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## TRANSIENT SIMULATION OF NATURAL GAS CITYGATES STATIONS

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### ABSTRACT

The demand of natural gas in the Brazilian energy market is increasing very fast over the few years and it was necessary to enhance the operational performance and safety of the gas distribution. The perfect operation of the natural gas citygate stations is essential to guarantee the delivery of natural gas for the end users like local distribution companies, thermoelectric power plants and large industrial customers within the contracted marketing conditions. These stations receive natural gas directly from high pressure pipelines and reduce the pressure using regulation valves that provoke a temperature reduction due the Joule-Thompson (JT) behavior, typical of natural gases. This temperature loss is compensated by forcing part of the gas flow through water/glycol bath heaters that use natural gas as fuel in the heating process. Usually the downstream gas temperature condition is controlled above a minimal set point while modifying the three-way valve position that regulates hot and cold streams flows. A numerical tool has been developed to simulate the dynamic process inside the natural gas citygate station, and proved to be a reliable tool to analyze the transient performance of the main equipments (filter, three way valve, heater, JT valve, relief valves) when submitted to abnormal conditions or changes in capacity. The methodology developed is able to handle a variety of citygate design.

### INTRODUCTION

The current scenario of high natural gas demand in Brazil forced gas transporter companies like Transportadora Brasileira Gasoduto Bolivia-Brasil (TBG) and Transpetro to increase the number of citygates and sometimes upgrade the capacity of existent ones to supply the demand. The TBG engineering and operation/maintenance departments made a briefly report to identify abnormal events in their remotely operated citygates. The most often abnormal event is the bath heater flame

extinguishment. The TBG citygates are designed with two bath heaters and when both are turned off, a technical must be sent to the remote station to fire the heaters again before the minimal temperature is reached. The survival time of the citygate depends on the bath heater thermal capacity and the delivery flowrate during the period. Besides the survival time calculation there are others applications for the citygate simulator, and the most important are:

- Design of newer citygate stations with different heat and flow capacities
- Simulate an upgrade of capacity and the necessity of an equipment substitution
- Obtain the temperature, pressure and flowrate at non-transmission points inside the citygate
- Study the control logic and automation used in the heating system and their interaction with the process variables
- Evaluate the performance of cyclone and cartridge filters
- Calculate the gas fuel consumption, heat capacity, heat transferred from water to gas, and burn efficiency of the indirect fire bath heaters

For this reason TBG and Transpetro are investing in research and development of an in-house dynamic process simulator for specific applications related to citygate stations. Common equipment models, like idealized heaters and JT valves found in many commercial process simulator, can be used to create simple static citygate models, but don't simulates the water bath heating capacity and the pressure/temperature control in an real citygate station. The main benefit of a customized tool relies on the creation of specific equipment models for these process plants, including equipments that are not usually found in commercial simulation tools.

A citygate simulator calculates the pressure drop, temperature difference and flowrate at the equipments and evaluates its performance based on design parameters and

operational conditions. The simulation methodology developed deals with the equations of state (EOS) used to calculate the natural gas thermodynamic properties (density, enthalpy, temperature), conservation and element equations necessary to reproduce the behavior of main equipments including their automation (temperature and pressure control) as follows.

- **EQUATION OF STATE:** Single phase (gas) approximation of cubic EOS (Peng-Robinson and Soave-Redlich-Kwong) with Lorentz-Berthelot Mixture Rules. (Reference 1).
- **CONSERVATION EQUATIONS AT NODES:** Mass, Energy and Composition.
- **STEADY STATE EQUATIONS FOR ELEMENTS:** Input Gas Point, Filter, Valves, Pipes, Idealized Heater, Output Gas Point.
- **TRANSIENT EQUATIONS FOR ELEMENTS:** Water Bath Heater, Temperature Control with Actuator in Three Way Valve, and Pressure Controller.
- **NUMERICAL METHODS:** Newton Method to solve the nonlinear system of equations and Runge-Kutta (4th order) to solve the water bath heater ordinary differential equation (ODE).

The citygate process simulator is programmed using C++ language. The software code is split into solver library and user interface. The simulator solver is a group of components and routines encapsulated in a library that manages all mathematical calculation. The user interface integrates all graphical objects and events necessary to create the interactive simulation environment.

### CITYGATE STATION

When a natural gas pipeline nears a delivery point, the high-pressure gas needs to be reduced to the distribution level. So a citygate station is a pressure reducing point. The complete natural gas conditioning process in citygates occurs in five sequential process areas: filtration, heating, pressure reduction, fuel control and metering. A schematic view of process areas and their equipments are presented in Annex A.

