ENERGY EFFICIENT ELECTRICAL HEATING OF SCR LINES

Boosting the efficiency of electrical auxiliary consumers in the vehicle is one approach to minimising total fuel consumption. The lines required for operation of an SCR system are primarily heated electrically, with the result that further electrical consumers are integrated as SCR technology becomes increasingly widespread. The development objective for SCR lines from Voss Automotive is therefore to have optimal performance with minimum energy consumption.

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THERMAL MANAGEMENT OF HEATED SCR LINES

Optimal application of diesel engines is in conflict of objectives between low fuel consumption and low NO_x emissions. The SCR technology suitable for compliance with current and future exhaust standards enables an effective reduction in nitrogen oxides. At the same time, the properties of the aqueous urea solution (AUS) as an ammonia precursor in the vehicle pose new challenges. To enable an operational readiness of the SCR systems even when the AUS is frozen (T < -11 °C), the medium must be defrosted and then kept fluid. Depending on the SCR system design (type, number and length of lines) total electrical outputs of up to several hundred watts occur, resulting from the SCR dosing system used. In particular, the requirements for SCR lines in respect to energy will be discussed in detail below.

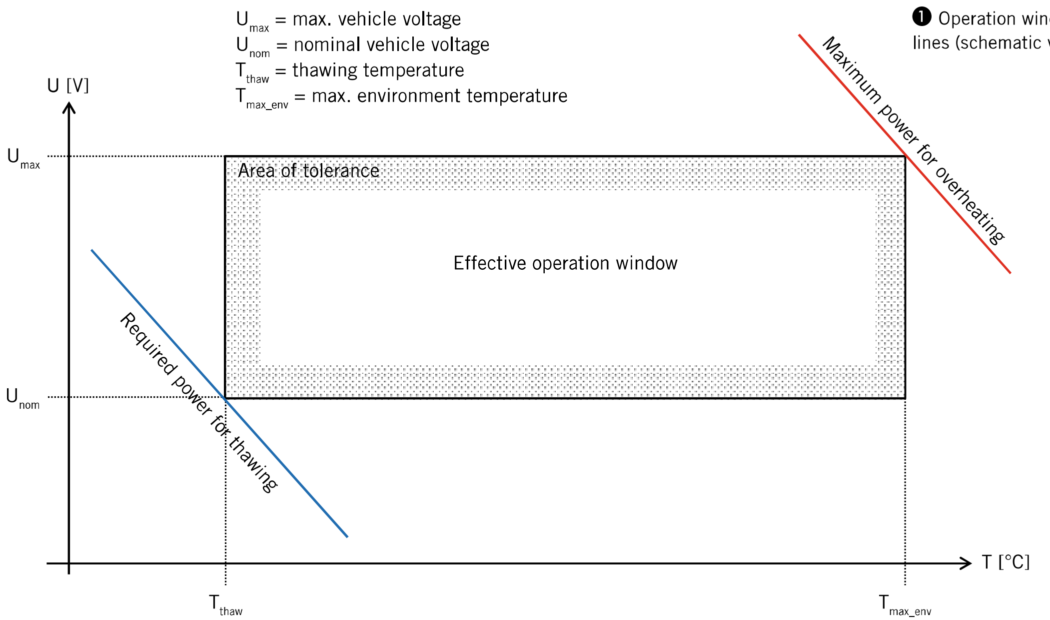
REQUIREMENTS FOR ELECTRICALLY HEATED SCR LINES

The principle tasks of heated SCR lines are to convey AUS without leakage while complying with statutory and customer-specific requirements in regard to the operational readiness of the SCR systems after starting the engine at cold ambient temperatures. The defrosting performance essentially depends on:

- t_{iso}: thickness of the thermal insulation [mm]
- λ: thermal conductivity of the insulation [W/m*K]
- V_{AUS}: AUS volume in relation to the connector type and size [mm³]
- d_{Line}: internal diameter of the line [mm]
- P_{Line}: specific heating power of the line [W/m]
- $P_{Connector}$: heating power of the connectors [W]
- U_{nom}: vehicle electrical system voltage [V]
- T_{Env}: ambient temperature [°C]
- v_{Env}: velocity of ambient air (airstream) [m/s].

