Pyrolysis and Properties of Endothermic Fuel in Minichannels at temperatures up to 750°C

BI Qincheng*, LIU Zhaohui

YANG Zhuqiang, YAN Jianguo, GUO Yong, PAN Hui, FENG Song

State Key Laboratory of Multiphase Flow in Power Engineering
Xi'an Jiaotong University, Xi'an 710049, China
Email: qcbi@mail.xjtu.edu.cn

Outlines

- Introduction
- Test facilities
- Results
- Conclusions

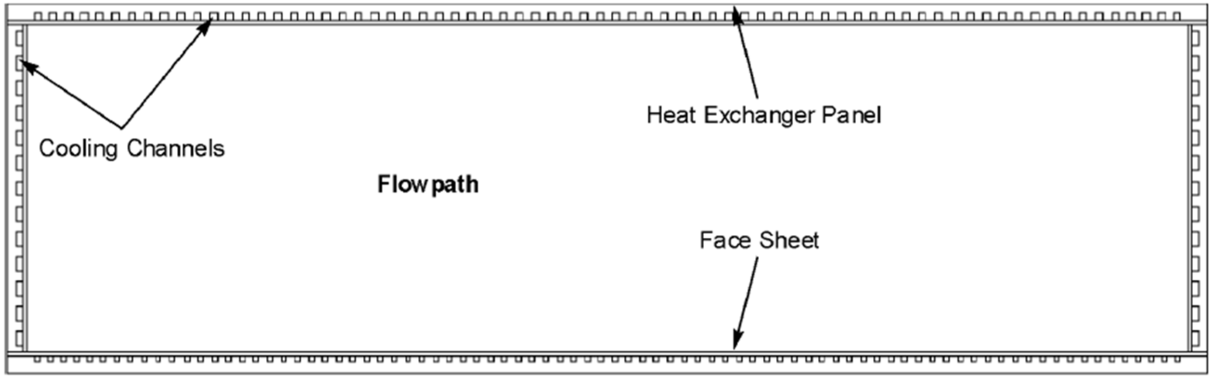
Introduction

Air-breathing hypersonic vehicles

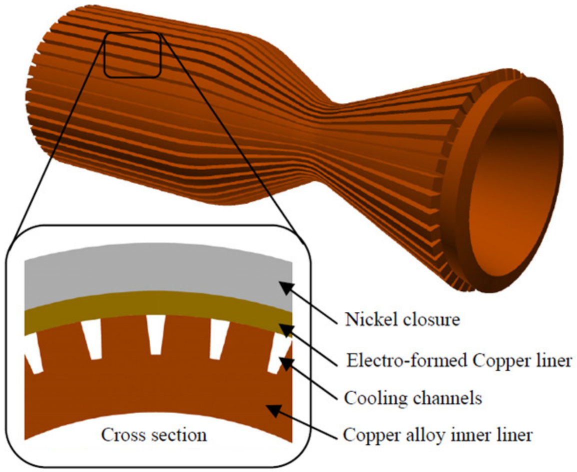
- ➢Aerodynamic heat is proportional to square of flight speed
- ➢Wall temperature of combustion chamber up to 3000K

Hydrocarbon fuel

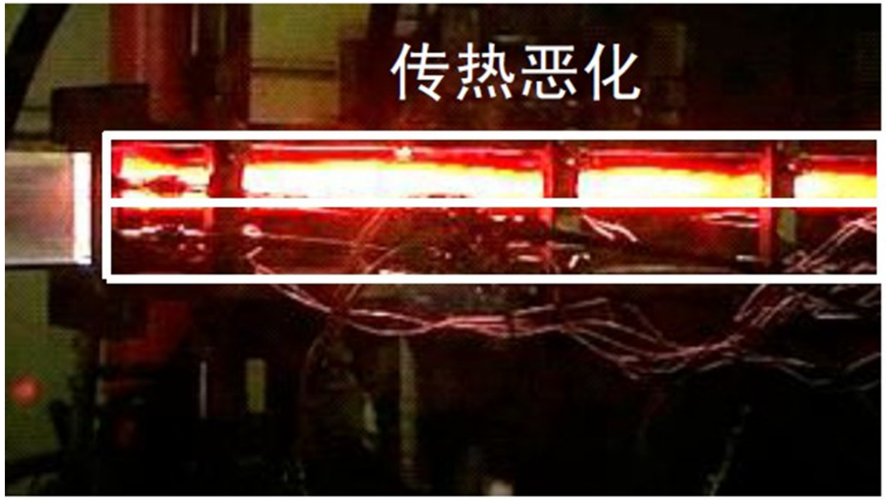
- ➢Used as both **propellant** and **coolant**
- ➢Coolant temperature up to 750℃
- ➢Thermophysical properties are necessary
- ➢Endothermic Chemical Reaction   Pyrolysis

