CO_2 Capture Utilizing Solid Sorbents

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CO_2 Capture & Separation –Sorbents (2) session

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Goals

- **President Bush's global climatic initiative/NETL carbon sequestration road map plan**
  - CO_2 capture from fossil fuels very important
  - Develop commercial systems that result in less than10% increase in the cost of energy services by 2012
- **Develop technologies to separate/capture CO_2**
  - **Combustion and gasification gas streams**
  - **Techniques for both low and high temperatures**
  - **Applications at both high and low pressures**
  - **Superior to the existing capture techniques**
  - **Commercialization of the developed techniques**

Technical Challenges

- **Desired sorbent properties**
  - **Adsorption capacity**
  - **Adsorption rate**
  - **Desorption/recovery rate**
  - **Recovery of concentrated CO_2 stream**
  - **Durability**
  - **Selectivity**
  - **Sensitivity to moisture and contaminants**
- **Suitable for operation with PSA or TSA**
- **Process optimization**
- **Scale up for commercial units**

Experimental Work

- **Volumetric gas adsorption studies – equilibrium adsorption isotherms up to 280 psi**
- **Flow reactor studies at 1 atm and at 20 atm**
  - Competitive sorption of CO_2 from gas mixtures representing coal combustion & gasification
- **Heat of reaction measurements – DSC calorimeter**
- **Thermo gravimetric analysis**
- **Physical and chemical characterization**
- **Spectroscopic characterization of CO_2/sorbent interactions**

Solid Sorbents

- **Zeolites**
  - Ambient temperature and 120 ^{0}C
  - Both atmospheric and high pressures
- **NETL liquid impregnated regenerable solid sorbents**
  - Ambient temperature (30 ^{0}C) & atmospheric pressure
- **NETL Warm gas alkali based sorbents**
  - 315 ^{0}C
  - Both atmospheric and high pressures
- **NETL moderate temperature sorbent**
  - 100 to150 ^{0}C
  - High pressure

Summary of the Results with Zeolites

- **Synthetic alkali alumino silicate zeolites showed excellent CO_2 adsorption at ambient temperature**
- **Alkali alumino silicates with pore diameter of 10 A showed good adsorption at 120 ^{0}C**
- **Presence of water vapor**
  - affected the capacity
  - regeneration at 350 ^{0}C is necessary
- **Combination of vacuum and mild temperature regeneration could be suitable**

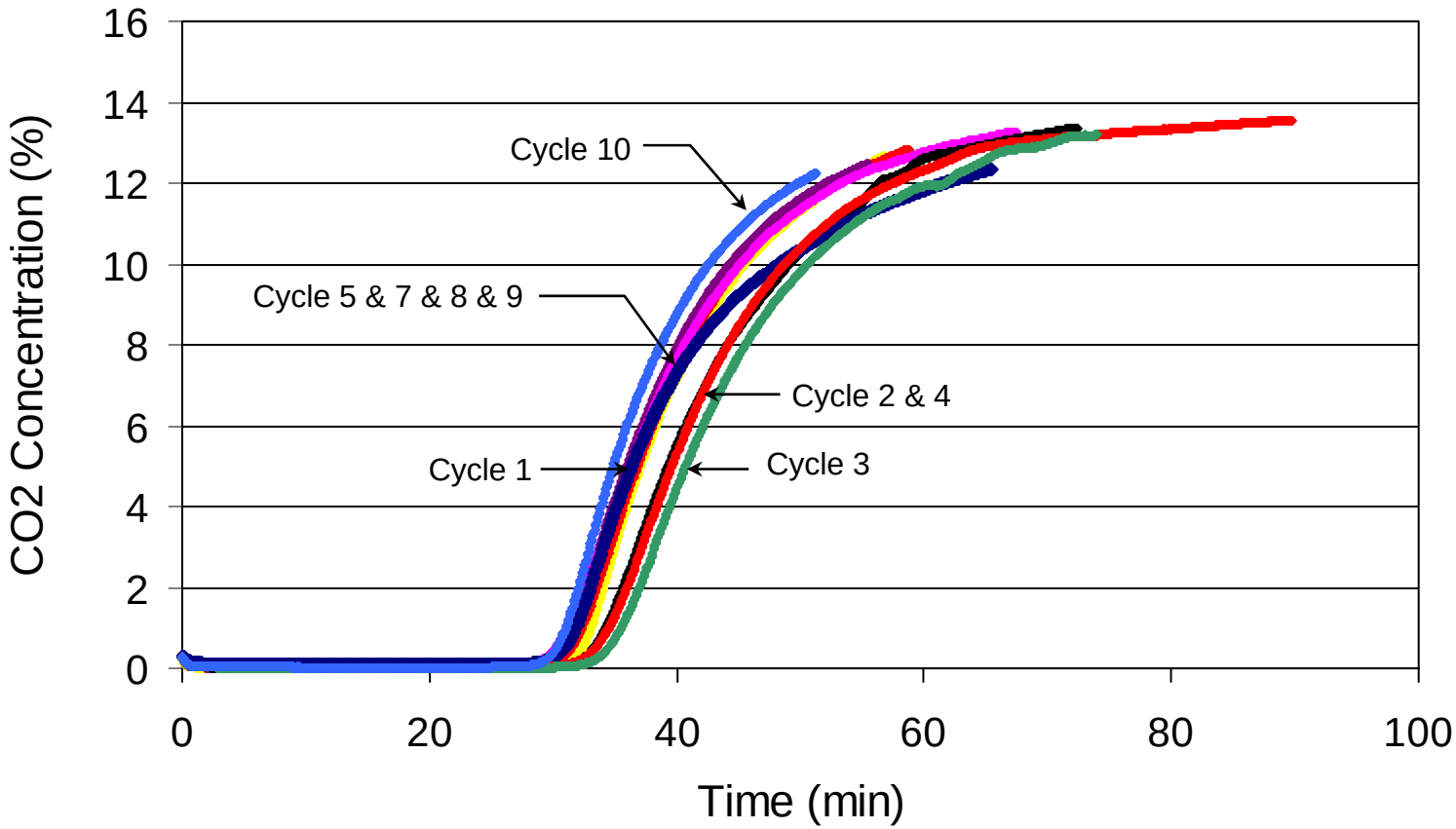
NETL Steam Tolerant Low Temperature Sorbent (NETL –LT) Development CO_2 Capture Temperature at 25-40 ^0C

Results with NETL steam tolerant liquid incorporated solid sorbent (NETL-LT)

- **Engineering analysis conducted at NETL**
  - Solid sorbent process has better efficiency than conventional amine technique when operated at
    - 25 ^{0}C sorption and 60 ^{0}C regeneration
    - High CO_2 sorption capacity during multiple cycles
- **Preparations by incorporating liquids in a solid matrix**
- **No corrosion problems**
- **Very good CO_2 capture capacity and good regenerablity**
- **Presence of steam does not affect the performance of the sorbent during multi-cycle tests**
- **Steam could be utilized for regeneration**