The heating of an SCR line must be dimensioned so that the defrosting of the AUS is achieved with minimum energy consumption. Furthermore, thermal damage due to overheating must not result at high ambient temperatures. The operating window in which the functionality has to be ensured is limited by the maximum and minimum vehicle voltage. Further design considerations are the defrosting temperature as well as the (application-dependent) maximum ambient temperature of the line. ❶ shows the operating window defined by the above parameters in terms of quality.

To keep the energy requirement and hence the fuel consumption low, an insulation against the line environment is necessary. The encasing of the line conveying the media with a corrugated



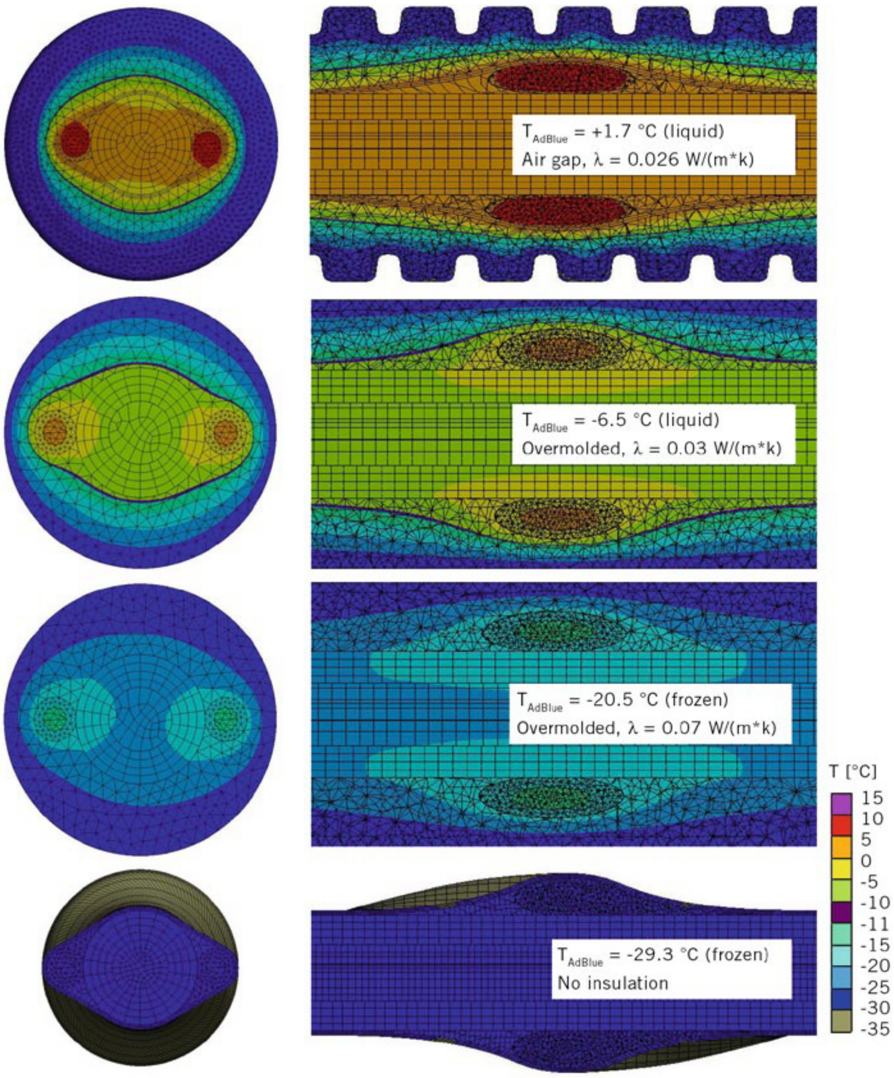
❶ Operation window of electrically heated SCR lines (schematic view) tube represents an effective and, at the same time, low-cost solution. An encapsulation of the quick connectors (QC) is also recommended. The resultant air cushion surrounds the QC and media line, while reducing the thermal losses to a minimum. ❷ shows the simulated heat transmission via the longitudinal and cross section of an SCR line with various insulation measures or without insulation at an ambient temperature of -30 °C, a specific heat output of 9.3 W/m and an internal diameter of 2 mm.

