Feasibility Study of a Turbo-Cracker

M. Wang, C. Ramshaw and H. Yeung

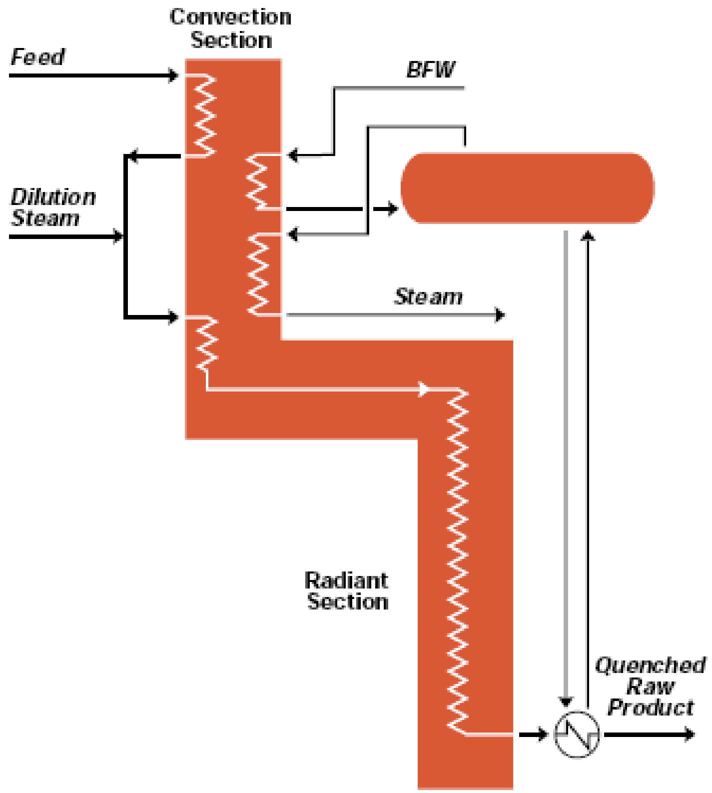
Cranfield University

Outline

- Thermal Cracking Furnace: Current Status
- The Idea of Turbo-Cracker
- Modelling of Propane Pyrolysis
  - Reaction Kinetics in Froment 1975
  - Simulation based on pilot plant in Froment 1975
- Case Studies
- Simulation of a Turbo-Cracker
- Conclusions

