PRJ, Vol. 4. (January 1992); P. 59–62, 5 FIGS, 2 TABLES.

Short Note

A COMPUTER PROGRAM TO SIMULATE TWO-PHASE PIPELINE FLOW

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منظومة حاسوبية لمحاكاة الإنسياب خلال خطوط الأنابيب ثنائية الطور

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يزداد هبوط الضغط خلال الإنسياب الثنائي الطور للمخاليط الهيدروكربونية نتيجة للتأثير المتبادل بين الطورين ، وتظهر تعقيدات أخرى نتيجة إلى تجمع كتل من السائل خصوصاً في تجاويف الأنابيب الطويلة الممتدة على الأرض أو قاع البحر، ولذلك تعد المعرفة الوثيقة بقطاعات الضغط وتشكيل نمو كتل السائل ضرورية لتصميم ومحاكاة خطوط الأنابيب الثنائية الطور. تعرض الورقة منظومة حاسوبية لإنجاز ذلك.

INTRODUCTION

Two-phase flow is commonly encountered during the transportation of hydrocarbon mixtures through land based or subsea pipelines. An important task during the design and simulation of pipelines is to predict pressure and temperature variations along the pipe length and to estimate build-up of liquid slugs at different locations in particular in the hollows of the pipelines. The information for the liquid build-up is required to compute both pressure variations as well as the volume of slugs during pigging operation. The above information is also vital in the mechanical design of pipeline and pipe supports and in the stress analysis. A rigorous approach to this problem involve dividing the whole pipe length into several finite length elements (FLE) and carrying out in each of them phase equilibrium, heat transfer and pressure drop calculations sequentially. Depending upon the available data and the objectives of the task the calculations may have to be carried starting from the upstream end, downstream end or from some intermediate locations. In view of the coupled nature of the physical processes and consequently the calculation techniques, digital computer application is essential to perform the computations. This paper presents general organization and calculation logic of a computer program developed to simulate two-phase flow line carrying hydrocarbon mixtures. The program has been tested by using IBM PC AT on a 30 miles long pipeline for which data was available in the literature [4].

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EQUILIBRIUM AND TRANSFER PROCESS MODEL EQUATIONS

The equilibrium flash calculations have been performed by using SRK equation of state (Table 1) [8] for computing the k-values. The physical and thermodynamic properties are estimated using a number of techniques given in the literature [1, 3–9].

The hydrodynamics of the two-phase calculations is based on Beggs and Brill Models [2], as shown in Table 2. The information for the friction factor and pipeline roughness is obtained from White [10].

Frequently the hydrocarbon mixtures contain both defined and undefined components. The program is written with capability to process the undefined

Table 1. Soave Equation of State

$$P=-\frac{RT}{V-b}-\frac{a\alpha}{V(V+b)}$$

Parameters

$a_i=0.42747R^2T_{ci}/P_{ci}$

$b_i=0.08664RT_{ci}/P_{ci}$

$\alpha_i=1.202\exp(-0.30288\ \mathrm{T}_r)$ (for Hydrogen)

$\alpha_i=[1+(0.48508+1.55171W_i-0.15613W_i^2)(1-T_{ri}^{0.5})]^2$ (for other components)

$A_i=a\alpha P^2/R^2T^2$

$B_i=bP/RT=0.08664P_r/T_r$

$a\alpha=\sum\sum Y_iY_i(a\alpha)_{ij}$

$b=\sum Y_ib_i$

$A=\sum\sum Y_iY_iA_{ij}$

$B=\sum Y_iB_i$

$(a\alpha)_{ij}=(1-k_{ij})\sqrt{(a\alpha)_i(a\alpha)_j}$

$k_{ij}=0$ for hydrocarbons pairs and hydrogen

$A_{ij}=(1-k_{ij})(A_iA_j)^{0.5}$

$Z^3-Z^2+(A-B-B^2)Z-AB-0$

$Z=$smallest positive value for liquids

$Z=$largest positive value for vapours

Table 2. Equations for Liquid Holdup

Horizontal Flow Pattern	Horizontal Holdup ($H_L(0)$)	C^+ (Uphill)	C^- (Downhill)
Segregated	$\frac{0.98\ \lambda^{0.4846}}{N_{FR}^{0.0868}}$	$(1-\lambda)\ln\left[\frac{0.011N_{LV}^{3.539}}{\lambda^{3.768}N_{FR}^{1.614}}\right]$	$(1-\lambda)\ln\left[\frac{4.7N_{LV}^{0.1244}}{0.3602N_{FR}^{0.5056}}\right]$
Intermittent	$\frac{0.845\lambda^{0.5351}}{N_{FR}^{0.0173}}$	$(1-\lambda)\ln\left[\frac{2.96\lambda^{0.305}N_{FR}^{0.0978}}{N_{LV}^{0.4473}}\right]$	As above
Distributed	$\frac{1.065\lambda^{0.5824}}{N_{FR}^{0.0609}}$	0.0	As above

mixture into one or more pseudo components, if provided in any one of the following form:

(1) Complete TBP and density of mixture
(2) GLC analysis giving carbon number distribution
(3) ASTM D-86 data along with density
(4) Density and molecular weight.

