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Multiphase Production Control: Application to Slug Flow

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Résumé — Contrôle en production polyphasique : application aux écoulements à bouchons — TACITE, développé à l'*IFP*, est un logiciel compositionnel capable de simuler le comportement des écoulements polyphasiques dans les pipelines et les puits de production avec différents équipements comme des contrôleurs, des vannes, des séparateurs, des injecteurs latéraux, des index de productivité ou des faisceaux de tubes. Cet article présente tout d'abord le système d'équations aux dérivées partielles qui est résolu dans ce logiciel. Puis, les différents modèles (thermodynamique, hydrodynamique, transfert de chaleur, numérique), sont brièvement décrits.

Nous montrons, à travers un exemple de champ réel, que l'utilisation d'un simulateur transitoire tel que TACITE est essentielle lors de la phase de design d'un système de production polyphasique. Il peut, en particulier, être utilisé pour tester différents systèmes de contrôle. Nous illustrons, sur ce cas, l'importance de l'approche compositionnelle qui a été mise en place dans ce code. Cet exemple est basé sur le champ de Dunbar. Pour certaines conditions de fonctionnement, cette installation est sujette à l'apparition du phénomène dit de *severe slugging* (écoulement à bouchons formé à la base d'un pipeline vertical). Les résultats de simulation de différents systèmes de production sont présentés puis analysés en termes d'efficacité à contrôler ce phénomène.

Mots-clés : écoulement polyphasique, production polyphasique, *severe slugging*, simulation transitoire.

***Abstract* — *Multiphase Production Control: Application to Slug Flow* —** *TACITE, developed at* IFP, *is a compositional software able to simulate the behaviour of transient multiphase flow in production pipelines and wells with process equipment such as controllers, valves, separators, lateral injectors, productivity index or bundles. This paper presents first the set of partial differential equations that are solved in this software. Then, the different models (thermodynamic, hydrodynamic, thermal and numerical) are briefly described.*

Through a field case example, we illustrate that the use of a transient simulator, such TACITE, is essential in the engineering design phase. For instance, it can be used to test control schemes for multiphase production installation. We also illustrate the importance of the compositional approach that has been developed in this code. This example deals with the Dunbar pipeline in which undesirable transient phenomena called "severe slugging" can occur. The simulation results of different production schemes that can prevent severe slugging occuring are presented and their efficiency is analysed.

Keywords: multiphase flow, multiphase production, severe slugging, transient simulation.

NOTATIONS

E_k	mass internal energy of phase k ($J \cdot kg^{-1}$)
g	gravity (m/s^{-2})
H_k	mass enthalpy of phase k (J/kg^{-1})
P	mixture pressure (Pa)
Q_w	wall heat flux between the pipe and the surrounding medium ($W \cdot m^{-3}$)
R_k	volumetric fraction of phase k (-)
S	pipe section (m^2)
T_w	wall friction (Pa/m)
U_m	mixture superficial velocity ($m \cdot s^{-1}$)
V_k	absolute velocity of phase k ($m \cdot s^{-1}$)
x_i^k	component i mass fraction in phase k (-).

Greek letters

ρ_k	density of phase k ($kg \cdot m^{-3}$)
θ	pipe inclination (rad).

Indexes

i	index for component, $i = 1, \ldots N$
k	index for phase; $k = 1, \ldots p$
m	index for mixture
N	number of components
p	number of phases (from 1 to 3).

INTRODUCTION

Unsteady phenomena appearance in multiphase production pipelines can cause severe operational problems, particularly for the receiving process facilities. Such phenomenon can be caused either by imposed operating condition variations or by the nonuniform profile of the pipeline. The TACITE Code, developed by *IFP*, *Total*[1] and *Elf*[1] is a compositional transient multiphase flow simulation tool [1, 2] used for the design and control of multiphase production pipelines and wells to avoid such phenomena.

In this paper, we describe the set of conservative equations used and the compositional approach implemented in this code. Then, we present the hydrodynamic, thermodynamic, thermal and numerical models main outlines.

We present a real case application on the Dunbar 16" (0.406 m) multiphase pipeline. The Dunbar field is located in the United Kingdom sector of the Northern North Sea, approximately 22 km to the South of the Alwyn North field which has been operated since the end of 1987. In this pipeline, mentioned in [3], riser-induced "severe slugging" occurs in the low flow-rate region. This phenomenon is first described, then we present simulation results for different control production system. The analysis of these results enables to discuss the efficiency of these systems to avoid "severe slugging" occurring.

1 TACITE CODE DESCRIPTION

The main objective of TACITE is to predict accurately the propagation of liquid slugs, the pressure and temperature profiles during transient flow due to boundary condition modifications such as inlet flowrate variation, outlet depressurisation, shutdown/restart, pigging operation or "severe/terrain slugging" phenomenon. Hereafter we present the set of equations, the closure laws, the numerical scheme and the different equipment implemented in TACITE.

1.1 Governing Equations

TACITE drift-flux model tracks the fluid composition so there is one mass conservation equation for each component. There is also one mixture momentum equation and one mixture energy equation. The corresponding equations are presented below:

Mass balance equation for each component:

$$\frac{\partial}{\partial t}\left\{\sum_{k=1}^{p} S\left(\rho_k R_k x_i^k\right)\right\} + \frac{\partial}{\partial x}\left\{\sum_{k=1}^{p} S\left(\rho_k R_k x_i^k V_k\right)\right\} = 0 \qquad \left(i = 1, \ldots, N\right) \tag{1}$$

Mixture momentum balance equation:

$$\frac{\partial}{\partial t}\left\{\sum_{k=1}^{p} S\left(\rho_k R_k V_k\right)\right\} + \frac{\partial}{\partial x}\left\{\left(\sum_{k=1}^{p} S\left(\rho_k R_k V_k^{\,2}\right)\right) + P\right\} = S(T_w - \rho_m g \sin\theta) \tag{2}$$

Mixture energy balance equation:

$$\frac{\partial}{\partial t}\left\{\sum_{k=1}^{p} S\left(\rho_k E_k\right)\right\} + \frac{\partial}{\partial x}\left\{\sum_{k=1}^{p} S\left(\rho_k R_k V_k H_k\right)\right\} = S\,(Q_w - \rho_m g U_m \sin\theta) \tag{3}$$

1.2 Closure Laws

To complete the systems, sets of physical closure laws are used:

- relations between volumetric fractions and between mass fractions;
- hydrodynamic model;

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[1] Total and Elf are now joined in *TotalFinaElf Company*.