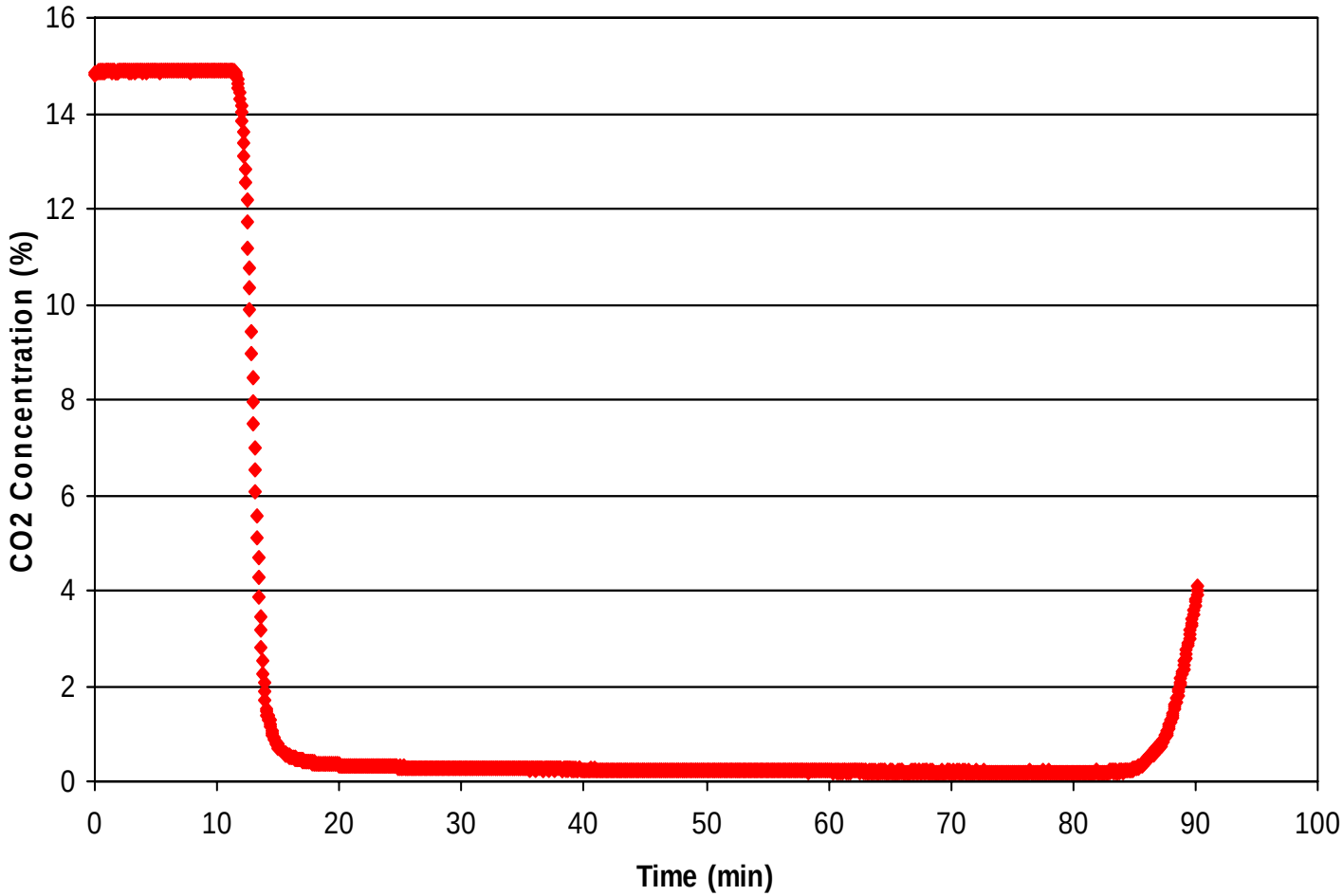
Adsorption of CO_2 on NETL-LT in Atmospheric Lab Scale Reactor

(15% CO_2, 3%O_2, 82% N_2, and Saturated With Water Vapor)



Adsorption of CO_2 on Reformulated NETL-LT to Obtain Better Capacity in Atmospheric Lab Scale Reactor

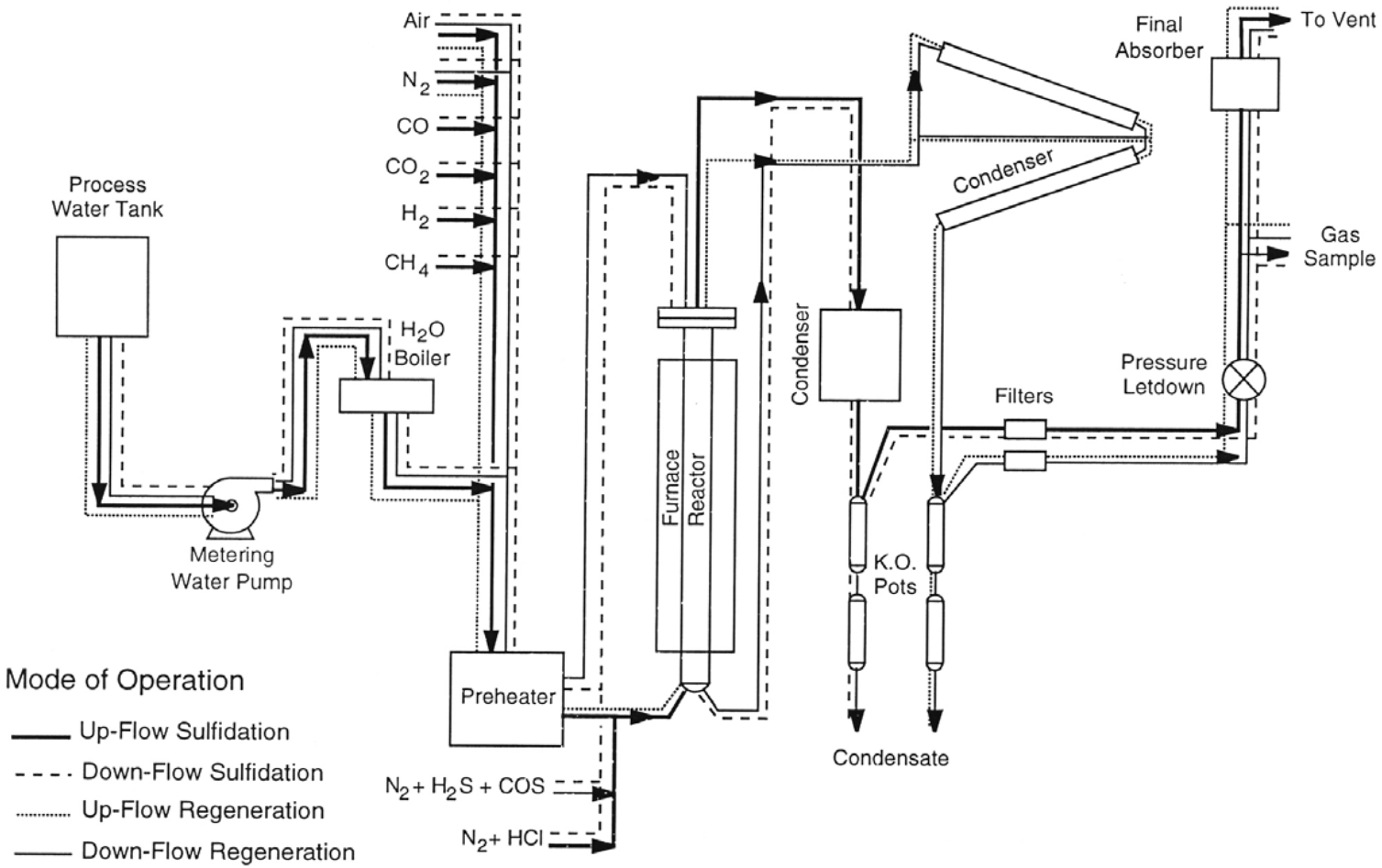
(15% CO_2, 3%O_2, 82% N_2, and Saturated With Water Vapor)



