Oxy-fuel retrofitting of heavy fuel oil fired refinery heaters,
A lab scale experimental approach on heavy Fuel oil No 6

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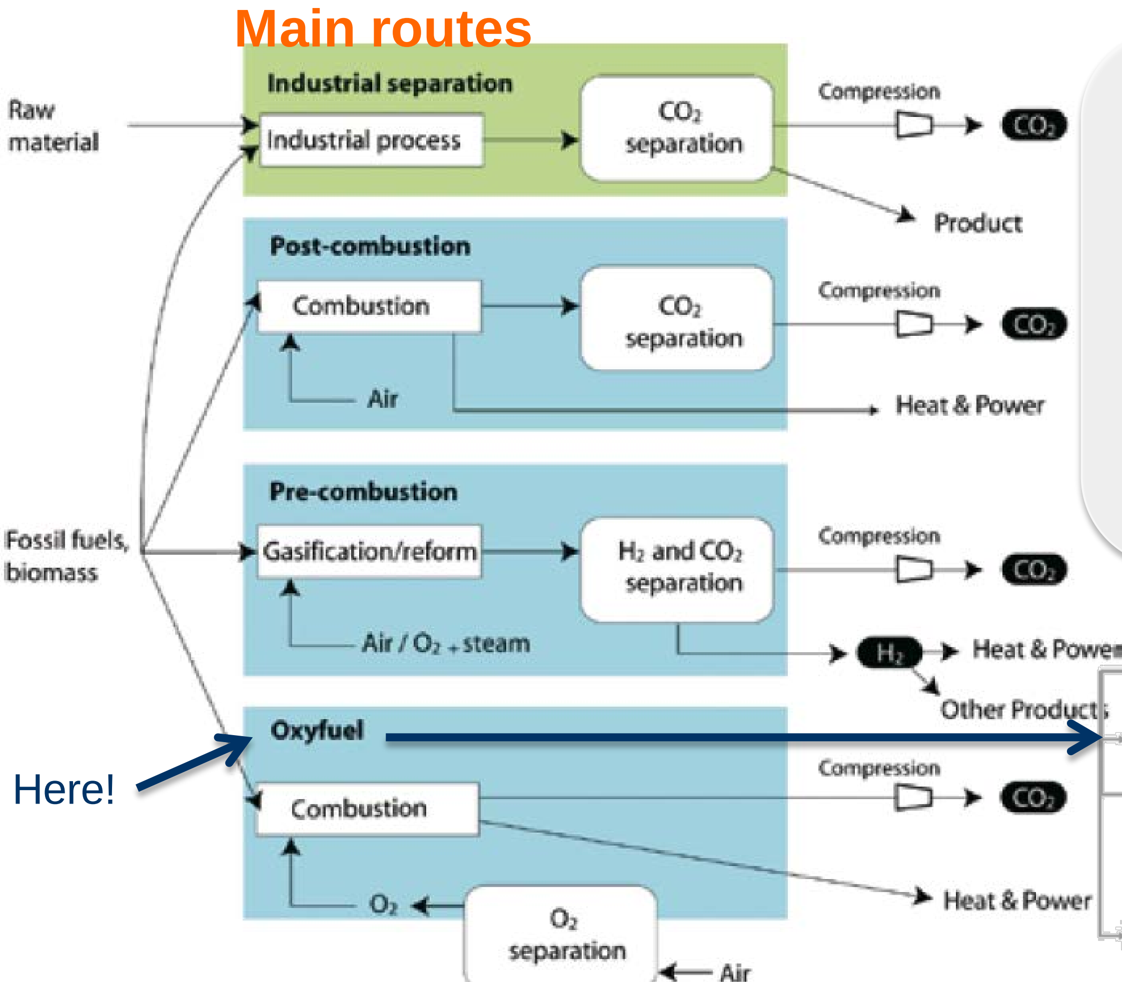
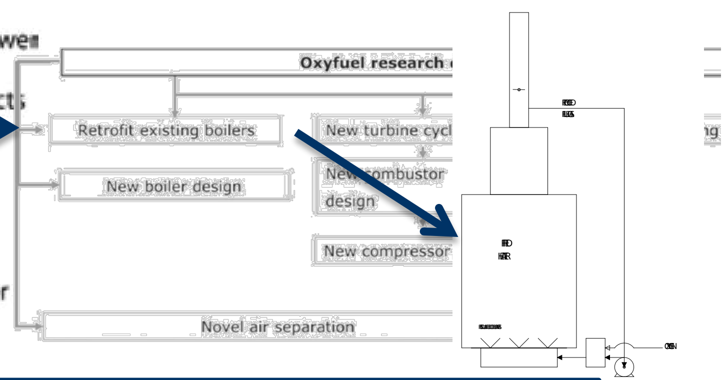
General classification of CO_2 capture methods