- thermodynamic model;
- heat transfer model.

1.2.1 Algebraic Relations

$$\sum_{k=1}^{p} \left(R_k\right) = 1 \tag{4}$$

$$\sum_{k=1}^{p} \left(x_i^k\right) = 1 \tag{5}$$

1.2.2 Hydrodynamic Model

The hydrodynamic model computes the flow regime, the slip velocity between phases and the friction terms. A mechanistic slip model has been developed and validated against experimental data.

General types of regimes are considered: dispersed flow, stratified flow, annular flow and intermittent (slug) flow. The hydrodynamic closure law reduces to a slip equation in the case of dispersed flow. It is a macroscopic momentum balance in stratified flow and it is a set of algebraic equations in the case of intermittent flow.

Thus this model is flow regime dependent. The transitions between the regimes are modelled and an important effort has been done to ensure continuity of slip solution when flow regime transitions occur.

More explanation can be found for the two-phase flow in [4, 5]. Three-phase flow modelling is still in progress, some information can be found in [6].

1.2.3 Thermodynamic Model and Lumping

TACITE contains an optimised integrated thermodynamic flash that can perform 2- and 3-phase equilibrium calculations for mixtures of hydrocarbon components including water. The Peng-Robinson [7] and the Soave-Redlich-Kwong [8] cubic equations of state are available in order to model thermodynamic properties of equilibrium phases. In both cases, molecular volumes can be corrected following the Péneloux method [9]. The flash algorithm module uses stability analysis based on Gibb’s tangent plane criterion [10] in order to determine the number of equilibrium phases, and minimisation procedures for calculating phase splits corresponding to a fixed number of phases. A range of transport and thermal properties is available for the different fluid phases.

This integrated thermodynamic flash insures a good computation of phase equilibrium and of phase properties for a given set of components within acceptable computation time. It also insures an accurate tracking of the fluid components both in space and time during the whole simulation.

A detailed composition of a production fluid may include around 25 components. In transient conditions the computing time increases a lot as the number of tracked components increases. So, when using TACITE for industrial studies it is not realistic to run a simulation with the detailed fluid, the fluid has to be lumped before using it in the simulation. A lumping procedure has been developed to be able to reduce the number of components, insuring a good representation of the fluid properties such as liquid density and vapour mass fraction. The two main stages of this method are:

- determine the best cut point;
- compute the pseudo components properties.

The best cut points for a given number of pseudo components is supposed to minimise an objective function that can be based on the vapour mass fraction or on the equations of state parameters. This method is based on the method presented in [11] and was first applied in the TACITE binary version. The binary representation was very precise for standard fluid but was found to be insufficient in the case of more complicated fluid such as gas-condensate.

1.2.4 Heat Transfer

TACITE allows a wide choice of heat transfer modelling options. These are:

- User defined fluid temperature profile.
- Fluid temperature profile based on steady state flow.
- Transient heat transfer: the radial heat transfer rate is assumed to be over successive steady states radial temperature field at a given location.
- Transient heat transfer which also includes layers inertia: this assumes that the radial heat transfer is over a transient temperature field due to the finite heat capacity of the pipe and insulation material.

1.3 Numerical Scheme

The model considered is a drift-flux type where the slip velocities between phases is given by a hydrodynamic model that accounts for the different flow regimes. Then, the system of equations obtained is hyperbolic. The complexity of the closure relations prevents us from using classical numerical schemes such as Godunov or Roe’s scheme, that’s why a specific finite volume scheme has been developed to insure an accurate component front tracking.

The TACITE numerical scheme described in [12] is conservative. It provides excellent mass and energy balance along the pipeline cells and along the iteration loops. It is nondissipative. It insures good front tracking capability and allows to simulate terrain/severe slugging phenomena. A mixed implicit/explicit scheme is used to optimise the computing speed and front tracking capability. This is particularly important in the case of a terrain or severe slugging phenomenon when void fraction waves travel in both directions.

1.4 Equipment

TACITE is able to simulate real field installation. For this purpose, it contains models for pipe inlet and pipe outlet and for various equipment installed on the pipeline such as: valves, lateral injectors, relief valves, multiphase pumps, pig, PID controllers, bundles.

The pipe inlet can be considered as a source containing given component mass flow rates or may have a productivity index behavior as described in [13]. The productivity index module modifies the upstream boundary condition using a correlation between the pressure profile within the reservoir, the bottom-hole pressure and the production flowrate.

At the pipe outlet, there is either a sink with an imposed pressure or a separator with controlled gas pressure and liquid level (two-phase separation). Some alarms for level are also taken into account.

The valves can be located anywhere on the pipe except at the inlet. The pressure drop through the valve is computed as a function of the flow-rate, the valve opening and geometrical valve characteristics: diameter and so-called Cd coefficient.

The lateral injectors, which can be located anywhere on the pipe except at the inlet and the outlet, are able, if necessary, to take into account compressibility in the injection line.

The relief valves can be located anywhere on the pipe except at the inlet and the outlet. It opens up when pressure in pipe exceeds the relief valve set point pressure.

The multiphase pump considered is rotodynamic and can account for a two-phase flow. The relation between pressure drop and flow-rate, described in [14] is a function of the rotation velocity, the number of stages (each stage contains an impeller and a diffuser), and of the geometrical characteristics of each stages.

