FLOWNEX®

SIMULATION ENVIRONMENT

CASE STUDY

ECONOMIC PIPE SIZING USING THE GENERAUX EQUATION

This case study investigates a pipe sizing method based on an implementation of the Generaux Equation. This method aims to determine the optimum pipe size by accounting for the total cost of ownership.

Download the Flownex network

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Challenge:

The main challenge is to analyse pipeline sizing in terms of its total cost of ownership using the Generaux Equation.

Benefits:

Flownex® allows the user to model pipe networks with ease but does not implement tools to optimise the design in terms of cost. Flownex®'s excellent scripting capabilities do however allow easy implementation of any additional analysis theory and in this case the Generaux Equation. This case study offers a ready-made script that implements the Generaux Equation in SI units.

Solution:

The Generaux Equation has been implemented in a simple script and is demonstrated by connecting it via a data transfer link (DTL) to a single pipe flowing gas or water.

"With Flownex®'s scripting capabilities, many problems which are not directly solved by Flownex®'s built-in components may be added by the user with relative ease."

Hannes van der Walt
Principal Thermal Engineer
Gasco Pty Ltd

Introduction

The Economic Pipe Sizing model implements the well-known Generaux Equation which aims to calculate the most cost effective flow velocity through pipelines from a total cost of ownership perspective. Larger diameter pipes will result in lower velocities and therefore lower pressure losses and hence less pumping costs. However, larger pipes are more expensive to purchase, install, operate and maintain. The Generaux equation aims to account for all these competing costs and optimise the fluid velocity accordingly.

As shown in Figure 1, fixed costs rise, and pumping costs fall as the pipe diameter increases.

> "The Generaux Equation is a well-known method to optimise pipeline size in terms of total cost of ownership. The scripting and compound component capability that Flownex® offers enables users with moderate programming skills the ability to implement powerful models and attach them to the solution of a Flownex® simulation."

