Development of Steam Distribution Network Simulation Program for Enhanced Oil Recovery

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Abstract: Steam injection networks are widely used in processes of Thermal Enhanced Oil Recovery (TEOR). It is desirable to maintain both the quality and flow rate of steam injected into the formation at certain specified values for optimum operation of the steam flood. This requires a surface distribution network designed to deliver uniform-quality steam to all wells. Unfortunately, unequal splitting of the liquid and vapor phases may occur at (tee junction) distribution network therefore Individual wells thus receive non-uniform and unknown distribution of the steam liquid and vapor. Unknown liquid and vapor phase distributions leads to inefficient project management, increased operating expenses and thereby detriment of the wells production. Simulation programs are important tools to monitor and evaluate steam distribution network. The main objective of this thesis is to develop a computer program to evaluate steam quality at well head of oil fields. Based on the Seeger model, a computer program for simulating the behavior of a large steam injection network was developed based on Mat Lab Graphical User Interface (GUI). Using this program a complete picture for the steam distribution network variables such as pressure, temperature and steam quality can be determined.

Keywords: Steam Distribution Network, T-junction, Two-Phase Flow, EOR

1. Introduction

Steam injection is the thermal method that add heat to the reservoir to expand the oil in-place, reduce oil viscosity, provide drive energy and thereby improve the displacement efficiency of injected fluid [1]. Crude-oil viscosity is inversely proportional to temperature. When the temperature increases, viscosity decreases. Less viscous oil results in greater mobility. Prats [2] indicated that the effect of steam injection on recovery is significantly greater as compared to hot-water injection. It is because steam carries more enthalpy per unit mass. The displacement of fluids by steam is self-stabilizing movement of the crude oil to the production well. Lake [3] emphasized that thermal methods, especially steam injection and steam soak, are easily the most successful enhanced oil recovery processes. Steam injection is widely applied to increase production. For the steam injection, several steam generators are located throughout the oil field to produce the steam that is fed into a distribution network. As the distribution network becomes more complex and larger. The steam flow becomes more complicated and the

steam properties along the pipes vary greatly [4]. Thus, In order to predict steam properties in the distribution network with highly accuracy, it is necessary to understand the behavior of two-phase flow and splitting two-phase flow in the tee-junction to maintain optimum steam quality entering the reservoir.

Unfortunately, unequal splitting of the liquid and vapor phases can occur at (tee junction) distribution network therefore Individual wells thus receive non-uniform and unpredictable distribution of the steam liquid and vapor. Uneven liquid and vapor phase distribution results in poor displacement efficiency and volumetric sweep of the reservoir while unknown liquid and vapor phase distributions leads to inefficient project management and increased operating expenses. Therefore, it is important to develop a stimulating models, and methods to predict or control the qualities of the split streams.

In fact, T-junctions are commonly used components in piping systems as show in figure 1. The behavior of dividing two-phase flow in a T-junction is critical in the design of the two-phase flow piping systems. When a two-phase flow is divided in a T-junctions, the branch and run qualities will, in

general, differ from the inlet quality such a phenomenon is known as phase splitting [5]. In the case of the branching Tee, the phase splitting phenomena is generally more severe because the liquid phase of the two-phase fluid has high density and inertia and tends to flow straight through rather than making a 90˚ turn. In other words, the branch stream tends to have a higher quality than that at the inlet while the run stream tends to have a quality less than that at the inlet. Furthermore, phase splitting also depends on the flow velocity, flow patterns, and quality of fluid at the inlet of the tee [6-7]. Over the years, there are general approaches have been used to describe the phase redistribution in T-junctions such as, experimental and numerical approaches. In this paper evaluated the empirical correlation models to simulate the behavior of a large steam injection network.
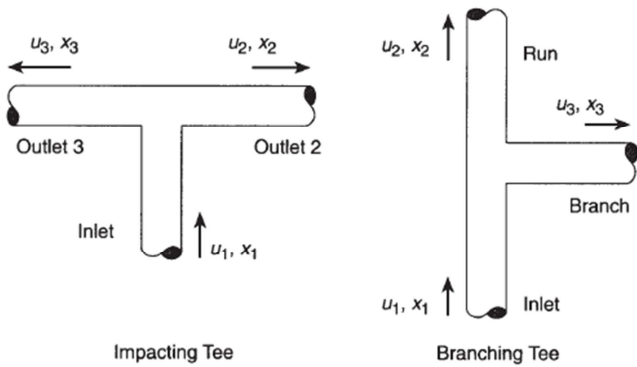