The pig motion all along the pipe from a given pig launcher to a given pig trap position can also be simulated. The corresponding model is described in [15]. Such facility can be used, for instance, to remove liquid accumulation.

PID (proportional, integral and derivative) controllers can be used to control the values of the main variables of the system, by acting on other variables. For instance such PID are installed on the separator unit to control the oil and water levels by acting on the opening of valves located respectively on the oil and water outlet and to control the gas pressure by acting on the opening of the valve located on the gas outlet.

Bundles can be used to optimise the heat transfer between the fluid and the outside environment. The corresponding model is described in [16] and this system can be used to control hydrates risk of apparition such it is mentioned in [17].

1.5 Validation

The hydrodynamic model has been validated on experimental loop data. The transient behavior of the code has also been validated for instance on the Miranda field data bank. The Miranda field data bank contains transient multiphase data from experiments carried out on real fields operated by *Agip*, *Total* and *Elf*. In particular the pig module has been validated on these data *(see [15])*. Heat transfer computation, in shut down situation, has been validated using Fluent™ Code (see www.fluent.com website). Other validations are planned to be done.

2 TACITE APPLICATION TO MULTIPHASE PRODUCTION CONTROL: THE SEVERE SLUGGING ON DUNBAR PIPELINE

The TACITE Code is able to simulate the behavior of transient multiphase flow in production pipelines and wells. Transient may be due to boundary conditions variations such as shut down, restart or depressurisation. But it may also be induced by the pipeline topography leading to severe or terrain slugging phenomenon.

We present an application of TACITE to the 22 km long, 16” (0.406 m) diameter Dunbar pipeline. It is designed to transport the Dunbar multiphase production to the Alwyn platform. Due to its profile, this pipe is typically subject to riser induced severe slugging for some given operating conditions corresponding to low flow-rates.

In this part, we first described the severe slugging phenomenon ant its consequences. Then we present results of the simulation of different installations schemes. These results are analysed to see how the proposed schemes are able to control the severe slugging occurring.

2.1 Severe Slugging Phenomenon

2.1.1 Physical Description

The severe slugging phenomenon occurring in multiphase transport system has been well described in [18-21] and is illustrated in Figure 1.

It occurs for low velocity of gas and liquid phases. Schematically it is a periodic phenomenon that can be split into 4 steps. In the first one, the liquid accumulates in the low point due to its low velocity and to the liquid that falls down and forms a slug. In the second step there is a blockage until the pressure becomes sufficient to lift the liquid column. In the third step, the liquid slug starts to go upward along the riser. The gas begins to flow in the riser and so accelerates

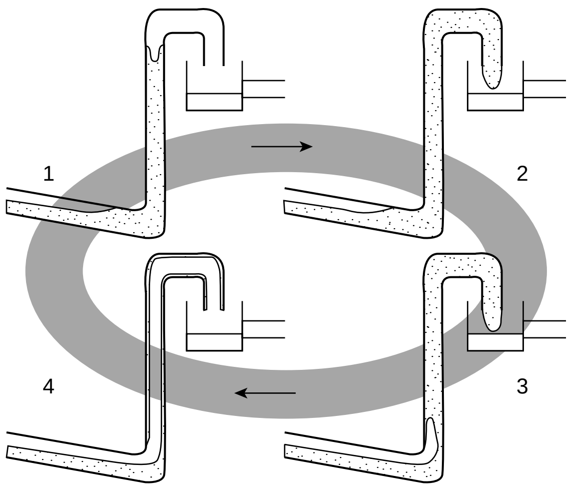

Figure 1

Severe slugging phenomenon.

the liquid. Finally, the gas arrives at the top of the riser and the pressure rapidly decreases causing liquid flow down. And so on.

Steps 3 and 4 can damaged the process facilities if the separator has not been correctly designed. But the pipeline can also be damaged during the liquid acceleration if the fluid contains solid particles or during the liquid accumulation if the fluid contains some eroding substances like salt for instance.

2.1.2 Operator Behavior

Usually, the operators try not to operate in the severe slugging region. But, the inlet conditions of a production pipeline are linked to the number and the capacity of the producing wells, the availability of wells and also to some undesirable operation such as shut down or restart. The natural trend when dimensioning a production line is to do whatever is possible to avoid critical flooding of the separator, and therefore to over dimension the separator unit. But in offshore production, over dimensioning the installation is very costly and not always possible. So, the petroleum engineers require more and more transient simulations to correctly design and dimension their production scheme, and to be able to propose new concepts suitable to every situation they can be faced to.

2.2 Simulation of the Nonequipped Field

The Dunbar pipeline profile is represented in Figure 2. It is typically a profile that can lead to riser induced severe slugging.

2.2.1 Fluid

When using a multiphase simulation tool, great care has to be taken on the fluid definition. Especially when the pipeline profile is such that accumulation can occur at low points. The compositional approach developed in TACITE presents an important advantage because the composition varies along the pipe and at each point the fluid properties are computed with the right local composition.

As mentioned above a lumping procedure has been developed. In the present study, the fluid initial description contains 22 components (pure components and petroleum cut). We choose to represent this fluid with 4 pseudo components. This composition is optimised with respect to liquid density and gas mass fraction. The representation

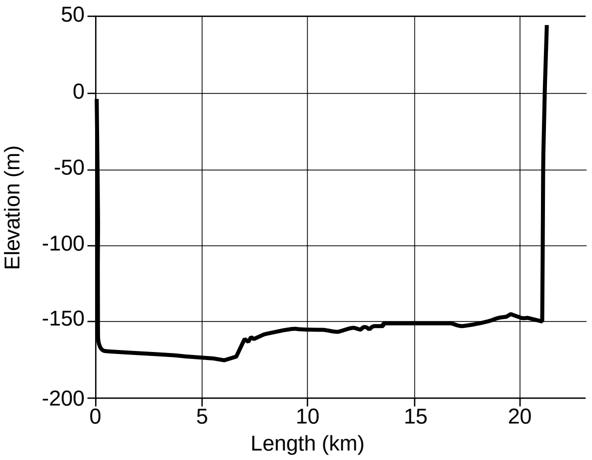

Figure 2

Dunbar pipeline profile.

