A Lumped Parameter Approach for Determining the Pressure Gradient in Gas-Liquid Annular Flows

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Abstract

This study defines a statistic-derived lumped parameter approach to determine the pressure gradient in two-phase annular flows. The statistical model was defined by coupling: (1) the ordinary least squares method (OLS) to determine the relationship between the variables, (2) the variance inflation factor (VIF) to check for multicollinearity issues, and (3) the least absolute shrinkage and selector operator (LASSO) to select the relevant predictors. Finally, a lumped parameter approach is derived based on the classification and regression tree (CART) approach. The model identifies the liquid and gas Reynolds numbers, the liquid phase properties, the pipe diameter, and the surface tension as significant variables influencing the two-phase pressure gradient.

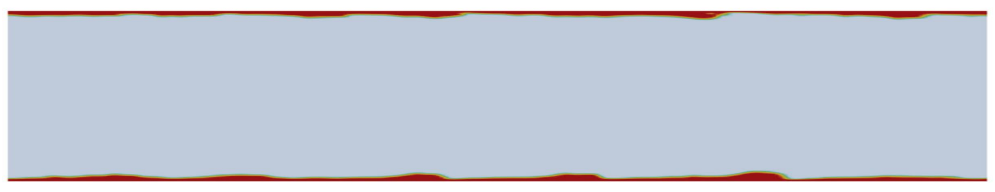
Keywords: Downwards annular flow, pressure gradient, statistical analysis, lumped parameter approach.

Independent variables
Pipe diameter
Liquid Reynolds number
Gas Reynolds number
Phases' properties

