

Test facilities and initial results for the improved Enefit[®] technology for processing different oil shale types

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Agenda

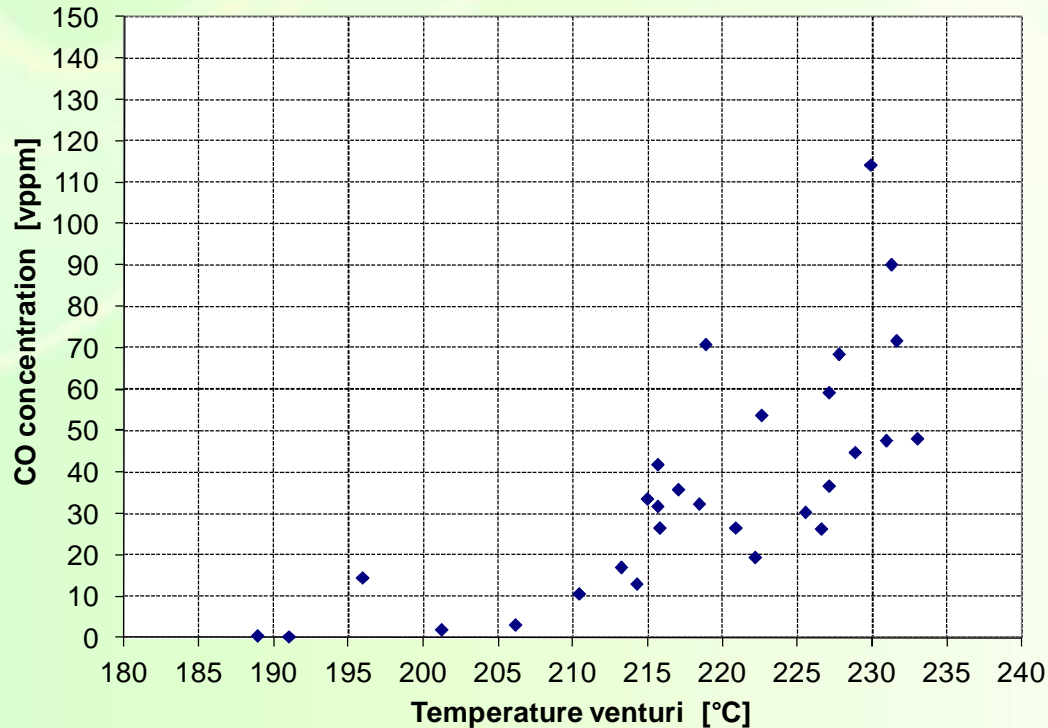
- Investigation of Enefit280 key process units in Outotec's existing pilot plants in Frankfurt/Germany
 - Combustion of semi-coke
 - Drying of oil shale in a venturi dryer
- Enefit bench scale plant for pyrolysis and oil winning
 - Flow sheet and key data
 - Results for Estonian oil shale, influence of heat carrier
 - Results for Jordanian oil shale
- Realization of a Enefit[©] demonstration plant for a capacity of 350 kg/h throughput of oil shale

Key units of Enefit280 process investigated in Outotec's pilot and bench scale plants