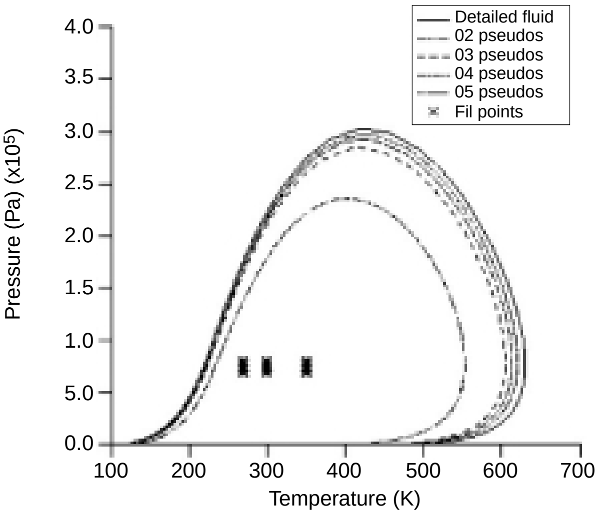

Figure 3

Phase envelopes for detailed fluid, and fluid lumped in 2, 3, 4 and 5 pseudo components.

for 2 pseudo components is to be very poor, we obtain a better result for 3 and even better for 4 components. In Figure 3 the phase envelopes for the detailed fluid, the 2, 3, 4 and 5 pseudo components lumped fluid is plotted. In Figure 4, we plot, for various pressure-temperature conditions the fluid vapour mass fraction of the lumped fluid with 2, 3 and 4 pseudo components versus the same value obtained for the detailed fluid. The solid lines represent the situation where both are equal. In Figure 5, the same graphics are plotted for the liquid density. We can see that for 4 components we have still a good approach. So the choice of 4 components is a good compromise between accuracy and computing time.

2.2.2 Boundary Conditions

The reference inlet total flow-rate is set to 27 kg/s, which corresponds to severe slugging occurrence. A higher value has been tested to show that, due to the inlet flowrate condition, the flow may be stable or not.

The outlet separator is horizontal; it is 12.5 m in length and 3.3 m in diameter. The separator pressure is set equal to 7.1 MPa. The oil level in the separator is set to 1.25 m. Oil and gas outlet pressure are set to 6.9 MPa. A maximum and a minimum levels are imposed to cause full opening or closing of the outlet valves. The temperature profile is imposed to linear decrease from 350 to 278°K.

2.3 Nonequipped Line Behavior

In all the Figures from 6 to 20 we have plotted the pressure variation versus time for different points located on the pipeline and the oil fraction variation versus time for the same points. In these figures, the square markers correspond to the upstream conditions, the circle markers correspond to the riser base conditions and the triangle markers correspond to the downstream conditions.

2.3.1 High Flow-Rates

The first total inlet flow-rate used was a high flow-rate, equal to 54 kg/s, which leads to a stable regime. In Figure 6 we can observe stable behavior.

2.3.2 Low Flow-Rates

The second total inlet flow-rate was set to a lower value equal to 27 kg/s leading to severe slugging occurrence. In this case we observe on Figure 7 the occurrence of severe slugging.

2.3.3 Influence of the Fluid Description on the Transient Behavior

If the simulation is done with a fluid lumped in two components (rather than with 4) we observe a slightly different behavior shown in Figure 8: the cyclic periods are not the same and the maximum values are still different. That illustrates the influence of the fluid description and the importance of fine modelling of the fluid properties in difficult situation that are the most common one for which transient simulation tools are needed. If we use 10 pseudo components to represent the fluid, we obtain the results shown in Figure 9 that are very close to those obtained with 4 pseudo components. From this study we conclude that with a reduced number of pseudo components we can have a good accuracy on the fluid transient behavior. Generally, for oil

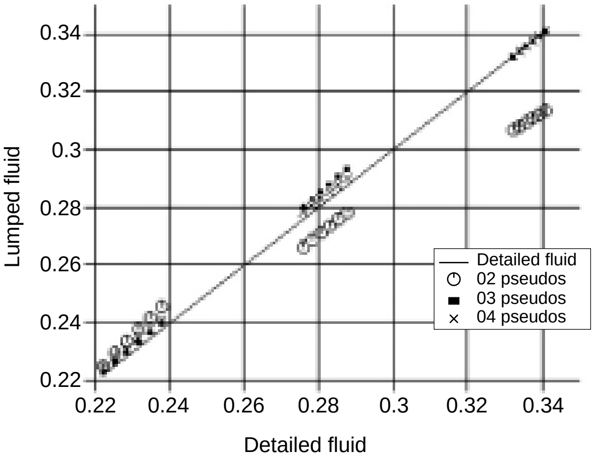

Figure 4

Comparison of vapour mass fraction of fluid lumped in 2, 3 and 4 pseudo components versus vapour mass fraction of detailed fluid.

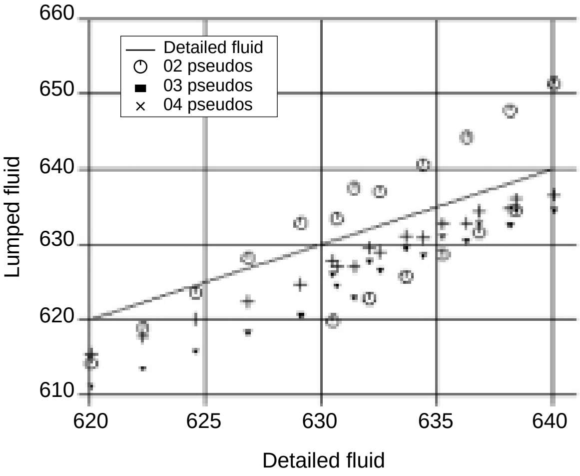

Figure 5

Comparison of liquid density fluid lumped in 2, 3 and 4 pseudo components versus liquid density of detailed fluid.