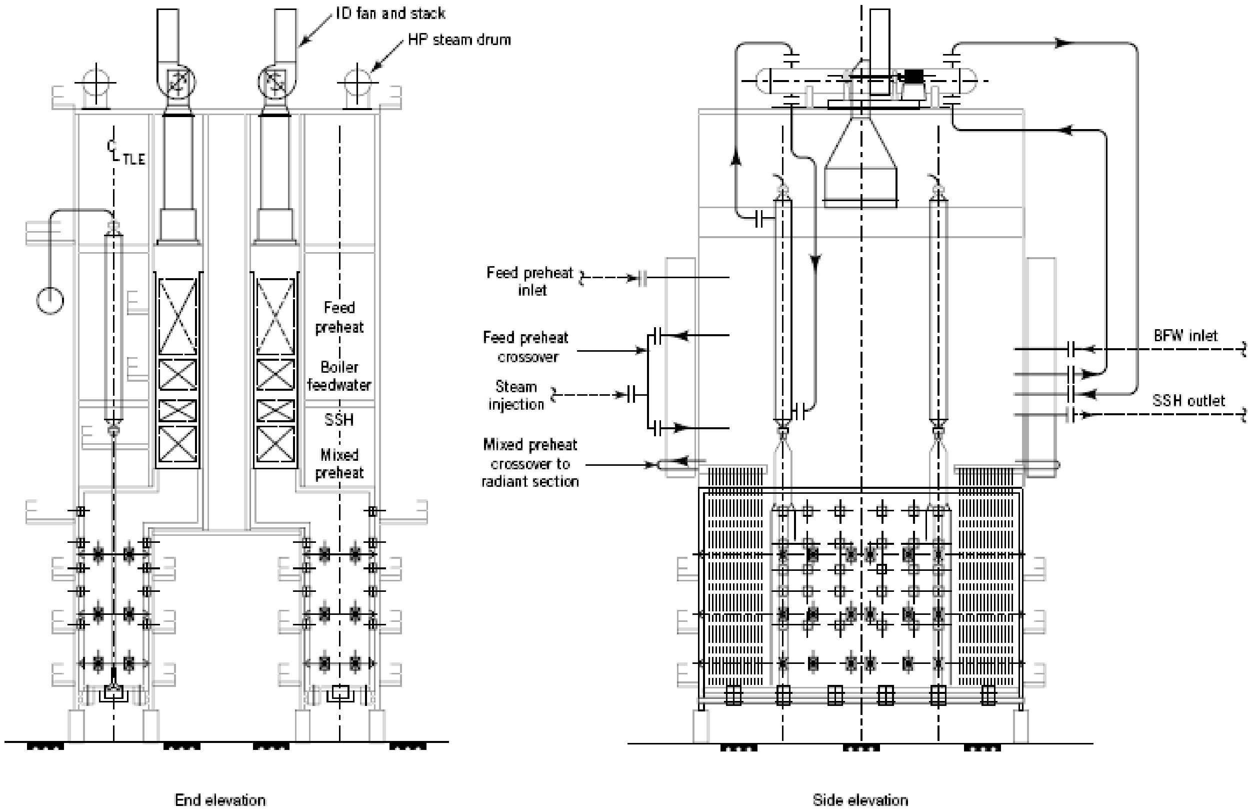
Thermal Cracking Furnace: Current Status

- Ethylene is the largest volume building block for many petrochemicals.
- Currently thermal cracking technology provided by ABB Lummus Global, Shaw Stone and Webster, Kellogg Brown & Root, Linde, and KTI.
- Thermal Cracking Furnace: tubular reactors where thermal cracking of hydrocarbon takes place.
- Cracking reactions are endothermic. Lots of energy transferred through the tube wall.



Thermal Cracking Furnace: Current Status

- Coke is formed during pyrolysis. Steam is added as a diluent to the feed.
- Product at the tubular reactor outlet must be cooled down quickly to avoid any further cracking.
- Currently transferline exchanger is used.



Thermal Cracking Furnace: Current Status

- Disadvantage/drawback in existing Thermal Cracking Furnace
  - Since thermal cracking reaction is very sensitive to temperature, high heat flux through tube walls is required, high surface temperature is involved.
  - At this high surface temperature, heavy coke deposits is formed during normal operation. De-coking every 40 to 100 days. Coking limits heat transfer, also reduces ethylene selectivity.
  - Thermal Cracking Furnace is huge in volume (approximately 10,000 m^3).

The Idea of Turbo-Cracker

- Use Compressor and Turbine to replace the existing thermal cracking furnace, so-called Turbo-Cracker.
- Heat is provided by compression in the Compressor of a Gas Turbine (GT).
- Product at the tubular reactor outlet is expanded with the Turbine of a Gas Turbine (GT).

The Idea of Turbo-Cracker

- Advantages
  - Higher temperature of the mixture of hydrocarbon and steam will increase the selectivity of ethylene.
  - Residence time should be much shorter.
  - Product at the tubular reactor outlet expands rapidly in the Turbine. This also helps to improve ethylene selectivity.
  - Coking will be less severe since no heat is transferred across the tube wall.
  - One GT (Compressor and Turbine only) can replace several existing thermal cracking furnaces due to its high processing capacity.