The critical properties and physical properties of the pseudo components are estimated using the relationships available in the literature [1, 2–10].

Program Organization and Calculation Logic

The general organization of the program is schematically explained in Fig. 1a, whereas Fig. 1b provides the calculations flow chart. The program is organized into a main program which controls the computations, takes in input and gives out output. The input information is distributed among various subroutines using "COMMON" statement. As it is obvious from Fig. 1, the program could be used in different cases:

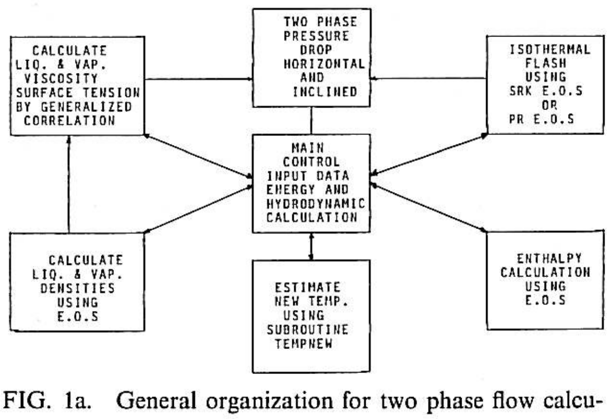

FIG. 1a. General organization for two phase flow calculation.

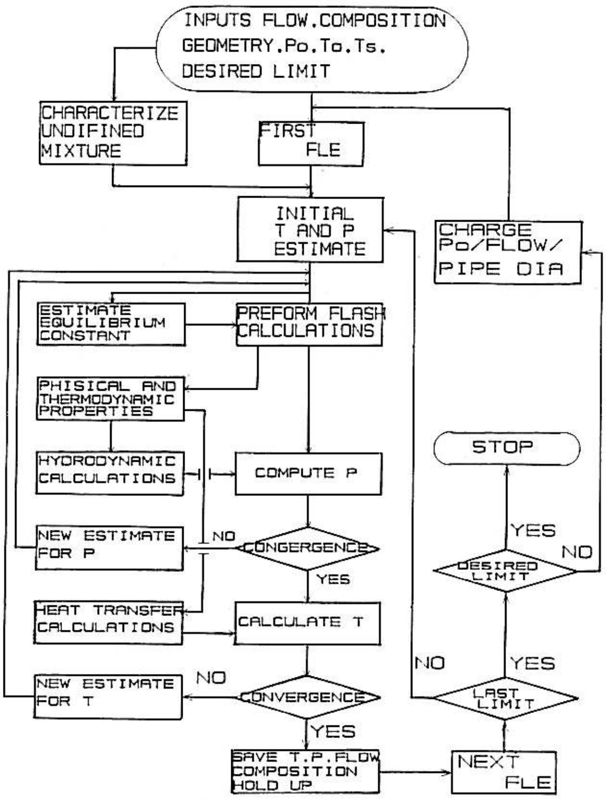

FIG. 1b. Flow chart for calculations of a single pipe.

(A) To simulate a single pipeline having single physical input and single physical output:

In this case the program could simulate the pipeline on stand alone basis and to carry out any of the following tasks.

(1) Upstream conditions are provided and it is required to estimate the intermediate and downstream conditions.
(2) The program must determine the upstream condition (or downstream) if mixed down stream/upstream conditions are available. For example it is required to compute total flow rate if delivery and upstream pressures are specified. In this case the program performs trial and error calculations until the convergence is achieved.
(3) To simulate a pipeline having one or more tie-in lines and/or branches. In the case of tie-in lines the flow rate and composition will change.

(B) Simulate a system of pipelines or to optimize a single pipeline conditions in conjunction with another:

In this case the program could not be used on stand-alone basis. It should be used as a back-up package or subroutine.

RESULTS AND DISCUSSION

A reference case for two-phase flow has been provided by Maddox and Erbar [4] for testing purposes. Complete geometrical, flow and compositional details are provided for a 30 miles long and 15 inch size pipeline. The flow rate is 100 MM SCF/day of gas and 67.3 barrels/day of liquid.

The data is provided for two cases:

(1) Smooth pipe
(2) Rough pipe (roughness 0.005 ft)

Fig. 2 gives the pressure profile for the rough pipe. The results obtained from the program are compared by the data provided by Maddox and Erbar [4]. The computed and given delivery pressures are 790 psia and 775 psia respectively. The agreement is within ±2%. Fig. 3 provides the results for non-adiabatic condition. The heat transfer coefficient has been taken as 0.1 Btu/(hr) (sq. ft) (deg. F). This represents an average value for an insulated pipeline. A comparison between Fig. 2 and Fig. 3 indicates that the pressure differences between the adiabatic and non-adiabatic case are a function of the absolute pressure.

The pressure drop for both cases remain identical as long as the total pressure remains above 700 psia.

