Catalytic Combustion for the Elimination of Methane, BTEX and Other VOC: IV

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Project definition and objective

- Evaluate combustion of concentrated methane streams that contain BTEX compounds.
- Evaluate catalytic combustion using a counter diffusive radiant heater.
- Develop mathematical models for the reactor to enhance design and understanding.
- Improve the catalyst for BTEX combustion.
- Target application – dehydrator units

Collaborators

- Bruce Peachey (New Paradigm Engineering)
- Peter Howie (Scott-Can Industries Ltd.)
- Husky Energy

Current Personnel

- Dr. Joseph Mmbaga (Research Associate)
- Dr. Long Wu (Research Associate)
- Naeimeh Jodeiri (PhD student)
- Guangyu Huang (MSc Student)

Options for VOC Combustion

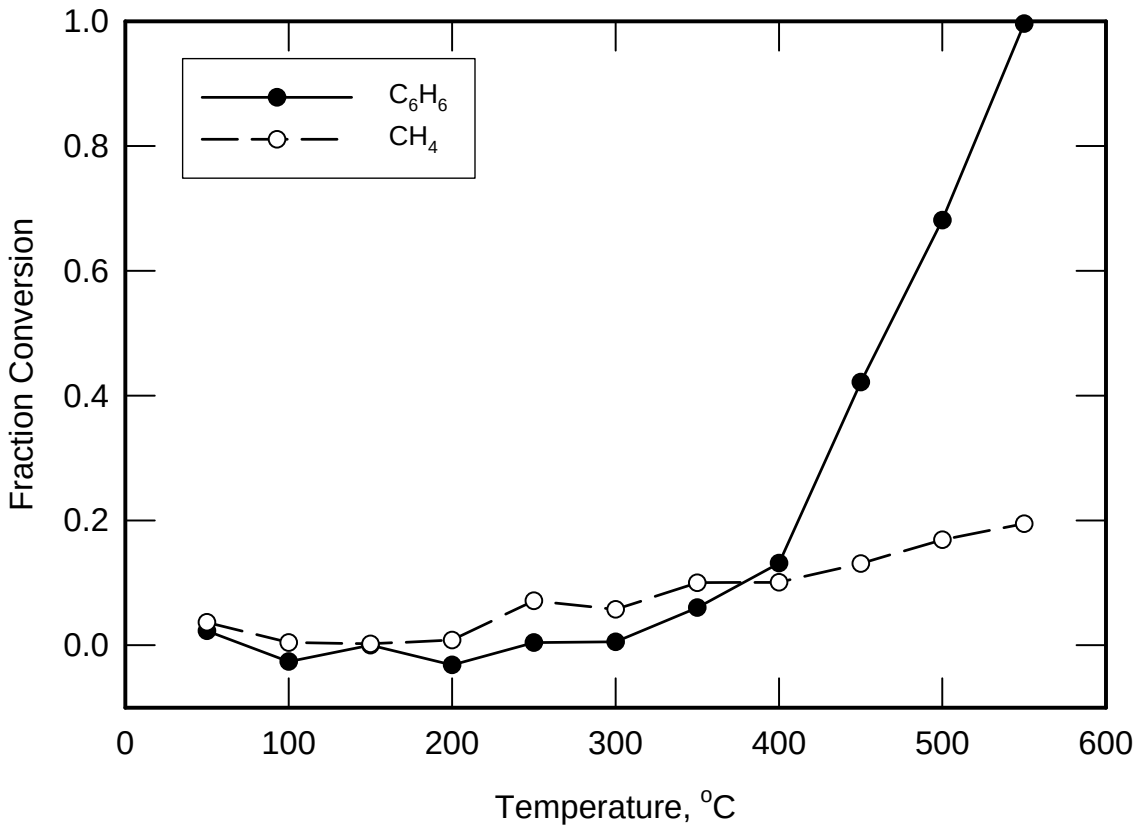
- Homogeneous combustion (Flaring)
  - Many problems may exist
- Catalytic combustion
  - A flameless combustion process that uses a solid catalyst to promote the combustion reaction.

Reactivity Testing

- Relative reactivity testing for VOC over commercial catalysts.
- Several commercial pad catalysts were tested, as well as other powders. Both Pd and Pt catalysts tried.
- Relative reactivity of methane, BTEX investigated.

Methane and Benzene Conversion

Commercial catalyst with air, methane and benzene



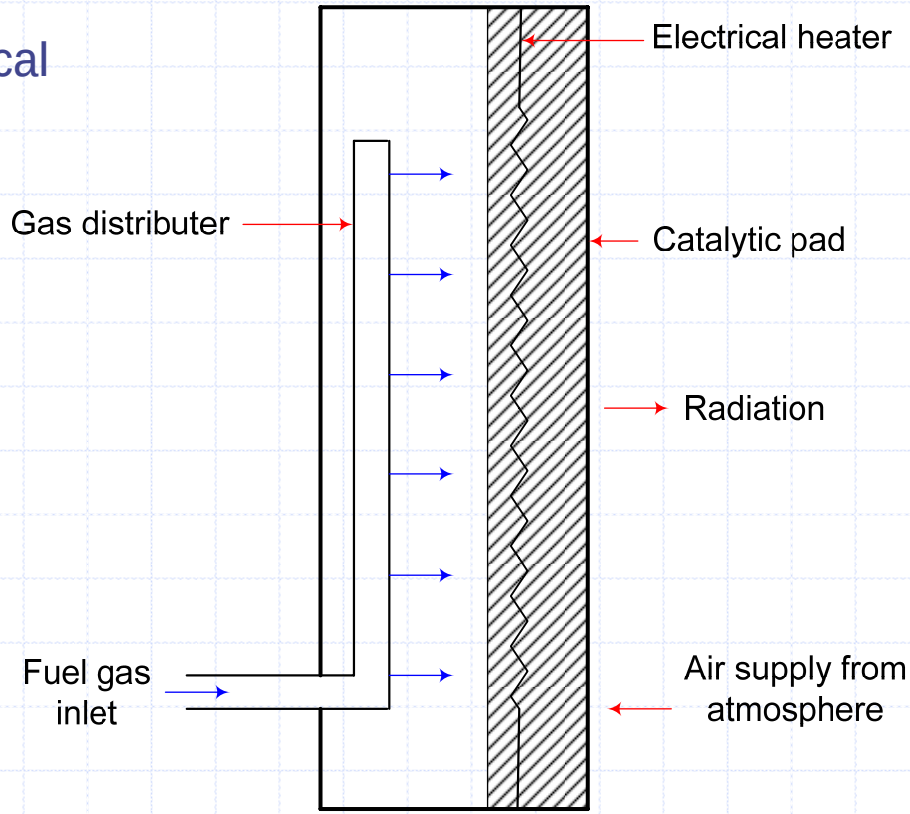
BTEX compounds are more reactive than methane over typical catalysts. Similar behavious was observed for all Pd and Pt catalysts tested.

Catalytic Radiant Heaters

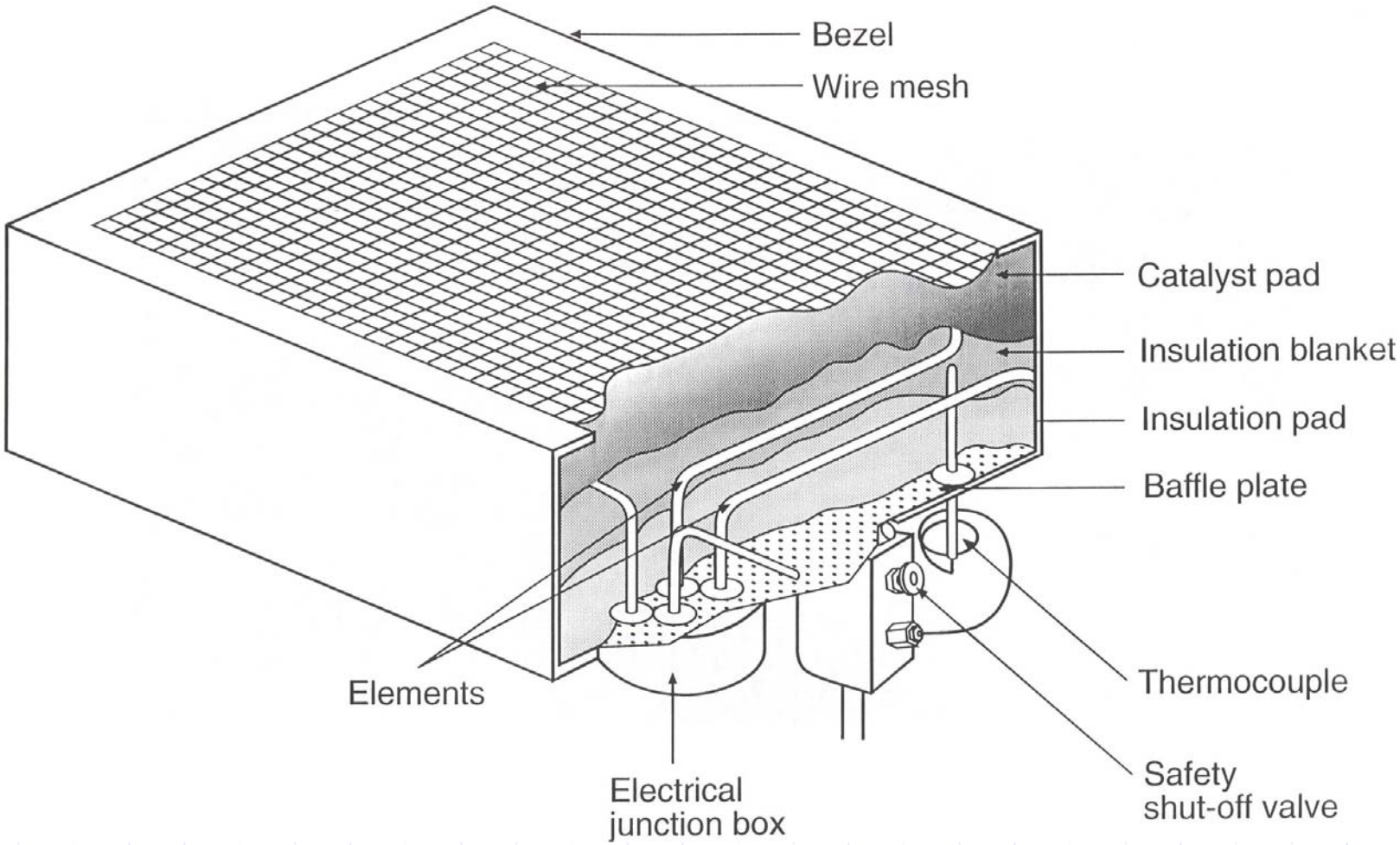
- Catalyst: commercial ceramic pad in which Pt or Pd are deposited.
- Pad is preheated using an electrical heating element to initiate the reaction:

$$CH_4 + 2O_2 \longrightarrow CO_2 + 2H_2O$$

- Modes of heat transfer
  - Convection
  - Conduction through metal frame
  - Radiation (main mode)