In the first process area the gas cleaning takes place in cyclone and cartridge filters. The cyclone filters uses centrifugal energy to separate denser material (condensate) from the gas received by the pipeline. The remaining solid and liquid particles are removed using filter. These two filters systems are necessary to avoid premature equipment downtime and ultimately failure of the equipments inside the station like control valves and meters. The gas heating area is composed of three-way control valves and heaters, like indirect fired water bath heaters. The main purpose of the heaters is to increase the gas temperature prior to the pressure reduction section, in order to prevent frost and hydrate formations that may occur because of the temperature drop. The pressure reduction area has control and relief valves. The control valves reduce the pressure output to values compatible to local gas distribution system, whereas the relief valves act in case of unexpected valve closure or failure. The fuel control area is composed of control valves that regulate the flow and pressure of the gas sent to combustion in the bath heater firetube. The metering area is composed of temperature and pressure sensors and a flow meter. The output

of these devices is used to calculate the volumetric gas flow at standard conditions for Brazilian Gas Transmission System (20°C e 1,033 kPa).

### STEADY STATE SOLVER FORMULATION

The steady-state solver is a single phase unidimensional gas network simulator with dedicated equipment formulas for heater, filters, and three way valves.. An important solver requirement is flexibility. So, it needs to deal with simple and complex citygate models with any layout. To achieve this goal, the element and node equations must be solved simultaneously, that is, the mass, energy and gas composition balance at nodes; and pressure drop and heat transfer equations for the elements. The schematic in Fig 1 shows a sample case with five elements (E<sub>1</sub> to E<sub>5</sub>) where the balance equations were applied for node N<sub>1</sub>.

*Mass Balance:*

$$\dot{m}_1 + \dot{m}_2 + \dot{m}_3 - \dot{m}_4 - \dot{m}_5 = 0 \quad (1)$$

*Energy Balance:*

$$\dot{m}_1 h_1 + \dot{m}_2 h_2 + \dot{m}_3 h_3 - \dot{m}_4 h_4 - \dot{m}_5 h_5 = 0 \quad (2)$$

*Gas Compositional Balance:*

$$\dot{m}_1 x_1 + \dot{m}_2 x_2 + \dot{m}_3 x_3 - \dot{m}_4 x_4 - \dot{m}_5 x_5 = 0 \quad (3)$$

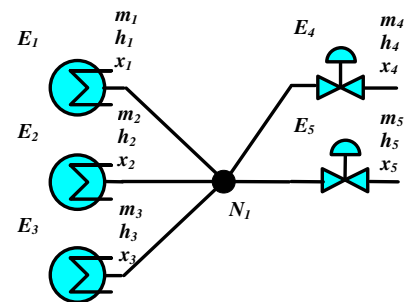


Figure 1- Mass, Energy and Composition Balance at Node (5 elements)

### Valve equations

When a gas flows through an adiabatic throttle there is a change in temperature due the Joule Thompson effect. For all natural gases mixtures the  $\mu_{JT}$  (Joule Thompson coefficient) is positive which means a temperature drop. This thermodynamic behavior is found in experimental JT inversion curves – (Reference 2) and can be predicted using non ideal gas EOS where the intermolecular forces are considered in the enthalpy evaluation. The equation (4) shows the standard thermodynamic definition for JT coefficient. A temperature difference is obtained by thermodynamics function with pressure and enthalpy  $T(h,p)$ .

The steady state approximation to momentum and energy equations applied to valve elements is shown in the equations (6) and (7). The  $K_v$  represents the pressure resistance coefficient, and its value can be converted to CV provided by valve manufacturer using expression (8). Considering the CV as function of the valve opening fraction  $f_o$  with position of the

valve, the methodology will evaluate the downstream pressure and temperature.

*JT Coefficient:*

$$\mu_{JT} = \left( \frac{\partial T}{\partial p} \right)_h \quad (4)$$

*Temperature Difference:*

$$\Delta T = T(p_{in}, h_{in})_{in} - T(p_{out}, h_{out})_{out} \quad (5)$$

*Momentum:*

$$Q^2 K - (p_{in}^2 - p_{out}^2) = 0 \quad (6)$$

*Energy:*

$$m_{in} h_{in} - m_{out} h_{out} - q = 0 \quad (7)$$

*Valve Resistance Coefficient:*

$$K_V = \frac{Z_{in} \cdot T_{in} \cdot \gamma_g}{CV(f_o)^2} \quad (8)$$

### Idealized Heater

The idealized heater is the steady-state version of the indirect fire water bath heater and can be employed when the dimensional and thermal properties of the water bath heater are not well-known. The idealized heater operates in two modes: downstream temperature mode or transfer rate mode.

