EXAMINATION of REAL WORLD OPERATING CONDITIONS and EMISSIONS of a HYBRID CITY BUS

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Objectives of this work

- Examination of the hybrid city bus
  - operating conditions,
  - engine operating conditions,
  - NOx emissions,
  - fuel saving potentials
    - under real world in-use operating conditions.
INTRODUCTION

Transport sourced emissions

Evitable

Inevitable

NOx, CO, N2, H2O, CO2, PM, HC
INTRODUCTION

Evolution of Emission Standards
Effects of transport sourced emissions
Vehicle emissions are dependent on;
- combustion technology,
- catalyst,
- fuel properties,
- age,
- operating conditions.
EURO VI and Portable Emission Measurement Systems (PEMS)

- EURO VI regulation for heavy duty vehicles requires application of portable emissions measurement systems (PEMS) for verifying the real world in-use and off-cycle emissions.
Advantages of PEMS

PEMS are very useful for many reasons:

- Quick installation
- Real world emission measurement
- Development of accurate emission factors.
Advantages of PEMS

PEMS examine,
- effects of road conditions on:
  - Vehicle operating parameters
    - Speed, location, road grade
  - Engine operating parameters
    - Speed, load, fuel consumption
  - performance of after-treatment technology,
All the tests were carried out on “university route” of Sakarya Municipality city busses. It is 22 km long and the altitude ranged from 30 m to 220 m. The travel time is approximately 60 minutes.
The test measurements were made by using a SEMTECH DS from SENSORS inc.
Vehicle Specifications

- TEMSA AVENUE Hybrid city bus, 12 m long.
- The bus is full and series hybrid.
- Hybrid system generator is powered with a
  - 6.7 liter CUMMINS ISB6.7 EURO 5 engine
  - which produces 250 HP at 2500 rpm.
SIEMENS ELFA ELECTRICAL TRACTION

- No mechanical connection between the engine and the wheels.
  - IC Engine drives a generator that feeds the electric motors.
  - ULTRACAP feeds the electric motors
RESULTS (bus speed profile)

- Maximum speed is as high as 50 km/h
- Many stops with corresponding decelerations and accelerations

City bus speed profile on the university route
Engine speed-load frequency map for the university route

<table>
<thead>
<tr>
<th>Load-speed</th>
<th>Engine Speed, rpm</th>
<th>Duration</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low load-speed</td>
<td>0-50 % 600-1000rpm</td>
<td>720s</td>
<td>37</td>
</tr>
<tr>
<td>Low load-High speed</td>
<td>0-50 % 1000-2200rpm</td>
<td>505s</td>
<td>26</td>
</tr>
<tr>
<td>High load-speed</td>
<td>50-100% 1000-2200rpm</td>
<td>676s</td>
<td>35</td>
</tr>
<tr>
<td>High load-low speed</td>
<td>50-100% 0-1000rpm</td>
<td>21s</td>
<td>2</td>
</tr>
</tbody>
</table>
Engine speed-load map for European Stationary Cycle (ESC) and European Transient Cycle (ETC)
Temperature map for the university route

NO$_x$ emission map for the university route
RESULTS (drive train parameters)

State of charge (SOC),
Hybrid system power (P_SYS),
Ultracapacitor driving power (P_ES_fst),
Bus speed (V),
Generator power (P_GEN),
Engine power (P_ENG)
Results (fuel saving)

- Fuel saving potential of the hybrid system can easily be estimated
  - either
    - integrating ultracapacitor driving power (P_ES_fst)
  - or
    - variation of charging level of the SOC
Fuel equivalent of this energy can be calculated by using the following formula:

\[
\text{Fuel saving} = \frac{n\_\text{stops} \times \Delta \text{SOC} \times \text{Capacity}}{Q\_\text{LHV} \times \eta}
\]

- \( n\_\text{stops} \) is number of the stops on the bus route,
- \( \Delta \text{SOC} \) is the change in charging level of the ultracapacitor during the acceleration,
- \( \text{capacity} \) is the ultracapacitor capacity,
- \( Q\_\text{LHV} \) is the lower heating value of the fuel,
- \( \eta \) is brake thermal efficiency of internal combustion engine.
CONCLUSION (frequency map)

- The total trip duration is 1922 seconds for the university route.
- Hybrid bus operated;
  - 720 seconds at low load-speed conditions,
  - 505 seconds at low load-high speed conditions,
  - 676 seconds at high load-speed conditions.
- No match with ESC and ETC cycles.
CONCLUSION (NOx emissions)

- Mean exhaust temperature remains lower than the SCR light-off temperature on the university route,

- NOx emissions are not reduced to the certification level (2.0 gr/kWh) but to the level of 4.7 gr/kWh, only.
CONCLUSION (fuel saving)

- The city bus fuel consumption for the university route was measured to be 3.56 liter.
- The fuel saving was calculated to be 1.78 liter.
- If this fuel had not been saved, total fuel consumption would have been 5.33 liter.
- As a result, the hybrid system provided 30% fuel saving on this trip.
CONCLUSION (fuel saving)

- Hybrid city bus is a very efficient fuel saver due to its regenerative braking but
  - the fuel saving potential is strongly dependent on
    - the speed profile of the bus route
    - hybrid system optimization strategy.

- While driving on the university route, fuel saving up to 30% was achieved.

- On other routes the fuel saving will not be necessarily the same
While optimizing a hybrid city bus for the best fuel economy and emissions,

- the real world drive characteristics
- the corresponding operating conditions of the engine
- specificiations of the after-treatment system

must be considered.
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Thank you...