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ASSESSMENT OF TRAC-PF1/MOD3 MARK-22 ASSEMBLY MODEL USING SRL "A" TANK SINGLE-ASSEMBLY FLOW EXPERIMENTS

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ABSTRACT

This paper summarizes the results of an assessment of our TRAC-PF1/MOD3 Mark-22 prototype fuel assembly model against single-assembly data obtained from the "A" Tank single-assembly tests that were performed at the Savannah River Laboratory. We felt the data characterize prototypic assembly behavior over a range of air-water flow conditions of interest for loss-of-coolant accident (LOCA) calculations.

This study was part of a benchmarking effort performed to evaluate and validate a multiple-assembly, full-plant model that is being developed by Los Alamos National Laboratory to study various aspects of the Savannah River plant operating conditions, including LOCA transients, using TRAC-PF1/MOD3 Version 1.10. The results of this benchmarking effort demonstrate that TRAC-PF1/ MOD3 is capable of calculating plenum conditions and assembly flows during conditions thought to be typical of the Emergency Cooling System (ECS) phase of a LOCA.

INTRODUCTION

This paper presents the results of TRAC-PF1/MOD3 benchmarks[1] of experiments performed at the Savannah River Laboratory (SRL to simulate prototypic Mark 22 assembly behavior over a range of air-water flows thought to be typical of the Emergency Cooling System (ECS) phase of a loss-of-coolant accident (LOCA). This analysis effort reflects part of a larger effort being undertaken at the Los Alamos National Laboratory for the US Department of Energy to develop an independent capability using TRAC-PF1/MOD3 to assess LOCA power limits for the SRL heavy-water reactors. TRAC-PF1/MOD3 is a version of the TRAC[2] computer program that contains several specific code modifications that were necessary to model the SRL heavy-water reactor.

Assembly power and effluent temperature limits for the SRL reactors are being determined based on the worst-case LOCA, which is considered to be a double-ended guillotine break (DEGB) in a process water line at the plenum inlet. For this LOCA, the reactor thermal-hydraulic transient response can be divided into two time frames, a flow-instability (FI) phase and an ECS phase. For the first few seconds after the break, when the pressure difference across the fuel assemblies and the corresponding coolant flow rapidly decrease, the fission power levels remain high, and a Ledinegg-type FI is possible. During the second, or ECS, phase of the LOCA transient, the water level in the reactor moderator tank drops as water is lost through the break. The ECS is activated, but the total core flow continues to decrease until a dynamic equilibrium is reached where the break and ECS flows are nearly equal. The power levels are the result of decay heat and therefore are low. However, the ECS flow is insufficient to keep the fuel assemblies liquid-full. Two-phase air-water flow provides the primary cooling mechanism for the fuel assemblies during this ECS phase. The flow and distribution of ECS liquid in the two-phase reactor upper plenum and the flow of liquid through the permanent and uniform sleeve housings (USHs) into the fuel assemblies become of prime importance in ensuring that adequate cooling takes place.

To better understand the flow of liquid and air from a prototypical upper plenum through complex geometry (slots and small holes in the sleeve housings) into a Mark 22 assembly, SRL performed a series of tests[3,4] using the "A" Tank single-assembly test facility (Fig. 1). These tests indicate that for steady low-liquid- and air-flow rates into the plenum, the liquid stratifies and the plenum liquid level becomes a good indicator of liquid flow into the assembly. The A-tank tests were performed to simulate conditions thought to be typical of the ECS phase of a LOCA, when air enters the plenum and liquid flows are low. Thus, the A-tank tests provide an essential benchmark to validate that TRAC is capable of calculating plenum and assembly flow conditions typical of the ECS phase of a LOCA.

For this benchmarking effort, we developed a single-assembly TRAC model that we compared with experimental data and empirical correlations provided by SRL. A number of Mark-22 prototypical single-assembly experiments were run by Durig using the A tank at SRL as part of the L Reactor Test.[3] These data characterize prototypic assembly behavior over a range of air-water flow conditions felt to be of interest for LOCA calculations [that is, assembly liquid flows from 10–100 gal/min (0.038–0.38 m^3/min) and airflows from 0–8 ft^3/min (0–0.227 m^3/min)]. Koffman[4] cites four different sets of Durig's data, classified as (a) draindown, (b) vented, (c) two-component, and (d) pressure drop. In our benchmarking effort, we simulated the following subsets of Durig's experiments with our TRAC model.

Fixed Moderator Tank Water Level

(a) Vented upper plenum with low liquid flows (vented)
(b) Unvented upper plenum with high liquid flows (pressure drop)

(c) Unvented upper plenum with air/water two-phase flow (two-component)

Moderator Tank Water Level Draindown Experiments (Draindown)
(d) Single-phase liquid flow with unvented upper plenum
(e) Two-phase air/water flow with unvented upper plenum

DESCRIPTION OF THE EXPERIMENTAL FACILITY

The experimental facility, which is shown in Fig. 1, consists of a moderator tank ("A" Tank), an upper plenum, a Mark-22 prototypical fuel assembly, and other external piping. The moderator tank is about 20 ft (5.08 m) tall and has an outside diameter of 3 ft (0.914 m). The plenum, which is on top of the A tank, is 8.75 in. (0.222 m) tall and has nearly the same diameter as the A tank. A cross-section view of the plenum also is shown in Fig. 1. As shown, there are two rows of assemblies on a hexagonal pitch around the Mark-22 assembly. Only the Mark-22 test assembly allows flow into the A tank. The other 18 assembly housings are open to flow within the plenum but are sealed to prevent downflow. The outer diameter of the Mark-22 assembly housing is 5.25 in. (0.133 m). The other 18 housings have a diameter of 5.53 in. (0.1405 m).

As depicted in Fig. 1, a prototypical "piston ring" has been used to seal the flow path between the permanent sleeve housing and the Mark-22 assembly USH. A significant amount of air leakage into the plenum can occur past the piston ring and between the gap where the two ends of the ring meet. The air leakage path is from the air space at the top of the A tank up the annulus between the USH and the permanent sleeve housing. The piston ring acts as the primary flow restriction in this annulus region. After leaking past the ring, air can enter the inlet to the assembly by passing through the holes in the USH or air can enter the plenum through the slots in the permanent sleeve housing. The actual air path will be dictated by the complex geometry and countercurrent flow hydrodynamics. The flow characteristics of this piston-ring seal leak path influence the results of the pressure drop; single-phase draindown; and low-flow, two-phase, fixed-level experiments as discussed later in this report.

Water is circulated between the plenum and the A tank by a pump. The water temperature was approximately 295 K. For two-phase injection experiments, air is pumped into the water injection line above the water pump level. The A tank is vented to the atmosphere during all experiments. Depending on the experiment, the plenum was either vented or unvented.

In the tests classified as vented, the plenum hydrodynamic variables were measured for five liquid flow rates up to 68.7 gal/min (0.2604 m3/min) and three different moderator tank liquid levels [24 in. (0.61 m), 50 in. (1.27 m), and 96 in. (2.438 m)], and the plenum was vented to the atmosphere.

The pressure drop experiments were performed without venting the plenum. In these tests, liquid flow rates ranged from 30–400 gal/min [(0.114–1.516 m^3/min). In different tests, the tank liquid level was fixed. The measured plenum pressures were plotted as a function of liquid flow rate. In this test series, a slight vacuum develops in the plenum for low liquid-injection flows, depending on the moderator tank level. This vacuum increases as the liquid-injection rate decreases, until at about -0.8 psig (0.55e+03 Pa) air begins to leak into the plenum past the piston-ring seal. The characteristics of this air inleakage through the piston-ring seal result in slight pressure fluctuations as seen in the experimental data.

In the two-component tests, air and water were injected into an unvented plenum. The moderator tank liquid level was fixed at either 1.5 or 5 ft (0.457 or 1.524 m) The liquid flow rates ranged from 24 gal/min (0.91 m^3/min) to 100 gal/min (0.379 m^3/min), whereas airflow rates ranged from 0–16 ft^3/min (0.0–0.453 m3/min)

The plenum was unvented in the draindown experiments. Single-phase water and two-phase air/water mixtures were injected into the plenum. In these experiments, the A tank was filled with water to 19.2 ft (5.85 m) and then drained slowly [approximately 1 ft (0.305 m) per 45 s] down to about the 2-ft (0.61-m) level. Plenum pressure and plenum level measurements were taken after each 1-ft (0.305-m) drop in the A-tank level. For given liquid and airflow rates, the plenum level and plenum pressure data are reported as a function of A-tank liquid level. In the single-phase draindown tests, at low liquid flows and low tank liquid levels, a vacuum developed in the plenum, resulting in air leakage past the piston-ring seal.

TRAC-PF1/MOD3 INPUT MODEL DESCRIPTION

The TRAC models of the prototype Mark 22 assembly, the plenum, and the moderator tank (Fig. 2) were consistent with the nodalization used in the full-plant model but have some modifications to accommodate the geometry of the experimental facility. Sensitivity studies were performed to assess the effect of modeling techniques, nodalization, and time-step size.

The A tank is modeled as a three-dimensional vessel with one radial ring, one azimuthal segment, and nine axial levels. The nine levels are consistent with the moderator tank nodalization used in the full-plant model. The total height is 19.729 ft (6.013 m), and the radius is 1.5 ft (0.457 m) The tank hydraulic diameter was 3.0 ft (0.914 m). The wall roughness was set to 0.59×10^{-4} in. (1.5e-06 m), similar to the full-plant model.

The plenum is modeled as a single-cell vessel (that is, one radial ring, one azimuthal segment, and one axial level). The plenum vessel component has the same radius as the A tank and is 8.75 in. (0.222 m) tall. Based on a review of test facility drawings, we assumed that the "dummy" assemblies extended through the A tank and had six slots extending the height of the plenum. The "dummy" assemblies were open to radial and azimuthal flow but were sealed to prevent axial downflow.