Modelling of Propane Pyrolysis

- Reaction Scheme in Froment (1975)

(1) $C_3H_8 \rightarrow C_2H_4 + CH_4$	A=1.6E09	E=44 kcal/mole
(2) $C_3H_8 \rightarrow C_3H_6 + H_2$	A=2.0E09	E=44 kcal/mole
(3) $2C_3H_8 \rightarrow C_2H_6 + C_4H_{10}$	A=2.2E09	E=54 kcal/mole
(4) $2C_3H_8 \rightarrow C_3H_6 + C_2H_6 + CH_4$	A=1.1E09	E=48 kcal/mole
(5) $C_2H_6 \rightarrow C_2H_4 + H_2$	A=0.34E13	E=60 kcal/mole
(6) $2C_2H_6 \rightarrow C_2H_4 + 2CH_4$	A=3.9E12	E=67 kcal/mole
(7) $2C_2H_6 \rightarrow C_3H_8 + CH_4$	A=0.5E11	E=50 kcal/mole
(8) $2C_3H_6 \rightarrow 3C_2H_4$	A=1.3E10	E=50 kcal/mole
(9) $C_3H_6 + H_2 \rightarrow C_2H_4 + CH_4$	A=1.0E15	E=60 kcal/mole
(10) $C_3H_6 \rightarrow C_2H_2 + CH_4$	A=1.4E10	E=50 kcal/mole
(11) $C_2H_4 + H_2 \rightarrow C_2H_6$	A=0.68E13	E=52 kcal/mole

Van Damme, P.S., Narayanan, S. and Froment, G.F. (1975), Thermal Cracking of Propane and Propane-Propylene Mixtures: Pilot Plant versus Industrial Data, *AIChE J*, Vol. 21, No. 6 (pp1065-1073)

Modelling of Propane Pyrolysis

- Reaction Scheme in Froment (1975)

(12) $C_2H_4 \rightarrow C_2H_2 + H_2$	A=6.0E13	E=76kcal/mole
(13) $3C_2H_4 \rightarrow 2C_3H_6$	A=1.3E11	E=45kcal/mole
(14) $2C_2H_2 + H_2 \rightarrow C_4H_6$	A=6.0E13	E=45kcal/mole
(15) $C_2H_2 + 2H_2O \rightarrow 2CO + 3H_2$	A=3.5E11	E=62kcal/mole
(16) $C_2H_2 + C_3H_6 \rightarrow C_5H_8$	A=9.0E16	E=64kcal/mole

Of these 16 reactions,

(5) and (11) are forward and reverse reactions;

(8) and (13) are forward and reverse reactions;

