Performance of Alkaline Fuel Cells:
A Possible Future Energy System ?

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National Seminar on Challenges in Fuel Cell Technology: India's Perspective

Indian Institute of Technology Delhi, New Delhi

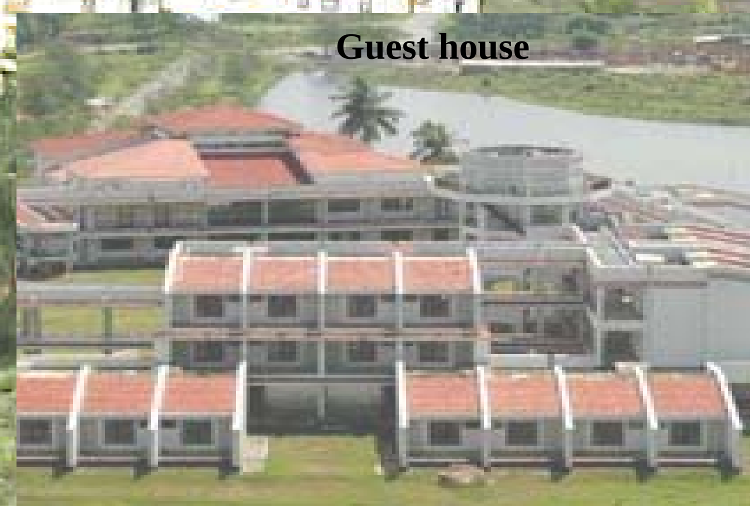
IIT Guwahati

Administrative building

Guest house (distant)

Faculty quarters

Academic building



Guest house

Fundamentals of alkaline fuel cell

Anode (Pt/C):

$$2H_2 + 4OH^- \rightarrow 4H_2O + 4e^-$$

Cathode (Pt/C):

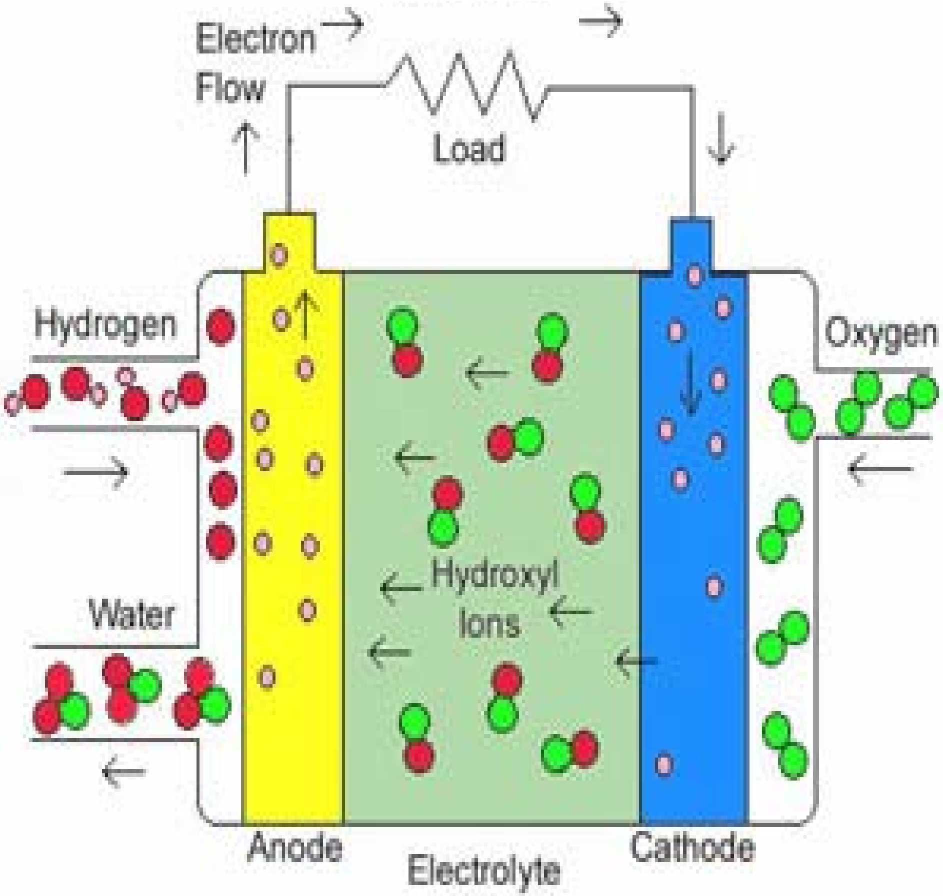
$$O_2 + 2H_2O + 4e^- \rightarrow 4OH^-$$

Overall Cell Reaction:

$$2H_2 + O_2 \rightarrow 2H_2O$$

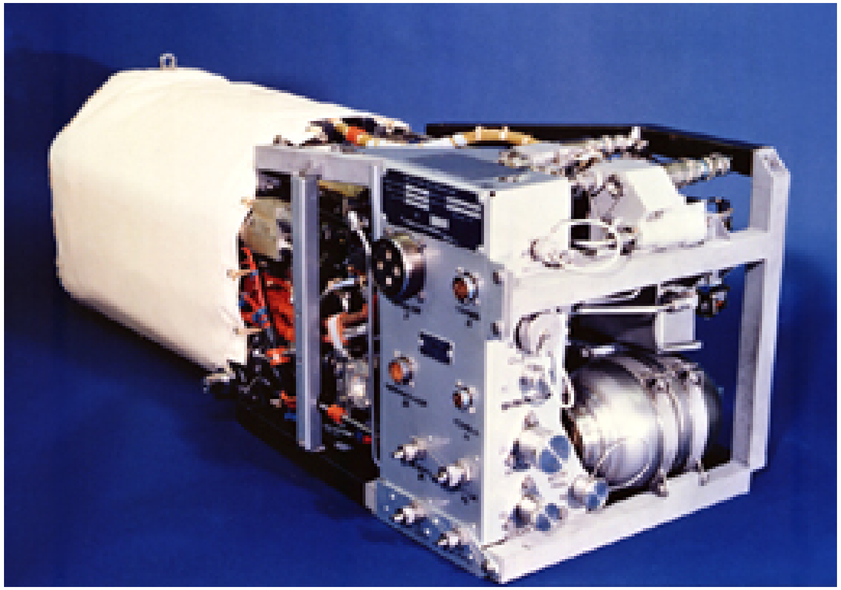
- Low temperature fuel cell technology
- Hydroxyl ions are the charge carriers