The Mark-22 assembly is modeled as a one-dimensional pipe component with 21 cells. All of the geometric data are obtained from the full-plant model and scaled down to a single assembly. Detailed assembly geometric data are available in Ref. 5. The flow area and hydraulic diameter at the assembly/plenum junction interface were set to 8.0104 in.^{2} (5.168e-03 m^2) and 0.6067 in. (1.54e-02 m), respectively. These flow areas correspond to the total flow area through the three slots [each 0.3125 in. (7.94e-03 m) wide] present in the permanent sleeve housing at the top of the USH, whereas the hydraulic diameter corresponds to 4 times the slot flow area divided by the wetted perimeter. The cell interface k-factors, or form losses, were determined in an iterative process using both A-tank and single-phase design pressure drop data obtained from SRL reports.[6,7] The interface k-factor between the assembly and the plenum (cell edge 22) was set at 1.869 to yield a "best fit" of the high-flow, single-phase, pressure-drop data. The remaining assembly cell-interface k-factors were selected to provide the required flow at the given plenum and tank bottom pressures, with approximately the correct pressure distribution along the length of the assembly.

Various pipes used to complete the model include the tank drain, pump suction, tank vent, piston-ring leak, and plenum vent pipes, respectively. Various break and fill components were used to provide proper boundary conditions consistent with the experiment being simulated. All of these components are modeled consistent with the facility geometry. Sensitivity studies indicated that the piping geometry had no effect on the overall results.

For the draindown, pressure drop, and two-component tests, the piston-ring leak path shown in Fig. 1 is modeled with a two-cell vertical pipe connected to the bottom axial face of the plenum. At the interface boundary between the two cells, a form loss (k) of 10.0, a flow area of 0.000258 ft^2 (2.40e-04 m^2), and a hydraulic diameter of .0181 ft (5.52e-03 m) were used to approximate the piston-ring seal leak geometry. The form loss was estimated from the draindown data, whereas the flow area and hydraulic diameter were order-of-magnitude estimates based on the height and depth of the ring slot. These three parameters had only small effects on the modeling results compared with the effect of the length of the cells. A cell length of 0.98 ft (0.3m) correlated well with the one-phase draindown data.

DESCRIPTION OF TRAC-PF1/MOD3

TRAC-PF1/MOD3 is an extension of the Transient Reactor Analysis Code (TRAC) that is being developed at the Los Alamos National Laboratory. TRAC-PF1/MOD3 incorporates several code modifications and additional user options that were deemed necessary to model the complex two-component, two-phase flow conditions expected to occur in the reactor plenum and fuel assemblies during the

ECS phase of a postulated LOCA. The specific code version (Version 1.10) used in this study contained the following code modifications.

Horizontal Flow Stratification Model

The A-tank Mark-22 assembly flow tests showed that under certain flow conditions typical of a LOCA, the flow between the upper plenum and the fuel assemblies is stratified and is dominated by the gravity force similar to weir flow. To model this phenomenon properly, the stratified flow-regime transition criterion used in TRAC-PF1/MOD2, which was based on the criterion developed for horizontal pipes, had to be modified to account for the complex geometry at the junction between the upper plenum and assembly. The new criterion for flow-regime transition to stratified flow is based on observations from the 1989 L-Area tests[9] performed by SRL. The 1989 L-Area tests showed that the upper plenum flow generally is stratified when the plenum liquid level is below 0.2159 m (8.5 in.). This plenum level was used as the criterion for the flow-regime transition. The TRAC model assumes that the flow in the upper plenum is stratified when the plenum liquid level is below 0.2159 m. Under stratified flow conditions, the interfacial and wall drags will be reduced significantly.

Using an assembly component number between 801 and 849 in TRAC-PF1/MOD3 automatically implements a special plenum stratified-flow model that adjusts the plenum/assembly cell interface (cell edge 22) k-factor based on assembly liquid flow. That is, at near-normal operating conditions with an assembly liquid flow of 400 gal/min (1.516 m^3/min), a form loss of 1.869 is required to obtain the proper pressure drop across the permanent sleeve and USH. At low liquid flows, when the plenum stratifies, a form loss based on Durig's proposed 1990 Sleeve Equation is required to obtain the required liquid head/flow relationship. That is, when the plenum is fully stratified, the liquid head is assumed to be the total driving force; therefore, the pressure drop across the assembly plenum interface is

$$\Delta p = \rho g z = 0.5\, k \rho v^2 \ .$$

Additionally, we have Durig's proposed 1990 Sleeve Equation:

$$\text{Flow } (m^3/\text{min}) = 0.0094 z^{1.53} \ ,$$

which represents a fit of the A tank draindown data. Solving these two equations for form loss k yields

$$k = 7.2278\, z^{-0.06} \ .$$

Integrating between plenum liquid heights of 2.0 in. (0.0508 m) and 8.5 in. (0.216 m) (the range of liquid flows of interest), an average form loss of k = 6.5 is calculated. Within the code, an interpolation from a form loss of k = 6.5 (cell edge 22) at an assembly flow of 100 gal/min (0.379 m^3/min) to a form loss of k = 1.869 (user input cell edge 22 form loss) at 150 gal/min (0.5865 m^3/min) takes place.

Wall Friction and Interfacial Shear Models For Annuluar Geometry

Because of the unique Mark-22 fuel assembly geometry and postulated LOCA ECS flow conditions, i.e., two-component, two-phase downflow in narrow-ribbed annuli, SRL performed numerous experiments to characterize the single- and two-phase flow behavior using prototypical test rigs. To accommodate the unique SRL reactor geometry and flow conditions, TRAC constitutive models, which were developed primarily for pressurized water reactor analysis, required modifications. The modified TRAC constitutive models (wall friction and interfacial shear) are discussed in detail in a report by K. Pasamehmetoglu and S. Birdsell.[10] Their report presents proposed wall friction and interfacial shear correlations along with the results of preliminary code assessment using the prototypical SRL experimental test data.

TRAC-PF1/MOD3 PREDICTION OF THE EXPERIMENTS

Using the TRAC input model previously described, we analyzed each of the different test configurations for plenum hydrodynamic behavior. Our results are reported in the following subsections.

Results of Vented Upper Plenum Tests with Low Liquid Flow (Vented)

During these vented tests, air enters or is inducted into the plenum through the plenum vent and is entrained by the liquid into the test assembly. Figure 3 compares the experimentally measured inducted airflow with the TRAC-calculated airflow for each of the three fixed moderator tank liquid level cases. The "bell" shape of the TRAC results reflects the experimental trend. As might be expected, both TRAC and the data indicate that as tank backpressure (that is, moderator tank liquid level) increases, entrainment decreases. These results qualitatively and quantitatively agree with the results from an earlier assessment of entrainment in ribbed annuli experiments.[8]

Figure 4 presents a comparison of the TRAC-calculated collapsed liquid levels with the 1990 Sleeve Equation for various liquid injection flows. The 1990 Sleeve Equation developed by Durig represents a fit of the one- and two-phase draindown experimental mixture level data. The TRAC-calculated levels appear to be essentially independent of the moderator tank level and air entrainment, similar to the results obtained experimentally.

Results of Unvented Upper Plenum Tests With High Liquid Flows (Pressure Drop)

The pressure drop tests were run by fixing the moderator tank water level to be consistent with experiment and then varying the liquid flow incrementally. At high liquid flow rates, the plenum is calculated to remain liquid- or mixture-full, which is consistent with experimental observations. Figure 5 presents results of the

TRAC-calculated plenum pressure and experimentally measured plenum pressures for various liquid flow rates and a 216-in. (5.486-m) moderator tank liquid level. The results indicate that the code-calculated, single-phase assembly pressure drop agrees closely with the experimental or actual assembly behavior. Figure 5 also indicates that the TRAC-calculated plenum pressures for the 216-in. tank level are 1–3 psig (6.9e+03 to 2.07e+04 Pa) greater than those predicted by the Koffman-Whatley equation,[4] which reflects a fit of experimental data between 200 gal/min (0.758 m^3/min) and 400 gal/min (1.516 m^3/min).

Results of Unvented Upper Plenum Tests With Low Liquid Injection Flow (Single-Phase Draindown)

In these single-phase draindown tests, the liquid flow rates were set at fixed values from 23–75 gal/min (0.087–0.284 m^3/min). The moderator tank was initially full of liquid at 19.2 ft (5.852 m). The TRAC code-calculated plenum pressures and plenum liquid levels are compared with experimental data as a function of moderator tank liquid level for the 23-gal/min (0.087-m^3/min) liquid flow rate test in Figs. 6 and 7. Figure 6 also shows the effect of not modeling the piston-ring seal leak path on the plenum pressure for the 23-gal/min (0.087-m^3/min) single-phase draindown test. Without the piston-ring seal leak model, TRAC calculations indicate that the plenum remains liquid-full and the plenum pressure decreases monotonically, consistent with the decrease in the moderator tank liquid level.

In Fig. 7, the TRAC-calculated plenum liquid levels are compared with experimental plenum levels as a function of moderator tank liquid level for the 23-gal/min (0.087-m^3/min) liquid injection flow case. As indicated, the TRAC model closely reproduces the experimental trends. In these draindown experiments, the plenum is initially liquid-full, as observed experimentally and shown by the TRAC calculations. However, as the moderator tank liquid level decreases and the plenum pressure decreases to about -0.8 to -1.0 psig (-5.516e+03 to -7.24e+03 Pa), the plenum liquid level suddenly drops. As shown in Fig. 7, the TRAC calculation exhibits the same behavior as observed experimentally. This drop in liquid level is the result of an air leak past the piston-ring seal between the permanent sleeve housing and the USH. This air inleakage acts to break the vacuum formed in the plenum and results in a sudden drop in liquid level. Proper modeling of the piston-ring seal leak path may be important for some LOCA calculations (that is, pump discharge LOCA with early ac pump trip) when the plenum pressure is calculated to drop below atmospheric.

