CTE - 150

BRAZILIAN TEST FACILITY FOR THERMAL-HYDRAULIC RESEARCH

Othon Luis Pinheiro da Silva
Sérgio Pereira da Cunha Garcia
Valdemir Gutierrez Rodrigues *
Coord. para Projetos Especiais-Min. Marinha / *IPEN/CNEN-SP

Summary

The first Brazilian Test Facility of high pressure and high temperature, to simulate the actual performance of Pressurized Water Reactor was already commissioned and is in operation. The Experimental Test Facility, named as CTE - 150, has several objectives, among these to improve the reactor's safety. Experimental studies are being carried out on thermal-hydraulic performance of Pressurizer and Steam Generator components.

INTRODUCTION

The Electrical Energy Generation in Brazil, is based mainly in hydraulic sources and since the last decade it began to scarce close to developed cities of the country, e.g. the south-east region. As a matter of fact, this is an emerging problem, since the construction of new power plants requires flooding of huge areas, creating great disturbances to the population and to the environment.

It is true that hydraulic energy cost is lower than nuclear energy, however, in the comparison it is impossible to figure out today the price of the ecological disaster in the cultivable land and in the climate, just to generate a few hundreds Megawatts. This troublesome problem can be avoided by instalation of a small modular nuclear reactor with passive safety concepts. In this concern a program to develop a small power reactor is going on.

Within the frame of a thermal-hydraulic research program sponsored by the Ministry of the Navy in joint venture with the Brazilian Atomic Energy Authority, the Instituto de Pesquisas Energéticas e Nucleares in São Paulo with participation of the national consulting firms and industries, it was designed, constructed and is operating the first brazilian high pressure and high temperature Experimental Test Facility to simulate the actual performance of Pressurized Water Reactor conditions(p,T) with scaled flow and power(Q,P).

The components of the first high pressure and high temperature test facility were entirely national and a few number of measurements devices was imported. Nevertheless we are the first Latin America Nation with such high-powered experimental facility enterily designed and constructed in the country. With the experience gained in the last ten years we are able to foresee further upgrades to our facilities in near future.

The Experimental Facility has several purposes, among these, to increase both Brazilian industrial capabilities and safety requirements.

This paper presents the main aspects of the Brazilian Test Facility(named as:CTE-150) and the experimental program to be carried out.

THE INTERNATIONAL SCENARIO

The international scenario of experimental facilities is quite large. Table 1 shows the characteristics of the main plants in operation.

Table 1. Main Test Facility in Operation

Facility -	VSR (*)	Power (MWth)	Pressure (bar)	Loops -	Country -
SEMISCALE	1:1600	2.0	170	2	USA
LOBI	1:712	5.4	170	2	EURATOM
ROSA II	1:400	2.2	170	2	JAPAN
PKL	1:150	1.5	35	3	GERMANY
LOFT	1:64	50.0	170	2	USA
BETHSY	1:100	3.0	170	3	FRANCE
ROSA IV	1:50	10.0	170	2	JAPAN
CCTF	1:20	10.0	6	4	JAPAN
SPES	1:427	6.5	200	3	ITALY
CTE-150	1:8	2.0	150	1	BRAZIL

* VSR - Volumetric Scaling Ratio

Each of these facilities has of course characteristic which are typical of the choosen reference reactor. One can see that among the plants listed in Table 1 the CTE - 150 facility even with just one loop has some special feature, since our reference is a small low power PWR reactor. The CTE - 150 facility has not been designed to simulate large LOCA's but other integral loops have already obtained several experimental results in this field. The main aims of the CTE-150 is therefore to collect data related to the operating system related to Special Transients and only for small Breaks LOCA's.

THE TEST FACILITY CTE - 150

The CTE - 150 facility is presented in Fig. 1. Its main components are the Pressurizer, one staged canned motor Pump, Heat Exchanger, Steam Dryer, Condenser and the Reactor Test Section. Table 2 shows the CTE - 150 main parameters. The facility consists basically of four systems:

High pressure primary system. The primary system consists of one recirculation loop. Demineralized Water flowing out the Reactor Test Section(or through the high pressure heater) transfer heat to the secondary circuit by means of a 106 U - Tube Steam-Generator Test Section(or by a Heat Exchanger). The pressure is controlled by the Pressurizer Test Section connected to the hot leg. The water is circulated by a canned motor centrifugal pump. The primary circuit has flexibility to operate without the Reactor Test Section(with the higher pressure heater) or the Steam-Generator(with the primary heat exchanger). Main parameters of high primary system are listed in Table 2.

Secondary system. The secondary system consists essentially of the feedwater pump, pre-heater, steam dryer, condenser and the secondary heat exchanger. At full power condition the main feedwater pump with a flow rate of 26,0 m³/h delivers 5,0 m³/h to the steam-generator and the rest returns to the condenser. According to the load change the feedwater is controlled by a step valve associated to a turbine flow meter. The water in the steam-generator is controlled by a standard net of 3 - elements like in PWR reactors. Table 2 shows the main parameters of secondary system.

