SIZING MODELS AND PERFORMANCE ANALYSIS OF WASTE HEAT RECOVERY ORGANIC RANKINE CYCLES FOR HEAVY DUTY TRUCKS (HDT)

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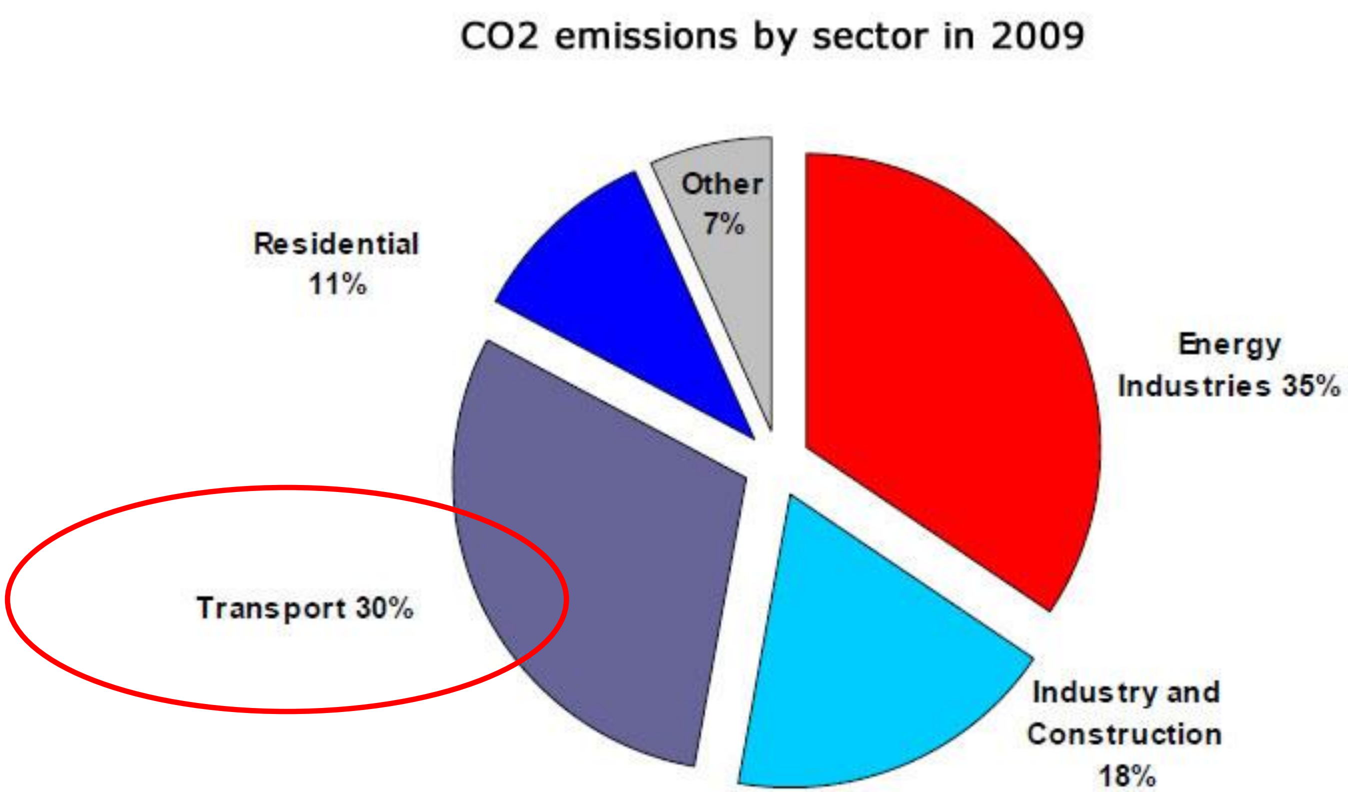
Introduction

Context



http://ec.europa.eu/energy/energy2020/energy2020_en.htm

Introduction

Context

- Reduction of emissions (European norms)
- Units: [g/kWh]