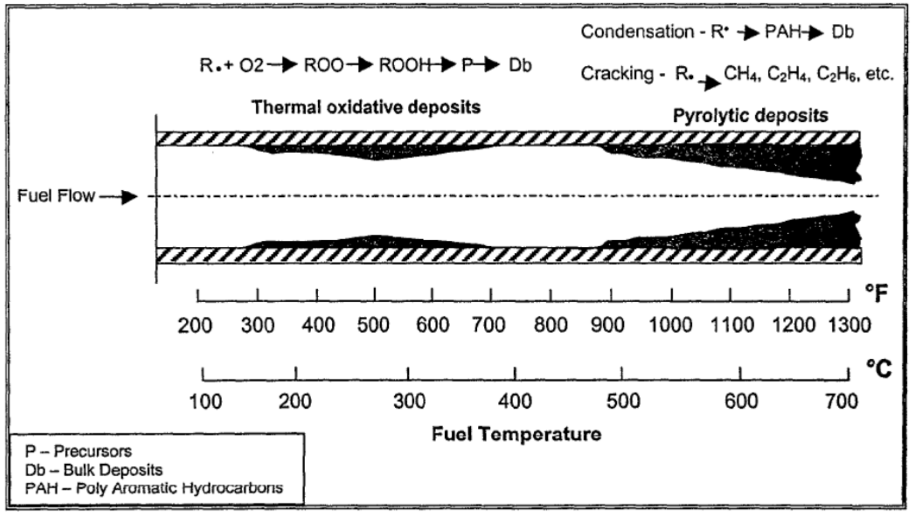


Cross section of the combustion chamber



Challenges in the design of cooling structures



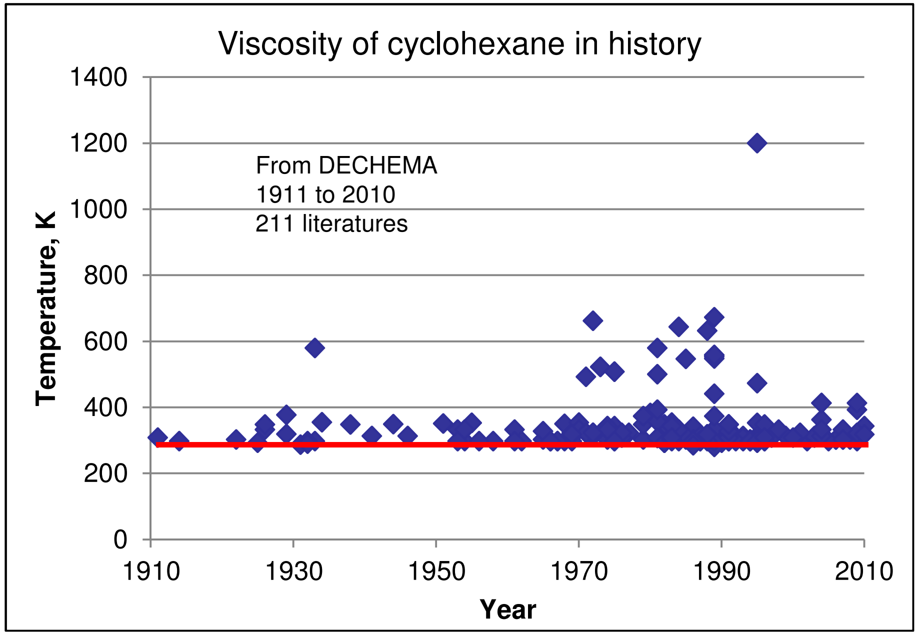


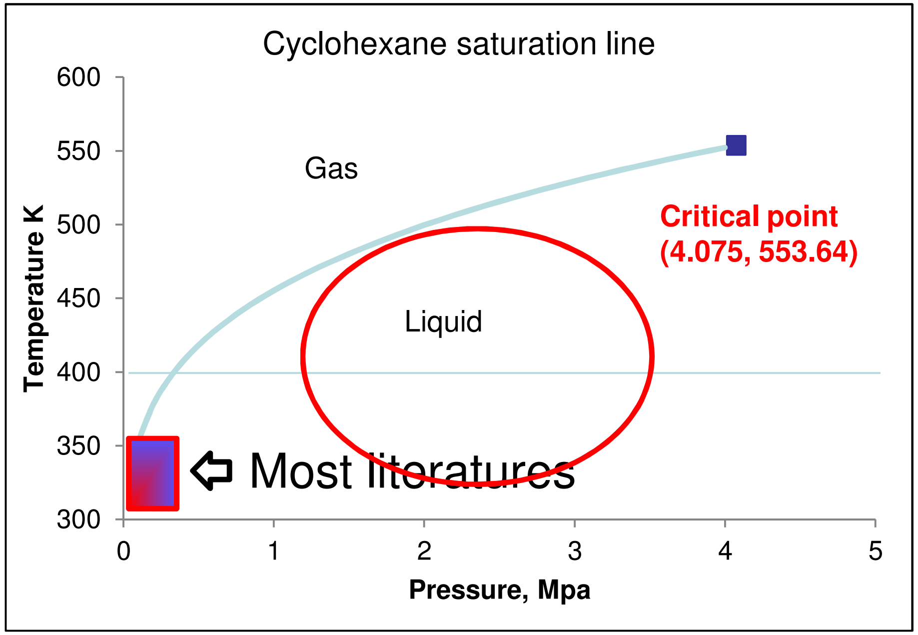
- Heat transfer deterioration in the heating plate with parallel multi-channels, due to the uneven flow rate distribution.
- Coke deposits in the cooling passage, which affect the long-period flight safety.

Introduction

Challenges: lack of property data

Few literatures at temperatures above 473.15K (200℃)





In all the 186 papers resulting in 1427 data points:
The vast majority (165 papers, 504 data points)
at atmospheric pressure around room temperature

Introduction

Research interests：

1. Fluid flow characteristics

such as pressure drop characteristics, flow instabilities.

2. Heat transfer characteristics

such as supercritical heat transfer, effects of chemical reaction and coking on heat transfer, and heat transfer correlations.

3. Coking propensities

coking evaluation methods like hydraulic resistance, visualization method.

4. Thermal physical and chemical properties

such as heat sink, specific heat, density, viscosity, conductivity, critical parameters.

