Derived Simplified Models for Estimating Venturi Scrubber Performance

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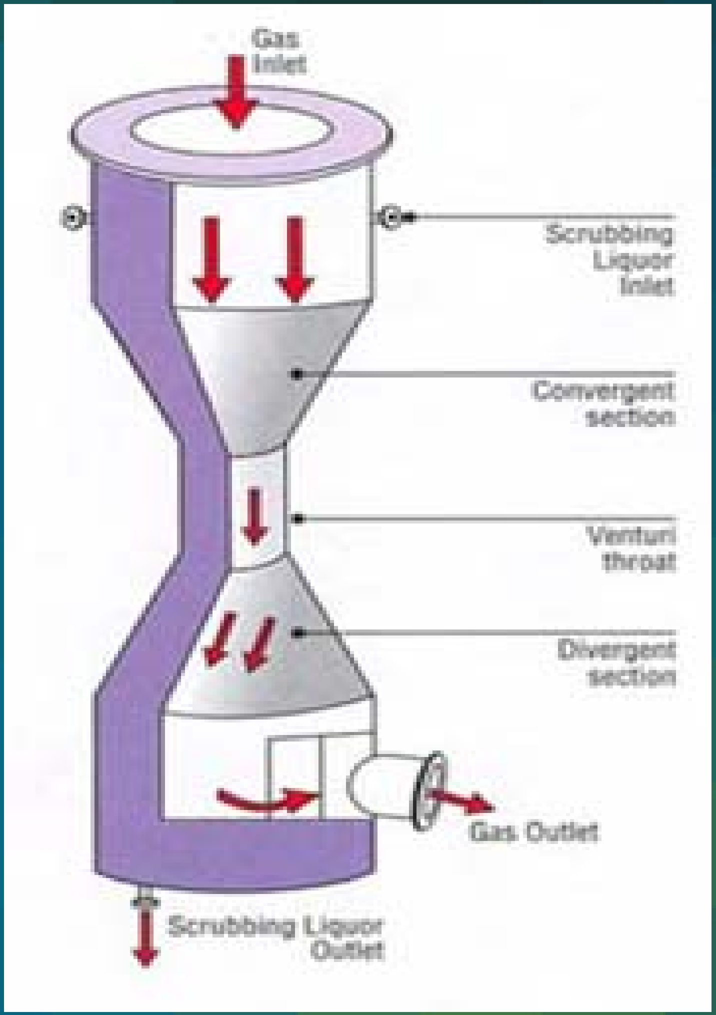
The Venturi Scrubber

- For nearly a century venturi type (atomizing) scrubbers have been a standard for effluent gas stream cleaning
- They are used because:
  - They effectively remove submicron particles
  - They are compact and easy to built
  - Initial investment costs are relatively low
  - They operate in problematic conditions such as high temperature or highly corrosive effluents
  - They also work well when sticky or high viscosity particles must be collected

- The cleaning mechanism of these scrubbers have been extensively studied, and they are recognized to be comprised of inertial impaction.
- The factor which limits the application of these control devices in the high operation costs.
- The expense is primarily a result of the amount of energy required to move the effluent gases across the high pressure drop required for efficient gas cleaning

- In a venturi scrubber the particle laden gas is accelerated in a converging section
- The accelerated gas atomizes a scrubbing liquid at or above the throat
- The impaction in the throat section is a function of the differential velocity
- A second stage of collection occurs in the diverging section as the gas slows faster than the scrubbing solution droplets



- The literature contains a number of models to predict venturi scrubber efficiency.
- The models are useful in optimizing and designing new scrubbers or predicting the effects of changes in existing ones.
- Some of these models are explicit analytical expressions while a vast majority are rather complex models requiring numerical solutions with a computer.

- The review of the literature showed that the use of current models to predict both pressure drop and collection efficiency may be somewhat limited.
- This limitation is primarily due to the complexity of the equations for performance prediction and the need for numerical solutions
- Also, some of the currently used simple models are limited in application because of their poor correlation to actual performance data from operating systems.

- The equations derived by Hesketh are usable only as predictors of total system efficiency and do not account for particle size variation or its effect on collection efficiency

$$\frac{C_o}{C_i} = 3.47 \Delta P^{-1.43}$$

or

$$\frac{C_o}{C_i} = \frac{9.52 x 10^4}{V_t^{2.86} \rho_g^{1.43} A^{0.19} L^{1.12}}$$

- Some other considerations in a new simplified model were in the work of Crowder. He found that a simplified model's accuracy was a relatively conservative estimate of efficiency as compared to the data of Behie and Beeckmans and that there was a general improvement in the ability to predict efficiency in the lower velocity ranges and small particle sizes when compared to Johnston's simplified equation

$$\mathrm{E} = 1 - e^{-KL\sqrt{\Psi}}$$

where

$$\Psi = C\rho_p V_r D_p^{\,2} / 18 D_d \mu_g$$

- The objective of this study was to propose a model(s) for venturi scrubber performance from existing data sets and calculated dependent variables as a regression equation for:
- L_{min} = minimum contactor length or the location of static velocity in the throat
- VR = the relative velocity within the venturi (Vg-Vd)
- VRR = absolute relative velocity (Vg-Vd/Vd)
- Using Gas volume (gvol), Gas velocity (gvel), Liquid to gas ratio (wrao), and Throat length (TL) as the design inputs

- Using the previous work on model estimates for the efficiency and the pressure drop, proposed model forms were input into the non-linear regression procedure of jmp™ (SAS Institute, Cary, N.C.) which produced a least-squares or weighted least-squares estimates of the parameters LMIN, VR and VRR. These identified parameters were taken from previous scrubber performance tests.

$$Y = A * e^{(gvol)^{B}(gvel)^{C}(wrao)^{D}(TL)^{E}}$$

- Using this procedure the convergence criteria set in the regression limits could only be met by two of the three variables (LMIN and VRR), but the resulting model equations were not good predictors at lower range of values for LMIN and VRR.
- The next operation was to assess the power law relationship of the form:

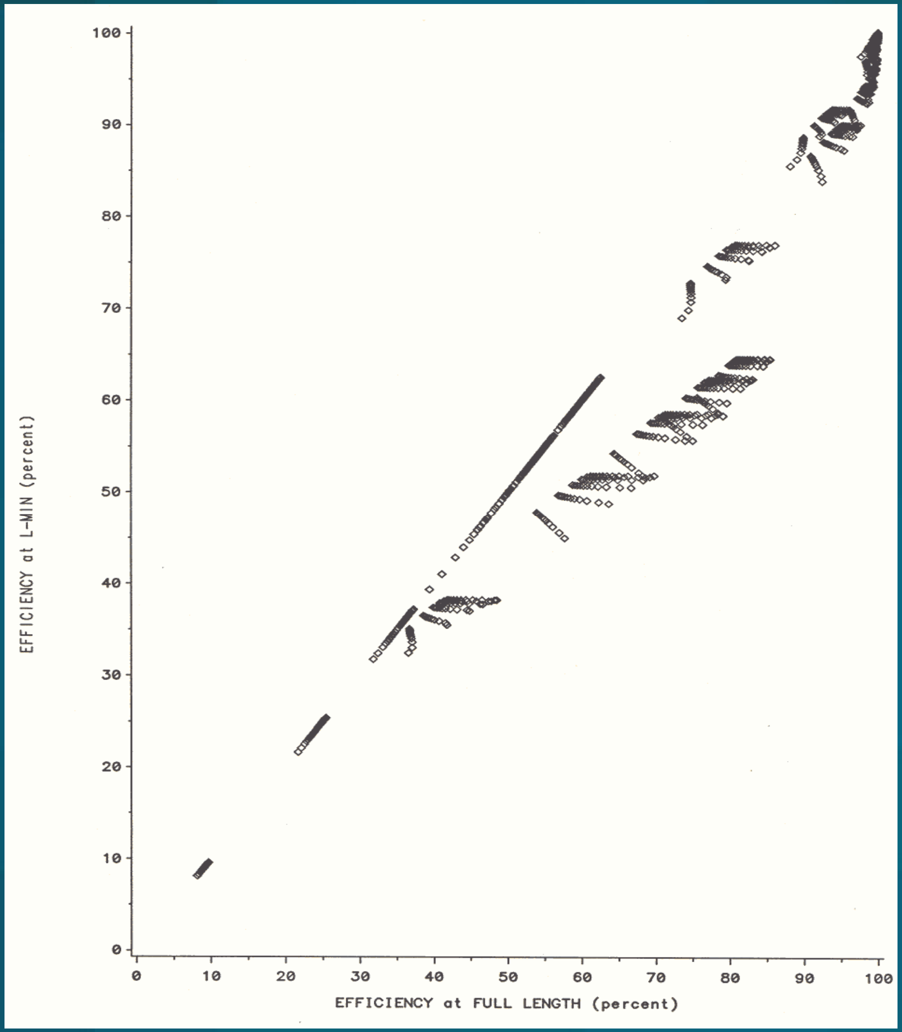
$$Y = A * (gvol)^{B} (gvel)^{C} (wrao)^{D} (TL)^{E}$$

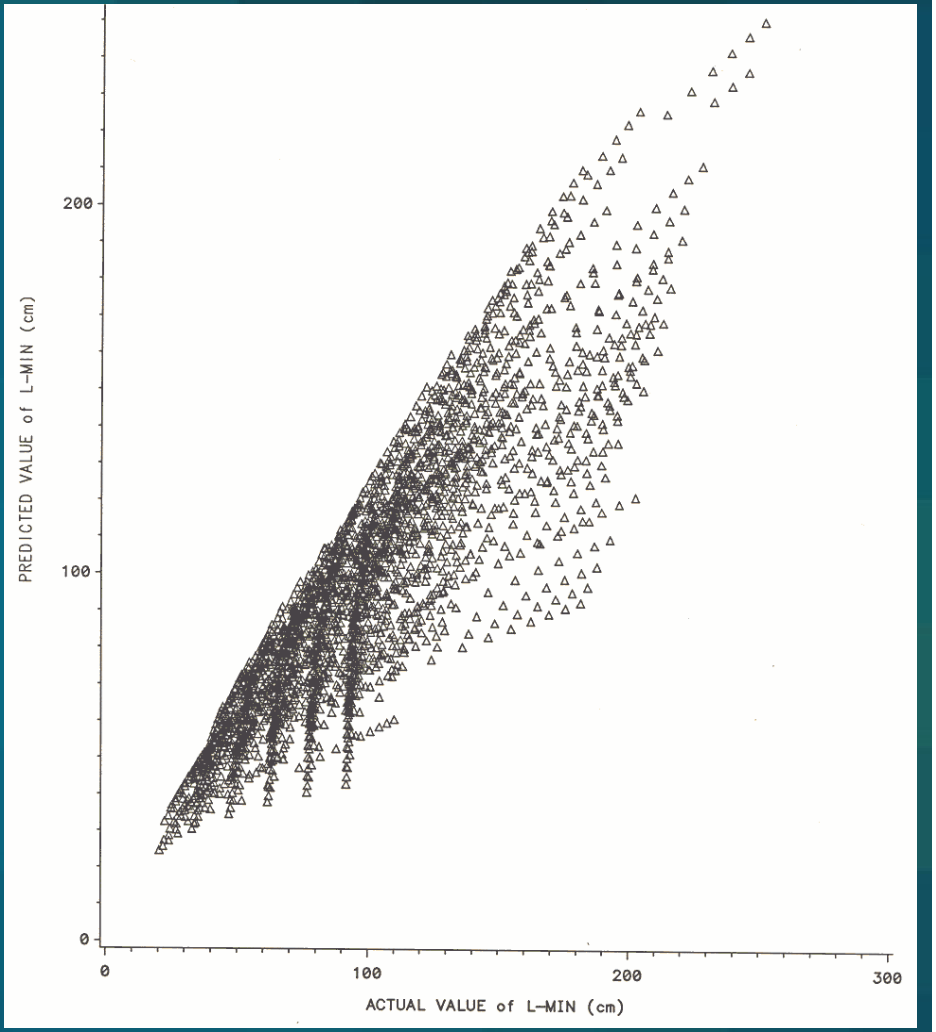
- In this form a log linearization of the operating parameters appeared appropriate and this transform would allow for the calculation of a general linear regression of the three variables.