Catalytic Radiant Heaters



Radiant Heaters - Oil & Gas Industry

- Over 200,000 heaters in service in western Canada's oil and gas industry today
  - Space heating for well site buildings, meter stations, dehydrators, compressor sites, etc.
  - Pipeline installation of shrink coating
- Familiar to most field operators
- Simple technology

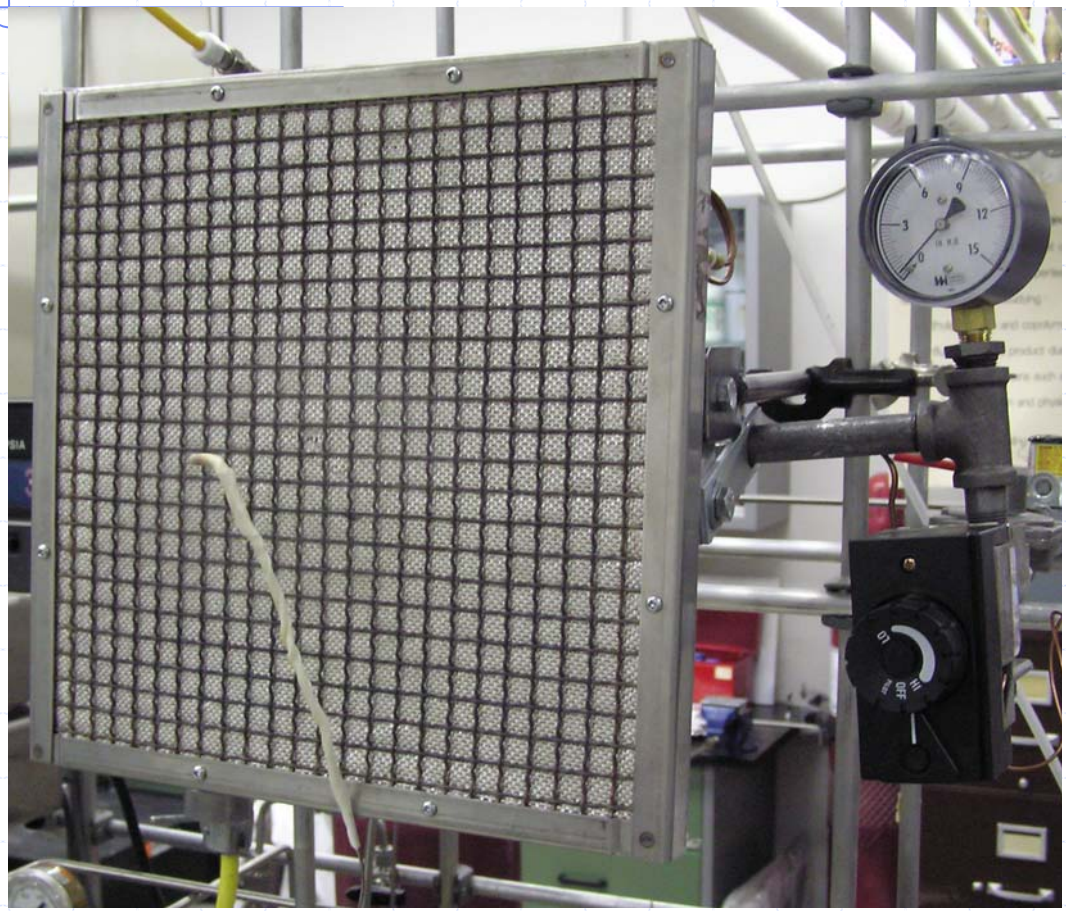
Some Issues

- Operation under variable inlet flowrate and concentration.
- Non-pure feed composition
- Fuel slippage – important for BTEX.
- Effect of water in the feed.

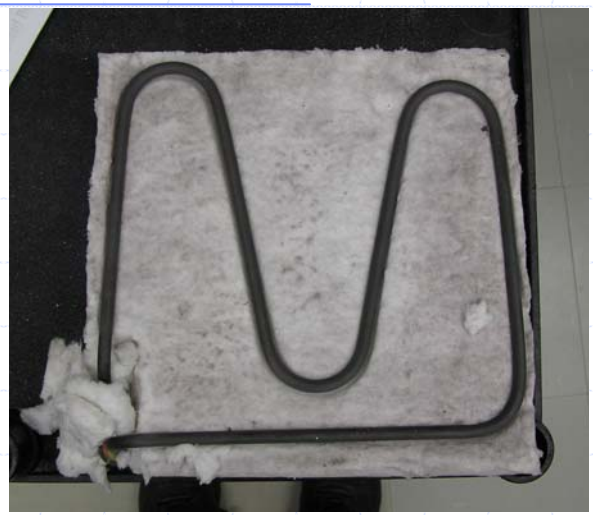
Small Industrial Unit

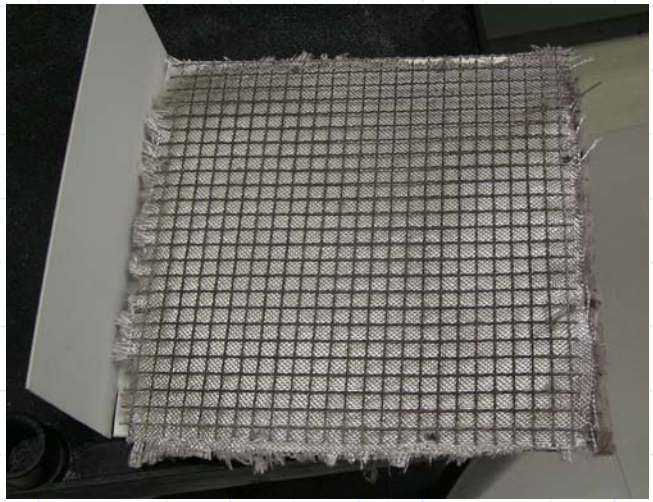
- Small radiant heater (30 cm X 30 cm) from Scott-Can Industries.
- Power approximately 1500 Watts (5000 Btu/h)
- Instrumented for temperature and concentration measurement.
- Hood used to capture and quantify effluent.