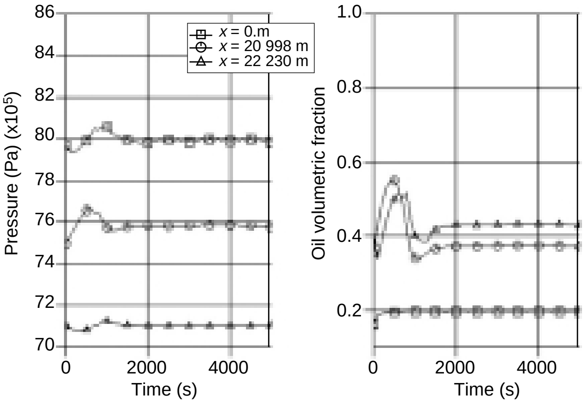

Figure 6

Nonequipped line and double production: pressure and oil volumetric fraction time evolution for 3 points located: at inlet, at the riser base, at outlet in the case.

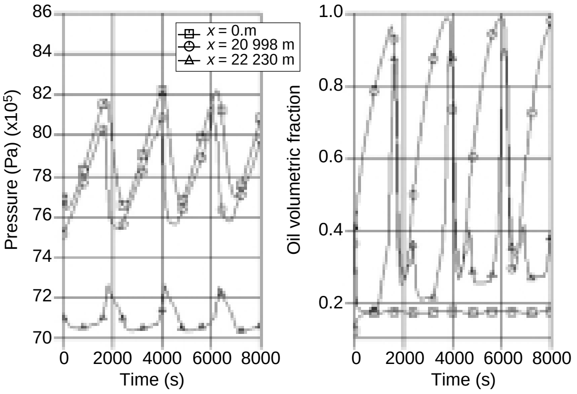

Figure 7

Nonequipped line and 4 pseudo fluid representation: pressure and oil volumetric fraction time evolution for 3 points located: at inlet, at the riser base, at outlet in the case.

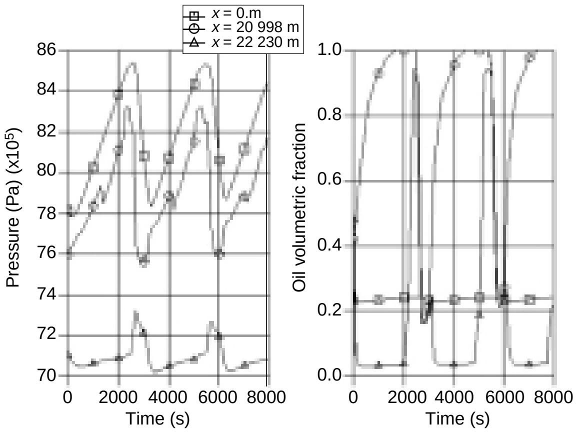

Figure 8

Nonequipped line and 2 pseudo fluid representation: pressure and oil volumetric fraction time evolution for 3 points located: at inlet, at the riser base, at outlet in the case.

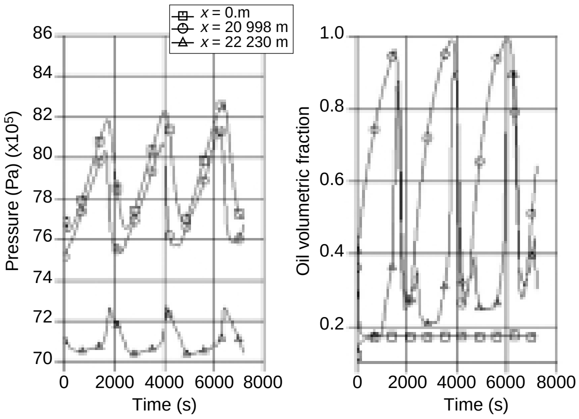

Figure 9

Nonequipped line and 10 pseudo fluid representation: pressure and oil volumetric fraction time evolution for 3 points located: at inlet, at the riser base, at outlet in the case.

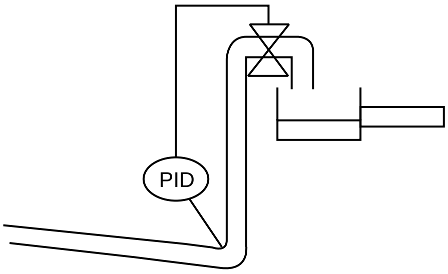

Figure 10

Line equipped with a control on the riser base pressure.

fluid such as the one used here, a good accuracy is insured by using 4 pseudo components. But, for some more complex fluid such as gas condensate, 5 or 6 pseudo components may be required.

2.4 Proposed Schemes

In this part, we propose a nonexhaustive list of production schemes which can be used to eliminate the severe slugging phenomenon.

2.4.1 Riser Base Pressure Control

In this case, illustrated in Figure 10, the line is equipped with a valve located upstream of the separator, a pressure transmitter located a the riser base, and a PID controller which has to act on the valve opening in order to respect a fixed set point on the riser base pressure equal to 7.7 MPa.

The inlet flow-rate of the first component varies 7000 s after the beginning of the scenario. We can see the PID behavior that acts to obtain again 7.7 MPa.