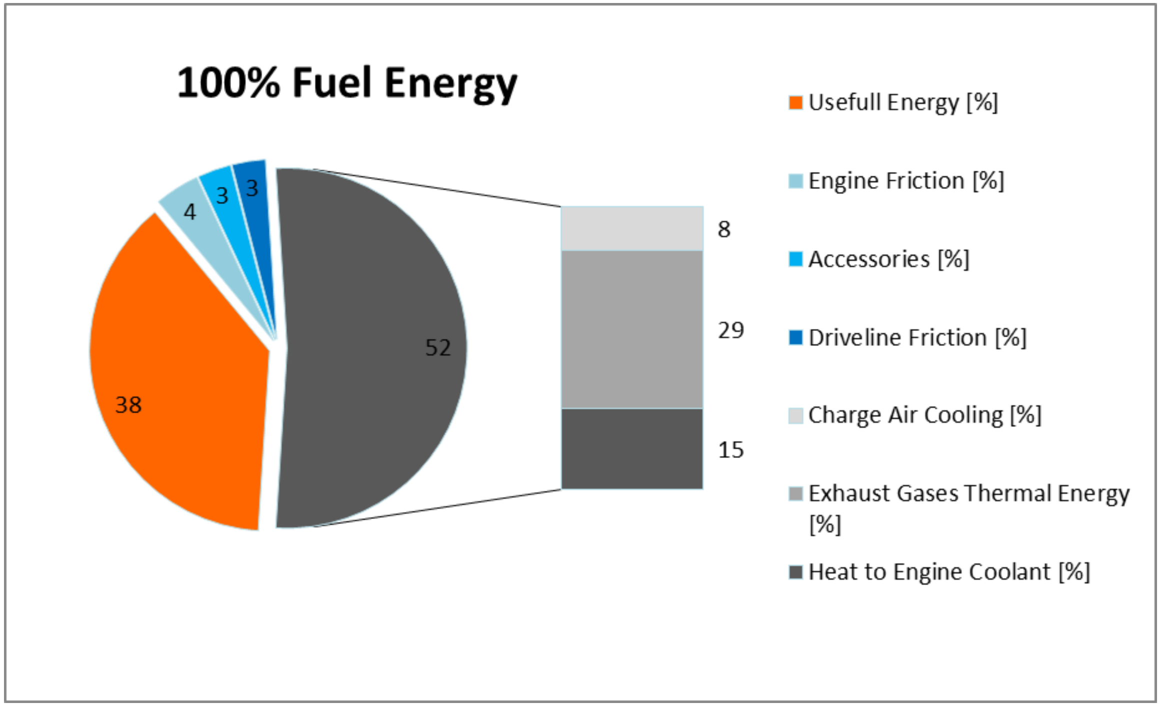
Norms	HC	CO	NOx	PM	Implementation
Euro 0	2.40	11.20	14.40	-	01/10/1990
Euro 1	1.23	4.90	9.00	0.36	01/10/1993
Euro 2	1.10	4.00	7.00	0.15	01/10/1996
Euro 3	0.66	2.10	5.00	0.13	01/10/2001
Euro 4	0.46	1.50	3.50	0.02	01/10/2006
Euro 5	0.46	1.50	2.00	0.02	01/10/2009
Euro 6	0.13	1.50	0.40	0.01	01/01/2014

http://www.europe-camions.com/

Introduction

Why WHR on HDV?

- => Reduce fuel consumption
- A very promising solution: Waste heat ≈ 60% of the combustion energy.

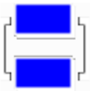


Introduction

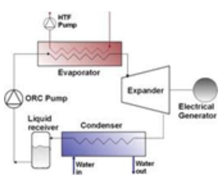
ORC on HDV

- Specific R&D activities required to
  - select and develop the system components,
  - identify the most appropriate system architectures and level of integration,
  - achieve sustainable costs (payback time) and the required level of reliability (life time).
- First task: System concept definition

1. 0D modeling (design)
2. 1D dynamic simulation models



3. Overall system definition



System concept

Design: 0D Modeling

- Definition of the working conditions on which the systems will be sized and optimized
  - exhaust gases flow rate and temperature, coolant loop flow rate and temperature, fuel consumption, ...