RELIABILITY

SCR lines are primarily installed on the underbody or vehicle frame, and are thus exposed to the effects of the weather. Off-road vehicles also result in increased requirements due to dirt and splash water. Penetrating and freezing water can crucially influence the defrosting performance or completely prevent a defrosting due to the formation of a thermal bridge. The penetration of water and dirt must therefore be prevented by a suitable corrugated tube seal in order to ensure the function of the line over its lifetime. The electrical contacting of the heating elements must be protected against the penetration of moisture. Parasitic transition resistance can otherwise form at the contact points due to corrosion, which then entail a not inconsiderable voltage drop at currents of up to 10 A. The defrosting output is reduced in this case and might no longer be adequate to fulfill the customer requirement. To counteract this effect, gaskets adapted to the material of the heating wire's insulation must be used at the connecting points, these not losing their sealing effect even in adverse conditions. The connecting point itself must also be manufactured so that it ensures a reliable contact over its service life.

ELECTRICAL DESIGN

The heat input into the medium must be homogenous over the circumference of the line length, in order to prevent local hot or cold areas. A constant pitch is therefore required in the case of SCR lines with wrapped heating wire. Also it is necessary to fix the heating wire on the media tube. In this way, it is ensured that the heating wire is located closely on the tube even in the case of small bending radii (routing in the vehicle), thereby guaranteeing an optimum heat transfer. In the area of the QC's, a uniform heat input as far as the holding mechanism of the QC is important so that disconnection points or transfer points to SCR system components such as pump or dosing module do not represent any defrosting limit in the case of multi-section lines. To optimally adapt the performance of the line to the complete integral system, extensive knowledge concerning the function and method of working of the SCR system components is necessary. Voss Automotive operates a specially developed SCR system test bench for this, which can be used to observe the performance of the overall system pump-line-dosing module. The parameter for the electrical conductivity of the SCR line is the specific heating power expressed in W/m. The electrical design of each line variant must be realised in close coordination with the customer. This allows an optimum response to every application. Precise knowledge concerning the application-relevant ambient conditions (convection, hot and cold areas) enables an effective performance design. This enables the operational readiness to be established in the required time, while unnecessarily using electrical energy is avoided. To keep the required energy input as low as possible, an electrical design of the line close to the minimum required performance for defrosting is necessary. In doing so, it must be considered that both the components and production process are afflicted with tolerances. As the ambient conditions and the line parameters statistically vary in terms of their tolerances, worst-case scenarios must be assumed for the



❷ Simulated heat transmission at -30 °C and 9.3 W/m heating power electrical dimensioning so as to permanently ensure the function. The lower the tolerances, the further the calculated performance of a line can be designed at the lower limit. This entails advantages resulting from the reduction in the electrical energy to be used. A higher maximum permissible ambient temperature for the heating operation also results from the lower self-heating. The effective operating window shown in ① becomes larger. A further advantage of an efficient SCR line with low power consumption is the lower current which a vehicle control unit has to provide for this line. Long lines can therefore also be produced, which do not exceed the maximum port currents.

TEST DESCRIPTION

Two test methods are adopted in order to be able to evaluate the various test lines in respect to efficiency and thermal management: Firstly, determination of the minimum output for heating operation; secondly, determination of the defrosting time at constant heat output. Current standard lines made by Voss and by three different providers serve as test lines for this. As not all lines are fitted with heated QC's, only the tube sections are considered in the tests. This consequently enables a direct comparison of these various line concepts. The conditions during the test correspond to those of typical customer requirements:

