Heat Transfer Characteristics of a Pipeline for CO_2 Transport

Øivind Wilhelmsen[1*], Michael Drescher[1], Armin Hafner[1], Gelein de Koeijer[2] and Jan H. Borch[2]

1) SINTEF Energy Research, 2) Statoil ASA * oivind.Wilhelmsen@sintef.no
Keywords: CO_2, transport, pipeline, heat transfer

Transport of CO_2 is an important component in the CO_2 capture, transport and storage (CCS) chain which has been identified as a possible way of mitigating the global warming. A currently operating CCS project is realised at Statoil's Snøhvit site. Here, natural gas is brought to land for liquefaction and export. The liquefied natural gas (LNG) facility at Melkøya near Hammerfest in Norway is the first plant of its kind in Europe and the world's northernmost LNG facility. CO_2 is separated from the natural gas mixture before liquefaction to avoid freeze-out of solid particles. The captured CO_2 is then transported in a pipeline and re-injected in geological formations in the sea bed. Knowledge about the heat transfer characteristics of the pipeline is important to be able to predict the behaviour in case of pipeline-depressurization, sudden pump stops and wellhead valve closures. Many different conditions and substances may be found around the 153 km long CO_2 pipeline between Melkøya and the re-injection site. Examples on surrounding substances are sea water, rock and gravel. Each of them has different heat transfer characteristics. To provide more accurate estimates of the heat transfer from the pipeline to the ambient and vice versa, a heat transfer test facility was built at the Statoil Research Centre in Trondheim as Phase II of the CO_2 IT IS project [1] (partly funded by the CLIMIT program). Here, an exact replica of the original pipeline used at Snøhvit was submerged in a container to investigate the heat transfer characteristics. Liquid CO_2 at controlled conditions was applied on the inside of the pipeline sample whereas various substances at different temperatures were used on the outside. In this work, the initial results associated with the heat transfer experiments at the test facility are presented. The initial experiments with tap-water as the surrounding substance show that the test facility successfully can be used to predict the heat transfer characteristics on both the inside and the outside of the pipeline. The saturation pressure of the liquid CO_2 was varied between 25 and 33 barg, whereas the overall mean water temperature was varied between 2 and 11 °C. In the introduction, the main components of the test-facility will be described. Furthermore, the method of calculating the heat transfer characteristics of the pipeline will be explained. Challenges and pit-falls will then be discussed. Subsequently, the initial results will be presented together with estimates of the inner, outer and the overall heat transfer coefficients of the pipeline and a comparison between these values and the performance of empirical expressions found in the literature. The heat transfer coefficients will change with both water and CO_2 conditions and these effects will be discussed, both with respect to the experiments and the theoretical modelling. The outer heat transfer coefficient takes into account the heat transfer between the water and the insulated pipeline. Figure 1 shows a comparison between values for the outer heat transfer coefficient as predicted by empirical expressions and experiments for six different water

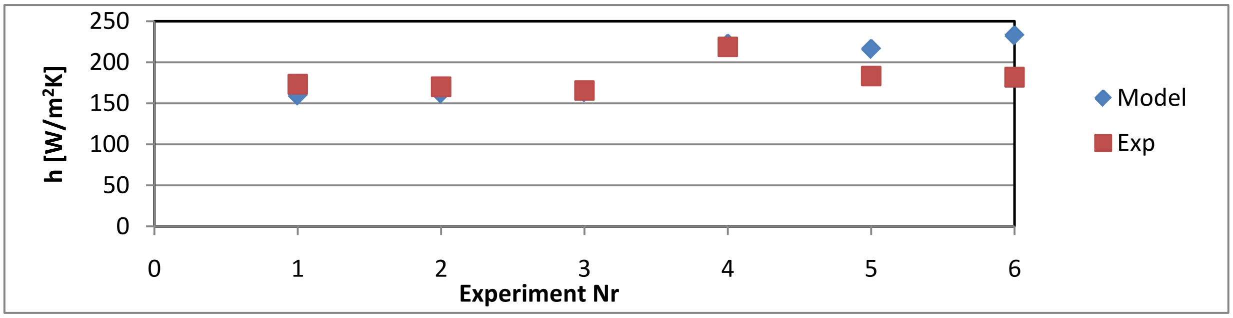

Figure 1. Outer heat transfer coefficients, h, of a CO_2 pipeline as predicted by experiments and empirical models.

temperatures. The figure shows that the empirical expressions perform well with tap- water as the surrounding substance. It will be discussed how this can be further used to gain insight into how different ambient conditions may affect the heat transfer. Future experiments at the test facility will also investigate the heat transfer characteristics of the pipeline with other surrounding substances such as mud, salt-water and gravel. In the initial experiments, both the heat transfer at the outside and the boiling regime inside the pipeline were dominated by free convection based on the measured temperatures and the calculated heat transfer coefficients. The effect of a changing boiling regime, from free convection to nucleate boiling will have a substantial effect on the heat transfer characteristics of the pipeline according to established models. This is thus a phenomenon which will be further investigated in future experiments. A quasi steady-state, one dimensional model for ice formation has been implemented in *Matlab 7.8.* The model takes advantage of the information about the heat transfer characteristics of the pipeline obtained at ice-free conditions and may be used to give estimates on how ice forms around the pipeline. Figure 2 shows how the ice thickness and the overall heat transfer coefficient change with time as predicted by this model. The figure shows that even modest ice formation is expected to have an effect on the heat transfer to the pipeline. A comparison between the ice formation experiments and predictions of the established model will be made, and this will be used to assess whether a simple ice-formation model is sufficient to predict the ice thickness around the pipeline.

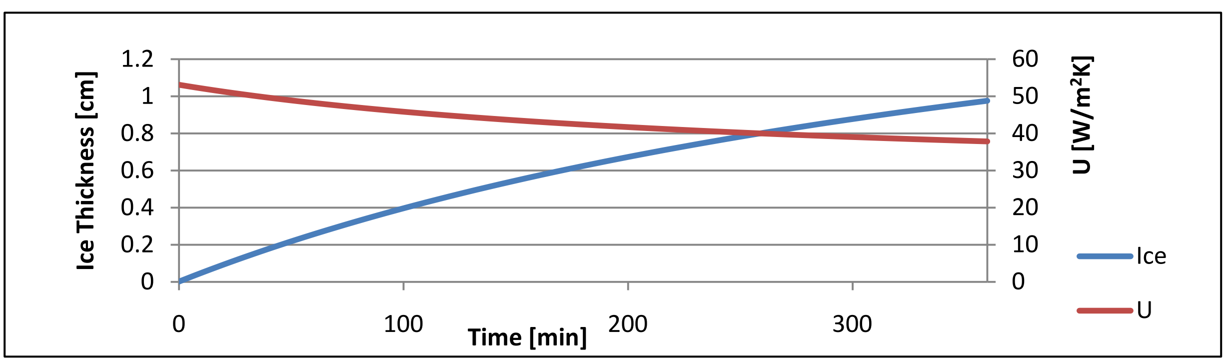

Figure 2 Model prediction of ice thickness and the overall heat transfer coefficient, U.

Reference

[1] De Koeijer G. et al. CO_2 Transport – Depressurization, Heat Transfer and Impurities, *GHGT-10 proceedings*, Sept. 2010