Task 1.5 of BIGCCS
"Application to industry and offshore"
Evaluating CCS as an option for other CO_2 sources than power plants
Case 2: Oil refineries - Crackers and reformers (proposed by Shell)

Main sources of CO_2 emissions in refineries are fired heaters (FH) exhaust:
-> about 65% of the total refinery emissions
-> about 4% of the total global CO_2 emissions

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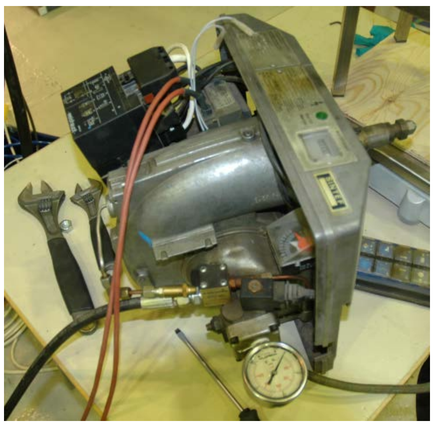
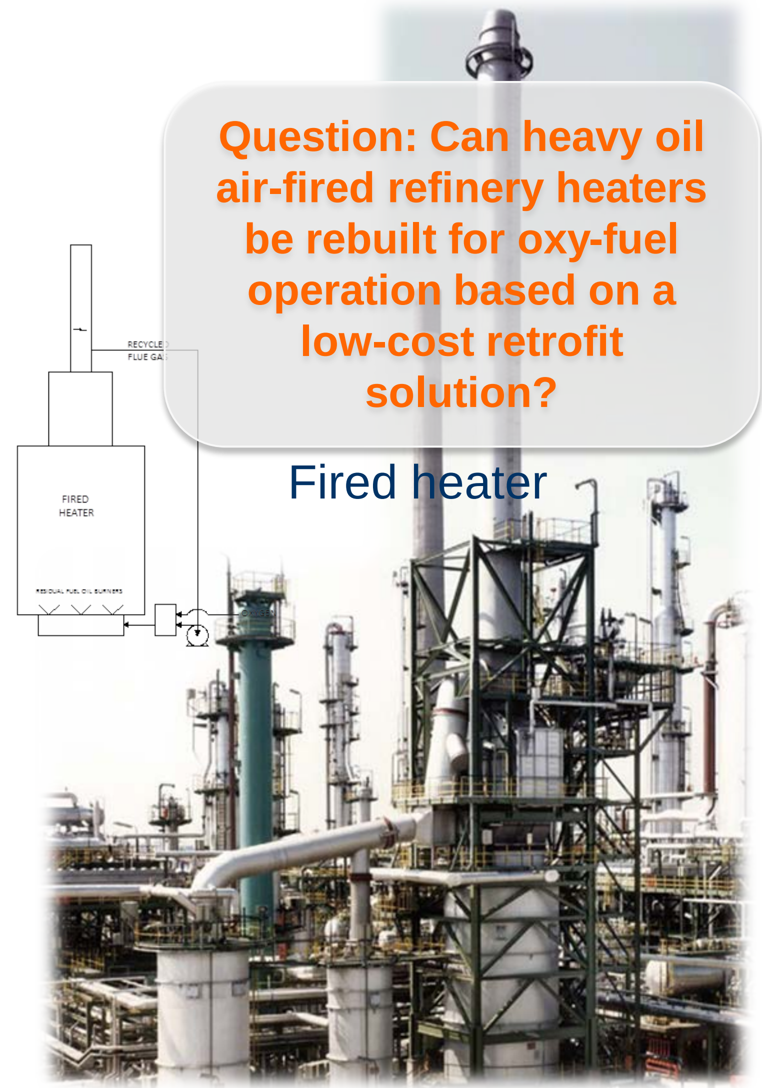
Instruments

