Chapter III

EXPERIMENTAL RESULTS AND CONCLUSION

3.1 Presentation of experimental results

The phenomena of flow characteristics and heat transfer with simultaneously developing velocity and temperature profiles in triangular ducts with constant wall temperature, covering laminar and transition regions, were experimentally investigated. Results are presented graphically in Fig.10 to Fig.13 For simplification, these graphs are separated into two subsections covering laminar and transition flow regimes. The corresponding tabulated results and sample of calculation are also presented in Appendix A.

3.2 Experimental results

3.2.1 Laminar region

The experiment on the equilateral triangular as well as right-angled isosceles triangular ducts was successively carried out with a range of differential pressure varying from 10 to 70 mm. H_2O with an increment of 5 mm. H_2O. Conversion of differential pressure to the flow rate of air was obtained by using a calibration curve shown in Fig.B-1 in Appendix B. For each flow rate the inlet and outlet air temperatures and the wall temperatures were obtained by

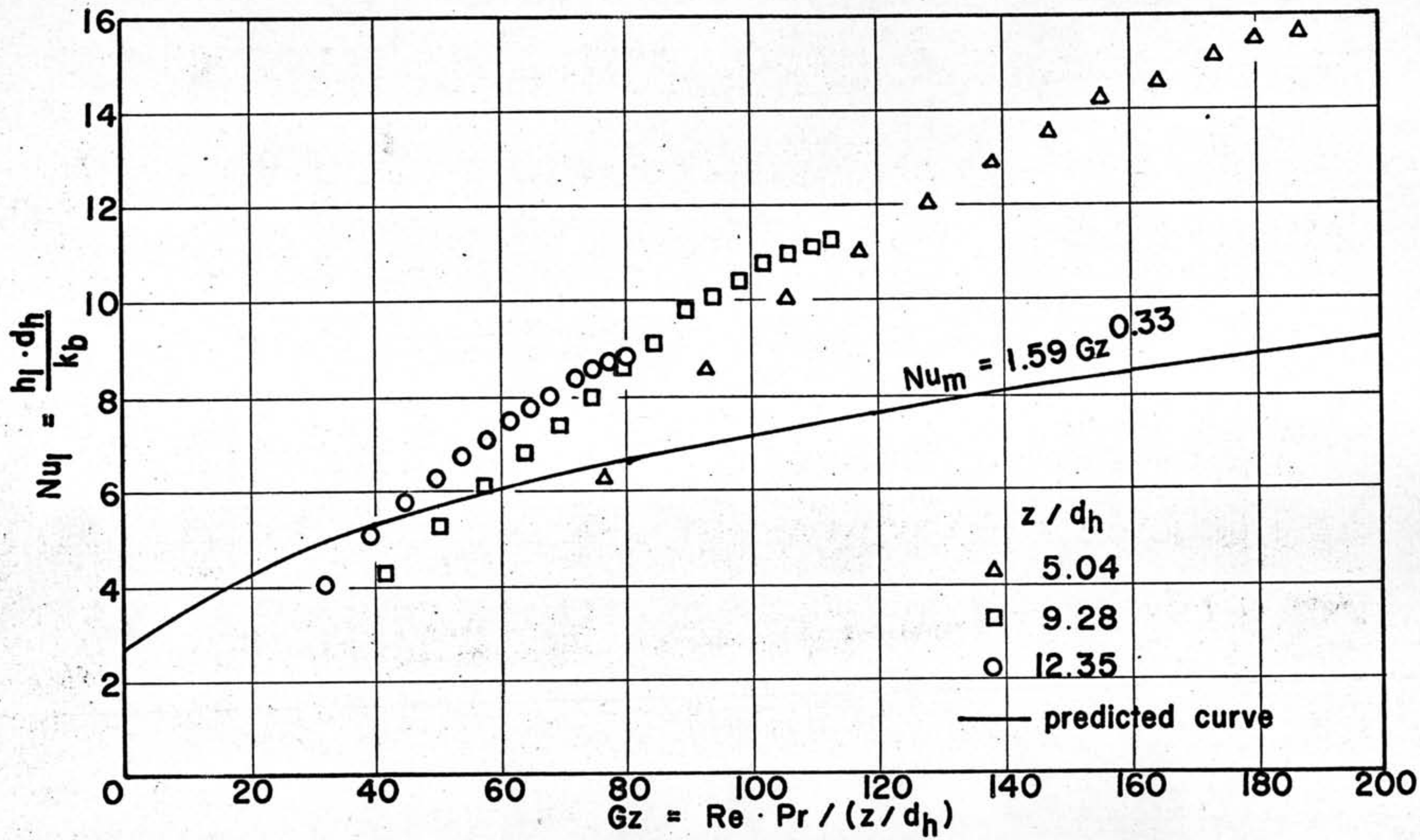

Fig. 10 Measured logarithmic mean Nusselt numbers plotted against Graetz numbers for simultaneously developing velocity and temperature profiles in an equilateral triangular duct with constant wall temperature. Pr = 0.72.

