that purpose, which is a common procedure nowadays.

104. Counsel for Velocys argued, however, that Velocys should be permitted to make these amendments even if claims 1 and 9 were found to be valid. I do not accept this. As counsel for Velocys accepted, Velocys would not be able to make such amendments in the context of EPO opposition proceedings by virtue of Rule 80 of the EPC Implementing Regulations: see T 993/07 *Fisher-Rosemount/Field device management system* (unreported, 20 May 2010) cited in *Case Law of the Boards of Appeal of the European Patent Office* (7th edition) at p. 899. The same principle has been applied to applications to amend under section 75 of the 1977 Act: see *Sara Lee Household & Body Care UK v Johnson Wax Ltd* [2001] FSR 17 and *DataCard Corp v Eagle Technologies Ltd* [2011] EWHC 244 (Pat) at [226].
105. Counsel for Velocys suggested that these decisions were inconsistent with the earlier case of *Norling v Eez-Away (UK) Ltd* [1997] RPC 160. I do not accept this. There is nothing in the report of that case to suggest that the nature of the amendment application was merely to add new subsidiary claims. It is true that the defendant had abandoned its validity attack, but the amendment application had been made in response to that attack and it may be inferred that the patentee was concerned that there was substance in it. In any event, section 75 has subsequently been amended so as to introduce subsection (5). This now requires the court when exercising the discretion to amend to have regard to the principles applicable under the EPC. This supports the approach adopted in *Sara Lee* and *DataCard*: see *Zipher Ltd v Markem Systems Ltd* [2008] EWHC 1379 (Pat), [2009] FSR 1 at [205]-[211] (Floyd J, as he then was).
106. Counsel for Velocys also suggested that Velocys could make such amendments by way of a request to the EPO for limitation under Article 105a EPC, and accordingly submitted that the court should allow Velocys to achieve the same result by an amendment under section 75. I do not accept this, for the simple reason that inserting the new claims as subsidiary claims would not amount to a limitation of the Patents.
107. The only substantive objection to the amendments is a clarity objection raised by the Intellectual Property Office to new claim 2 of 508 and new claim 10 of 509. The objection is that the word “about” makes the boundary of the claim unclear. CompactGTL did not actively support this objection, no doubt recognising that the wording is firmly based on the specifications at [0035]. It was not suggested to Dr Brophy that the skilled person would have any real difficulty in interpreting these claims, nor did Dr Mauldin suggest this. I agree with the IPO that the use of the word “about” in relation to a numerical limit is undesirable, but in the present case I am not persuaded that the resulting claims are sufficiently lacking in clarity to make the amendments unallowable.
108. For these reasons I would allow Velocys’ second application if it was necessary for Velocys to amend the Patents because claim 1 of 508 and claim 9 of 509 were invalid, but not if those claims are valid.

Construction

109. There are a small number of issues as to the construction of the claims.

Porous structure/porous support

110. Claim 1 of 508 and claim 1 of 509 both require a catalyst structure comprising a “porous structure”. Claims 9 and 16 of 509 have the same requirement, but refer to it as a “porous support”. Velocys contends that “porous” has its ordinary English meaning, that is to say, as denoting something with holes through which fluids can penetrate. CompactGTL did not in the end dispute this. CompactGTL contends, however, that the pores must be a feature of the material before it is made into the structure/support. Thus on CompactGTL’s construction the claims do not cover a structure/support made from metal foil which is not porous even if the foil is formed into a structure/support which is porous. I do not accept this for three main reasons. First, as a matter of language the word “porous” in the claims qualifies the structure/support, not the material from which it is made. Secondly, the preferred embodiment in the Patents is a metal foam. The metal from which the foam is made is not itself porous, it is the foam structure which is porous. Thirdly, the specifications state in [0014] of 508 and [0017] of 509 that other porous media such as ceramic or metal honeycombs may be used. Again, a metal honeycomb is porous not because the metal from which it is made is porous but because the structure is porous.

Buffer layer

111. CompactGTL contends that the buffer layer must be a distinct layer from the porous support and the interfacial layer. I did not understand Velocys to dispute this. CompactGTL also contends that the buffer layer must be laid down by vapour deposition or solution coating, which are the only methods disclosed in the specifications. There is no such restriction in the claims, however. Accordingly, I agree with Velocys that the claims cover a buffer layer produced by oxidising an underlying layer of metal.

For Fischer-Tropsch synthesis

112. It is common ground that “for” means suitable for. Counsel for Velocys submitted that the skilled person would not regard a catalyst structure as suitable for FT if it only worked momentarily or very badly. I agree with this.

Novelty over Hunter

113. CompactGTL contends that United States Patent No. 4,289,652 published on 15 September 1981 (“Hunter”) anticipates claim 1 of 509.

Hunter

114. As Hunter explains (at column 1 lines 9-17), the invention it discloses is concerned with improvements in catalysts which are supported on metal substrates and which operate at elevated temperatures. Such catalysts are capable of a wide variety of uses, but a particularly important application is the treatment of automobile exhaust gases to remove pollutants.

