Coupling between Continuity/Momentum and Energy Equation in 1D Gas Flow

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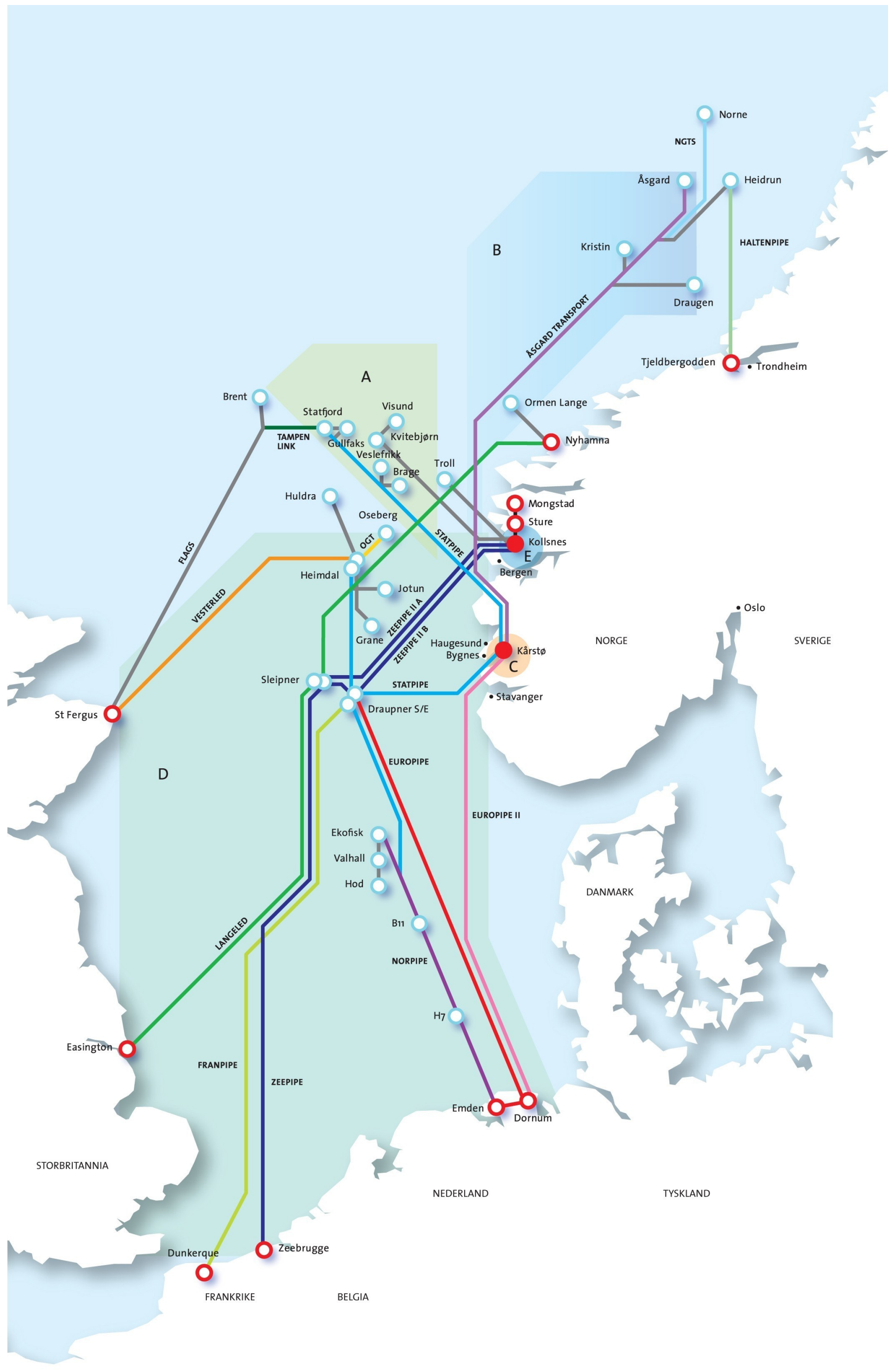
Introduction

Natural gas is transported from the Norwegian continental shelf to continental Europe through high pressure offshore transmission pipelines.



Overview of the Norwegian natural gas transport system which Gassco operates.

To know the state of the gas between two measuring points one has to rely on computer models. These models are used for general monitoring of the gas and predicting the pipeline hydraulic capacity. It is therefore crucial that these models are as accurate as possible.

1D Flow Model

For long pipelines one assumes a 1D model. The governing equations are

Continuity

$$\frac{\partial\rho}{\partial t}+\frac{\partial(\rho u)}{\partial x}=0 \tag{1}$$

Momentum

$$\frac{\partial(\rho u)}{\partial t}+\frac{\partial(p+\rho u^2)}{\partial x}=-\frac{f\rho u|u|}{2D}-\rho g\sin\theta \tag{2}$$

Energy (internal energy form)

$$\rho c_v\frac{DT}{Dt}+T\left(\frac{\partial p}{\partial T}\right)\frac{\partial u}{\partial x}=\rho\frac{fu^3}{2D}+\rho q \tag{3}$$

The density can be related to the pressure through a real gas equation of state

$$\frac{p}{\rho}=ZRT \tag{4}$$

where $Z=Z(p,T)$ is the compressibility factor.