Input

Experimental data

CFD simulations

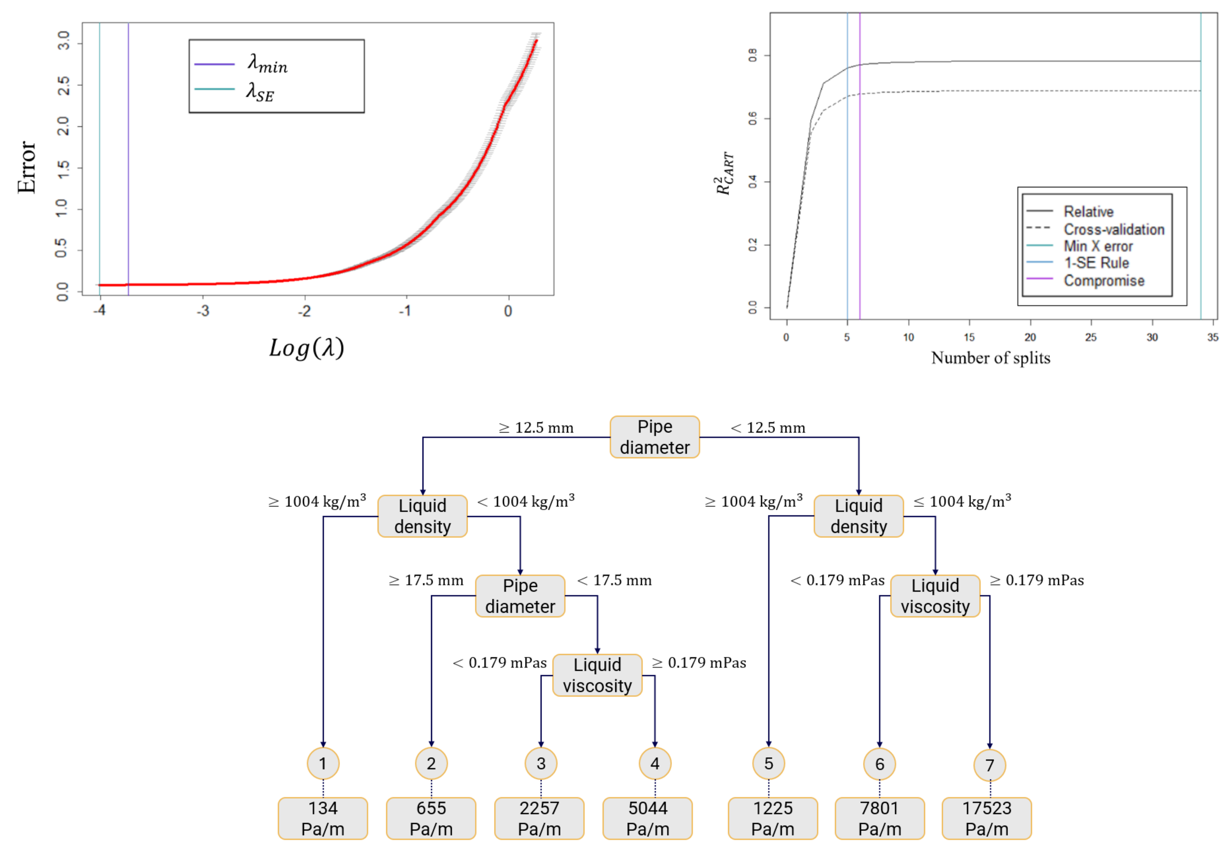


Correlation results

$$\left.\frac{\Delta p}{\Delta L}\right|_{tp,f} = \Phi_l^2 \left.\frac{\Delta p}{\Delta L}\right|_l = \Phi_g^2 \left.\frac{\Delta p}{\Delta L}\right|_g = \Phi_{lo}^2 \left.\frac{\Delta p}{\Delta L}\right|_{lo} = \Phi_{go}^2 \left.\frac{\Delta p}{\Delta L}\right|_{go}$$

OLS+ VIF + LASSO + CART

Results



Methods

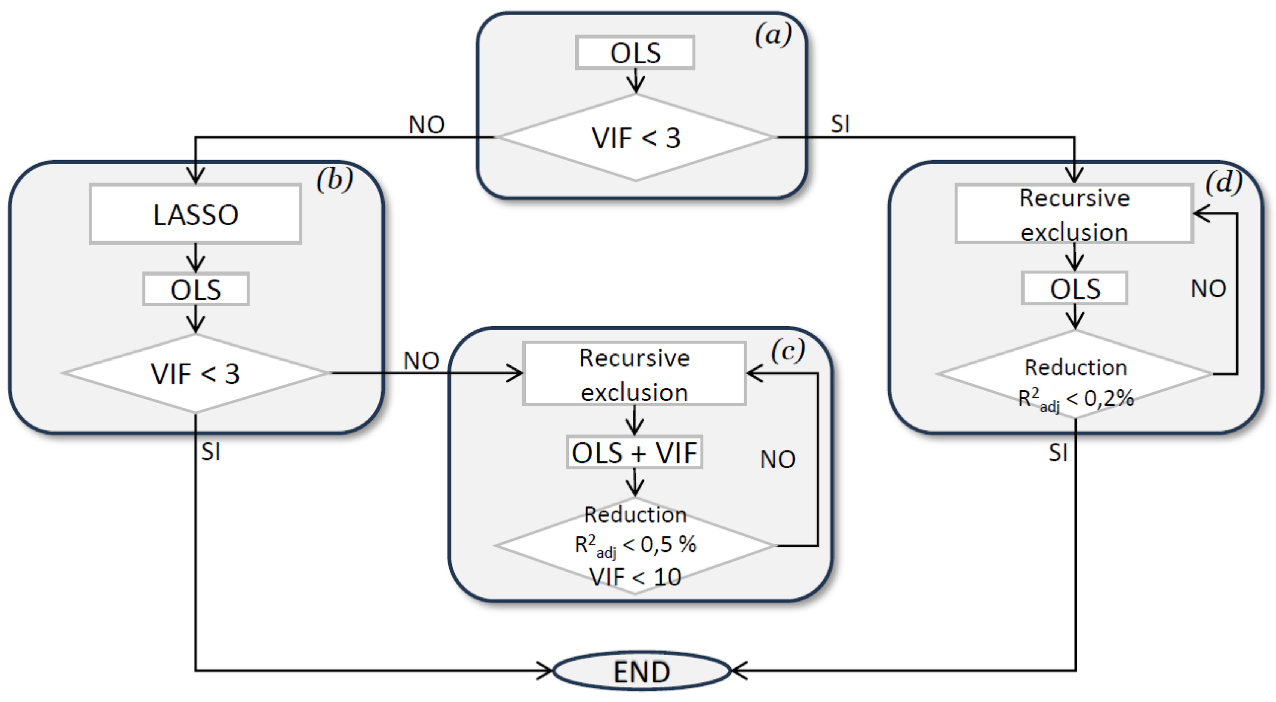
Independent variables

The independent variables selected for the statistical analysis are:

- **pipe diameter**: from 10 mm to 35 mm;
- **liquid Reynolds number**: from 2 000 to 5 500;
- **gas Reynolds number**: from 10 000 to 40 000;
- **phases' properties**: the independent variables that characterize the fluids are the gas and liquid densities, and dynamic viscosities ($\rho_g, \rho_l, \mu_g, \mu_l$) along with surface tension σ for the interaction between the fluids. The fluids considered are: (I) air-water at 22 °C and 50 °C, (II) vapor-water at saturation temperature and atmospheric pressure, (III) refrigerants at saturation temperature and atmospheric pressure (R22, R134a, R125, R32, R236ea, R114, R152a, R12).

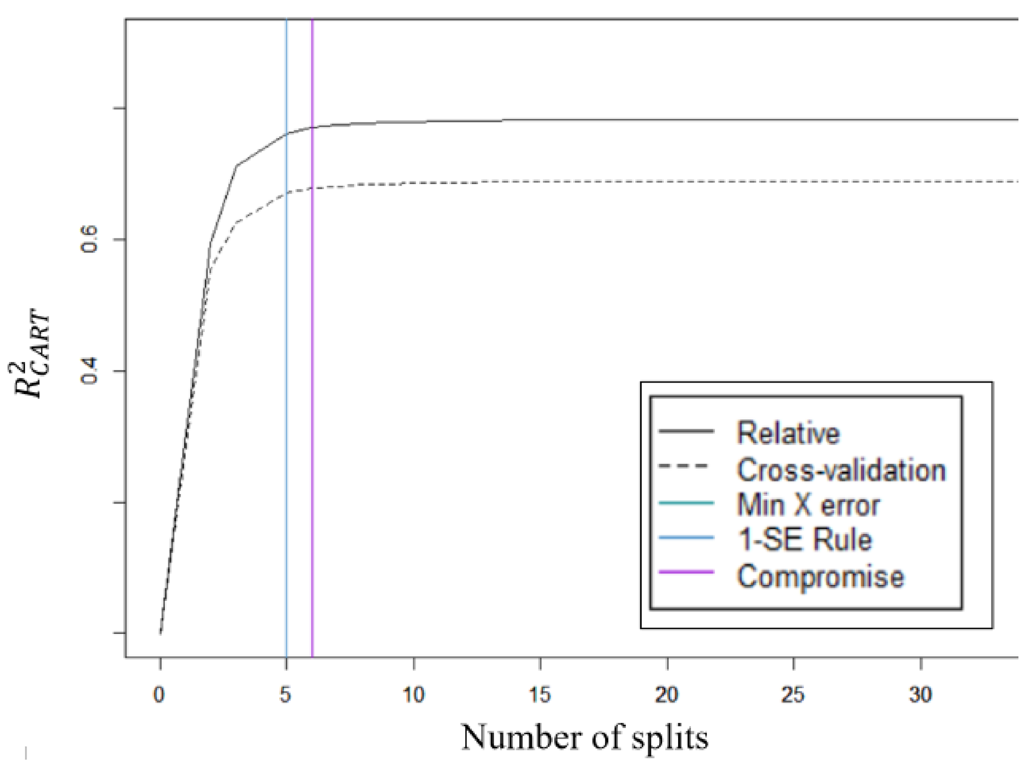
Methods

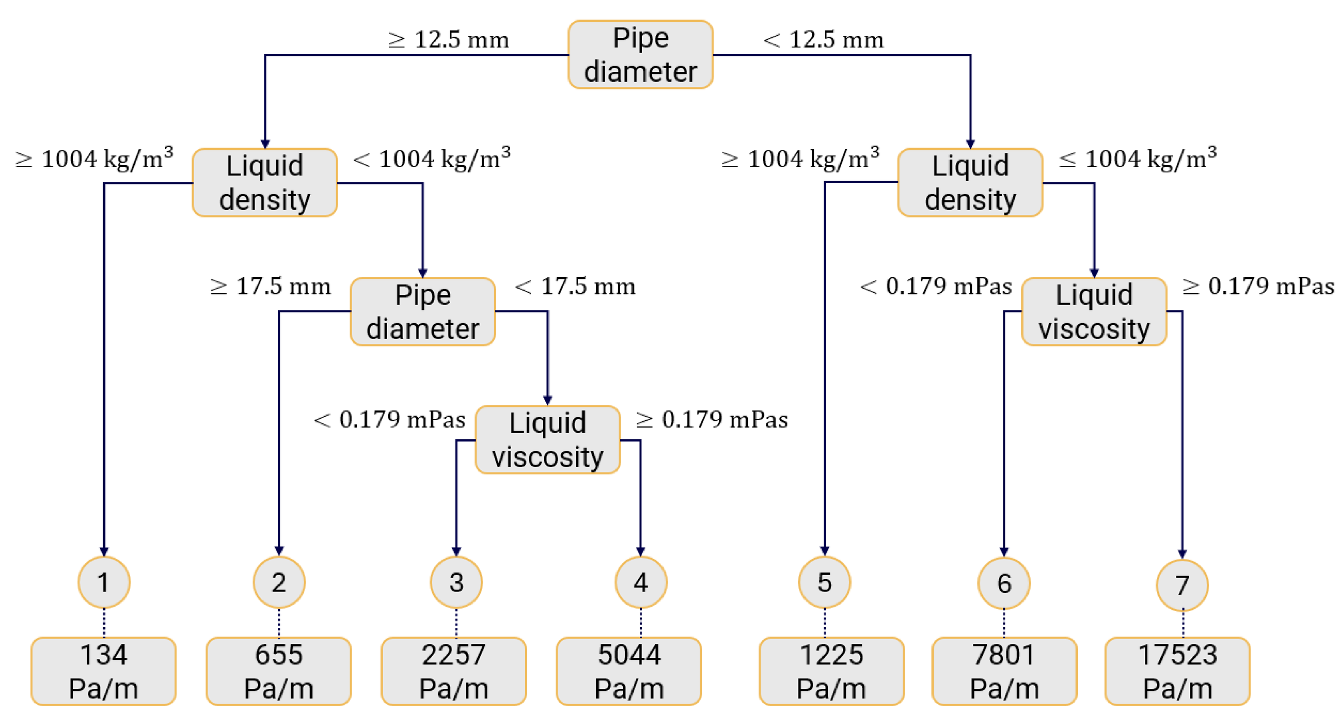
The statistical method was defined by coupling the ordinary least squares method (**OLS**) to determine the relationship between dependent and independent variables, the variance inflation factor (**VIF**) to check for multicollinearity issues, and the least absolute shrinkage and selector operator (**LASSO**) to select the significant predictors. Finally, based on the regression results, the classification and regression tree approach (**CART**) is used to segment the dataset and to define a lumped parameter approach for determining the pressure gradient.



Results

Independent variables	Significance	VIF
Gas Reynolds number	***	1
Liquid Reynolds number	***	1
Pipe diameter	***	1
Liquid density	***	3.62
Liquid viscosity	***	2.05
Surface tension	***	5.27





Conclusions

This study proposed a statistics-derived lumped parameter model to determine the pressure gradient in two-phase annular flows.

The statistical model implemented identifies the pipe diameter, the gas and liquid Reynolds numbers, the liquid phase properties, and the gas-liquid surface tension as significative predictors. An increase in the phases Reynolds numbers increases the pressure gradient. Conversely, an increase in the liquid density and a decrease in the liquid viscosity reduces the pressure gradient, and the same was found for an increase in the pipe diameter.

The proposed approach could be applied to other operating conditions and flow regimes as a further development.