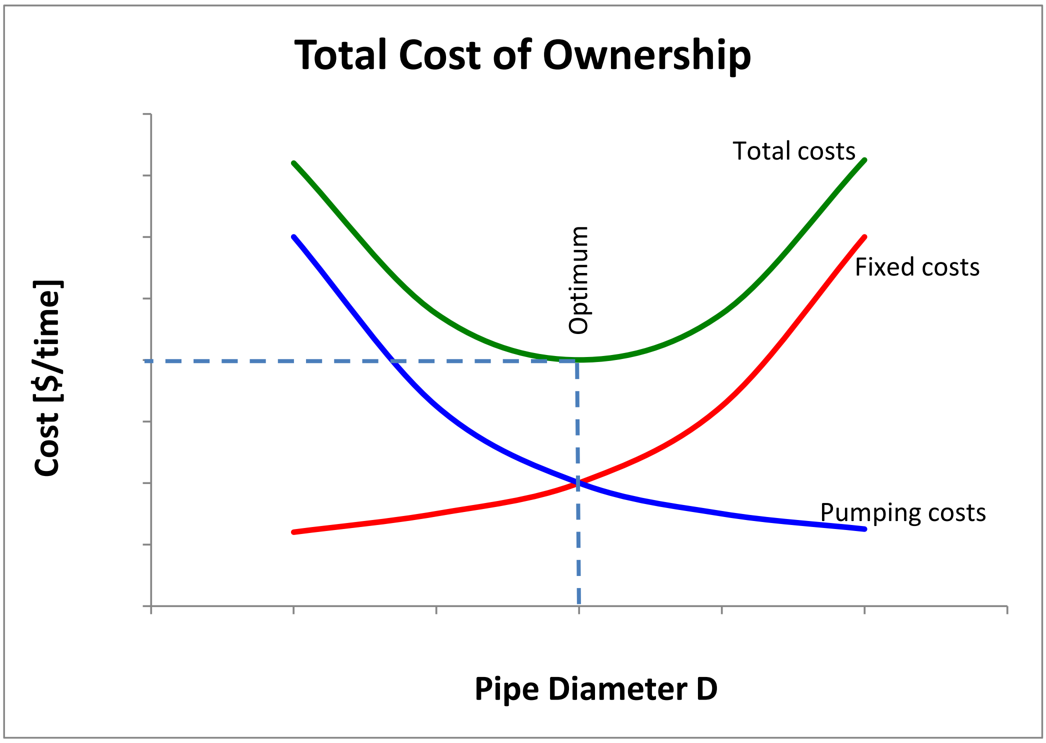

Figure 1: Typical cost optimisation curve

The Generaux Equation

A relatively recent publication by Durand et al. (2010) discusses the downward trend of flow velocities between 1998 and 2008. The Generaux Equation, as presented in this publication, is quite comprehensive and accounts for a broad range of costing variables as shown below. The publication provides suggested variables for use in the Generaux equation and shows changes in some of these variables between 1998 and 2008. It further provides calculated recommended velocities for carbon steel, stainless steel, aluminium and brass piping for a range of fluid densities and viscosities. Unfortunately, the original equation was developed in a mixed-bag of inconsistent units; therefore, for the modern post-middle-ages engineer, the equation presented here has been converted to SI units:

$$V = \frac{4}{\pi D^2}\left\{\frac{(3.28084\,D)^{4.84+n}\,nXE(1+F)[Z+(a+b)(1-\Phi)]}{(1+0.794\,Le'D)(1.5\,YK\rho^{0.84}\mu^{0.16})\left[(1+M)(1-\Phi)+\frac{ZM}{(a'+b')}\right]}\right\}^{\frac{1}{2.84}}$$

Where:

a	Fractional annual depreciation on pipeline, dimensionless.	M	$= \frac{(a'+b')(E\cdot P)}{(24\cdot K\cdot Y)}$ Factor to express cost of piping installation, in terms of yearly cost of power delivered to the fluid, dimensionless.
b	Fractional annual maintenance on pipeline, dimensionless.		
a'	Fractional annual depreciation on pumping installation, dimensionless.		
b'	Fractional annual maintenance on installation, dimensionless.	P	Installation cost of pump and motor, \$/kW.
C	Installed cost of pipeline, including fittings, \$/m.	V	Velocity, m/s.
D	Inside pipe diameter, m.	X	Cost of 1 m length of 300 mm diameter pipe, \$.
E	Combined fractional efficiency of pump and motor, dimensionless.	Y	Days of operation per year (at 24 h/day).
F	Factor for installation and fitting, dimensionless.	Z	Fractional rate of return of incremental investment, dimensionless.
K	Energy cost delivered to the motor, \$/kWh.	Φ	Factor for taxes and other expenses, dimensionless.
Le'	Factor for friction in fitting, equivalent length in pipe diameter per length of pipe, 1/m.	ρ	Flow density, kg/m^3.
n	Exponent in pipe–cost equation $(\mathrm{C} = \mathrm{X}\cdot\mathrm{D}^{\mathrm{n}})$, dimensionless.	μ	Fluid viscosity, mPa.s.

Suggested values for these variables as published by Durand et al. (2010) are given in the following table. Note that the variables are given for different materials as well as comparing 1998 and 2008 values. For the present, 2008 values may be used, or they may be determined by extrapolation using the 1998-2008 trend. At least the energy cost *K* should be updated.

Table 1: Suggested values (SI Units) to use in the Generaux Equation (from Durand et al.)

Terms	Unit	Carbon Steel 1998	Stainless Steel 1998	Carbon Steel 2008	Stainless Steel 2008	Aluminium 2008	Brass 2008
n	-	1.35	0.7793	1.472	0.924	0.769	0.907
X	\$/m	96.85	426.51	21.68	100.72	73.03	105.97
Le'	1/m	8.99	8.99	8.99	8.99	8.99	8.99
E	-	0.5	0.5	0.5	0.5	0.5	0.5
P	\$/kW	201.15	201.15	201.15	201.15	201.15	201.15
K	\$/kW.h	0.04	0.04	0.07	0.07	0.07	0.07
Y	days	365	365	365	365	365	365
Φ	-	0.55	0.55	0.55	0.55	0.55	0.55
Z	-	0.1	0.1	0.1	0.1	0.1	0.1
F	-	6.7	7.5	6.5	7.4	7.1	7.2
$a + b$	-	0.2	0.2	0.2	0.2	0.2	0.2
$a' + b'$	-	0.4	0.4	0.4	0.4	0.4	0.4

Case Study 1: Pipe Sizing for Gas Flow

As a first case study, the application of the Generaux Equation is demonstrated for natural gas flowing through a pipeline. Assuming for simplicity that natural gas is mostly methane (CH4), the flow conditions are as follows:

Fluid:	Methane.
Pressure:	15000 kPa-g.
Temperature:	15°C.
Flowrate:	20 kg/s.
Density:	128.154 kg/m^3
Viscosity:	0.01658 mPa.s.

