UNITING CATALYSTS

IICHe-NRC & FAI Seminar

Magcat SMR Catalyst to Increase Hydrogen Production

Mar 21st 2023
New Delhi, India

Abhinav Deshwal
Himanshu Chauhan

Timelines

2000: Unicat was founded in Texas, Now over 200 unique products

2009: Magma group was founded in U.K (mainly a ceramics company)

2017: Magma starts catalyst production

2023: we are now 250 people strong company providing solutions to companies worldwide.

2021: Unicat acquires Magma Group

2021: Unicat receives investment from White deer Energy, a US based equity firm

General Information

Owned by White Deer Energy

A multi Billion Dollar Private Equity Firm

Sales

UNICAT has grown tremendously since being formed in 2000.

R & D Facilities

UNICAT Facilities in USA, UK and China

Customer Base

> 900 Industrial references throughout the USA, Europe, South America and Middle and East Asia

Specialty catalysts

New JV Vanguard Catalyst LLC with a Manufacturing plant in the USA

Technical Service

Knowledgeable Engineers able to provide on site service to customers

ISO Certified

ISO-14001 & 9001 production sited in Asia, UK and the USA

UNICAT
CATALYST TECHNOLOGIES, INC.

CUSTOMERS

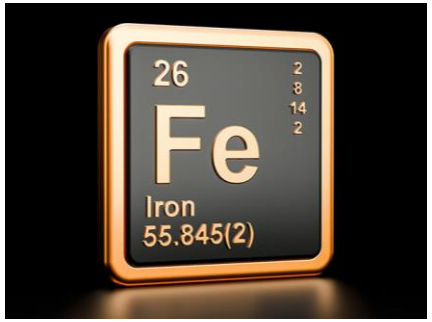
- Total
- Slovnaft (MOL Group)
- Unipetrol
- Kuwait Oil
- Statoil
- Repsol
- Cepsa
- ExxonMobil
- Shell
- Saudi Aramco
- BP
- ConocoPhillips
- Nippon Oil
- Valero
- Phillips-66
- PKN Orlen
- Suncor
- Tesoro
- Farmland
- Foster Wheeler
- BOC Linde
- Marathon Ashland
- Holly Oil
- Pertamina Oil
- Petrorin
- Sabic
- Frontier
- Citgo
- Calumet
- Irving Oil
- Giant Refining
- SunOil Refining
- Cross Oil
- ENI Group
- PCS
- Yara
- Qafac
- Nippon Group
- Koch Nitrogen
- Cargill
- ADM
- AGP Refining
- PIC Kuwait
- Qafac MEOH
- AGP Refining
- Krakatau Steel
- Arcelor Mittal
- Slavnaft
- Gazprom
- Lukoil
- Mozyr
- Hanwha Total/Chemical
- SK Energy
- Mozyr
- S-Oil
- PTT Thailand
- Bangchack Refinery
- Equinor
- Satorp

INDUSTRIES

We span a range of industries

- **Ammonia**
- **Iron-DRI**
- **Oil & Gas Processing**
- **Hydrogen**
- **Methanol Production**
- **Petrochemical**
- **Oil Refining**

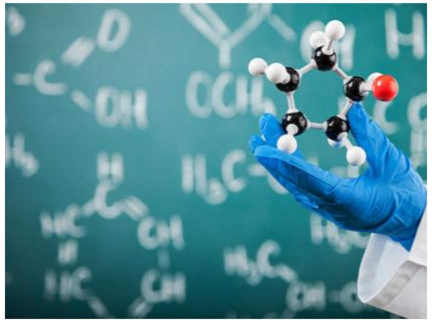
AMMONIA



IRON-DRI

OIL & GAS

HYDROGEN



METHANOL PRODUCTION

PRODUCT RANGE

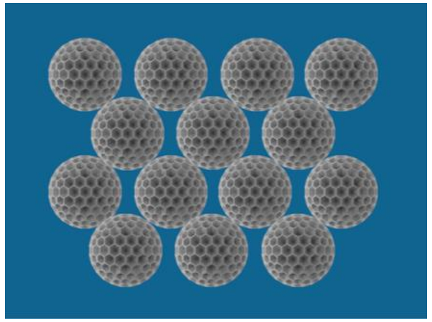
Major Product Range

- Purification
- Polycat
- Magcat®
- PSA adsorbents
- Shift converters
- Methanator
- Control Systems

Purification

PSA

Polycat



Magcat®

Magcat production Site

- Dewsbury, England
- Site manufacturers Catalysts, Ceramics & Combustion equipment
- 25,000 m^2 of manufacturing space.
- Fully equipped catalyst laboratory. New heat transfer testing capability
- Plant expansion to 6 Tonnes/day since 1st May 2021
- Further $3 MM catalyst expansion plan throughout 2023

Catalysts in >28 commercial tubular reformers (>1,000 tubes). Performing well, repeat orders received.

Organisation – management / product development

Mark Stuckey – Managing Director

Oversaw buyout from Dyson Precision Ceramics and since we have enjoyed continual and significant growth. We have three divisions, notably Ceramics, Catalysts and Combustion and operate worldwide from our facilities in the UK & Vietnam.

Dr John Dunleavy – Consultant

Over 30 years of experience in managing commercial/ technical activities for profitable multi-national organisations. Selection/ negotiation of contracts. Business development activities associated with chemical, oil and gas industries.

Abhinav Deshwal– Technical Sales Manager

Over 13 years of experience in Technical Services and sales of Refinery/Ammonia/Hydrogen/petrochemical catalysts. Involved in multiple plant commissioning and troubleshooting for various catalyst worldwide.

Gary Bennington – Regional Manager Asia

30 years of experience within the syngas catalyst, chemical & steel industries, has included sales, technical, marketing and business development.

Himanshu Chauhan – Bus. Dev. Manager

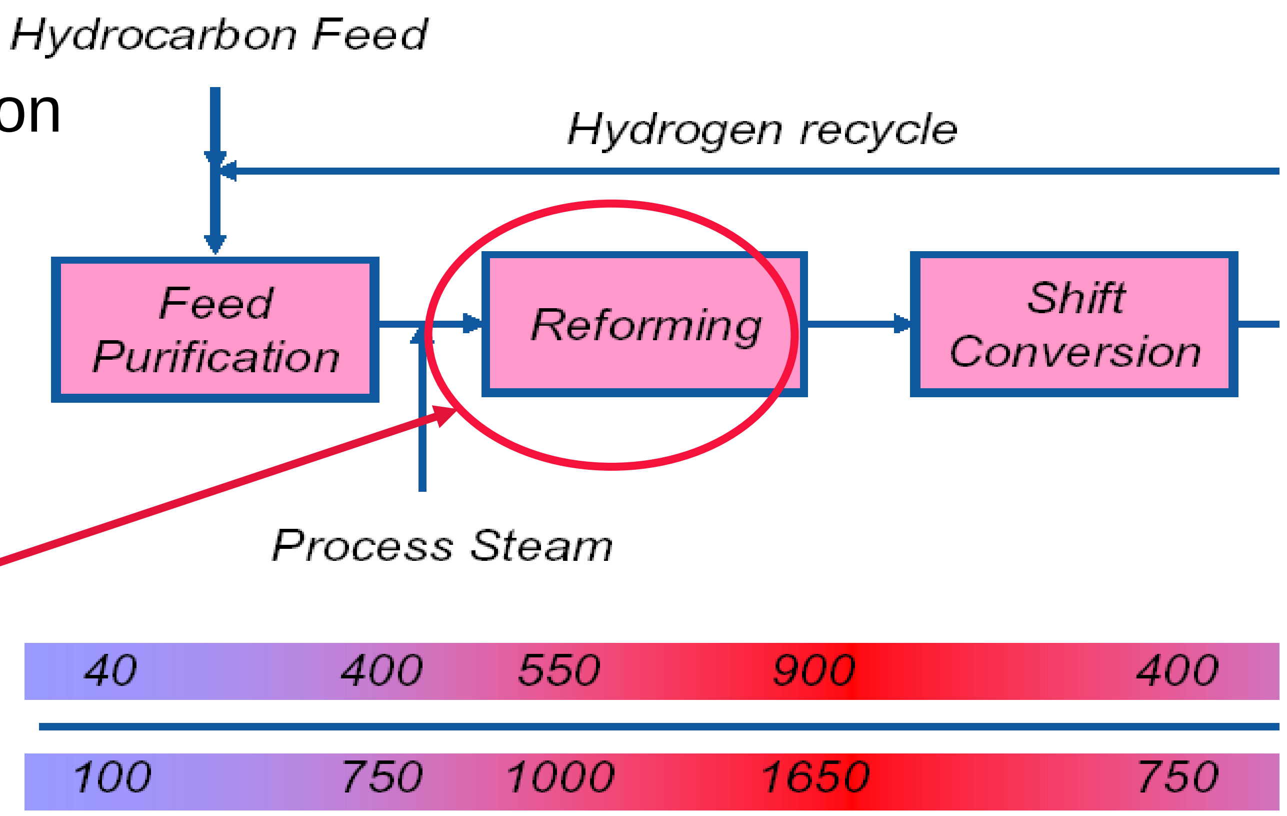
A Chemical Engineer with over15 years experience with leading catalyst technology companies in technical and commercial roles in the syngas industry. Experience in catalyst operation, troubleshooting and chemistry for Hydrogen, Ammonia and Methanol plants.