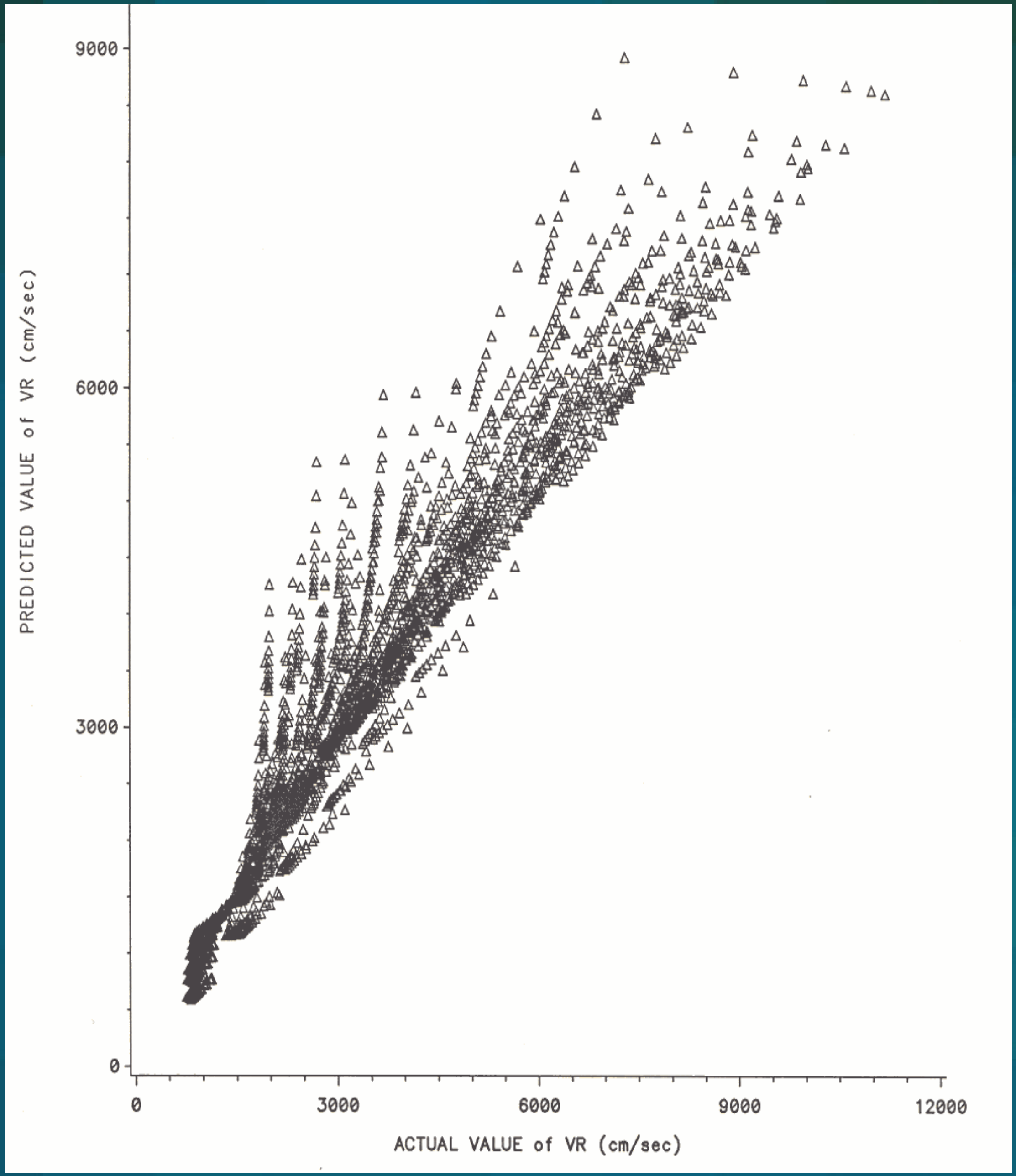
$$\ln Y = \ln A + B\ln(gvol) + C\ln(gvel) + D\ln(wrao) + E\ln(TL)$$

Operating parameters of the venturi to be modeled were set in the ranges of (gvel) 100 to 600 fpm, (gvol) 5000 to 100,000 cfm, (wrao) 1 to 30 gallons per 1000 cubic feet, and (TL) 0.5 to 3 feet. The particle distributions used in the model development were 0.5 to 5.0 micrometers

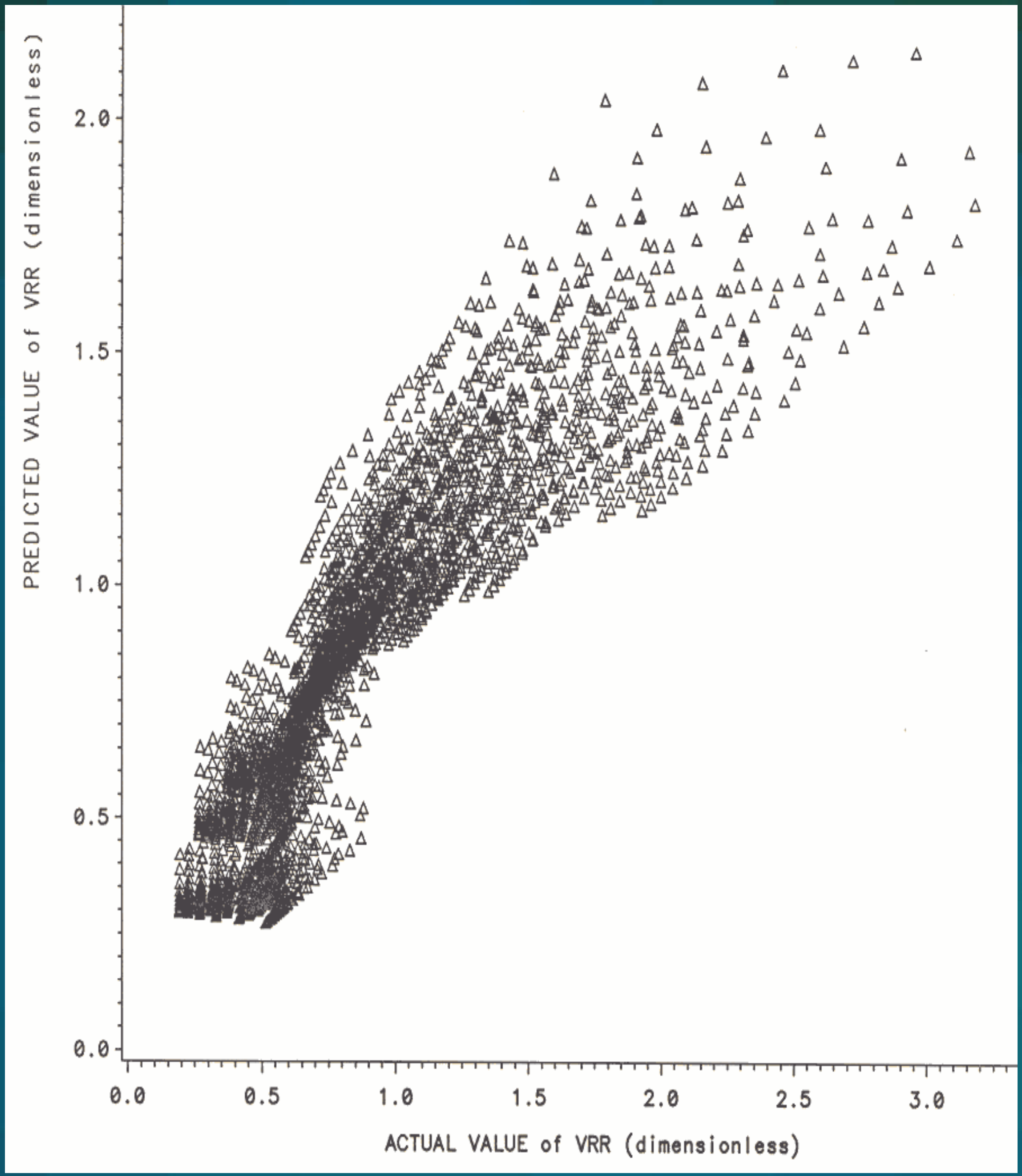
Efficiency of Full Throat length vs LMIN and LMIN prediction versus actual complex model calculation