Cooling system. The system has the function of cooling the pumps, heat exchangers and the auxiliary system, rejecting heat to a 2,5 MW Cooling Tower.

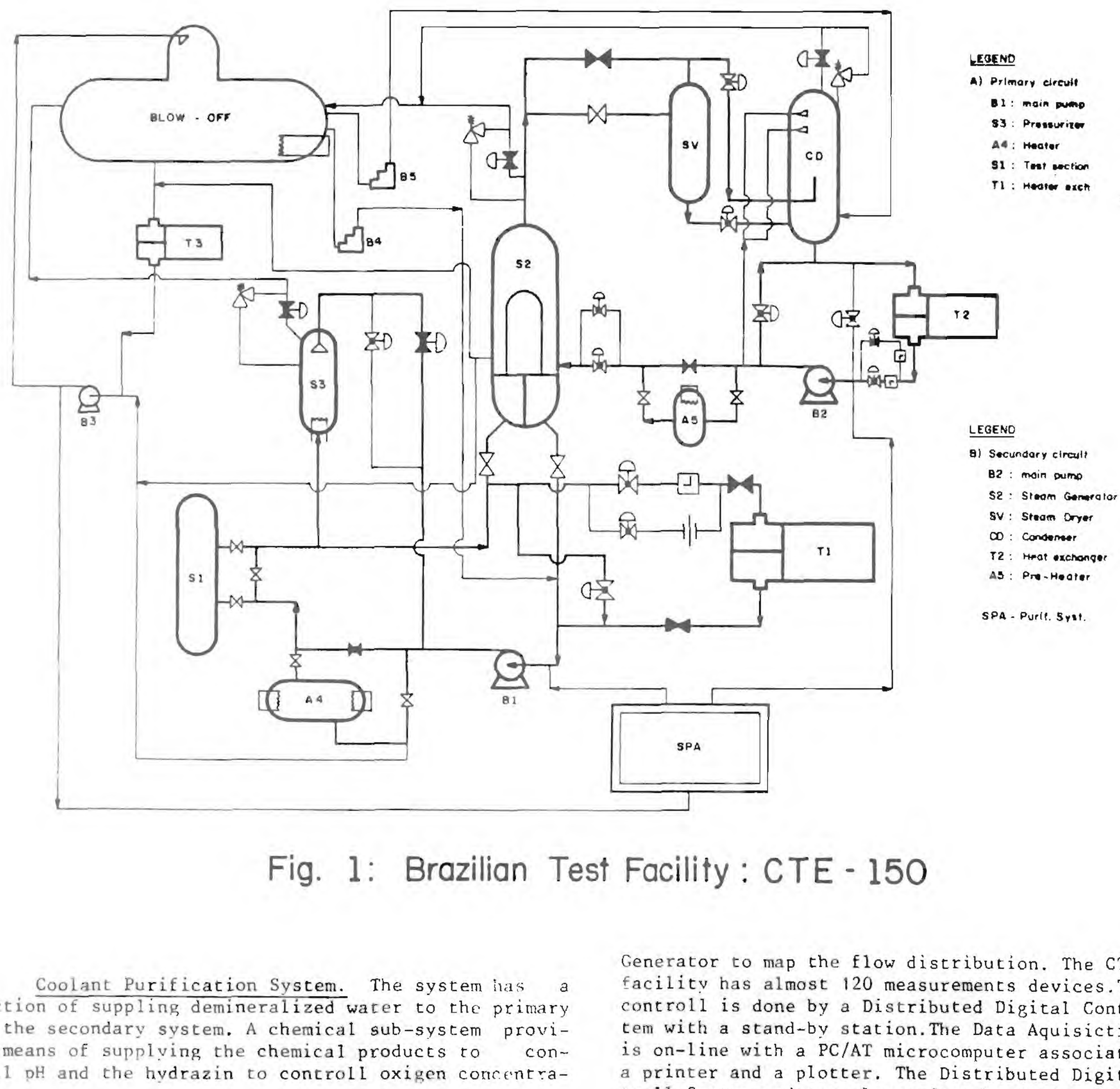

Fig. 1: Brazilian Test Facility : CTE - 150

Coolant Purification System. The system has a function of suppling demineralized water to the primary and the secondary system. A chemical sub-system provides means of supplying the chemical products to controll pH and the hydrazin to controll oxigen concentration.

INSTRUMENTATION

Several points are selected to obtain a detailed thermofluid-dynamic map of CTE - 150 facility during an experiment (flowrates, temperatures, pressure, pressure drops, levels, etc...). Carefull attention has been given to the Reactor Test Section, Pressurizer and the Steam Generator instrumentations since we have interest in the thermal-hydraulic behavior of these components. The temperature measurements are taken with RTD-detectors and type K-Thermocouples. Flow measurements are done with Turbine Flowmeters, Pitot Tubes and Orifice Plates distributed at interest points. The Pressurizer and the Steam Generator instrumentation is shown in Figure 2 and Figure 3 respectively. Remarkable are the micro turbines located in the downcomer of the Steam-Generator to map the flow distribution. The CTE - 150 facility has almost 120 measurements devices. The plant controll is done by a Distributed Digital Controll System with a stand-by station. The Data Aquisiction System is on-line with a PC/AT microcomputer associated with a printer and a plotter. The Distributed Digital Controll System updates almost four hundred points at every half minute.