115. Hunter notes (at column 1 lines 32-45) that a catalytic converter for use in automobile exhausts may comprise a honeycomb structure including a substrate that is capable of withstanding the high temperature of the exhaust gas which has been coated first with alumina and then with a catalytically active platinum group metal. Hunter acknowledges (at column 1 lines 46-60) previous proposals to use metals which are oxidation resistant as the substrate, including an earlier US patent describing a substrate from Fecralloy (an alloy of iron, chromium, aluminium and yttrium). This was subjected to a heat treatment to develop an aluminium oxide surface which served to key the washcoat and catalyst to it. Hunter also acknowledges another proposal to use a similar alloy called Kanthal (column 1 lines 61-68).
116. Hunter says (at column 2 lines 29-45) that the drawbacks with Fecralloy and Kanthal are that they are expensive and the supply is not always adequate. In addition, in the case of Fecralloy, the pre-oxidation step adds to the time and cost involved. Accordingly, there is a real need for a simple and convenient way of using less expensive metals which normally do not possess adequate high temperature oxidation resistance, such as stainless steel, as substrates for catalysts to be used at high temperature e.g. auto exhaust gas catalysts.
117. Hunter summarises the invention as follows (at column 2 lines 48-56):
- “Broadly stated, the invention contemplates rendering a metal which normally would be unsuitable as the substrate for a catalyst to be used at high temperature (e.g. above 1200° F.), suitable for such use by first coating the metal with a thin high temperature oxidation resistant layer, as defined below; prior to conventional washcoating with alumina or other material and application of the catalytically active material, e.g. platinum group metal.”
118. After describing the preparation and application of the oxidation resistant layer, Hunter states (at column 4 lines 62-67):
- “After application of the oxidation resistant coating, a conventional high surface area refractory oxide washcoat, preferably alumina, is applied in the usual fashion followed by drying and calcining and application of the platinum group metal or metals, all as conventionally employed in the preparation of exhaust gas catalysts ...”
119. Hunter describes two examples. In Example 1 two automobile exhaust catalysts A and B are compared. Both were made “by wrapping alternating sheets of flat and corrugated metal around a ¼” mandrel to form cylindrical honeycomb substrates about 3” long and 2” diameter” (column 5 lines 18-21). In the case of catalyst A, which is representative of the invention, the sheets were stainless steel, while in the case of catalyst B, they were Fecralloy. Hunter states (column 5 lines 24-30):
- “The Fecralloy substrate had been heat treated at high temperature to form an aluminum oxide ‘keying’ surface. Catalyst B was completed by dipping the heat treated Fecralloy cylinder in a conventional alumina washcoat, followed by

drying, calcining and then depositing platinum group metals (2 parts Pt, 1 part Pd) on the washcoat in conventional fashion.”

Hunter also states (at column 5 lines 36-38) that “washcoat and platinum group metal” were applied to catalyst A “exactly as in the case of the Fecralloy substrate”. Example 2 involves eight catalysts of the same two kinds.

120. Having described the two examples, Hunter states (column 7 lines 26-41, emphasis added):

“Various modifications may be made in the invention as described in the foregoing. Thus, while the catalyst has been described in connection with the treatment of exhaust gas for the control of hydrocarbon and carbon monoxide pollutants, the catalyst may be used for other purposes. For example, the present catalyst may be used in processes involving catalytic (flame less) combustion, ammonia oxidation, high temperature catalytic oxidations other than automobile exhaust control (e.g. fume and/or odor abatement), high temperature catalytic hydrogenation *including methanation, Fischer Tropsch reaction, coal liquefaction, nitric oxide abatement, and the like. More specifically, methanation and Fischer Tropsch reactions can be carried out by contacting CO and H₂ gas, with or without added steam, with the present catalyst...*”

Hunter goes on to describe certain other possible modifications.

Assessment

121. CompactGTL contends that Hunter discloses all the features of claim 1 of 509. Velocys disputes that two features are disclosed.
122. First, Velocys disputes that Hunter discloses a catalyst structure which is “for”, that is to say, suitable for, FT synthesis. Hunter is primarily concerned with catalysts for automotive applications at much higher temperatures than are used in FT synthesis. Heat transfer is not an issue in such applications, whereas it is a major issue in FT applications. Dr Brophy’s evidence was that the structure disclosed in Hunter was “wholly unsuitable for FT” because the structure and dimensions were such that the heat transfer would be very poor. This would lead to a number of problems, and in particular thermal run away. Counsel for CompactGTL did not directly challenge that evidence. Instead he suggested that “the structure would be able to convert carbon monoxide to hydrocarbons”. That is not enough, since if those hydrocarbons are all methane, then that is not FT at all. But even if some small quantities of longer-chain hydrocarbons were produced, that would not mean that the structure was suitable for FT for the reasons explained above. Likewise the suggestion made by counsel for CompactGTL that it wouldn’t matter if the reactor ran away, since in the brief moments before it did it would produce some product. For his part, Dr Mauldin agreed that the structure would have a heat transfer problem, but suggested that this could be mitigated by reducing the catalyst loading. Hunter does not disclose that suggestion, however. Accordingly I conclude that Hunter does not disclose a catalyst structure “for” FT synthesis.

123. Secondly, Velocys disputes that Hunter discloses a catalyst selected from the group consisting of cobalt, ruthenium, iron, nickel, rhenium, osmium and combinations thereof. As is common ground, osmium and ruthenium are platinum group metals. There are four other platinum group metals, including platinum itself and palladium. The only specific disclosure in Hunter is of the combination of platinum and palladium used in Example 1. Accordingly, CompactGTL relies on the general references in Hunter to the use of “platinum group metal or metals”. As counsel for Velocys submitted, however, these passages do not disclose the use of osmium and ruthenium. They do not disclose the use of any individual member of the platinum group. Furthermore, in context, what they disclose is the use of platinum group metals conventionally used in automobile catalysts: see, for example, the passage quoted in paragraph 118 above. Accordingly, they do not disclose the use of platinum group metals used in FT synthesis. The passage quoted in paragraph 120 above does not assist CompactGTL, since this merely says that the invention may be modified for use in, *inter alia*, FT synthesis, but without giving any specific directions.
124. Accordingly, I conclude that claim 1 of 509 is novel over Hunter.