Figure 1. *Tee Junction.*

2. Review of Literature

A considerable amount of research has been conducted on the two-phase flow of dividing Tee junctions. Comprehensive researches can be found in the literature including Collier [8], Hong [9], Azzopardi & Whalley [10], Seeger et al. [11], Lahey [12], Azzopardi and Hervieu [13], Azzopardi [14], Azzopardi & Nicholson [15], and Baker &Azzopardi [16]. These works demonstrated that the ratio of branch to inlet qualities x3/xl, which is indicative of phase distribution, is influenced by several parameters such as the inlet flow pattern, inlet quality x1, branch-to-inlet diameter ratio D3/D1, branch orientation (from vertically up to vertically down) and extraction rate W3/W1, where W1 and W3 are the inlet and branch mass flow rates, respectively. The large number of investigations is evidence of the importance and complexity of the problem. Most of this research was directed to the geometry of branching tees. In contrast, few studies are based on the geometry of the impacting Tee junction. It should be taken into consideration that the branching and impacting Tee junctions are treated almost independently in the literature regardless to the similarities between them.

These studies have concluded that the problem of phase distribution at branching junctions has not as yet been solved, no model is currently available with general applicability to all operating conditions. This is mainly due to the large number of variables on which phase distribution depends,

such as junction geometry, fluid properties, inlet mass flow rate and quality, inlet flow regime, and mass split at the junction.

Wellhead steam quality is an important variable that determines thermodynamic properties of fluid. Among these properties which are important in evaluating steam injection process are specific volume and enthalpy. Doschar and Huang [17] conducted laboratory steam floods in a physical model to show that oil recovery vs. time increased with increasing steam quality. Experiments with a physical models showed that, at a constant mass injection rate, oil recovery increases with increasing steam quality. Based on the Marx-Langenheim model [18], The Boberg and Lontz [19] method estimates the oil production response during cyclic steam injection. Gomaa's [20] method can be used to predict steam oil ratio for steam flooding. All methods were based on steam quality and enthalpy in their procedures to calculate heat injection rate and heat effected zone in order to predict steam oil ratio.

3. Phase Splitting Model Formulation

In general, empirical correlations are used to deduce phase distribution in T-junction. The process of creating the empirical equations for a certain application always requires an iterative experimentation work which is boring and expensive to perform. The empirical correlations are easy to use and the predicted results are usually reasonable if they are used in their appropriate range of conditions.

Seeger Model

Seeger et al. (1986) developed empirical correlations based on a large data bank for both air/water and steam/water flow with a horizontal inlet and equal inlet and branch diameters (D1 = D2 = D3 = 50 mm) covering the ranges of 500<G1<7500 kg/m^2.s, 0.002<X1<0.33, 0.1<P1<10 MPa. They recommended empirical correlations for different branch orientations, i.e. horizontal, vertically upward and vertically downward.

For horizontal branch T-junction:

$$\frac{X3}{X1} = 5\left(\frac{U3}{U1}\right) - 6\left(\frac{U3}{U1}\right)^2 + 2\left(\frac{U3}{U1}\right)^3 + a\left(\frac{U3}{U1}\right)\left(1 - \frac{U3}{U1}\right)^4 \qquad (1)$$

The parameter 'a' relates the peak of the phase separation curve, $(x3/x1)$ max, to the ratio of the gas to liquid momentum flux ($\rho_g\ U_g{}^2/\rho_L\ U_L{}^2$) in the inlet Section. From their experiments, equal separation was approached as the ratio of momentum fluxes approaches unity. The value of 'a' was determined from an empirical fit of their data as, a = 14.6 for bubbly flow and for all other flow patterns.

$$a = 13.9\left[\left(\frac{vg1}{vf1S1^2}\right)^{0.26} - 1\right] \qquad (2)$$

S1 is the ratio of the vapor-phase velocity to the liquid-phase velocity. Its correlation as adapted from Rohani.4

$$S1 = \left\{[1 + 0.12(1 - x1)]v1 + \frac{Vg1}{U1} - x1vg1\right\}\frac{1}{(1-x1)vf1} \qquad (3)$$

Where v1 is the specific volume of steam at the inlet of the

tee and Vg1 is the weighted mean drift velocity of the vapor phase at the inlet of the tee,

$$\bar{V}g1 = 1.18 \, vf1^{0.5} \left[\left[g\sigma \left(\frac{1}{vf1} - \frac{1}{vg1} \right) \right] \right]^{0.25} \quad (4)$$

Seeger et al. presented, as shown in Figure 2, that the quality of the fluid existing the branch stream in a horizontal tee is generally higher than that entering the inlet. Based on the branching tee data obtained by Texaco, Rubel et al. evaluated the accuracy of several phase-splitting models for flow through branching tees. These included models proposed by Seeger et al., 3 Azzopardi and Whalley, Shoham et al., Hwang et al., and Hart et al. Seeger et al.'s model predicted closest to the experimental data, to within +- 30% for about 90% of Texaco's data.