EXPERIMENTAL PROGRAM

The CTE - 150 experimental program here presented is not to be considered as the final one; it undergoes a continuos revision process. Often it is necessary to change some parameters and even the aim of one experiment as the person involved in the test specification, preparation, pre-test prediction goes deeper into the problems concerning that particular transient. Furthermore during the CTE-150 operation a lot of new problems, interesting phenomena and ideas for new transients will arise. Finally the CTE-150 experimental program is open to take into account suggestion from other organization. Anyway, the test program here presented has been subjected to the second revision. The experimental program has the following main goals:

.Scalled electrically heated test section to simulate rod bundle. This test section will investigate the phenomena of critical heat flux, mixing, pressure drop and heat transfer coefficients at normal and transient conditions.

.Steam Generator behavior(including Steam Separator and Dryer).

.Dynamic behavior of Pressurizer.

.Behavior of CTE-150 safety valve in two-phase flow conditions in the interesting range of operational transients and accidental situation.

.CTE-150 primary pump performance in single phase and in two-phase flow.

.Behavior of a primary and secondary control systems under abnormal conditions.

.Single phase natural circulation.

.Pipe vibration.

.Operator training.

.Evaluation the effect of the operator intervention for an emergency plant recovery.

.Improvement the knowledge of physical phenomena occuring during plant transients and to asses the available safety codes.

Table 2. CTE - 150 : Main Parameters

Primary Circuit		
Thermal Power	, MW	2.0
Design Pressure	, bar	150
Mean Temperature	, ºC	275
Flow Rate	, m^3/h	126
Volume	, m^3	1,5
Secondary Circuit		
Design Pressure	, bar	67
Feedwater Inlet Temperature	, ºC	175
Steam Flow Rate	, m^3/h	4,5
Steam Generator		
Type	,	U - tube
Height	, m	6,0
Number of tubes	, -	106
Pressurizer		
Design Pressure	, bar	155
Design Temperature	, ºC	350
Height	, m	2,5
Volume	, m^3	0,15

SAFETY SERIES TESTS

As mentioned the CTE-150 facility has not been designed to perform large LOCA's however among the tests related, Special Transients and Small Break can be simulated. These safety tests are:

.PORV stuck open

.Pump coastdown

.Loss of feedwater with/without Auxiliary Feed Water

.Feed Line Break

.Small Break in cold leg(less than 4")

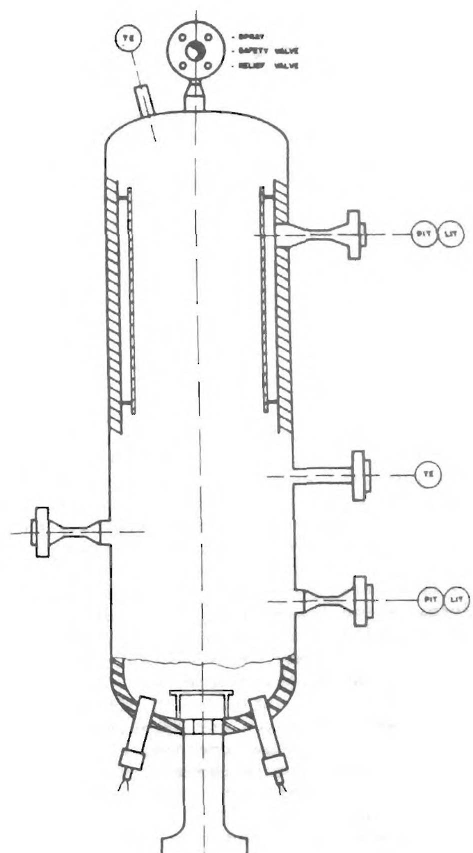

Fig. 2 Pressurizer test section

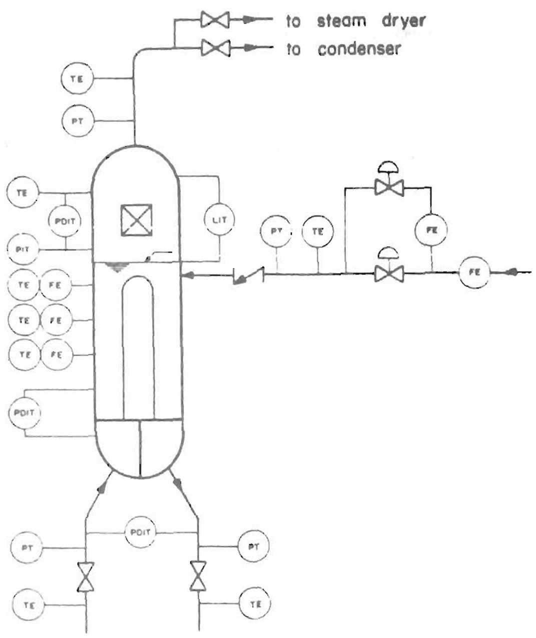

Fig. 3 : Steam Generator

CONCLUSION

The CTE-150 will cover the lack between theory and practice, and it shall answer many questions in our project. Besides we are thinking that the most important is the academic and experimental level that will be offered to our graduating students in their thesis.