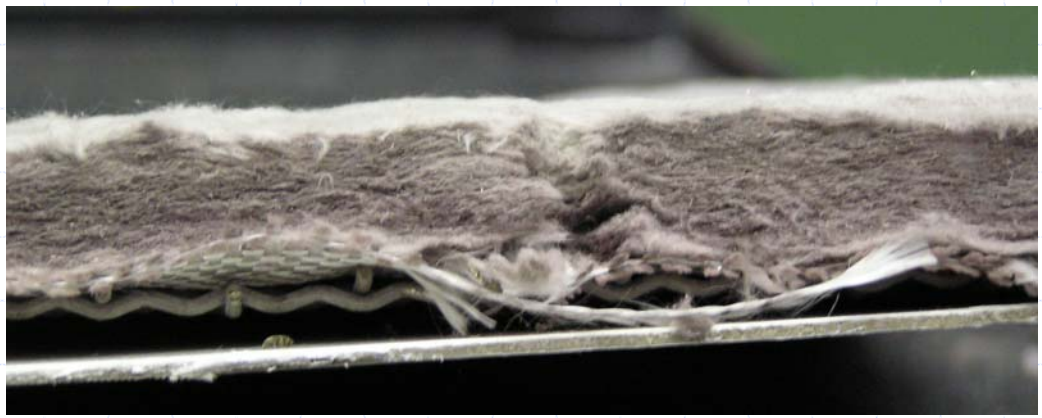
Small Commercial Unit



Small Commercial Unit

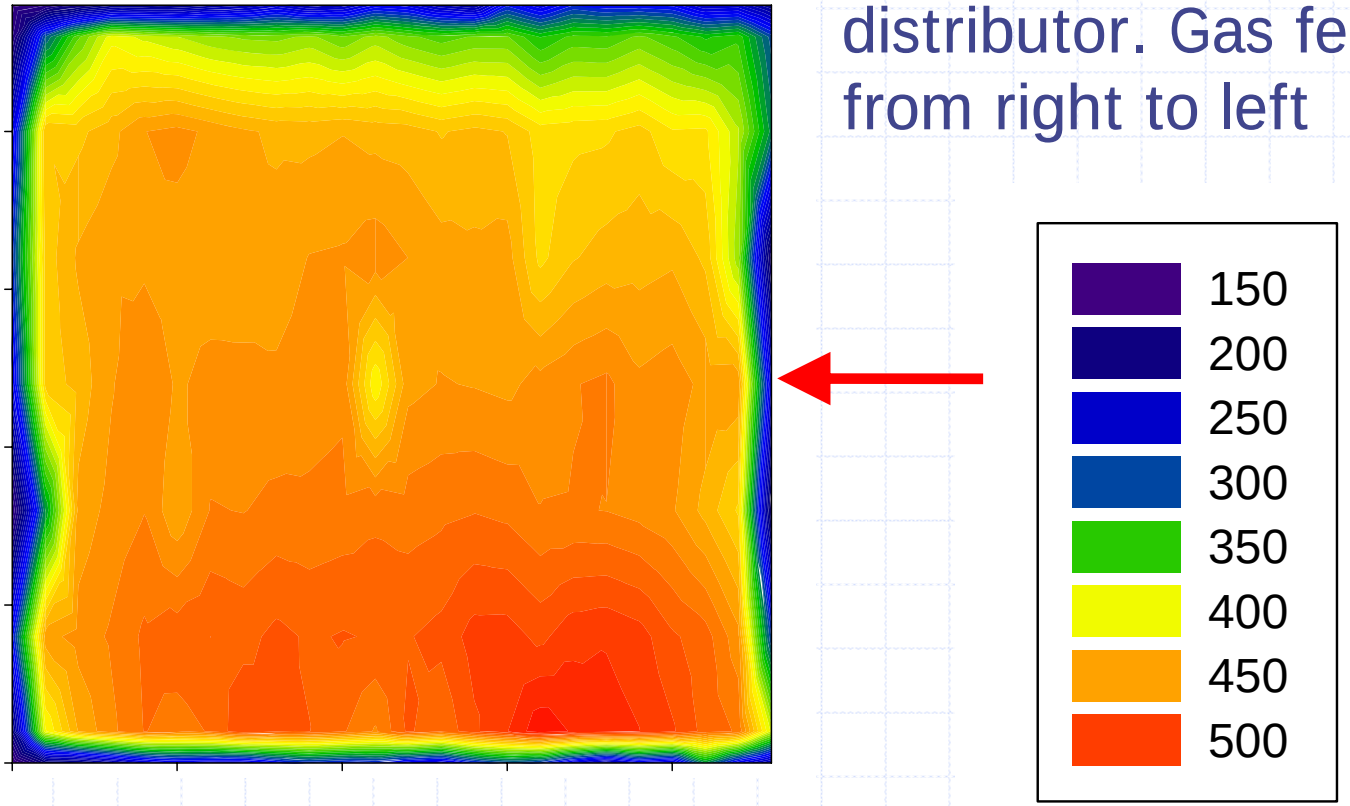






Measured Temperature Distribution

Horizontal gas distributor. Gas feed from right to left



Standard operating mode, 2.5 litres/min at STP

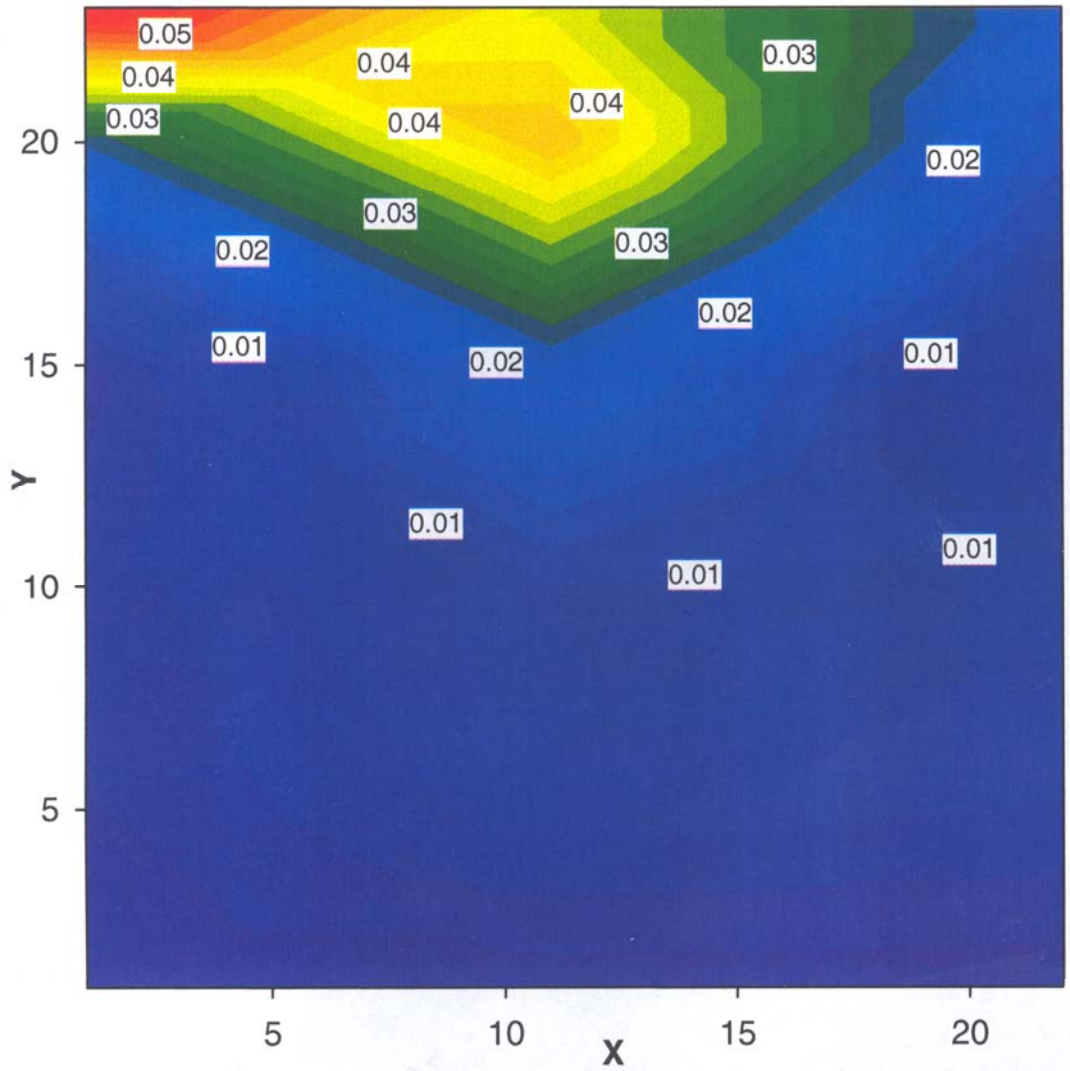
Temperature distribution

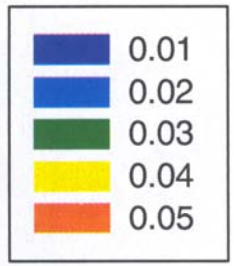
- The same result was observed regardless of feed pipe design and heater orientation.
- Oxygen transfer through the boundary layer seems to be the most important factor.

Fuel Slippage

- Fuel slippage of methane was measured at the front of the pad by localized sampling.
- Slippage increases with flow rate.
- Preliminary results were qualitative.
- Next step was more quantitative by capturing the flow over the surface.

Fuel Slippage

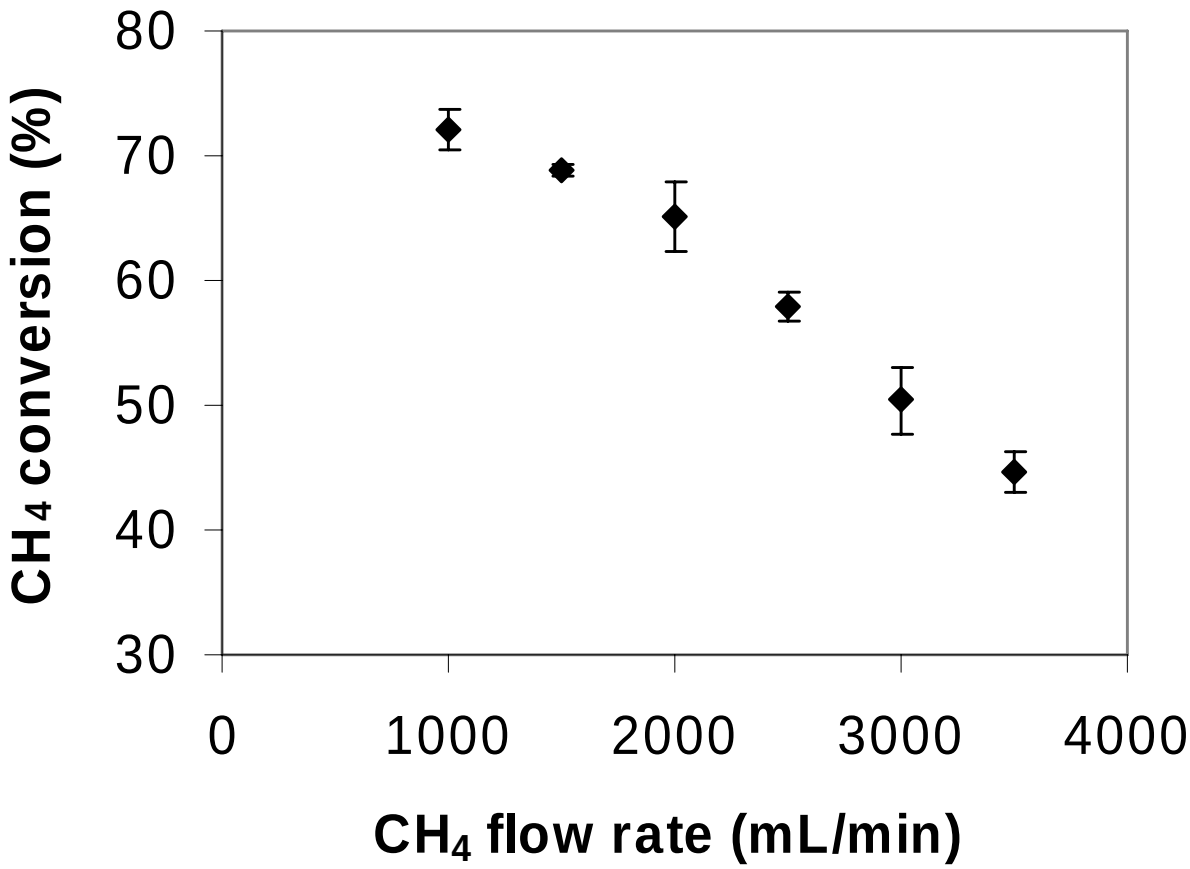




Legend: mole fraction CH_4

Local concentration various with position.