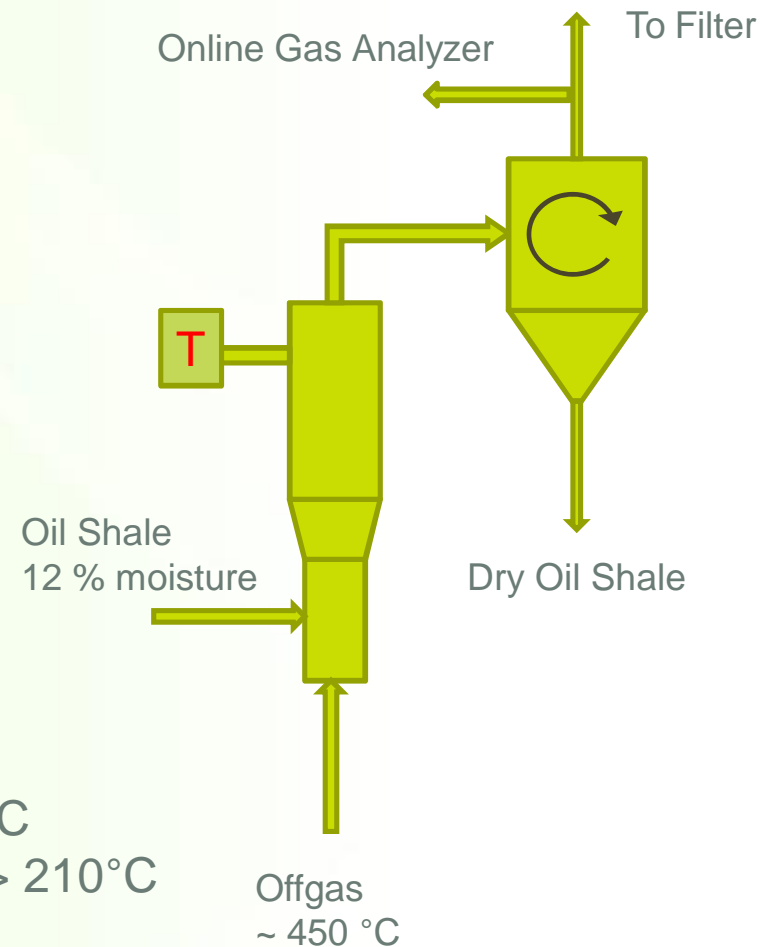
- I. Oil Shale drying
 - Pilot venturi dryer was integrated in Outotec's existing 700 mm CFB pilot plant
 - Three day test campaign with combustion offgas and 650 kg/h oil shale feed (Estonian oil shale: < 6mm, 12% moisture)
 - Investigation of temperature, gas velocity, retention time on emissions (to meet EU environmental standards), residual moisture (~ 0%), grain size
- II. Semi-coke combustion
 - Two test campaigns in existing 700mm CFB pilot plant with Estonian semi-coke
 - Investigations: control of emissions, namely SO₂, CO, NO_x, TOC (EU standards)
 - Organic carbon burnout, carbonate decomposition
 - Particle breakage and abrasion, grain size of ash
 - Ash discharge distribution: bottom ash – flue ash
- III. Pyrolysis & oil winning – Enefit bench scale plant
 - Outotec and EE's joint venture, **Enefit Outotec Technologies (EOT)**, commissioned the Enefit bench scale plant at Outotec's R&D center in Frankfurt in November 2010.

I. Oil Shale drying - results

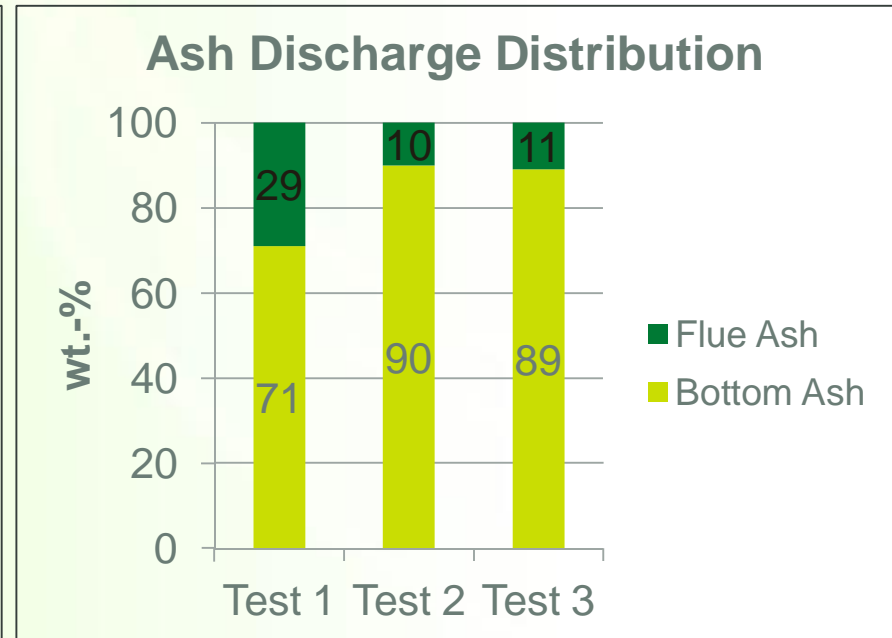
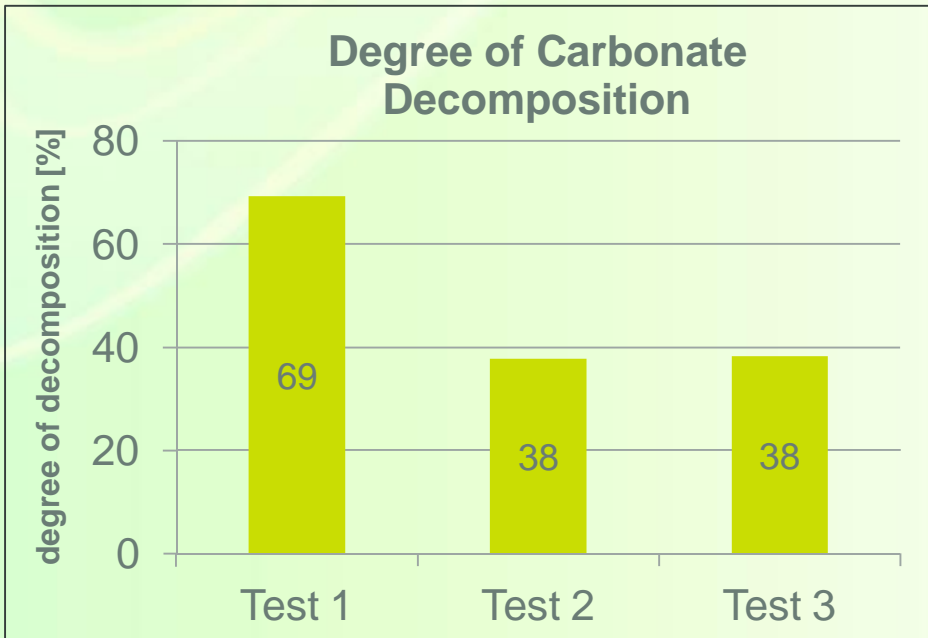
CO emissions during oil shale drying