Since the startup we have already had almost 500 hours in operation and many experiments were done e.g., pump coastdown, pressurizer and steam generator performance and recirculation rate of Steam Generator.

In spite of big computers to simulate all kind of physical problems, experimental facilities should be expanded rather than decreased. In this concern we follow Lord Kelvin quotation " I often say that when you can measure what you are speaking about,and express it in numbers, you know something about it; but when you cannot express it in numbers, your knowledge is of a meagre and unsatisfactory kind; it may be the beginning of knowledge, but you have scarcely, in your thoughts, advanced the stage of science. Whatever the matter may be...".

Interfacial areas in bubbly flow : measurement, data and prediction

H.P. Bensler, P. Bricard, J.M. Delhaye & C. Favreau
Commissariat à l'Energie Atomique
Centre d'Etudes Nucléaires de Grenoble
Service de Thermohydraulique pour les Applications Industrielles

One describes an ultrasonic technique which enables the simultaneous measurement of the void fraction, the interfacial and the Sauter mean diameter in a bubbly flow. Experimental data on interfacial areas obtained in bubble columns and in forced circulation flows are presented. These data are then compared with existing correlations and a new correlation is proposed.

INTRODUCTION

Preliminary Definitions. The geometric structure of a bubbly two-phase flow can be characterized by three parameters : the volumetric interfacial area, the volumetric void fraction, and the Sauter mean diameter.

(i) The instantaneous *volumetric interfacial area* $\Gamma(t)$ is defined as

$$\Gamma(t) \triangleq \frac{A_i(t)}{V} \quad (1)$$

where $A_i(t)$ is the instantaneous interfacial area of all the bubbles found in a control volume (fig. 1). Generally, however, the averaged value of Γ is of prime interest :

$$\overline{\Gamma(t)} \triangleq \frac{\overline{A_i(t)}}{V} \quad (2)$$

where the bar represents the time averaging operator. For convenience, the time averaged value $\overline{\Gamma(t)}$ will be written as Γ.

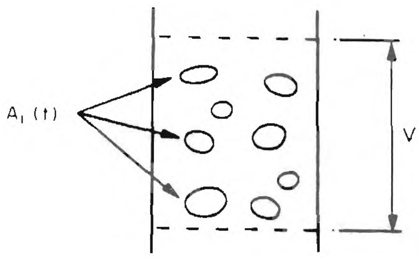

Fig. 1 Definition of the instantaneous volumetric interfacial area.

(ii) The instantaneous *volumetric void fraction* $\varepsilon(t)$ is defined as

$$\varepsilon(t) \triangleq \frac{V_g(t)}{V} \quad (3)$$

where $V_g(t)$ is the instantaneous volume of the N bubbles enclosed in volume V at time t. The time averaged value $\overline{\varepsilon(t)}$ of the void fraction $\varepsilon(t)$ is defined by the following relationship

$$\overline{\varepsilon(t)} \triangleq \frac{\overline{V_g(t)}}{V} \quad (4)$$

The time averaged value $\overline{\varepsilon(t)}$ will be noted as ε.

(iii) The instantaneous *Sauter mean diameter* is given by the expression

$$d_{SM}(t) \triangleq \frac{\sum_{j=1}^{N} d^3_{V_j}(t)}{\sum_{j=1}^{N} d^2_{A_j}(t)} \quad (5)$$

where $d_{V_j}(t)$ is the instantaneous equivalent volume bubble diameter defined as

$$d_{V_j}(t) \triangleq \left(\frac{6\ V_j}{\pi}\right)^{1/3} \quad (6)$$

where V_j is the volume of the jth bubble. Furthermore, the instantaneous equivalent surface area bubble diameter $d_{A_j}(t)$ is given by

$$d_{A_j}(t) \triangleq \left(\frac{A_j}{\pi}\right)^{1/2} \qquad (7)$$

where A_j is the surface area of the jth bubble. Finally, the time averaged Sauter mean diameter is defined by

$$\overline{d_{SM}(t)} \triangleq \overline{\frac{\sum_{j=1}^{N} d_{V_j}^3(t)}{\sum_{j=1}^{N} d_{A_j}^2(t)}} \qquad (8)$$

which will be simply noted as d_{SM}. If the fluctuations in time of the all previously mentioned geometric parameters are small, one can utilize the classic expression for Γ given by

$$\Gamma = \frac{6\,\varepsilon}{d_{SM}} \qquad (9)$$

Importance of Determining Interfacial Areas. The interfacial area is a parameter of prime interest in two-phase flow. It appears in the interfacial transfer terms which should be modelled as follows [1,2] :

Interfacial transfer ~ interfacial area × generalized force

The interfacial area represents the geometrical structure of the flow whereas the generalized force is directly connected to the local transport mechanism. The above relation is general and applies to mass, momentum and energy transfers.