Electrolyte: KOH solution



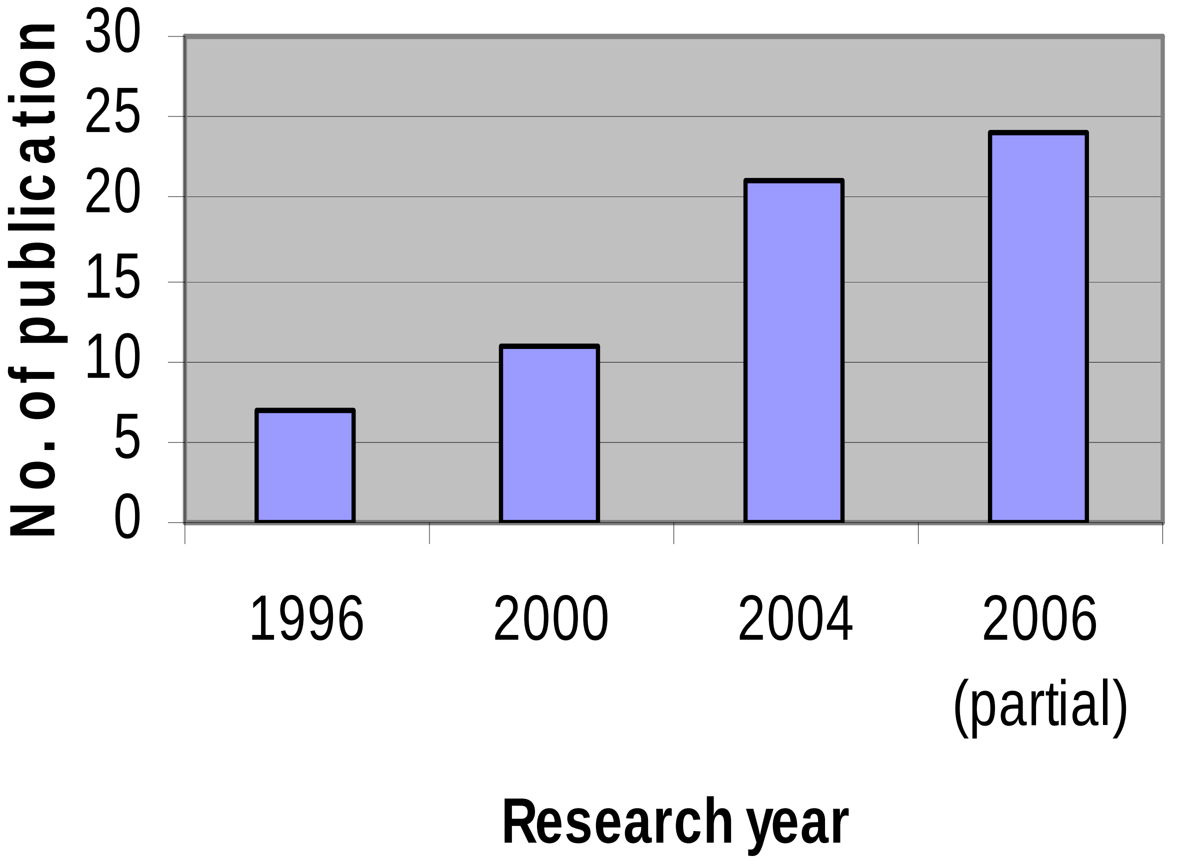
Laptop run by AFC

- Most mature fuel cell technology in the past
- Used in National Aeronautical and Space Administration’s (NASA) space shuttle programs
- The research was almost stopped due to many **myths**, technical bottlenecks and with the advent of Polymer Electrolyte Membrane (PEM)



Alkaline fuel cell used in Apollo space shuttle

AFC Research Trend at Present



Source: Compiled using search in Compendex and Inspec

Major research locations throughout the globe

Industries

1. Astris Energy Inc., Canada
2. Cenergie Corporation Plc., UK
3. ZeTek Power Plc. UK
4. Electrochem Technik, UK
5. Independent Power Technologies, Russia
6. Ovonic Fuel Cell Company, Rochester, USA

Institutes/Universities

1. Pennsylvania State University, USA
2. Mingchi University of Technology, Taiwan
3. Fudan University, China
4. DLR (German Aerospace Organization), Germany
5. Graz University of Technology, Austria
6. Kyoto University, Japan
7. University of Newcastle upon Tyne, UK
8. University of Alberta, Canada

Myths

- Expensive and useful only for applications in space
- Require very pure and costly gas feeds
- Can not work using air
- Poisoned by carbon dioxide
- Liquid electrolyte is the serious drawback
- Carbon monoxide is a problem

So what is true and what is false?

One thing is atleast clear: each type of fuel cell technology has its own advantages and disadvantages, BUT the disadvantages stated for AFCs are grossly EXAGGERATED or, often, simply incorrect.

Debunking the Myths

Cost

Catalysts need not be based on expensive noble metals

Cheap electrolyte and less corrosive compared to acids: aqueous KOH solution

Modest system design: process-gas-humidification not required

Low power ambient fuel cell prices

Company (Fuel Cell Product)	Nominal Power	Type of Fuel Cell	Price (US$)
Astris (LC200-16)	240 W	AFC	2400
H-Power (PowerPEM-PS250)	250 W	PEMFC	5700
DAIS-Analytic (DAC-200)	200 W	PEMFC	8500

AFC peripheral costs

	Cost (US$)	%
Air blower	14	5.5%
CO_2 scrubber	14	5.5%
H_2 recirculation ejector	22	8.6%
Electrolyte recirculation	100	39.2%
Nitrogen purge	15	5.9%
Electronic engine control (EEC)	50	19.6%
Piping, valving, misc.	40	15.7%
Total periph. sys. cost (incl. mark-up and cost contingency)	255	100%

PEMFC peripheral costs

	Cost (US$)	%
Air compression subsystem (Compr./Expander/Motor Unit—CMEU)	330	41.4%
Air humidifier subsystem	65	8.1%
H_2 recirculation ejector	22	2.8%
Radiator subsystem	92	11.5%
DI filter	14	1.8%
Electronic engine control (EEC)	220	27.5%
Piping, valving, misc.	55	6.9%
Total periph. sys. cost (incl. mark-up and cost contingency)	798	100%

Source: McLean et al., Int. J. Hydrogen Energy 27 (2002) 507-526.

Liquid Electrolyte

- ✓ Circulating electrolyte is a self-healing layer of liquid in which any defect (say in the form of a bubble) will not remain stationary
- ✓ Heat management is easy in liquid circulating electrolyte

Challenges

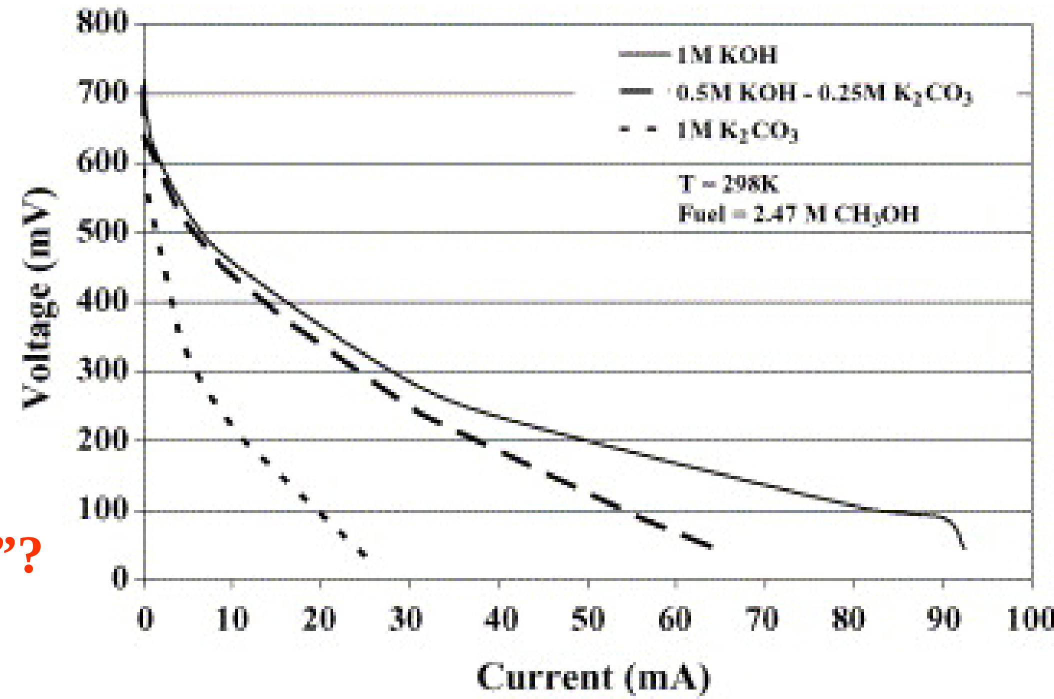
Circulating electrolyte poses some unique design/engineering challenges owing to its corrosive nature