Bench Scale Flow Reactor Tests with Large Scale Preparation of NETL-LT

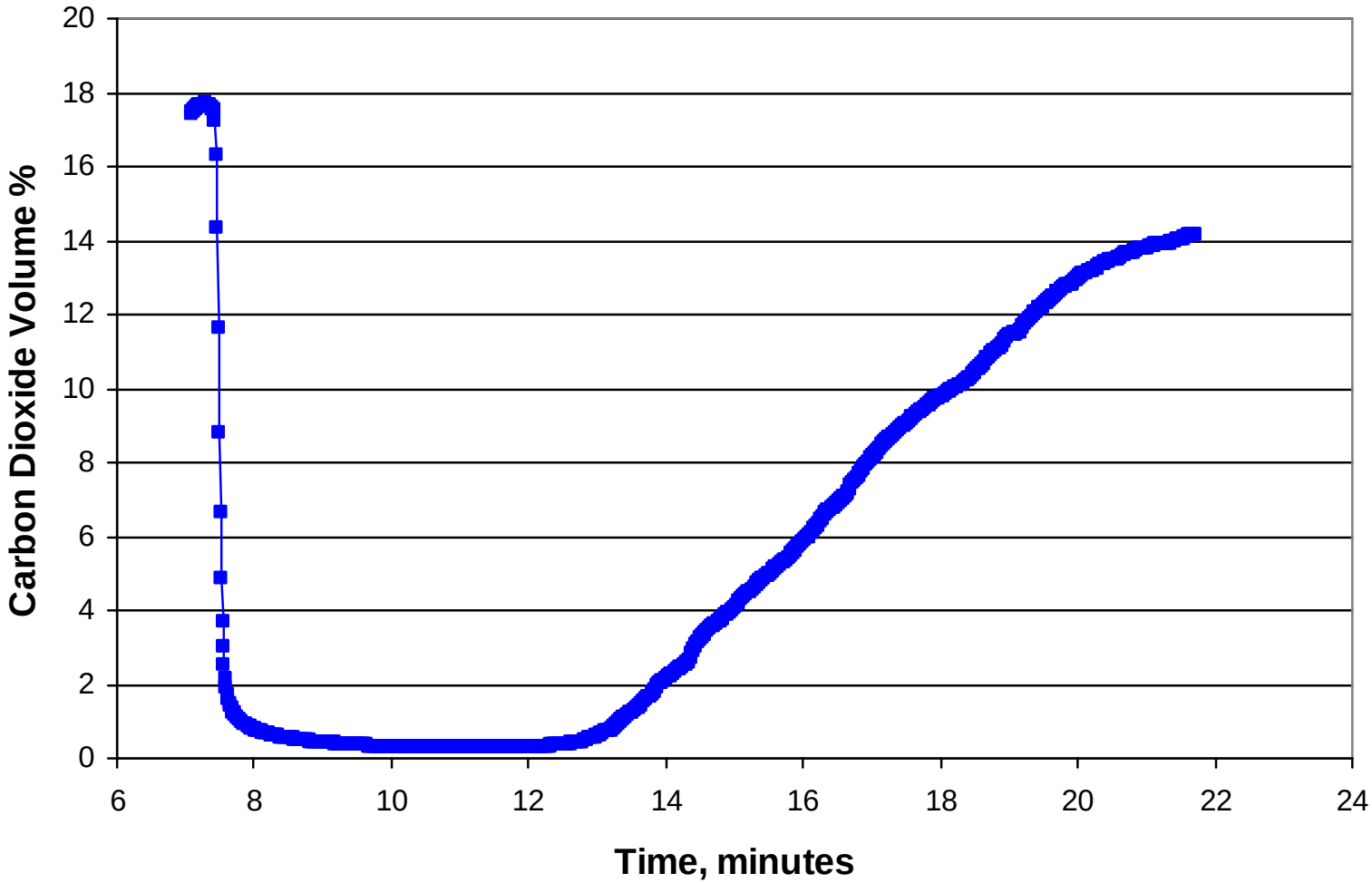
- Industrial level preparation
- Mixer –Pelletizer
- Bench scale reactor tests – two inch diameter reactor with six inch bed height
- ~350 grams of sorbent
- Tests conducted at both 500 hr^{-1} and 1000 hr^{-1} space velocity
- Temperature of the CO_2 sorption – 25-30 ^0C
- Temperature of regeneration – 80 ^0C