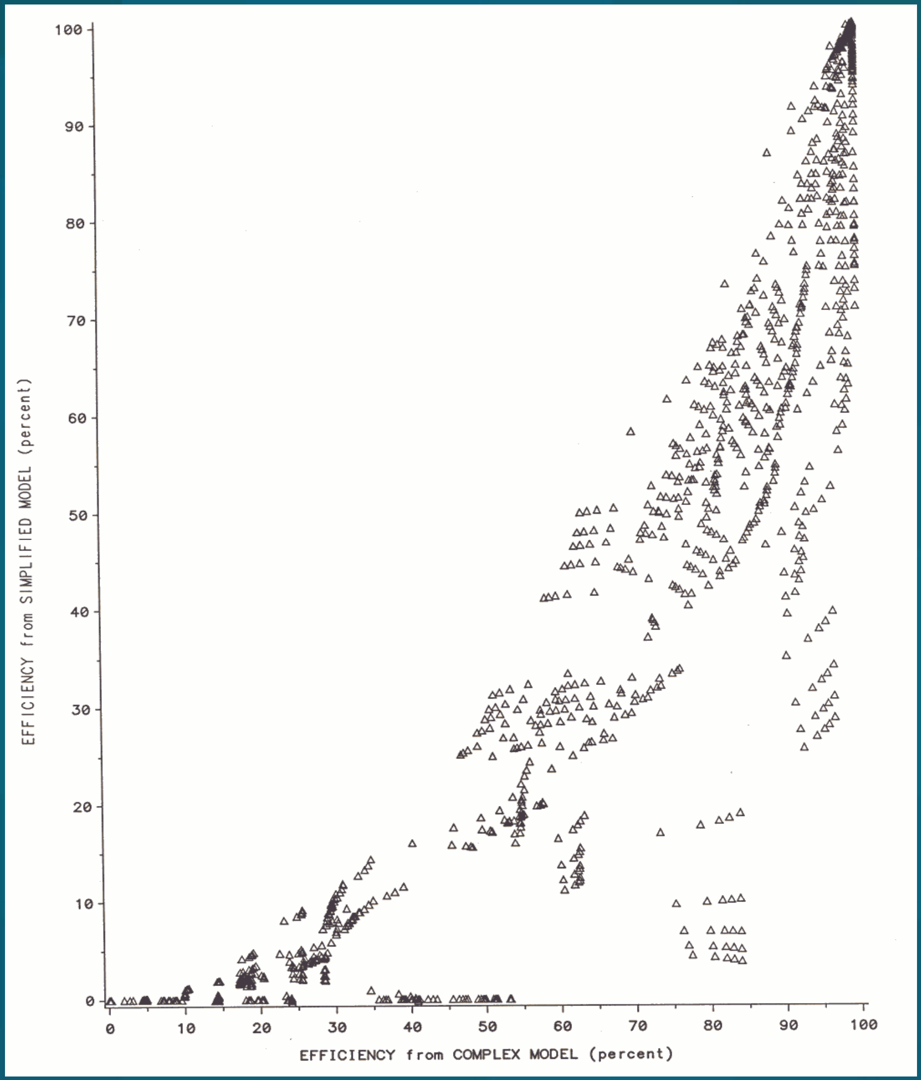


Plot of predicted values of VR against actual values generated by numerical solution using complex model



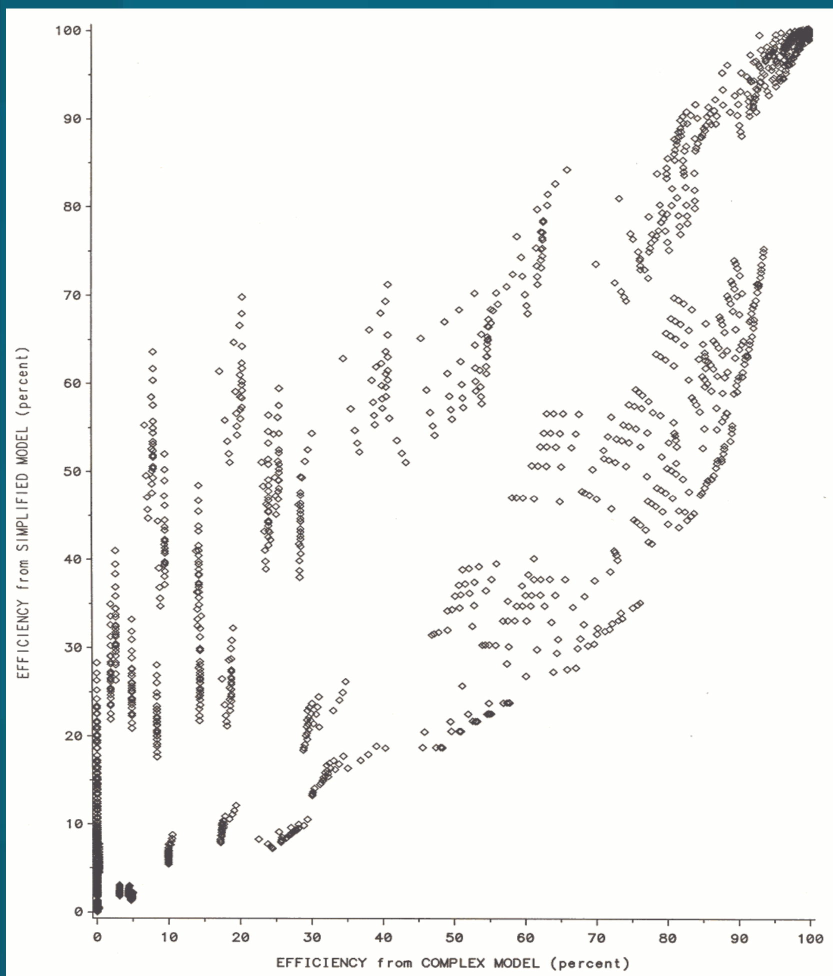
Plot of predicted values of VRR against actual values generated by numerical solution using complex model

Choice of single target efficiencies to use in efficiency model



Behie and Beeckmans empirical relationship for η as a function of Stokes number which was developed from the data of Ranz and Wong