- no CO emissions for venturi temperatures $< 210^{\circ}\text{C}$
- CO emissions increase for venturi temperatures $> 210^{\circ}\text{C}$
- venturi design temperature (160°C) is well below critical temperature



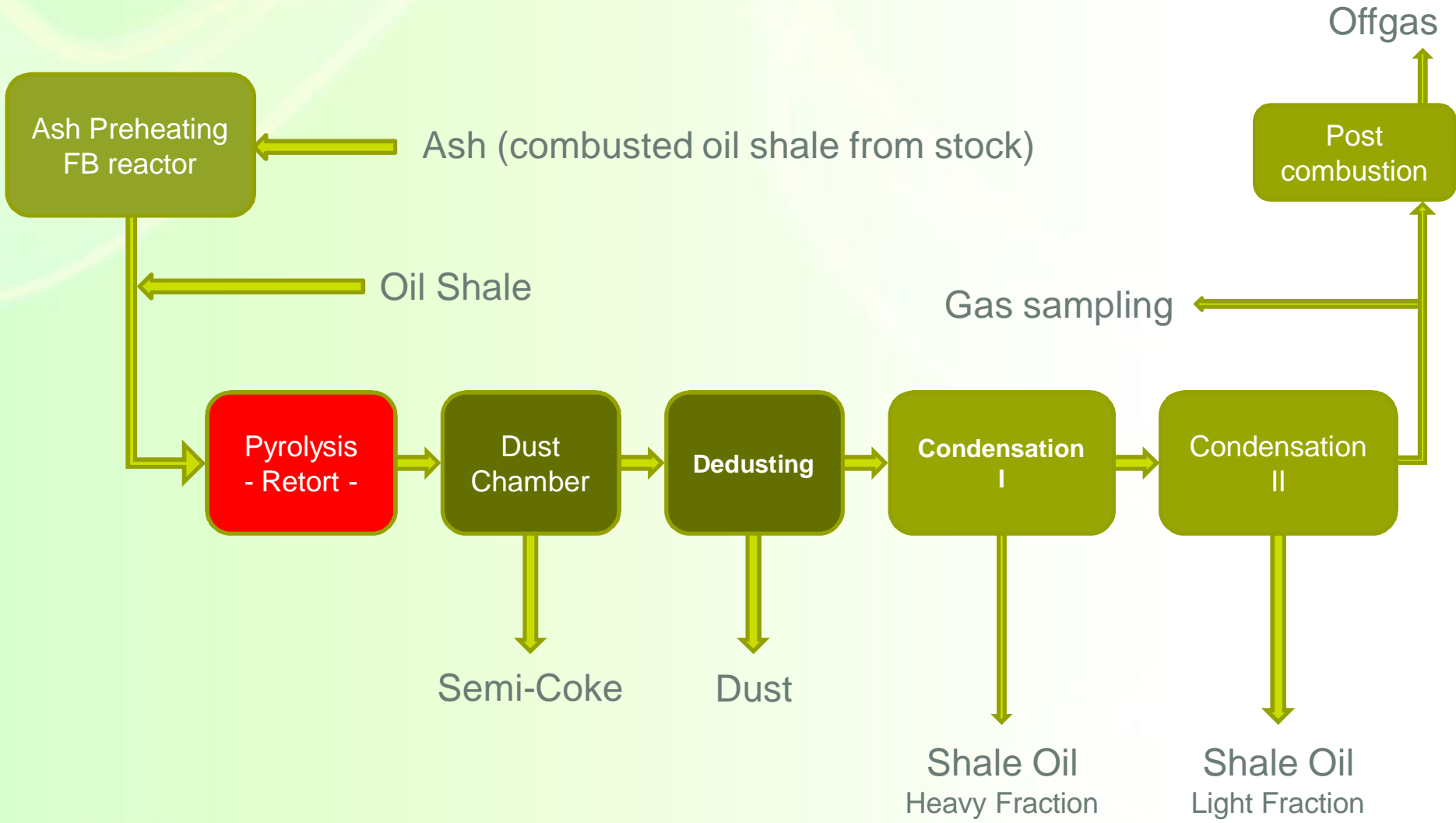
II. Semi-coke combustion – results



- Test 1: **790 °C**, 400 kg/h semi-coke, **45 min** solids retention time
- Test 2: **755 °C**, 400 kg/h semi-coke, **32 min** solids retention time
- Test 3: **790 °C**, 600 kg/h semi-coke, **22 min** solids retention time