The governing equations are solved numerically using a linearized implicit finite difference scheme. This scheme is second order correct in time and first order correct in space [1].

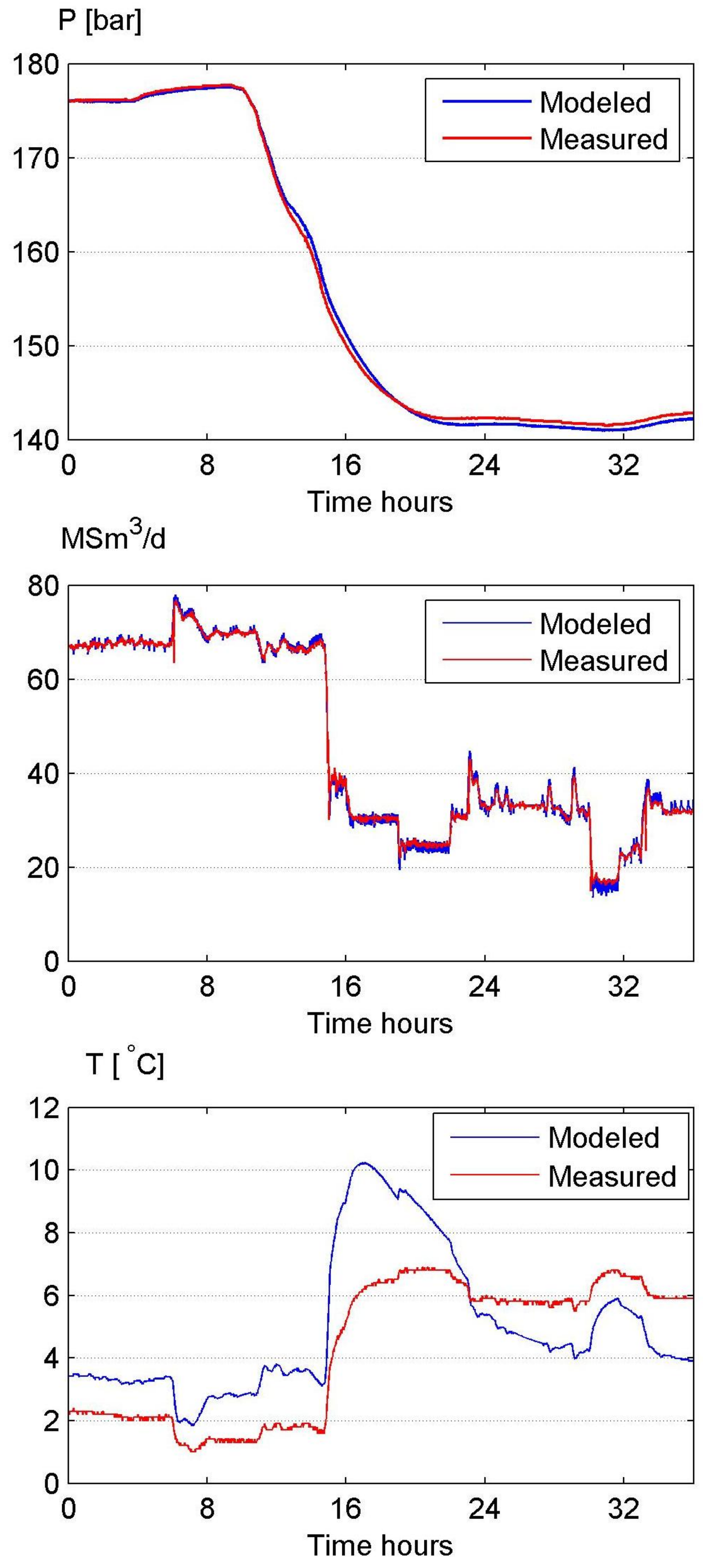
Solution Strategy

Because the flow field depends on temperature, all three governing equations should be solved simultaneously. For large networks this can become impractical due to the demand on CPU time. The CPU time can be reduced by solving the energy equation separately from the continuity and momentum equation.

Two options for solution strategy will be considered; fully coupled or one-way coupled momentum-energy budget.

Results

Simulations were performed on 650 km offshore pipeline. Both solution strategies were applied. Results are validated against operational data.