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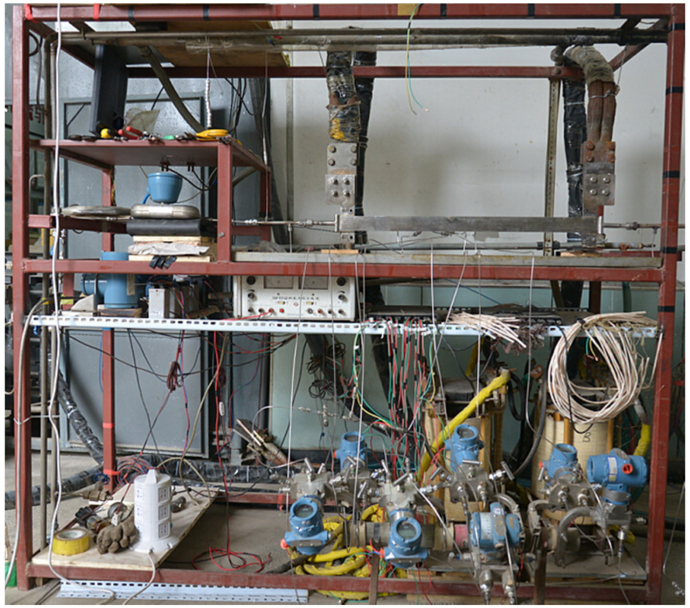
Test facilities



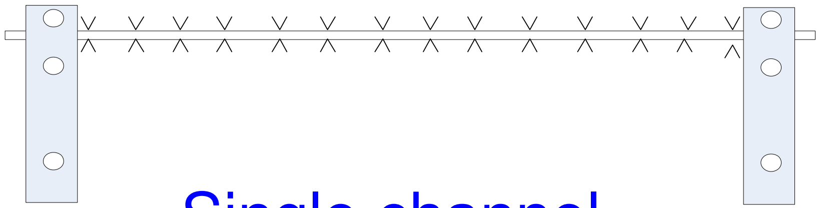
b	a
d	c

No.	Mass flow rate
a	~ 278 g/s
b	~ 56.7 g/s
c	~ 6.67 g/s
d	0.1~3.0 mL/min

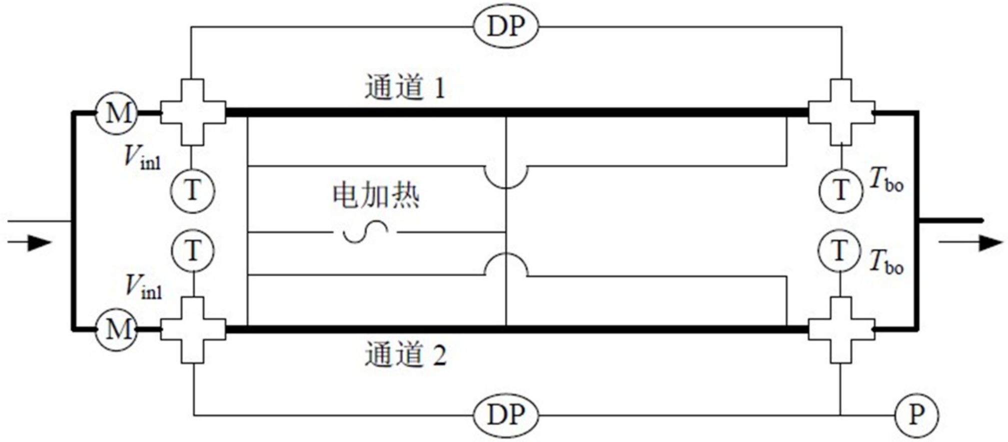
Pressure：0.1~10 MPa
Fuel Tem：~750 °C
Wall Tem：~ 1000 °C
Heat flux：~3 MW/m^2
Heating power: ~1.4MW