Results of Unvented Upper Plenum Tests With Two-Phase Flow (Two-Phase Draindown)

Figure 8 presents comparisons of TRAC-calculated collapsed liquid levels with experimentally reported plenum mixture levels and the 1990 Sleeve Equation. Both TRAC and the experimental results indicate that, even at very low airflow rates, the plenum always remained pressurized over atmospheric pressure for the duration of the draindown; hence, the modeling of the piston-ring seal leak is irrelevant for these tests. Note that both the TRAC calculations and experimental results indicate that the plenum liquid level remains nearly constant for the duration of the draindown (that is, the plenum liquid level is essentially independent of the draindown process or moderator tank liquid level). The plenum is reported to be full at liquid flows greater than 70 gal/min (0.265 m^3/min) even though large airflows [1–8 ft^3/min (0.028–0.2266 m^3/min)] are injected. The reported levels imply unrealistic slip and air velocities (that is, approaching infinity) in some instances. In reality, at high two-phase flow conditions, the plenum is not liquid-full, but a two-phase condition is present. This behavior is reflected qualitatively in different collapsed liquid levels for the TRAC calculations as a function of airflow rate; that is, at liquid flow rates greater than 60 gal/min (0.227 m^3/min), TRAC-calculated levels are somewhat below the reported mixture levels. TRAC liquid-level calculations appear to exhibit less sensitivity to airflow than is observed experimentally. The code does tend to predict the transition from sleeve-limited to assembly-limited flow at a liquid flow between 60 and 70 gal/min (0.227–0.265 m^3/min), which is consistent with what is observed experimentally.

Figure 9 presents comparisons of TRAC-calculated plenum pressures with experimentally measured plenum pressures for the two extreme experimental test conditions simulated. As shown, the predicted plenum pressures agree reasonably well with the experimental pressures for both the 23-gal/min/1-ft^3/min (0.087/0.028-m^3/min) and 100-gal/min/8-ft^3/min (0.379/0.226-m^3/min) cases. As shown in Fig. 9, TRAC underpredicts the plenum pressure by up to 0.8 psig (5.516e+03 Pa) for the 23-gal/min/1-ft^3/min case and overpredicts the plenum pressure by up to 2.0 psig for the 100-gal/min/8-ft^3/min case. Overall, TRAC-calculated plenum pressures for the eight draindown experiments agreed with the experimental data to within ±2.0 psig (1.38e+04 Pa).

Results of Unvented Plenum Tests With Two-Phase Injection and Fixed Moderator Tank Liquid Level (Two-Component)

Summary comparisons between TRAC calculations and the two-component plenum injection [18-in. (0.457-m) fixed moderator tank liquid level] experimental results are shown in Figs. 10 and 11.. Figure 10 compares the TRAC-calculated plenum collapsed liquid level with experimentally measured mixture levels and the 1990 Sleeve Equation at fixed airflow rates from 2–8 ft^3/min (0.056–0.2266 m^3/min). In all cases, the TRAC-calculated collapsed liquid levels show excellent agreement with the experimental data (that is, the 1990 Sleeve Equation).

Figure 11 compares code-calculated plenum pressures with experimental results for various airflows and liquid injection rates. In general, the code calculations match the trends in the experimental data within ±0.4 psig (2.76e+03 Pa) of the data for the 4-, 6-, and 8-ft^3/min (0.1133-, 0.17-, and 0.2266-m^3/min) cases. As shown in Fig. 12, in the 2-ft^3/min (0.056-m^3/min) airflow cases, the piston-ring seal leak path opens up, acting to pressurize the plenum, although TRAC still underpredicts the plenum pressure by up to 0.5 psig (3.45e+03 Pa). Interestingly, following the trends exhibited by the limited data, the code calculations indicate a minimum in the plenum pressure curve for low airflows at about 40 gal/min (0.1516 m^3/min). Thus, for these steady-state situations, there are conditions at which, for a given plenum pressure or fixed-assembly pressure difference, two different assembly flows are possible.

Experimental plenum pressures and levels were compared with TRAC calculations for the two-phase draindown test at the 60-in. (1.83-m) moderator tank liquid level and two-component, 60-in. (1.83-m) moderator tank liquid level (that is, steady-state) tests. Results indicate that the experimentally reported plenum levels for both the draindown and fixed-level tests show close agreement for a given liquid and airflow. Similarly, the TRAC-calculated collapsed liquid levels in the plenum agree closely (within a few per cent) for both the draindown and fixed-level tests at the same conditions. The plenum pressures measured in the steady-state two-component experiments are lower [from 0.6 to 2.2 psig (4.14e+03to1.517e+04 Pa)] than the plenum pressures measured in the two-phase draindown tests for similar test conditions. Similarly, the TRAC-calculated steady-state plenum pressures for the two-component, fixed-level tests are from 0.5 to 2.6 psig (4.14e+03 to 1.793e+04 Pa) higher than the code-calculated, two-phase draindown, test plenum pressures. In conclusion, TRAC results, consistent with experimental data, indicate that the plenum pressures observed in the two-phase draindown tests do not reflect steady-state conditions.

SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

In this paper, we documented the results of our efforts to benchmark our TRAC-PF1/MOD3 Mark-22 assembly model against single-assembly data. When the TRAC-PF1/MOD3/Version 1.10 calculations are compared with the experimental data, the following observations can be made.

1. For the two-phase draindown tests, the two-component/fixed-level tests, and single-phase water injection into a fully vented plenum, the TRAC-predicted plenum levels are in excellent agreement with the 1990 Sleeve Equation and the experimental data. Therefore, TRAC results, consistent with the experimental data, indicate that when the upper plenum is stratified, the plenum liquid level is an accurate indicator of assembly flows. Assembly liquid flows, under conditions when the plenum stratifies, are essentially independent of entrained airflow, assembly backpressure, and slow transient draining of the moderator tank.

2. TRAC indicates, consistent with experimental observations, that the piston ring seal leak path will act as a vaccum breaker to allow air into the plenum during situations when a vaccum occurs in the plenum. The introduction of air into the plenum results in stratification and a draining of liquid from the plenum.

3. TRAC-PF1/MOD3 can be used to calculate plenum behavior and assembly flows during conditions thought to be typical of the ECS phase of a LOCA in the SRL heavy water reactors.

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Figure Captions

Fig. 1.
Experimental test facility.

Fig. 2.
TRAC model of A-Tank facility.

Fig. 3.
Vented plenum. Plenum air entrainment vs liquid flow at different moderator tank levels.

Fig. 4.
Vented plenum. Plenum liquid level vs liquid flow at different moderator tank levels.

Fig. 5.
One-phase pressure drop (216-in. tank level). Plenum pressure vs liquid flow.

Fig. 6.
One-phase draindown [Qliq = 23 gal/min (0.087 m^3/min)]. Effect of piston-ring seal leak model on plenum pressure.

Fig. 7.
One-phase draindown [Qliq = 23 gal/min (0.087 m^3/min)]. Effect of piston-ring seal leak model on plenum liquid level.

Fig. 8.
Two-phase draindown tests. Summary of TRAC and experimental plenum liquid levels.

Fig. 9.
Two-phase draindown. Plenum pressure vs tank liquid level at two air and liquid flows.

Fig. 10.

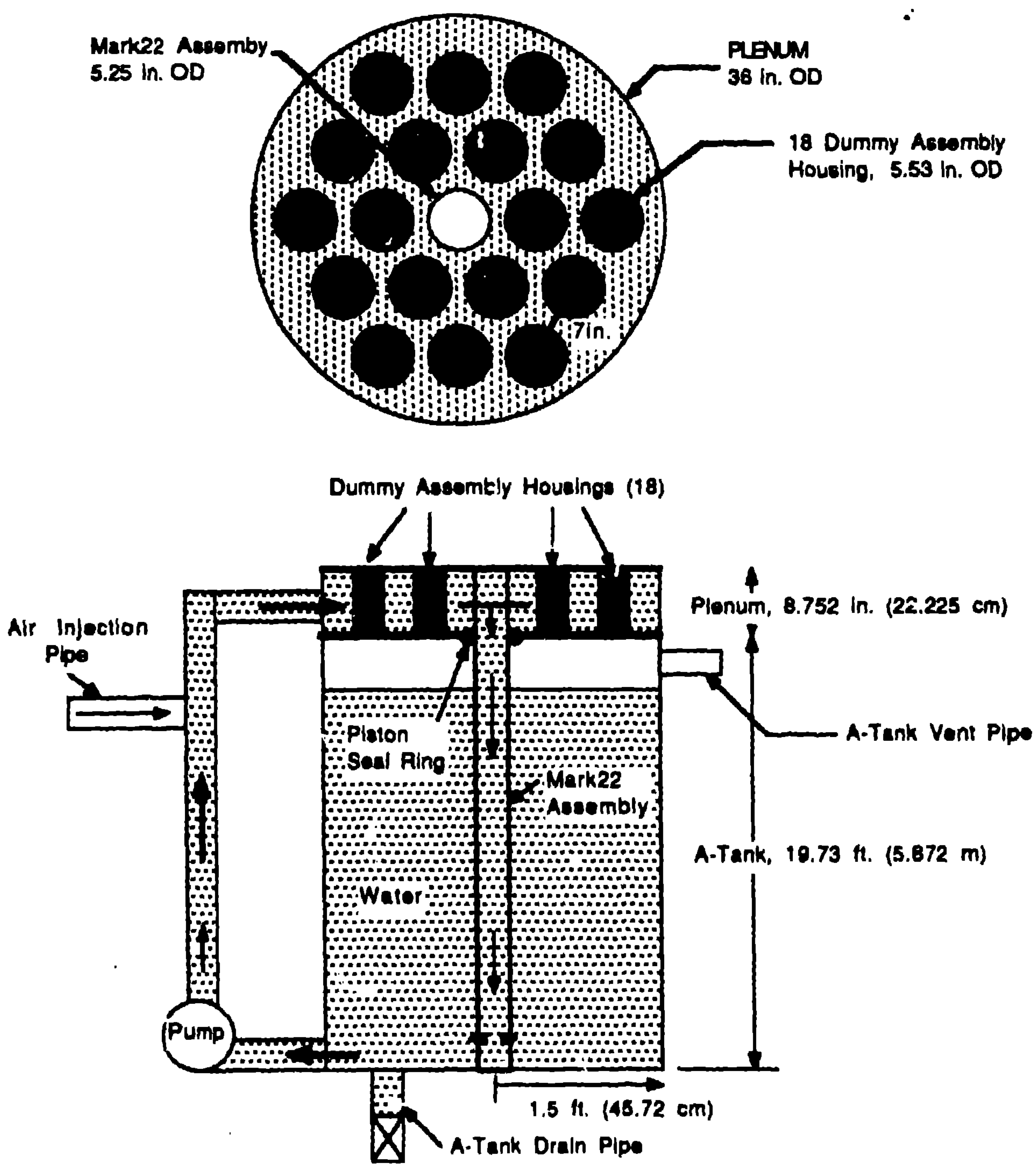
Two-phase injection (18-in.(0.457m) tank level). Effect of air injection rate on plenum liquid level.