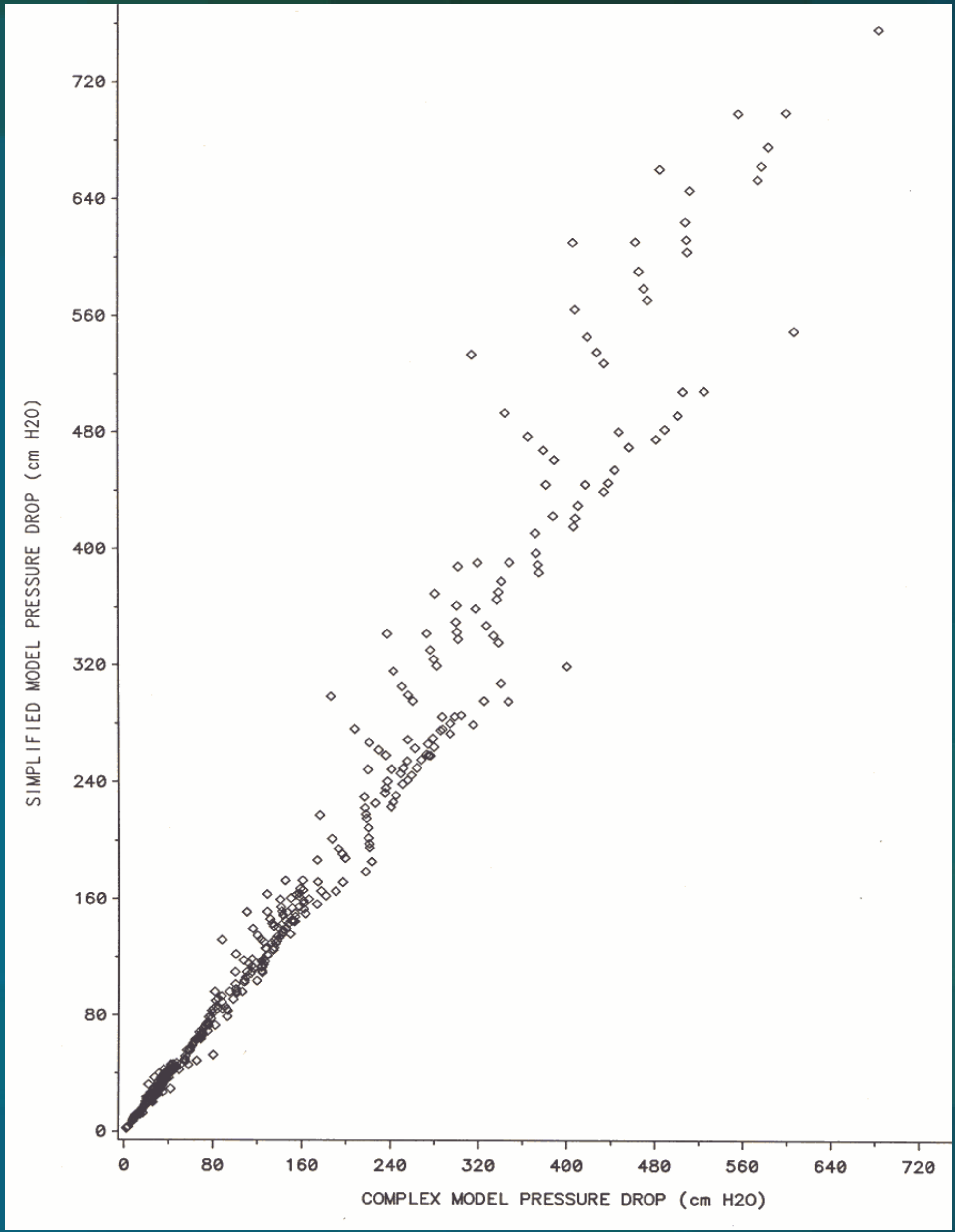
Choice of single target efficiencies to use in efficiency model



Calvert's simplified relationship for η

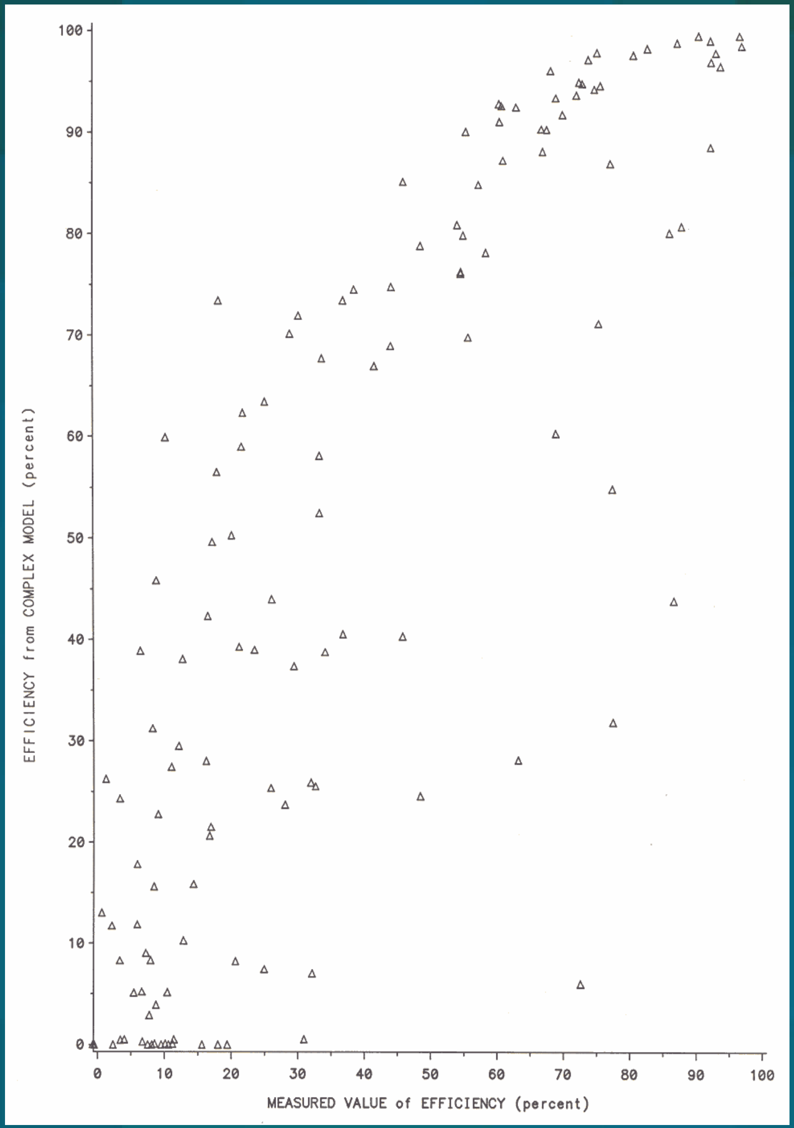
$$\eta = \left[\frac{\Psi}{\Psi + 0.7} \right]^2$$