- lower carbonate decomposition degree at lower combustions temperatures and shorter retention times
- less flue ash at lower carbonate decompositons degrees

Enefit bench scale unit for the solid heat carrier process

Basic flow sheet



Enefit bench scale unit for the solid heat carrier process



Enefit[®] Bench Scale Plant

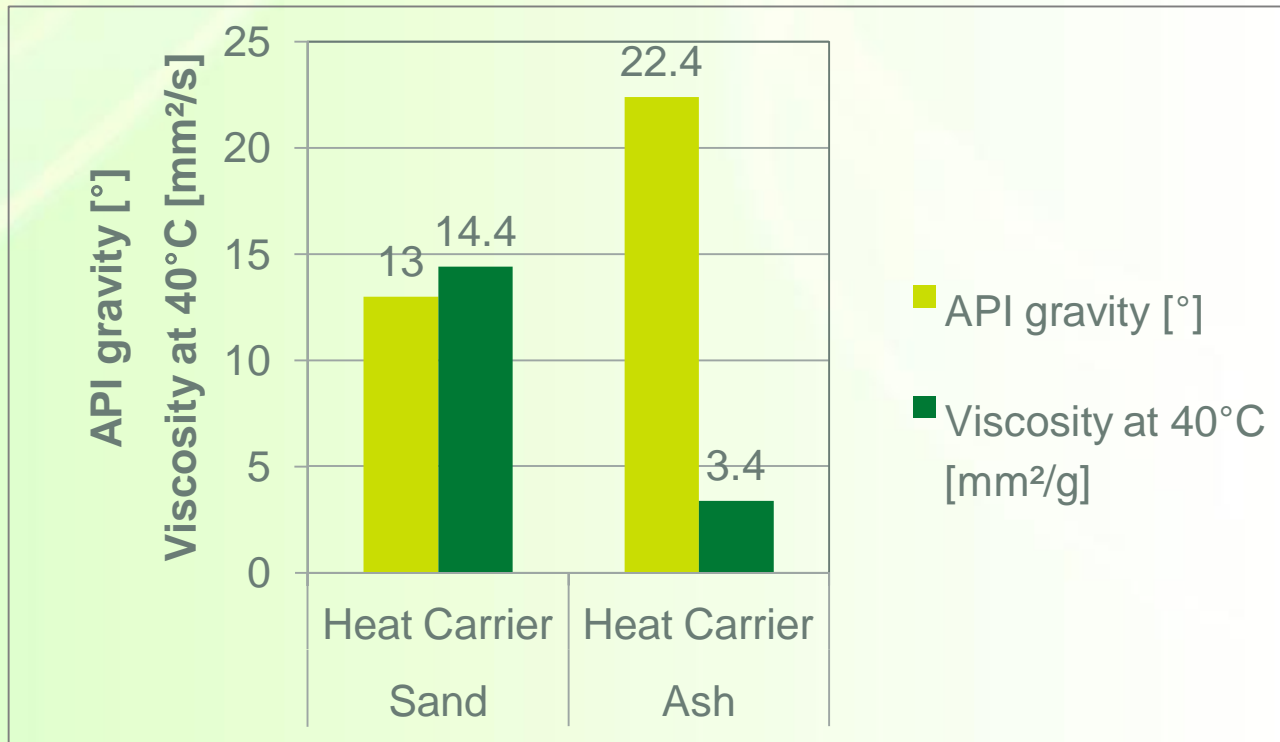
- Designed by Enefit & Outotec
- Erected in Outotec's R&D center in Frankfurt/Main, Germany
- Operated by Enefit Outotec Technology
- Commissioned in November 2010
- Tests carried out with Estonian, Chinese and Jordanian oil shale