100 kW veteran burner



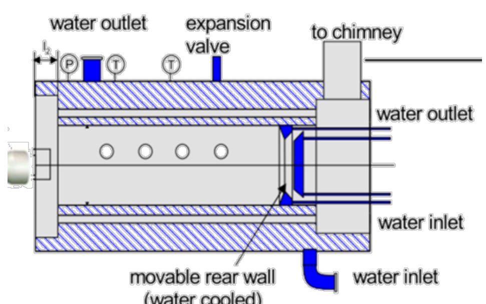
O_2/CO_2



Question: Can heavy oil air-fired refinery heaters be rebuilt for oxy-fuel operation based on a low-cost retrofit solution?

Fired heater

250 kW boiler



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APPROACH

Base-case Fuel oil No 1

- Provide experimental results
  - Fuel oil No 1
  - Lab-scale base-case of 90 kW
  - Both for air- and dry oxy-fuel operation
- Chemical kinetics for base-case
  - Come up with an appropriate reaction scheme
  - Perform simulations using CHEMKIN©

Fuel oil No 6/bunker

- Select representative fuel for the refinery case
- Design and commissioning of appropriate system
  - Able to handle selected quality of Fuel oil No 6
  - Lab-scale 150 kW
  - Primary/secondary heating system
- Run experimental matrix with on both air and O_2/CO_2

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Differences when switching from air to oxy-fuel combustion (coal)*

- To achieve a similar adiabatic flame temperature the O_2 concentration must be higher -> typically 30%, higher than that for air
- Require between 65-75 % flue gas recycling
- High concentrations of CO_2 and H_2O in the flue gas -> higher gas emissivities -> however comparable radiative heat transfer for oxy-fuel retrofit can be obtained with an O_2 concentration around 30 %.
- Oxy-fuel requires excess O_2 comparable to air firing meaning an O_2 concentration in the flue gas in the range of 3-5%.
- Increased concentration of minor species as a result of the recirculation.
- Increased density of flue gas: $M_{CO2} > M_{N2}$
- Increased heat capacity: Cp_{CO2} and $Cp_{H2O} > Cp_{N2}$ leads to higher heat transfer in the convective section of the boiler.
- $V_{oxy\text{-}fuel} < V_{air}$ (reduced by about 80 %.) leading to increased heat transfer in the radiative section of the boiler

*PECS oxy fuel review, 31, 283-307, 2005

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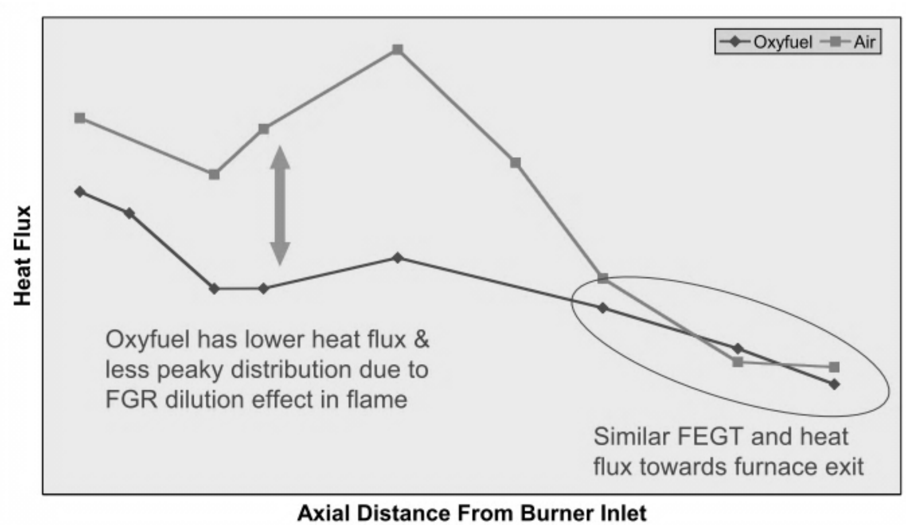
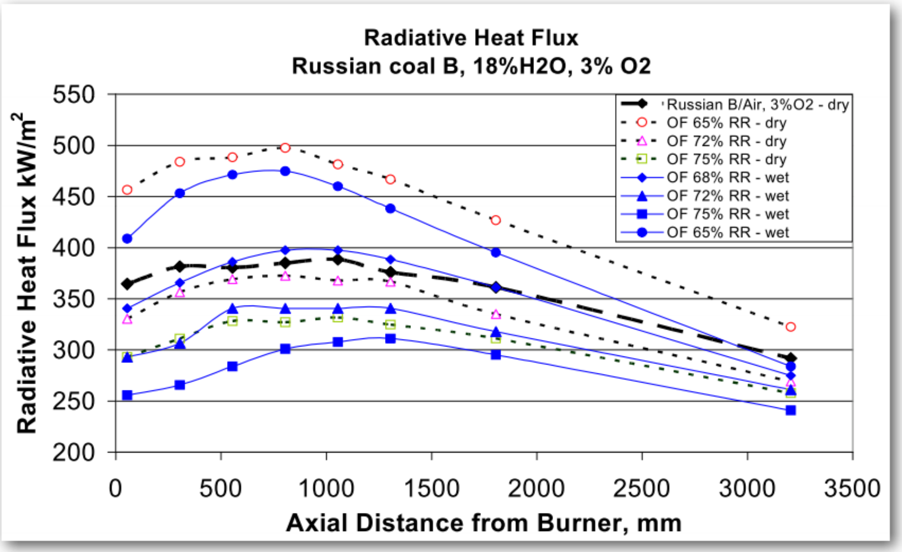
Differences when switching from air to oxy-fuel combustion