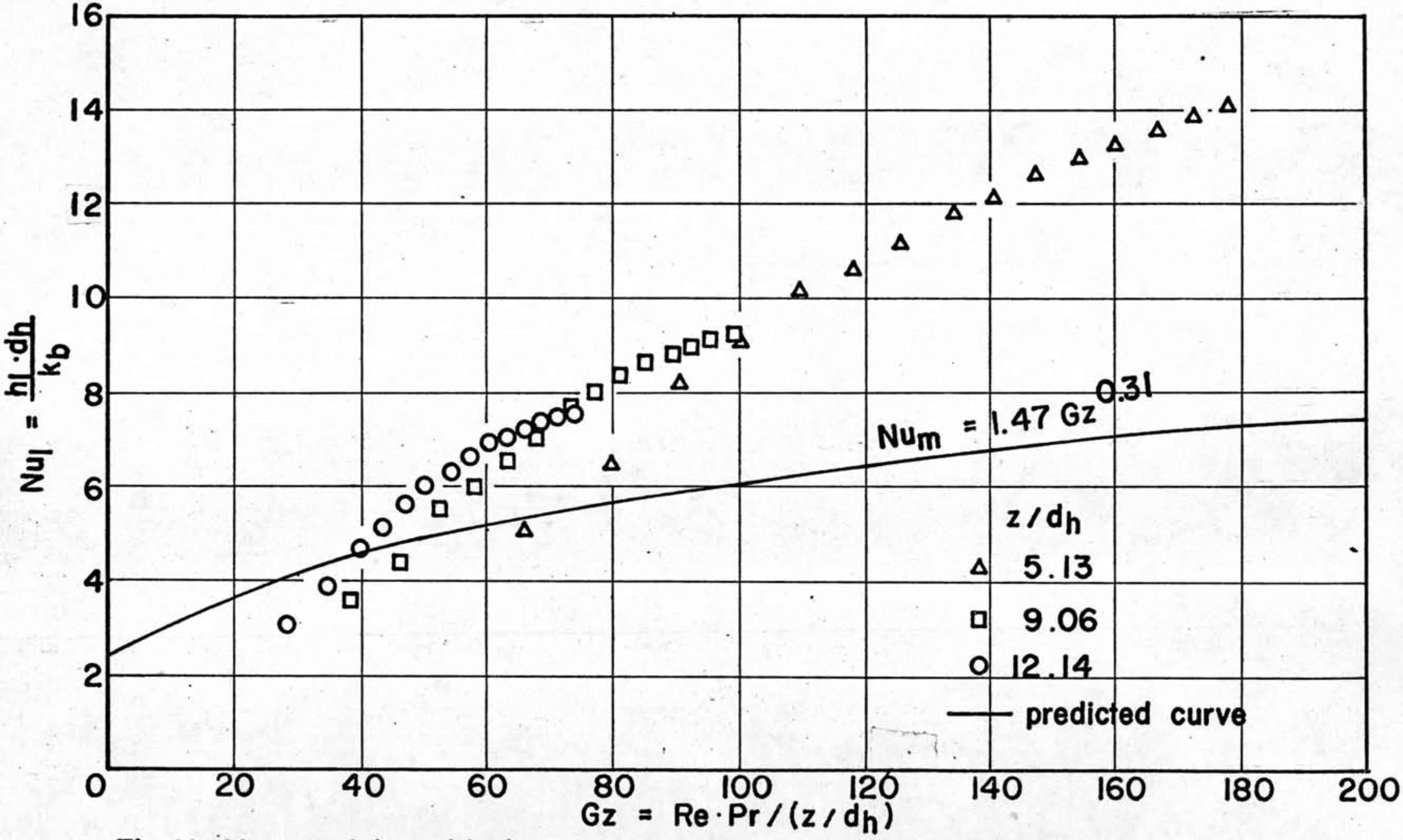

Fig. 11 Measured logarithmic mean Nusselt numbers plotted against Graetz numbers for simultaneously developing velocity and temperature profiles in a right-angled isosceles triangular duct with constant wall temperature. Pr = 0.72.

means of thermocouples. More details of the operating procedure have been explained in the preceding chapter.