Peter Farnell – Independent Consultant

World-renowned expert in steam reforming technology with a demonstrated track record of technical capability, innovation and understanding of the many complex processes involved in steam reforming.

Ammonia/Hydrogen plant block diagram

- Four sections
  - Hydrocarbon feed purification
  - Steam reforming
  - Water gas shift

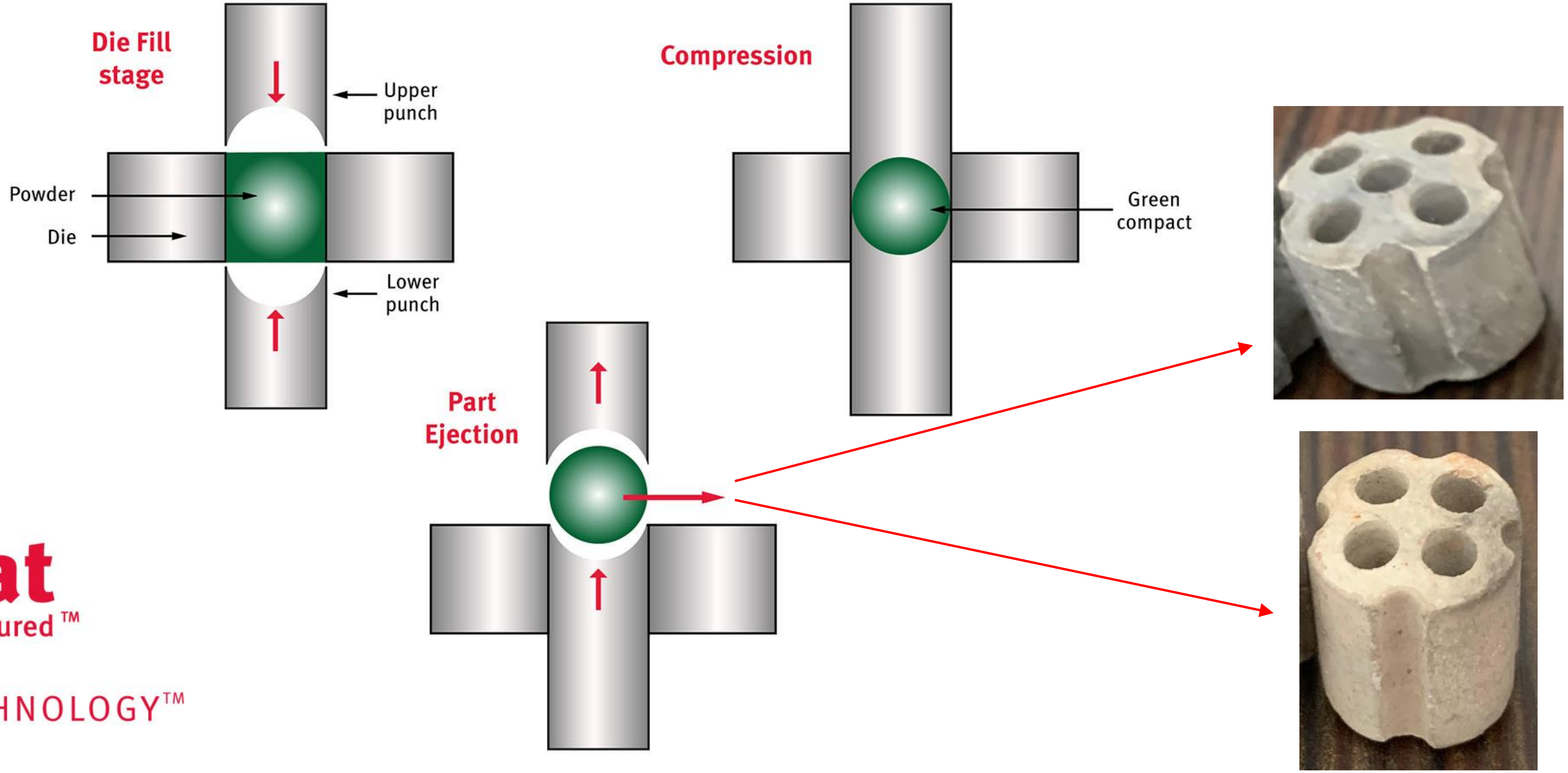


Presentation will concentrate on SMR Catalyst, MagCat
Magma can supply ALL necessary products

Conventional casting process

UNICAT CATALYST TECHNOLOGIES, LLC
Magma Group

Compression Casting

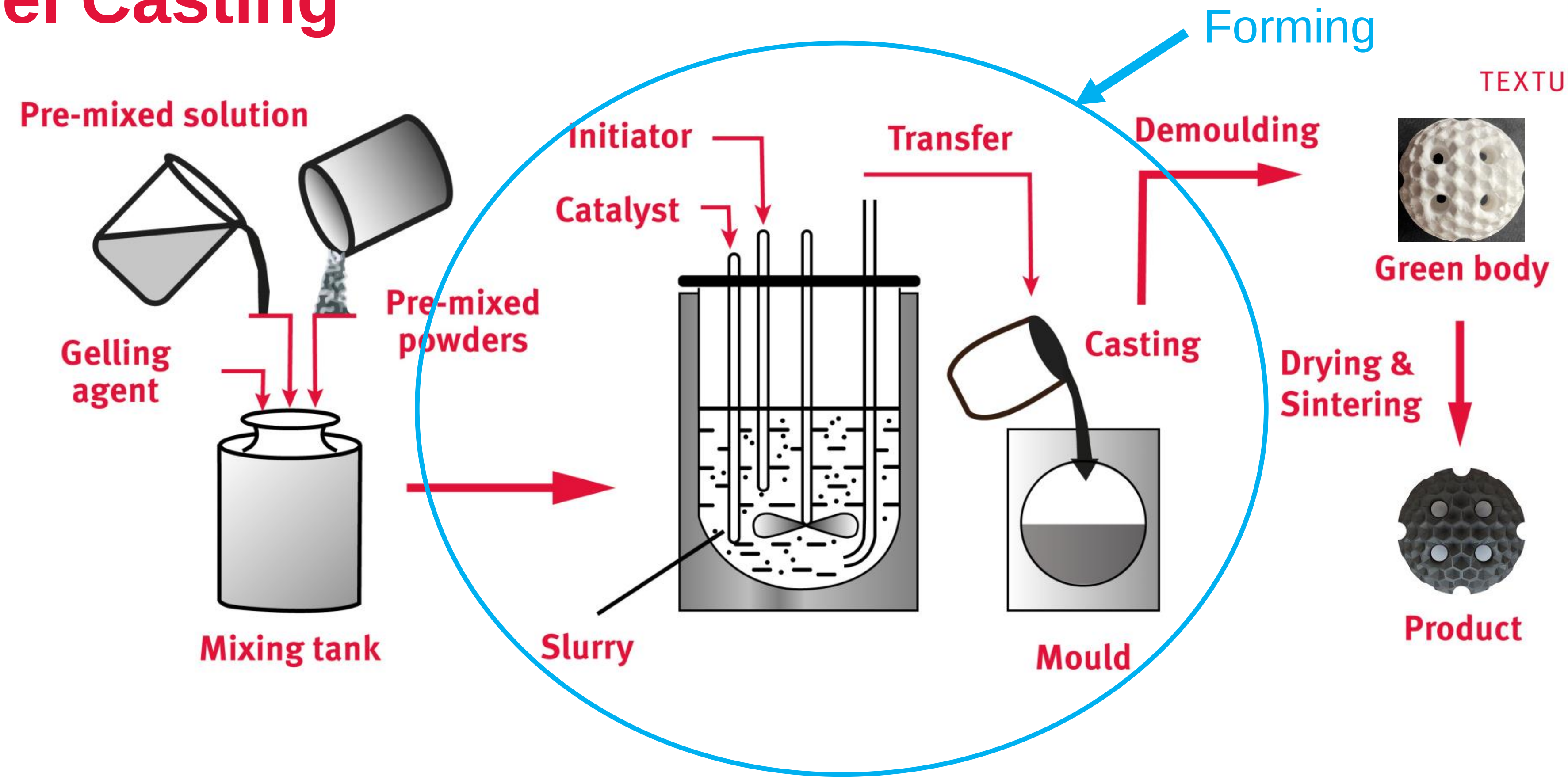


Magcat Textured™

TEXTURED CATALYST TECHNOLOGY™

MagCat production process

Gel Casting



Conventional Reforming catalyst is being used in the industry for last >50 years…