The results of the horizontal branch showed preferential gas removal. Total separation was approached for high values of branch flow split. The branch quality generally peaked at flow splits (u3/u1 of approximately 0.3). Also it showed that an increase in inlet quality resulted in reducing the peak and the degree of the phase separation, x3/x1, and increasing the flow split ratio u3/u1.
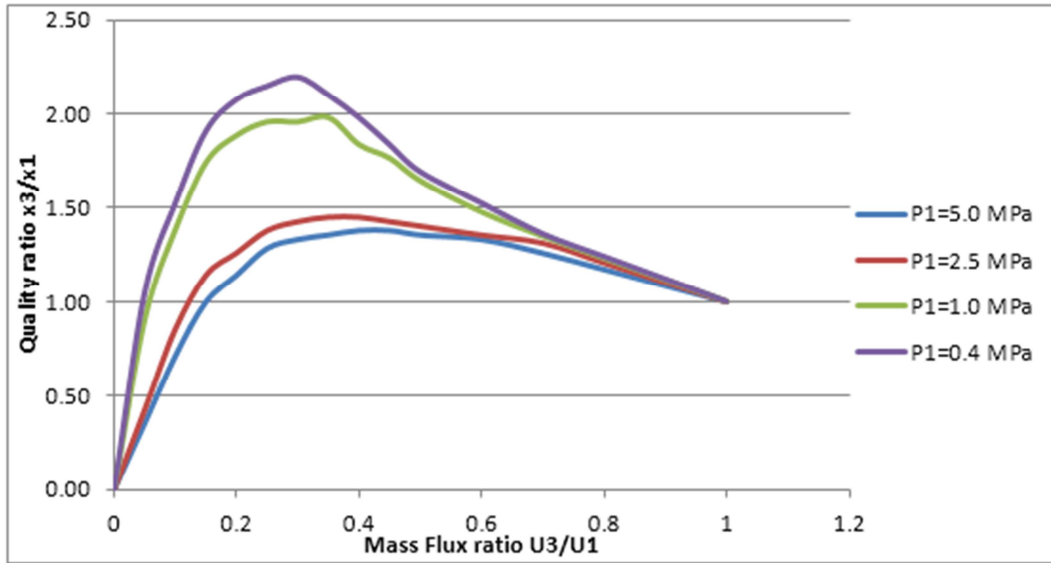

Figure 2. Seeger et al flow through a horizontal branching tee.

4. Simulation Program for Network Quality Prediction

To face a steam quality measure problem in the two-phase steam network. It became necessary to have a program installation able to record steam quality, temperature and pressure data across a whole steam network. Simple program have been designed based on MATLAB able to it. The program provides a dedicated user interface for operators to build the distribution network model easily and to visualize the simulation results. The program takes into account T-junction effect on phase separation. Then the operators can build the distribution network model by major factors such as actual distance of pipes, individual well injection rate, pipes diameter, and number of wells etc. are defined by the operator inputs. The results can be visualized as a numeric form or a graphical form. The program adopted on Seeger model to descript phase separation in T-junction in steam distribution network.

4.1. Graphical User Interface GUI of the Main Program

The GUI is demonstrated with snapshot of the program. The first snapshot gives the background for the program. The second snapshot is about calculations for any steam network with take into account T-junction effects with input parameters. The third snapshot is the output parameters for specified Steam network. The fourth and fifth snapshot is the output tables with ability to repeat calculations for selected branch. The sixth snapshot is about the post-processing for viewing the results in figures for steam quality, steam pressure, and steam temperature along the steam network.

First snapshot of the program is shown Figure 3, it is seen that there are several Input parameters for specially steamer outputs parameters for steam network. User can choose numbers of branches expressed by the number of T-junctions. Figure 4 shows the diagram for main line of the network and the number of T-junction that existing in the steam distribution network. Figure 5 and Table 1 are shown results after the calculation done and user able to save those data to excel sheet. The user is able to restore the calculation at any branch containing more than T-junction. Therefore could evaluate and design any steam distribution network through GUI that was explained.