- Comparison of different Rankine cycle architectures through steady state simulations (Efficiency, power recuperation potential, heat rejection requirements and technical complexity)

  - Different heat sources available on the vehicle.
  - Thermodynamic analysis of working fluids and working fluid mixtures
  - Expansion machines comparison

System concept

0D Modeling

- Several heat sources are available on a vehicle:

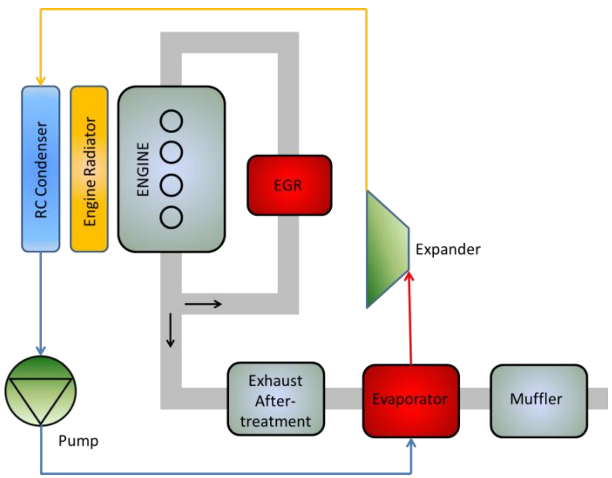
Heat Source	Temperature	Capacity flow rate
Exhaust gases	mid to high	high
EGR gases	high	low
Charge Air	low to mid	high
Coolant	low	high
Oil	low	low
Retarder	Low	high

- The more interesting sources: Exhaust gases and EGR gases (higher temperature leads to the usage of higher energy content fluid)