Novelty and obviousness over Schanke

125. CompactGTL contends that claim 1 of 508 lacks novelty and that all the claims in issue are obvious in the light of International Patent Application No. WO 98/38147 published on 3 September 1998 (“Schanke”).

Schanke

126. The principal objective of Schanke is described (at page 1 line 30 to page 2 line 1) as follows:

“It is an object of the present invention to provide a reaction system for an F-T synthesis which has high mass transfer characteristics at the catalyst and in which heat transfer is not a significantly limiting factor, without the drawback of a difficult catalyst separation.”

127. Schanke goes on to summarise the invention (at page 2 line 24 to page 3 line 19) as follows:

“Accordingly, the invention is directed to the use of a monolithic catalyst to conduct a Fischer-Tropsch synthesis, in which the monolith comprises a solid body defining a series of discrete and continuous channels extending from one end of the body to the other, the walls of the channels consisting of or containing a Fischer-Tropsch catalyst.

The invention also provides a method of conducting a Fischer-Tropsch synthesis reaction which comprises:

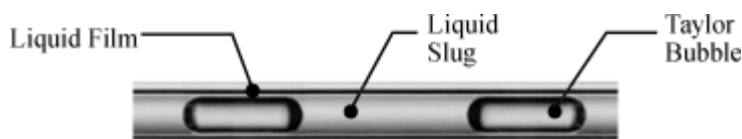
passing synthesis gas comprising H₂ and CO through discrete and continuous channels in a monolithic catalyst the walls of the channels consisting of or containing a Fischer-Tropsch

catalyst; removing the liquid product from the monolith; and removing heat produced in the reaction in the liquid product.

Preferably heat from the reaction is removed from the liquid product stream outside the reactor and a portion of the liquid product stream is recycled to the reactor. Unreacted synthesis gas may be recycled from the reactor, for example to the synthesis gas production unit.

Preferably, the synthesis gas feed and the liquid product flow co-currently. Preferably the synthesis gas feed and liquid product travel along the channels in a slug flow or Taylor Flow regime. Taylor Flow of a gas and liquid in a channel is defined as periodic cylindrical gas bubbles in the liquid having almost the same diameter as the channel and without entrained gas bubbles between successive cylindrical bubbles. Preferably, the flow is downwards.”

128. Dr Brophy helpfully illustrated Taylor Flow by means of the following diagram:



129. The advantages of this arrangement are described by Schanke as follows (at page 5 lines 24-29, page 6 lines 3-9 and page 7 lines 6-12):

“In the proposed monolith reactor design, cooling is performed by direct heat removal by the production stream (preferably the heavy FT products) which may circulate. The circulating liquid can then be cooled in an external heat exchanger. If necessary, the cooling can be carried out in stages by dividing the reactor in different sections with separate cooling circuits.

...

In a monolithic reactor operating in two-phase flow (gas + liquid), particularly under Taylor Flow conditions, mass transfer occurs mainly in the thin film between the cylindrical bubbles and the channel walls containing the catalytic material. This mode of flow occurs over a wide range of gas and liquid superficial velocities.

...

... a monolith reactor will show negligible backmixing, i.e. near plug-flow. The narrow channels of a monolith and the Taylor-flow mode of operation in two-phase flow results in almost perfect plug-flow. Scale-up is therefore simple since the entire reactor can be described by a single channel.”

130. Schanke describes monolithic catalysts suitable for use in the invention in a passage which, having regard to the arguments on obviousness, it is necessary to quote at some length (page 9 line 5 to page 11 line 3):

“In many monolith applications, the thermal stability of the material and the ability to withstand rapid temperature variations are both of great importance. Therefore, the channel structure of a monolith usually consists of a low-surface area ceramic material. The surface area can be increased by depositing a high surface area material (like $\gamma\text{-Al}_2\text{O}_3$) e. g. by the so-called washcoating technique. Catalytically active materials can then be incorporated into the washcoat by known techniques, like impregnation, precipitation, ion-exchange, vapour deposition etc. Alternatively, the low surface area base material can be washcoated with the catalytic material itself.

Thus in one preferred form, the monolithic catalyst comprises an inactive substrate with a relatively low specific surface area, and, lining the channels, a relatively high specific area catalyst support impregnated with a catalytically active material. Preferably the catalyst support material and the active material are deposited simultaneously on the walls of the channels. Alternatively, the catalyst support material is first deposited on the walls of the channels and is subsequently impregnated with the active material. The inactive substrate may be a ceramic material or a metal. Examples of suitable materials are set out in Table 1 (taken from ‘Monolithic Catalysts for Nonautomobile Applications’ by S Irandoust and B Andersson, Catal. Rev. Sci. Eng., 30(3), 1988).

Table 1
Materials for Monolithic Substrates

Name	Composition
α - and γ -Alumina	Al_2O_3
Cordierite	$2MgO \cdot 2Al_2O_3 \cdot 5SiO_2$
Cordierite-mullite	$2MgO \cdot 2Al_2O_3 \cdot 5SiO_2 - 2Al_2O_3 \cdot 2SiO_2$
Magnesium aluminate-spinel	$MgO - MgO \cdot Al_2O_3$
Mullite	$3Al_2O_3 \cdot SiO_2$
Mullite-aluminum titanate	$3Al_2O_3 \cdot 2SiO_2 - Al_2O_3 \cdot TiO_2$
Silica	SiO_2
Silicon carbide	SiC
Silicon nitride	Si_3N_4
Spinel	$MgO \cdot Al_2O_3$
Titania	TiO_2
Zeolites	$Al_2O_3 - SiO_2$
Zirconia	ZrO_2
Zirconia-spinel	$ZrO_2 - MgO \cdot Al_2O_3$
Metallic	$Fe - Cr - Al - Yt$

A monolith-based FT catalyst can thus be made by impregnation (or by other techniques) of an active FT-metal (Co,Fe,Ru,Ni) and suitable promoters on a high-surface area washcoated monolith or by washcoating the finished FT-catalyst onto the low-surface area monolith.