Fig. 11

Two-phase injection (18-in.(0.457m) tank level). Effect of air injection rate on plenum pressure.

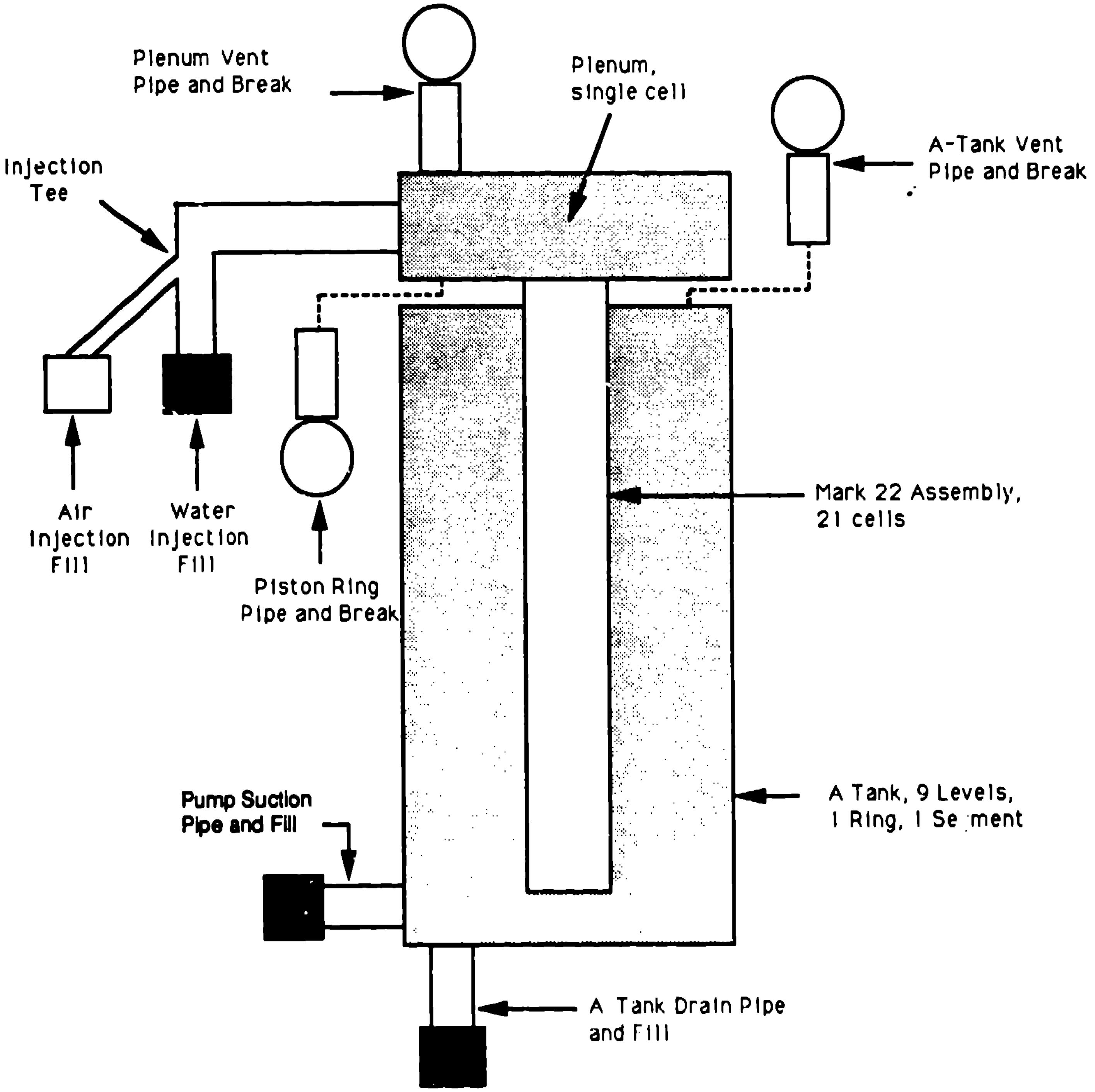
Fig. 12

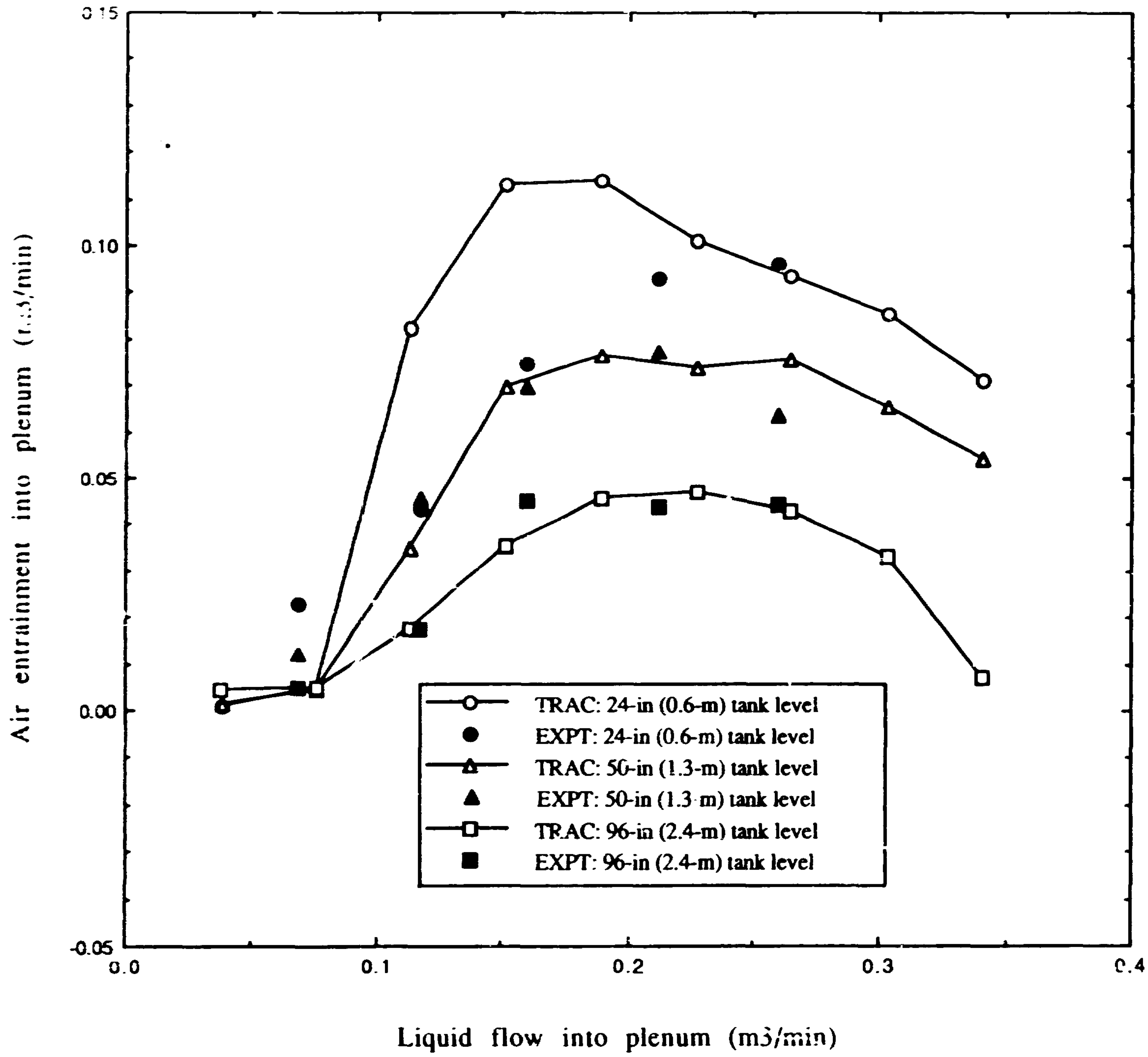
Two-phase injection (2-cfm(0.0565 m3/min) air flow, 18-in.(0.457m) tank level). Effect of piston-ring seal leak model on plenum pressure.