Oxy-fuel Firing and Lessons Learned from the Demonstration of a Full-Sized Utility Scale 40MW OxyCoalTM Combustion System, South African Carbon Capture and Storage Conference, Johannesburg, 29th - 30th Sep 2009, G Hesselmann et al.



Radiative and Convective Heat Transfer in Oxy Coal Combustion Transfer in Oxy Coal Combustion, John Smart Phil O'Nions Gerry Riley Ed Jamiesion John Smart, Phil O Nions, Gerry Riley, Ed Jamiesion, RWEnpower

Factor	Air firing	Oxy-fuel	Implications
$CO_2 + H_2O$	0.3	0.9	Higher emissivity
H_2O/CO_2	1	0.1 (wet)	
		0.3 (dry)	

Fundamentals of Oxy-Fuel Combustion, Prof Terry Wall Chemical Engineering, University of Newcastle, 2308, Australia Oxy-fuel Combustion Research Network Vattenfall Europe, Cottbus, Germany, 29/30 November 2005

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NO_x controlling with oxy-fuel

- Difficult/costly to perfectly eliminate nitrogen in oxidant (up to 5 %) -> the NO_x emission control remains an issue.
- Three sources of N_2:
  - Inherent N_2 in produced O_2
  - Inherent N_2 in fuel
  - Air leakage into furnace
- Ditaranto et al.
  - showed that the oxy-fuel combustion has a great potential to reduce NO_x emission.
  - They observed that the NO_x emission is highly sensitive to air leaks into the combustion chamber.

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Experimental matrix

Base-case

Expermental matrix

Exp no	Lambda	O2 l/min	CO2 l/min	[O2] in oxidant	[CO2] in oxidant	[N2] in oxidant
Air 1-1	1.25	375		0.2095	-	0.7905
1-1	1.25	378	403	0.4815	0.5161	0.0024
1-2	1.25	378	459	0.4492	0.5485	0.0023
1-3	1.25	378	526	0.4159	0.5820	0.0021
1-4	1.25	378	612	0.3801	0.6180	0.0019
1-5	1.25	378	717	0.3435	0.6547	0.0017
Air 3-1	1.2	357		0.2095	-	0.7905
3-1	1.2	357	493	0.4180	0.5799	0.0021
3-2	1.2	357	526	0.4021	0.5959	0.0020
3-3	1.2	357	605	0.3693	0.6288	0.0019
3-4	1.2	357	701	0.3357	0.6626	0.0017
3-5	1.2	357	784	0.3113	0.6871	0.0016
Air 4-1	1.15	343		0.2095	-	0.7905
4-1	1.15	343	403	0.4575	0.5402	0.0023
4-2	1.15	343	459	0.4255	0.5723	0.0021
4-3	1.15	343	531	0.3906	0.6074	0.0020
4-4	1.15	343	612	0.3576	0.6406	0.0018
4-5	1.15	343	717	0.3221	0.6763	0.0016
Air 5-1	1.1	328		0.2095	-	0.7905
5-1	1.1	328	403	0.4460	0.5517	0.0022
5-2	1.1	328	459	0.4143	0.5836	0.0021
5-3	1.1	328	531	0.3797	0.6184	0.0019
5-4	1.1	328	612	0.3471	0.6512	0.0017
5-5	1.1	328	717	0.3121	0.6863	0.0016