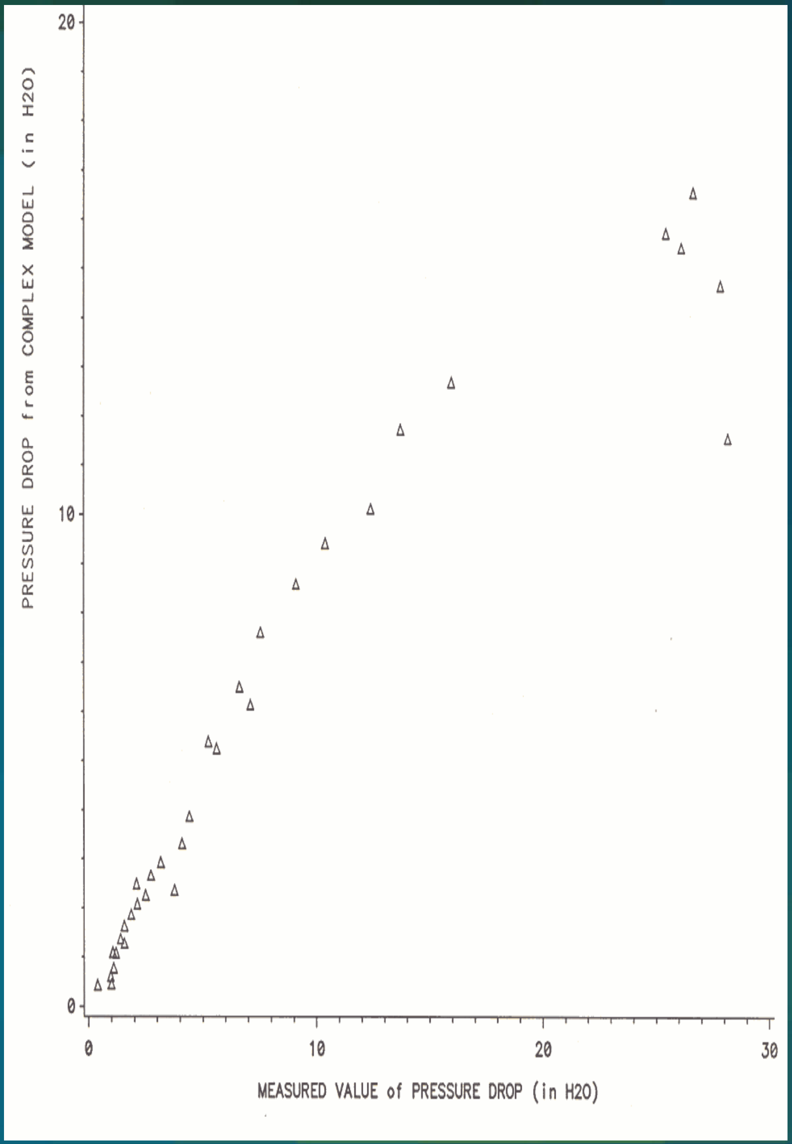
Equation results for pressure drop prediction



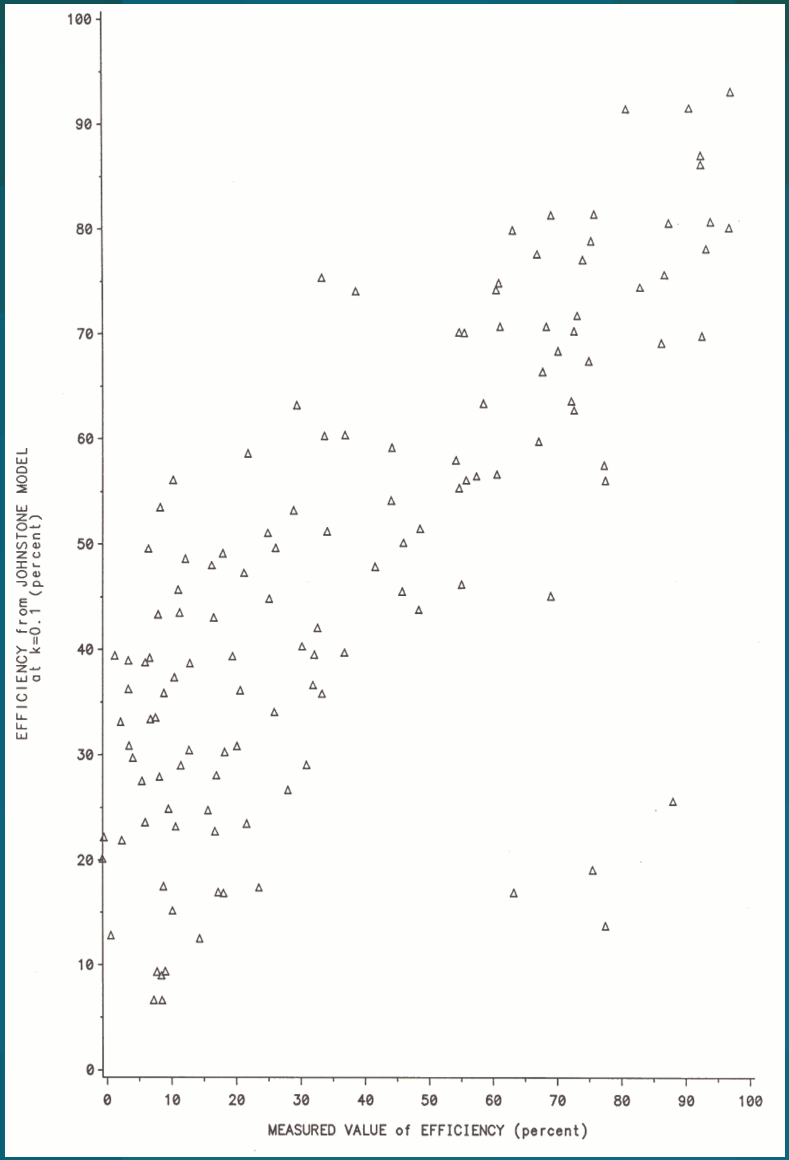
Comparisons to actual venturi performance