Figure 3. *Graphical User interface input parameters.*
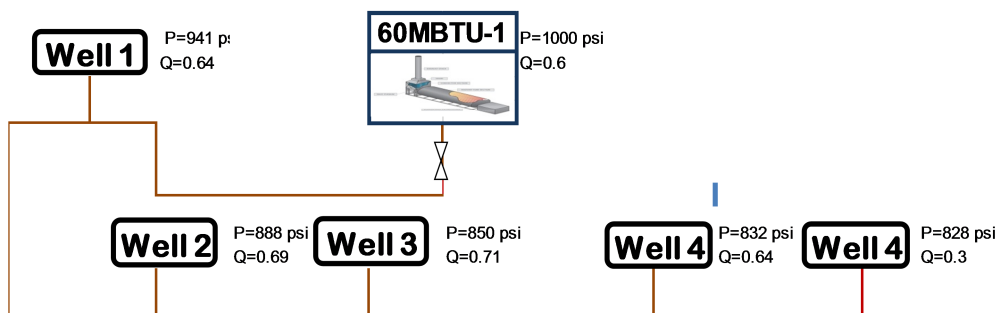
Figure 4. *Graphical User interface for layout of main line and branches.*

Figure 5. *Graphical User interface after calculation with ability of restart calculation*

Table 1. *Results shown as excel sheet.*

Length (m)	Flow (bbl)	flow branch (bbl)	pressure (psi)	T1	X1 Quality	X3 Quality
600	600	600	941	284	0.6	0.64
800	600	600	888	280	0.58	0.69
1000	600	600	850	276	0.55	0.71
1200	600	600	832	273	0.47	0.64
1400	600	600	828	272	0.3	0.3

4.2. Validation of Steam Distribution Network Program

From the previous, illustrated that it possible develop a computer Program able to design or evaluate any steam distribution network based on Seeger model. To validate multiphase, looped network cases, comparisons are made to existing software with actual network (ISSRAN Oil Field).

4.3. Experimental Setup

Due to the scarcity of published results in multiphase fluid flow in networks, it is also important to consider the validity of the solutions obtained from the program developed here with the actual data network. To illustrate the steam distribution network program, the layout system installed on the steam network for Issran oil field is shown in Figure 6.

4.4. Example

Steam at 800 psi with 520 F and 0.8 quality is flowed through 4" in main stream pipes line at steam flow rate of 6000 B/D. Thus main stream pipes will divided to branches 3" to complete network. Results parameters were listed for program solver and Issran actual data in Tables 2 and 3 respectively. Figure 7 and Figure 8 present steam pressure well head and the steam quality at well head found by the program solver and field reading.
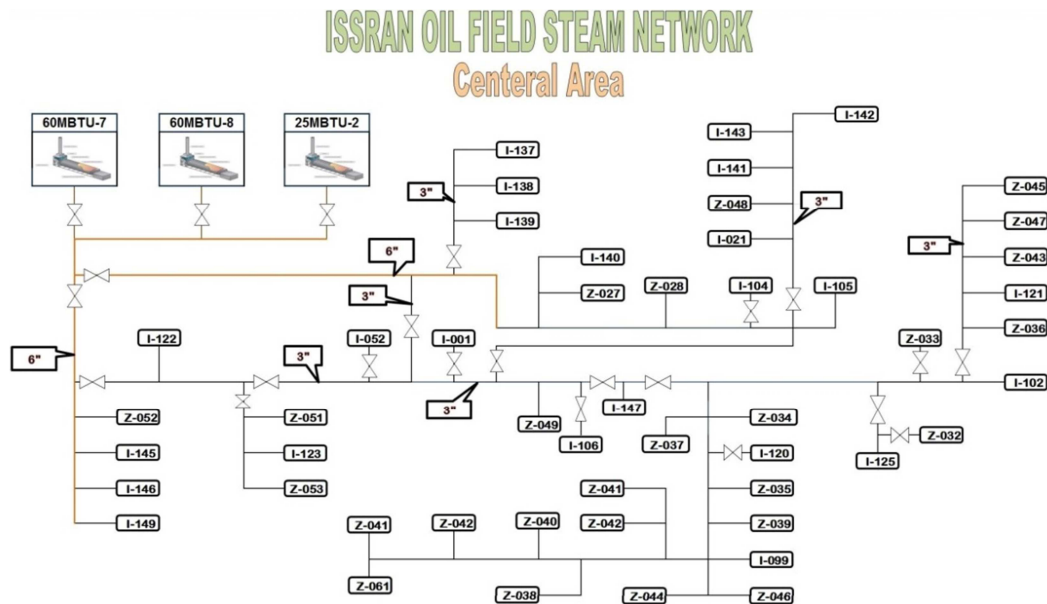