In slower reactions like the Fischer Tropsch synthesis, thermal stability is not a critical factor. In such cases, monoliths can be made directly from high surface area materials, for example gamma- Al_2O_3 , SiO_2 , TiO_2 or zeolites. The catalytic material (e.g. cobalt, iron ruthenium or nickel in the case of FT-synthesis) and optionally suitable promoters can then be incorporated into the total volume of the monolith (by any of the known techniques), thus increasing the catalyst loading of the reactor compared to the washcoat method. Alternatively, the monolith can be produced directly from the FT-catalyst. Production of high surface area monoliths is usually achieved by extrusion.”

131. It is worth emphasising that Table 1 has simply been cut-and-pasted into the specification from the paper by Irandoust and Andersson cited. Although it is not referred to by name, the last item in Table 1 is Fecralloy.
132. Schanke goes on to say that the monolithic catalyst can be prepared in a number of other ways, in particular by impregnating the walls of the channels of an inactive substrate having a high surface area with catalysts and by extruding a high surface area material incorporating a catalyst. A number of options and parameters for the monolithic catalyst are described.

133. Schanke describes a number of specific embodiments by reference to a series of figures. Figure 1 is a schematic diagram of a reaction system according to the invention which employs a monolithic catalyst 12. Most of the details do not matter for present purposes, but Schanke explains that the synthesis gas and recycled liquid product are “drawn down through longitudinal channels in the monolith 12 under a Taylor flow regime” (page 13 lines 20-22).
134. The monolithic catalyst 12 is shown in more detail in Figure 3, which I reproduce below:

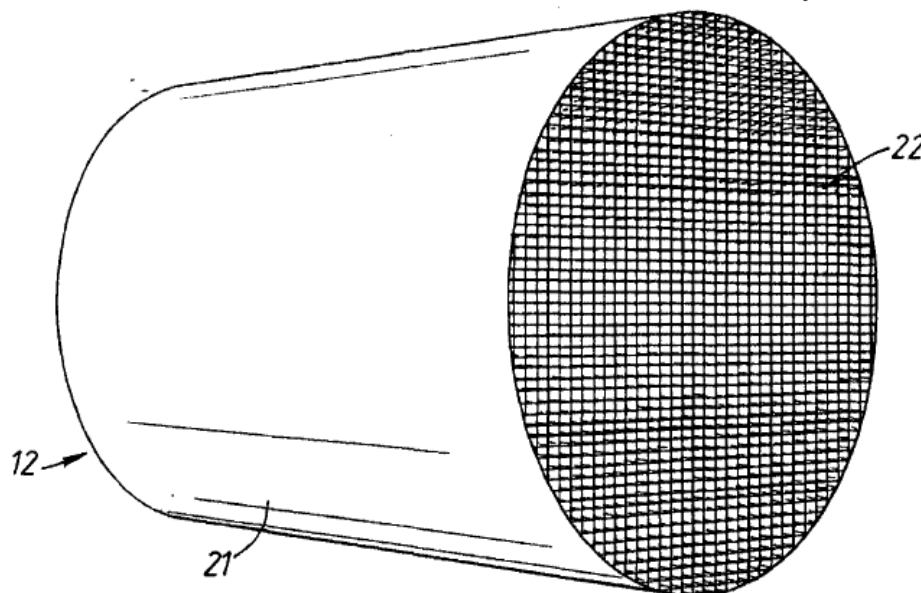
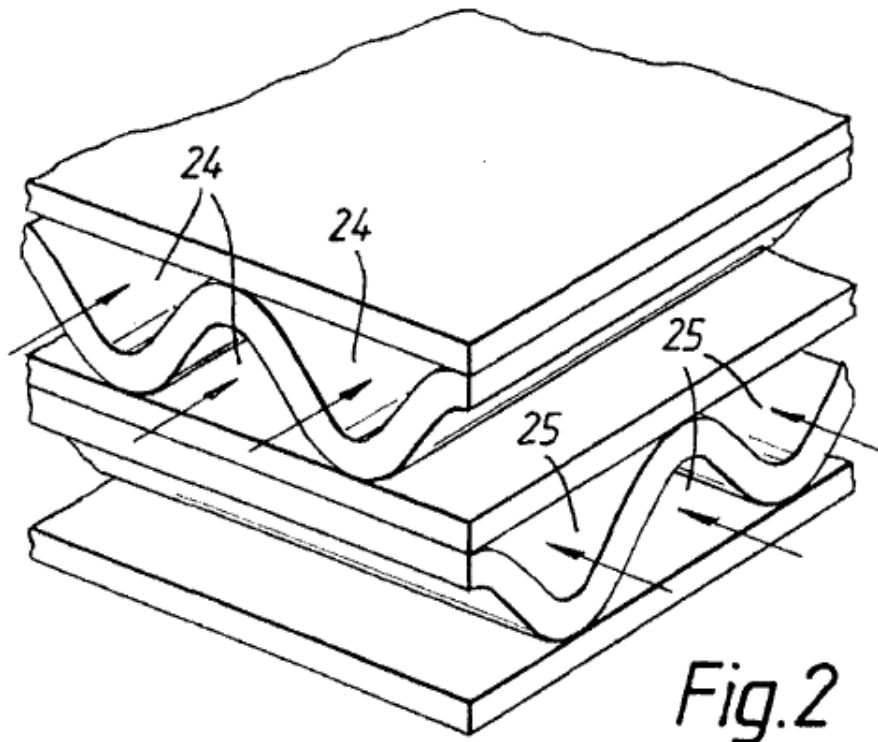