Key data

- | | |
|----------------------------------|--------------|
| • Oil shale feed < 6mm | 4 – 12 kg/h |
| • Ash feed to preheater | 10 – 25 kg/h |
| • Ash temperature preheated | 700 – 800 °C |
| • Pyrolysis temperature | 440 – 530 °C |
| • Shale oil (dependent on yield) | up to 2 l/h |

Influence of Heat Carrier

Test run in bench scale unit with ash and quartz sand as heat carrier

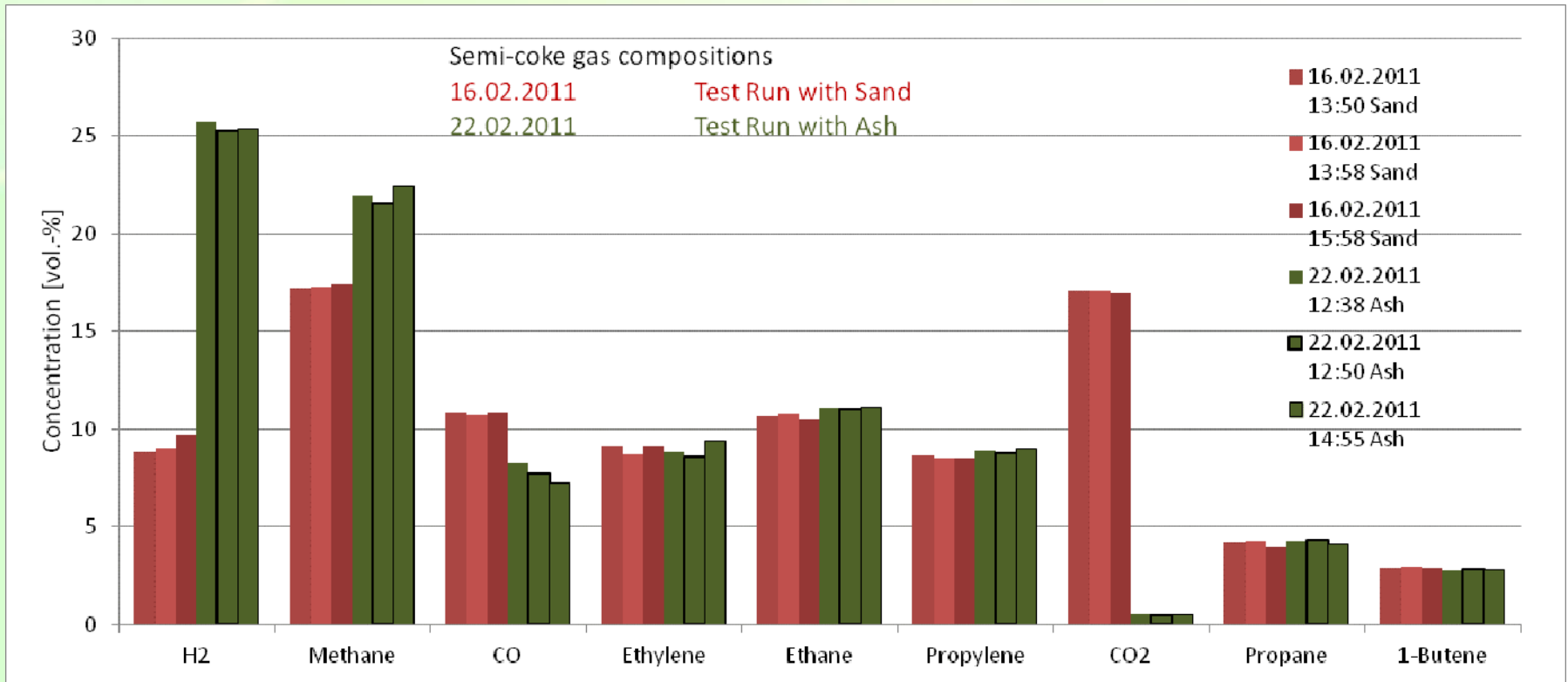


- Heat carrier properties significantly influence oil quality at the same pyrolysis temperature and retention time
- Important to use the „right“ oil shale ash in order to investigate a specific oil shale