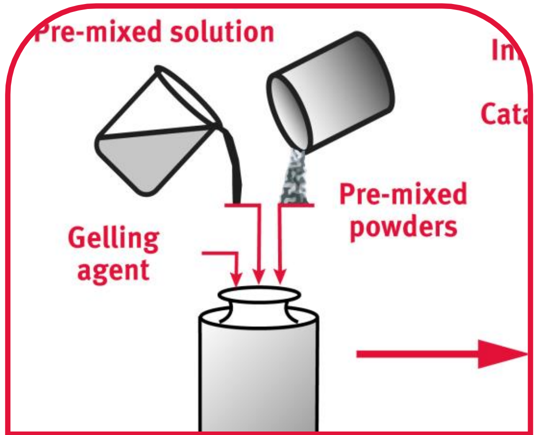
What next?

New Shape

Unicat Magma have come up with the latest innovation in reforming catalyst

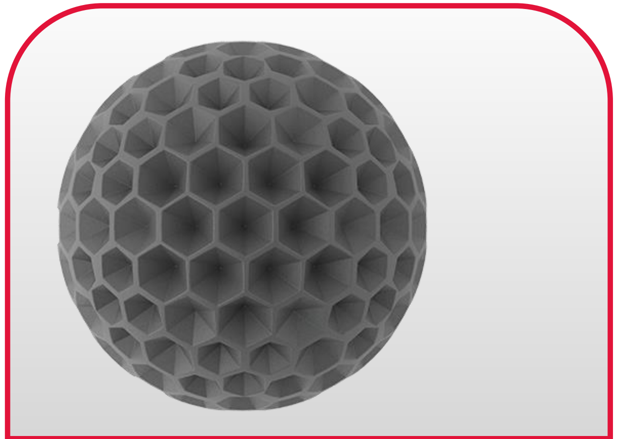
New Textured Spheres

How Magcat is different



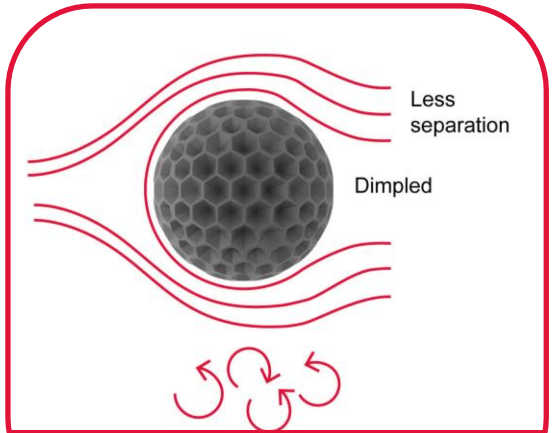
Gel Casting

- Ceramic
- Inherent Strength



Shape

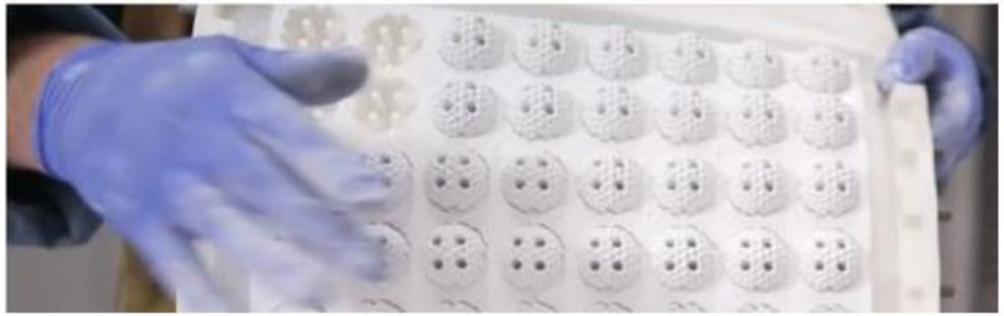
- Spheres
- Uniform Loading
- Porosity



Texturing

- Heat Transfer
- High Activity
- Low Delta P

How MagCat is different



MAGMA CATALYST OFFER OPTIONS TO SYNGAS OPERATORS TO ACHIEVE

- **VERY HIGH ACTIVITY**
  - Significant increase in process flow through same tubes whilst achieving same methane slip. More syngas (H_2, CO) for downstream processes
  - Lower tube temps through increased catalyst heat transfer characteristic
- **GREATER CATALYST RESILIENCE TO PROCESS UPSETS**
  - Higher crush strength than competitor catalysts (250kg_f)
  - MgO/potash catalyst for carbon laydown protection
- **REDUCED ENERGY COSTS AND LOWER CARBON FOOTPRINT**
  - Reformer firing lowered, due to higher Heat Transfer Coefficient, leading to lower CO_2 evolution and reduced energy costs

MagCat, What Customers & the Patent Office are saying!

DRI plant, Mexico;

Our Conclusions comparing to previously used catalyst:

- *The overall reformer pressure dropped by 40% compared to the previous charge*
- *Reformer gas quality remained equal*
- *Approximately 15% energy saving was acquired*
- *Increase in total plant capacity from 190 MT/hr and 210 MT/hr*

US Top 5 Refiner;

“everything’s looking good and healthy, we’re achieving record production”

European Patent Office;

After much dedication and hard work from everyone involved, the Patent on our Magcat Textured Catalyst technology has been approved.

“Your invention can no longer be produced or sold without your consent.”

Magcat Catalyst Operational Results – H_2 Client, Korea

Comparing Magcat and Competitor filled tubes

항목	Range	J* SOR 15th Feb. ~ 20th Feb. 2017	J* EOR 16th Oct. ~ 20th Oct. 2020 With Fuel gas from PSA In.	MAGMA SOR 12th Mar. ~ 15th Mar. 2021
1. Feed rate	kg/hr	1,230	1,253	1,241
2. Tube Outlet Temp.	880±20 ℃	872	869	868
3. Tube inlet pressure	kgf/cm2	22.10	**22.35**	**21.64**
4. Tube Outlet Pressure	kgf/cm2	20.01	19.94	19.97
5. Tube ΔP	kgf/cm2	2.09	2.40	**1.67**
6. Tube Outlet 조성	CH4 %			
7. Furnace Outlet Temp.	℃	998	**988**	**989**
8. Combustion Air	kg/hr	9,317	**9,600**	**9,600**
9. LNG usage	NCMH	377	172	183
10. Fuel gas ① (PSA purge)	kg/hr	157	257	242
11. Fuel gas ② (Cold Box)	kg/hr	86	87	99
12. Fuel gas ③ (off plant)	kg/hr	177	157	160
13. Fuel gas ④ (PSA inlet)	kg/hr	17	104	88
14. Flue gas boiler pressure	kgf/cm2	27.30	**27.20**	**27.02**
15. Excess STM generated	kg/hr	556	**493**	**714**
16. Pre-reformer inlet STM feed	kg/hr	2,720	**2,700**	**2,700**
17. SMR inlet STM feed	kg/hr	1,279	**1,236**	**1,235**
18. CO2 recycle	kg/hr	1,276	1,226	1,249
19. Pre-reformer inlet Temp.	℃	458	458	455
20. SMR inlet Temp.	℃	614	614	613

Pressure Drop 0.42 bar lower at SOR (20% lesser) – value estimated at $21,000/year

Export Steam increased by 28% – Auxiliary boiler switched off so less fuel used and CO_2 generated