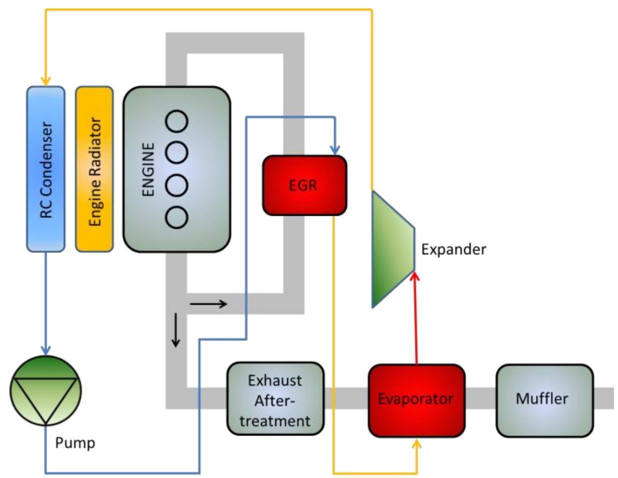
System concept

0D Modeling

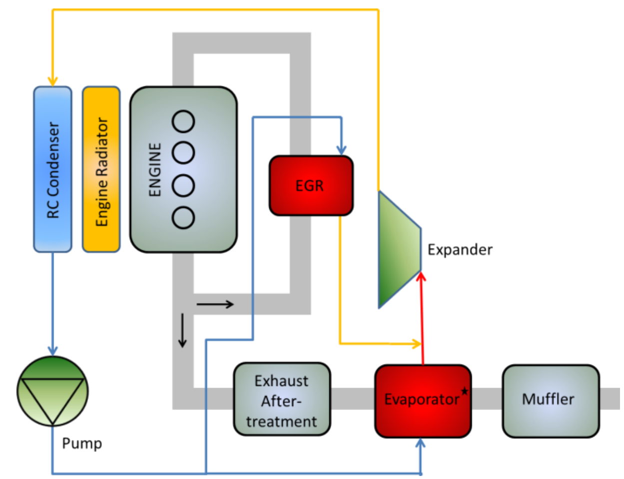
- **3 architectures investigated:**



WHR on exhaust gases only



WHR on exhaust gases and EGR gases in serial

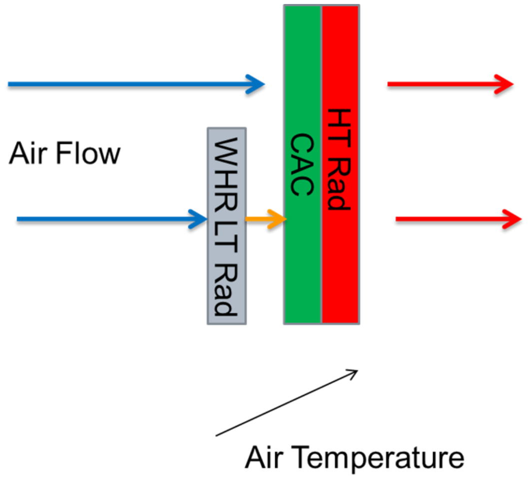


WHR on exhaust gases and EGR gases in parallel

System concept

0D Modeling

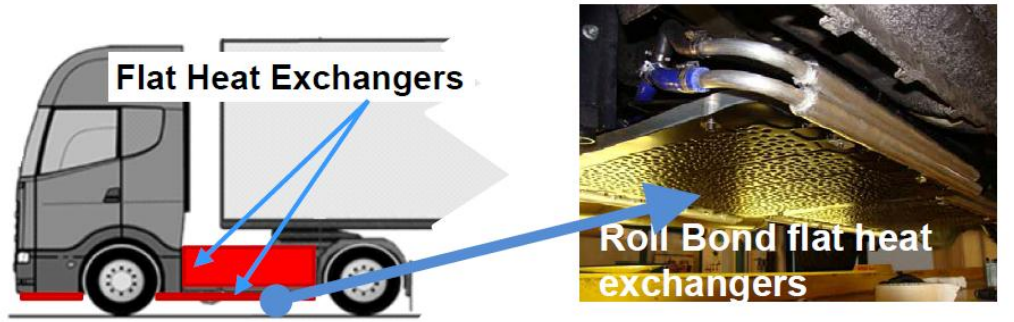
- **Major design constraints:**
  - Heat rejection added to the cooling package:
    - waste heat re-use system: risk to increase the heat rejection needs of the vehicle.
    - Air temperature increases through dedicated Rankine LT Rad or Condenser having an impact on other components of the cooling package
    - Increase of the intake air temperature
    - Increase of the coolant temperature



System concept

0D Modeling

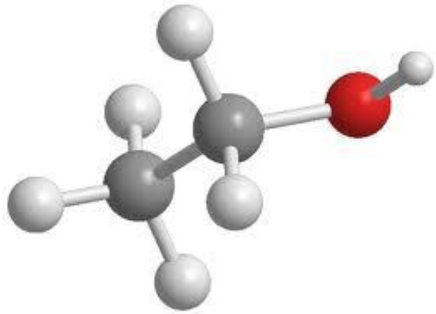
- Minimize its impact
  - Additional innovative heat exchangers integrated in the vehicle body panels.



The flat heat exchangers allow minimising the impact of the heat rejection on the cooling drag. The flat heat exchangers can be manufactured with the roll bond technology (aluminium) or could be polymeric (e.g. twin sheet thermoforming)

System concept

Goal of the study



System concept
0D Modeling

- Working fluid selection:
  - Several criteria to take in account:

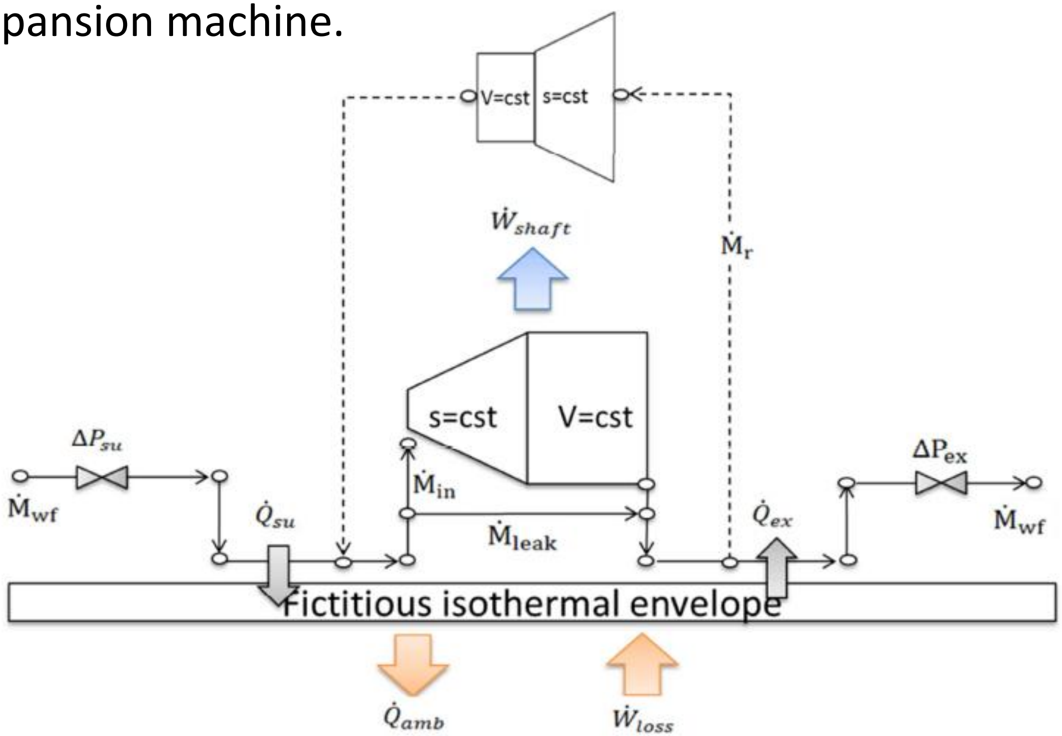
    1. Environmental aspect:
       - in 2017 GWP < 150
    2. The GADSL (Global Automotive Declarable Substance List)
    3. Physical properties:
       - Freezing point
       - thermal stability
       - …
    4. Safety:
       - Fluids ranked as F+ (EEC) or 4 in NFPA (red class) have to be avoided.
       - Flash point and auto-ignition temperature (vehicle crash).

System concept
State of the art

Expander technology	Scroll	Screw	Piston
Rotational speed [RPM]	<10000	<25000	500-6000
Max. Inlet temperature [°C]	215 [2]	490 [3]	>500 [4]
Built-in volume ratio [-]	1.5-4.1	4-5	6-14
Pressure ratio [-]	25 [5]	50 [6]	Same as in ICE

System concept
0D Modeling

- Simulation models for the 3 volumetric expanders:
  - Around 10 parameters to retain the most important physical phenomena inherent the expansion machine.



System concept

0D Modeling

- Simulation models for the volumetric expanders:
  - Calibration of the models on existing machines using experimental data.
    - ➢ References
  - Scaling of the parameters to adapt the models to the machine being currently designed (characteristic length).

Scaling relations applied
to the model
parameters

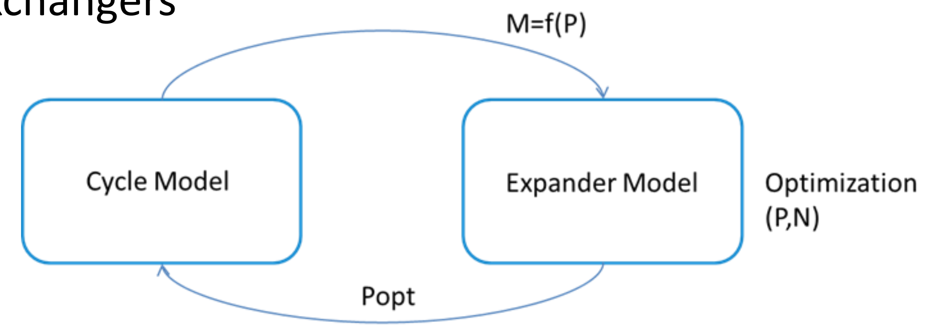
→

Model calibrated on a existing machine (reference)