When transfer rate mode is chosen, the heater can be set to gas heating or cooling depending on the signal defined to heat transfer rate. Per convention, a positive value for heat transfer rate results an increase of temperature downstream. Both momentum and energy formulas are implemented in the idealized heater model as show in equations (6) and (7). A pressure drop can be imposed if a positive value for K is set.

### Three-Way-Valve

The temperature controller system is composed of temperature sensor placed downstream of pressure reduction valve and the temperature controller that sends signal to three way valve actuator. The three-way valve has one inlet and two outlets and is responsible to regulate the gas passing through the water bath heater. For a complete modeling of the three way valve for steady state and transient scenarios it is necessary to specify the curve (CV versus opening fraction) for both outlets. With these curves defined, the simulator calculates the correct gas flow, pressure and temperature at both outlets as function of the normalized actuator position. The equations that model a three-way-valve is similar of two JT valves (with reciprocal CV curves) connected to same upstream node. An illustration of typical reciprocal curves is presented at Fig 2.

### Cyclone Filter

According to Reference 3 the kinetic energy losses are of the major impact in the pressure drop estimation. After experimental data analysis the authors established a relation between the pressure drop and cyclone dimensions, considering the same operating conditions. With the cyclone size (barrel

diameter) and design formula (Lapple, Swift, Stairmand) it is possible to calculate the dimensionless number of gas inlet velocity heads  $\xi$ , also called pressure drop coefficient. The cyclone filter manufacturers commonly adopt dimensional relations between inlet height  $a$ , inlet width  $b$  and outlet diameter ( $D_s$ ) with barrel diameter D as shown in Fig 3.

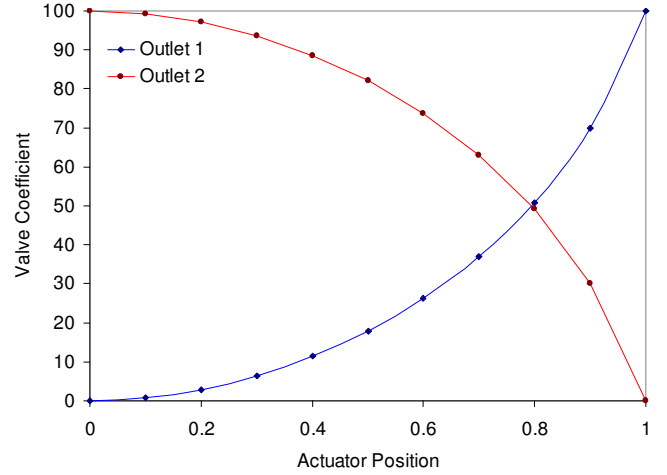


Figure 2- CV Curves for TWV Outlets (Equal Percent)

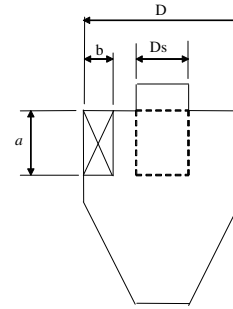


Figure 3 – Cyclone Filter Schematic and Dimensional Relations

The pressure drop coefficient  $\xi$  is a ratio of inlet and outlet dimensions as defined in equation (9). The valves momentum equation (6) can be extended to cyclone filter assuming a pressure resistance coefficient  $K_F$  of the filtration process instead of  $K_V$ . The expression that calculates pressure resistance coefficient  $K_F$  using pressure drop coefficient value is show in equation (10). The energy equation for cyclones adds a term to kinetic energy as noticed in equation (11).

*Pressure Drop Coefficient:*

$$\xi = \left( \frac{a \cdot b}{D_s^2} \right) \quad (9)$$

*Cyclone Filter Resistance Coefficient:*

$$K_F = \frac{p_{in}^2 - \left( p_{in} - \xi \left( \frac{1}{2} \rho_g v_{in}^2 \right) \right)^2}{Q^2} \quad (10)$$

Energy:

$$m_{in}h_{in} - m_{out}h_{out} + \frac{1}{2g}(v_{in}^2 - v_{out}^2) = 0 \quad (11)$$

- $T_{out} = T(h_{out}, p_{out})$
- $error = T_{out} - T_{out}^*$
- $T_{out}^* = T_{out}$

## SOLVER TRANSIENT AND DYNAMIC FORMULAS

The indirect fire water bath heater (IFWBH) is one of transient formulation elements provided in the citygate simulator solver. In the IFWBH element, the heat is transferred at first from gas combustion to water mass –  $q_b$ , and afterward from water to flowing gas –  $q_w$ . As shown in equation (12) the water temperature  $T_w$  varies with the energy accumulation indicated as the second term. The evaluation of the energy accumulation depends on some dimensional and thermal parameters like: water heat capacity ( $m_w \cdot cp_w$ ), overall heat transfer area  $A$ , global heat transfer coefficient  $U$ , and log mean temperature difference (LMTD). Also, other scenario variables like upstream gas flow rate or combustion heat transfer rate can interfere with water bath temperature and consequently the heater downstream temperature.