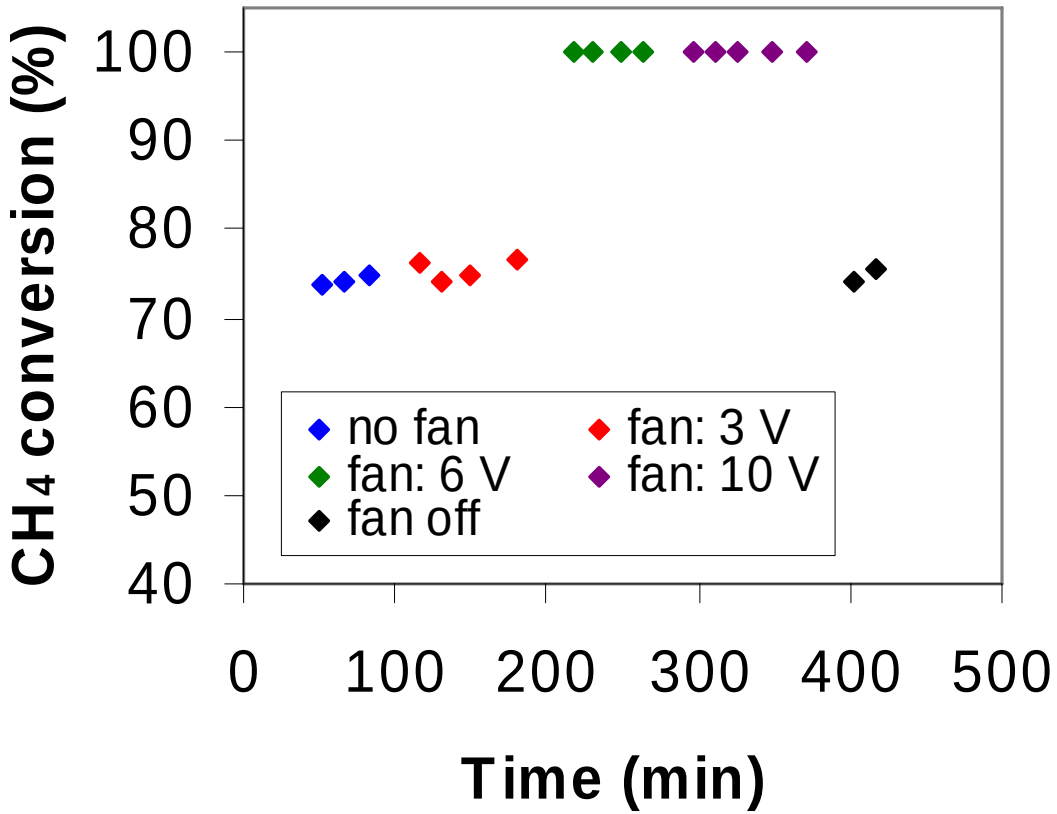
Methane Conversion



Conversion drops as the flow rate increases.

Increasing oxygen mass transfer at pad face

- A fan was used to increase the convective air flux in front of the radiant heater.
- By increasing the speed of the fan complete conversion of CH_4 is achieved.
- No significant change in temperature was observed.



Dehydrator regenerator emissions

Typical values.

Flowrate 286 scf/h

Equals 8.1 m^3/h
Or 135 L/min

Gives a heater of 54 ft^2
Or 5 m^2

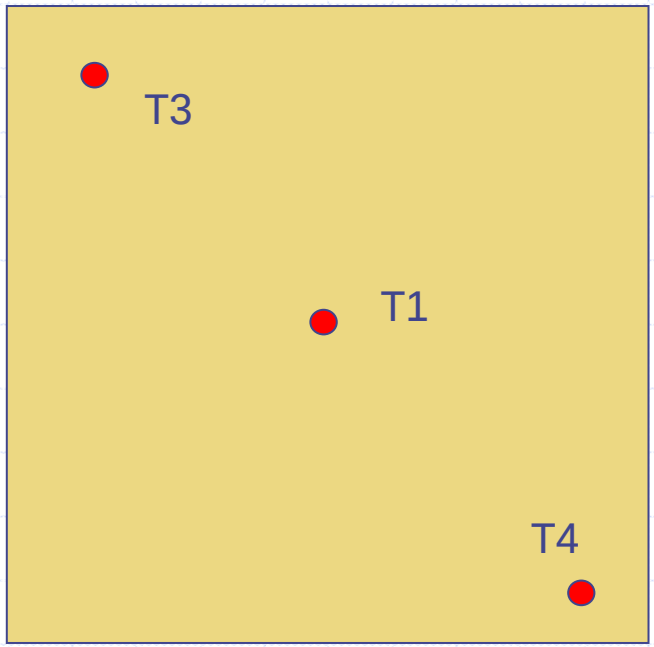
Water: 40.4 %v
CH_4: 40.1 %v
C_2H_6: 6.37 %v
C_3H_8: 4.6 %v
i-C_4H_{10}: 0.685 %v
n-C_4H_{10}: 1.84 %v
i-C_5H_{12}: 0.521 %v
n-C_5H_{12}: 0.607 %v
Benzene: 0.541 %v
Toluene: 0.762 %v
Xylenes: 0.435 %v
CO_2: 0.541 %v
N_2: 0.208 %v
Methylcyclohexane: 0.399 %v
Ethylbenzene: 0.197 %v

rest is higher alkanes (hexanes +)

Effect of Water and Hydrocarbons

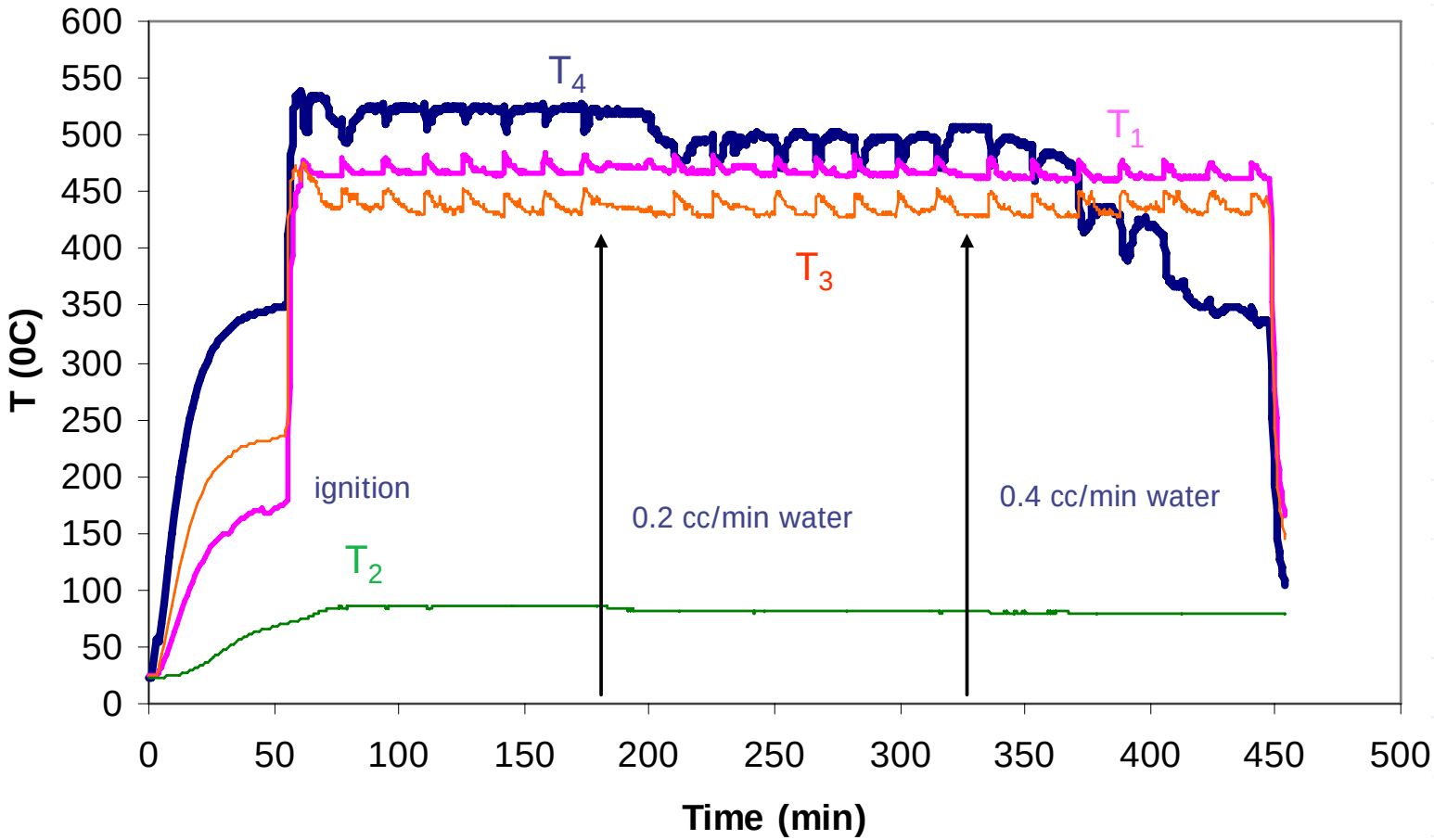
- Liquid water injected at various flow rates.
- Flow rate of methane also varied.
- Pentane and toluene added for some runs
- Liquids injected at room temperature through a separate injection system (not combined with methane feed).
  - Used to control the methane and other feeds more efficiently.