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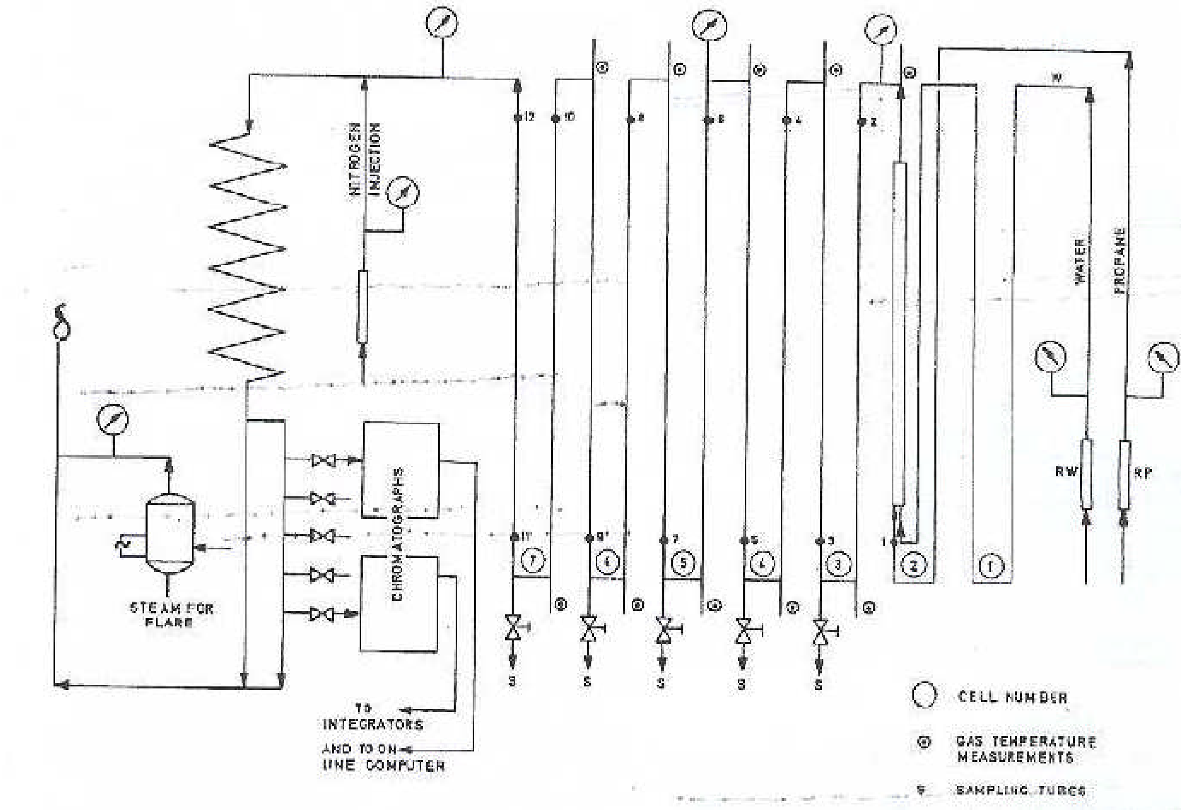
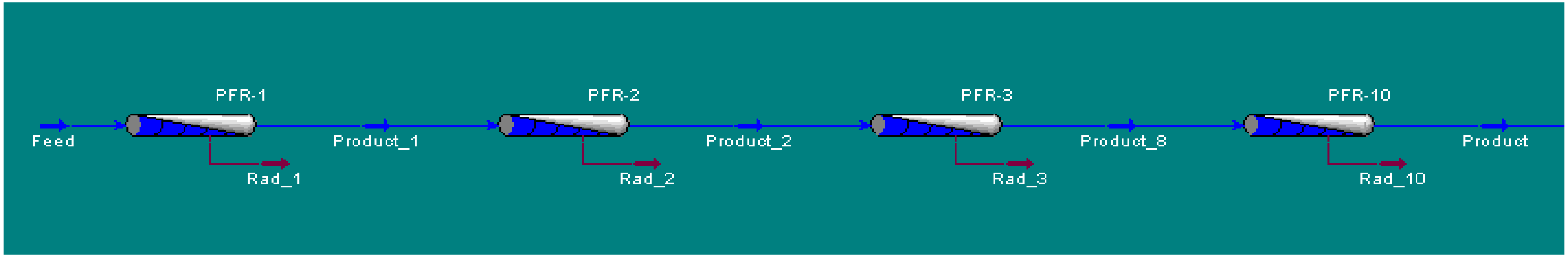
Modelling of Propane Pyrolysis

- Simulation based on pilot plant in Froment 1975





Modelling of Propane Pyrolysis

- Simulation based on pilot plant in Froment (1975)

Feed conditions

Steam dilution rate	0.4 kg steam / kg C3H8	(i.e. steam mass fraction 0.2857)
Pressure	3 bar	
Temperature	600 °C	
Mass Flowrate	0.7655 kg/s	

Product conditions

Pressure	2 bar
Temperature	838 °C
Mass Flowrate	0.7655 kg/s

Plug Flow Reactor details

Length	95m
Diameter	0.108m
Wall thickness	0.008m

Modelling of Propane Pyrolysis in HYSYS

- Conclusions from simulating the pilot plant in Froment (1975):
  - At the same operating conditions (P, T and flowrate) for the PFR as described in Froment (1975)
  - The product composition is close to those data published in Froment (1975)
  - This shows the HYSYS model can be used as the basis of various case studies.