Flow 230Nm3/hr

www.unicatcatalyst.com | www.magmagroup.com

Magcat Catalyst Operational Results – US Refiner

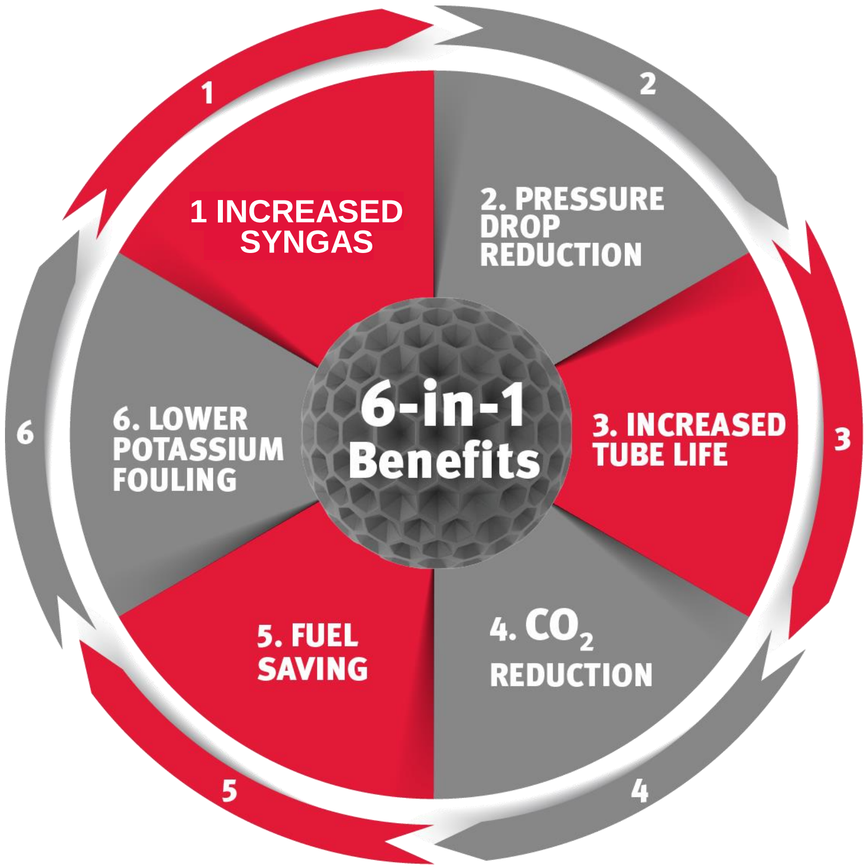
- 2.0MMSCFD plant based loaded in November 2020 with a 40:60 split of MagCat 16mm textured spheres
- Previous charge (competitor) achieved 1.795MMSCFD, maximum

	H2 Feed Gas (SCFM) U1900.FT0702.PV	H2 MakeUP (SCFH) U1900.FI1504.PV	Reformer InletTemp (degree F) U1900.TI0711.PV	Reformer OutTenp (degreeF) U1900.TI0707.PV	H2Product (MMSCFD) U1900.FI1002.PV
01/01/2020	416.5313	992.4272	935.9355	1448.84	1.686614
02/01/2020	406.4795	1027.766	940.6641	1449.93	1.644121
03/01/2020	401.3094	1042.721	921.7559	1446.245	1.794797
04/01/2020	405.6217	1032.984	944.6836	1458.648	1.707279
05/01/2020	403.5922	1006.804	920.625	1444.689	1.672554

- 2.6 MMSCFD per day once Magcat installed, cooler outlet temperature

	H2 Feed Gas MSCFH **1900FC0702**	**H2 Makeup** SCFH **1900FC1504**	**Reformer Inlet** deg F **1900TI0711**	**Reformer Out Temp** deg F **1900TI0707**	**H2 Production** MMSCFD **1900FI1002**
01/01/2021	450.6242578	550.5568585	931.0275795	1407.34401	2.647948055
02/01/2021	558.6594337	867.6034653	946.9926446	1429.27114	2.634702785
03/01/2021	556.8728797	896.1288905	946.7462934	1438.091072	2.630765084
04/01/2021	400.6261962	700.0956917	967.66148	1328.502409	2.627041612
05/01/2021	566.7375397	679.8271583	965.670719	1424.307079	2.637413265

6-in-1 Benefits of Textured Spheres



1. Increased Syngas
2. Pressure Drop Reduction - Lower for Longer
3. Increased Tube Life - +40%
4. CO_2 Reduction
5. Fuel Saving
6. Lower Potassium Fouling

Huge Savings for the Reformer operator!

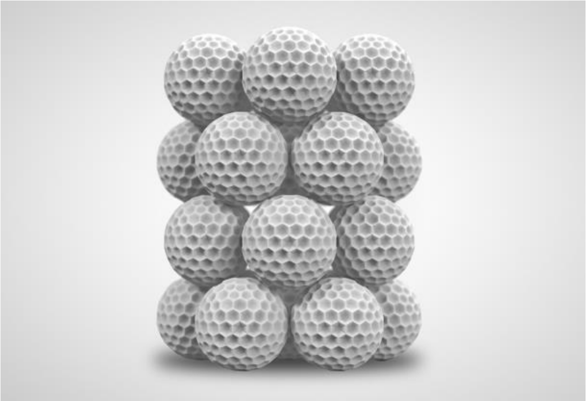
1. Tube Filling & Packing

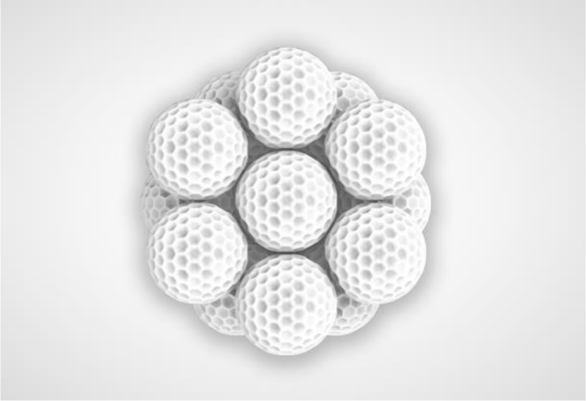
Magcat Textured spherical catalysts

- Pack uniformly within reformer tubes settling evenly and predictably despite the orientation of any individual pellets.
- The higher and consistent “coordination number” (how many other pellets are touching each pellet) means there is more even packing at the tube wall.
- This decreased voidage and increased wall contact will disrupt the flow at the wall, causing turbulence and bring heat from the outside into the centre of the tube where it is needed.
- This Creates optimal gas flow throughout the packed bed, and leading to improved catalyst – gas contact.

Video link:

Tube Filling & Packing Animation.mp4

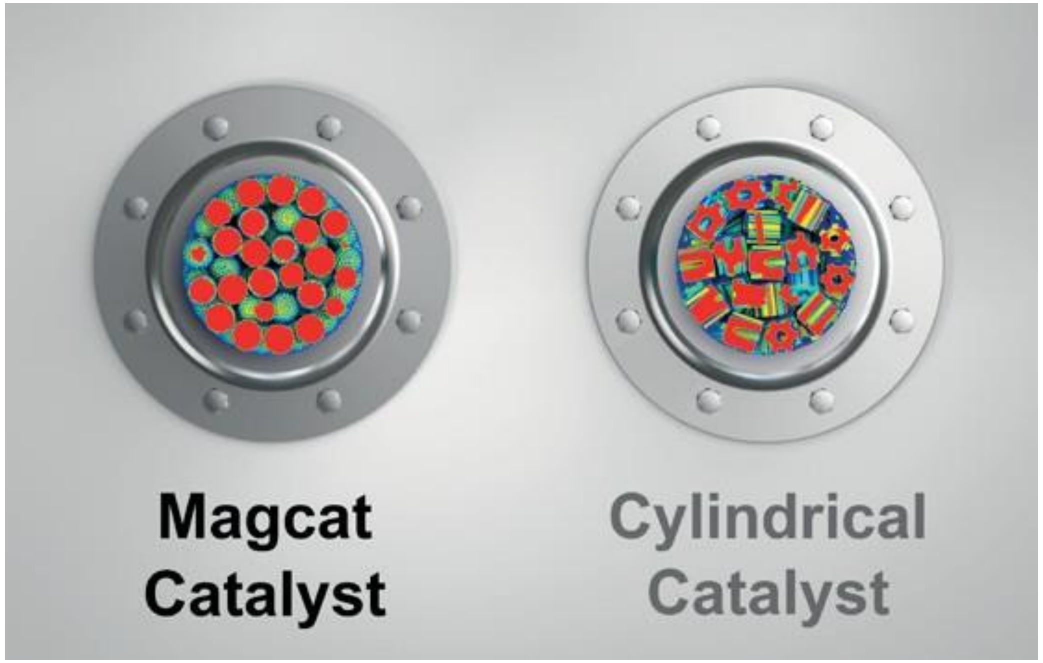




2. Gas Flow & Heat Transfer

Magcat's ideal gas flow patterns

- Increase heat transfer rates from the tube wall which in turn increases reforming capability and reduces tube wall temperatures.
- The average reduction in tube wall temperature is 10°C, which in turn can deliver a 30-40% increase in tube life.