Flow Diagram of the High Pressure Bench Scale Flow reactor



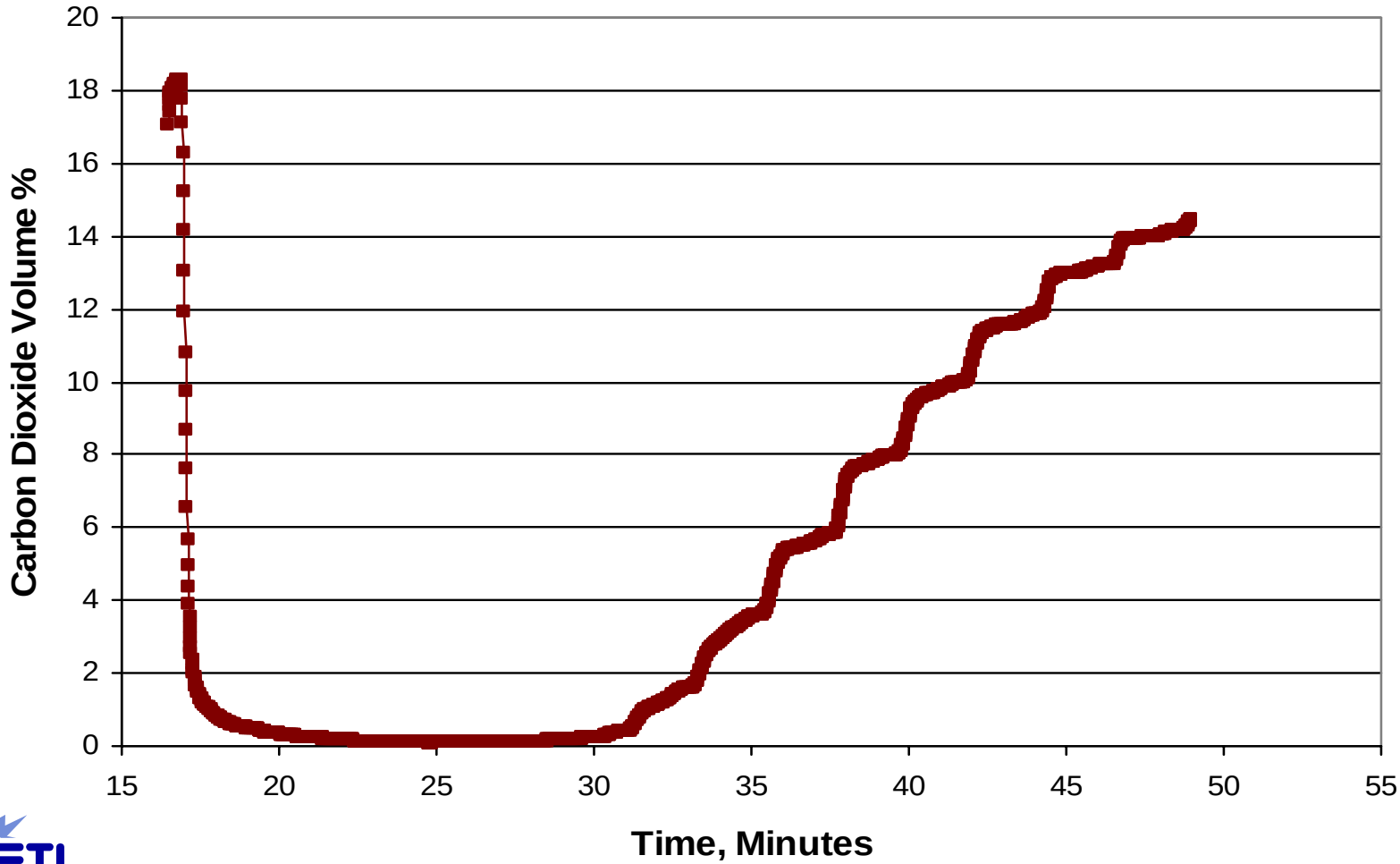
Adsorption of CO_2 on NETL-LT in Atmospheric Bench Scale Reactor- 1000 hr^{-1}space velocity, 25-30 ^{0}C

(17% CO_2, 3%O_2, 80% N_2,)



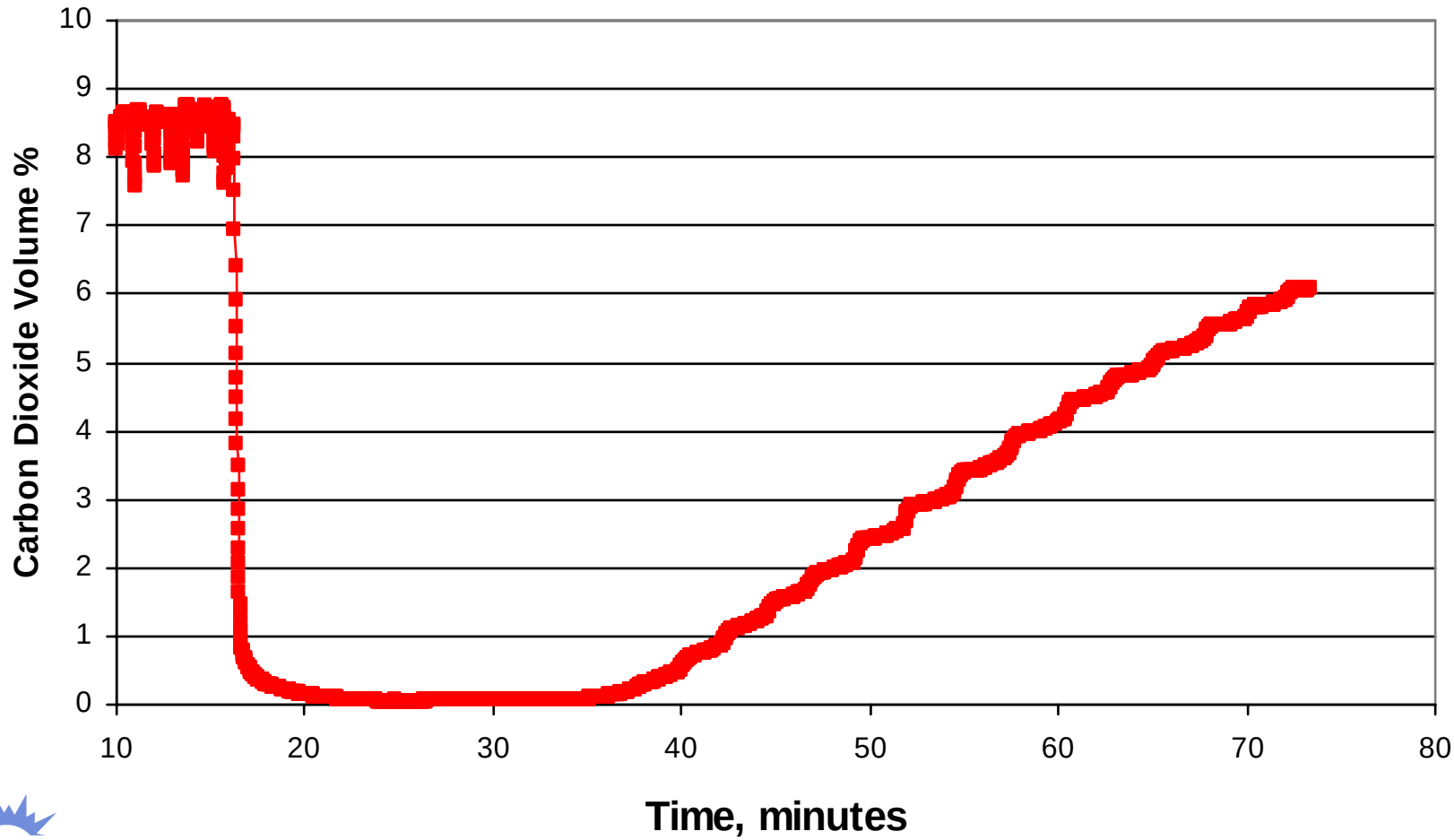
Adsorption of CO_2 on NETL-LT in Atmospheric Bench Scale Reactor- 500 hr^{-1}space velocity, 25-30 ^0C

(17% CO_2, 3%O_2, 80% N_2,)