Debunking the Myths contd…

Carbon dioxide: The bogeyman

It is commonly accepted that CO_2 intolerance is the most pronounced disadvantage of air-breathing AFCs

$$CO_2 + 2OH^- \rightarrow CO_3^{2-} + H_2O \quad \text{and/or}$$
$$CO_2 + 2KOH \rightarrow K_2CO_3 + H_2O.$$



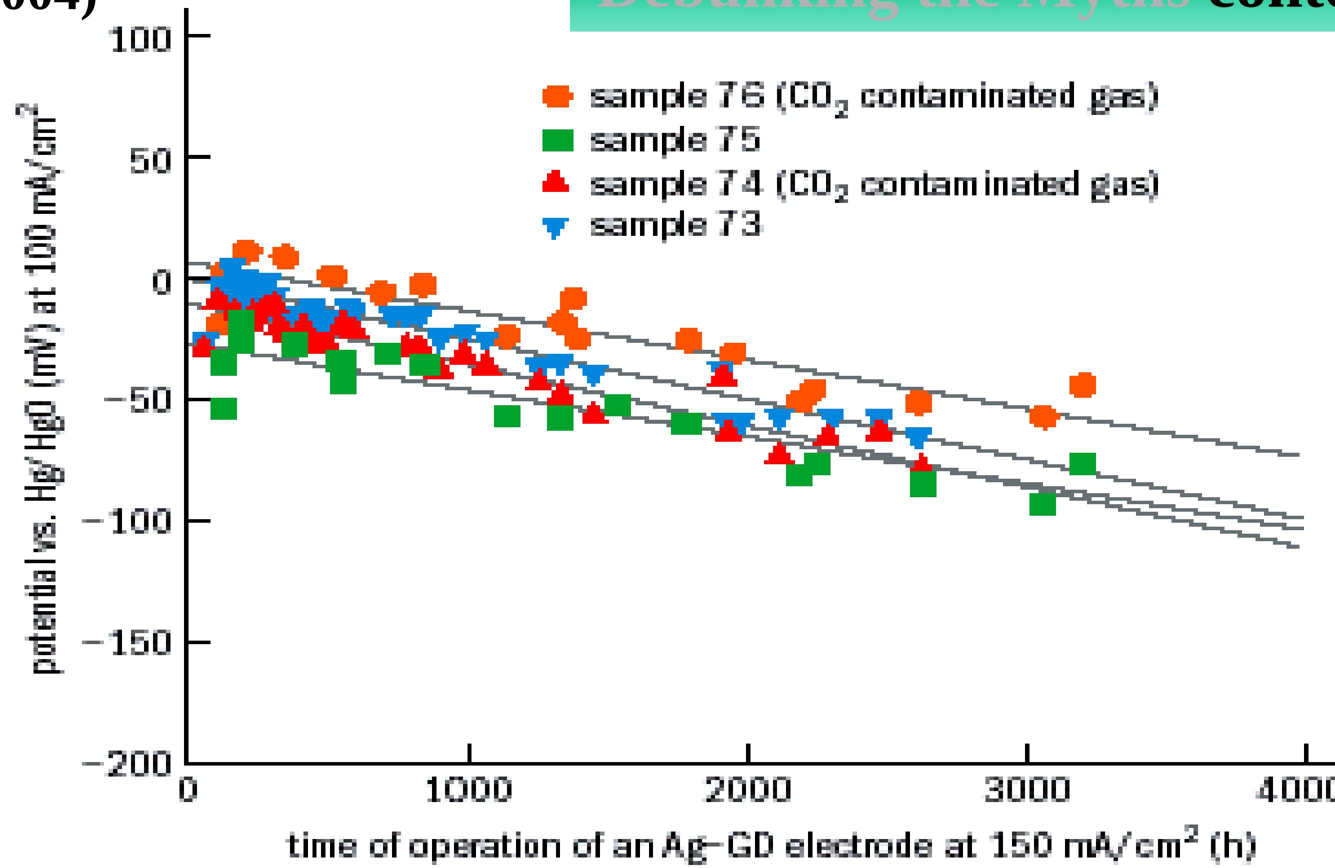
But is this the really "Show-Stopper"?

Some of the research findings

Saleh et al. (1994)	1% CO_2	72 °C	No significant effect (200 h)
		25 °C	Adversely affect the performance
Gulzow (1996)	With/without CO_2		17 µV/h degradation (with/without CO_2)
Michael et al. (2000)	50 ppm CO_2	6000 h (intermittent)	30% drop in power
Kordesch et al. (2001)	Circulating electrolyte		Improves the performance

Debunking the Myths contd…

Gulzow et al. (2004)