Video link:

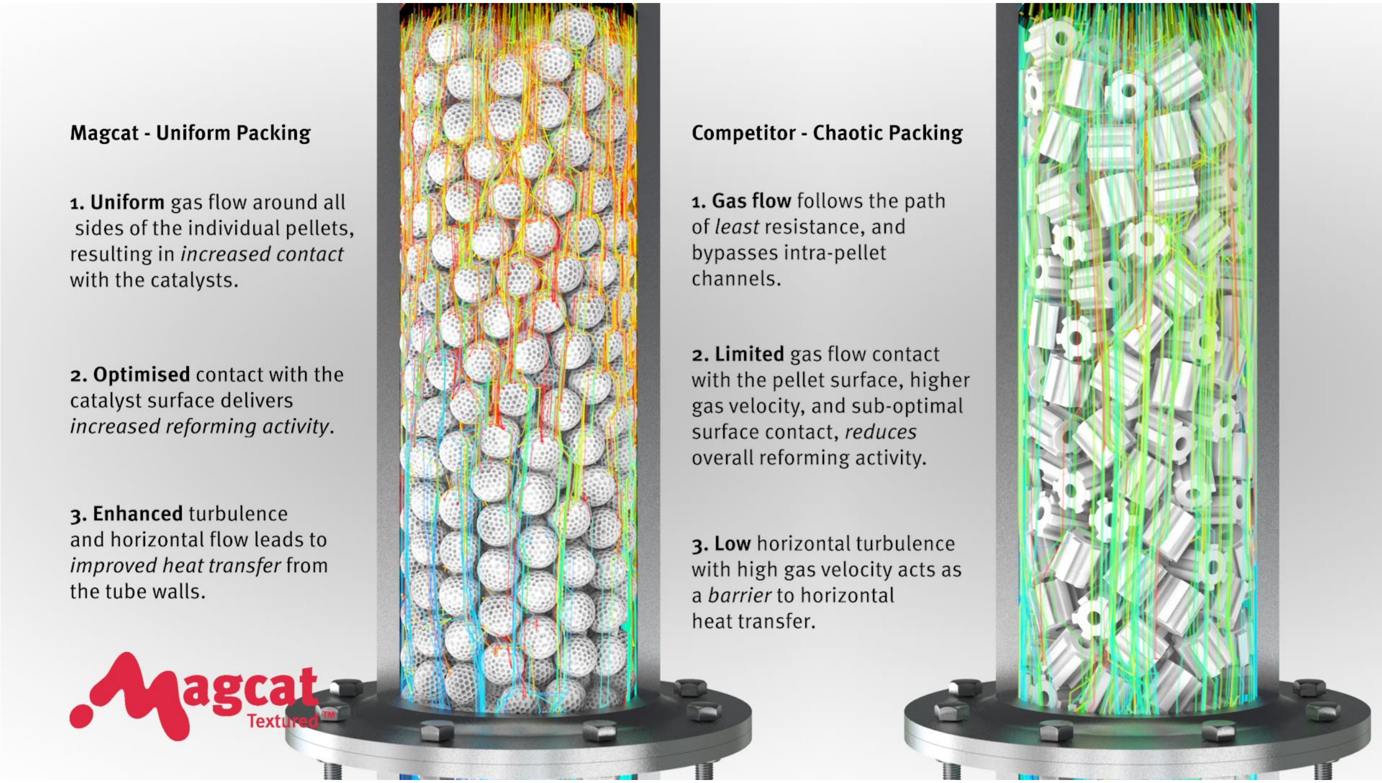
Gas Flow & Heat Transfer.mp4

3. Gas Flow Comparison

1. **Uniform** gas flow around all sides of the individual pellets, resulting in increased contact with the catalysts.

2. **Optimised** contact with the catalyst surface delivers increased reforming activity.

3. **Enhanced** turbulence and horizontal flow leads to improved heat transfer from the tube walls.

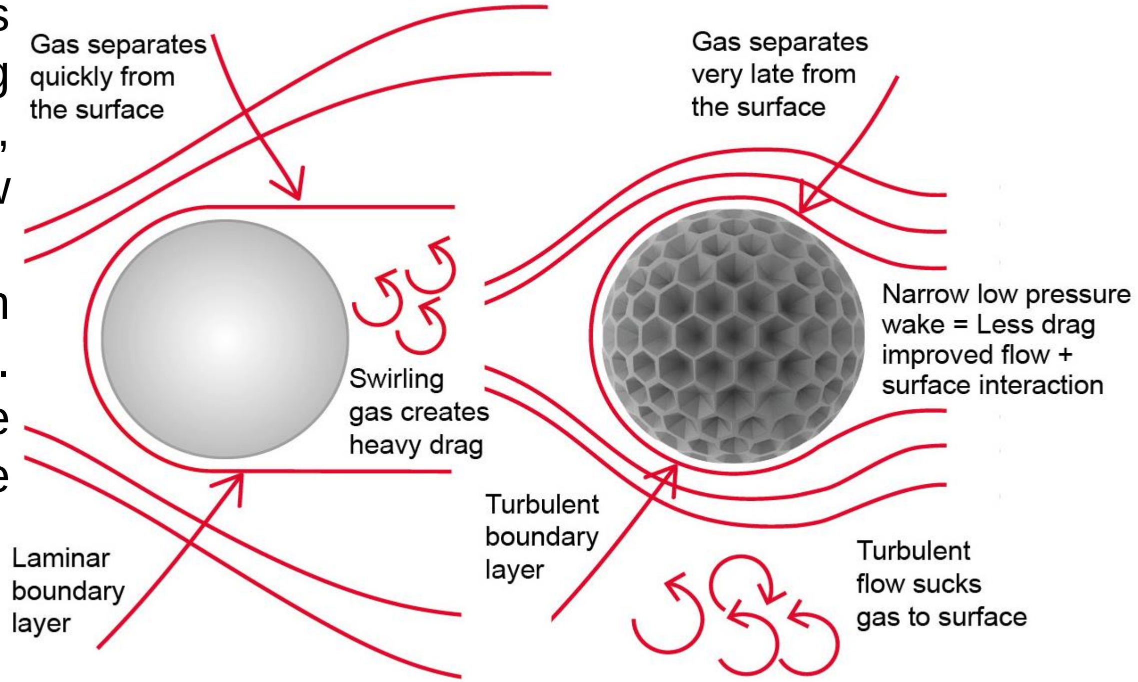


Video link:

Gas Flow Comparison Clip.mp4

4. Smooth vs Textured

- With **Magcat** the "Golf ball" texturing generates turbulent flow around the catalyst, reducing drag coefficient and pulling reactant gases around the pellet, seeing all sides evenly and also allowing gas to flow smoothly into the spaces behind each pellet.
- The flat surfaces and lack of texture on the smooth surfaced catalyst creates laminar flow and heavy drag. The flow passes over the presenting side of the catalyst, but will not effectively contact the rear side causing dead zones and voidage



The increased Reynolds number leads to reduced pD and the turbulent flow improves heat transfer

Video link:

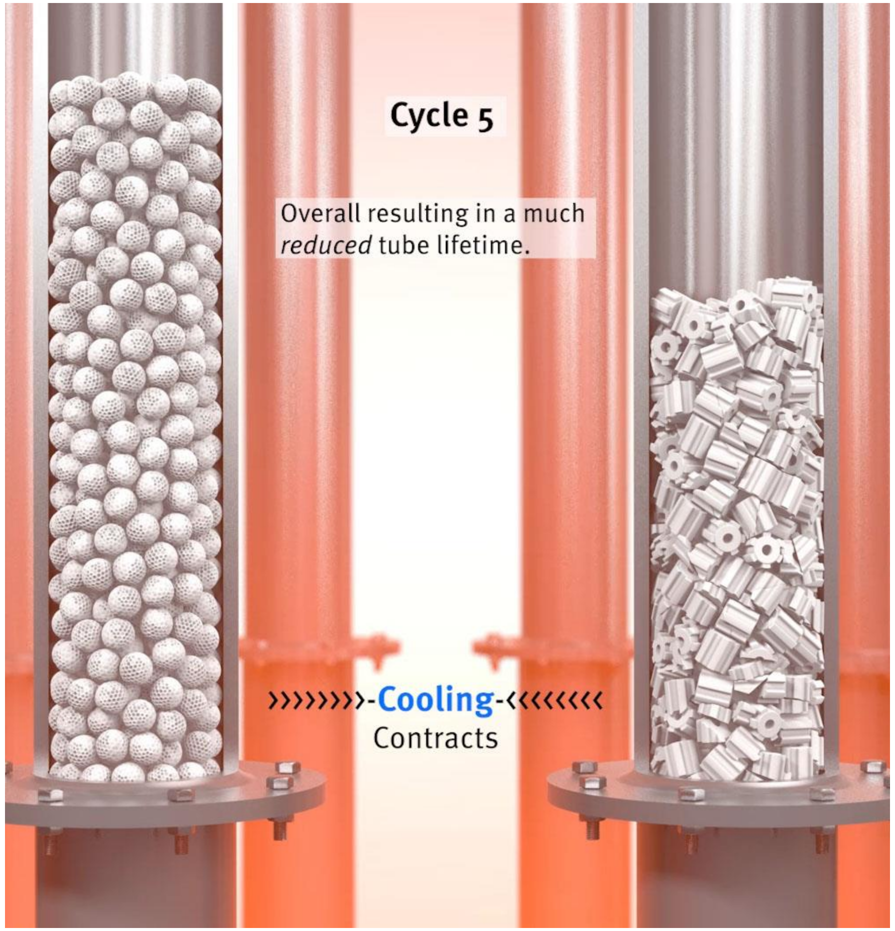
Smooth vs Textured Clip.mp4

5. Heating & Cooling of Tubes

- Traditionally when hot tubes expand and cool (contract) catalysts reorder, and the catalyst levels drop causing increases in pressure drop.
- **Magcat** spheres respond differently, as those in the central core barely move from the original position.
- A stable catalyst core and uniform packing means large voids will NOT be present to cause a cascade of pellets down the bed or significant rearrangements from initial loading.

Video link:

[Heating & Cooling of Tubes.mp4]



6. Loading of Tubes

Traditionally tubes are loaded using a “Dense Loading” technique first developed by Norsk Hydro, now Unidense GmbH or “Sock loaded”

Magcat spheres respond differently because they load uniformly and as such can simply be poured in directly!

As we didn’t think people would believe us we got a 40’ Perspex tube and videoed the results

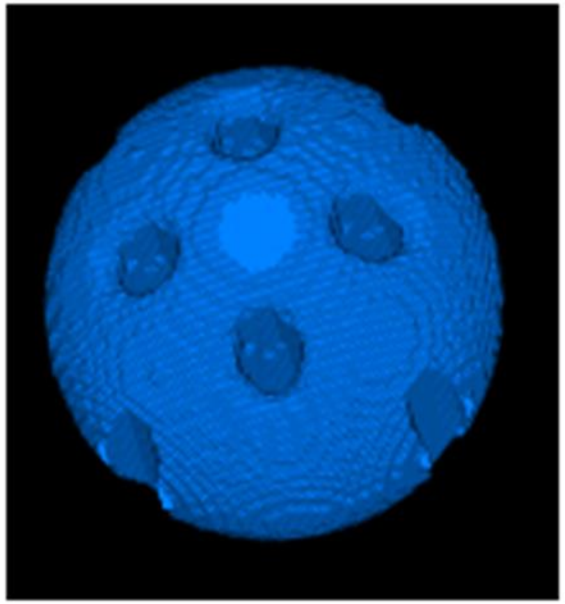
Video link:

Tube Fill Test 14mm 26th Sept.mov

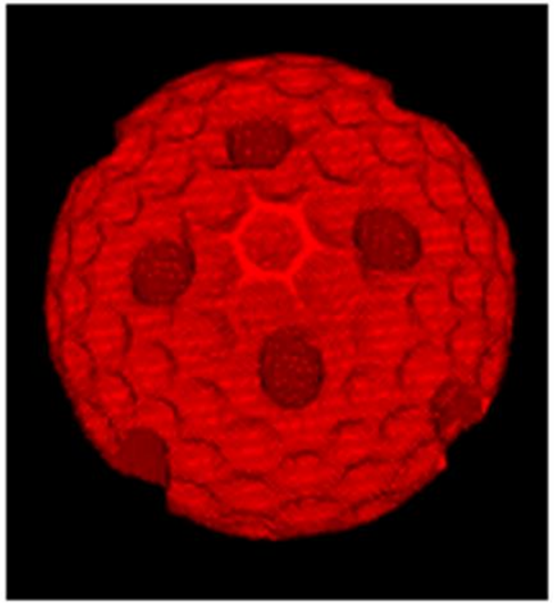
6. Loading of Tubes

CFD Flow Modelling, Surface Effects

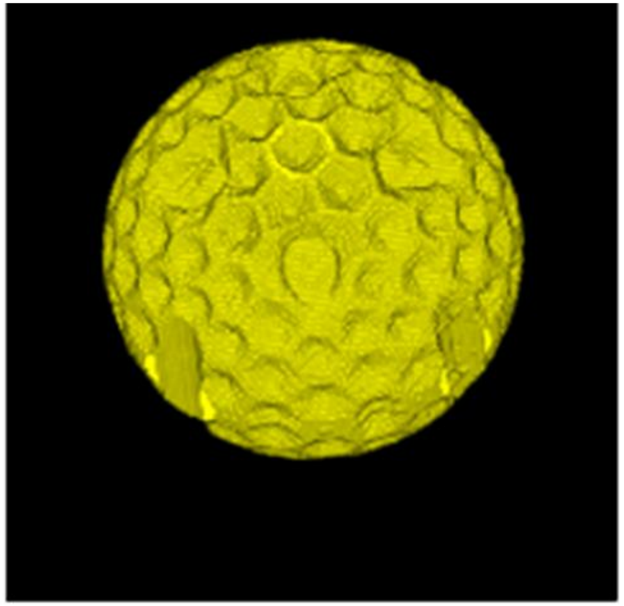
Smooth sphere



Textured sphere

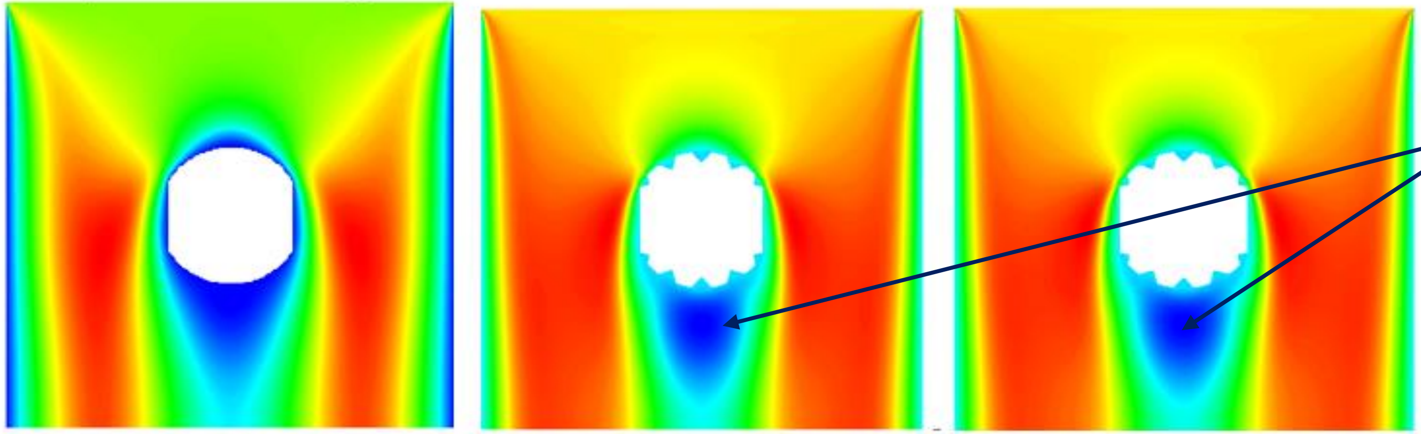


Textured sphere, NO HOLES

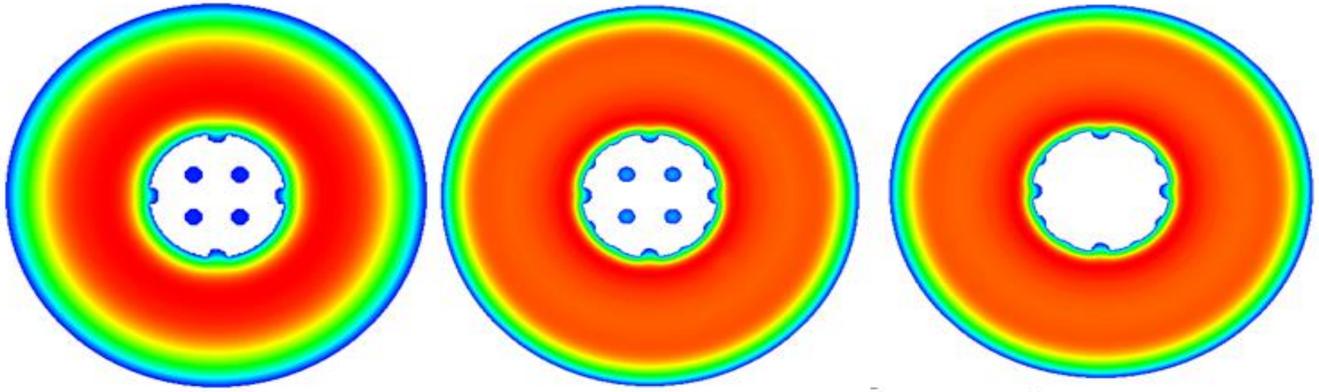


CFD Flow Modelling, Surface Effects

Holes/side-channels aligned with direction of flow:



Above: cross-section from side of column (left) smooth, (middle) textured w./ holes, (right) textured NO holes



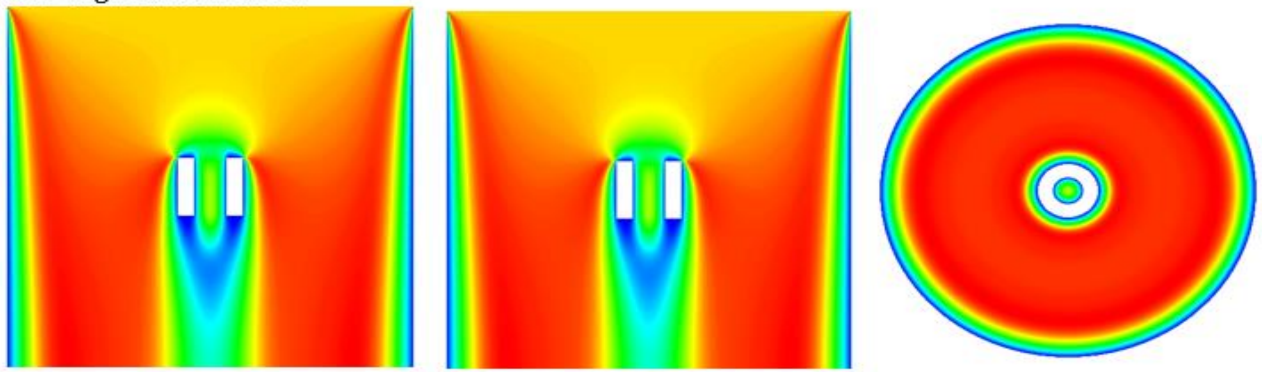
Above: cross-section from top of column (left) smooth, (middle) textured w./ holes, (right) textured NO holes

“Dead” Zone

Smaller with texturing, more contact with Ni

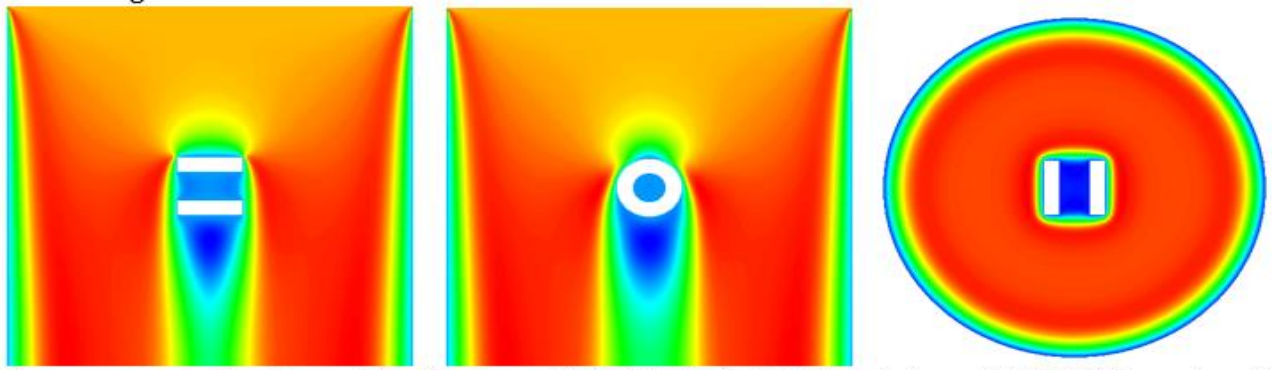
Raschig Ring demonstrating effect on orientation

Hole aligned with flow:



Above: cross-section from side of column (X) (left), (Y) (middle) and above (Z) (right) 8mm Raschig ring for pellet aligned with direction of flow

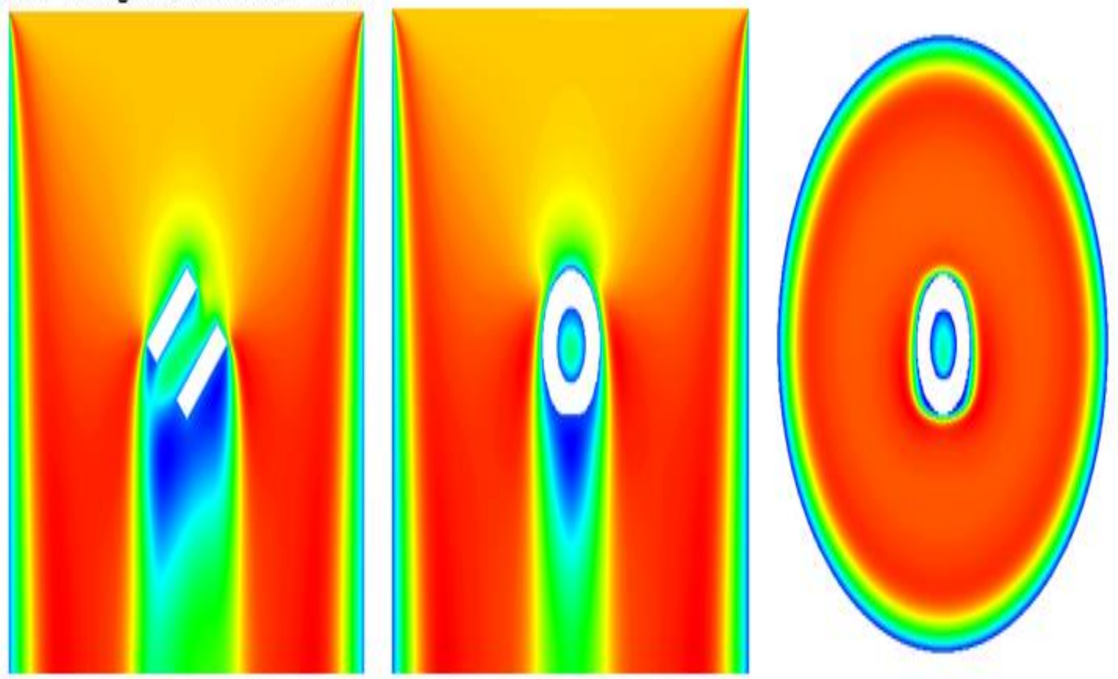
Hole 90deg to direction of flow:



Above: cross-section from side of column (X) (left), (Y) (middle) and above (Z) (right) 8mm Raschig ring for pellet aligned with hole 90deg to direction of flow

Raschig Ring at 45 Degrees to flow

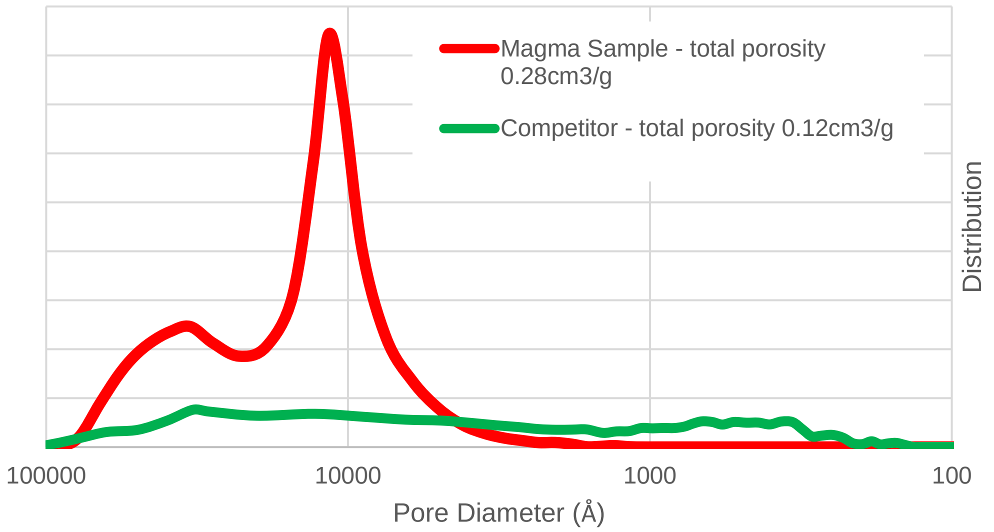
Hole 45deg to direction of flow:



Above: cross-section from side of column (X) (left), (Y) (middle) and above (Z) (right) 8mm Raschig ring for pellet aligned with hole 45deg to direction of flow

Measured stagnant velocity zone below pellet			
	8mmRR, holes with flow	8mmRR, holes 90deg to flow	8mmRR, holes 45deg to flow
Height of dead zone below pellet	3.4mm	7.3mm	9.8mm
Volume of dead zone	160.6mm3	191.5mm3	210.5mm3
Domain avg velocity	0.05015	0.05011	0.05010
Re		1382.6	
Dead zone ht relative to pellet diameter, %	42.50%	91.25%	122.5%
Dead zone vol relative to pellet vol, %	56.39%	67.24%	73.91%

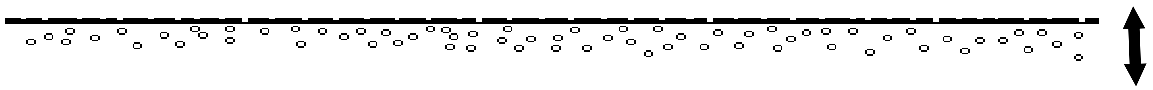
Porosity - Maximising available reaction surface



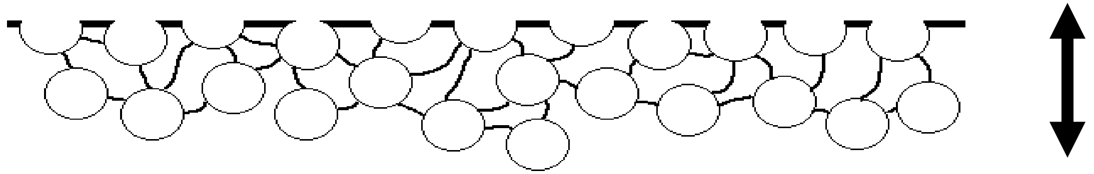
Magcat advantages over competition:

- Much larger porosity
- Significantly higher total pore volume
- Avoidance of "popcorning" during wetting

Schematic of current market surface porosity.



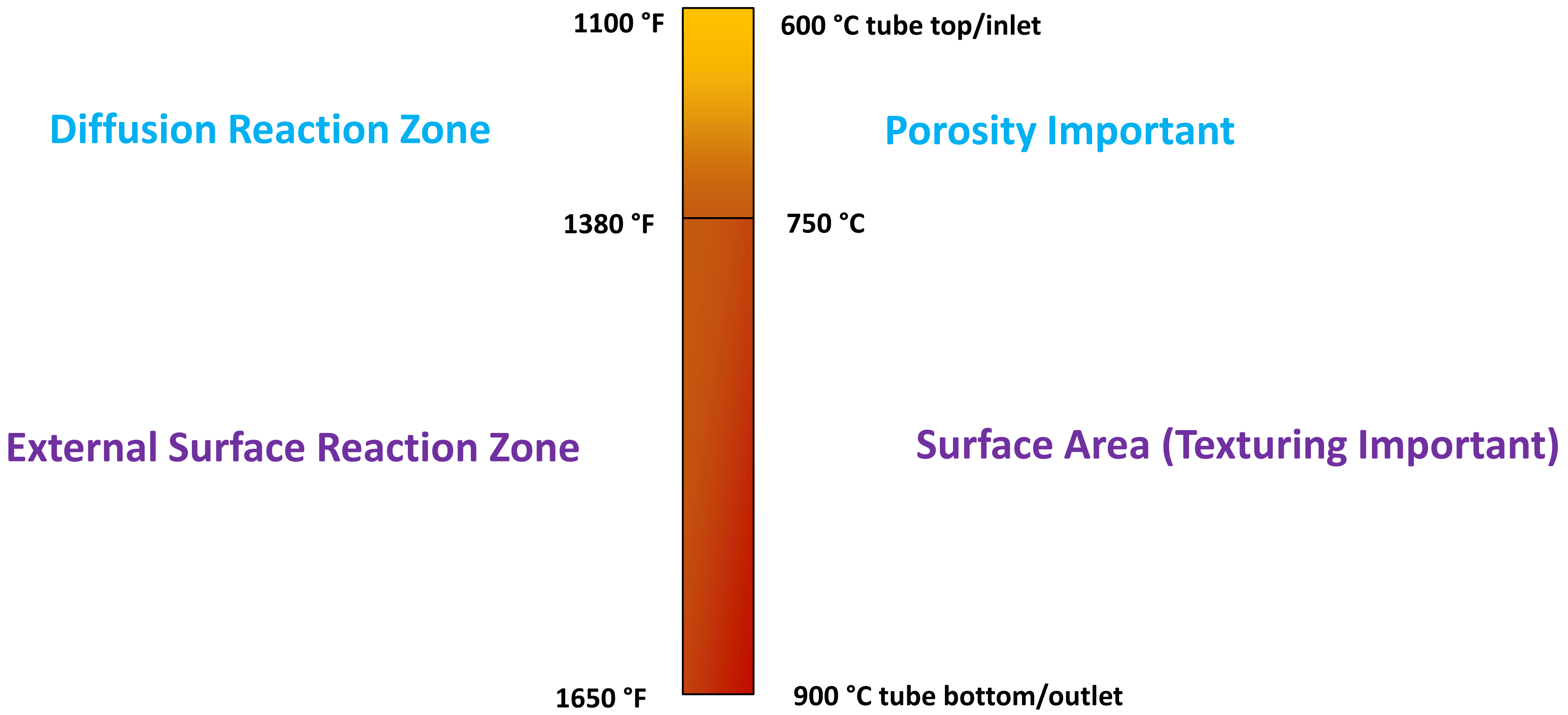
Schematic of Magma's surface porosity.



Current market catalyst has interstitial pore channels so porosity is not closed off as the diagram might imply, but these channels are much smaller and will be less able to allow a transfer of gas between and through them

Optimised loading - Positioning MagCat benefits

Relative permeability of reactant gases at increasing temperature



- As temperature in the tube increases, rate of reaction increases. Molar flow rises meaning reactant gas has less time to penetrate catalyst pores. MagCat has reaction benefits through the whole tube

MAGCAT Value addition Higher feed case

- Min. 6 % extra Ammonia Production without breaching any of the process constraints
(Though the Ammonia SynGas compressor inlet pressure could be tricky!)
- Clear value addition amid high energy prices and Ammonia prices

MAGCAT Value addition Higher feed case

- Min. 10 % extra Methanol Production without breaching any of the process constraints (though distillation will be tricky!)
- Clear value addition amid high energy prices and Methanol prices

MagCat reference list

Customer	Plant	Country	Number of tubes	Start up
Phillips 66	Ponca City (2 units)	USA	88	June 2019
Marathon	St Paul Park (2 units)	USA	80	Sept 2019
Confidential	Midrex	Americas	5	Sept 2019
Confidential	Busan	South Korea	24	Feb 2020
Marathon	Dickinson	USA	36	Dec 2020
Neste	Jurong Island	Singapore	114	Jan 2023
MIDREX	VoestAlpine	USA	5	Dec 2020
Confidential	Daejon	South Korea	20	Feb 2021
Confidential	Busan (10 Fuel Cell Units)	South Korea	10	Feb 2021 onwards*
US Top 5 Refiner	US Mid-West	USA	216	July 2021
Air Products Inc	Confidential	USA	26	June 2022
Phillips 66	Wood River	USA	192	Spring 2021
Phillips 66	Billings (2 units)	USA	144	January 2022
Independent Energy Ltd	New Build H2	Canada	10	January 2022
Confidential	Existing Plant	Mexico	40	Jan 2022
Calumet	Montana	USA	92	Nov 2021
Calumet	Montana (New Build)	USA	48	Jan 2023
Calumet	Montana	USA	40	Feb 2022
Calumet	Louisiana	USA	40	Nov 2022
Pan American	Existing H2	Columbia	8	Nov 2022
Confidential	NH3 Plant	Indonesia	240	June 2023*
UPM	Kymmene	Finland	31	June 2023*

*Planned start up

Thank you