Influence of Heat Carrier

Test run in Enefit bench scale unit with ash and quartz sand as heat carrier

- Significant influence of heat carrier properties on semi coke gas composition

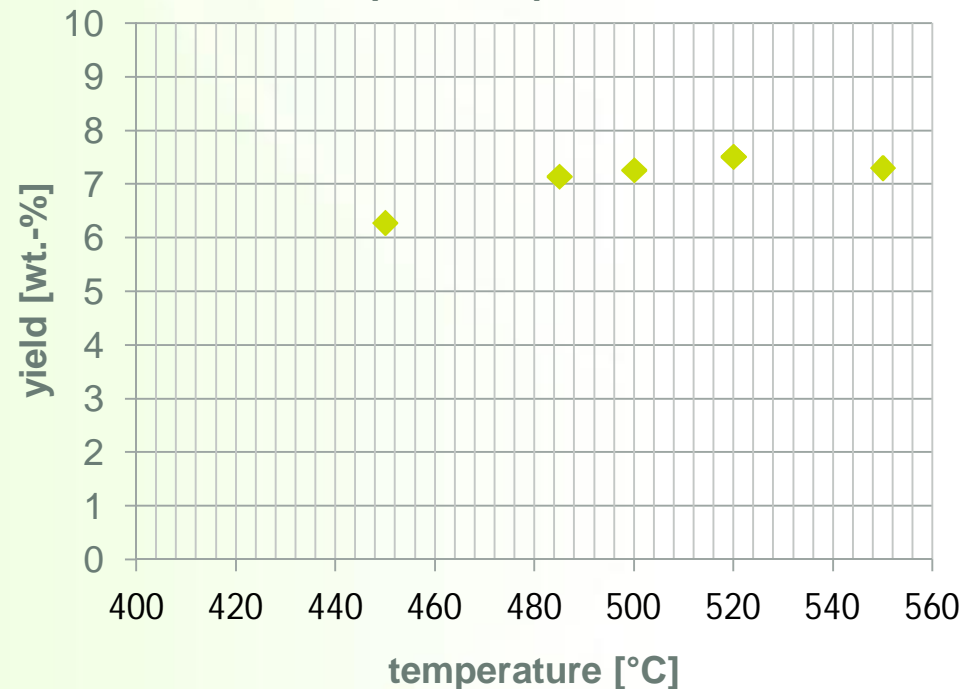


Results for Jordanian (Attarat) Oil Shale

Ultimate analysis and assay results

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Sample: Oil shale Attarat #41/11		
Ash	wt.-%	63.33
C total	wt.-%	16.64
Carbonate-C	wt.-%	6.41
Organic-C	wt.-%	10.23
H2 total	wt.-%	1.45
H2 organic	wt.-%	1.42
N	wt.-%	0.27
S-tot	wt.-%	2.42
S-sulfate	wt.-%	0.2
F	wt.-%	0.224
Cl	wt.-%	0.037
Oil yield (Fisher-Assay, 520 °C)	wt.-%	7.5

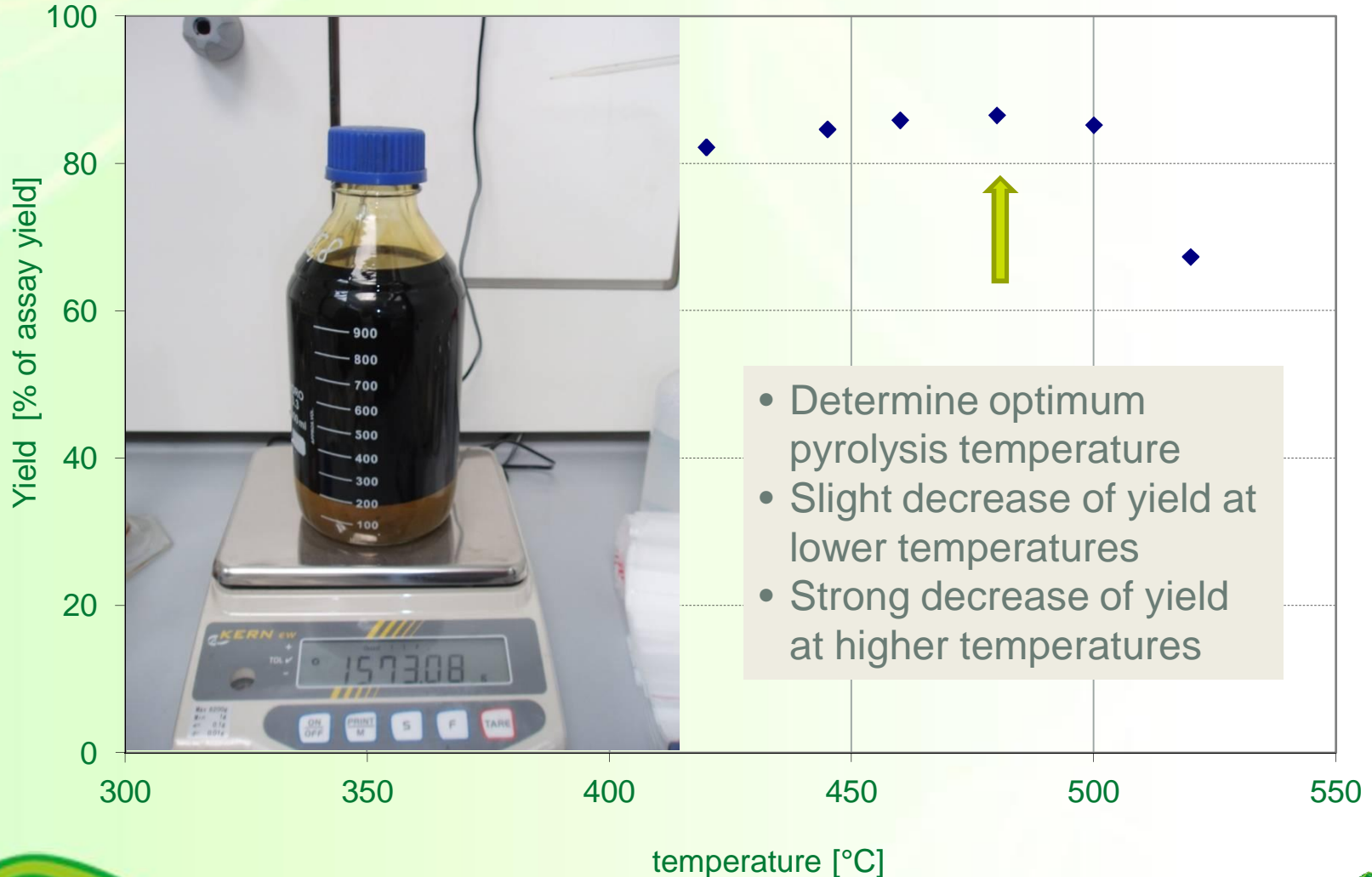
Assay-yields for Jordanian (Attarat) Oil Shale