Test facilities

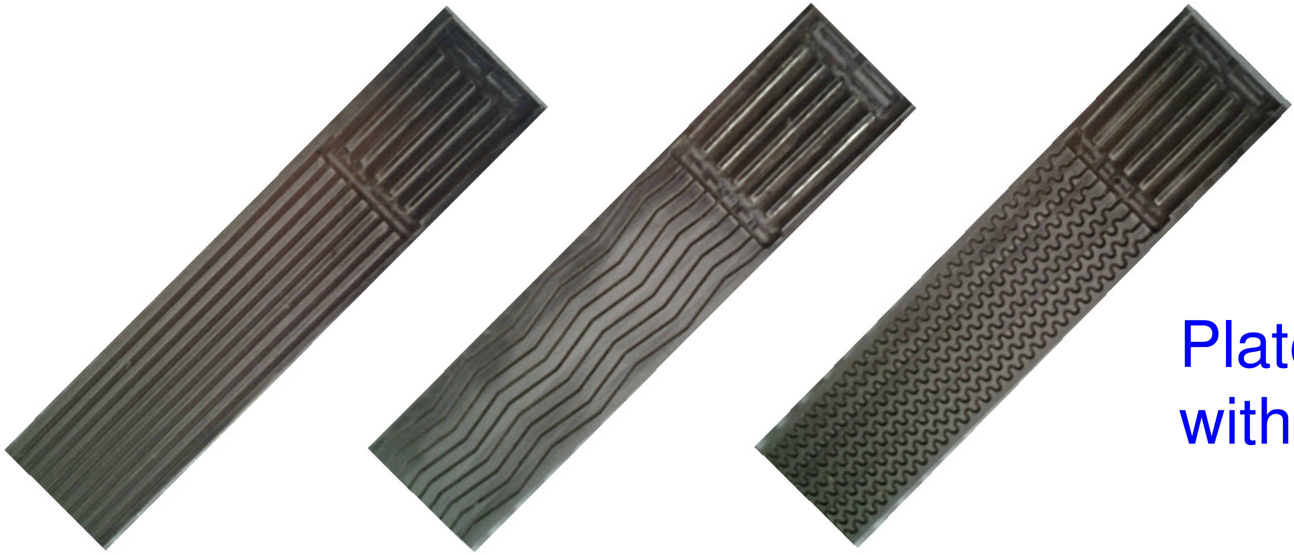
Test sections



Single channel



Parallel channels



Plates
with multi-channels

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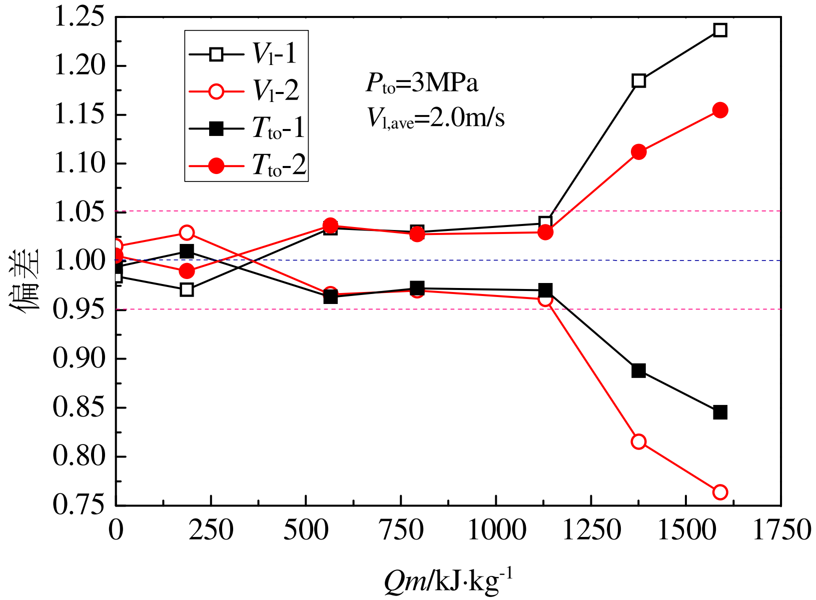
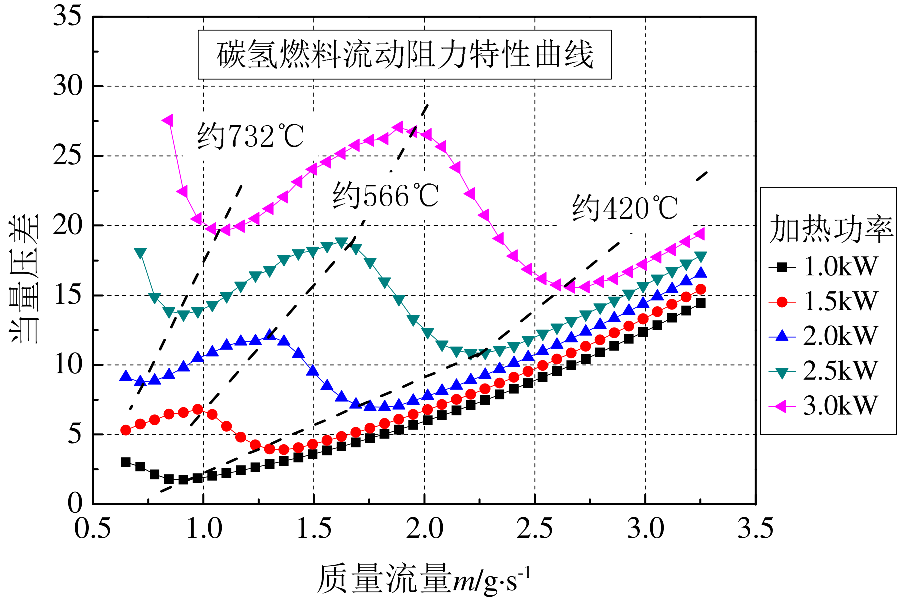
Fluid flow characteristics