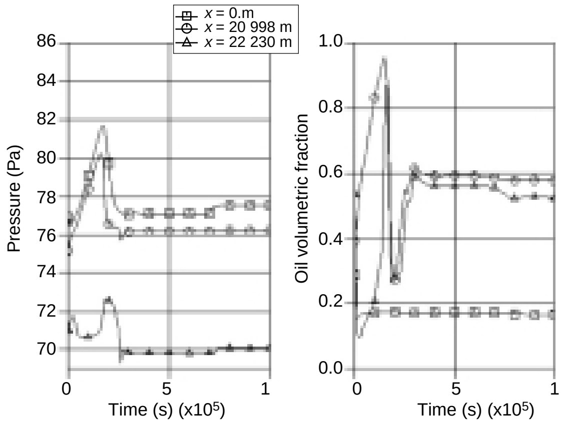

Figure 11

Upstream valve controlled by a PID fitting the riser base pressure: pressure and oil volumetric fraction time evolution for 3 points located: at inlet, at the riser base, at the outlet.

In Figure 11, we can see that, after a stabilization period, the corresponding flow is stable. This stabilization period can be reduced if we start with a lower initial valve opening.

Figure 12 illustrates the evolution of the valve opening and Figure 13 illustrates the riser base pressure versus time. We clearly see the efficiency of the PID controller: as soon as the pressure tends to increase, the PID makes the valve close so the riser pressure decreases and the liquid flows upward instead of staying at the base. Then, when the pressure is again at the setting value, the PID reopens the valve.

This system has been installed on the Dunbar line and has proven to be very efficient.

2.4.2 Gas-Lift

Another well-known system has been simulated: gas-lift injection, see for instance [1]. The aim of this system is to accelerate the fluid around the riser base to avoid liquid accumulation. In this part we have tested different schemes (different location of the injection point, different injection flowrate values).

Two technical solutions have been envisaged *(see Fig. 14)*:

- gas-lift injection at the bottom of the riser;
- gas-lift injection before the riser base.

Two injection rates have also been envisaged for each case:

- injection of 3 kg/s;
- injection of 8 kg/s.

Figure 15 and Figure 16 respectively illustrate the behavior of the 3 kg/s and 8 kg/s gas-lift injection located at the bottom of the riser. The two injection flowrate conditions lead to kill severe slugging phenomenon. But, the higher the flowrate is, the longer the stabilization time is.

Figure 17 and Figure 18 respectively illustrate the behavior of the 3 kg/s and 8 kg/s gas-lift injection located before the bottom of the riser. For the 3 kg/s the severe slugging phenomenon has been lowered but there are still oscillations and so there is still risk of damage for the outlet facilities. At the high flow-rate, severe slugging has disappeared and the solution is more stable than for a riser base injection.

The aim of this part is clearly to demonstrate how a dynamic simulator can be used to design an installation for a given technology. In fact, after the analysis of those simulations the designer should have enough information to be able to propose a safety scheme answering to the technical possibility of the installation. If he wants a stable flow he would prefer an injection before the bottom of the riser. But in this case, he needs a more important injection flow-rate. That can be difficult in some cases, for instance if there is not enough gas available at the vicinity of the installation.

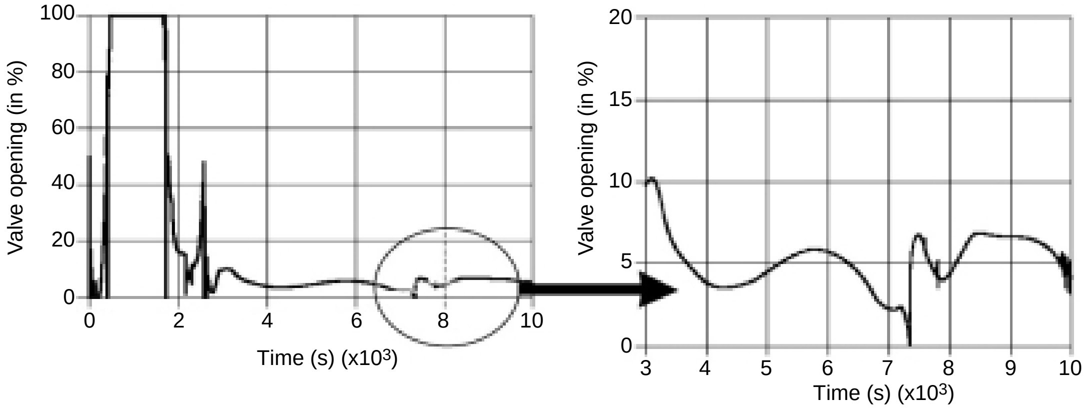

Figure 12

Upstream valve controlled by a PID fitting the riser base pressure: valve opening due to PID behaviour. The right scheme is a zoom of the surrounded region of the left scheme.

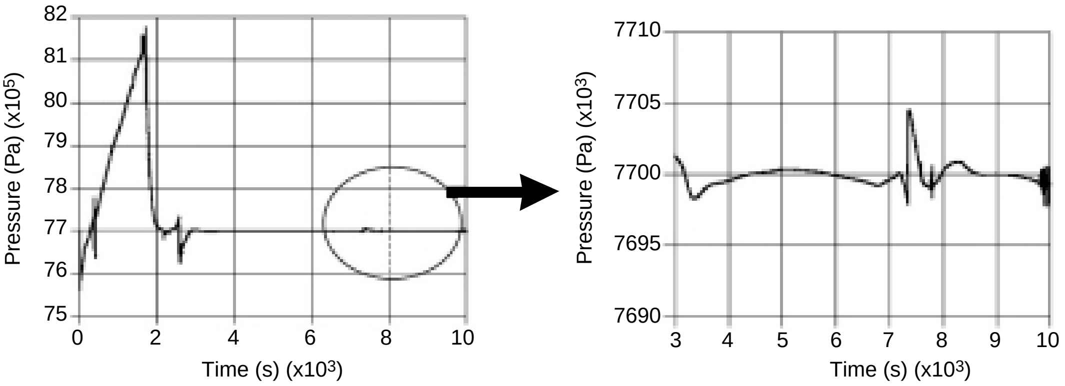

Figure 13

Upstream valve controlled by a PID fitting the riser base pressure: riser base pressure due to PID behaviour. The right scheme is a zoom of the surrounded region of the left scheme.