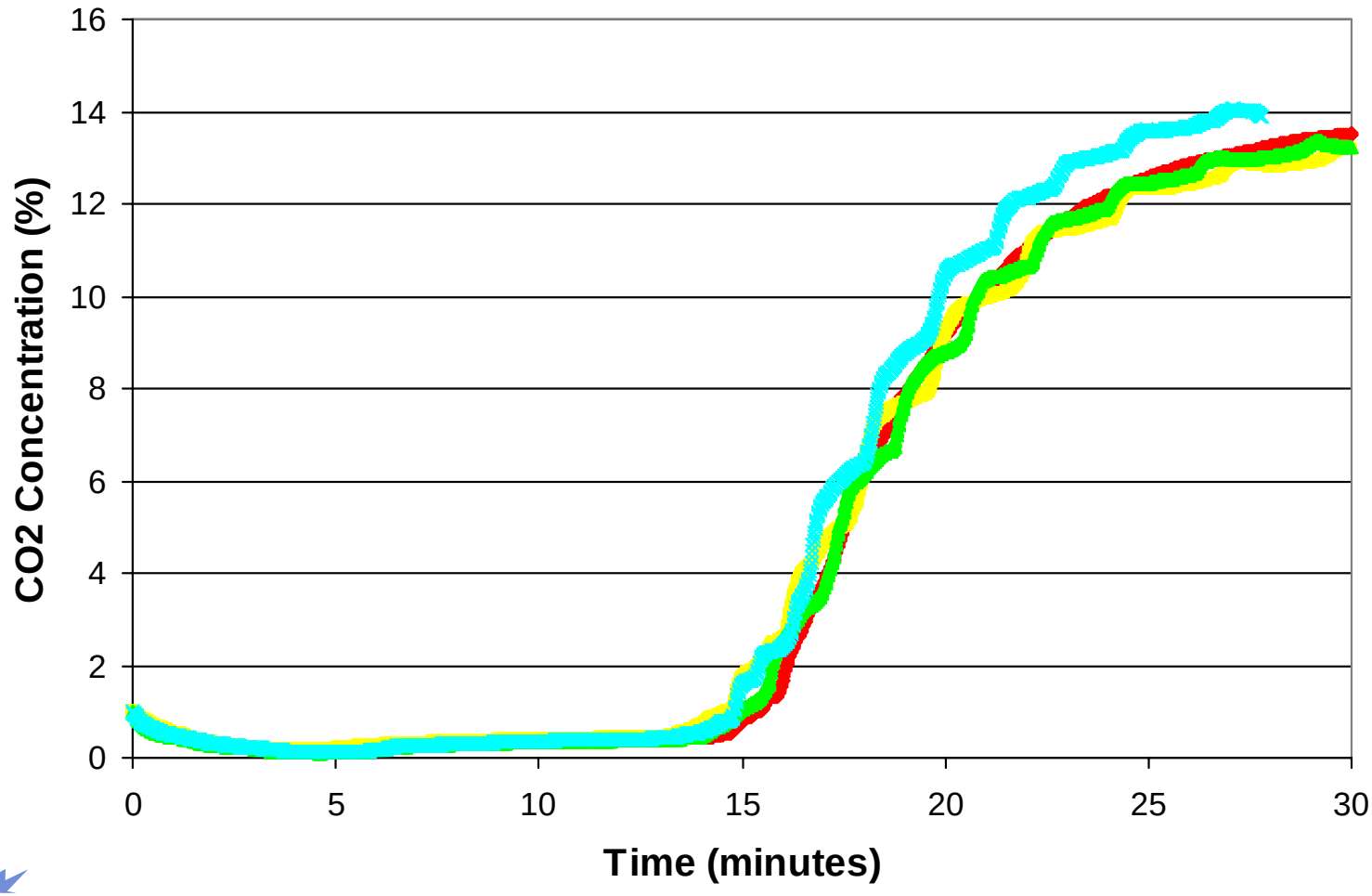
Adsorption of CO_2 on NETL-LT in Atmospheric Bench Scale Reactor- 500 hr^{-1}space velocity, 25-30 ^0C

(8% CO_2, 3%O_2, 89% N_2,)



Multi cycle sorption of CO_2 on NETL-LT in Atmospheric Bench Scale Reactor

17% CO_2, 3%O_2,80% N_2,500 hr^{-1}space velocity, 25-30 ^{0}C



Summary of the Bench Scale Multi Cycle Tests with NETL-LT

- **Stable performance during multi cycle tests after regenerating at 80 ^{0}C for one hour**
  - Regeneration did not affect the capacity and efficiency
- **CO_2 capture capacity of 2 – 2.5 moles/liter**
  - Twice the capacity that of liquid amine process
- **99% CO_2 removal during multi cycle tests**
- **Temperature increase due to exothermic reaction**
  - No temperature control in the flow reactor
  - Better capacities may be obtained with proper temperature control
  - Exothermic heat may be utilized for regeneration

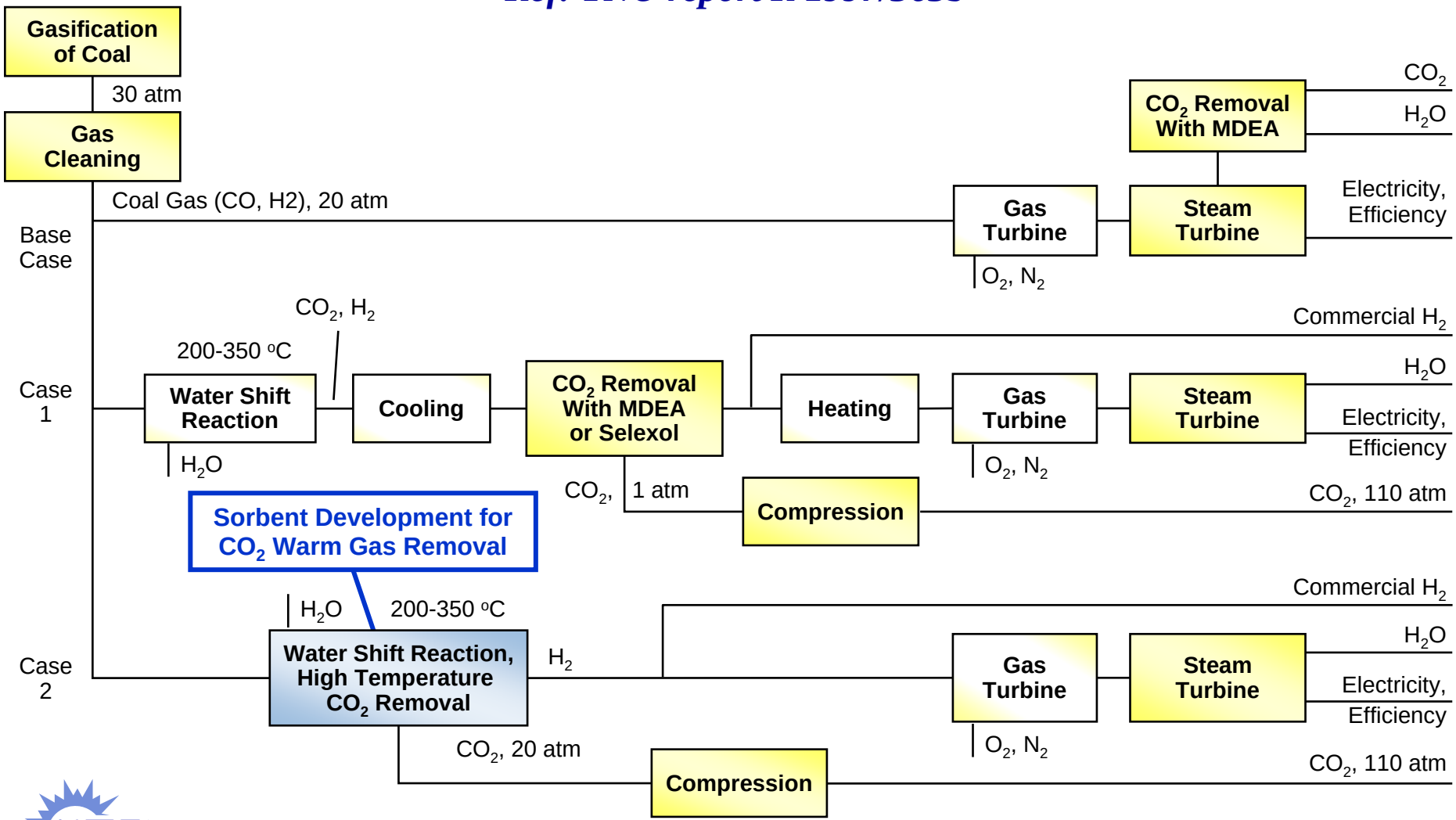
NETL Warm Gas Temperature Sorbent (NETL-WT) Development
CO_2 Capture Temperature at 315 -500 ^{0}C