Water Temperature:

$$\frac{dT_w}{dt} - \frac{q_b - q_w}{m_w \cdot cp_w} = 0 \quad (12)$$

Water Heat Transfer

$$q_w - UA \cdot F \cdot LMTD = 0 \quad (13)$$

Burner Heat Transfer

$$q_b = \eta \cdot Q_b \cdot \hat{h} \quad (14)$$

Log Mean Temperature Difference:

$$LMTD = \frac{(T_w - T_{out}) - (T_w - T_{in})}{\ln\left(\frac{T_w - T_{out}}{T_w - T_{in}}\right)} \quad (15)$$

A fourth order Runge-Kutta algorithm with explicit approach was implemented to evaluate the water temperature, an approach usually employed for the solutions of ordinary differential equations. The iterative routines to solve the set of equations are presented below.

Heater Downstream Temperature using Iteration Routine: (HDTIR)

This is an implicit method that combines the energy equation (7) with the water heat transfer  $q_w$  to obtain an estimated solution to downstream temperature. The routine employs two thermodynamic relation derived from EOS equation  $h(T,p)$  and  $T(h,p)$  to convert from enthalpy to temperature and vice-versa. The input pressure and mass flow data at present time is always available because the mass and momentum solver is executed before energy solver.

- Set  $T_{out} = T_{in} + 1$
- Set  $T_{out}^* = 0$
- Repeat until (error < tolerance)
  - $q_w = UA \cdot LMTD(T_w, T_{in}, T_{out})$
  - $h_{out} = m_{in} \cdot h_{in}(T_{in}, p_{in}) + q_w$

Water Temperature using Runge-Kutta (RK4)

In the RK4 method the next water temperature value  $T_{w4}$  is determined by the present temperature  $T_{w0}$  plus the product of the time step ( $\Delta t$ ) and the weighted slope. The weighted slope is obtained in averaging four slope functions ( $f_1, f_2, f_3, f_4$ ). Greater weight is given to the slopes  $f_2$  and  $f_3$  that are based on the midpoint of the time interval. For every slope function evaluation the HDTIR routine is called to update the  $T_{out}$  and  $q_w$  values. The algorithm adopted to calculate the water temperature is presented as follows:

- $T_{out_0} = HDTIR(T_{w_0}, T_{in_0})$
- $q_{w_1} = UA \cdot LMTD(T_{w_0}, T_{in_0}, T_{out_0})$
- $f_1 = \frac{q_b - q_{w_1}}{mw \cdot cp_w}$
- $T_{w_1} = T_{w_0} + f_1 \cdot \frac{\Delta t}{2}$
- $T_{out_1} = HDTIR(T_{w_1}, T_{in_0})$
- $q_{w_2} = UA \cdot LMTD(T_{w_1}, T_{in_0}, T_{out_1})$
- $f_2 = \frac{q_b - q_{w_2}}{mw \cdot cp_w}$
- $T_{w_2} = T_{w_0} + f_2 \cdot \frac{\Delta t}{2}$
- $T_{out_2} = HDTIR(T_{w_2}, T_{in_0})$
- $q_{w_3} = UA \cdot LMTD(T_{w_2}, T_{in_0}, T_{out_2})$
- $f_3 = \frac{q_b - q_{w_3}}{mw \cdot cp_w}$
- $T_{w_3} = T_{w_0} + f_3 \cdot \Delta t$
- $T_{out_3} = HDTIR(T_{w_3}, T_{in_0})$
- $q_{w_4} = UA \cdot LMTD(T_{w_3}, T_{in_0}, T_{out_3})$
- $f_4 = \frac{q_b - q_{w_4}}{mw \cdot cp_w}$
- $T_{w_4} = T_{w_0} + \frac{\Delta t}{6}(f_1 + 2f_2 + 2f_3 + f_4)$

The high-level algorithm for IFWBH model that refer to HDTIR and RK4 routine is presented as follows:

- Set  $t \rightarrow t_0$
- Get initial values from scenario:  $T_{in}$ ,  $Q_{in}$  and  $Q_b$
- Repeat until ( $t > t_{end}$ )
  - Evaluate  $T_w$  using RK4
  - Evaluate  $T_{out}$  using HDTIR
  - Set  $t \rightarrow t + \Delta t$
  - Get interpolated values from scenario to next step ( $t + \Delta t$ ):  $T_{in}$ ,  $Q_{in}$  and  $Q_b$