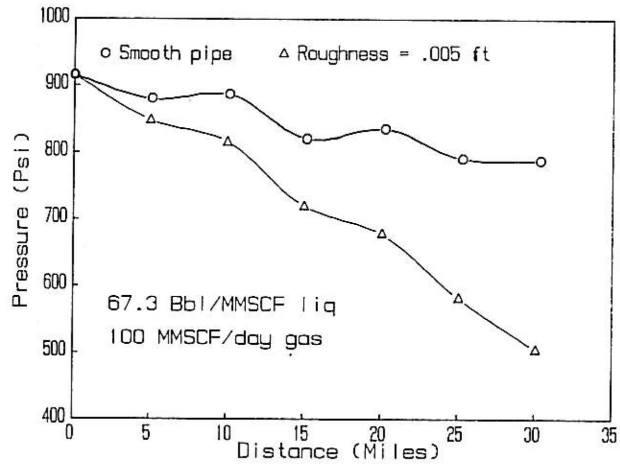

FIG. 2. Pressure profile for two phase flow (no heat transfer, 15 inch inclined pipe).

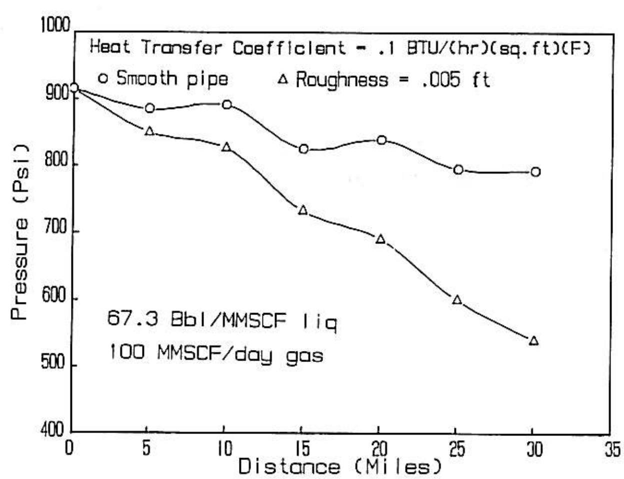

FIG. 3. Pressure profile for two phase flow (15 inch inclined pipe), with heat transfer.

Below 700 psia high temperatures and lower pressure encountered in the adiabatic case have lead to higher pressure drop. It may thus be inferred that operating a gas phase rich and liquid defficient line at high pressure offer advantages from the pressure drop point of view (and consequently lower pumping power).

Fig. 4 and Fig. 5 present the temperature profiles. An increase in the heat transfer coefficient from 0.0 (adiabatic) to 0.2 Btu/(hr) (sq/ft) (Deg. F) has lead to a 3 fold increase in the cooling. Asymptotic behavior is apparent for the case of h = 0.20 at temperatures below 112°F. For the longer pipes the operation may approach isothermal conditions.

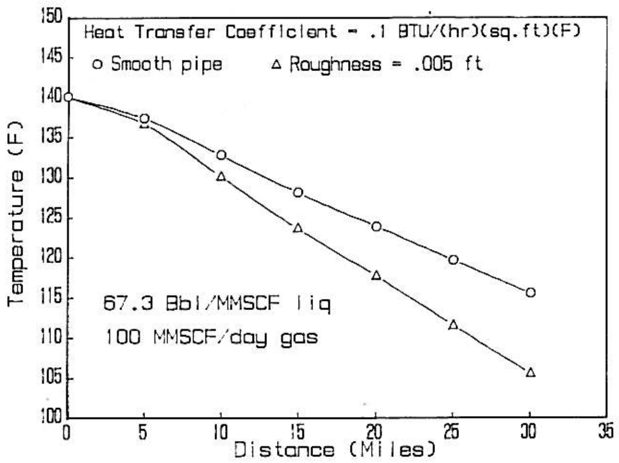

FIG. 4. Temperature profile for two phase (15 inch inclined pipe).

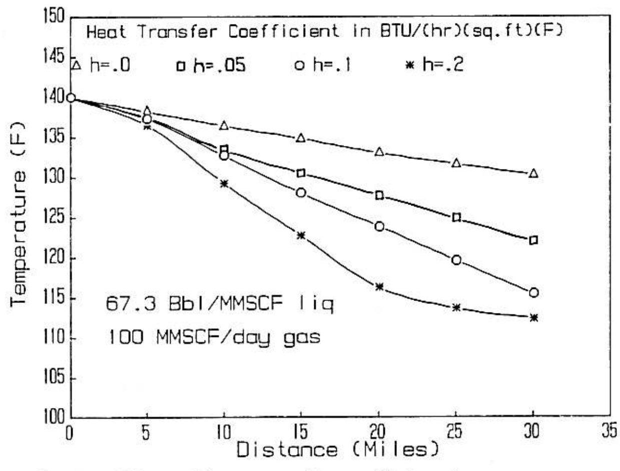

FIG. 5. Effect of heat transfer coefficient (on temperature of two phase flow inclined 15 inch pipe).

CONCLUSIONS

(1) A simulation program has been presented which has applications in simulating two-phase pipelines on either stand-alone basis or as a subroutine of another program.

(2) The program reproduced the results of a reference case wih an accuracy of $\pm 2\%$.

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