Importance of the Sorbent Development at Warm Gas Temperatures

- **Reported system studies**
  - CO_2 removal at warm gas temperatures (200 -350 ^{0}C) is the most energy efficient for IGCC systems
- **Existing commercial cold gas technologies**
  - Loss of thermal efficiency due to cooling of gas
- **Warm gas temperature sorbent**
  - Utilize gas without cooling after shift reactor and pure hydrogen stream can be obtained
  - No commercial processes
- **No regenerable sorbents for CO_2 removal at 250-350 ^{0}C reported in the literature**

Comparison of Different Options for CO_2 Removal and H_2 Production from IGCC Power Plants

Ref: TNO report R 1997/363b

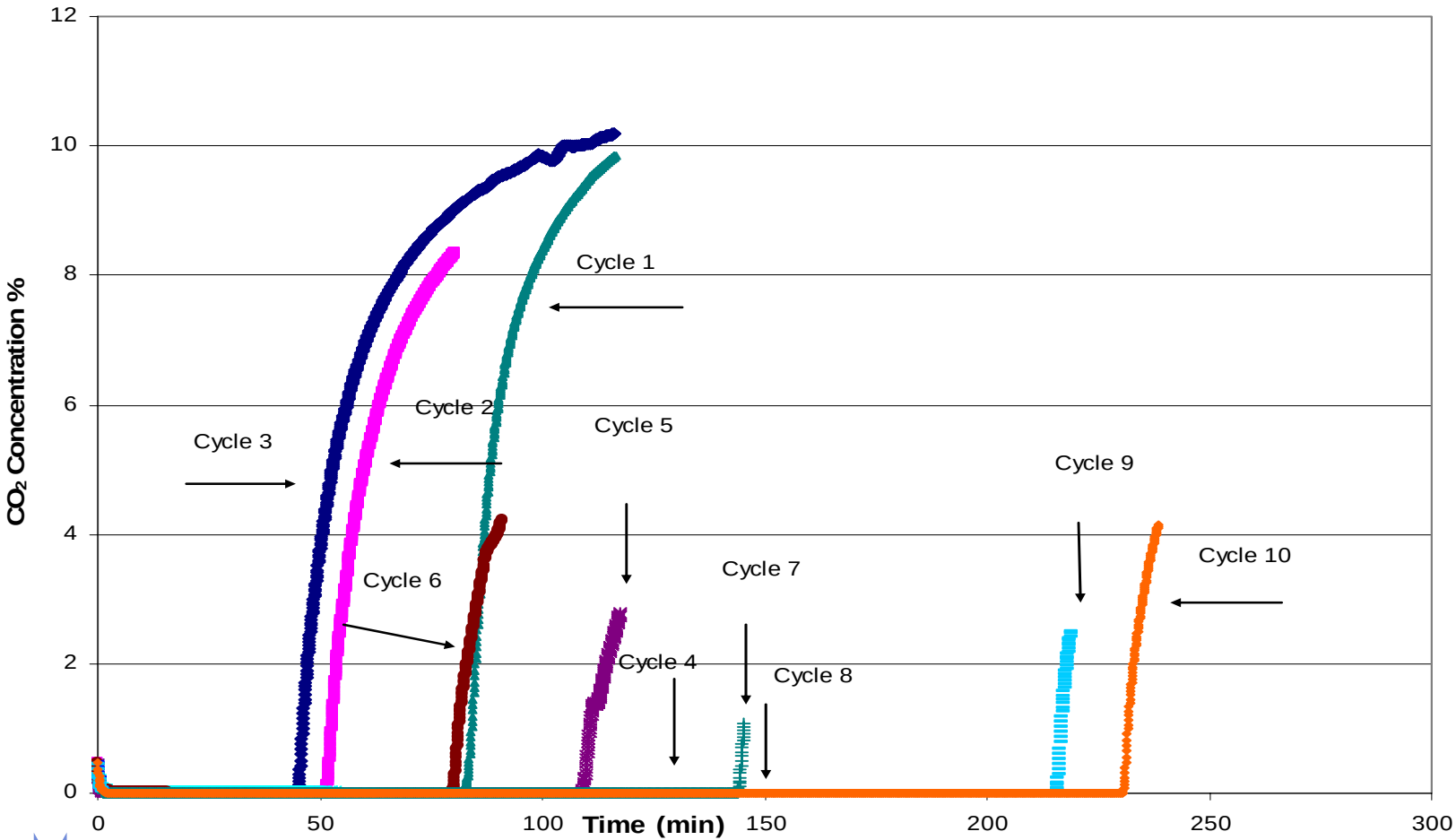


Experimental work

- New sorbent for warm gas tempertures - Sodium based compounds
- Involves chemical reaction – “Sorption”
- Tests were conducted at 315 ^{0}C – both with simulated IGCC fuel gas and simulated post shift gas reactor gas
- Both low pressure and high pressure flow reactor tests
- Regeneration at 700 ^{0}C during ten cycle test

Ten Cycle Test of CO_2 with Warm Gas Sorbent at 315 ^{0}C

(Simulated IGGC Gas Stream :12% CO_2, 35.9% CO, 27.1% H_2, 25% He, sat. with H_2O, 5cc/min, 1 atm)