Ledinegg instability

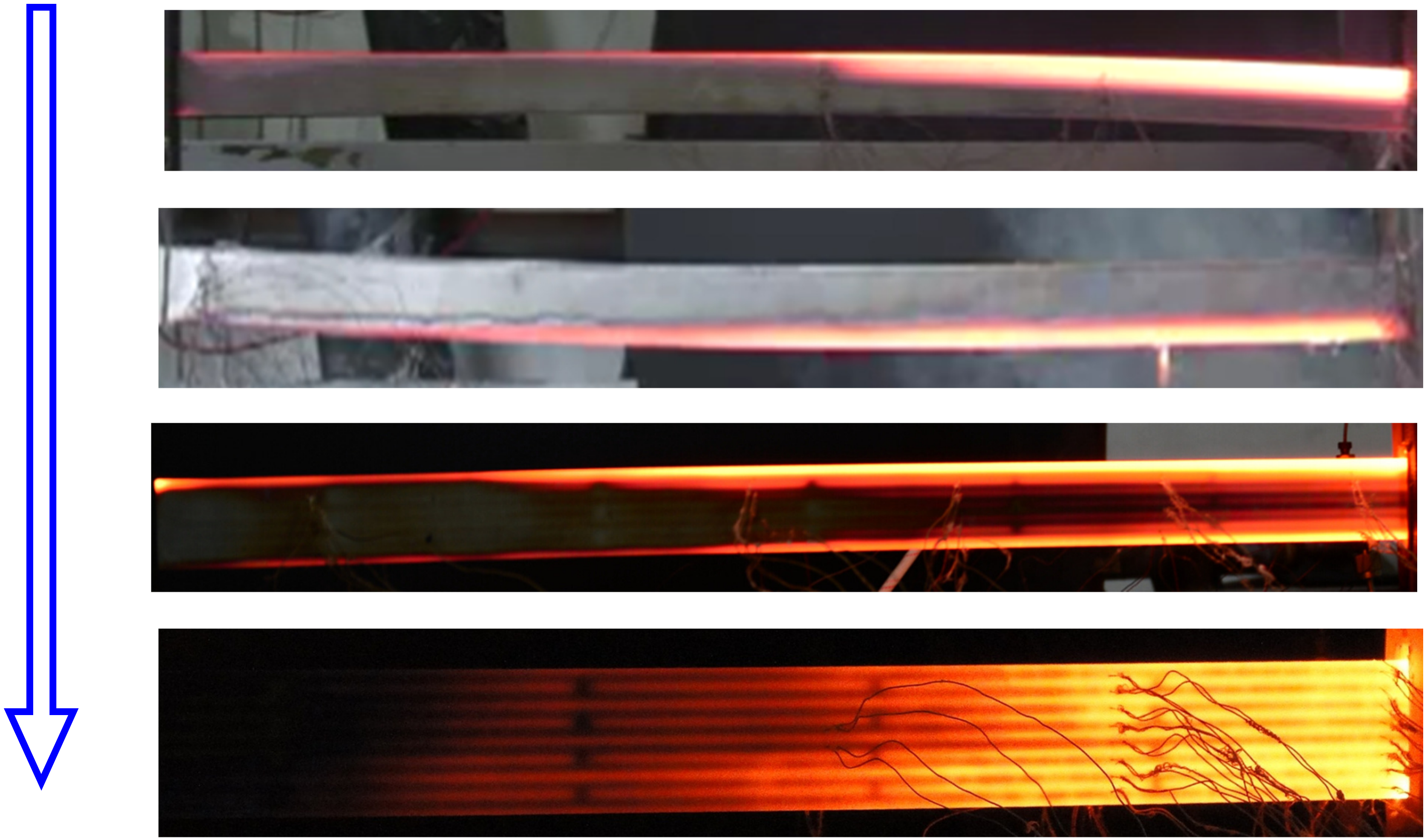




- Two parallel channels is used to simulate the regeneratively cooled structure of hypersonic vehicles.
- The ledinegg instability was found in the two-phase flow boiling system to explain the static flow excursion.
- pressure drop vs. flow rate characteristic curves are modeled from the thermophysical properties of hydrocarbon fuel.

Fluid flow characteristics

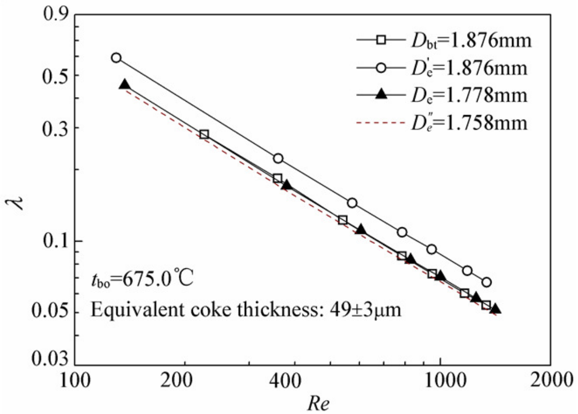
Structure optimization



Coking propensities

Methods for coking and deposition evaluation

Qualitative methods

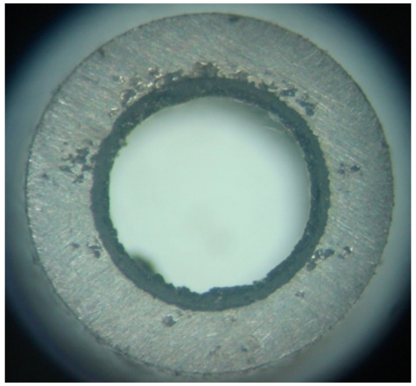


Hydraulic resistance

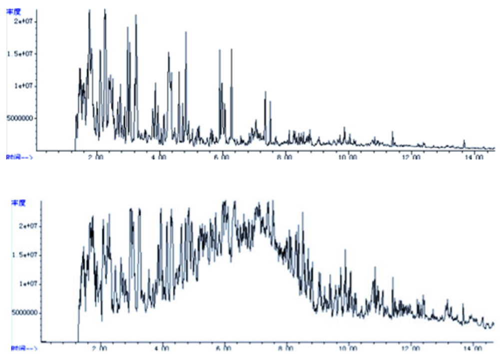
(a) Cyclohexane (b) n-hexane (c) Toluene (d) EHF1 (e) EHF2 (e) Blank