## NUMERICAL METHOD

### Dynamic Solution Routine

In resume the dynamic solution routine is an interactive routine that loads the scenario variables for the actual time, evaluates the nonlinear system of equations composed of balance equations for nodes and conservation equations for elements and calculate the bath heater transient problem using the RK4 algorithm. The solver equations needs the evaluation of the natural gas properties (enthalpy, density, temperature, heating value) for each node that is function of the gas composition and the state condition, that generally is given at the entrance of the station. With this data and the selected EOS is possible to calculate the EOS based functions:  $h(p,T)$ ,  $\rho(p,T)$  and  $T(h,p)$  using thermodynamic properties correlations. The dynamic solution routine executes several process tasks and decisions as presented in the workflow scheme of Fig 4. Each task performed by the dynamic solution routine is described as follows:

- Initial Gas Composition: Uses a default composition for all nodes of the model.
- Load scenario: Read time variables for actual time.
- Gas properties: Evaluates thermodynamic properties for all nodes using the selected EOS
- Mass-Momentum Solver: Solves mass balance at nodes and momentum conservation for elements
- Energy Solver: Solves energy balance at nodes and energy conservation for elements
- Composition Solver: Solves composition balance at nodes.
- Save scenario variables: Evaluate actual time element properties and write the time variables
- IFWBH RK4 Routine: Estimate water bath temperature and the heat transferred from water to gas for the next time using RK4 explicit formulation. Write next time variables.

### Pre-Processing and Post-Processing Routines

Various functions and routines of the solver library are auxiliary and are not called during the convergency process. The pre-processing occurs only once when the user start the dynamic solution calculation. At this moment that routine start several tasks like input parameters validation based in preset limits range, element connection validation, data interpolation and unit conversion from user system (english or SI) to internal solver system. When the pre-processor validation are successful, the dynamic solution routine is called. And only when the final time is reached at the end of the iteration process (see Fig 4) the post-processing routine is executed and the output values are converted and passed to user interface.

### Non Linear System of Equations Algorithm

At present, a C++ numerical toolkit named KINSOL (Reference 4) has been applied to solve the system of equations generated by the steady-state problem. The toolkit is based on Blas and Lapack methods to solve directly dense and banded linear system of equations in a real n-space. A modified Newton's method was applied to solve nonlinear system of equations like momentum and energy element equations. Essentially an algebraic system of equations can be represented by two real vectors: unknown variables vector  $y$  and residual

function vector  $R(y)$ . The size or length of  $y$  and  $R(y)$  vectors must be equal to the total number of problem equations  $N_{eq}$ , that consist of the summation of node variables (eg. enthalpy) plus element variables (eg. heat transfer rate). The residual function vector  $R(y)$  holds the formula that approximates to zero like energy equation (7). The Jacobian matrix is calculated by difference quotients of the residual functions as indicated in equation (16).