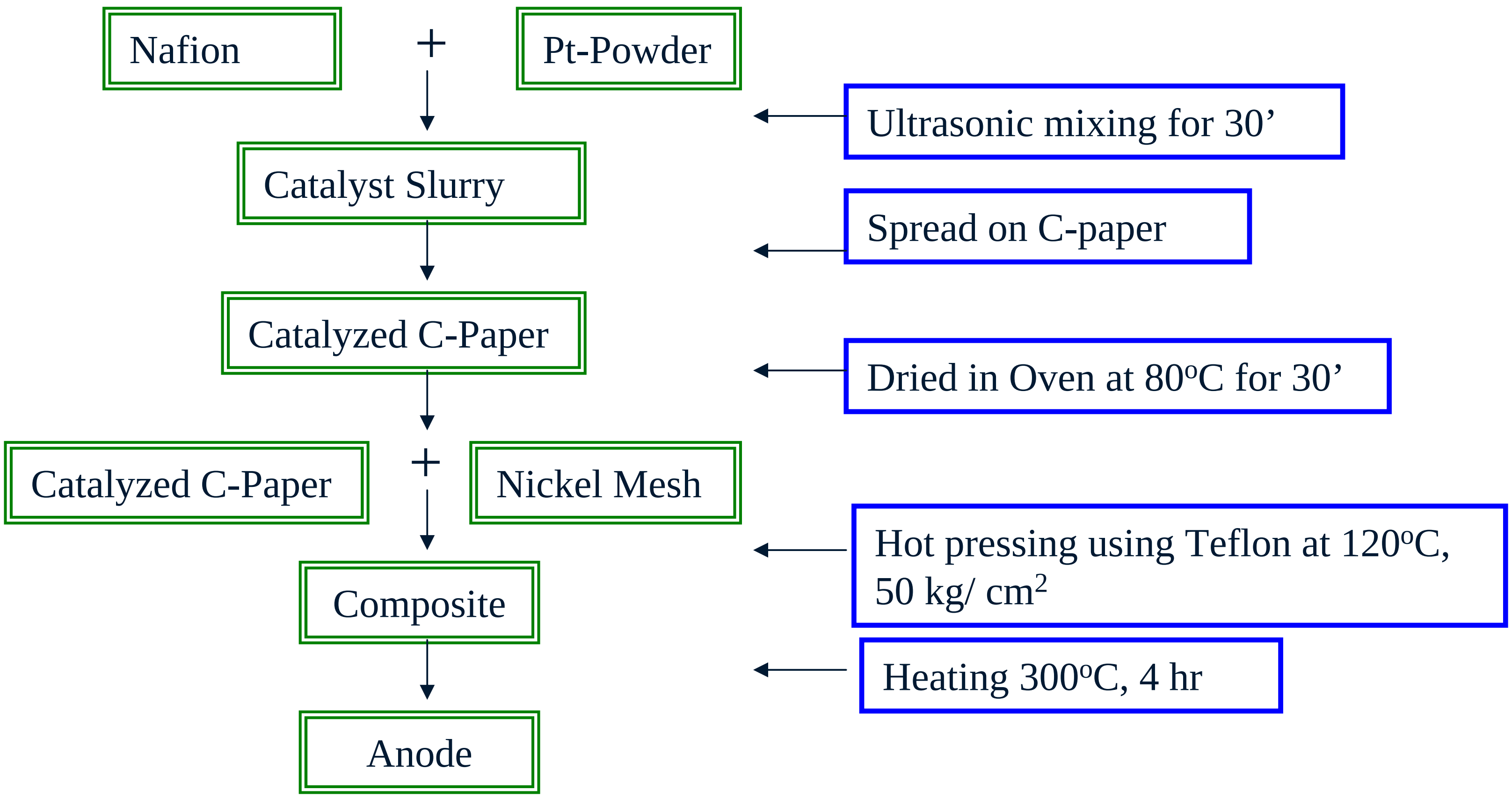
Tiwari et al. (2006) *Methanol-Air*

- Significant decrease in cell performance only after about 60% of KOH has been converted to K_2CO_3
- KOH and K_2CO_3 electrolytes: Cell performance decreases because of sluggish methanol oxidation kinetics at the anode in the presence of carbonate

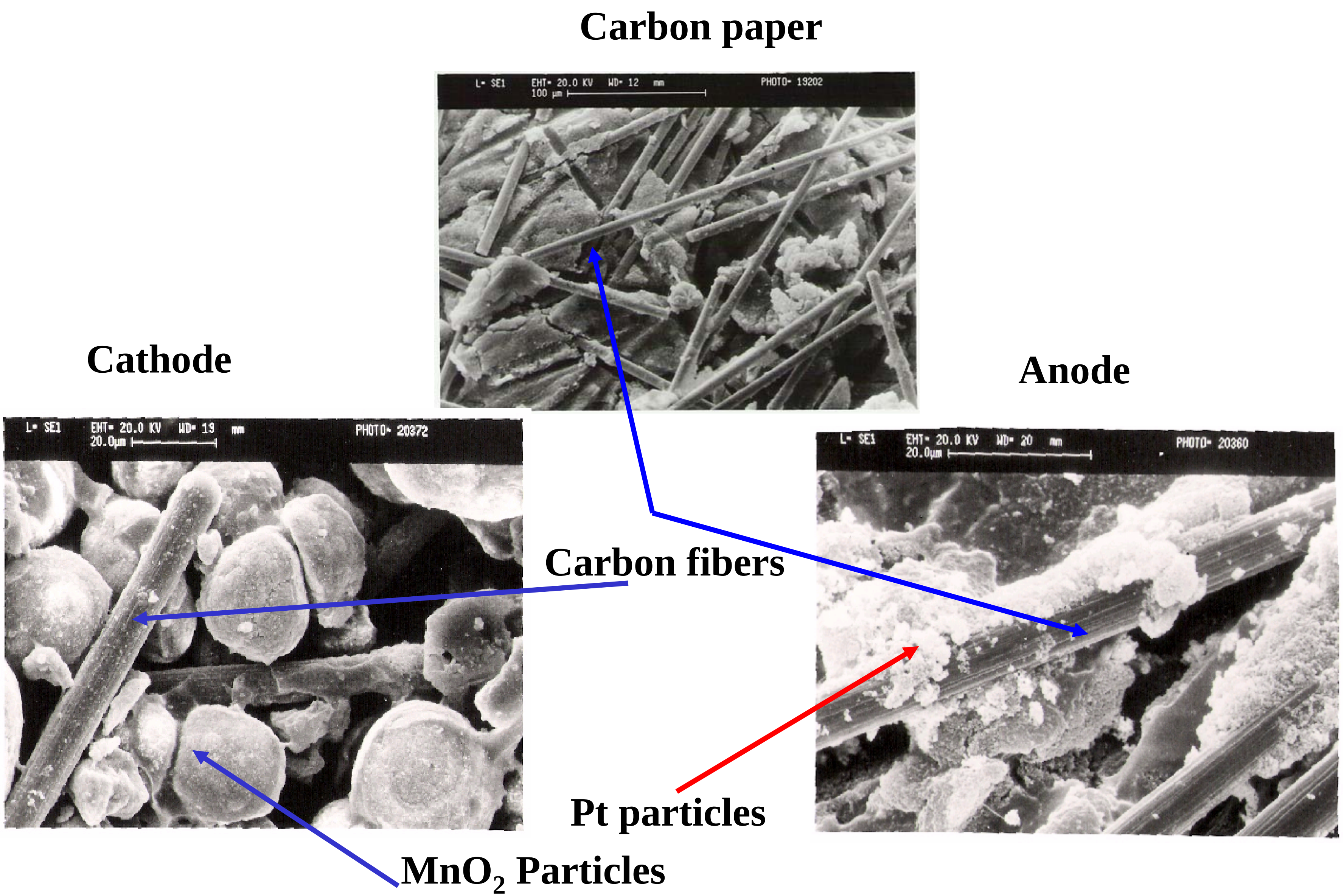
Direct alcohol alkaline fuel cell developed in IIT Delhi

Anode

Electrode development (Flow diagram)