Liquid and solid products

Quantitative methods

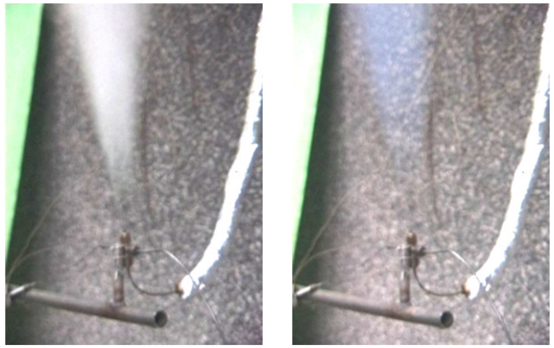


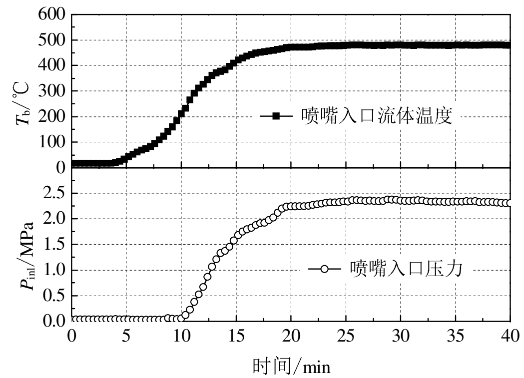
Visualization



Liquid and gas products

Feasibility testing

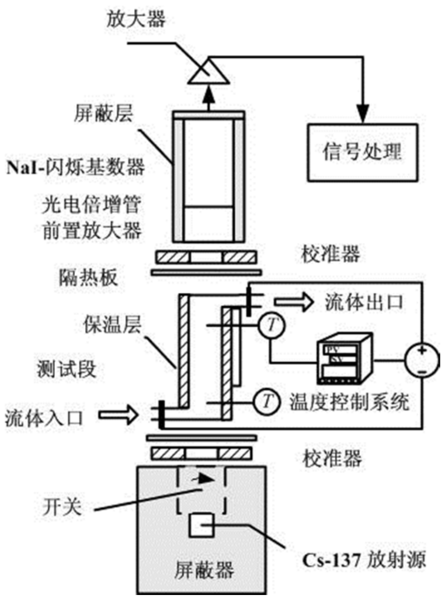




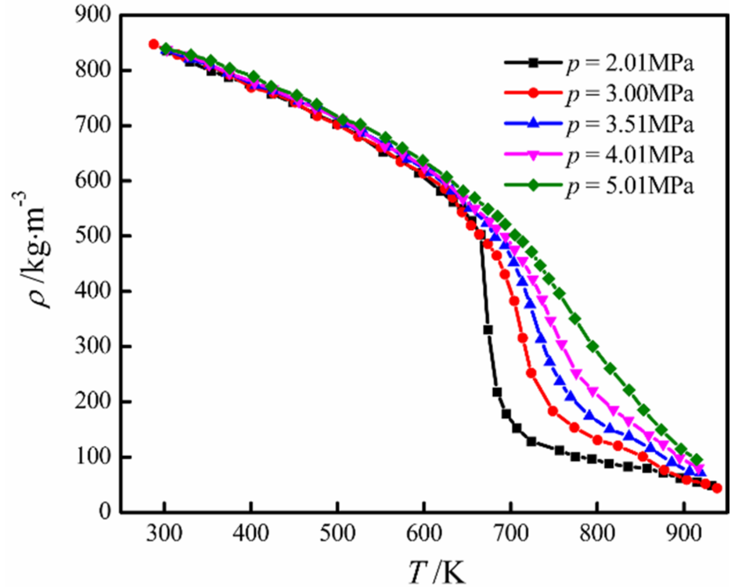
Spray through nozzle

Density measurement by γ-ray densitometer

- Gama-ray densitometer based on the source (Cs-137)，can realize the in-situ density measurement at high temperature and high pressure.
- Temperature of 280-950K，pressure of 0.1-10MPa. Expanded relative uncertainty of (0.29-2.29)% in confidence of 95%。
- Density of pure substances like cyclohexane, binary mixtures and hydrocarbon fuels were measured.

γ-ray densitometer

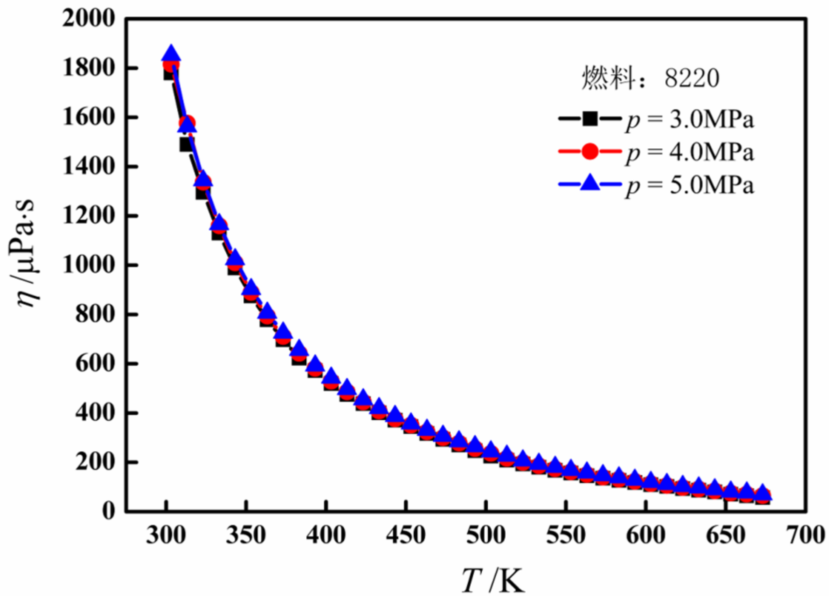


Experimental result of fuel density

Viscosity measurement by capillary viscometer

- Dual-capillary viscometer worked at temperatures up to 400 °C now，and was expected to operate at higher temperature conditions.
- Temperatures of 303.2-673.2K，pressure of 0.1-10 MPa. Expanded relative uncertainty of 2.20-5.27% in confidence of 95%.
- Viscosities of pure substance like cyclohexane, binary mixtures, and hydrocarbon fuel were measured.