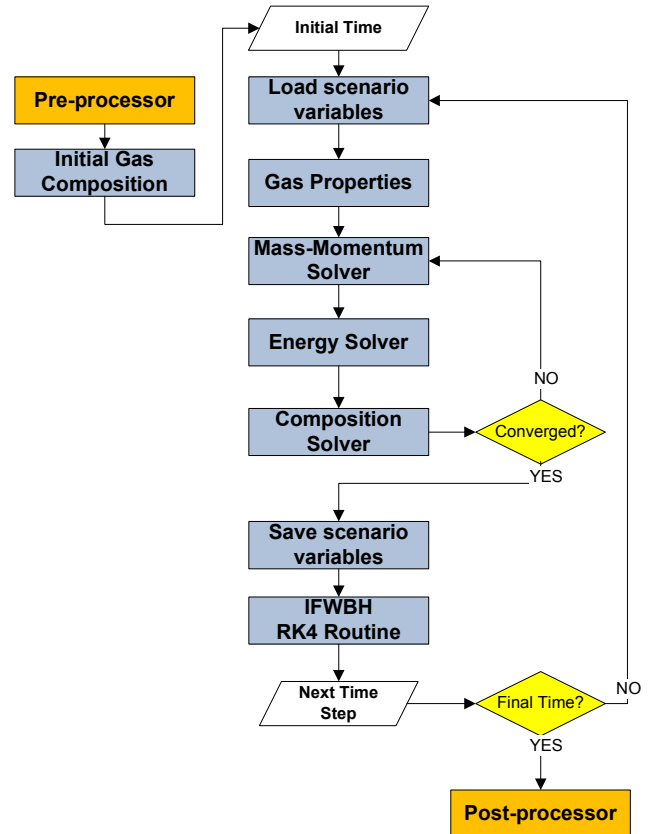


Figure 4 – Dynamic Solution Routine Workflow

$$J_F(y) = R'(y) = \begin{pmatrix} \nabla R_1^T \\ \nabla R_2^T \\ \vdots \\ \nabla R_n^T \end{pmatrix} = \begin{pmatrix} \frac{\partial R_1}{\partial y_1} & \frac{\partial R_1}{\partial y_2} & \dots & \frac{\partial R_1}{\partial y_n} \\ \frac{\partial R_2}{\partial y_1} & \frac{\partial R_2}{\partial y_2} & \dots & \frac{\partial R_2}{\partial y_n} \\ \vdots & \vdots & \ddots & \vdots \\ \frac{\partial R_n}{\partial y_1} & \frac{\partial R_n}{\partial y_2} & \dots & \frac{\partial R_n}{\partial y_n} \end{pmatrix} \quad (16)$$

The Newton's method algorithm can be represented using the following iteration scheme:

- Set  $y_0$  = initial guess value
- For  $n = 0, 1, 2, \dots$  until convergence do
  - Solve  $J(y_n)\delta_n = -R(y_n)$
  - Set  $y_{n+1} = y_n + \lambda \delta_n$
  - Test convergence

The Newton's method algorithm is employed in phases 2, 3 and 4 to solve the mass, energy and composition system of equations.

## USER INTERFACE

For the sake of completeness in functionality, the citygate simulator has an user interface programmed in C# that allows to build several types of citygate models using an schematic viewer. Inside this schematic viewer the user can add new equipments from the citygate toolbar, and connect them using a connectivity tool. Besides that, the user can interact directly with the equipments and see the impact of this modification on simulation results. The Annex B shows a screen captured of the simulator user interface for a typical citygate station model. This simulation model that will be detailed in the next topic.

## SIMULATION RESULTS AND COMPARISON

### Temperature Variation for Idealized Heaters and JT Valves

This simulation case was created to verify the energy and momentum equations applied to idealized heaters and JT valves models, as well to compare the EOS equations implemented in the solver. Fig 5 illustrates the schematic view captured from the citygate simulator user interface that shows the connectivity of the first simulation case.

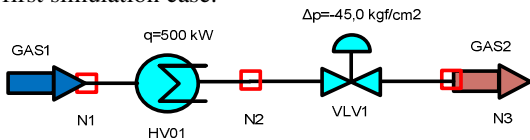


Figure 5 –Schematic Diagram (Case 1)

The following input parameters are defined based on common citygate operation conditions:

- State conditions at input gas are 8140 kPa and 300,65 K
- Input gas molar composition is: 90% C1, 6% C2 and 4% C3
- Input gas standard flow range:  $1.0 \cdot 10^6$  to  $1.8 \cdot 10^6$  Sm<sup>3</sup>/day.
- Constant heat transfer rate at idealized heater HV01 is 500 kW (Heat transfer mode selected. Temperature will be calculated)
- Pressure drop at valve VLV1 is 4413 kPa. (Pressure mode selected . Valve fraction and CV will be calculated)
- Standard condition is 288,15K and 101,325 kPa

Another model were built using Aspen HYSYS software and the presented elements and input parameter data. HYSYS was selected because it has the EOS equations implemented in the actual solver, as well an a idealized heater and JT valve to compare the results. The results were generated using both simulators for maximum and minimum standard flow rates (1000 and 1800 SMm<sup>3</sup>/day) and two EOS (Peng-Robinson and Soave-Redlich-Kwong). The most important simulation results for this case are found in the temperature variation of HV01 and VLV1 elements as shown in Table 2.

### GASBOL Citygate Model

A typical GASBOL (Bolivia-Brasil Natural Gas Pipeline) delivery station model with filtration, heating, pressure control, and metering areas was built using the developed citygate

simulator. The complete model schematic view is shown in Annex B. The simulation model is composed of a cyclone filter at entrance point, two three-way-valves and two heaters working in parallel, and pipes linking the heating section with pressure control area.

Table 2 – Simulation Comparison between Citygate Simulator and HYSYS (Temperature Diff. in Idealized Heaters and Valves)

EOS Peng-Robinson Standard Vol. Flow: $1.0 \cdot 10^6$ Sm <sup>3</sup> /day		
Temp. Difference (K)	HYSYS	Citygate Simulator
Heater HV01	20.07	19.96
Valve VLV1	-19.59	-19.56
EOS Peng-Robinson Standard Vol. Flow: $1.8 \cdot 10^6$ Sm <sup>3</sup> /day		
Temp. Difference (K)	HYSYS	Citygate Simulator
Heater HV01	11.05	11.06
Valve VLV1	-20.93	-20.93
EOS Soave-Redlich-Kwong Standard Vol. Flow: $1.0 \cdot 10^6$ Sm <sup>3</sup> /day		
Temp. Difference (K)	HYSYS	Citygate Simulator
Heater HV01	19.98	19.90
Valve VLV1	-18.42	-18.39
EOS Soave-Redlich-Kwong Standard Vol. Flow: $1.8 \cdot 10^6$ Sm <sup>3</sup> /day		
Temp. Difference (K)	HYSYS	Citygate Simulator
Heater HV01	11.00	10.95
Valve VLV1	-19.79	-19.75