Results for Jordanian Oil Shale

Tests in Enefit bench scale unit

Oil yield in Enefit bench scale unit



Results for Jordanian Oil Shale

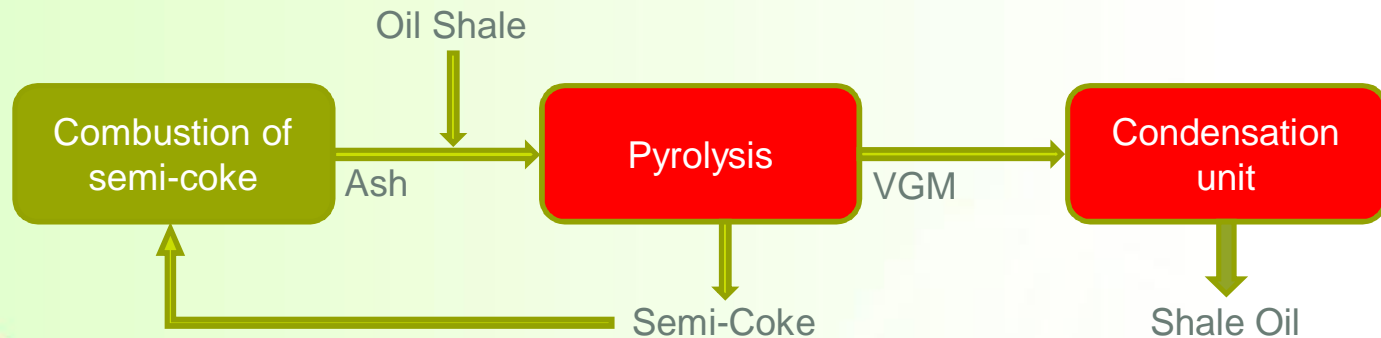
Enefit bench scale unit

Oil properties, summary

- Water content 0.12 % centrifuge
 0.35 % decanted
- Ash content 60 ppm
- Density@15 °C 16 API°/ 960 kg/m³
- Viscosity@40 °C 3.5 mm²/s
- TAN 0.02 mg KOH/g
- Recovery@360 °C 65 – 70 % (SIM-DEST !!)
- N+O content ~ 2 %
- Sulphur 8 – 10 %