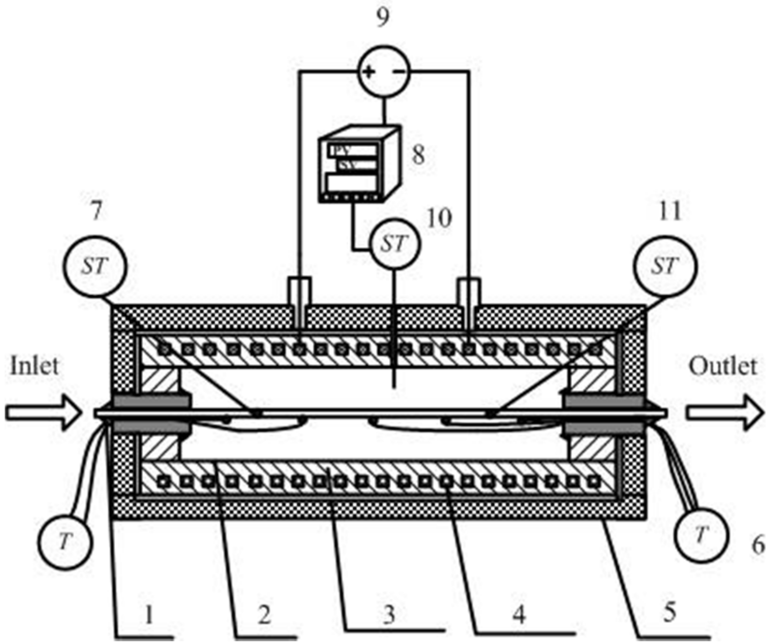
Dual-capillary viscometer



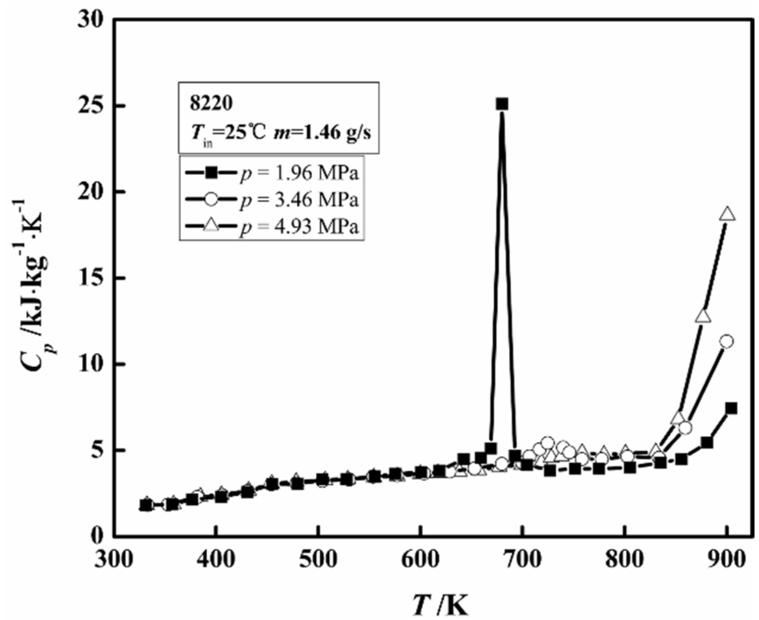
Experimental result of fuel viscosity

Heat capacity measurement by calorimeter

- An calorimeter constructed to measure specific heat and heat sink
- Temperatures ranging of 330-970 K, pressures of 0.1-10 MPa. Expanded relative uncertainty of 2.42-3.54% in confidence of 95%.
- Heat capacity of pure substance like cyclohexane, binary mixtures, and hydrocarbon fuel were measured.



Calorimeter

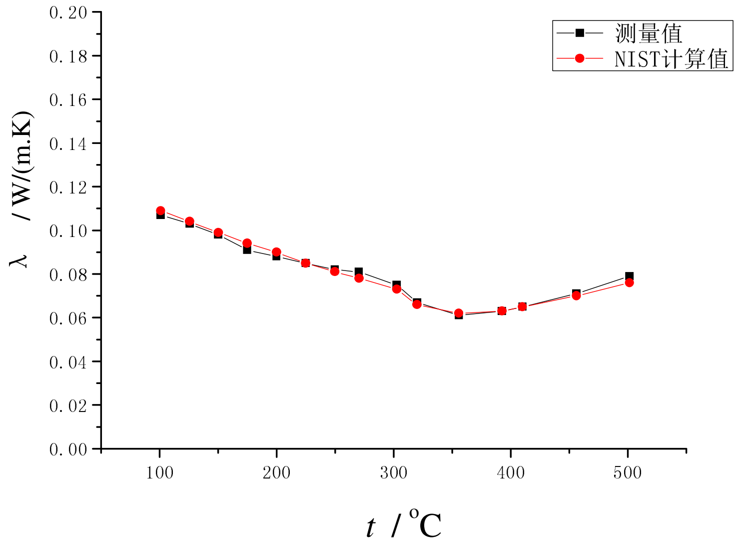


Experimental result of heat capacity

Thermal conductivity measurement

- Based on transient hot-wire method, a thermal conductivity analyzer for hydrocarbon fuel was constructed.
- Temperatures ranging of 330-773 K, pressures of 0.1-10 MPa. Expanded relative uncertainty of 5% in confidence of 95%.
- Pure substance like cyclohexane, and hydrocarbon fuel were measured.

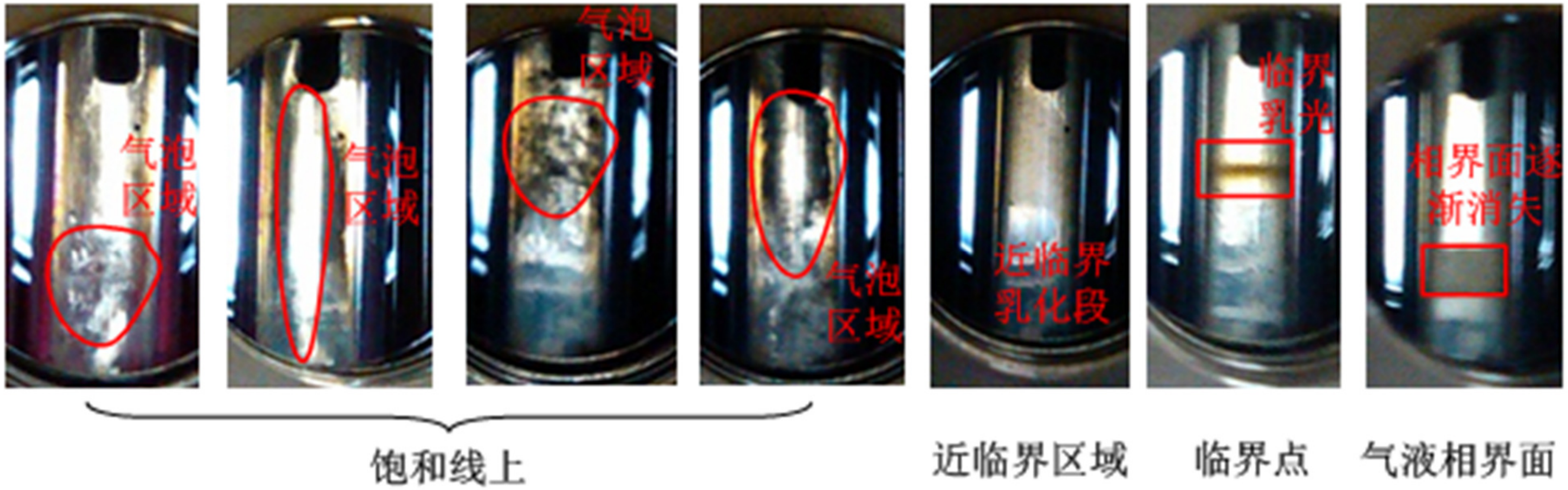
Hot disk TPS2500 thermal constant analyzer