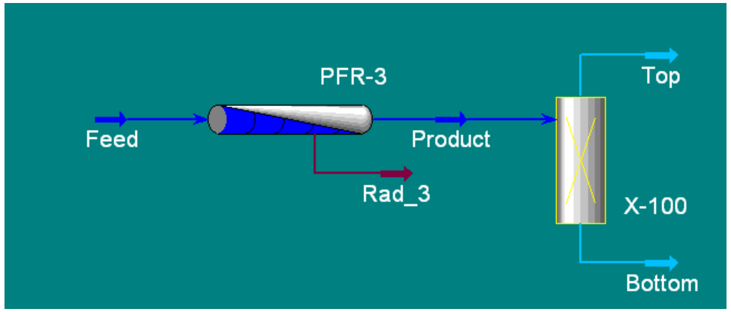
Case Studies

- To investigate the relationship between tubular reactor outlet temperature and the residence time
  - The criterion is to achieve the same propane conversion.
- To investigate the pressure impact

- The reaction kinetics in Froment (1975) were used. These were obtained from 650 °C to 900 °C and under pressure about 3 bars.
- Actually wider pressure range and temperature range are used in the Cases studied.

Case Studies

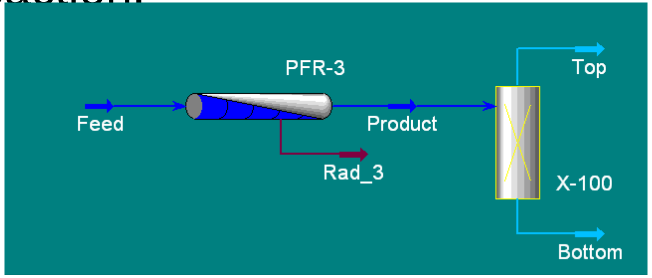
- Base Case Design
  - Use the Reaction Scheme in Froment (1975)
  - Feed same as before
  - PFR details (D=0.108m, L=95m and one long tube only)
  - Operating conditions slightly changed
    - Pressure decreases linearly from 3 bar to 2 bar
    - Temperature increases linearly from 600 C to 880 C (Since only outlet temperature at 880 C, can the propane conversion and ethylene selectivity be similar as before).
    - Residence time: about 970 ms (calculated with average density)



Case Studies

- Summary of results from cases studied
  - Same mass flowrate for mixture of propane and steam
  - Temperature still around 3 bar
  - Reactor length varied from 95 m to 25 m, 6m and 2.5 m
  - Residence time decrease about 0.9s to 0.28s, 0.06s and 0.027s
  - Outlet temperature increased 880C to 965 C, 1084 C and 1170 C to achieve the same propane conversion.

  - For 2.5m length reactor, when pressure increased from 3 bar to 6 bar, 9 bar, outlet temperature required from 1170 C decrease to 1099 C, 1061 C and the product yield for ethylene and propylene increased.
    - This means increasing pressure helps to speed up reaction.



Simulation of Turbo-Cracker

- A standard Compressor is chosen with
  - Compressor Pressure Ratio 23.3:1
  - 17 stages
  - Mass Flow rate 84.5 kg/s (for air)
  - Diameter approximately 2 m and 2.5 m in length
- A standard Turbine is chosen with
  - 6 stage power turbine
  - Diameter approximately 1.5 m and 1.0 m in length
- The same feed is used as in Froment (1975)
- The results from the simulation indicates that
  - Slightly more steam is required to achieve the same propane conversion.
  - One Compressor and Turbine can process 4-5 times of the flowrate of existing thermal cracking furnaces.

Conclusions

- Preliminary simulation indicates that Turbo-Cracker concept worth exploring in more detail.
- The main advantage is that one Turbo-Cracker can replace 4-5 conventional Thermal Cracking Furnaces and is much smaller.
- Main Challenges
    - The kinetics of thermal cracking of propane and naphtha under higher pressure are not clear.
    - Information on existing commercial thermal cracking furnace not enough.
    - Compressor requires more power than Turbine can generate.

Thanks for your attention!