Fig.3

135. Schanke states (at page 14 lines 2-4) that, although the monolith shown in figure 3 is cylindrical, any suitable shape could be employed, such as rectangular. It goes on to describe a first method of manufacturing the monolith by references to figures 5a to 5c, a second method by reference to figures 6a and 6b, a third method by reference to figures 7a and 7b and a fourth method by reference to figures 8a and 8b. The details of these methods do not matter for present purposes.
136. Figure 2 is said to show an alternative arrangement to Figure 1. I reproduce this below:



137. All that Schanke says about figure 2 is this (page 13 line 31 to page 14 line 1):

“In an alternative construction shown in Figure 2, the monolith is a cross-flow design. In this case, the gases are arranged to travel along one series of channels 24 and the cooling liquid along the transverse channels 25 which alternate vertically with the gas channels.”

It is not clear precisely how this is supposed to work. It appears that it does not involve the Taylor Flow regime, since the synthesis gas and the cooling liquid flow in separate channels.

138. Schanke illustrates the invention with three examples. Example 1 describes the preparation of conventional powdered catalysts A, B and C. Example 2 describes the preparation of washcoated monolithic catalysts D and E. This states (page 16 lines 18-21):

“Approximately 10 cm long cylindrical low surface area cordierite monoliths (Celcor (reg. trademark) from Corning) with a diameter of about 0.9 cm were used as base materials.”

Cordierite is a magnesium iron aluminium cyclosilicate. The cordierite monolith is washcoated with one (D) or two (E) layers of cobalt/rhenium/alumina catalyst. Example 3 describes the preparation and testing of a high surface area monolithic catalyst F from a cylindrical alumina monolith dipped into a solution of cobalt/rhenium catalyst and then dried, together with a crushed and sieved sample G. Thus catalysts D-F are according to the invention, while catalysts A-C and G are included for comparison.

139. The catalysts were tested in a “20 cm long 1 cm ID [internal diameter]” fixed bed reactor (page 17 lines 26-27). The results are set out in Table 2, which I reproduce below:

CATALYST	Temp. (°C)	GHSV (h ⁻¹) ^a	CO conv. (%)	Reaction rate		Selectivity (%)			
				(g _{HIC} /g _{cat} *h)	(g _{HIC} /g _{Co} *h)	CH ₄	C ₂ -C ₄	C ₅ +	CO ₂
A (53-75 micron powder)	210	10.900	27.7	0.61	3.6	9.0	7.4	82.9	0.7
B (75-150 micron powder)	210	10.100	26.2	0.54	3.2	9.1	7.5	82.7	0.8
C (425-850 micron powder)	210	7.300	33.0	0.49	2.9	21.5	12.7	64.4	1.5
D (Cordierite base, 0.3 g cat.)	210	16.800	16.3	0.56	3.3	8.2	7.3	83.8	0.7
E (Cordierite base, 0.7 g cat.)	210	8.400	29.1	0.50	2.9	8.9	6.5	84.0	0.6
F (High surf.area monolith)	195	4.060	27	0.22 (0.5)**)	1.8 (4.0)**)	7.1	6.2	86.4	0.3
G (Crushed high surf.area monolith)	210	6.000	30	0.36	2.9	8.2	7.1	84.5	0.2

140. Schanke comments on these results as follows (page 18 line 23 to page 19 line 8):

“It is shown that the washcoated monolith catalysts (D&E) are as active as the conventional (powder) catalysts (A-C). The application of two washcoat layers (cat. E) on the cordierite base does not influence the catalyst performance compared to the single layer monolith (cat. D).

The high-surface area monolith catalyst (F) contained more cobalt per volume of reactor than the other catalysts and it was found that 195°C was the maximum acceptable reactor temperature due to heat removal limitations in a gas-phase reactor. These limitations will not be present in a monolith reactor operating with liquid coolant. After correcting for the temperature difference, it is evident that the high-surface area monolith is at least as active per unit mass of cobalt as the conventional (powder) catalysts and also similar to the crushed high-surface area monolith catalyst (G). The high C5+ selectivity indicates that hot-spots were not present during reaction.”

Novelty of claim 1 of 508

141. CompactGTL contends that claim 1 of 508 is anticipated by Schanke. Schanke’s catalyst E satisfies the structural requirements of the claim. Furthermore, it achieved the CO conversion and methane selectivity required by the claim. The only issue is whether it satisfies the requirement for a contact time less than 5 seconds. CompactGTL relies on calculations from the data given in Schanke to demonstrate this.

142. As is common ground, however, the results of the calculations depend on the dimensions of the catalyst. Schanke says that the catalyst was “approximately 10 cm” long (see paragraph 138 above). It does not appear to be in dispute that a reasonable interpretation of this is that the length was between 9.5 and 10.5 cm. Accordingly, the catalyst could be as long as 10.5 cm. Dr Brophy calculated that, if the length was 10.5 cm, the contact time would be 5.2 seconds. Counsel for CompactGTL submitted that this was within the claim. I do not accept this. 5.2 seconds is not “less than 5 seconds”.
143. Counsel for CompactGTL also submitted that Dr Brophy’s calculation was flawed and that Dr Mauldin’s calculation, which produced a figure of less than 5 seconds even if the length was 10.5 cm, was to be preferred. The principal difference between Dr Brophy’s calculation and Dr Mauldin’s calculation is that Dr Brophy used the internal diameter of the reactor to calculate the “volume [of the catalyst chamber] in immediate proximity and surrounding the catalyst zone” referred to in [0033], whereas Dr Mauldin used the diameter of the monolith. In my judgment, Dr Brophy’s calculation is the correct one. As Dr Brophy convincingly explained, there is a small gap between the monolith and the reactor wall and some catalysis will take place in this gap. It is not dead space. It therefore forms part of the volume of the chamber which the specifications require to be included in the calculation.
144. Accordingly, claim 1 of 508 is novel over Schanke.