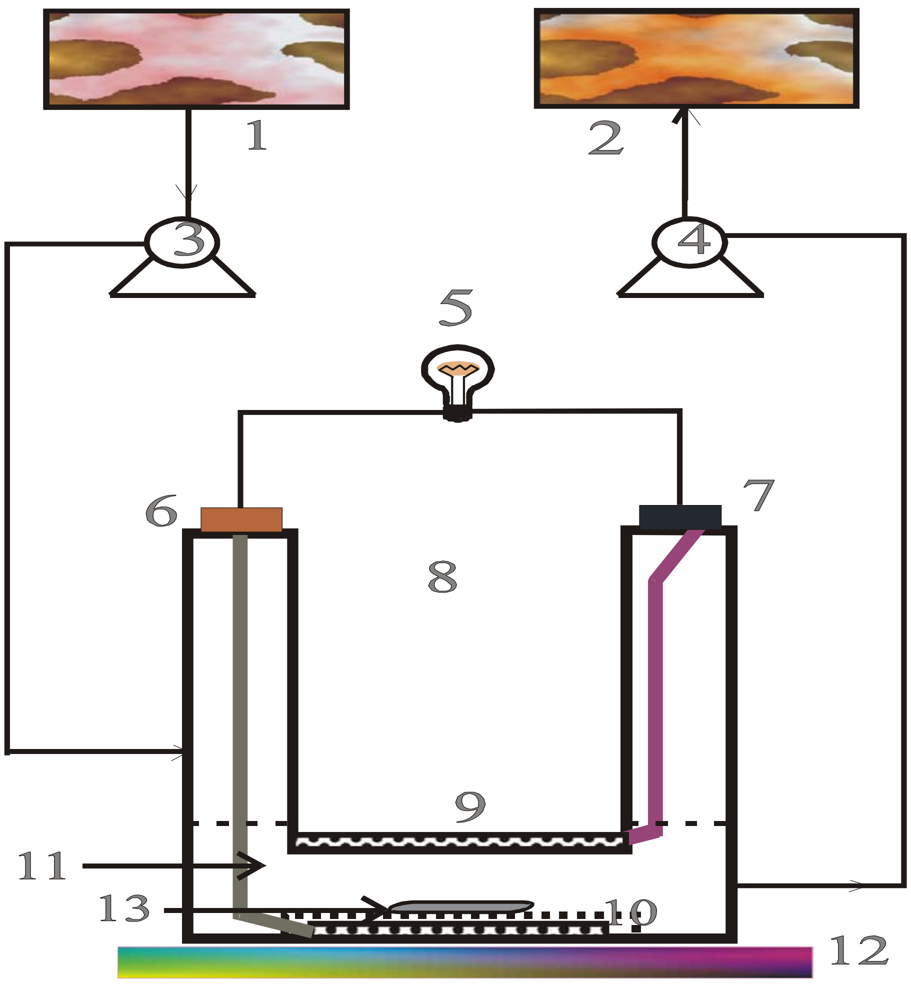


Surface morphology of electrodes



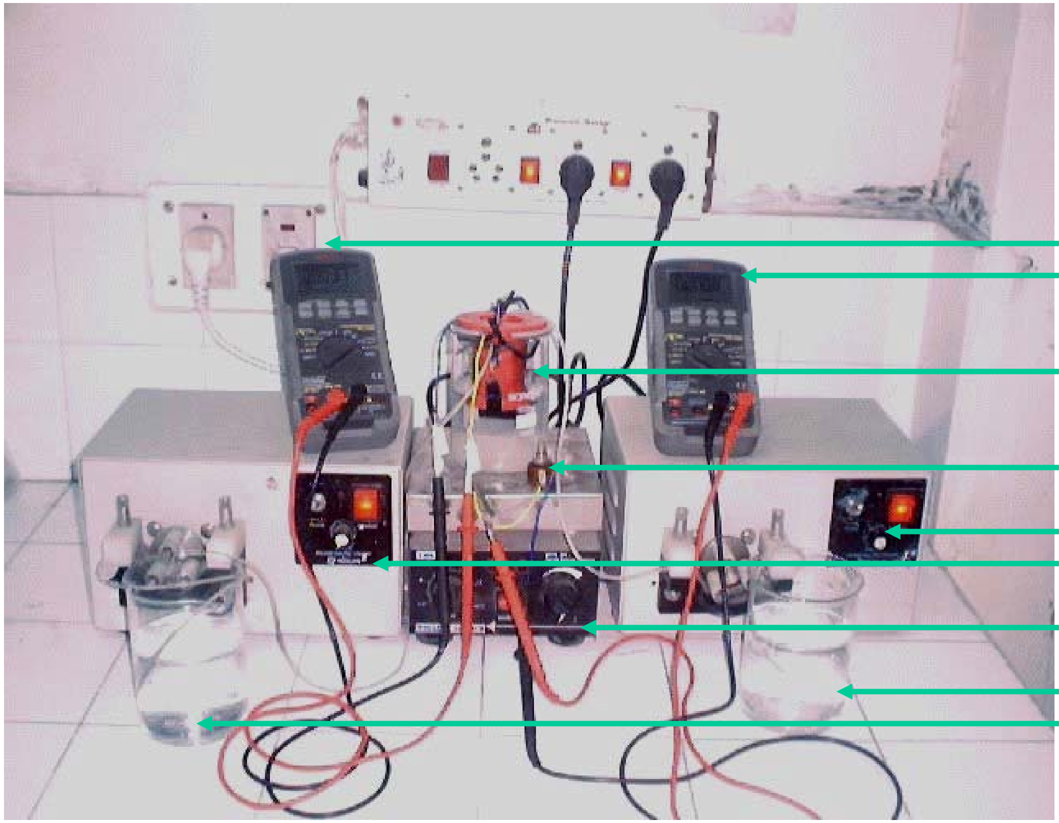
Fuel Cell Analysis

Schematic diagram of direct alcohol alkaline fuel cell



1. Fuel-electrolyte mixture storage; 2. Exhausted-fuel-electrolyte mixture storage; 3, 4. Peristaltic pump; 5. Load; 6. Anode terminal; 7. Cathode terminal; 8. Air; 9. Cathode electrode; 10. Anode electrode; 11. Fuel and electrolyte mixture; 12. Magnetic stirrer; 13. Anode shield