Model of the machine being designed for the truck application

System concept
0D Modeling

- **Optimization strategy (iterative algorithm)**
  - The evaporating pressure and the rotational speed were optimized in order to maximize the power output of the different systems.
  - Performance are obtained (Shaft power, optimal rotational speed,…)
  - From this optimization also results the size of the different components (design):
    - Displacement of the expanders
    - Exchange area of the exchangers



System concept

0D Modeling

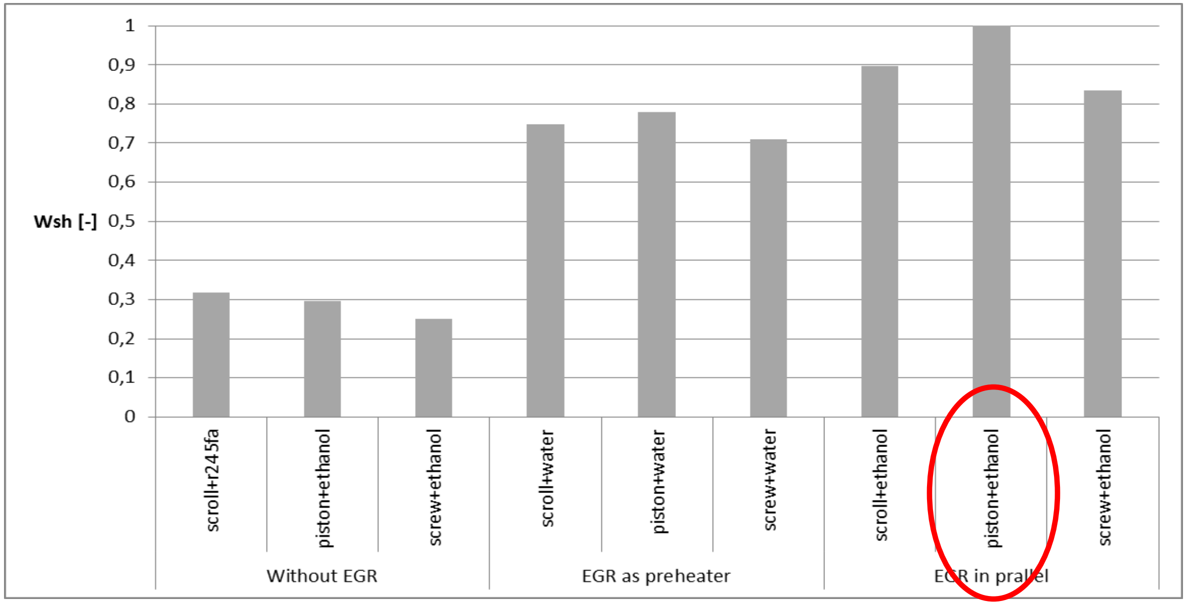
- **Selected operating conditions**

Exhaust gases temperature [°C]	300-400
Exhaust gases mass flow rate [kg/s]	0,2-0,4
Recirculated exhaust gases temperature [°C]	400-500
Recirculated exhaust gases mass flow rate [kg/s]	0,05-0,06
Cooling liquid temperature [°C]	~ 60
Cooling liquid mass flow rate [kg/s]	~ 0,65
Superheating [°C]	5
Subcooling [°C]	5

System concept

0D Modeling

- **Nominal results**



System concept
0D Modeling

- **Conclusion**
  - Help ORC designers to best select the expansion machine and working fluid for truck applications.
  - Selection of the fluid and expansion machine together
    - Preliminary design
  - Performance is not the only criteria
    - Decision array to select the components
  - Future work
    - Fluids comparison
      - Mixtures water/ethanol
    - 1D dynamic simulations for best “solutions “(driving cycle)

Acknowledgement

Thank you