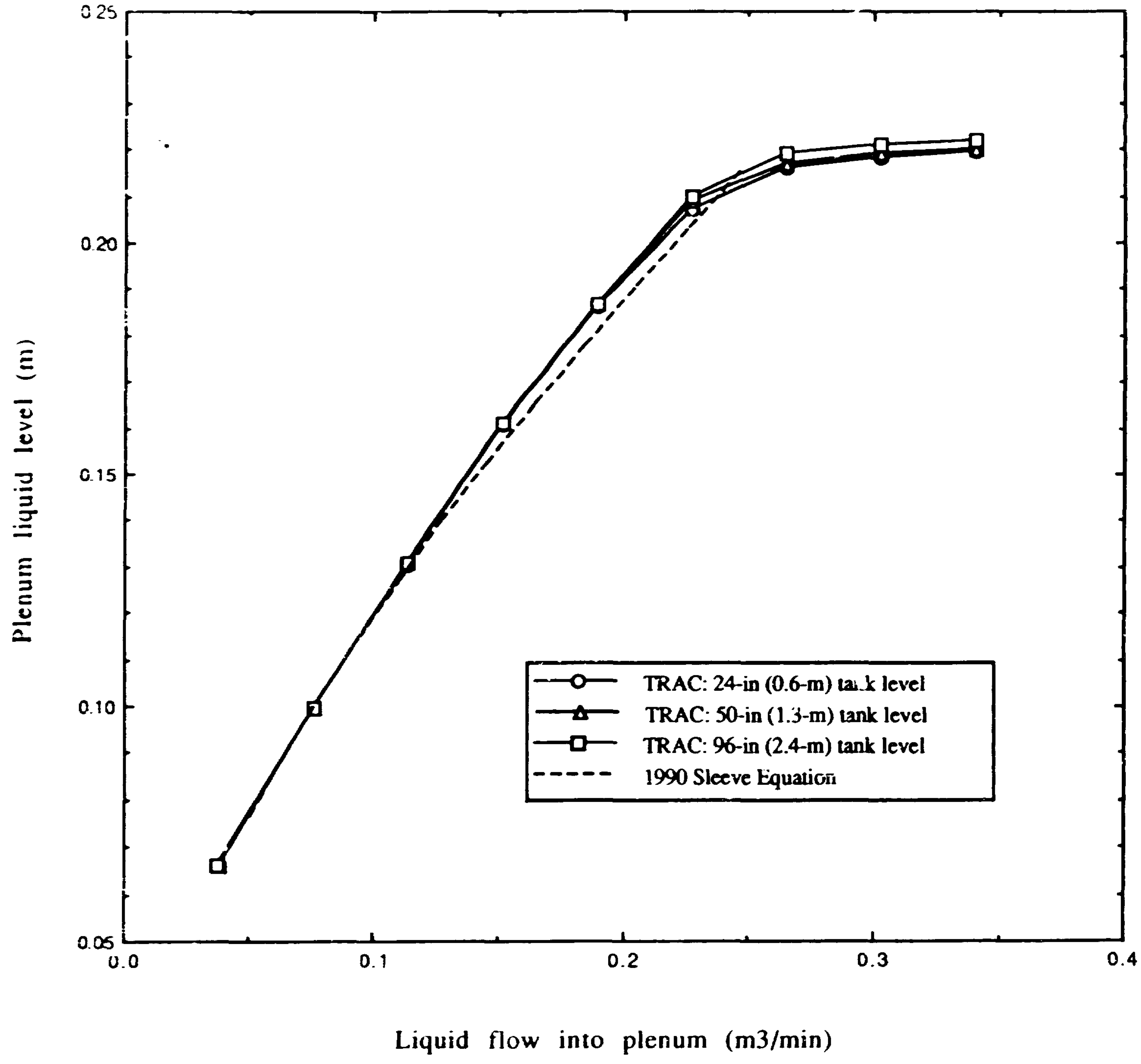
Mark22 Assemby
5.25 in. OD
PLENUM
36 in. OD
18 Dummy Assembly
Housing, 5.53 in. OD
7in.
Dummy Assembly Housings (18)
Plenum, 8.752 in. (22.225 cm)
Air Injection
Pipe
A-Tank Vent Pipe
Piston
Seal Ring
Mark22
Assembly
A-Tank, 19.73 ft. (5.872 m)
Water
Pump
1.5 ft. (45.72 cm)
A-Tank Drain Pipe

Fig. 1

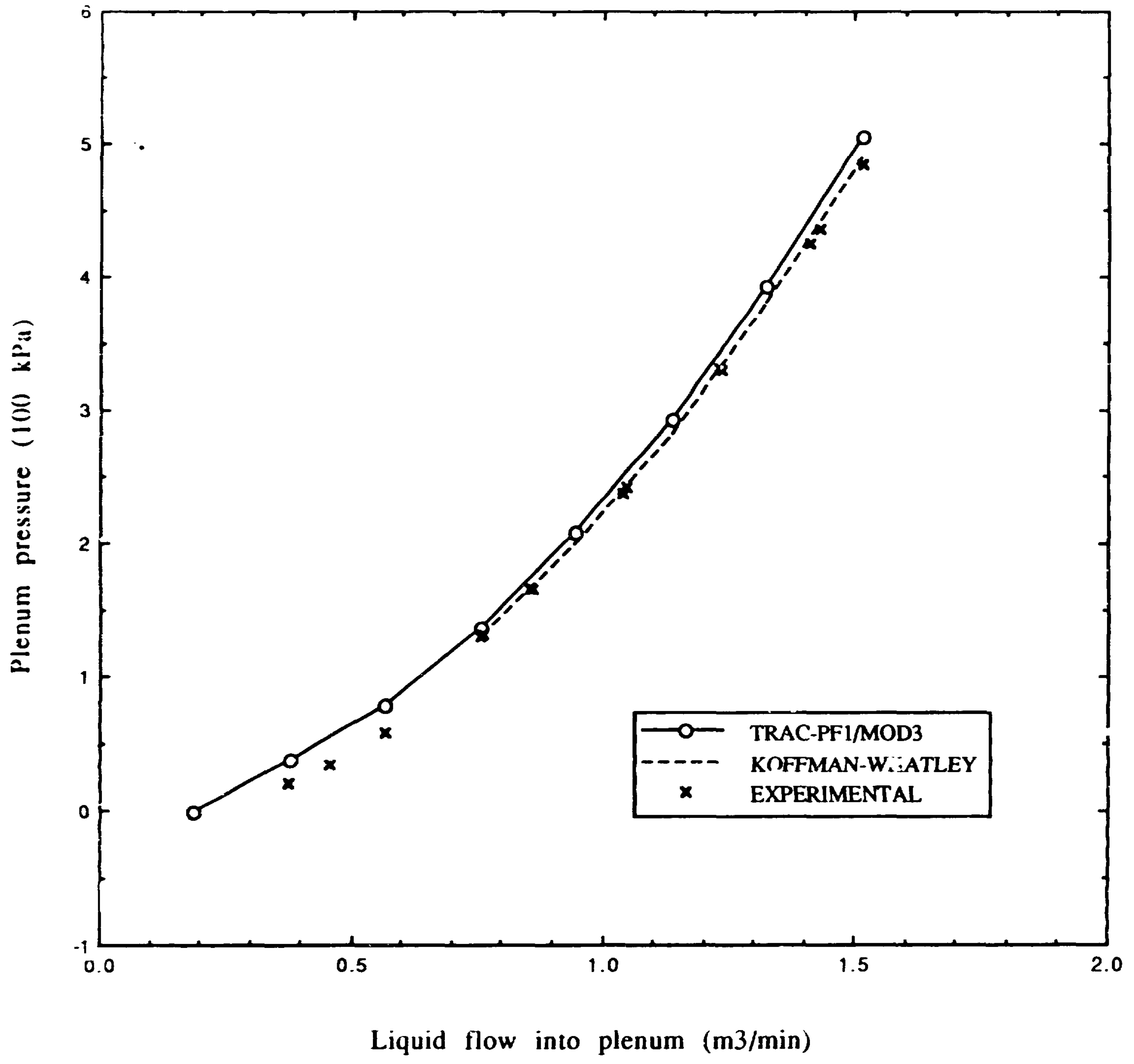

Plenum Vent
Pipe and Break
Plenum,
single cell
A-Tank Vent
Pipe and Break
Injection
Tee
Mark 22 Assembly,
21 cells
Air
Injection
Fill
Water
Injection
Fill
Piston Ring
Pipe and Break
Pump Suction
Pipe and Fill
A Tank, 9 Levels,
1 Ring, 1 Segment
A Tank Drain Pipe
and Fill



Air entrainment into plenum (m3/min)
Liquid flow into plenum (m3/min)
TRAC: 24-in (0.6-m) tank level
EXPT: 24-in (0.6-m) tank level
TRAC: 50-in (1.3-m) tank level
EXPT: 50-in (1.3-m) tank level
TRAC: 96-in (2.4-m) tank level
EXPT: 96-in (2.4-m) tank level
0.15
0.10
0.05
0.00
-0.05
0.0
0.1
0.2
0.3
0.4