Thermocouple placement

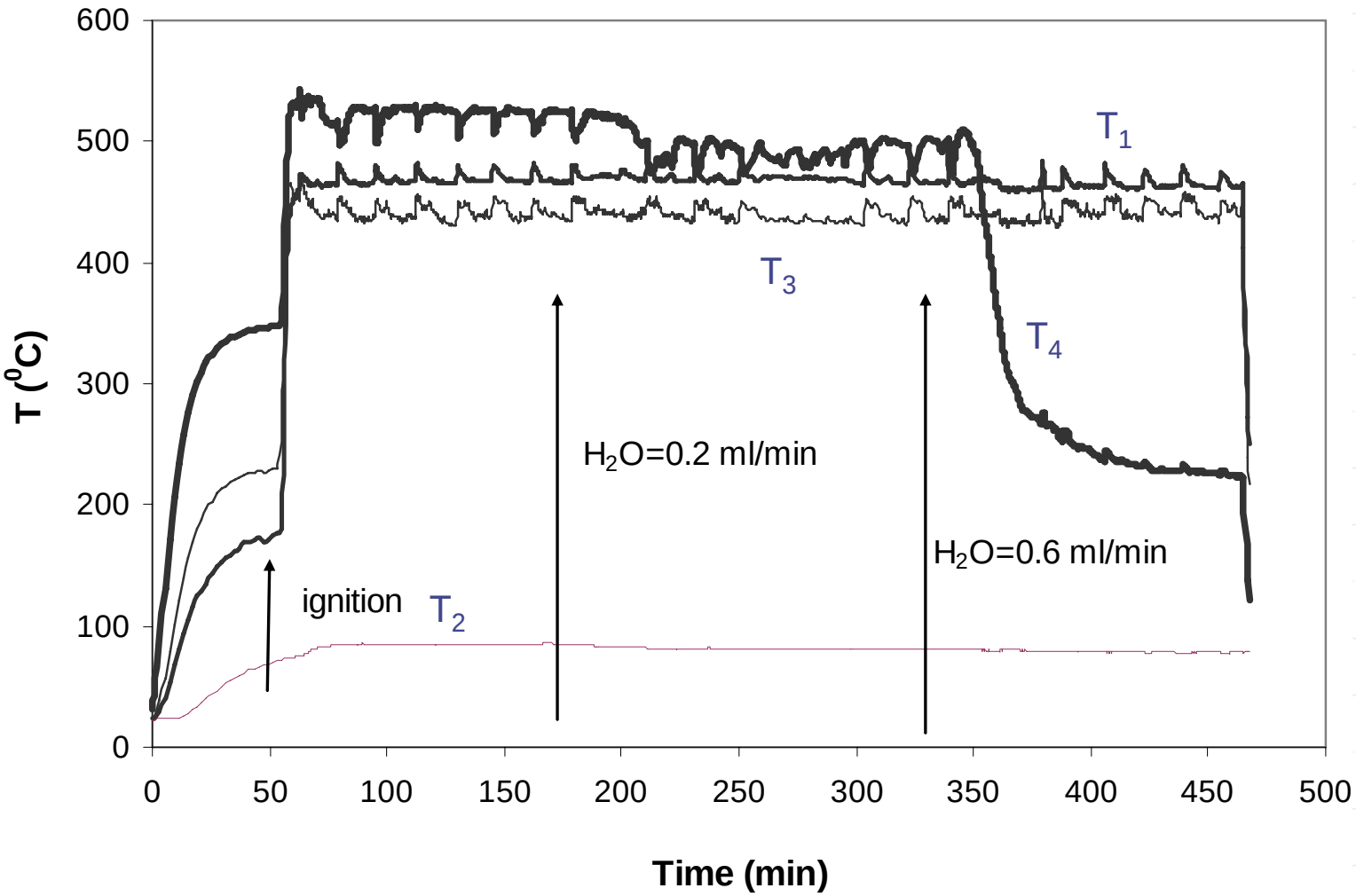


T2 in back space
(empty space)