Photograph of direct alcohol alkaline fuel cell



Multimeters

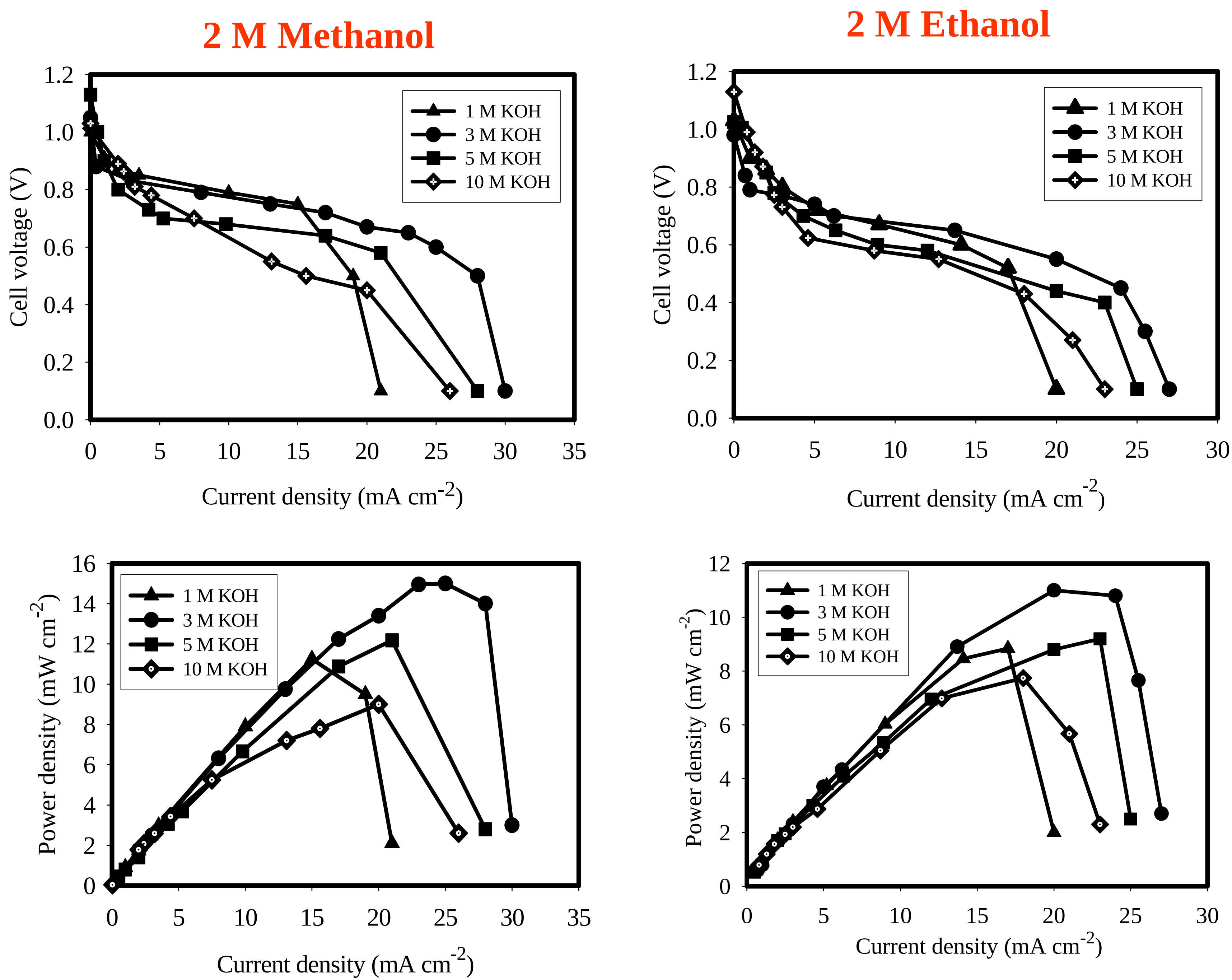
Fuel cell

Potentiometer

Peristaltic pumps

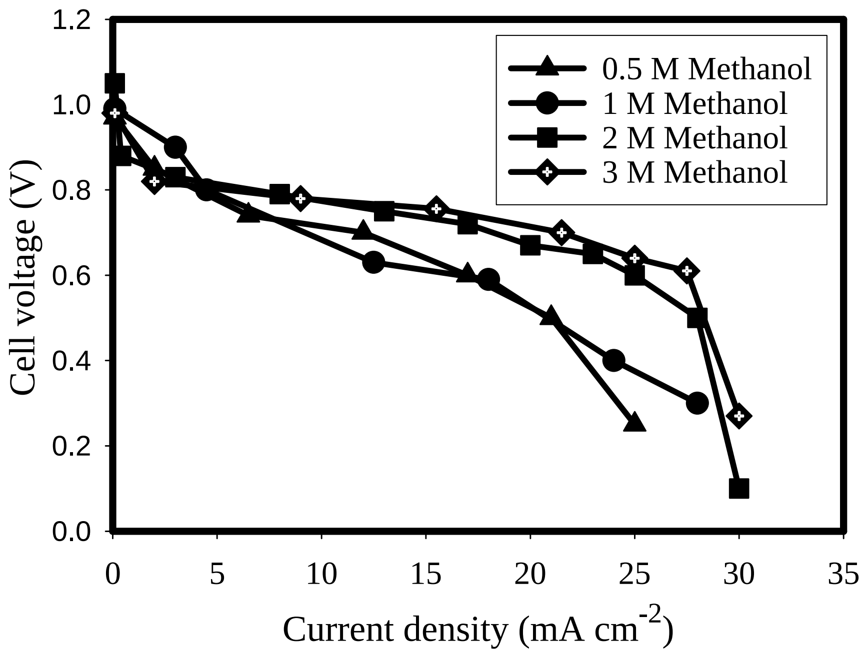
Magnetic stirrer

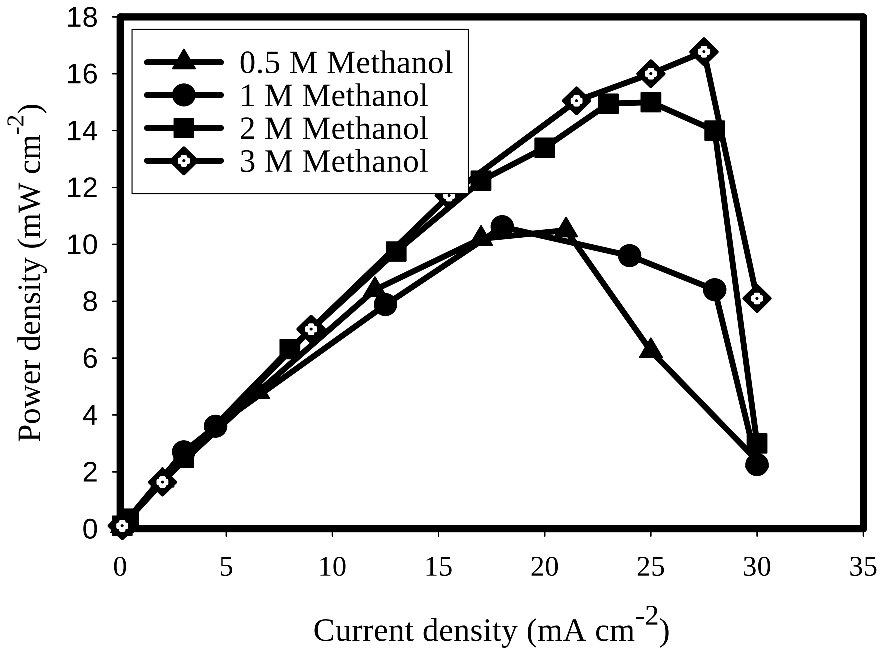
Fuel and electrolyte storage tanks



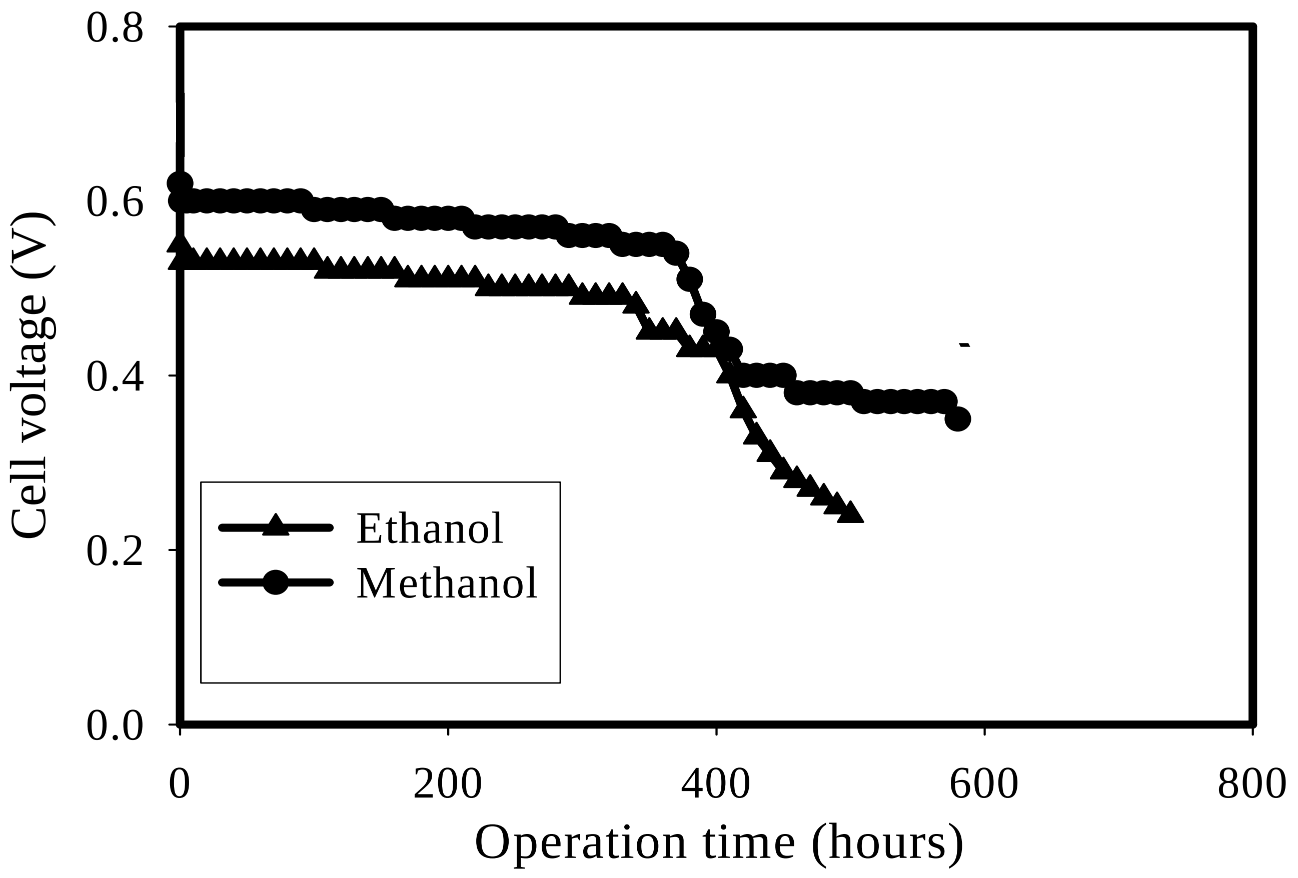
2 M Methanol
2 M Ethanol
Cell voltage (V)
1.2
1.0
0.8
0.6
0.4
0.2
0.0
0 5 10 15 20 25 30 35
Current density (mA cm-2)
1 M KOH
3 M KOH
5 M KOH
10 M KOH
Power density (mW cm-2)
16
14
12
10
8
6
4
2
0