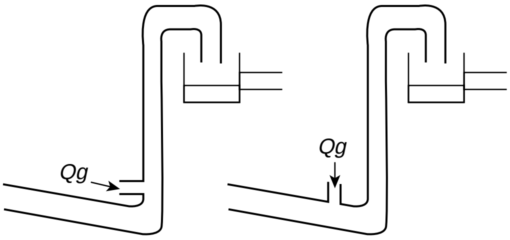

Figure 14

Line equipped with gas-lift injection. On the right scheme the injection is located just before the bottom of the riser. On the left scheme, the injection is located at the bottom of the riser.

2.4.3 Pumping

The pump module we have in TACITE is an helico-axial pump module describes in [14]. This pump module may have a given number of stages to accelerate enough the fluid. Generally this equipment is used to boost the production in the case of a non-eruptive well. But pumping has also been proposed to eliminate severe slugging as mentioned in [14].

In the first part, the pump was located at the bottom of the riser *(see Fig. 19)* its aim is also to boost the flow to avoid accumulation leading to severe slugging. The problem is still to correctly dimension this equipment module. In this study, we have taken a given stage definition and we have tried to find the optimum number of stages to be installed to avoid completely the severe slugging. Figure 20 shows the flow behavior with a 12 stages pump module: the severe slugging is attenuated but is still there. Figure 21 shows the flow behavior with a 14 stages pump module: the severe slugging has disappeared.

In the second part, the pump has been located at the top of the riser *(see Fig. 19)*. In this case the purpose of the pump is to suck up the liquid to avoid the blockage. Figure 22 shows the flow behavior with a 14 stages pump module: the severe slugging is attenuated but is still there. Figure 23 shows the flow behavior with a 16 stages pump module: the severe slugging is even more attenuated.

The riser base pump scheme seems to be more efficient and need a smaller pump, but perhaps it is easier to install a pump at the top of the riser.

2.4.4 Other Ideas

Among the schemes proposed there is only one system that is based on controllers, but we think that some other controlled schemes should be proposed to optimise the design. For instance, we could optimise gas lift injection flow-rate by controlling the riser base pressure. Using the simulator we could have tested other schemes such as multivariable control schemes. In fact, such control schemes may be technically difficult to install because they require adapted and accurate sensors in some difficult place. But, it will be the price to pay to safely operate fields located in severe or terrain slugging operating conditions.

CONCLUSION

Today, the installations are currently designed to avoid undesirable situation and they are over dimensioned to be sure that for every variation of inlet conditions due to well opening or closing or any other possible facilities transient operations, the design is sufficiently conservative to avoid problem. The trend is now to reduce costs.

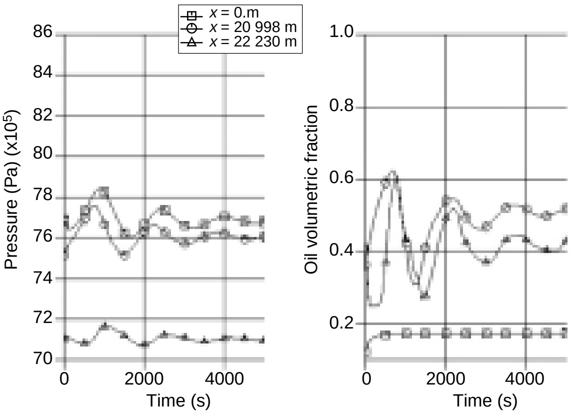

Figure 15

Gas-lift injection of 3 kg/s at the bottom of the riser: pressure and oil volumetric fraction time evolution for 3 points located: at inlet, at the riser base, at outlet.

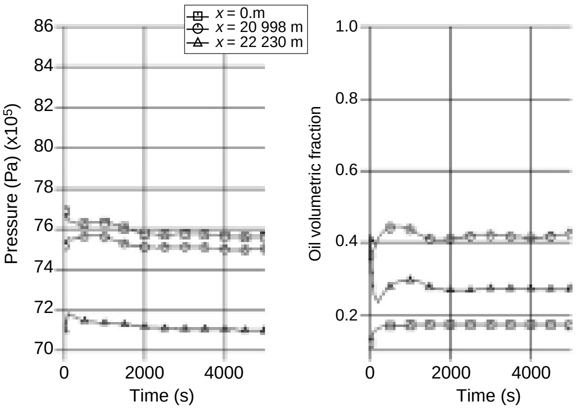

Figure 16

Gas-lift injection of 8 kg/s at the bottom of the riser: pressure and oil volumetric fraction time evolution for 3 points located: at inlet, at the riser base, at the outlet.

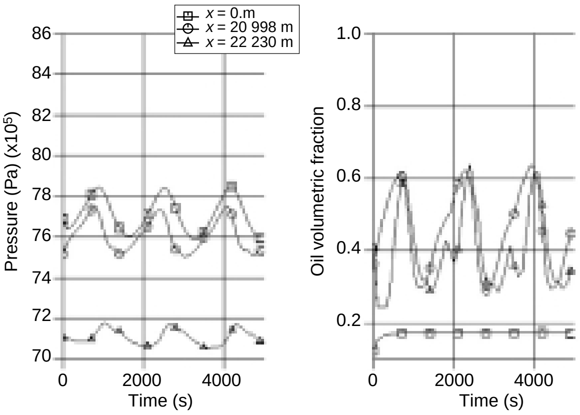

Figure 17

Gas-lift injection of 3 kg/s before the bottom of the riser: pressure and oil volumetric fraction time evolution for 3 points located: at inlet, at the riser base, at outlet.