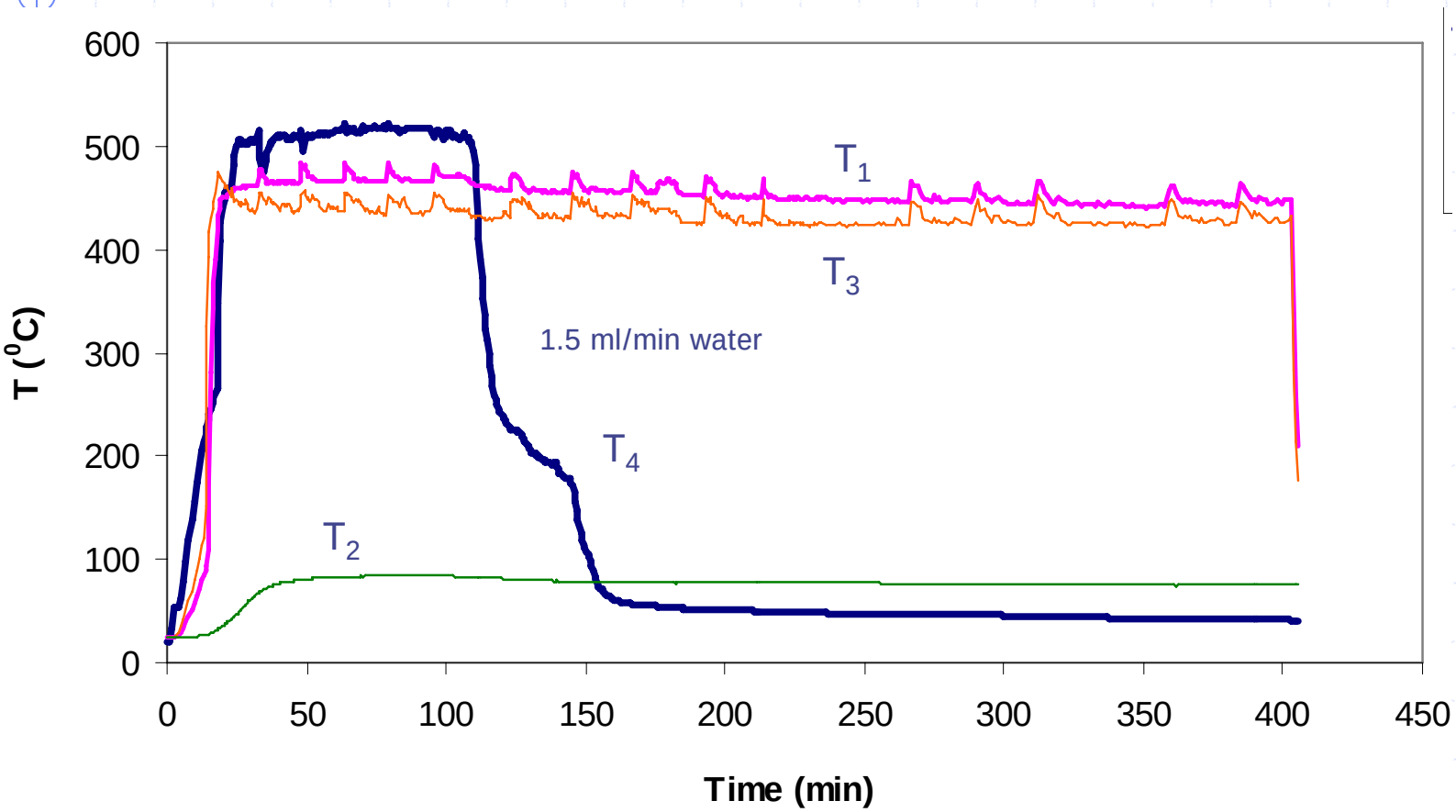
Water added at 2500 ml/min methane



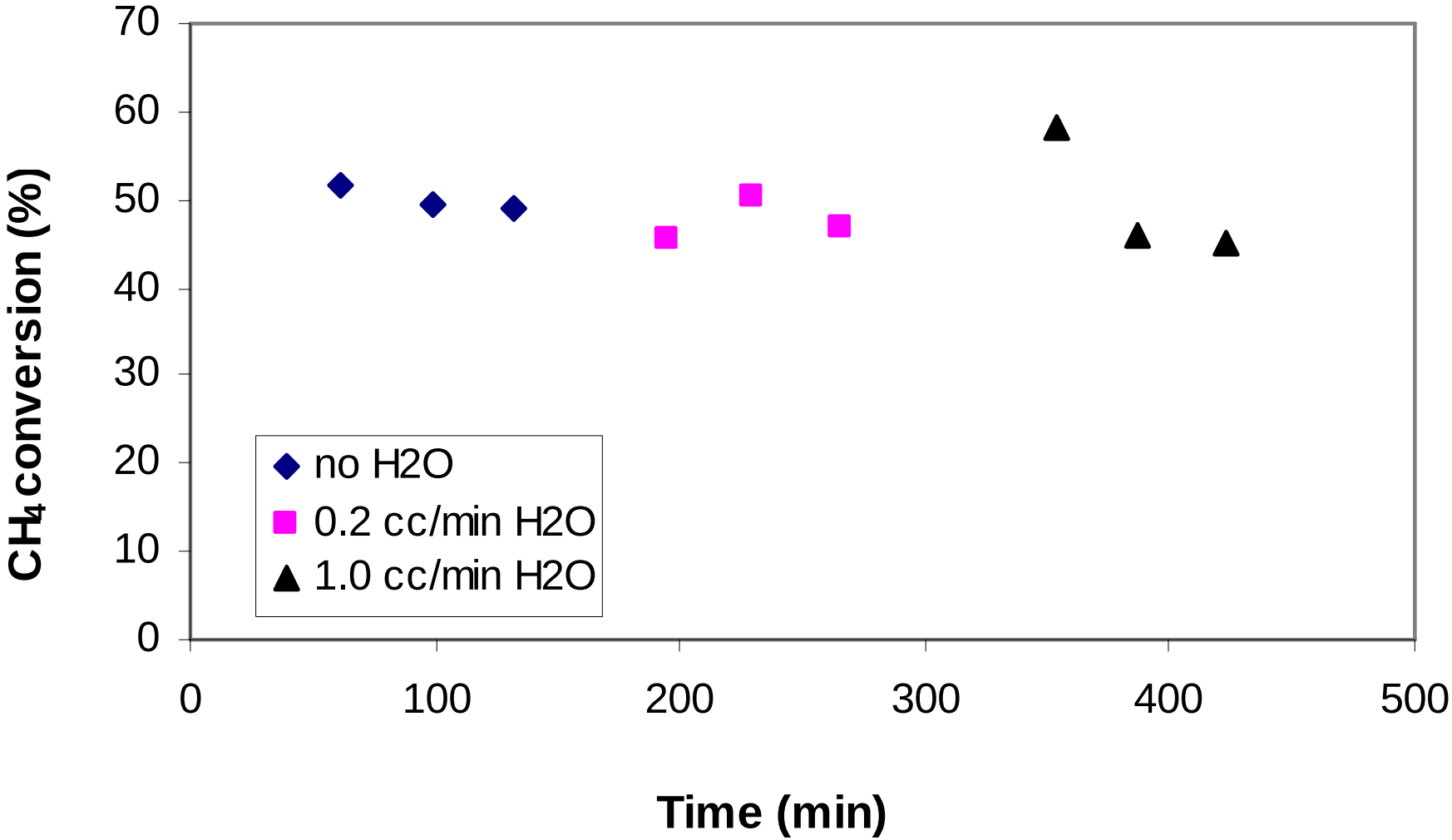
Water added at 2500 ml/min methane



Water added at 2500 ml/min methane



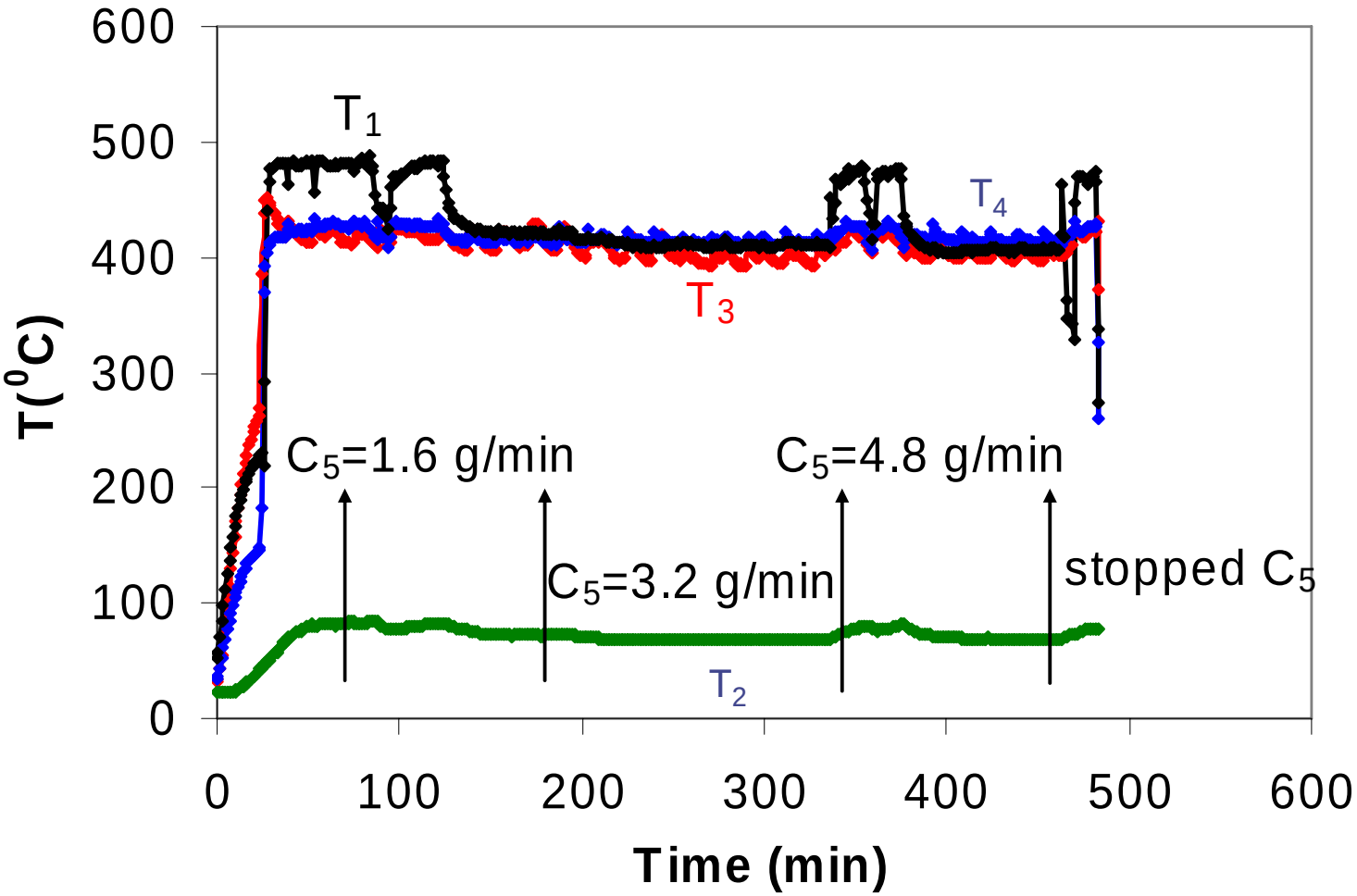
Methane Conversion with Water



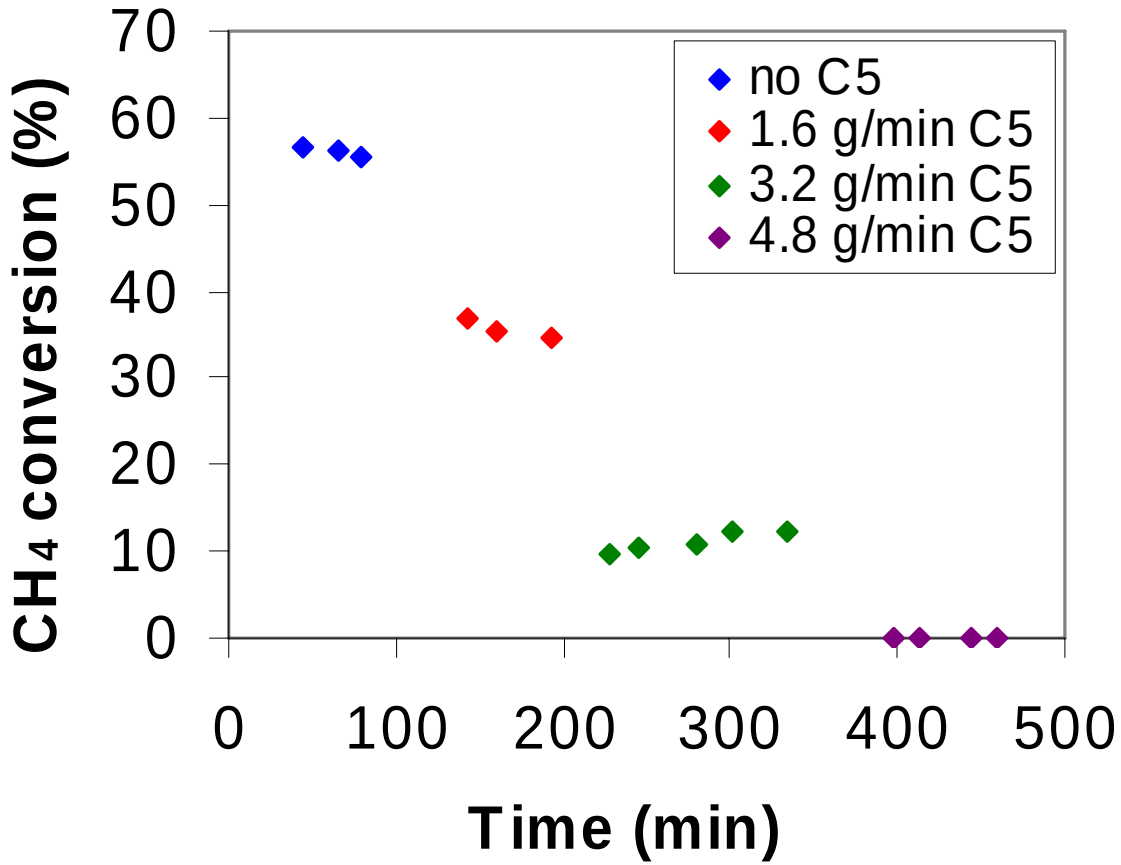
Effect of Water – Liquid injection

- Injecting liquid water at increasing flow rate causes progressive cooling of the pad from the bottom. As more water is added, the cold section expands upwards.
- At higher flow rates the bottom of the pad was observed to become noticeably damp.
- After shutting off the water feed, the temperatures returned to original values.
- Results for water injection are reproducible.
- Conversion is not affected much, with some reduction seen at 2 g/min.