ULTRASONIC TRANSMISSION TECHNIQUE

Basic Principle. The basic principle of the *ultrasonic transmission technique* is the attenuation of ultrasound by the bubbly flow. One measures the electrical voltages (A_0 and A) which linearly correspond to the received acoustic pressures for the single-phase liquid and the bubbly two-phase flow (fig. 2). The ultrasonic transmittance T is defined by the relation :

$$T \triangleq \frac{A}{A_0} \qquad (10)$$

An attenuation coefficient α based on T will be presented in the following paragraphs ; it will then be shown how the knowledge of α and the Sauter mean diameter (or the void fraction) determines the interfacial area.

Modeling of ultrasound attenuation. The ratio of the received ultrasound intensities I/I_0 with and without bubbles is given by :

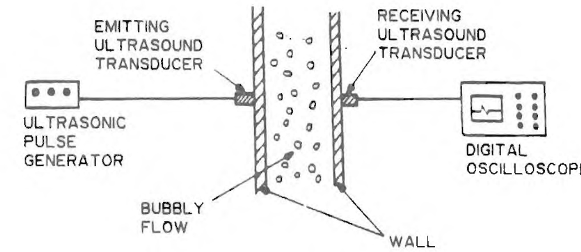

Fig. 2 Ultrasonic transmission measurement system.

$$\frac{I}{I_0} \triangleq \exp\,(-\,\alpha\,L) \qquad (11)$$

where α is the attenuation coefficient corresponding to a bubbly flow with a pathlength L. From the definition of the acoustic intensity, one can write :

$$\left(\frac{I}{I_0}\right) = \left(\frac{A}{A_0}\right)^2 \qquad (12)$$

Consequently, the attenuation coefficient is expressed as

$$\boxed{\alpha = -\frac{2}{L}\ln T} \qquad (13)$$

For a homogeneous bubbly flow consisting of nonuniform spherical bubbles, the attenuation coefficient can be written as

$$\alpha = n \int_{a=0}^{a=\infty} S_{app}\,(ka)\;\pi\,a^2\;f(a)\;da \qquad (14)$$

where n is the bubble number density, a is the bubble radius, f(a) is the bubble size distribution, and $S_{app}(ka)$ is the *apparent scattering coefficient* which is a function of the following : 1) the absorption and scattering characteristics of a bubble which are expressed through the scattering coefficient S(ka) where k is the wave number ($k \triangleq 2\pi/\lambda$ where λ is the ultrasound wavelength in the pure liquid), 2) the absorption of the ultrasound by the continuous single-phase liquid, and 3) the experimental geometry which includes the diameters of the emitting and receiving ultrasound transducers, the distance between them, and the position of the bubble relatively to them.

The scattering coefficient S is expressed as an extinction cross section σ_{ext} normalized by the cross-sectional area of the bubble being considered :

$$S(ka) \triangleq \frac{\sigma_{ext}}{\pi a^2} \tag{15}$$

where σ_{ext} is given by :

$$\sigma_{ext} = \sigma_{sca} + \sigma_{abs} \tag{16}$$

where σ_{sca} and σ_{abs} are the scattering and absorption cross sections of the bubble. Physically, σ_{ext} can be considered as the cross-sectional area corresponding to the part of the ultrasound wave that was removed by the bubble. It represents the acoustic energy loss caused by the bubble which is defined as the power loss of the ultrasound wave divided by the incident intensity of the wave.

We assume that, in our conditions, the absorption cross section σ_{abs} can be neglected compared to the scattering cross section [3]. Consequently, the scattering coefficient for a spherical bubble can be written as :

$$S(ka) = \frac{\sigma_{sca}}{\pi a^2} \tag{17}$$

Furthermore, if one assumes that the absorption of the continuous liquid phase and the forward scattering effects are negligible, the apparent scattering coefficient can be written as

$$S_{app}(ka) = S(ka) \tag{18}$$

This basically implies single scattering [4].

Through the use of Eq. (18), the attenuation coefficient given by Eq. (14) becomes :

$$\alpha = n \int_{a=0}^{a=\infty} S(ka)\, \pi a^2 f(a)\, da \tag{19}$$

The actual use of Eq. (19) is not simple because of the required knowledge of the bubble size distribution of the bubbly flow. Nevertheless, if one bases the scattering coefficient as a function of the Sauter mean diameter d_{SM}, the attenuation coefficient can be expressed as

$$\alpha = n\, S(k\, d_{SM}/2) \int_{a=0}^{a=\infty} \pi a^2 f(a)\, da \tag{20}$$

This form of the attenuation coefficient is more useful than Eq. (19) and will be utilized in the following paragraphs for the establishment of the expression for the interfacial area. The error associated with using Eq. (20) instead of (19) was estimated to be less than 2 % by numerical simulations [4].