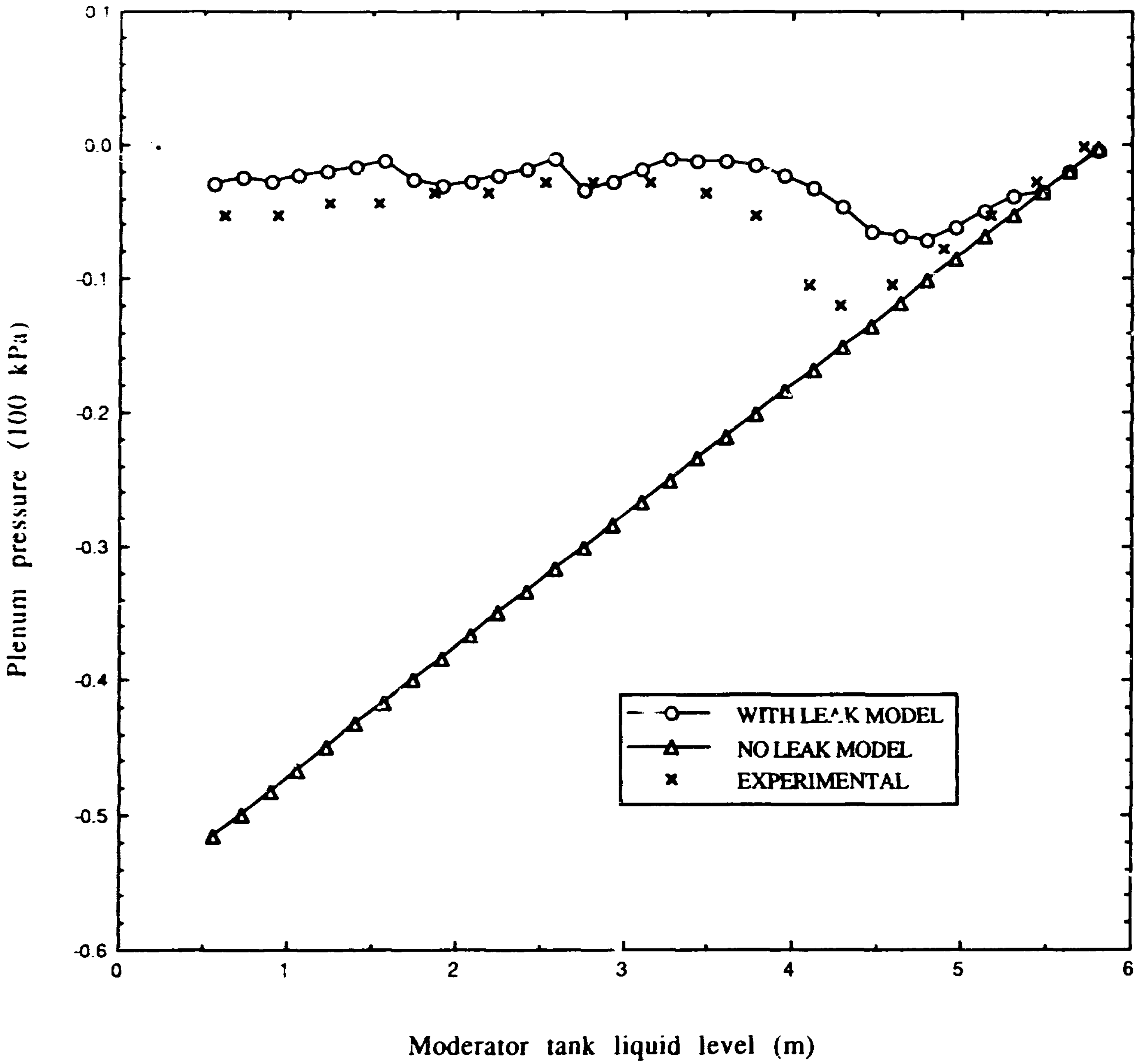


0.25
0.20
0.15
0.10
0.05
0.0
0.1
0.2
0.3
0.4
Plenum liquid level (m)
Liquid flow into plenum (m3/min)
TRAC: 24-in (0.6-m) tank level
TRAC: 50-in (1.3-m) tank level
TRAC: 96-in (2.4-m) tank level
1990 Sleeve Equation

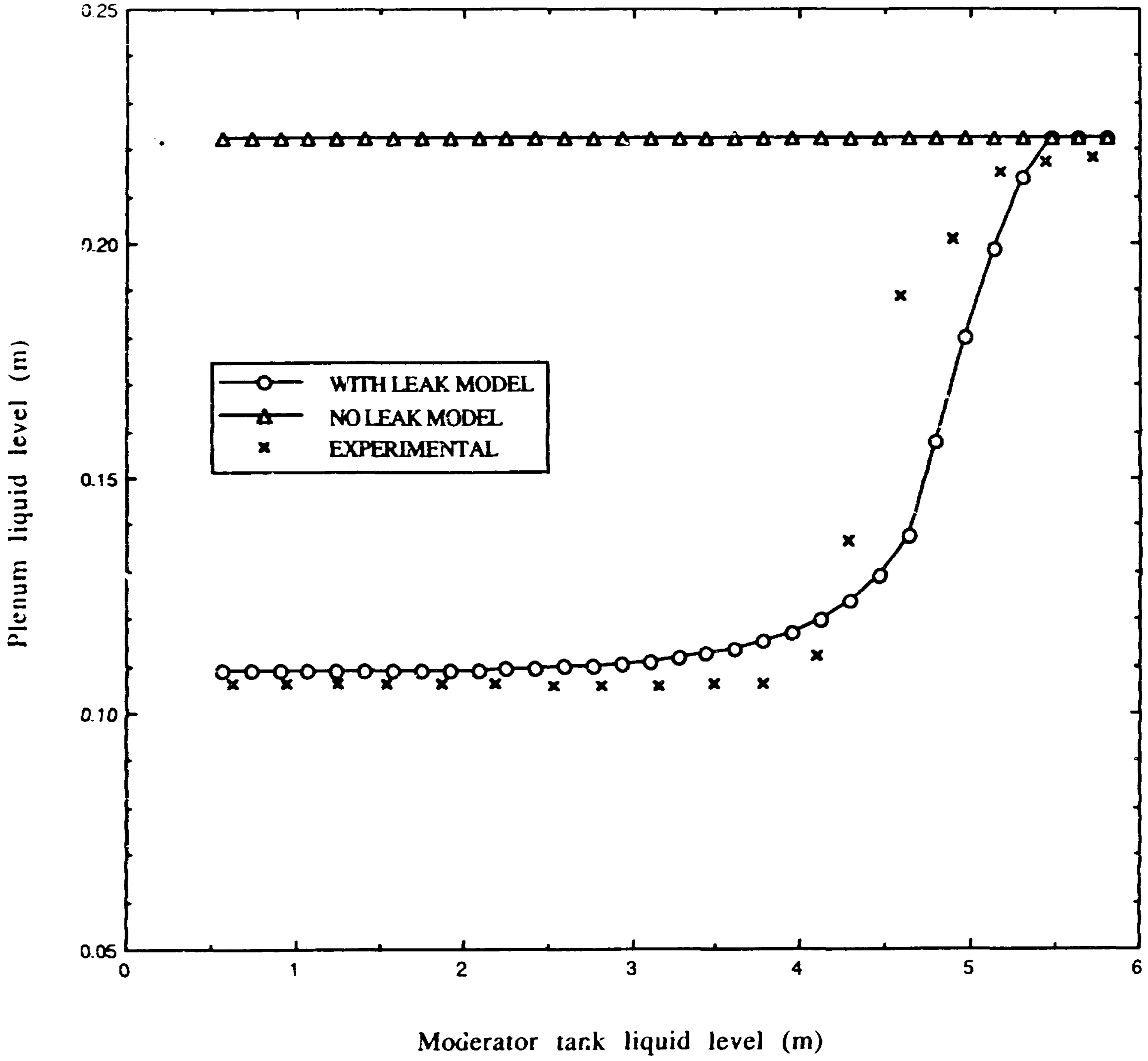


Plenum pressure (100 kPa)
Liquid flow into plenum (m3/min)
TRAC-PF1/MOD3
EXPERIMENTAL
0.0
0.5
1.0
1.5
2.0
-1
0
1
2
3
4
5
6

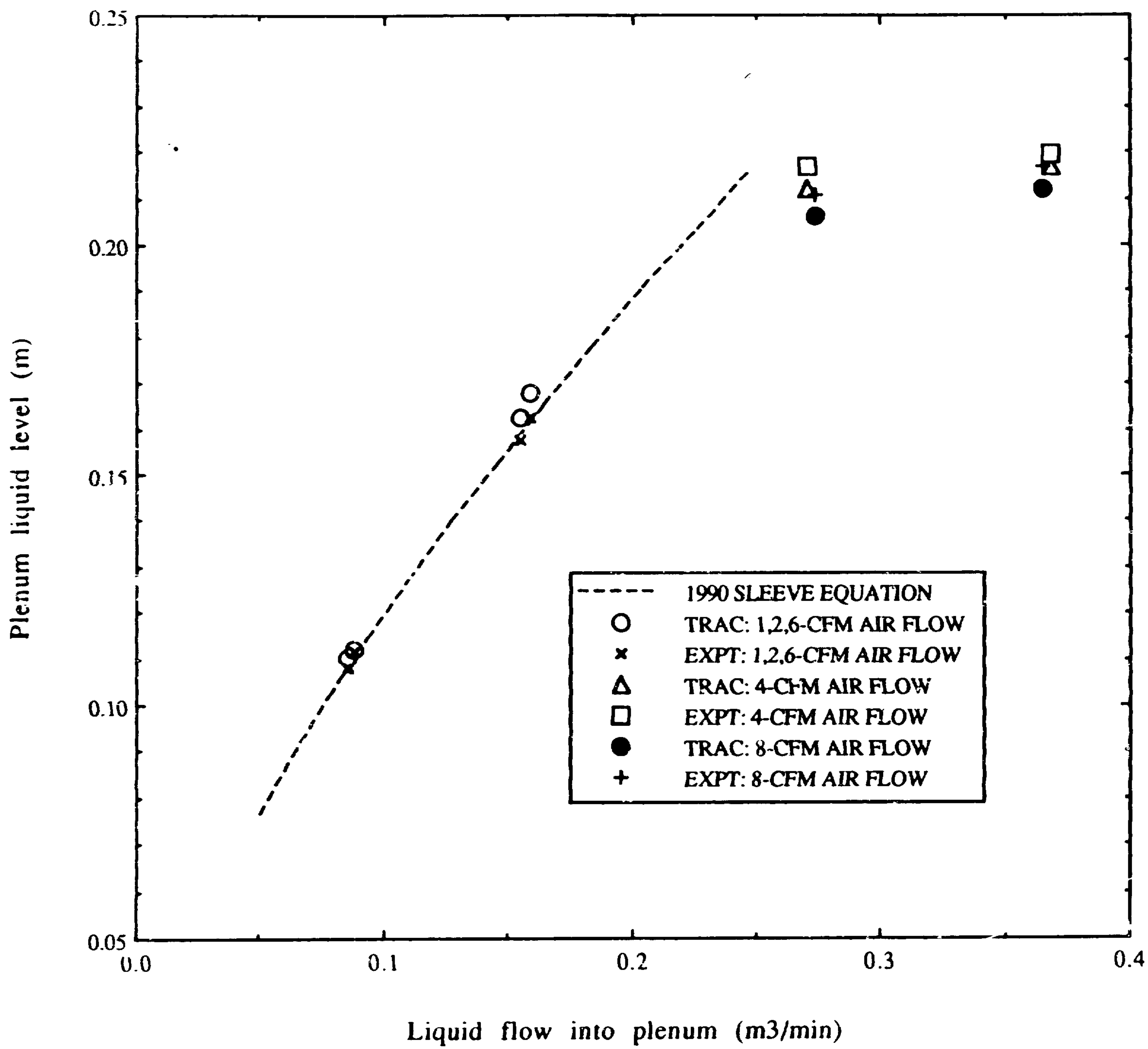
(c)