General points on obviousness

145. Before turning to the details of the arguments on obviousness, it is first convenient to consider some general points which counsel for Velocys made about how the skilled person would approach Schanke. The first is that monolithic catalysts had been known and used in other catalytic fields - particularly, but not exclusively, automotive catalytic converters - for a couple of decades. They had not been adopted for use in FT synthesis, however. The obvious reason for this is that their heat transfer properties would have been assumed to be unacceptable. Heat transfer is unimportant in the applications in which monoliths were used, but the skilled person in FT was obsessed by it. Monoliths are adiabatic by nature – i.e. they lock the heat in. An FT reaction run in adiabatic conditions will heat up to 1800°C, above the melting point of steel. Accordingly, counsel for Velocys submitted and I agree, the skilled person can be assumed to come to Schanke with a mindset highly sceptical of the utility of monolithic catalysts in FT.
146. Secondly, it can be seen from Table 2 and Schanke’s discussion of it that, just as the skilled person would expect, the results Schanke obtained were not very promising. Dr Brophy gave unchallenged evidence that an acceptable productivity for a reactor intended for commercial use was 150 gmHC/Lcat/hr, but that catalyst E fell well short of this. (Dr Mauldin’s answer to this was that the conditions used in the examples could be varied, a point I shall return to below.) Furthermore, Schanke encountered the expected heat transfer problem with catalyst F. The skilled person would be intrigued by Schanke’s proposed solution to this problem, which is to use a reactor design in which the monolith operates under two-phase Taylor Flow conditions. In this way recycled liquid product cools the reactor. But the skilled person would appreciate that Schanke does not actually tell him how to do this, or even state that the inventors have successfully achieved it. In those circumstances, the skilled person

would realise that attempting to implement this proposal would involve a research project. (Indeed, the evidence shows that it would be a difficult project, since Schanke and his colleagues had still not achieved it years later.)

147. Thirdly, so far as the evidence goes, Schanke was a paper proposal which was not commercialised and received little or no attention. Dr Mauldin's team followed patents very closely, yet Dr Mauldin had never come across Schanke before the litigation.
148. Given (i) the scepticism with which the skilled person would approach Schanke, (ii) the absence of attention which it had received, (iii) the underwhelming results it reported, (iv) the fact that Schanke had not demonstrated that his solution to the heat transfer problem would work and (v) the fact that any attempt to make it work would involve a research project, I consider that the skilled person would conclude that Schanke did not represent a worthwhile starting point for development. It follows that it does not render any of the claims of the Patents obvious. In case I am wrong about that, however, I shall go on to consider the arguments in more detail on the assumption that the skilled person would regard Schanke as a worthwhile starting point.

Obviousness of claim 1 of 509

149. The sole difference between claim 1 of 509 and Schanke is that Schanke does not disclose a catalyst structure with a buffer layer. CompactGTL contends that it would be obvious to make such a structure in the light of Schanke. In summary, CompactGTL says that (i) it would be obvious to make a structure of the kind disclosed in Schanke from the Fecralloy identified in Table 1 and (ii) it would be obvious to pre-oxidise the surface of the Fecralloy in order to obtain a good bond with the washcoat, which would result in a buffer layer.
150. As counsel for Velocys pointed out, however, a basic flaw in CompactGTL's obviousness case is that it was never made clear either in Dr Mauldin's evidence or in the cross-examination of Dr Brophy precisely how it was suggested that the skilled person would proceed in the light of Schanke. In particular, would the skilled person implement Figure 2 or Figure 3? Only when I pressed him on this point in his closing submissions did counsel for CompactGTL make it clear that his case was based on implementing Figure 2. I shall consider it on that basis.
151. As noted above, Schanke says very little about Figure 2. It is simply put forward as an alternative embodiment to Figure 1. No experimental results are given for a monolithic catalyst constructed in accordance with Figure 2. Given how little is said about it, and given that it does not appear to involve Taylor Flow, I consider that the skilled person would conclude that, even if other aspects of Schanke were worth pursuing, Figure 2 was not. Accordingly, I conclude that Schanke does not render claim 1 of 509 obvious. That is not the end of CompactGTL's difficulties, however.
152. The next step in CompactGTL's argument in fact appears to be based on an implementation of Figure 3, not Figure 2, since it was monoliths of that kind that Schanke used in the examples. CompactGTL contends that it would be obvious to make a monolithic catalyst of the kind in examples 2 and 3, and in particular catalyst F, from Fecralloy, rather than the ceramics used by Schanke, for two reasons. The

first is that Fecralloy is among the list of suitable materials in Table 1. On its own, this is not persuasive. Schanke does not use Fecralloy in its examples, it uses two ceramics (cordierite and alumina). Fecralloy is at the bottom of a list of potential substrate materials cut-and-pasted from another source, with all the others being ceramics. Schanke gives the skilled person a considerable number of combinations of options to explore in terms not only of substrate material, but also other variables such as manufacturing method, catalyst and so on. Furthermore, as Dr Mauldin himself said, the skilled person who wanted to improve Schanke could well start by changing the FT process variables Schanke employed in his examples, which would be much more straightforward than making a different monolithic catalyst. Thus Schanke on its face gives the skilled person no reason to believe that making a monolithic catalyst of the kind shown in Figure 3 from Fecralloy would offer any improvement. Furthermore, there would in fact be difficulties in doing so as I shall discuss below.