Pentane added with 2500 ml/min methane



Pentane added with 2500 ml/min methane



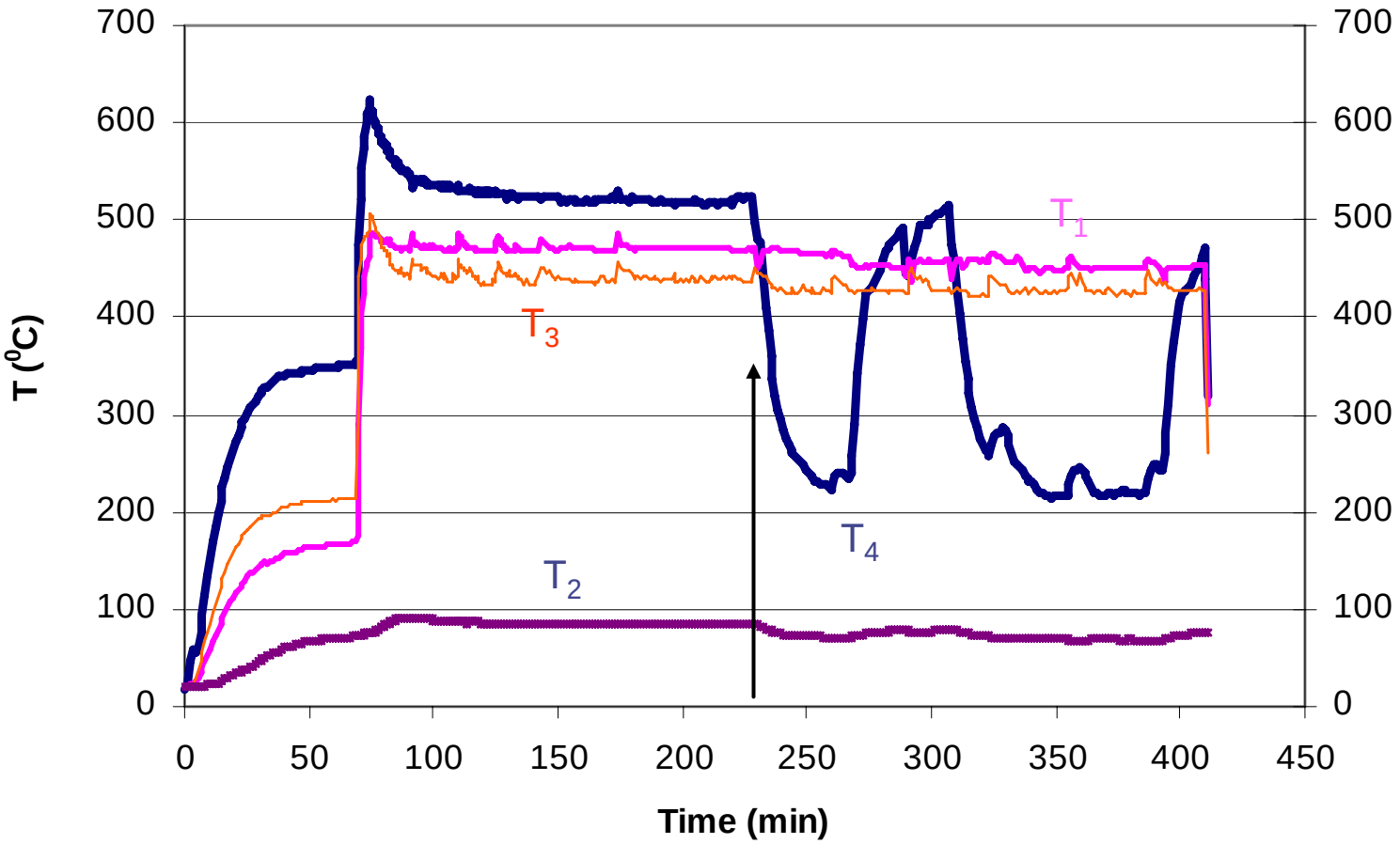
Pentane is preferentially combusted.

At 0 % conversion of methane, pentane breakthrough occurs.

Turning on the fan increases the methane conversion to 100 %.

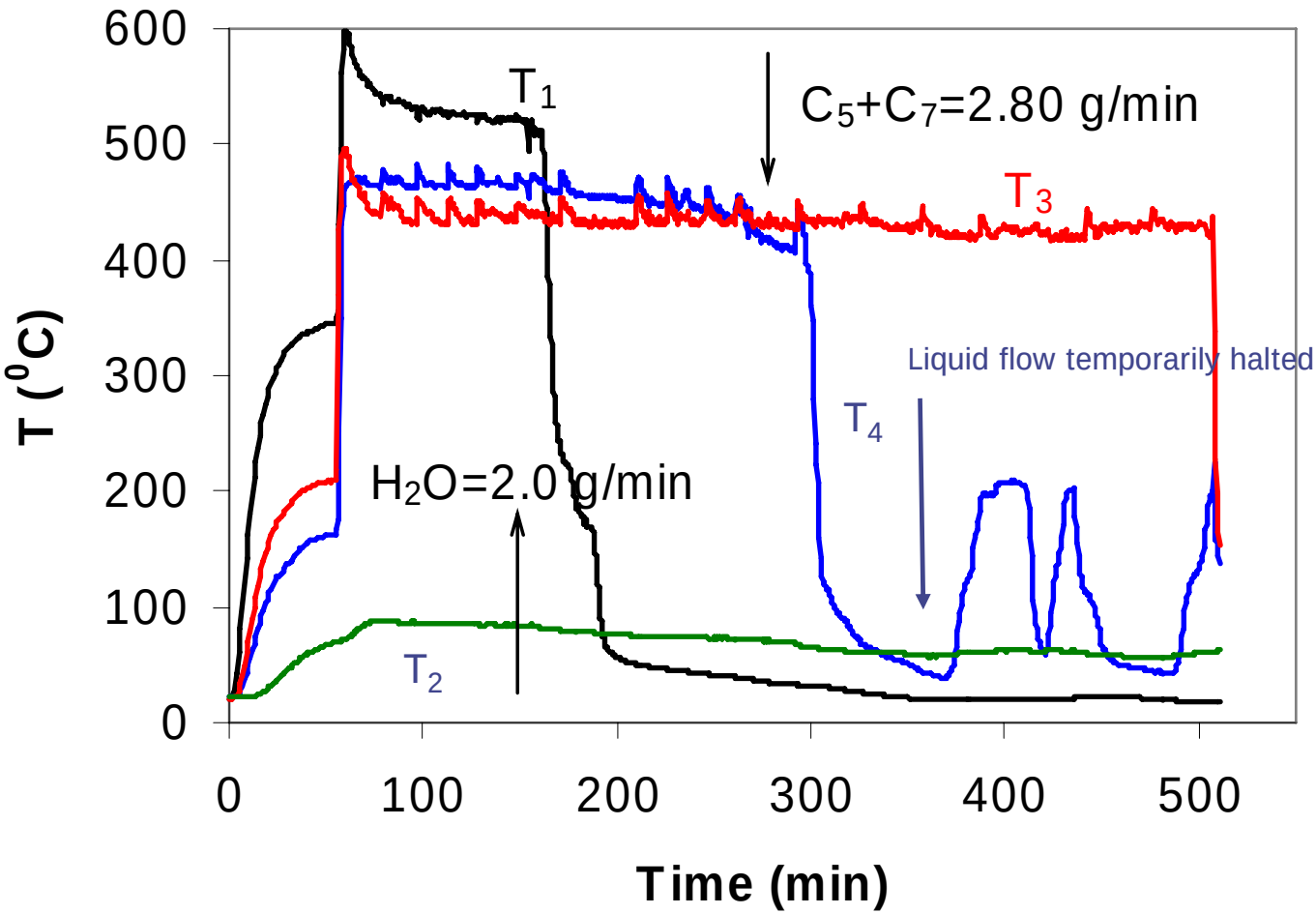
HC added with 2500 ml/min methane

Pentane and Toluene at 2.8 g/min combined



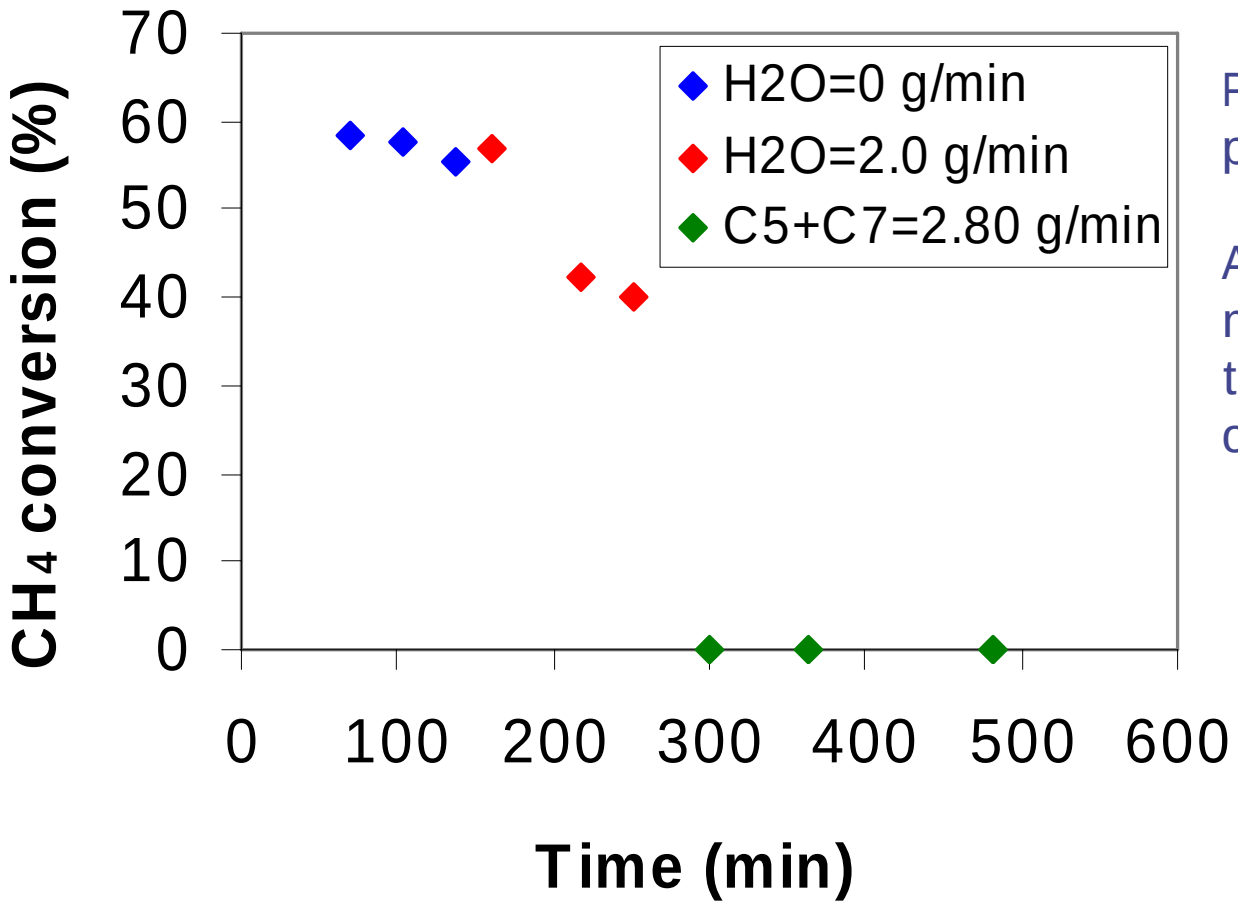
HC and water added with 2500 ml/min methane

Most representative of the composition from a dehy unit.