Performance curves for different methanol concentration at 25 ºC; 3 M KOH; Anode: Pt black; Cathode: MnO_2



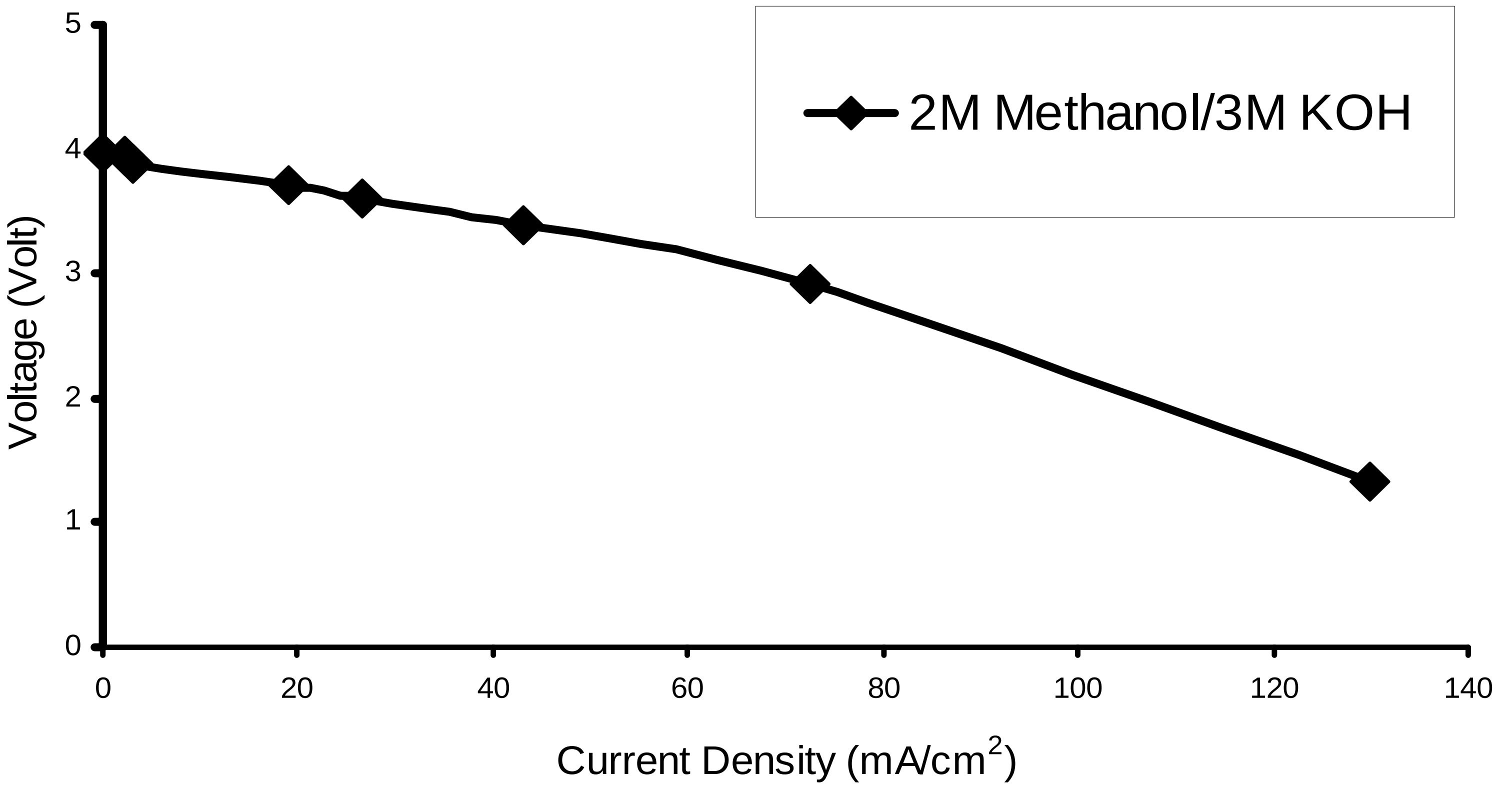


Lifetime of the direct methanol and ethanol alkaline fuel cell at constant load (22 mA cm^{-2})



- Regeneration of electrodes using HCl solution
- Electrodes regain 80% of its original OCV

Preliminary study of a direct methanol alkaline fuel cell stack (4 cells)



Poisoning by Carbon monoxide

- Co poisoning is a serious problem in acidic fuel cells relying on platinum catalysts. In this case, the OH^- groups needed for the electrochemical oxidation of CO must produced by dissociation of water, under the kinetically unfavorable conditions of the acid environment
- In contrast, in alkaline condition, the OH^- groups are a part of the electrolyte and the CO oxidation is not hindered
- This appears to underpin the higher tolerance for catalyst poisoning in case of platinum-catalyzed AFCs