Measurement accuracy

CO2 + - 2%	0.98
CO + - 2%	0.98
O2 + - 1%	0.99
NOx (testo) + - 5%	0.95
NOx Horiba + - 1%	0.99
Kalibreringsgass: + - 2 %	0.98
Rotametre (begge) + - 1,6 %	0.984

Err NO	4.5
Err CO	5.5
Err O2	4.5
Err CO2	5.5
T_ad_calc	9.2

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Experimental results will be presented in a paper later this year

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Base-case simulations

- The CHEMKIN PRO v4 chemical simulator was procured in 2010
- CHEMKIN is considered as the de facto standard simulation tool for solving complex chemical design problems
- Fuel oil No 1 = n-heptane
- A reduced mechanism from Lawrence Livermore National Laboratory (LLNL) was selected (No NO formation/reburning)
- The above was combined with GRI-Mech v3.0 -> **181 species and 1748 reactions**
- The setup is a network of reactors where some of the flue gas is re-circulated back into the flame

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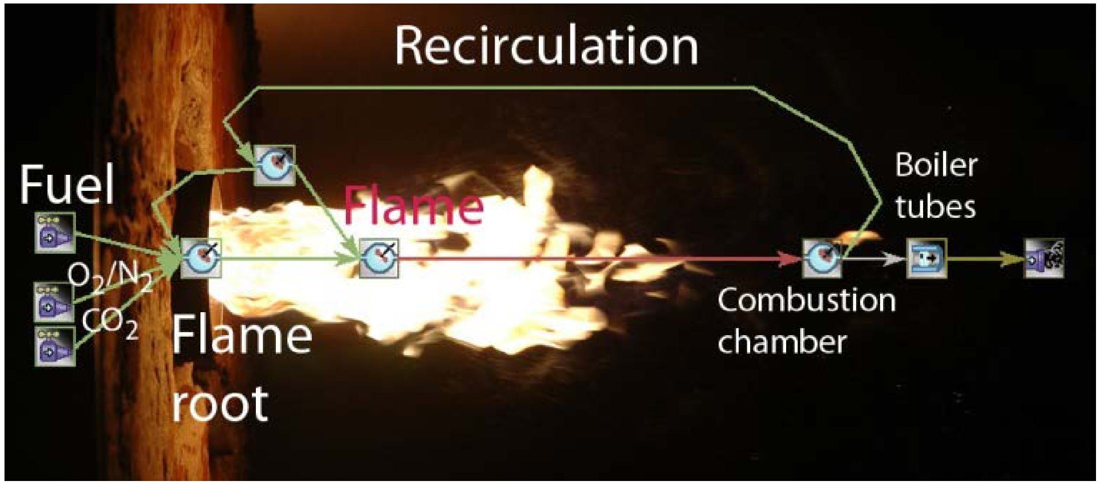
Base-case simulations



Properties for All Reactors | Reactor Properties Table | Species-specific Data for All Reactors

Reactor Property	Units	Fill Row	Clear Row	InletMixing	Flame	C1_R3 PSR	Comchamber
Residence Time	sec	Fill	Clear	0.005	0.05	0.0005	0.1
Temperature	K	Fill	Clear	900.0	2000.0	900.0	1600.0
Pressure	atm	Fill	Clear	1.0	1.0	1.0	1.0
Volume	cm3	Fill	Clear				
Heat Loss	cal/sec	Fill	Clear		75.0	75.0	75.0
Heat Transfer Coefficient	cal/cm2-K-sec	Fill	Clear				
Ambient Temperature	K	Fill	Clear				
Surface Temperature	K	Fill	Clear				
Wall Heat Transfer Coefficient	cal/cm2-K-sec	Fill	Clear				
Wall Thermal Mass	cal/K	Fill	Clear				
Internal Surface Area	cm2	Fill	Clear				
External Surface Area	cm2	Fill	Clear				
Gas Reaction Rate Multiplier	none	Fill	Clear				

Please specify all the recycle ratios listed here and make sure that all recycle ratios originating from the same reactor sum to 1.0.