The following input parameters defines the GASBOL citygate station model:

- Input Gas (GASBOL)
  - State condition: 8590 kPa and 27.5 °C
  - EOS : Soave-Redlich-Kwong
  - Natural Gas Molar Composition: 89.12% C1, 5.84% C2, 1.74% C3, 0.28% i-C4, 0.38% n-C4, 0.11% i-C5, 0.07% n-C5, 0.09% C6+, 1.66% CO2 and 0.7% N2.
- Cyclone Filter Type Lapple (FILT01)
  - Body diameter of 12 inches
- Three-way valve (TV01A/B)
  - Both using Equal Percentage Curve – See Fig 2
- Heaters (HV51A/B)
  - Downstream temperature A: 72 °C
  - Downstream temperature B: 30 °C
- Control Valve (PCV013A)
  - Pressure Setpoint : 3412.7 kPa
- Gas Fuel Consumption (FUEL)
  - Flow rate:  $2.2 \cdot 10^3$  Sm<sup>3</sup>/day
- Delivery Condition (CUSTOMER):
  - Standard Flowrate:  $577.1 \cdot 10^3$  Sm<sup>3</sup>/day
  - Temperature: 21 °C

- Internal Pipes (HD058A/B)
  - Internal Diameter: 7.0 m
  - Length: 500 m
  - Roughness: 0.02 mm
  - Friction Formula: Weymouth

The citygate simulator calculates the pressure drop and the input/output velocities of the cyclone filter, the actuator position of 3-way valves, the heaters duty, and the control valve position. The status and performance of the modeled equipments and operational variables in intermediary points are presented in Table 3.

Table 3 – GASBOL Station Model - Simulation Results

Device Name	Device Output	Flowrate Sm <sup>3</sup> /day	Point	Pressure kPa	Temp. °C
FILT01	P.Drop(kPa)	579300	Upstream	8590.6	27.5
			Downstream	8512.7	27.2
HV51A	Duty (kW)	198440	Upstream	8497.0	27.1
			Downstream	8497.0	72.0
HD058A	-	289610	Upstream	8497.0	57.57
HV51B	Duty (kW)	142970	Upstream	8497.0	27.1
			Downstream	8497.0	30.0
HD058B	-	289690	Upstream	8497.0	28.54
PCV013A	Position %	579300	Upstream	8490.7	42.83
			Downstream	3412.7	20.87

### IFWBH Shut-Down and Restart

The next simulation case shows a citygate dynamic scenario where one of the IFWBH has shut-down and restarted. The design parameters and operational conditions of the IFWBH are presented below:

#### IFWBH Design Parameters:

- Heat Transfer Area A: 23.38 m<sup>2</sup>
- Heat Transfer Rate U: 405.5 W/m<sup>2</sup>K
- Mass of Water m<sub>w</sub>: 1000 kg
- Water Specific Heat c<sub>p</sub>: 4.185 kJ/kgK
- Burn Efficiency: 70%

#### IFWBH Operational Conditions:

- Fuel Flowrate (Fixed): 1.35 · 10<sup>3</sup> Sm<sup>3</sup>/day
- Heating Gas Flowrate (Fixed): 500 · 10<sup>3</sup> Sm<sup>3</sup>/day
- Bath Temperature (Initial): 85°C

The specific heat value of 35802.5 kJ/Sm<sup>3</sup> is estimated using the typical gas composition of the GASBOL pipeline.

The simulated scenario runs with only one IFWBH turned on, the second is already turned off. The upstream and downstream gas temperature trends and water temperature trend are illustrated in Fig 6. The IFWBH is shutdown at the start of the scenario and restarted after the complete cool down, when both downstream and upstream temperature became equal. For the assumed operational condition the IFWBH takes 67 minutes to complete the cool down process. This information will help the maintenance staff to establish the procedures to deal with that extreme event.

### CONCLUSION

The project started on September 2009, as a specific demand of TBG and Transpetro, and is still being developed at the moment. The main goal is to develop an “in house” customized tool capable to help the design and the process analysis of citygates. The simulation methodology solves the

conservation and element equations necessary to reproduce the equipments behavior coupled with equations of state (EOS) used to evaluated the natural gas thermodynamic properties (density, enthalpy, temperature).