Scattering of an acoustic wave by a spherical bubble. The analytical solution for the scattering coefficient of a spherical bubble exposed to an acoustic plane wave was presented by Nishi [3] and has the form

$$S(ka) = \frac{4}{(ka)^2} \sum_{l=0}^{\infty} (2\ell+1) \frac{j_l^2(ka)}{j_l^2(ka) + n_l^2(ka)} \tag{21}$$

where j_l and n_l are spherical Bessel functions of the first and second kind. The assumptions associated with Eq. (21) are : 1) plane waves, 2) a spherical bubble in a viscous liquid, 3) ka > 1, and 4) a > 100 μm.

Determination of the volumetric interfacial area. The volumetric interfacial area for a homogeneous bubbly flow is given by :

$$\Gamma = 4\, n \int_{a=0}^{a=\infty} \pi a^2 f(a)\, da \tag{22}$$

By eliminating n using Eq. (20), Eq. (22) gives rise to the fundamental equation for the ultrasonically determined volumetric interfacial area :

$$\boxed{\Gamma = \frac{4\,\alpha}{S(kd_{SM}/2)}} \tag{23}$$

In this equation, the attenuation coefficient α is determined from the measured transmittance T and Eq. (13). A detailed analysis considering the assumptions associated with Eq. (23) is found in [4]

Multi-frequency correlation coefficient method. This method requires the knowledge of the *spectral transmittance* $T_j(f_j)$, i.e. the values of T over a frequency range. From the spectral transmittance, the interfacial area Γ_j at frequency f_j can be determined by the equation

$$\Gamma_j = -\frac{8}{L\, S_j(k_j\, d/2)} \ln T_j(f_j) \tag{24}$$

where d is the bubble diameter. Physically since the interfacial area does not depend on the ultrasound frequency, the correlation coefficient $r_{\Gamma f}$ between the measured Γ_j values and the corresponding frequencies f_j must equal zero. This correlation coefficient [5] is defined as

$$r_{\Gamma f} \triangleq \frac{\frac{1}{N-1}\left[\sum_{j=1}^{N} f_j \Gamma_j - \frac{1}{N}\sum_{j=1}^{N} f_j \sum_{j=1}^{N} \Gamma_j\right]}{S_f \; S_\Gamma} \qquad (25)$$

where N is the number of data points being considered and where S_f and S_Γ are the standard deviations corresponding to f and Γ, respectively.

Consequently, the Sauter mean diameter d_{SM} is the value of d which minimizes $r_{\Gamma f}$. After substitution of d_{SM} into Eq. (24), the volumetric interfacial area determined by the *multi-frequency correlation coefficient method* is obtained by a least-squares regression analysis. Finally, from the values of d_{SM} and Γ, the volumetric void fraction can easily be obtained using Eq. (9).

ULTRASONIC TRANSMISSION MEASUREMENT SYSTEM

Determination of the spectral transmittance. A *novel* experimental technique has been developed which is based on the use of : 1) sound pulses, 2) broadband ultrasonic transducers and 3) spectrum analysis.

The only previous studies which ultrasonically determined the volumetric interfacial area [,6,7,8] utilized wave trains and narrow band transducers working at specific resonance frequencies.

The measurement system of our study (fig. 2) consisted of a pulse generator (Panametrics 5052 UA), an emitting broadband ultrasound transducer, a receiving broadband ultrasound transducer, and a numerical oscilloscope (LeCroy 9400 A). The acquisition procedure utilized is the following :

1) Average the received pulses for a single-phase liquid flow,
2) Fast Fourier transform this averaged pulse,
3) Average the received pulses for the bubbly two-phase flow,
4) Fast Fourier transform this averaged pulse,
5) Determine the spectral transmittance by subtracting the two logarithmic spectra.

Utilization of the multi-frequency correlation coefficient method. The procedure utilized is the following :

- find the value of the Sauter mean diameter which minimizes the correlation coefficient (Eq. 25) for all the frequencies in the usable bandwidth of the spectral transmittance,
- for the value of the Sauter mean diameter found, determine the coefficient of degree zero of a least squares regression analysis of the individual interfacial areas as a function of the frequency. This zeroth degree coefficient then equals the volumetric interfacial area.
- from the values of the Sauter mean diameter and the interfacial area, determine the volumetric void fraction using Eq. (9).

EXPERIMENTAL APPARATUS

The BUS loop. The BUS loop consisted of a vertical natural recirculation (air-lift) air-water bubble column. Two square plexiglass test sections were utilized which were each 675 mm long and had internal dimensions of 80 × 80 mm and 120 × 120 mm. The ultrasound transducers were mounted on the outside of the test sections for both cases with and without bubble-free chambers. Two pairs of ultrasound transducers were used which had nominal frequencies of 3 MHz and diameters of 10 and 20 mm. The void fraction ranged from 0.01 to 0.16 and the bubble sizes were between 3 and 4 mm. The measurements carried out on the loop were the test section pressure drop which permitted the determination of the volumetric void fraction ε, the temperatures of the water and air, the gas mass flow rate, the Sauter mean diameter from video images, and the spectral transmittance. The above mentioned measurements are described in detail in [4].