0.1
0.0
-0.1
-0.2
-0.3
-0.4
-0.5
-0.6
0
1
2
3
4
5
6
Plenum pressure (100 kPa)
Moderator tank liquid level (m)
WITH LEAK MODEL
NO LEAK MODEL
EXPERIMENTAL

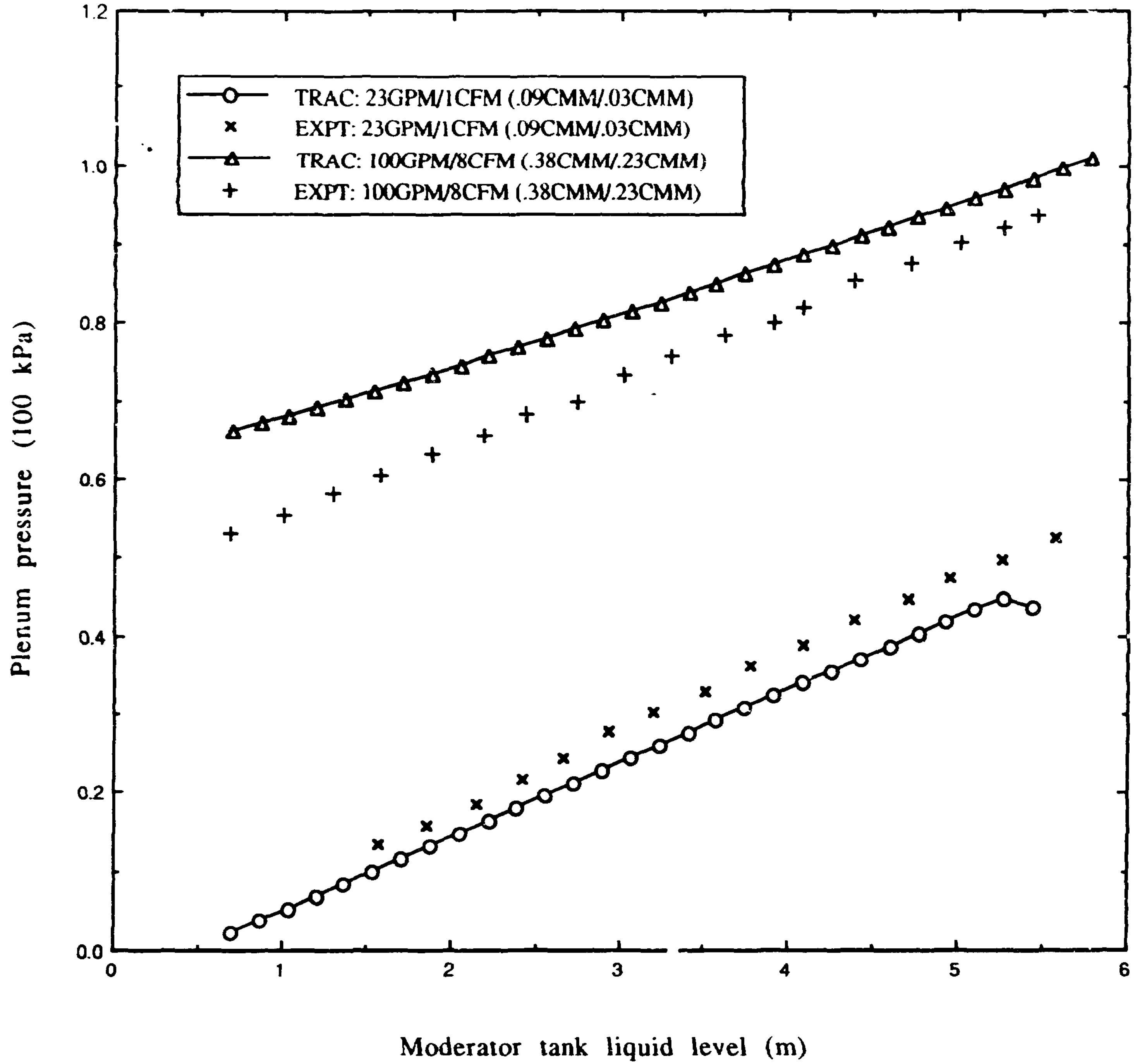
(7)



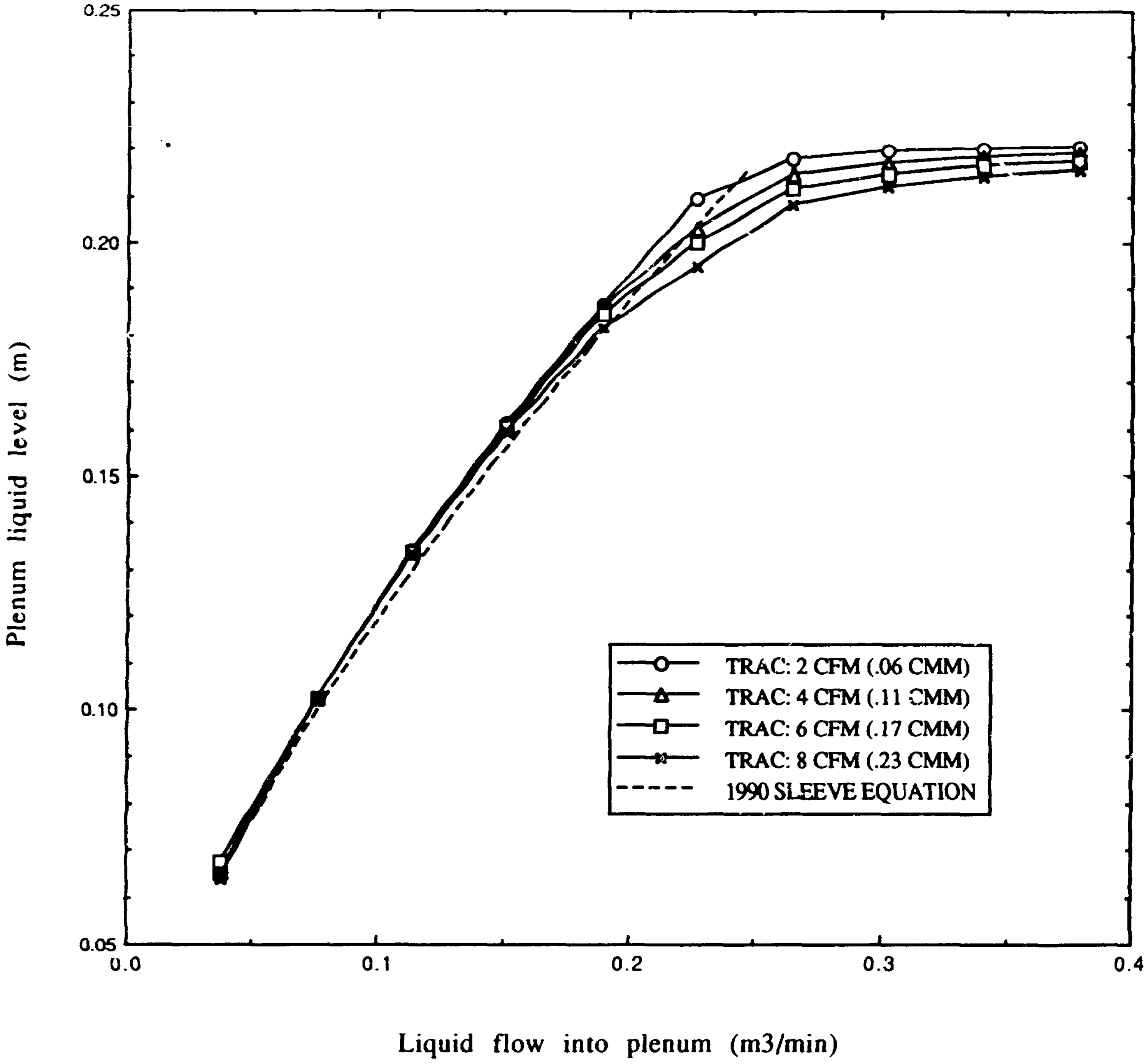
0.25
0.20
0.15
0.10
0.05
0
1
2
3
4
5
6
Plenum liquid level (m)
Moderator tank liquid level (m)
WITH LEAK MODEL
NO LEAK MODEL
EXPERIMENTAL