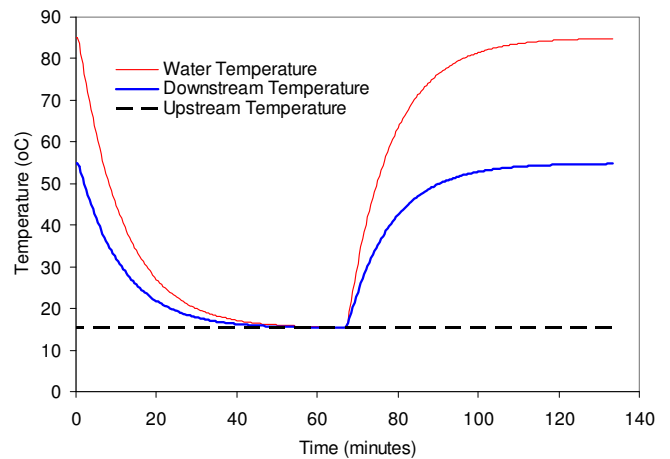


Figure 6 – IFWBH Temperature Trends (Shut-Down and Restart Scenario)

Equipments, like three way control valves and fire water bath heater, not usually found on traditional process commercial software, were modeled. The initial results obtained with the steady-state model of common equipments show good agreement with traditional simulators used in the area. A shut down heater event, a typical transient problem, has been simulated and has shown reasonable results. It has been modeled based on a typical GASBOL citygate datasheets and design information. The next development step will incorporate a dynamic control model to the three way valve in order to compare that dynamic simulation with real citygate historical data.

### NOMENCLATURE

- CV: valve coefficient
- K: pressure resistance coefficient
- m: mass flow rate
- Q: standard flow rate
- h: enthalpy
- q: heat transfer rate
- p: pressure
- T: temperature
- ρ<sub>g</sub>: gas density
- K: pressure resistance coefficient
- Z: compressibility factor
- γ: gas specific weight
- v: velocity
- GASBOL: Gas Pipeline Bolivia-Brazil
- IFWBH: indirect fire water bath heater

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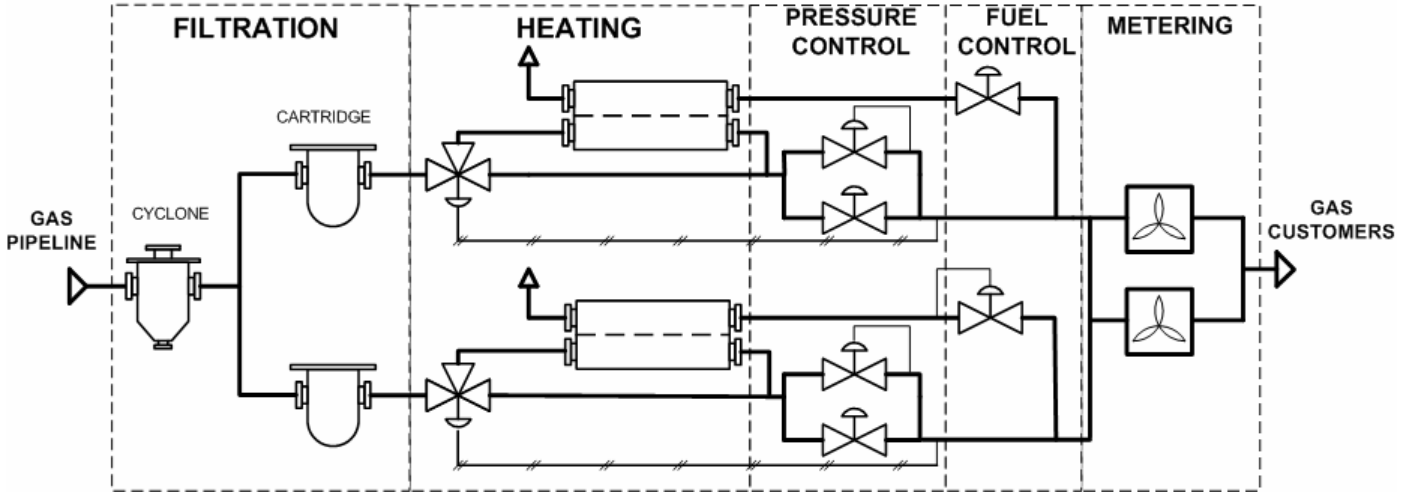
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## ANNEX A

### NATURAL GAS TREATMENT IN CITYGATES (SIMPLE SCHEMATIC VIEW)



## ANNEX B

### SIMGAS USER INTERFACE – TYPICAL CITYGATE MODEL