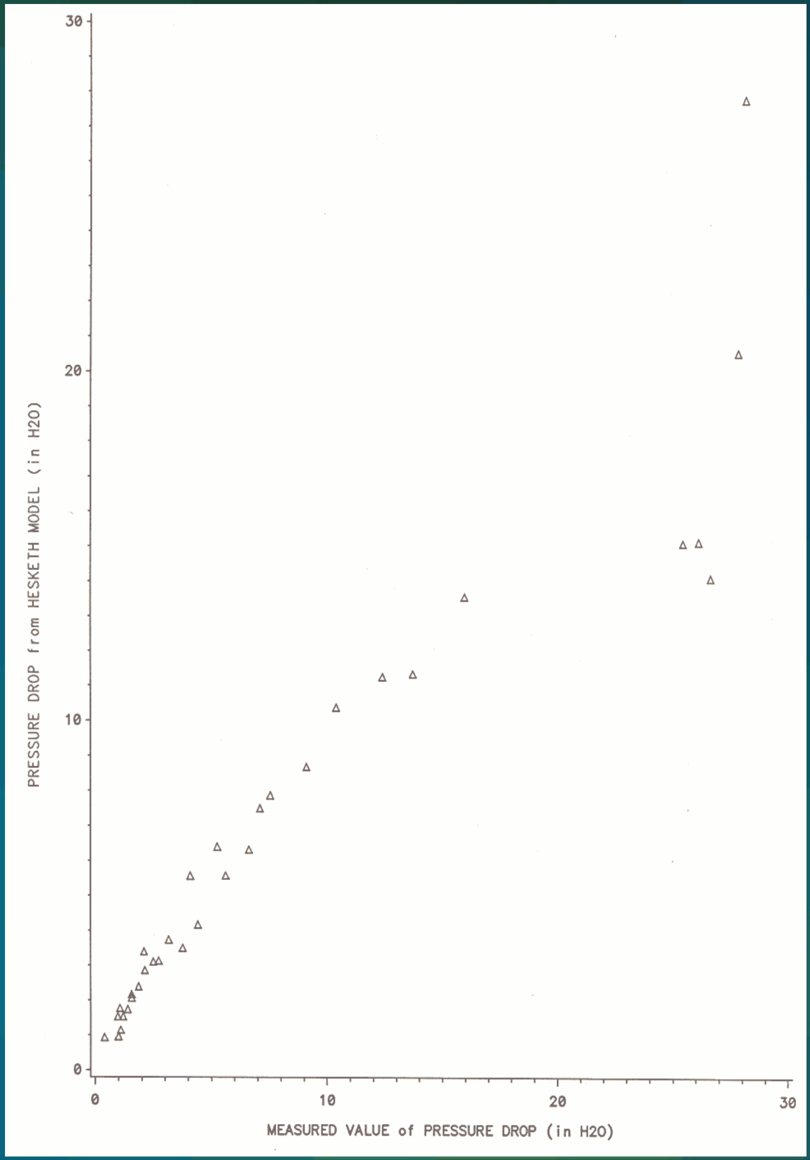
- The models for efficiency and pressure drop (complex and simplified) were compared to actual venturi design parameters and their performance in the published work of Rudnick, et al.