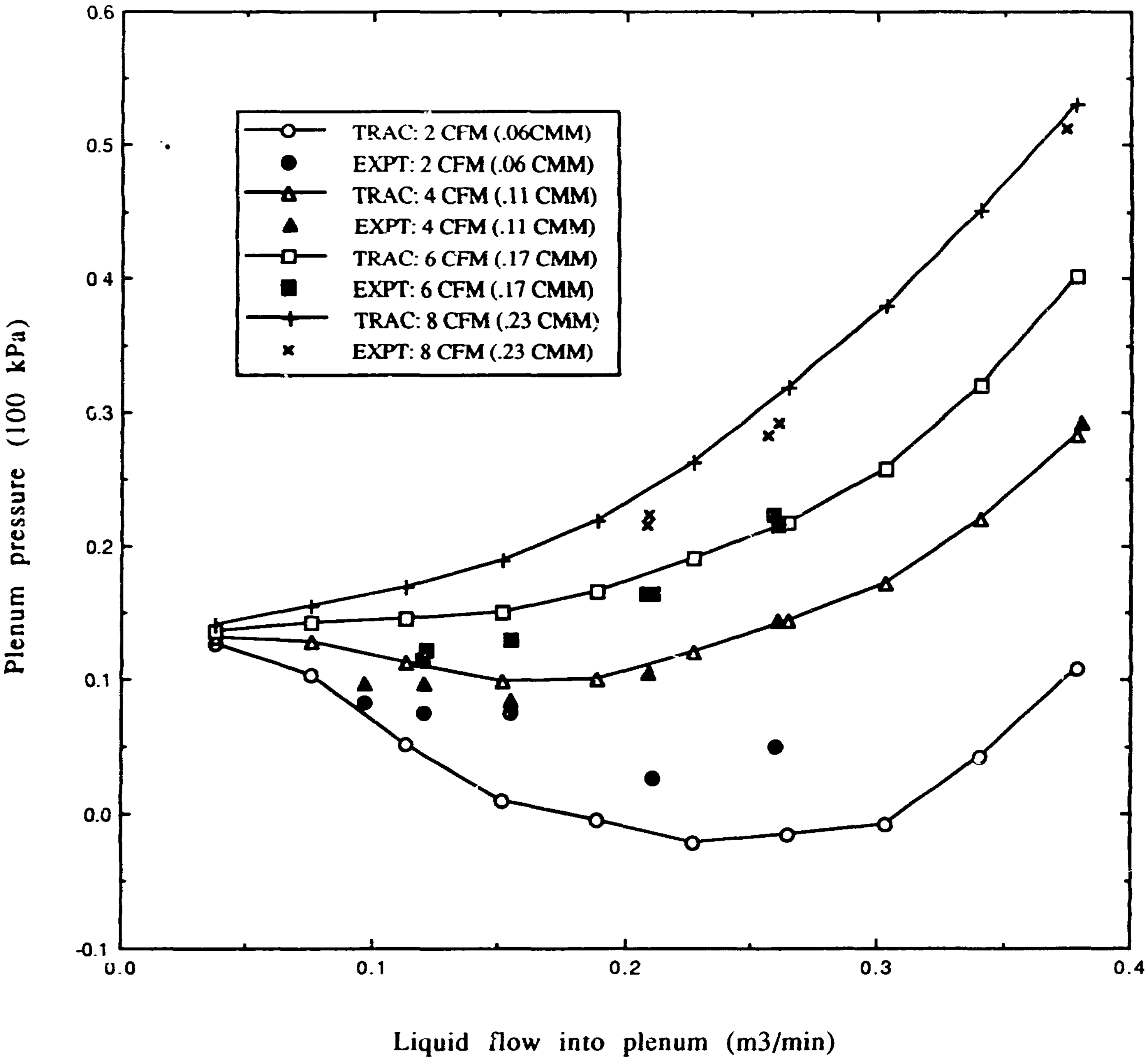
0.25
0.20
0.15
0.10
0.05
0.0
0.1
0.2
0.3
0.4
Plenum liquid level (m)
Liquid flow into plenum (m3/min)
1990 SLEEVE EQUATION
TRAC: 1,2,6-CFM AIR FLOW
EXPT: 1,2,6-CFM AIR FLOW
TRAC: 4-CFM AIR FLOW
EXPT: 4-CFM AIR FLOW
TRAC: 8-CFM AIR FLOW
EXPT: 8-CFM AIR FLOW

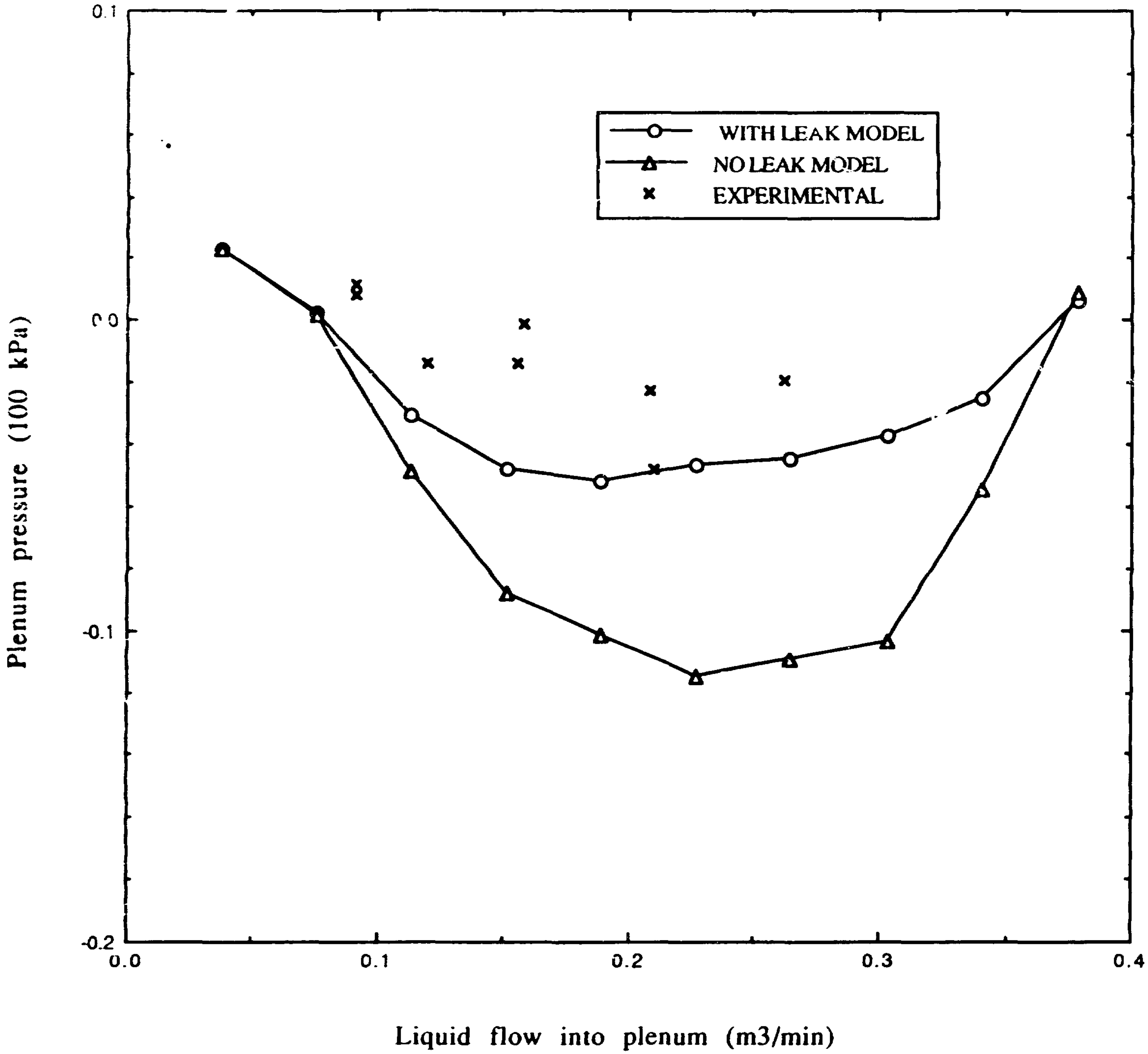


TRAC: 23GPM/1CFM (.09CMM/.03CMM)
EXPT: 23GPM/1CFM (.09CMM/.03CMM)
TRAC: 100GPM/8CFM (.38CMM/.23CMM)
EXPT: 100GPM/8CFM (.38CMM/.23CMM)
Plenum pressure (100 kPa)
Moderator tank liquid level (m)
0.0
0.2
0.4
0.6
0.8
1.0
1.2
0
1
2
3
4
5
6



0.25
0.20
0.15
0.10
0.05
0.0
0.1
0.2
0.3
0.4
Plenum liquid level (m)
Liquid flow into plenum (m3/min)
TRAC: 2 CFM (.06 CMM)
TRAC: 4 CFM (.11 CMM)
TRAC: 6 CFM (.17 CMM)
TRAC: 8 CFM (.23 CMM)
1990 SLEEVE EQUATION


TRAC: 2 CFM (.06CMM)
EXPT: 2 CFM (.06 CMM)
TRAC: 4 CFM (.11 CMM)
EXPT: 4 CFM (.11 CMM)
TRAC: 6 CFM (.17 CMM)
EXPT: 6 CFM (.17 CMM)
TRAC: 8 CFM (.23 CMM)
EXPT: 8 CFM (.23 CMM)
Plenum pressure (100 kPa)
0.6
0.5
0.4
0.3
0.2
0.1
0.0
-0.1
0.0
0.1
0.2
0.3
0.4
Liquid flow into plenum (m3/min)



WITH LEAK MODEL
NO LEAK MODEL
EXPERIMENTAL
Plenum pressure (100 kPa)
0.1
0.0
-0.1
-0.2
0.0
0.1
0.2
0.3
0.4
Liquid flow into plenum (m3/min)