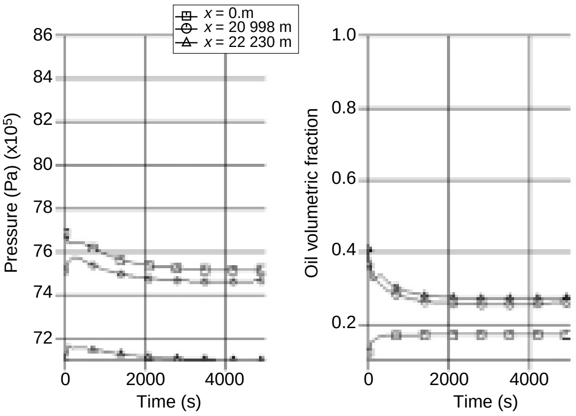

Figure 18

Gas-lift injection of 8 kg/s before the bottom of the riser: pressure and oil volumetric fraction time evolution for 3 points located: at inlet, at the riser base, at the outlet.

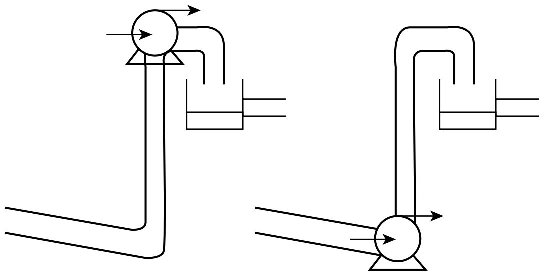

Figure 19

Line equipped with a multiphase pump. On the right scheme the pump is located at the bottom of the riser. On the left scheme, the injection is located at the top of the riser.

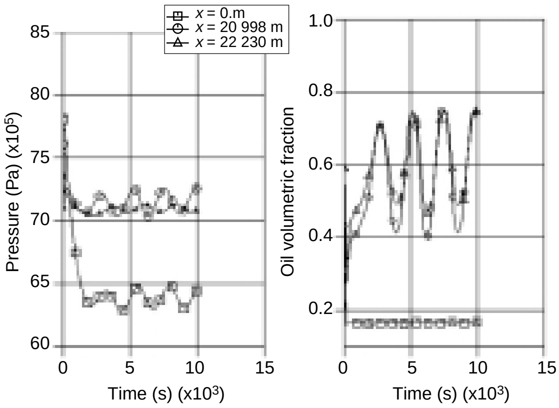

Figure 20

12 stages pump at the bottom of the riser: pressure and oil volumetric fraction time evolution for 3 points located: at inlet, at the riser base, at the outlet.

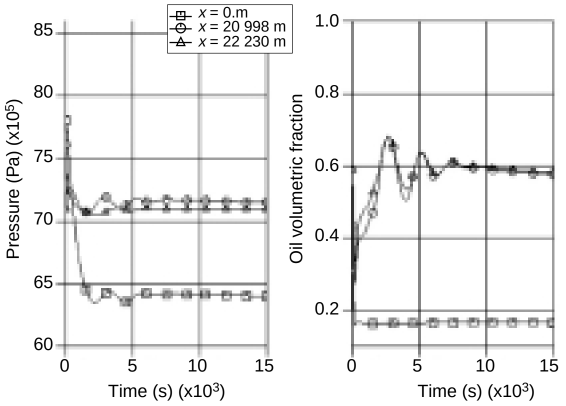

Figure 21

14 stages pump at the bottom of the riser: pressure and oil volumetric fraction time evolution for 3 points located: at inlet, at the riser base, at the outlet.

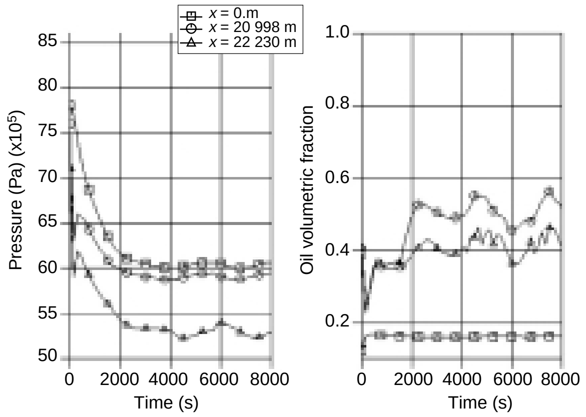

Figure 22

14 stages pump at the top of the riser: pressure and oil volumetric fraction time evolution for 3 points located: at inlet, at the riser base, at the outlet.

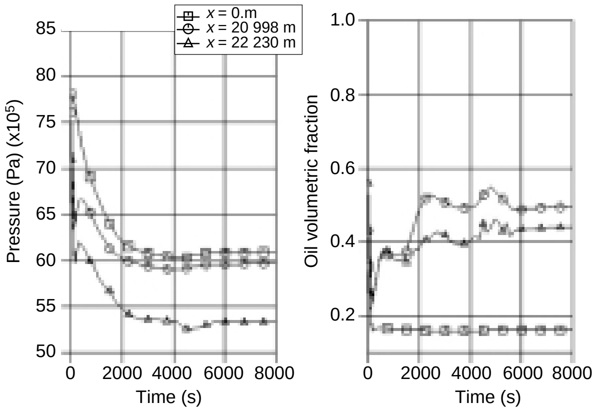

Figure 23

16 stages pump at the top of the riser: pressure and oil volumetric fraction time evolution for 3 points located: at inlet, at the riser base, at the outlet.

We have shown that to reach this objective, the use of a transient simulator can help to test a lot of production scheme, and to choose for each one the optimum design. We have also highlighted the importance of an accurate computation of the fluid properties in particular when the topographic effects could lead to severe slugging phenomenon. We have proposed and simulated with TACITE some efficient schemes to prevent severe slugging: riser pressure control, installation of a pump (at the riser base or topside), gas-lift injection at or before the bottom of the riser.

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