Figure 6. *Issran steam injection field schematic steam distribution line.*

Table 2. *Case study, Results adopted on Simulation Program.*

| Wells	Diameter inch	Length M	Run Flow BWPD	Branch Flow BWPD	pressure psi	X1 %	X3 %
1	6	500	3800	1500	987	0.8	0.93
2	6	800	2300	800	978	0.7	0.78
3	6	1000	1500	400	973	0.66	0.6
4	6	1500	1100	400	969	0.69	0.69
5	6	1800	700	700	940	0.68	0.68
C-23	3	200	1500	400	940	0.93	0.73
C-28	3	400	1100	400	890	1	1
C-037	3	600	700	400	850	1	1
C-041	3	800	300	300	840	1	1
C-169	3	300	800	500	956	0.78	1
C-003	3	400	300	300	948	0.43	0.43
C-002	3	300	400	400	973	0.64	0.64
C-132	3	400	400	400	969	0.69	0.69
Zs-006	3	300	700	300	918	0.68	0.85
C-355	3	400	400	400	900	0.55	0.55

Table 3. *Case study, results adopted on real reading.*

Wells	Diameter inch	Length M	Run Flow BWPD	Branch Flow BWPD	pressure psi	X1 %	X3 %
1	6	500	3800	1500	987	0.8	0.75
2	6	800	2300	800	978	0.8	0.75
3	6	1000	1500	400	973	0.8	0.75
4	6	1500	1100	400	969	0.8	0.75
5	6	1800	700	700	940	0.8	0.75
C-23	3	200	1500	400	960	0.8	0.75
C-28	3	400	1100	400	900	0.8	0.75
C-37	3	600	700	400	890	0.8	0.75
C-41	3	800	300	300	880	0.8	0.75
C-169	3	300	800	500	960	0.8	0.75
C-37	3	400	300	300	950	0.8	0.75
C-2	3	300	400	400	960	0.8	0.75
C-132	3	400	400	400	940	0.8	0.75
Zs-006	3	300	700	300	930	0.8	0.75
C-355	3	400	400	400	925	0.8	0.75
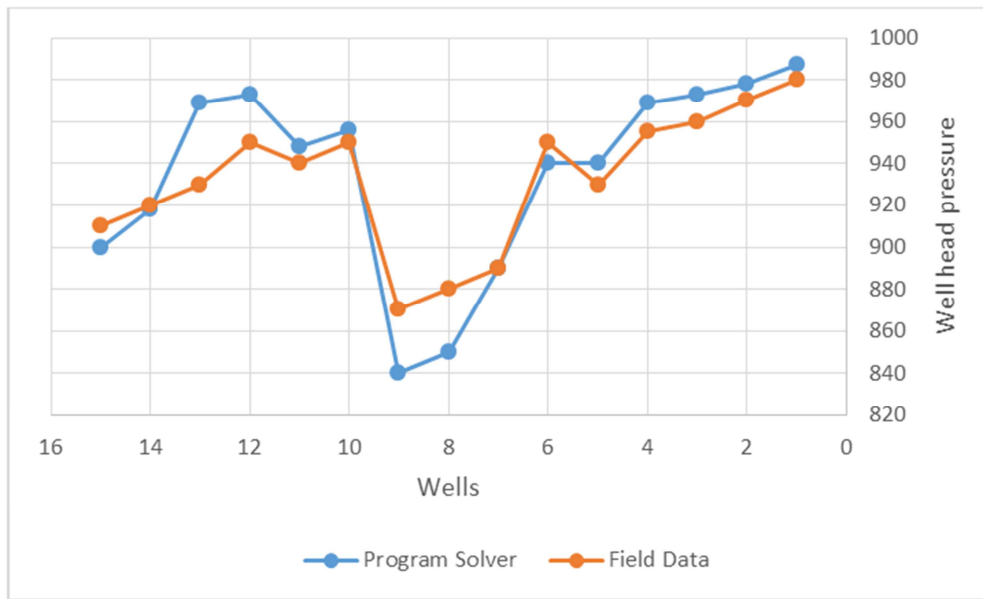
Figure 7. *Well head pressure comparison between program solver results and actual data results.*
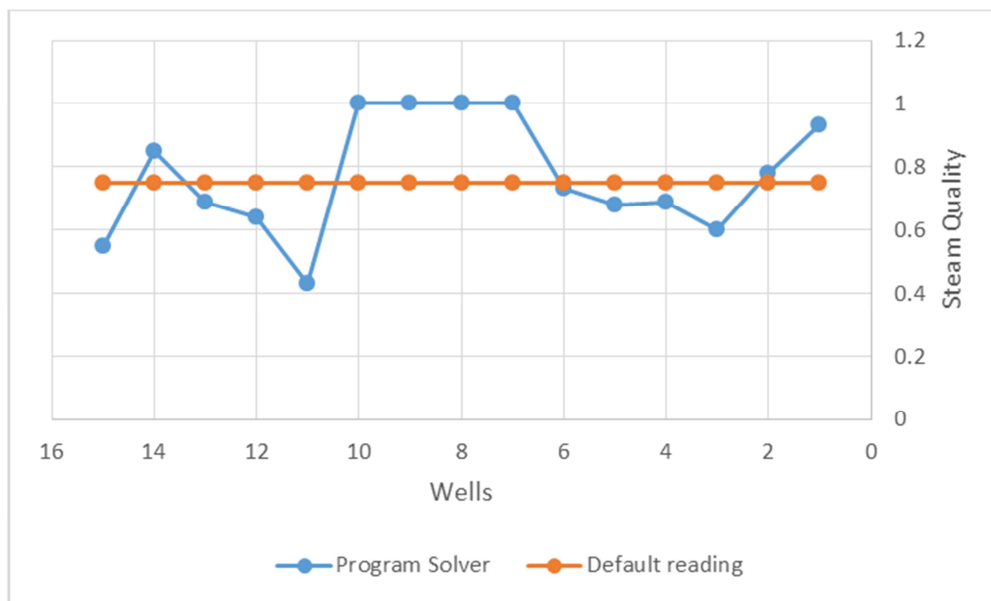
Figure 8. *Comparison between program solver results of steam quality at well head and default data results.*