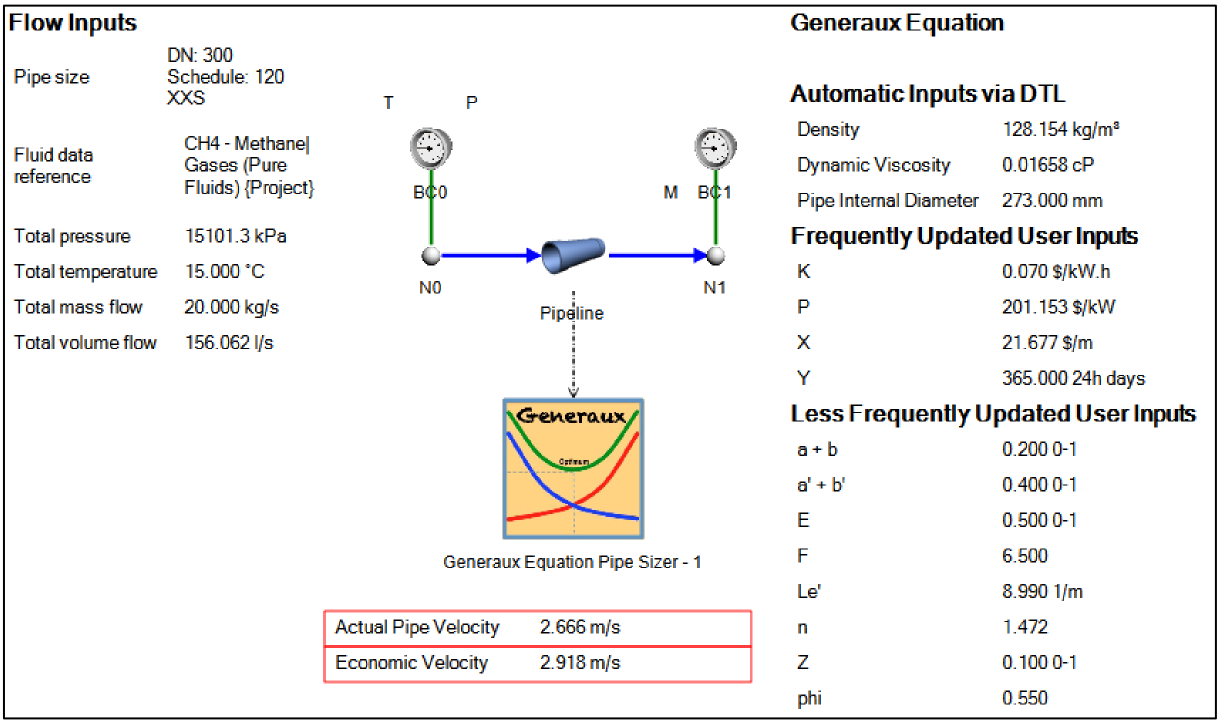

Figure 2: Economic pipe sizing using the Generaux Equation for gas flow

The *Flow Inputs* are entered at the boundary conditions as well as the pipe element. The *Automatic Inputs via DTL* are the fluid properties and pipe inside diameter that are automatically transferred from the pipe element to the *Generaux Equation Pipe Sizer* component via the data transfer link (DTL). The *Frequently Updated User Inputs* are those variables that are more likely to change with the application as well as time and are therefore listed first. Similarly, the *Less Frequently Updated User Inputs* are grouped together.

It is noted that the calculated economic velocity of 3 m/s is significantly lower than typical gas flow velocities of 10-15 m/s and even higher typically encountered in the oil and gas industry.