153. CompactGTL's second reason is that the skilled person would appreciate that the monolith made from catalyst F had serious heat transfer issues (i.e. the very reason why such monoliths had not previously been used for FT). CompactGTL suggests that he would have chosen to use a metal in order to overcome those heat transfer issues, rather than the solution proposed by Schanke, i.e. liquid/gas cooling using Taylor Flow. But if it had been obvious that use of a metal monolith would have overcome the heat transfer problems of monolithic structures for FT, then it is hard to understand why it had not been done long before in FT given the availability and use of metal monoliths in other fields.
154. Furthermore, it turns out that Fecralloy's thermal conductivity is $16 \text{ W m}^{-1} \text{ K}^{-1}$ (which is very poor for a metal). This is actually worse than that of alumina ($26 - 35 \text{ W m}^{-1} \text{ K}^{-1}$), not better. Thus, if the skilled person did consider trying to solve the heat transfer problem Schanke encountered with catalyst F by substituting a substrate with higher thermal conductivity, that would lead him away from Fecralloy.
155. Counsel for CompactGTL tried to get out of this difficulty by relying on the fact that the thermal conductivity of cordierite is even worse ($3 \text{ W m}^{-1} \text{ K}^{-1}$). In my view, this makes no difference. Cordierite is the ceramic Schanke used in catalysts D and E, but CompactGTL is relying on reasoning that starts from catalyst F and what Schanke says about it. Furthermore, the fact remains that, even though it is better than cordierite, Fecralloy has very poor thermal conductivity. If the skilled person was prompted to try a metallic monolith which had significantly better thermal conductivity, he would choose a metal such as aluminium (which has a thermal conductivity of $205 \text{ W m}^{-1} \text{ K}^{-1}$).
156. Counsel for CompactGTL complained that the point about the relative thermal conductivities of Fecralloy and alumina only emerged in cross-examination of Dr Mauldin. He suggested that this was unfair because CompactGTL had been taken by surprise. I do not accept this. It was Dr Mauldin who suggested that the skilled person would be led to Fecralloy based on its supposedly superior thermal conductivity, but as noted above he just assumed this rather than checking it. Velocys cannot be criticised for checking the facts and putting the true position to Dr Mauldin in cross-examination. Counsel also suggested that the datasheet relied on by Velocys as showing the thermal conductivity of alumina might not be representative of the porous γ -alumina used by Schanke. But the datasheet relied on by Velocys is the best

evidence available, and there is no evidence that porous γ -alumina has a different thermal conductivity.

157. CompactGTL also relies on the fact that, if the skilled person pursued the reference in Schanke to Irandoust and Andersson, he would find that those authors state (at pages 372-373) that:

“Difference in thermal conductivity is of particular importance. Metallic monoliths gave about two orders of magnitude higher thermal conductivity than ceramic monoliths. Ceramic monoliths are almost adiabatic, while radial heat transfer in metallic monoliths is of the same magnitude as in packed beds.”

158. This does not assist CompactGTL, however, for two reasons. First, although Table 6 of Irandoust and Andersson sets out information regarding the thermal characteristics of various monoliths, including Fecralloy, the characteristics listed do not include thermal conductivity. The skilled person would appreciate that the statement in the text was a generalisation, and would need to check the relative thermal conductivities of Fecralloy and alumina. Having done so, he would find that Fecralloy was worse.

159. Secondly, reading on at page 373 of Irandoust and Andersson, the skilled person would find the statement:

“According to Pratt and Cairns [11], who studied the use of metal catalysts on metallic substrates, the use of metal substrates is favourable for applications involving high-flow, high-temperature environments.”

This would confirm the skilled person’s preconception that such monolithic catalysts were useful for high temperature applications such as automobile exhausts, but not for FT.

160. Even if the skilled person reading Schanke would be prompted to try making a monolithic catalyst from Fecralloy, that would not be enough to bring him within the claim. The final step in CompactGTL’s case is that the skilled person would pre-oxidise the surface of the Fecralloy, which would result in the production of an alumina buffer layer and thus bring him within the claim. CompactGTL puts its case that this would be obvious in a number of different ways, which I shall deal with in turn.

161. First, CompactGTL contends that it would be part of the skilled person’s common general knowledge that it was advantageous to pre-oxidise the surface of metals like Fecralloy so as to key the surface in order to enable a washcoated layer of catalyst to bond well to that surface. I have considered this contention above and concluded that this was not common general knowledge.

162. Secondly, CompactGTL relies on the following statement in Irandoust and Andersson (at page 367):

“Metallic monoliths are made to withstand oxidating atmosphere at high temperatures. ... Aluminum containing ferritic steels produce [sic] layer of aluminium oxide which makes the alloy operative up to 1500 K [11].

Metallic monoliths are usually made of the alloys Kanthal and Fecralloy (Table 6). Fecralloy contains iron, chromium, aluminum and a small percentage of ytterium.”