HC and water added with 2500 ml/min methane

Most representative of the composition from a dehy unit.



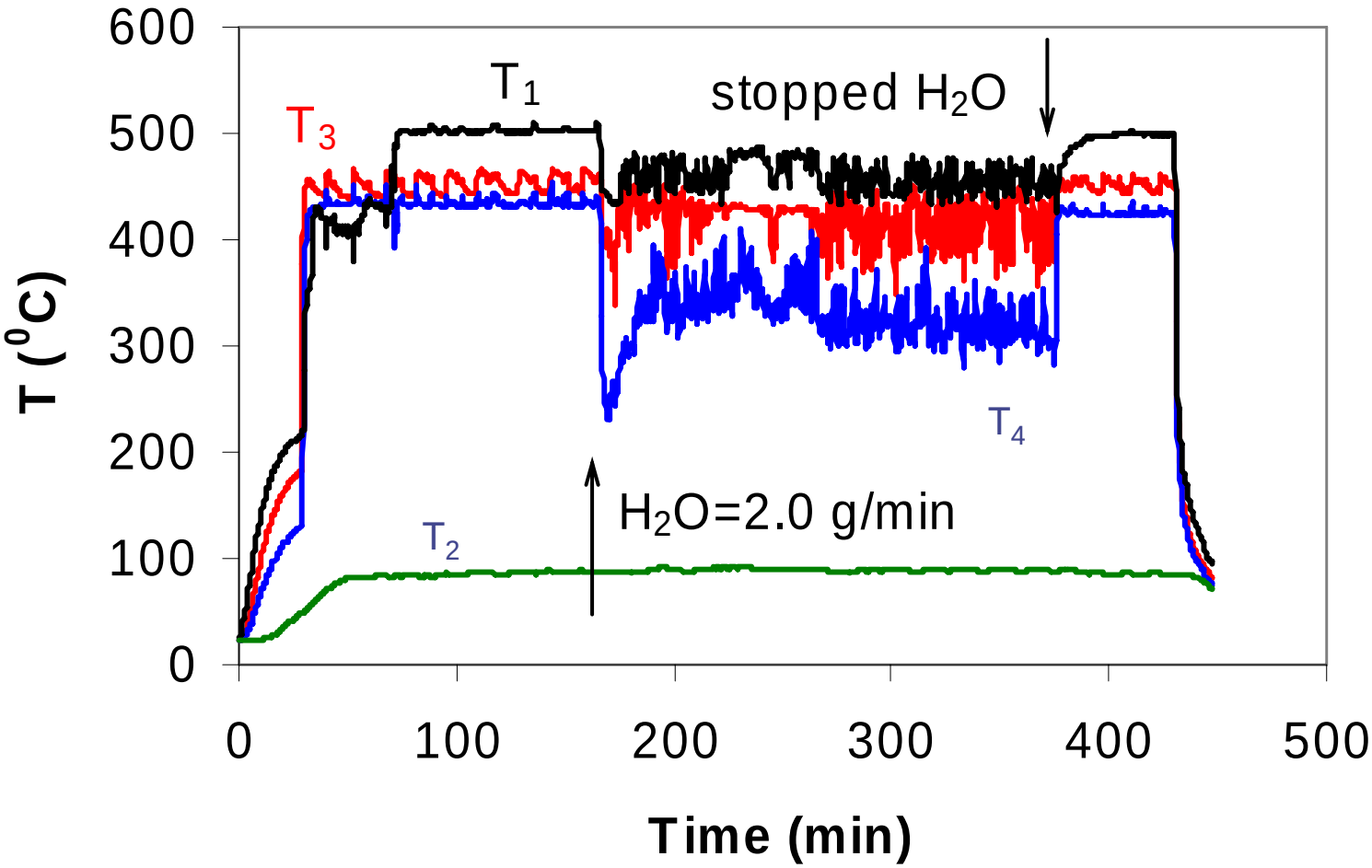
Pentane, toluene preferentially combusted.

At 0 % conversion of methane, pentane and toluene breakthrough occur.

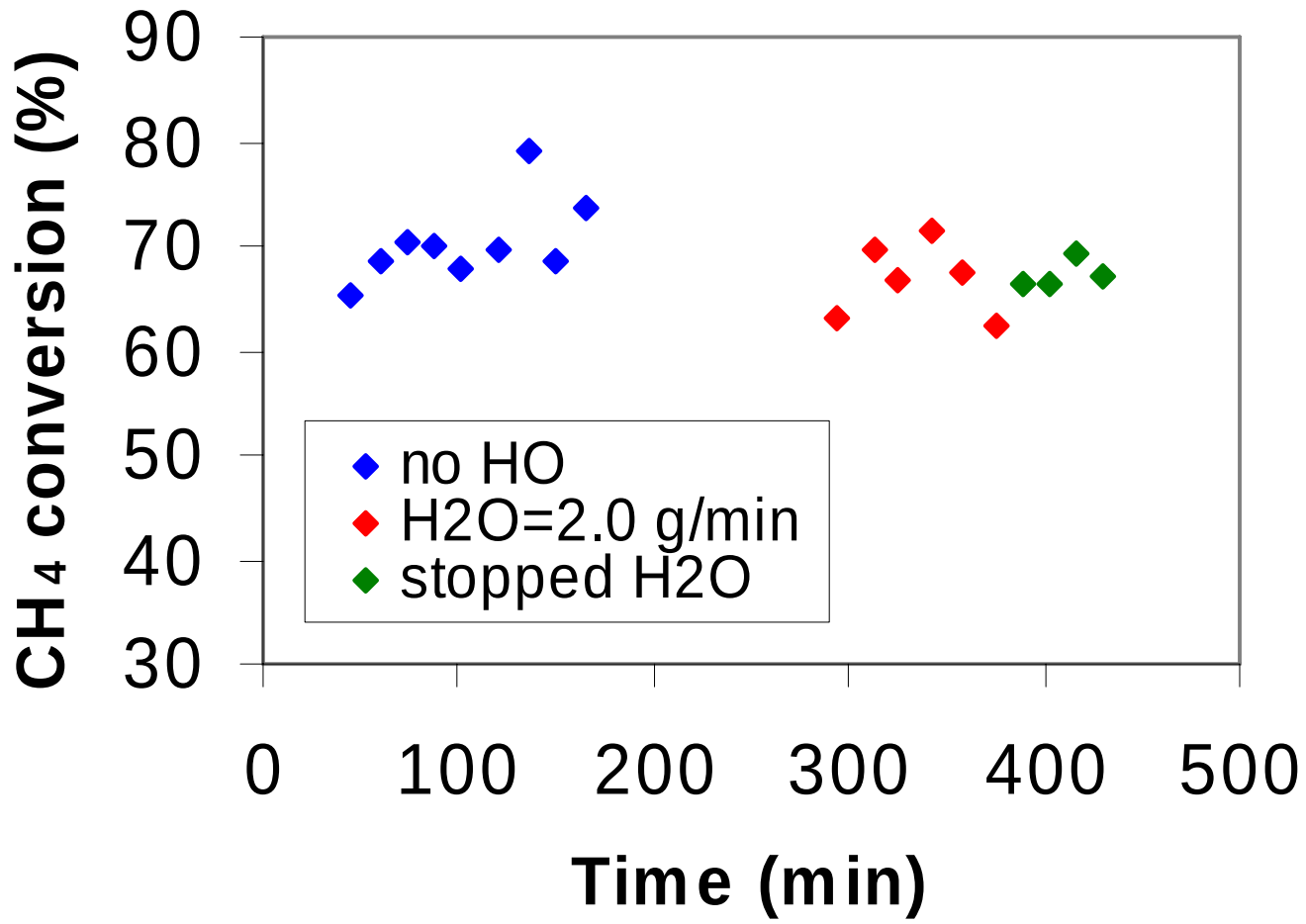
Conversion

- Conversion of methane declines as the percentage of toluene and pentene increases.
- CO_2 production was constant, indicating diffusion of oxygen is rate limiting (which is indicated from other evidence).
- Increasing the oxygen mass transfer enhances conversion.

Water Addition as Vapour



Water Addition as Vapour



Observations

- High percentages of injected liquid water can reduce reactor operating temperature.
- Combustion of BTEX remains highly efficient, however liquid injection also can cause temperature reductions and ultimately reactor will extinguish.
- Pre-heating of feed eliminates the temperature drop and pad wetness problem. Reactor design is underway.

Conclusions

- BTEX compounds are reactive, and this technology looks promising.
- Units perform with high water levels, although long term studies should be done.
- Adequate flow across the pad face should ensure complete conversion. Design has been developed for reactor driven fan.

Modelling the Heater

- Solution of the fundamental equations of momentum, mass and energy transport.
- Finite element solution method.
- First model in two dimensions.
- Second model in three dimensions.

Details available on request.