Case Study 2: Pipe Sizing for Liquid Flow

This section discusses the modelling of water flowing through a large pipeline. The flow conditions are as follows:

Fluid:	Water (liquid).
Pressure:	150 kPa-g.
Temperature:	15°C.
Flowrate:	200 kg/s.
Density:	999.031 kg/m^3.
Viscosity:	1.15237 mPa.s.

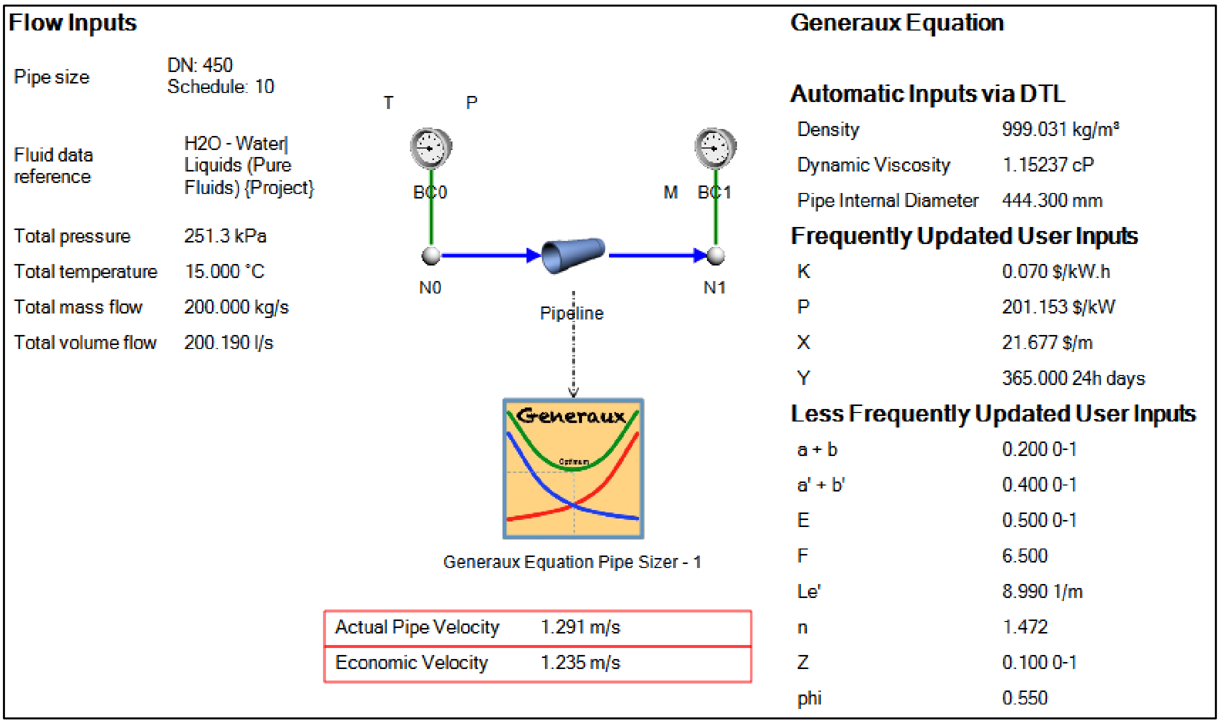

Figure 3: Economic pipe sizing using the Generaux Equation for liquid flow.

As before, the suggested economic velocity for a water pipeline is lower than what many engineers may expect.

Summary

The Generaux Equation has been packaged in a compound component for ease of use with any Flownex® project. The case study presented two cases demonstrating the economic sizing of gas flow and water flow pipelines.

Flownex® offers the user the ability to implement calculations of almost any kind in stand-alone and reusable compound components which can then be used like any other Flownex® element to form part of the solution network. In this way, it is a relatively simple exercise to extend Flownex®'s capabilities to include other technologies such as the economic sizing of pipelines in this case. This ease of extendibility sets Flownex® apart from the competition is its ability to model even the temperature profiles through a multi-layered pipe wall subjected to heat transfer.

References

Durand, A.A., de Villafranca Casas, M.J., Cornejo, A.S.G., Carranza, D.J., Román, F.J.P., Suárez, R.G.S., Espinoza, J.S., Villalobos, L.F. & de la Parra, V. (2010) Updating the Rules for Pipe Sizing, *Chemical Engineering*, January 2010, 5p, www.che.com.