163. This does not assist CompactGTL. The problems encountered in high temperature oxidising reactions are the opposite of those faced by the skilled person seeking to use Fecralloy in FT: the environment of FT is low temperature and reducing, not oxidising. Accordingly, even if the skilled person followed the reference in Schanke to Irandoust and Andersson, this statement would not prompt him to pre-oxidise the Fecralloy surface.
164. Thirdly, CompactGTL also relies on a passage in the paper by Pratt and Cairns which is reference 11 cited in Irandoust and Andersson in the passages quoted in paragraphs 155 and 158 above. I do not propose to go into this in any detail. It suffices to say that by now we are a long way from what would be obvious to a skilled person reading Schanke.
165. Finally, CompactGTL contends that, even if the skilled person did not deliberately choose to pre-oxidise the Fecralloy surface, he would be likely to use Fecralloy which was in fact supplied in a pre-oxidised form and thus would arrive within the claim, albeit unwittingly. The only basis for this contention is a suggestion by Dr Mauldin in cross-examination that the vendor might supply Fecralloy heat treated, which would result in the surface being oxidised. Although there is evidence that suggests that heat treated Fecralloy may have been available in 1999, however, there is no evidence that Fecralloy would be supplied in that form whether it was requested or not.
166. For these reasons, I conclude that claim 1 of 509 is not obvious in the light of Schanke.

Obviousness of claim 9 of 509

167. Given that claim 1 of 509 is not obvious, it follows that claim 9 is not obvious either. For completeness, however, I shall briefly consider claim 9 on the assumption that claim 1 is obvious. Even on that assumption, CompactGTL has not proved that a Fecralloy version of one of Schanke’s catalysts would satisfy the performance requirements of claim 9, and in particular the requirement for a contact time of less than 5 seconds.
168. Again, CompactGTL’s obviousness case is vitiated by the basic flaw identified in paragraph 150 above. If one supposes that the skilled person decides to make a Fecralloy version of Figure 2 of Schanke, there is no reliable evidence as to what contact time it would achieve. Certainly, CompactGTL conducted no experiments to demonstrate this. Instead, it relied on speculation by Dr Mauldin which was flawed because Dr Mauldin did not appear to have considered what structure the skilled person would make.

169. Turning to Figure 3, Dr Brophy explained that it would not be possible to make a Fecralloy version of catalyst E which had precisely the same structure and geometry. This would mean that its performance was different. Moreover, its performance might well be worse rather than better: when Schanke and his colleagues tried to implement a metal monolith some years later, they found that it worked only about 70% as well as the ceramic version. The same goes for a Fecralloy version of catalyst F. Thus CompactGTL has not established that going down this route would produce a catalyst structure which achieved a contact time of less than 5 seconds.
170. Counsel for CompactGTL tried to meet this difficulty by arguing that it was obvious to test a Fecralloy catalyst in a laboratory reactor at a contact time of 1 second. I am prepared to accept that, but it does not assist CompactGTL, because one has no idea what CO conversion or methane selectivity would be achieved in those circumstances.
171. Accordingly, I conclude that claim 9 of 509 is not obvious even if claim 1 is.

Obviousness of claim 1 of 508

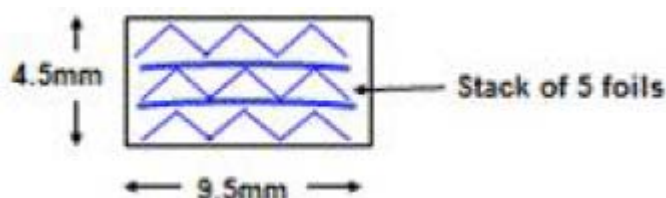
172. Again, counsel for CompactGTL argued that it would be obvious to test catalyst E at a contact time of 1 second. Again, however, CompactGTL has not shown that the CO conversion or methane selectivity requirements would be met if that was done.

Infringement

173. The infringement allegation relates to a pilot plant operated by CompactGTL at Wilton. The relevant aspects are concisely described in CompactGTL's Product and Process Description. There is no dispute as to the facts. There is no need to set them all out here, because the issues on infringement are quite narrow and turn on construction.

Porous structure/porous support

174. CompactGTL uses a catalyst structure made from Aluchrom foil strips. The strips are formed into corrugated and non-corrugated (arced) sheets. The sheets are coated a number of times with the FT catalyst in the form of a washcoat (a slurry of powdered catalyst, solvent and binder) which is then dried. The sheets are then assembled into a stack of five sheets consisting of alternating corrugated and arced sheets. The resulting structure may be schematically represented as follows:



175. In my judgment this is a porous structure/porous support as I have construed those terms. In principle, it is little different to a honeycomb.

Buffer layer

176. The foil strips referred to above are “pre-oxidised” by heating them at 940°C for 14 minutes before they are washcoated. Dr Brophy and Dr Mauldin agreed that the result of this treatment was to produce a layer of alumina on the surface of the strips. In my judgment this is a buffer layer as I have construed that term.

Claim 16 of 509

177. Counsel for CompactGTL submitted that the process by which CompactGTL’s catalyst structure was formed did not comply with claim 16. I disagree. In so far as it was suggested that the pre-oxidation step does not amount to “depositing” a buffer layer, I consider that this term is wide enough to cover such a process. As for depositing the interfacial layer, Dr Mauldin accepted that what CompactGTL do is identical to what is described in the specification. In so far as it was suggested that the washcoating step did not amount to “placing” the FT catalyst, I can only say that I disagree.

Conclusion

178. Accordingly, I conclude that CompactGTL’s catalyst structure and process infringe claims 1 and 6 of 508 and claims 1, 7, 9 and 16 of 509 (using the numbering given above). The process would also infringe claims 2 and 3 of 508 and 10 and 11 of 509 if those claims were introduced as a result of Velocys’ second amendment application.

Summary of conclusions

179. For the reasons given above I conclude that:

- i) Velocys’ first amendment application should be allowed;
- ii) Velocys’ second amendment application should be refused since it is unnecessary;
- iii) claim 1 of 509 is novel over Hunter;
- iv) claim 1 of 508 is novel over Schanke;
- v) none of the claims of 508 and 509 is obvious over Schanke; and
- vi) CompactGTL’s catalyst structure and process infringe claims 1 and 6 of 508 and claims 1, 7, 9 and 16 of 509.