The TORUS loop. In order to investigate the effect of the liquid velocity and the void fraction profiles on the ultrasonic technique, an air-water bubbly flow forced-circulation loop, known as TORUS, was employed. A square vertical plexiglass test section was used which was 4 m long and had internal dimensions of 40 × 40 mm. This test section was also equipped for measurements with and without bubble-free chambers.

The experimental test conditions were the following :

	Type	Nominal Frequency	Diameter
Ultrasound transducers	F2D24	2 MHz	24 mm
	F3D10 ou F3D20	3 MHz	10 or 20 mm

Liquid velocity	0, 1, 2, 3 m/s
Gas mass flow rate	0.1, 0.3, 0.5, 0.7 g/s
Void fraction	$0.01 \leqslant \varepsilon \leqslant 0.32$
Bubble size	$2 \text{ mm} \leqslant d_{SM} \leqslant 5 \text{ mm}$

The measurements taken were the test section pressure drop, the line void fraction (by X-ray densitometry), the liquid and gas temperatures, the gas flow rate, the liquid volumetric flow rate, the inlet absolute pressure, the Sauter mean diameter from video images, and the spectral transmittance. For more information concerning the loop and experimental procedure, see reference [4].

INTERPRETATION OF DATA

Effect of the Gas and Liquid Superficial Velocities. Figure 3 shows the volumetric interfacial area Γ as a function of the gas superficial velocity J_G for the 32 experimental points obtained on the BUS and TORUS loops. All the data lie on different lines, each one corresponding to a particular value of the liquid superficial velocity J_L. One can observe that the influence of J_L decreases when J_L increases. This trend is clearly shown in figure 4 where the volumetric interfacial area is plotted against J_L for constant values of J_G.

A New Empirical Correlation for Interfacial Area in Bubbly Flow. Some conclusions can be drawn from the above comparisons. The correlations proposed by Banerjee et al., Jepsen, Kasturi and Stepanek and Akita and Yoshida do not predict interfacial areas correctly. The

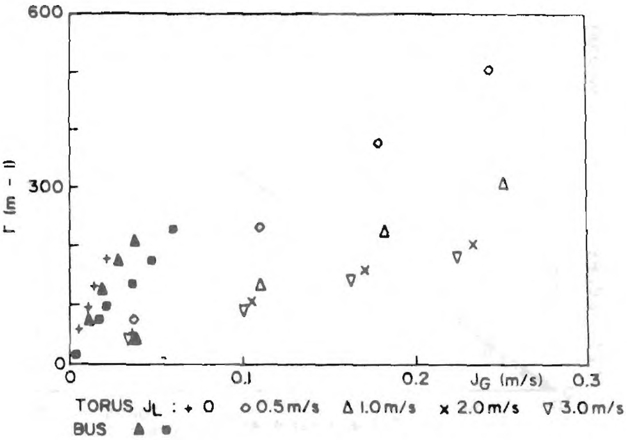

Fig. 3 Volumetric interfacial area Γ as a function of the gas superficial velocity J_G (BUS and TORUS data).

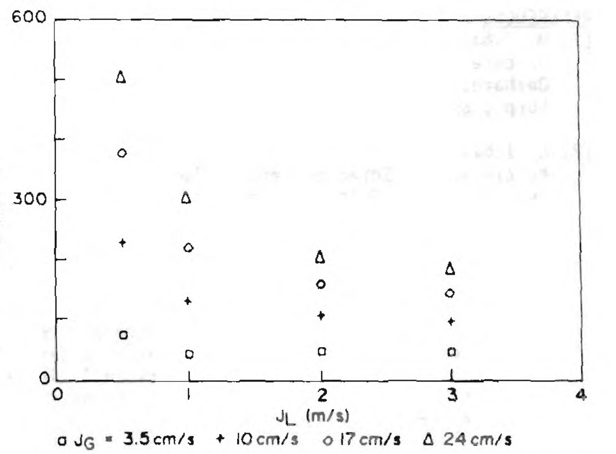

Fig. 4 Volumetric interfacial area Γ as a function of the liquid superficial velocity J_L (BUS and TORUS data).

correlation suggested by Trambouze et al. is rather good but its constants depend on the experimental conditions and therefore limit the applicability of the method. Carderbank's correlation is satisfactory but concerns perforated plates only. Finally Tomida et al. correlation agrees fairly well with all Bensler's data with an accuracy of ± 30 %.