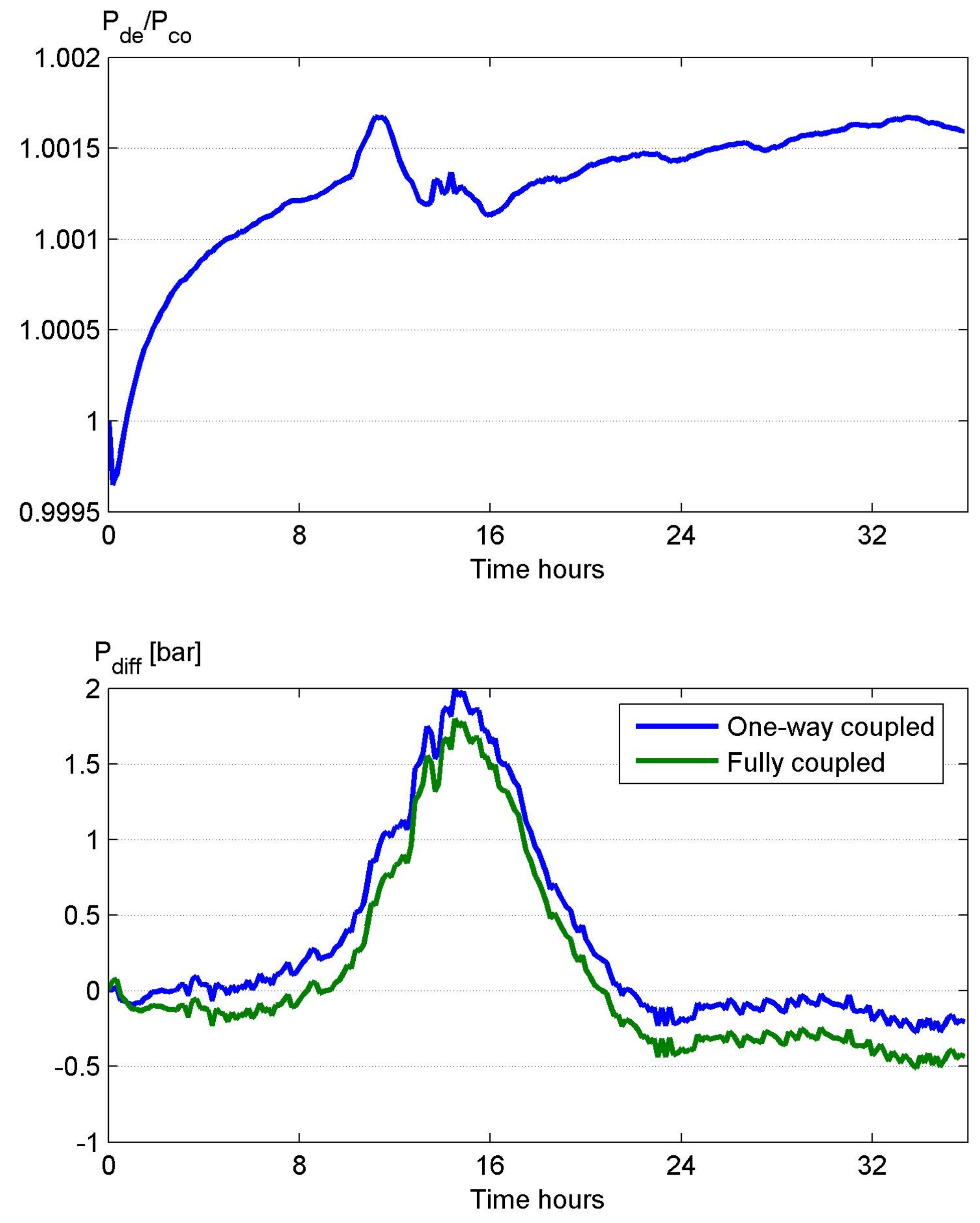


Top figure inlet pressure, middle outlet mass flow and bottom outlet temperature. Results are for fully coupled model.

Difference between the two solution strategies is not visible on figure. CPU time reduced by 25% when decoupling energy equation.

Results for inlet pressure and mass flow agree well with measured values. Noticeable error in outlet temperature. Uncertainty in temperature most likely due to total heat transfer coefficient U and ambient temperature T_a.

Difference in Solution



Top figure: Ratio of pressure between fully coupled and one-way coupled solution. Bottom: Difference between modeled and measured inlet pressure.

Ratio of modeled inlet pressure between a fully coupled and one-way coupled solution is shown in the top figure. The difference is small, at most 0.15%. For outlet mass flow and temperature the difference is even smaller.

The difference between modeled and measured inlet pressure is shown in the bottom figure. There is a slight difference during the transient.

Conclusion

- PMS tools often decouple energy equation from continuity and momentum equation to reduce CPU time.
- For a typical Gassco case it is shown that this simplification is acceptable. Changes in state variables are so slow that one can safely solve the energy equation separately.
- For a 650 km pipe the CPU time can be reduced by 25%.
- Modeled pressure and mass flow agree well with measured values. Error in temperature most likely due to uncertainty in total heat transfer coefficient and ambient temperature.

Acknowledgment

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References

[1] M.Abbaspour and K.S.Chapman, “Nonisothermal Transient Flow in Natural Gas Pipeline,” *Journal of Applied Mechanics*, May 2008.