Sum of Recycle Fractions from Flame	1.0
Recycle Fraction from Flame to Comchamber	**1.0**
Sum of Recycle Fractions from C1_R3 PSR	1.0
Recycle Fraction from C1_R3 PSR to InletMixing	**0.3**
Recycle Fraction from C1_R3 PSR to Flame	**0.7**
Sum of Recycle Fractions from Comchamber	1.0
Recycle Fraction from Comchamber to C1_R3 PSR	**0.3**
Flow fraction from Comchamber to C2_ PFR	0.7

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Results from simulations will be presented in a paper later this year

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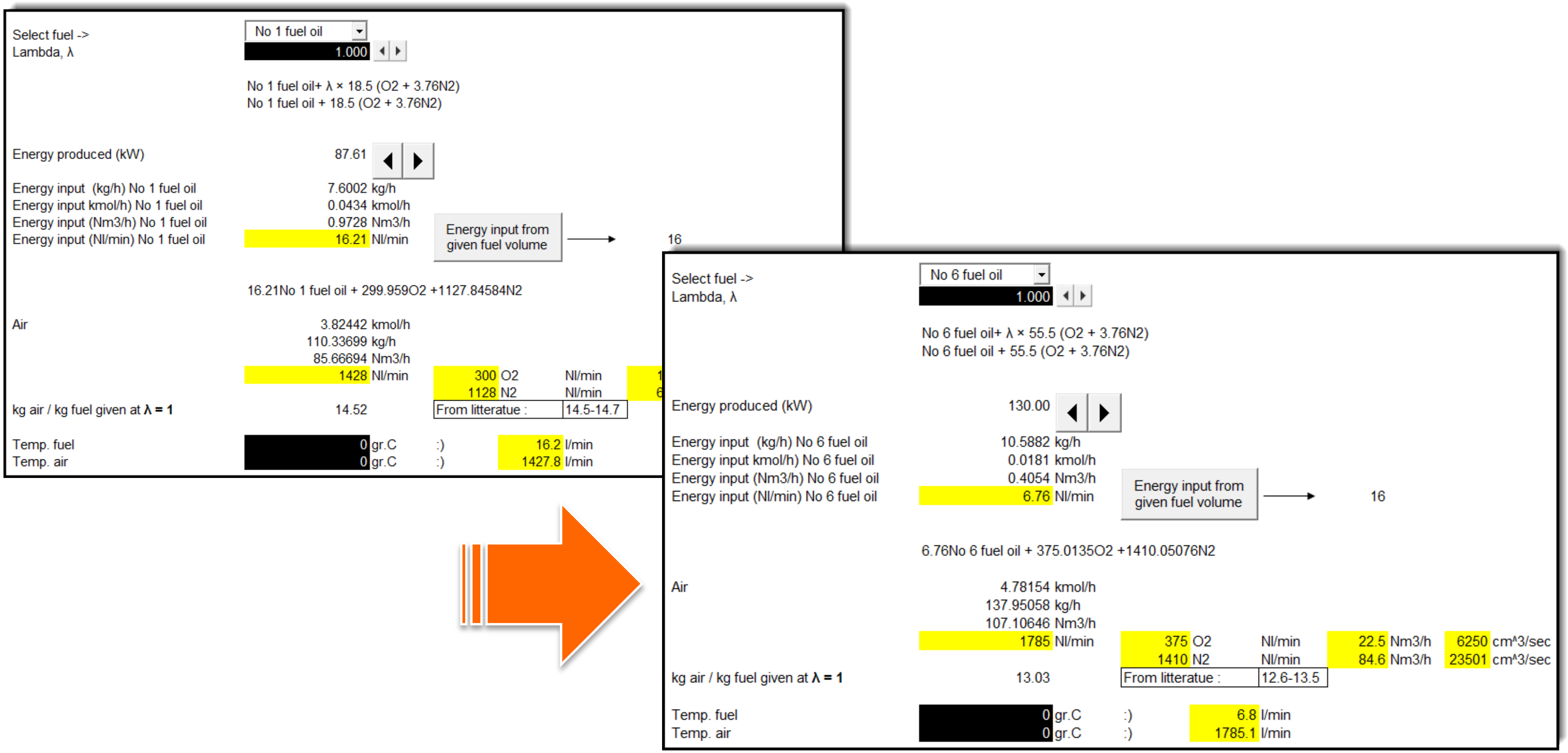
Progressing from base case No. 1 fuel oil to No. 6 fuel oil/bunker fuel