In computation physical properties of air which are μ, C_p, and k, based on the bulk temperature of air, were obtained from Chemical Engineers' Handbook;[1] the density, ρ, was obtained from ASHRAE Guide and Data Book.[2] Hence, the measured logarithmic mean Nusselt number and Graetz number were computed from equation (8) in Chapter I and from the relation, $Gz = RePr/(z/d_h)$, respectively. The results thus obtained are plotted in Fig.10 and Fig.11 and the theoretical results are also shown for comparison.

From the figures, it is seen that the measured Nusselt numbers of both duct configurations show similar deviations as those for fully developed velocity profile in a rectangular duct with the same boundary condition.[3] For a Graetz number under 70, experimental and predicted results agree quite well, at higher Graetz numbers such as 120, 180, for instance, the deviations are about 45 and 75% respectively for the equilateral triangular duct. For the right-angled isosceles

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[1]Perry J.H., "Chemical Engineers' Handbook," (3rd ed., New York: McGraw-Hill Book Company, Inc., 1950).

[2]ASHRAE Guide and Data Book, Fundamental and Equipment for 1965 and 1966.

[3]Montgomery S.R., and Wibulswas P., "Laminar Flow Heat Transfer in Ducts of Rectangular Cross-Section," Proc. Third Int. Heat Transfer Conf. Vol.I (1966), pp. 85 - 98.

triangular duct the deviations at the same Graetz numbers, are about 65 and 94% respectively. The discrepancy is partly due to the effect of the variation of fluid properties with temperature. At a high Graetz number or a short distance from the entry plane, the wall temperature and fluid temperature close to the wall are much higher than the bulk temperature, and as a result, fluid properties of the formers are much different from that of the latter. Though the opposite effect occurred at the central part of the cross section where fluid temperatures are much lower than the bulk temperature, their deviations are less than those of the temperatures near the wall, and hence the overall effect resulted in a higher measured value of the bulk temperature than the predicted value. Furthermore, the deviations may probably be caused by systematic errors occurring during calibration of equipments, and random errors being the fluctuations in observations which yield results that differed from experiment to experiment. The deviation may also be due to an effect of duct corners which were not really sharp as assumed in the theory because of the method of construction that has already been explained in the preceeding chapter. An obvious evidence in the literature[4]

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[4]Shah R.K., and London A.L., "Laminar Flow Forced Convection Heat Transfer and Flow Friction in Straight and Curved Ducts - A Summary of Analytical Solutions." <u>Technical Report No. 75,</u> (November 1971).

showed that the more rounded corners of a triangular duct, the greater its Nusselt numbers.

Moreover, in computation of the predicted results by numerical method, the finite step in the z-direction may be too large and as a result, the predicted Nusselt numbers are lower than those obtained from a short finite one. Furthermore, lower predicted solutions may partly be a result of neglecting the axial viscous and conduction terms in the theoretical assumptions.

At a low Graetz number or a large distance from the entry plane, the temperature difference between the wall and the fluid bulk is much less than that at a high Graetz number, the effect of varying fluid properties is therefore very small and a closed agreement between the measured and predicted results is obtained.

At a low Reynolds number below 600 the measured result is lower than the predicted value. This appears to be due to the effect of the opposing free convection which becomes more apparent at a low flow rate.

3.2.2 Transition region

The experiment was performed on the equilateral triangular as well as right-angled isosceles triangular ducts with a range of differential pressure varying from 30 to 115 mm. H_2O and 10 mm. H_2O interval. Again, like subsection 3.2.1, inlet and outlet air temperatures and wall temperatures were obtained. Details of experimental procedure could be found in the previous chapter. Thereafter, the measured logarithmic