Experimental result of cyclohexane

Critical parameters

Critical properties measured by critical opalescence phenomena.



Critical properties of cyclohexane

- Results well agreed with the NIST values with errors not exceeding 0.95%；
- Experimental results：3.03MPa，507.52K
- NIST values：3.034MPa，507.82K

Most recent publications

Heat transfer characteristics

1. Zhaohui Liu, Qincheng Bi. Onset and departure of flow boiling heat trasnfer characteristics of cyclohexane in a horizontal minichannel. **International Journal of Heat and Mass Transfer, 2015**, 88: 398-405.

2. Zhaohui Liu, Qincheng Bi, Zhuqiang Yang,Yong Guo, Jianguo Yan. Critical heat flux of cyclohexane in uniformly heated minichannels with high inlet subcooling. **Experimental Thermal and Fluid Science, 2015**, 63: 106-114.

3. Yang ZQ, Bi QC, Liu ZH, et al. Heat transfer to supercritical pressure hydrocarbons flowing in a horizontal short tube[J]. **Experimental Thermal and Fluid Science, 2015**, 61:144-152.

4. Jianguo Yan, Qincheng Bi, Zhaohui Liu*, Ge Zhu, Laizhong Cai. Subcooled flow boiling heat transfer of water in a circular tube under high heat fluxes and high mass fluxes. **Fusion Engineering and Design, 2015**, http://dx.doi.org/10.1016/j.fusengdes.2015.07.007.

5. Zhaohui Liu, Qincheng Bi, Yong Guo, Jianguo Yan, Zhuqiang Yang. Convective heat transfer and pressure drop characteristics of near-critical-pressure hydrocarbon fuel in a mini-channel. **Applied Thermal Engineering. 2013**, 51: 1047-1054.

6. Zhaohui Liu, Qincheng Bi, Yong Guo, Qianhua Su. Heat transfer characteristics during subcooled flow boiling of a kerosene kind hydrocarbon fuel in a 1mm diameter channel. **International Journal of Heat and Mass Transfer, 2012**, 55: 4987-4955.

Most recent publications

Thermal physical properties

1. Zhaohui Liu, J P Martin Trusler, Qincheng Bi. Viscosities of liquid cyclohexane and decane at temperatures between (303 and 598) K and pressures up to 4 MPa measured in a dual-capillary viscometer. **Journal of Chemical Engineering & Data, 2015**, 60: 2363-2370.

2. Zhuqiang Yang, Zhaohui Liu*, Qincheng Bi, Yong Guo, Jianguo Yan, Song Feng, and Hui Pan. Design of a Flow Calorimeter for Hydrocarbon Fuel at Temperatures from (330 to 900) K and Pressures up to 6.0 MPa. **Journal of Chemical Engineering & Data, 2015**, 60, 1434–1439.

3. Zhuqiang Yang, Zhaohui Liu∗, Qincheng Bi, Song Feng, Hui Pan, Yong Guo. Viscosity measurements of hydrocarbon fuel at temperatures from (303.2 to 513.2) K and pressures up to 5.1 MPa using a two-capillary viscometer. **Thermochimica Acta**, 2015, 617: 1–7.

4. Zhuqiang Yang, Qincheng Bi,* Yong Guo, Zhaohui Liu, Jianguo Yan, and Qiang Zhang. Design of a Gamma Densitometer for Hydrocarbon Fuel at High Temperature and Supercritical Pressure. **Journal of Chemical Engineering & Data 2014**, 59, 3335–3343

Most recent publications

Coking characteristics

1. Zhaohui Liu, Qincheng Bi, Jiangtao Feng. Evaluation of heat sink capability and deposition propensity of supercritical endothermic fuels in a minichannel. **Fuel, 2015**, 158: 388-398.

2. Zhaohui Liu, Hui Pan, Song Feng, Qincheng Bi. Dynamic behaviors of coking process during pyrolysis of China aviation kerosene RP-3. **Applied Thermal Engineering 2015**, 91: 408-416.

3. Zhaohui Liu, Qincheng Bi, Yong Guo, Xuesong Ma, Zhuqiang Yang, Jianguo Yan, Shenlin Hu. Hydraulic and thermal effects of coke deposition during pyrolysis of hydrocarbon fuel in a mini-channel. **Energy & Fuels, 2012**, 26: 3672-3679.

Conclusions

- Our lab has a experimental capacity of heating power up to **1.4 MW**, flow rate from **0.1mL/min to 4t/h** with mini-scale to conventional scale test facilities.
- Flow and heat transfer of supercritical fluids, coking and deposition, thermal physical properties have been widely investigated in our lab at **fluid temperatures up to 800 °C**, **wall temperatures up to 1000 °C and pressures up to 37 MPa**.
- We accumulated numerous experiences for the measurement of thermal physical properties like density, heat capacity, viscosity, thermal conductivity, critical properties at temperatures up to 750 °C and pressures up to 10MPa.

Thanks for your attention!