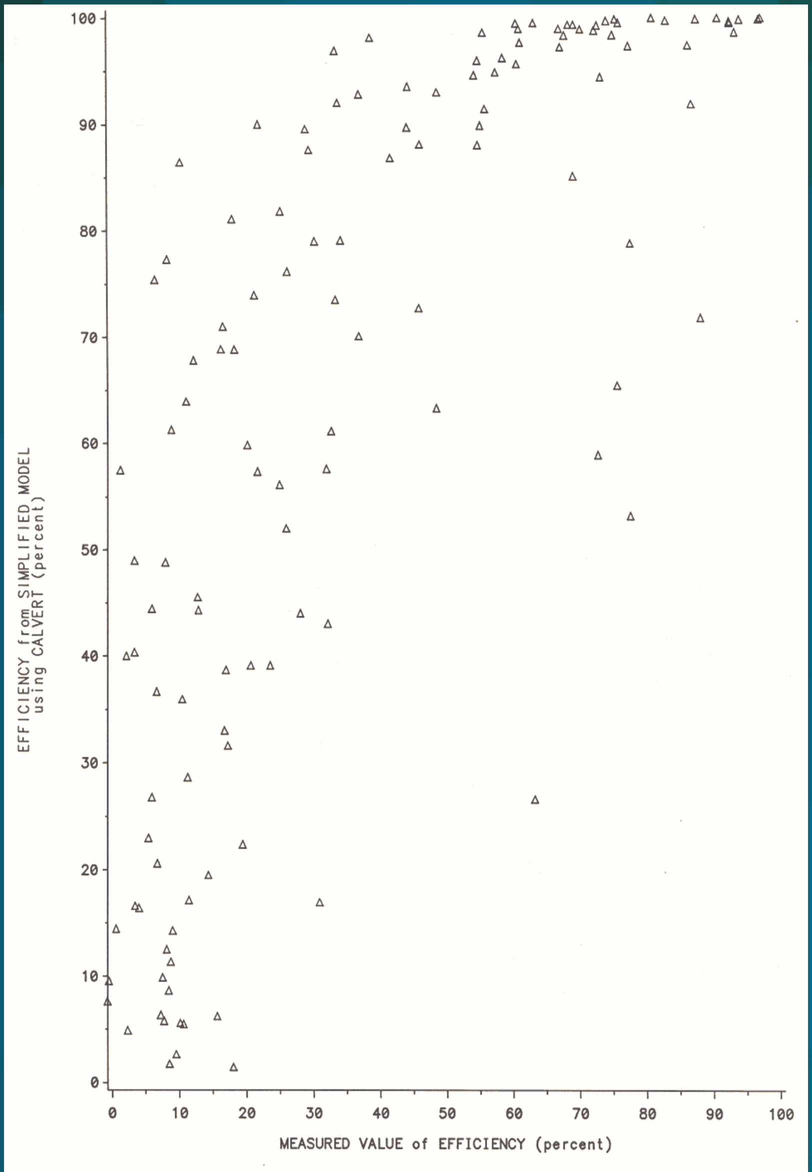


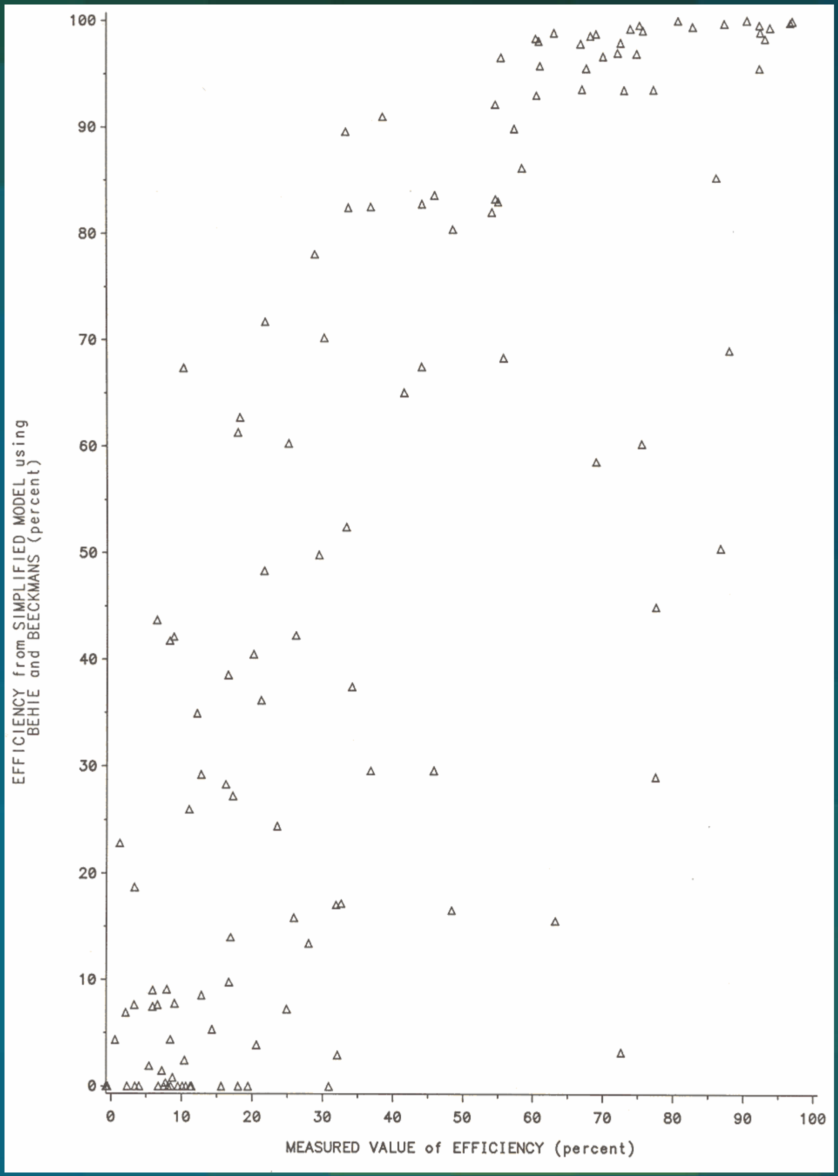
Actual vs. complex model for Efficiency and Pressure Drop



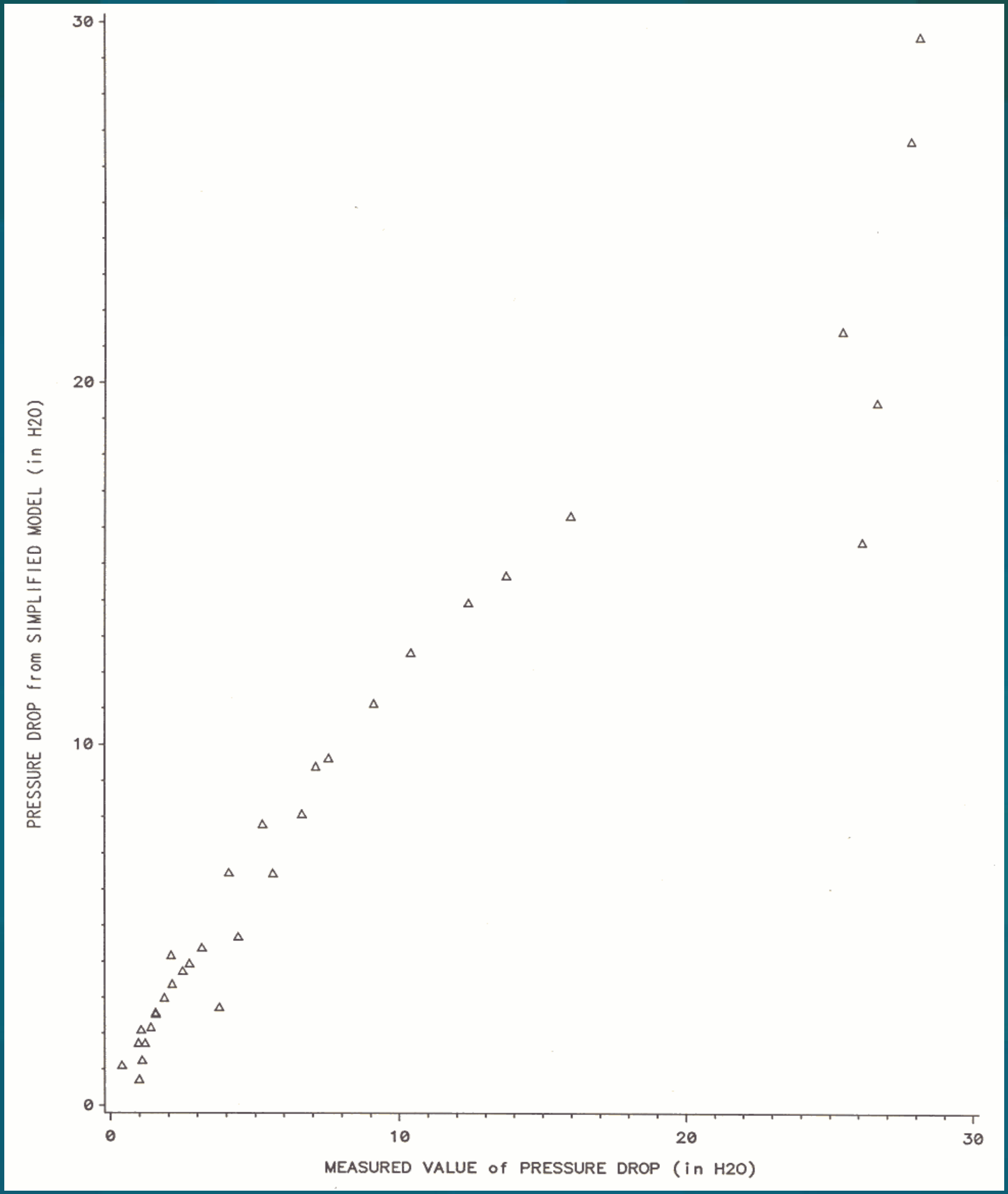


Actual vs. other simplified models for Efficiency and Pressure Drop





Actual vs. developed simplified models for Efficiency with Calvert and with B&B single target efficiency relationship



Actual pressure drop vs. predicted using simplified model

Conclusions

- Simplified models can be developed and simplified further to reduce the calculations necessary to predict venturi scrubber performance
- Although an equation for efficiency was developed, and has relatively good correlation, further work can be done to strengthen the model’s relationships
- A model for pressure drop is a far better predictor of that performance parameter and correlates well with the complex models and actual, operating venturi performance data

Opportunities for future development

- Revisit efficiency relationships in fundamental equations and refine the simplified equation form
- Develop a single equation for efficiency to yet further simplify the calculation of efficiency
- Develop a cost model that takes into account the two parameters of efficiency and pressure drop into a predictive evaluation of effectiveness vs. operating costs

Thank You.