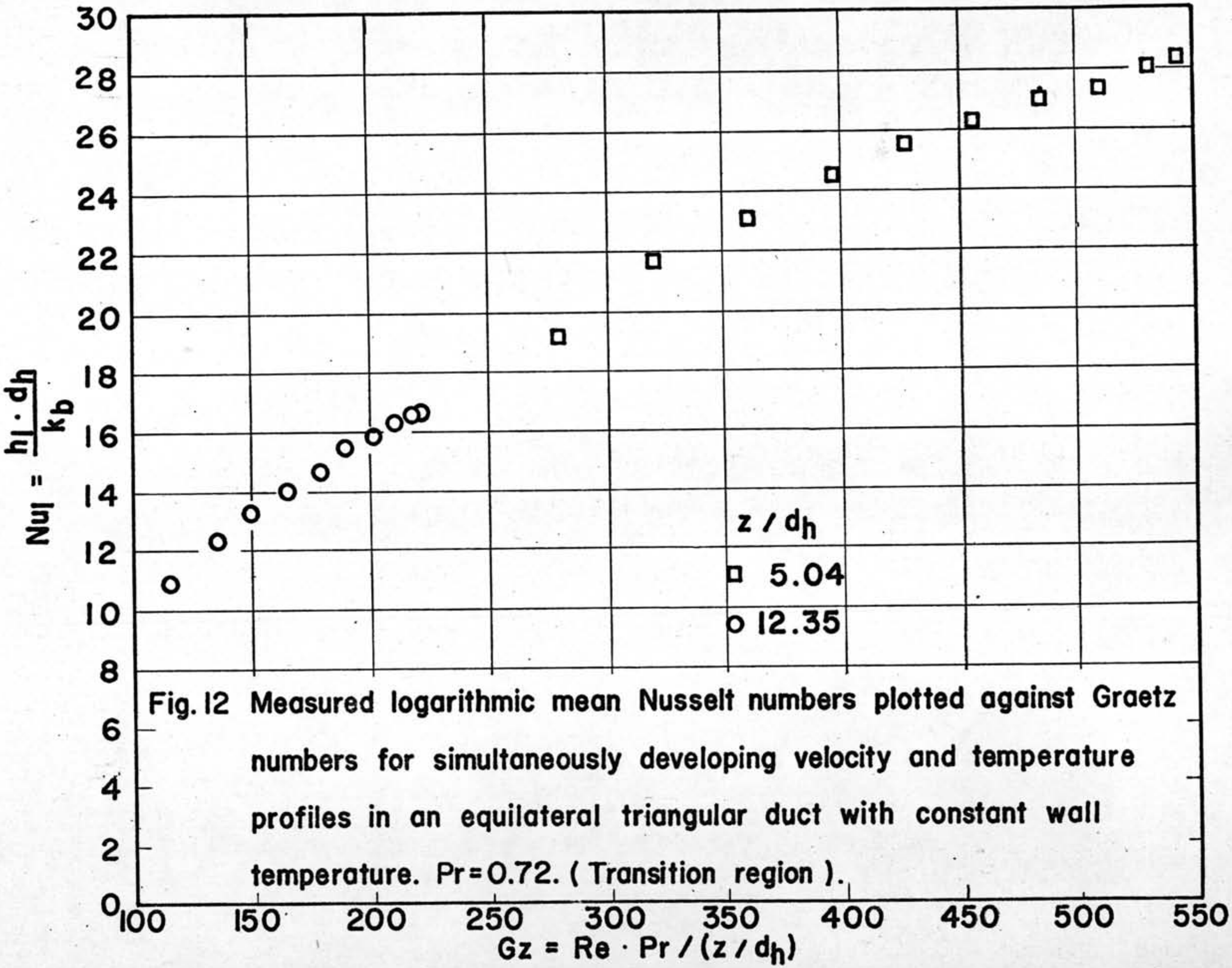

Fig. 12 Measured logarithmic mean Nusselt numbers plotted against Graetz numbers for simultaneously developing velocity and temperature profiles in an equilateral triangular duct with constant wall temperature. Pr = 0.72. (Transition region).