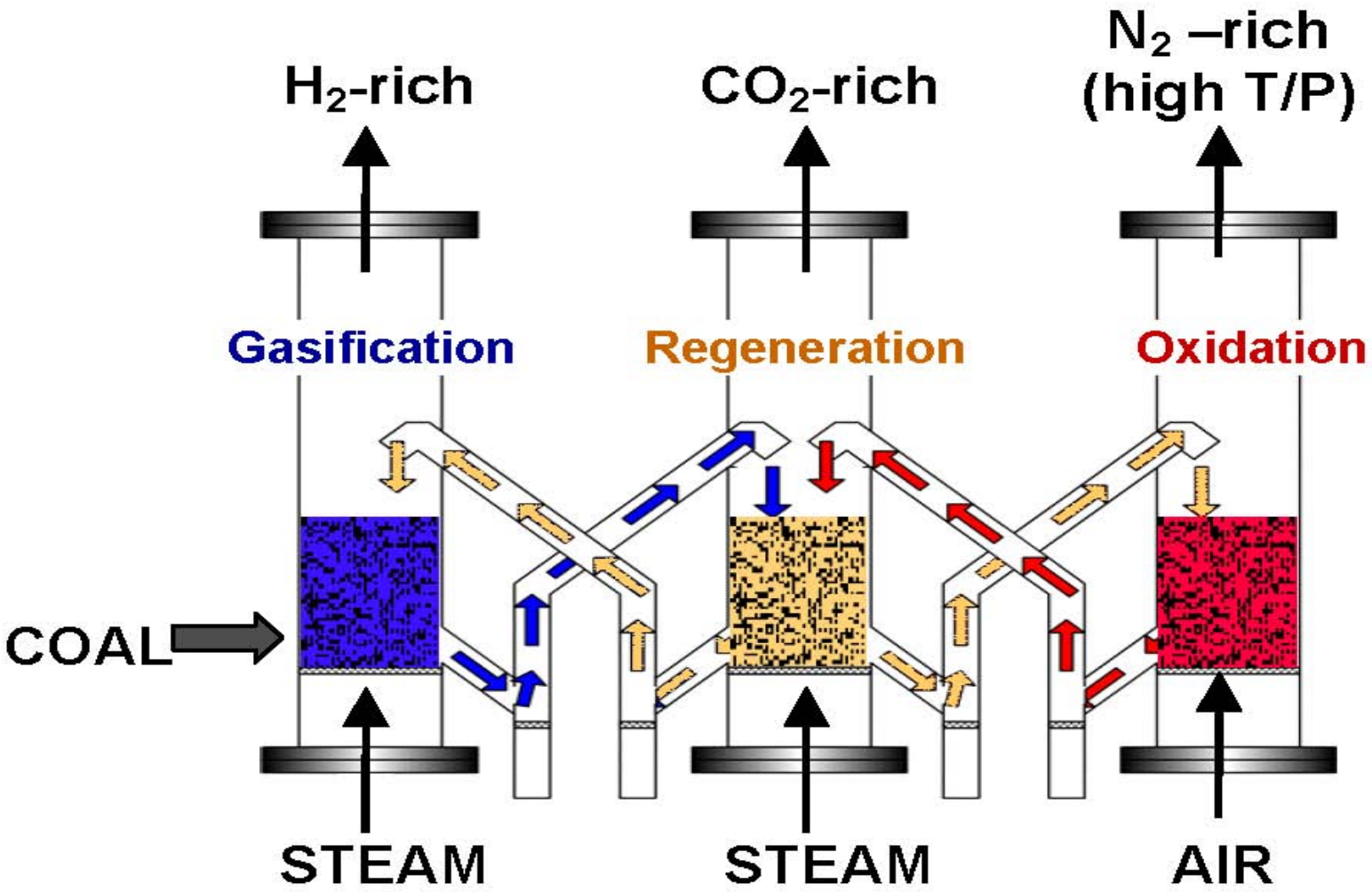
Advantages and disadvantages of the warm gas temperature sorbent

- **CO_2 removal efficiency is >99% at 315 ^{0}C**
- **CO_2 capacities improved during 10 cycle test**
  - Cycle 10 : 6.0 moles/kg (38 times that of selexol)
  - low regeneration cost and small vessel size
- **System studies at NETL**
  - Regeneration at 700 ^{0}C is not optimum for direct IGCC
- **Additives/conditions for lowering regen.T investigated –TPD/XPS studies**
  - Additives can lower the decomposition temperature
  - Decomposition can take place at 400 ^{0}C in vacuum
- **Applications in GE Fuel Flexible Gasification-Combustion system**

Application of Warm/High Temperature Sorbents

Fuel Flexible Gasification-Combustion Technology for Production of H_2 and Sequestration-Ready CO_2 by GE Global Research

Final Technical report –DE FC26 00FT40974 –Nov. 2004



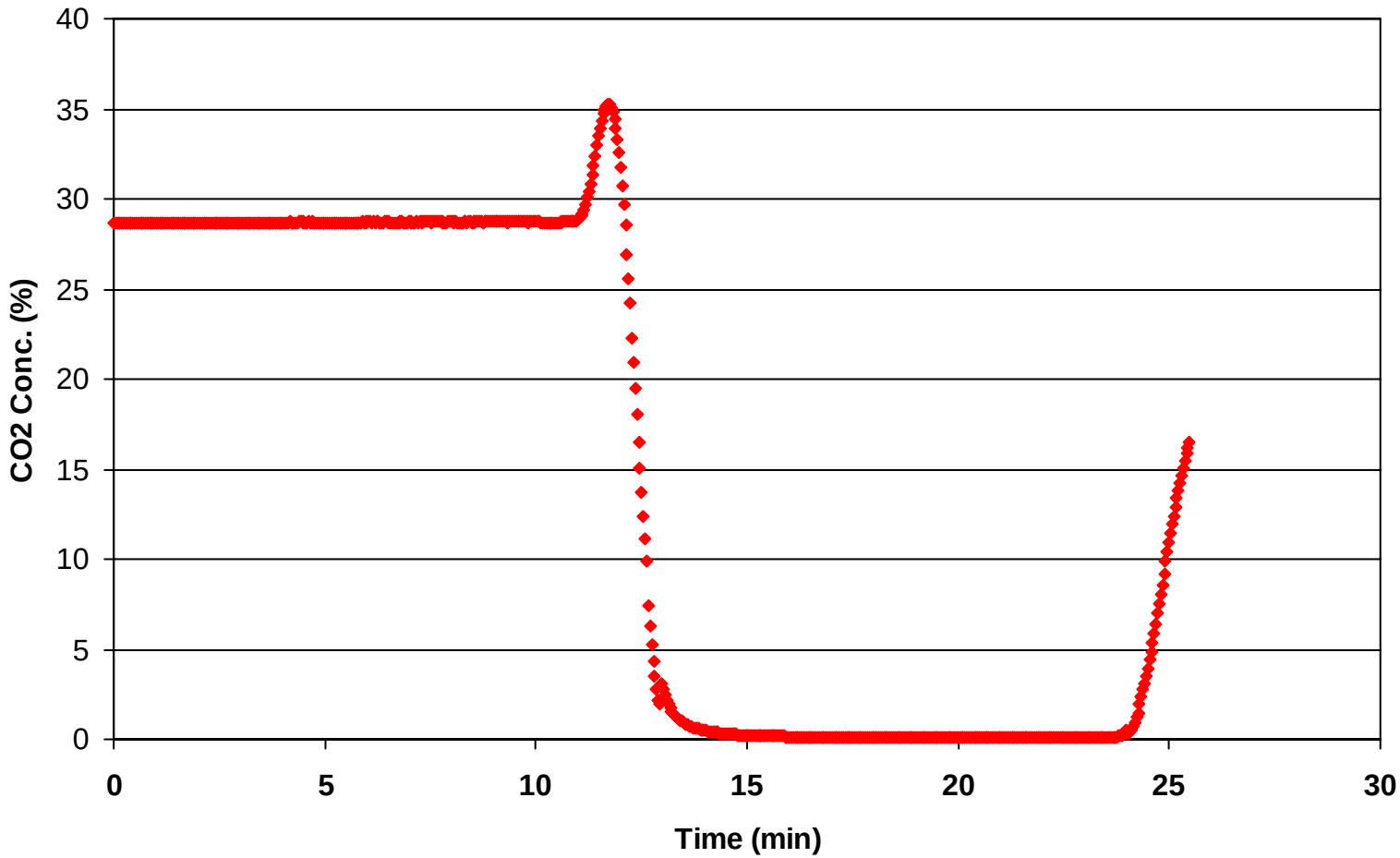
NETL Moderate Temperature Sorbent (NETL –MT) Development CO_2 Capture Temperature at 100–150 ^{0}C