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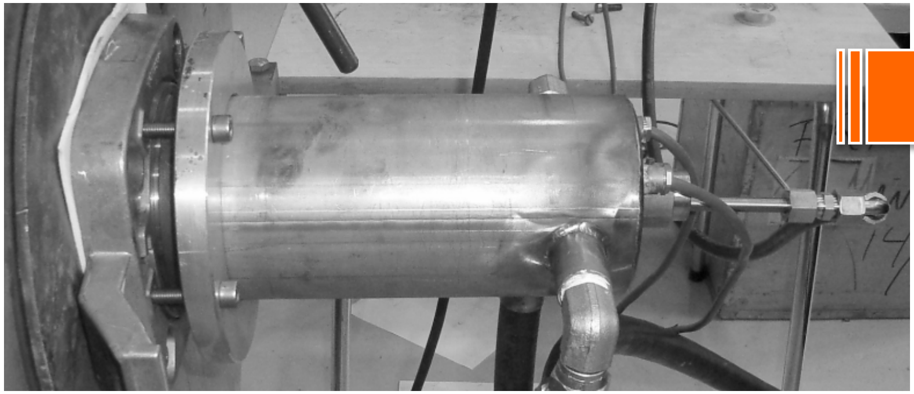
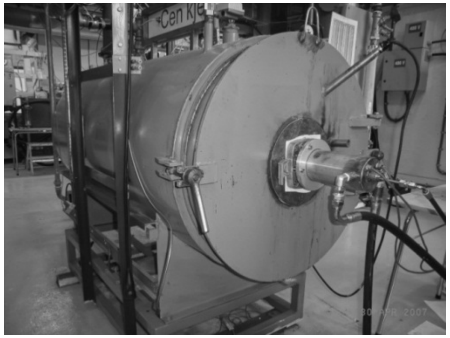
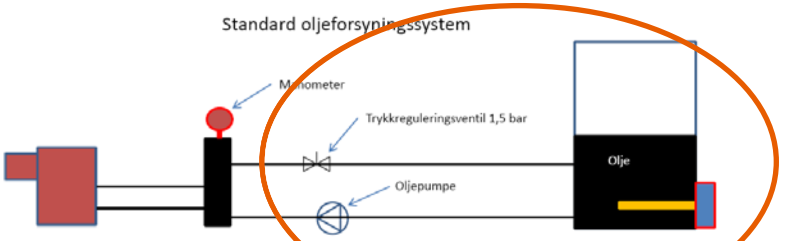


~ 90 kW Fuel oil No 1

250 kW CEN boiler



~ 150 kW Fuel oil No 6/Bunker C



+ Pre-heating system

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Summary and status

- The No 6 fuel oil experiments are scheduled in June 2011
- The experimental matrix is planned around $\lambda = 1.1$ with varying CO_2 dilution.
- New 150 kW heavy oil burner arrive in mid-June
- Pre-heating system has been designed and build
- Five 200 liter barrels of Bunker C oil has been procured in Sweden a will arrive in Trondheim in mid-June

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Summary and status

- Literature/experiments is scarce on heavy oil oxy-firing
- Much more research has been done on pulverized coal oxy-firing

Is low-cost retrofit enough?

- Flue gas recirculation
  - Wet/dry?

Not too costly

Optional physical changes

- ~~New burners?~~
- ~~New radiant section?~~

OK

Additional equipment

- Air separation unit

Costly

Acceptable?

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Thank you for your attention!