5. Conclusion

Controlling and monitoring of steam quality and steam flowrate in steam distribution network is very difficult. Simulation program have considered easy way to predict the steam quality at wellheads. Performed simulation program by MATLAB while took into account Tee-Junction effect depending on Seeger correlations. The program provides a dedicated graphical user interface (GUI) for operators to build the distribution network model easily and to visualize the simulation results. Thus, a computer program for simulating the behavior of a large steam injection network was developed. Required major factors to properly design a steam distribution system are Steam quality needed at wellhead, steam pressure in the reservoir, forecast of individual well injection rate, location and number of wells, timetable for injection rate or quality reduction, and future expansion requirements. Finally need more experimental investigation for Tee-junction to collect huge data bank.

6. Nomenclature

a = coefficient in Seeger et al.'s quality ratio equation

g=gravitational acceleration, ft/sec2

p_1= steam pressure of the inlet stream, psig

S_1= velocity ratio in Seeger et al.'s correlation, dimensionless

u_1= mass flux of steam in the inlet stream, Ibm/(ft^2-s)

u_2= mass flux of steam in the run stream, Ibm/(ft^2-s)

u_3= mass flux of steam in the branch stream, Ibm/(ft^2-s)

ug_1= mass flux of vapor phase in the inlet stream, Ibm/(ft^2-s)

ug_2= mass flux of vapor phase in the run stream, Ibm/(ft^2-s)

ug_3= mass flux of the vapor phase in the branch stream, Ibm/(ft^2-s)

u_2/u_1= mass-flux ratio of the run stream, dimensionless

u_3/u_1= mass-flux ratio of the branch stream, dimensionless

vf_1= specific volume of saturated liquid at the inlet pressure,ft^3/Ibm

vg_1= specific volume of saturated vapor at the inlet pressure, ft^3/Ib

v_1= specific volume of steam at the inlet pressure, ft^3/Ibm

V^*g_1= critical velocity of saturated vapor at the inlet pressure, ft/sec

$\bar{V}g_1$= superficial vapor velocity at the inlet, ft/sec

x_1= steam quality of the inlet stream, fraction

x_2= steam quality of the run stream, fraction

x_3= steam quality of the branch stream, fraction

x_2/x_1= quality ratio of the run stream, dimensionless

x_3/x_1= quality ratio of the branch stream, dimensionless

σ= interfacial tension, Ibm/sec

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