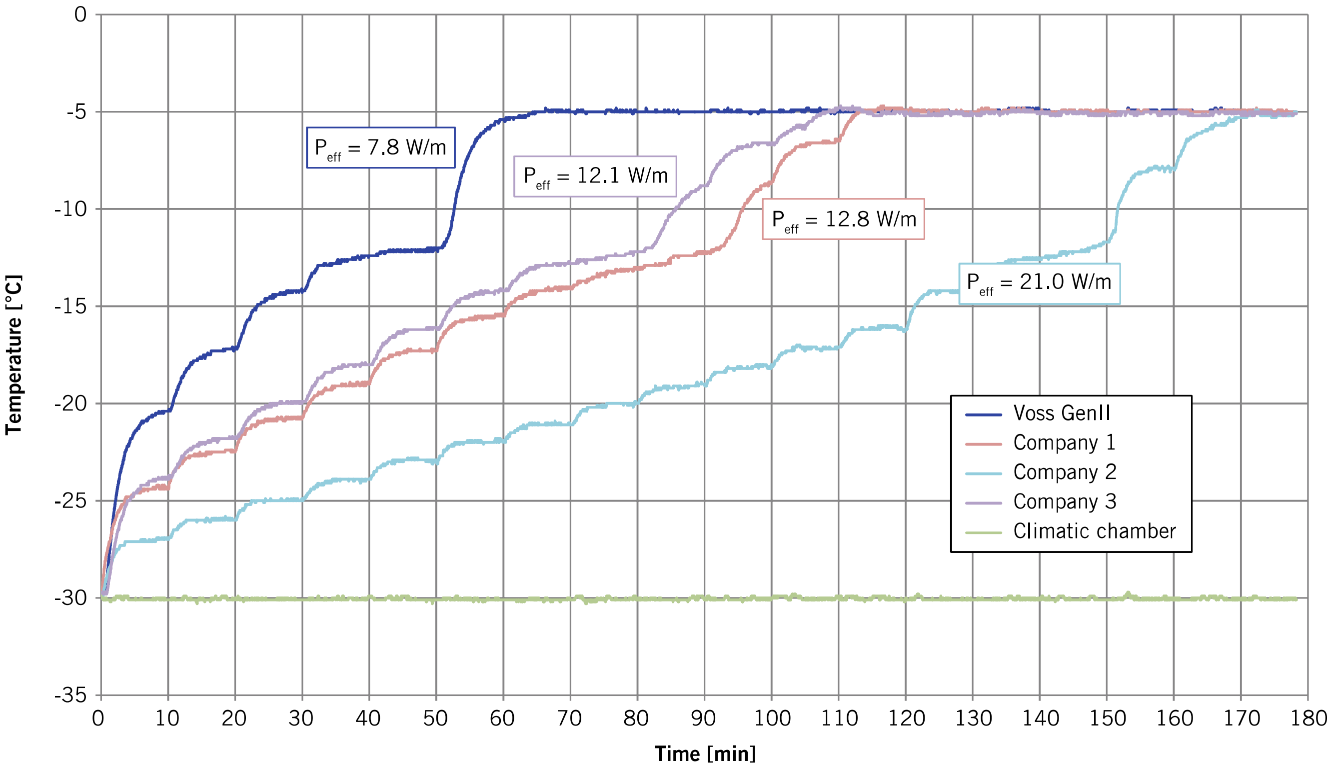
❸ Test setup and alignment of specimens in climatic chamber

: initial temperature: T_{Env} = -30 °C
: wind velocity: v_{Env} = 2.5 m/s
: medium: non-aged AUS as per ISO 22241/DIN 70070.