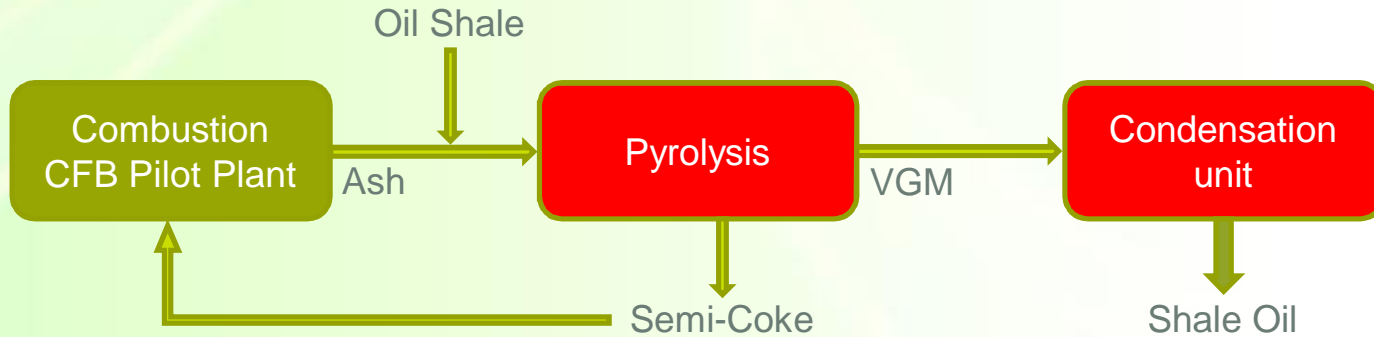
Realisation of a Enefit[®] Demonstration Plant

- Outotec and EE's joint venture, **Enefit Outotec Technologies (EOT)**, concluded a contract on building a new oil winning demonstration plant at Outotec's R&D center in Frankfurt.
- The Demo Plant will employ the solid heat carrier technology with a capacity of 350 kg/h throughput of oil shale
- The Demo Plant will be built to test specific oil shales and their properties (yield, oil quality, solids behaviour and ash characteristics)
- Production of shale oil (approximately 4000 kg) for further oil quality investigations (up-grading tests)
- Complete core process cycle:
pyrolysis – combustion of semi-coke – oil winning

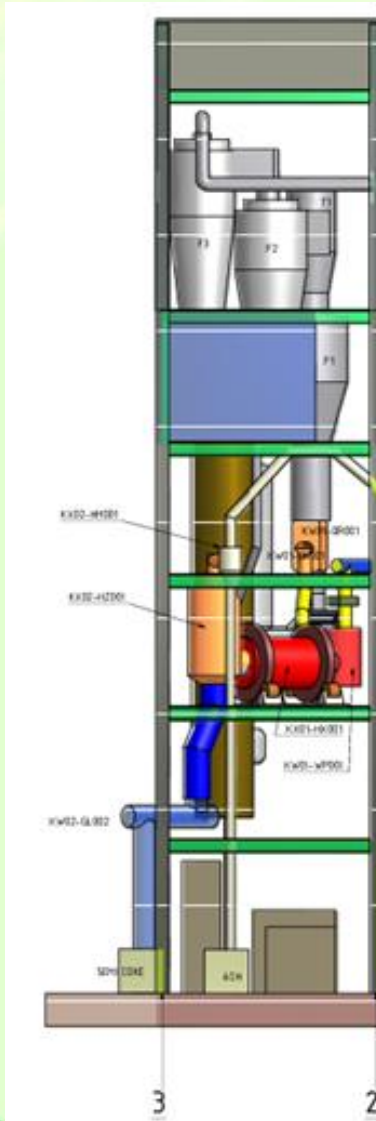


Enefit[®] Demonstration Plant

Integrated in Ouotec's 700mm CFB Pilot Plant



Conceptual arrangement for Enefit Demo Plant



General

- Connection to existing plant: Duct for hot recycle ash (solid heat carrier) from existing seal-pot of CFB cyclone to new retort
- Two-stage concept for the condensation unit; winning of a heavy and light oil fraction (similar to in Enefit Bench Scale Plant)
- Spent shale (semi-coke) will be fed to the CFB combustion reactor

Project status

- Basic process design completed considering local boundary conditions
- Arrangement design developed
- Possible suppliers/vendors have been contacted
- Various equipment cannot be bought from the market as standard solutions → own design

Summary

- Key process units of Enefit280 technology were investigated in Outotec's and EOT's pilot plants and test facilities
- A bench scale unit with a capacity of 4 – 12 kg/h throughput of oil shale for the pyrolysis and oil winning has been developed and built by Enefit and Outotec's joint venture company
- Various oil shale types have been tested in the Enefit bench scale plant - oil yield, quality and optimum process condition can be determined. Heat carrier properties significantly influence oil quality and semi coke gas composition
- An Enefit[©] demonstration plant with a capacity of 350 kg/h throughput of oil shale is currently being developed for integration into Outotec's existing CFB pilot plant
- Enefit[©] demonstration plant will enable the production of shale oil (approximately 4 t) for further up-grading tests