Sorbents for CO_2 Sorption at 100-150 ^{0}C

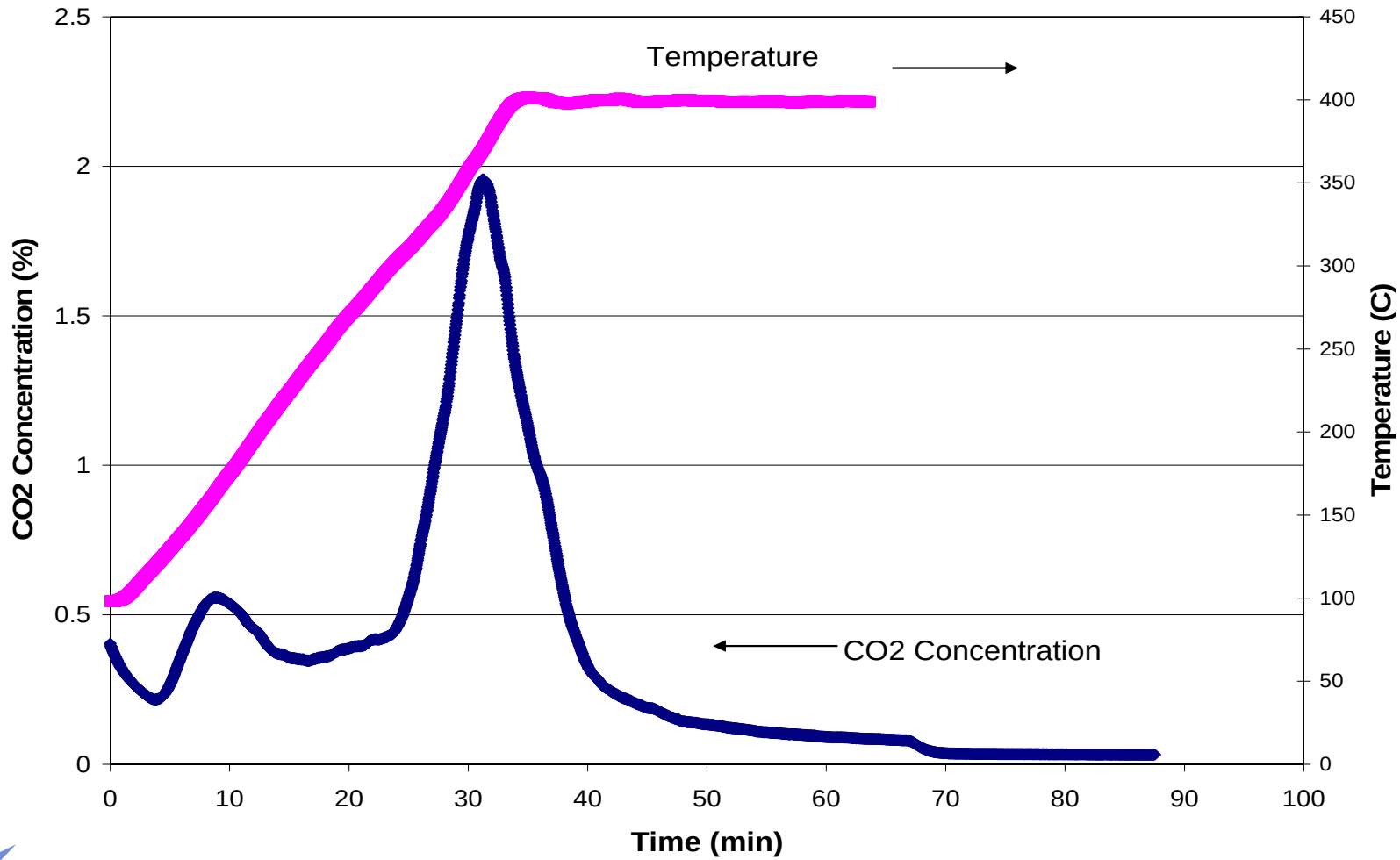
- Alkali/alkali earth based sorbent
- Performance best at high pressure according to the reaction mechanism
- Performs best in the presence of steam
- CO_2 capture at 100-150 ^{0}C and Regenerates at 350 ^{0}C
- Conducted micro reactor tests with post shift reactor CO_2 composition (28% CO_2 in He) at atmospheric reactor
- High pressure reactor studies planned
- System studies is currently being conducted

Adsorption of CO_2 on NETL-MT sorbent in Atmospheric Lab Scale Reactor at 100 ^{0}C

(28% CO2 in He, and Saturated With Water Vapor)



Temperature Programmed Desorption of NETL-MT Sorbent after CO_2 Sorption at 100 ^{0}C



Conclusions

- **Performance of zeolites affected by water vapor**
- **NETL-LT sorbent at 30 ^{0}C abs./ 60-80 ^{0}C reg.**
  - Resistance to water vapor
  - Achieved 99% removal at industrial approved space velocity
  - Capture capacity is about 2.5-3 moles/liter
  - Better capacities with proper temperature control
  - Utilize exothermic heat for regeneration
- **NETL-WT sorbent at 315 ^{0}C abs./700 ^{0}C reg.**
  - Promising results during multi-cycle tests.
  - Additives can lower regeneration temperature
  - Other applications
- **NETL moderate T sorbent at 100 ^{0}C abs./350 ^{0}C reg,**
  - 99% removal efficiency from 28% CO_2 with steam.
  - System studies currently being conducted