This rather pessimistic conclusions led us to look for a correlation drawn from figure 3 where the volumetric interfacial area Γ is shown to be a linear function of J_G for a constant value of J_L. We thus found the following dimensional correlation in SI units :

$$\Gamma = \left(10710 - 10100 \frac{J_L}{J_L + 0.081}\right) J_G \qquad (26)$$

A nondimensional form of this correlation could be :

$$\Gamma\left[\frac{\sigma}{(\rho_L - \rho_G)g}\right]^{1/2} = \left(7.23 - 6.82 \frac{Re_L}{Re_L + 3240}\right) 10^{-3}\, Re_G \qquad (27)$$

where :

$$Re_G \triangleq \frac{\rho_G\, D\, J_G}{\mu_G} \qquad (28)$$

$$Re_L \triangleq \frac{\rho_L\, D\, J_L}{\mu_L} \qquad (29)$$

A comparison of Eqs (26) and (27) with Bensler's experimental data obtained on the TORUS loop are shown in figures 5 and 6. From figure 3 it is easy to guess the values of the liquid superficial velocities in the BUS loop :

- for D = 80 mm J_L = 0.13 m/s
- for D = 120 mm J_L = 0.06 m/s

It is then possible to compare the BUS data with the nondimensional form of correlation (27). This comparison is presented in figure 7. Up to now, correlations (26) and (27) have no physical bases. They are valid for upward bubbly flows in vertical channels, either in stagnant or forced circulation flows.

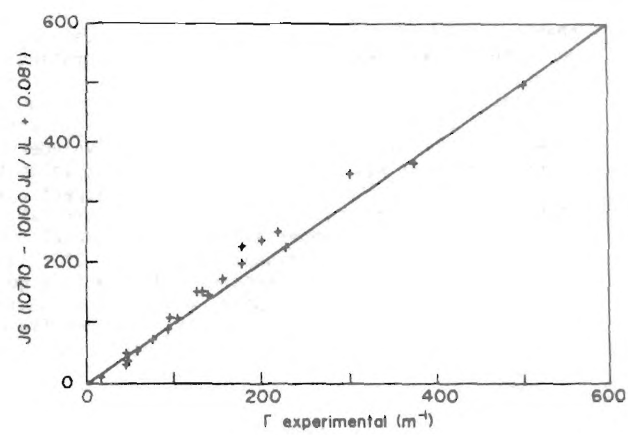

Fig. 5 New dimensional correlation for interfacial area in bubbly flow.

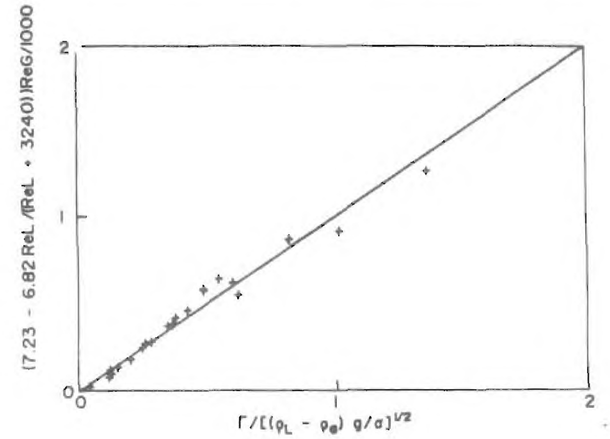

Fig. 6 New nondimensional correlation for interfacial area in bubbly flow.

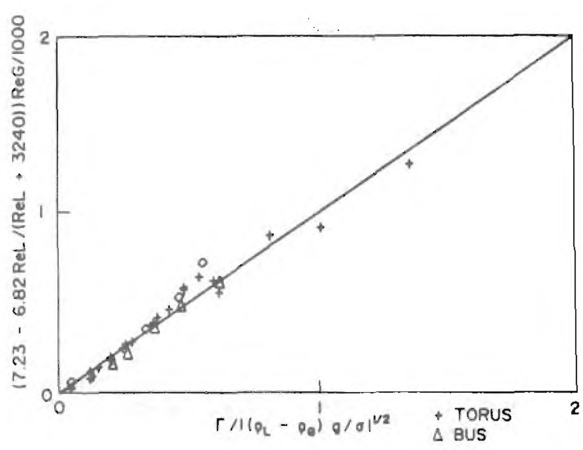

Fig. 7 Comparison of all Bensler's data with correlation (27)

CONCLUSIONS

1. The ultrasonic transmission technique is a powerful method capable of correctly determining the volumetric interfacial area, volumetric void fraction and Sauter mean diameter in bubbly two-phase flow solely from the knowledge of the measured spectral transmittance.
2. The ultrasonic transmission technique uses commercially available equipment which can be easily installed. It can be used with opaque pipings or fluids, corrosive or radioactive fluids and is a noninvasive, nonintrusive technique.
3. The ultrasonic transmission technique has however some limitations. Volumetric void fraction should be less than 0.30 for a two-phase pathlength L of 4 cm, 0.16 for L = 8 cm and 0.13 for L = 12 cm. Values of kd_{SM} should be greater than 6 and values of ΓL less than 23.
4. Although bubbly flows are encountered in many chemical processes, very few experimental data exist on interfacial areas in bubble columns operating in natural or forced circulations. No existing correlations were satisfactory when compared to Bensler's extensive set of data. Figure 1 clearly shows a linear dependency of the volumetric interfacial area against the gas superficial velocity for constant values of the liquid superficial velocity. This property leads to a simple correlation which can be written under either a dimensional form (Eq. 26) or a nondimensional form (Eq. 27). This correlation represents all Bensler's data with a good accuracy (figs 5 and 6). Future work should consist in checking this correlation against different fluids and trying to find a physical basis for its derivation.

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