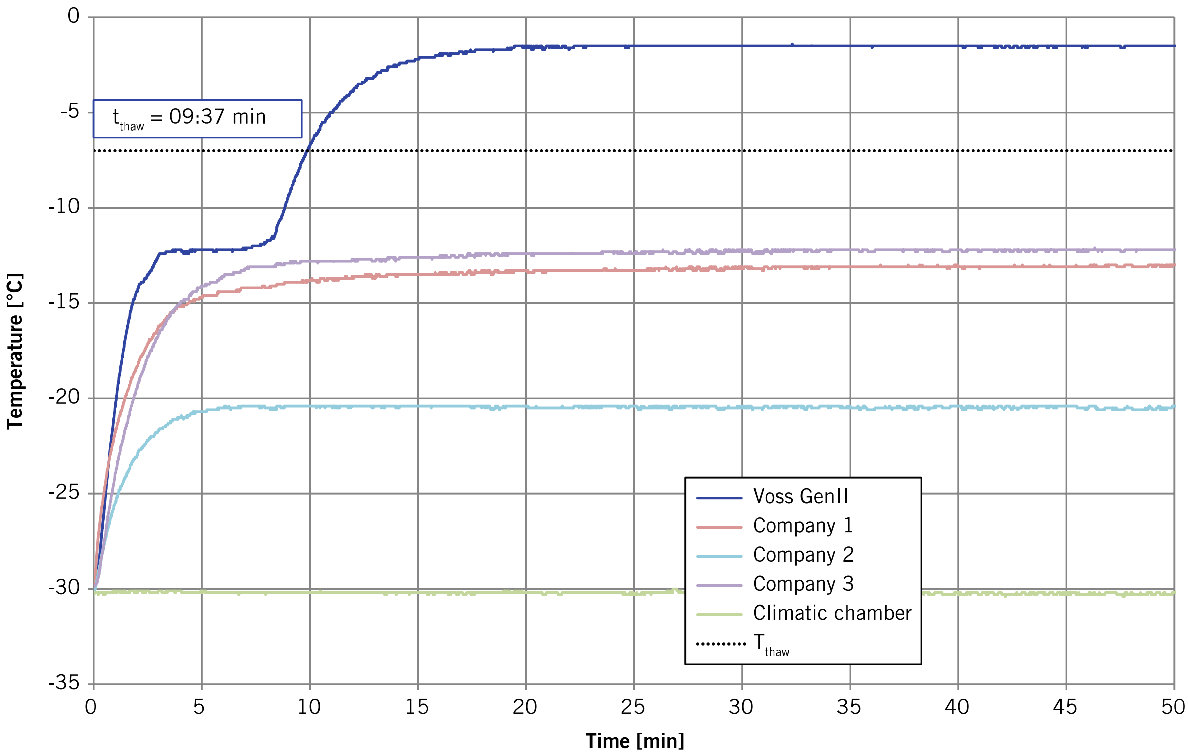
Four test specimens are set up U-shaped in the climate chamber and filled with AUS free of gas bubbles. Two thermo couples are inserted into each line. All lines are oriented to the air flow in the climate chamber in a longitudinal direction so as to avoid mutual influences. A sufficient distance to the floor and walls of the chambers as well as the test specimens amongst themselves is ensured, ❸. The freezing/inertia time before beginning each measurement is 60 min so that the medium is fully frozen within the lines and the same start conditions prevail.

MINIMUM SPECIFIC HEATING POWER TO ATTAIN THE NOMINAL TEMPERATURE

Determination of the minimum specific heating power required to attain and maintain an AUS temperature of -5 °C. At this temperature, a complete liquefaction can be assumed even in the case of aged AUS. The test simulates the heating operation to keep the AUS fluid during



❹ Determination of specific minimal heating power for target AUS temperature of -5 °C



❺ Determination of thawing time with constant specific heating power of 9.3 W/m

dosing, as can occur at cold ambient temperatures. The heating power is successively raised up at uniform time intervals via a four-channel voltage supply until the AUS nominal temperature is attained. The voltage drop via the electrical supply line is taken into account when calculating the effective heating power.

DETERMINING THE DEFROSTING TIME

All lines shown are operated with 9.3 W/m. This corresponds to the Voss reference heating power for SCR lines made from PA tube in the dimension 4x1. This reveals how effectively the heat is transferred into the medium at identical heating power.

TEST RESULTS

The retention of a liquid condition of the AUS simulated in the first test can last for several hours (from vehicle start to vehicle stop), especially in the case of commercially used applications. The electrical energy used cumulatively is correspondingly high.

❹ clearly reveals the need for an effective insulation to the line environment. The provider lines without air gap insulation (provider 1 and 2) require much more electrical energy to reach -5 °C in comparison to the Voss SCR line. Provider 3 uses a corrugated tube with a divergent line setup in which the enclosed air volume is significantly smaller.

❺ clearly shows the different efficiencies of various heating and insulation concepts. The comparison lines of the other providers cannot be defrosted after 50 min operating time, whereas the Voss SCR line is ready for dosing after 9:37 min.

SUMMARY

Compliance with the relevant statutory or customer-specific requirement for the operational readiness of the SCR line can be realised by an effective insulation concept even at comparatively low heating powers. The operational readiness of the overall system must also be taken into consideration, as in particular the coolant-heated AUS tank with a large thermal mass needs a longer time until it is ready for operation. The operational readiness of the overall system essentially depends on the light-off temperature of the SCR catalyst as well as the defrosting time of the AUS tank. Designing an excess heating power is thus not conducive to the objective target in respect to the energy balance.

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