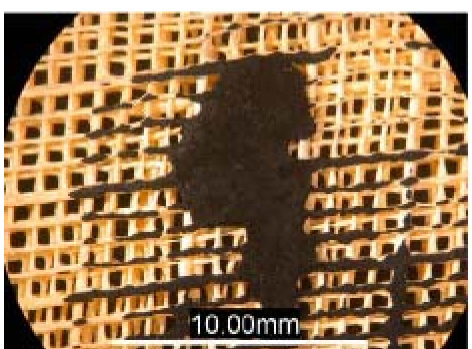
Debunking the Myths contd…

Power density

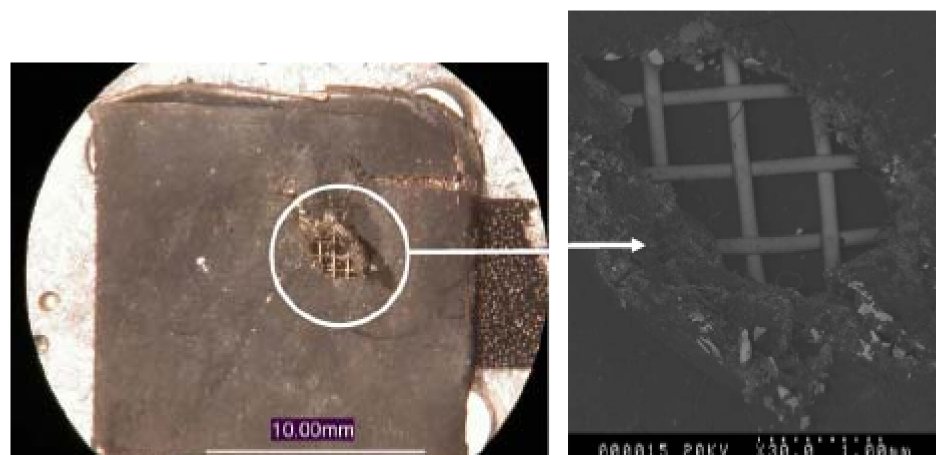
- AFCs are often dismissed as a fringe technology capable only of low power densities
- This unfair declaration comes from comparing apples and oranges
- Every thing being equal , however, AFCs will match or out perform the PEMFCs at high or low pressure because of high O_2 reaction kinetics

Lin et al. (2006)

Anode active layer damage due to poor microfluidics



Cathode perforation due to O_2 gas overpressure



Temperature

- AFCs work well at low temperature
- John Appleby, Texas University, USA, points out that aqueous alkaline electrolyte system have low activation energy for the cell reaction
- Electrolyte does not freeze (26-40% KOH solution freezes below -40^o C) and AFCs are generally capable of starting, alas at reduced power

AFC Golf car by Astris Energy Inc.

Catalyst

AFC catalyst combinations (Gulzow et al. 2006)

AFC developer	Fuel system	Operating pressure (bar)	Anode catalyst	Cathode catalyst
Bacon*	H_2-O_2	45	Ni	NiO
UTC-Apollo	H_2-O_2	3.4	Ni	NiO
UTC-Orbiter	H_2-O_2	4	Pt/Pd	Au/Pt
Elenco	H_2-air	atmospheric	Pt	Pt
Siemens	H_2-O_2	2.2	Ni	Ag
DLR	H_2-air	atmospheric	Ni	Ag

* AFCs developed by F T Bacon at the University of Cambridge, UK, in the 1940s and 50s.

AFC Backup power by Astris Energy Inc.

Conclusion and challenges to AFCs

- ✓ CO_2 neither enhances the degradation process nor induces any detrimental effect
- ✓ CO_2 poisoning is the incorrect word
- ✓ Slightly lower performance is due to reduced conductivity of the electrolyte
- ✓ CO_2 is not a problem and the electrolyte can be changed periodically as changing oil in IC engine
- ✓ Liquid electrolyte is not a problem however it manages heat and water management
- ✓ Manages even alcohols

  - ➢ For wider application, research on anion exchange membrane is required
  - ➢ Non-noble metal catalyst ??????
  - ➢ Electrode fabrication techniques
  - ➢ Electrolyte circuit design/engineering aspects due to corrosive nature of alkali

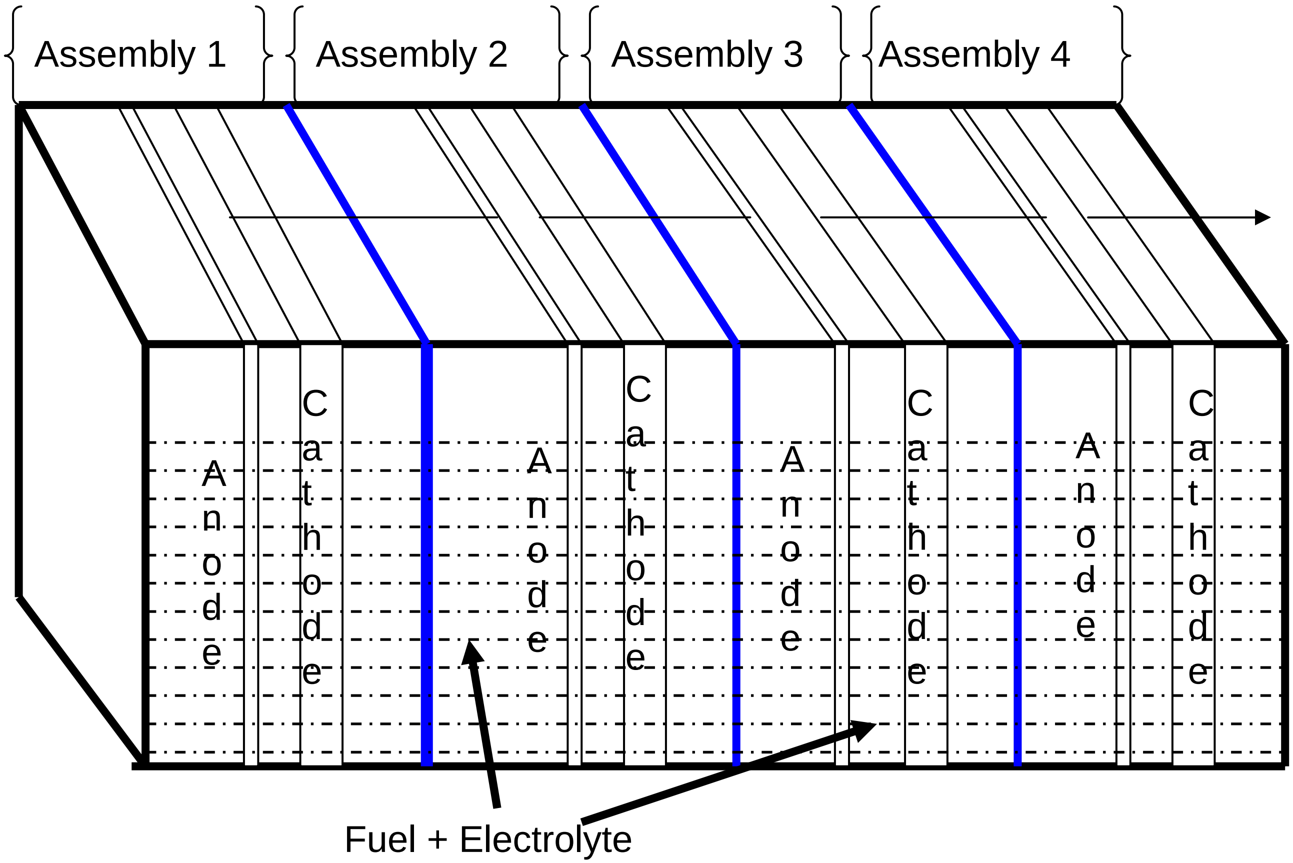
AFCs have the potential to become one of the key technologies

AFC should be seen as positive not negative technology

Acknowledgements

- MNES, IIT Delhi and IIT Guwahati
- Dr. S. Basu
- Lab members

Thank you for your kind attention



Assembly 1
Assembly 2
Assembly 3
Assembly 4
Anode
Cathode
Anode
Cathode
Anode
Cathode
Anode
Cathode
Fuel + Electrolyte