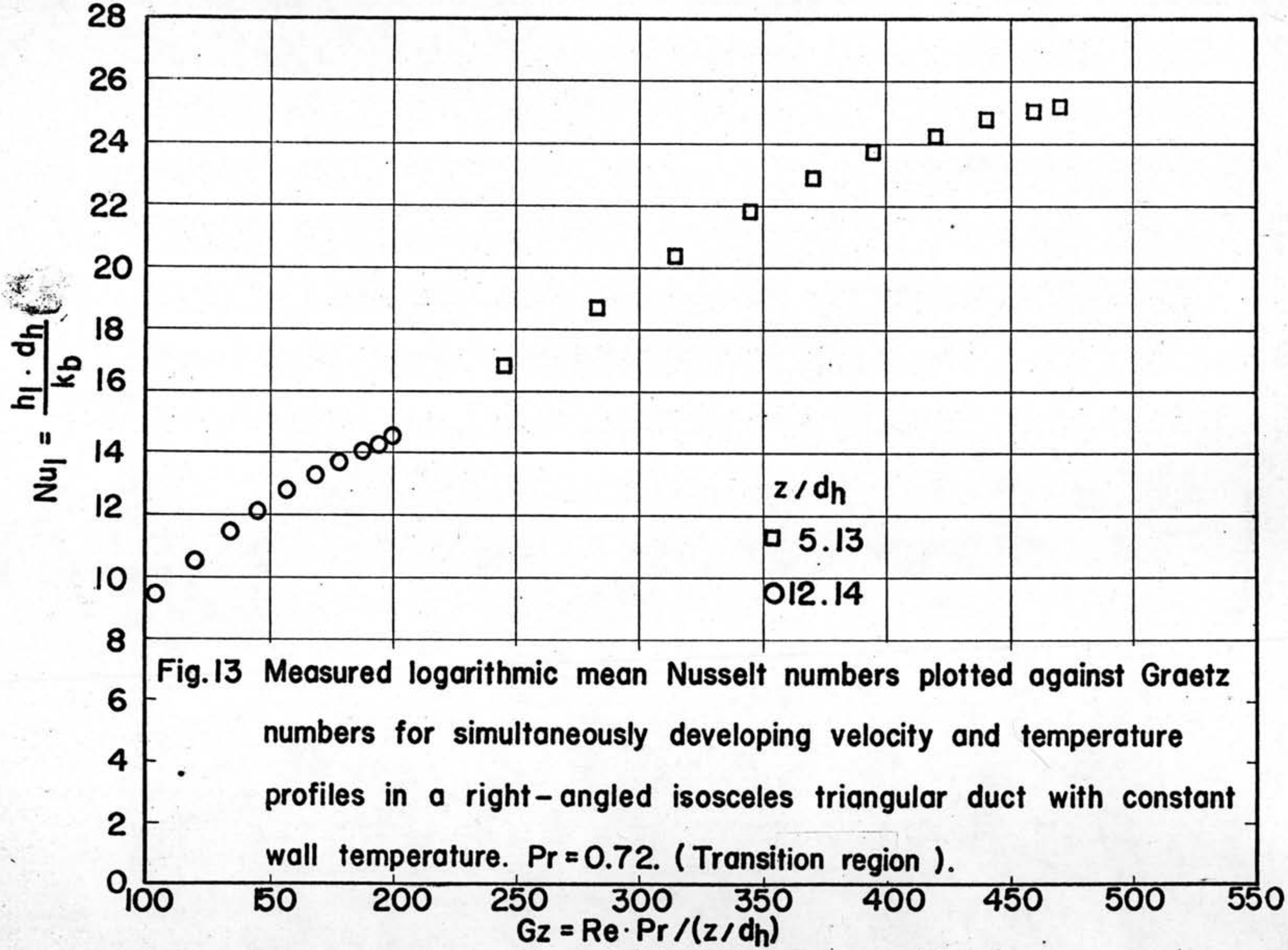

Fig. 13 Measured logarithmic mean Nusselt numbers plotted against Graetz numbers for simultaneously developing velocity and temperature profiles in a right-angled isosceles triangular duct with constant wall temperature. Pr = 0.72. (Transition region).

mean Nusselt numbers and Graetz numbers, obtained by similar computing procedure as those in subsection 3.2.1, were plotted in Fig.12 and Fig.13. It should be noted that flow rates of air were obtained from Fig.B-2 in stead of Fig.B-1.

From the figures, the experimental results seem to show, just like laminar flow heat transfer in subsection 3.2.1, similar trends. In other words, it may be said that the greater Graetz numbers, the higher Nusselt numbers. On account of the fact that there are no corresponding theoretical values available it will be possible, in the future, to devise an alternative theoretical approach to solve these more complex problems. Nevertheless, a substantial effort is being devoted to this problem.

3.3 Conclusion

From closer inspection of Fig.10, 11, 12 and 13, it is clearly seen that results for the equilateral triangular ducts appear to be equal or slightly above the corresponding quantities for the right-angled isosceles triangular ones. Furthermore, all values seem to form the same trend, that is, the greater Graetz numbers, the higher Nusselt numbers. It is therefore advantageous to plot all results on the same logarithmic paper to establish an empirical relationship, as illustrated in Fig.14, between the logarithmic mean Nusselt numbers and Graetz numbers. The predicted solutions have also been shown for comparison. A straight line has been

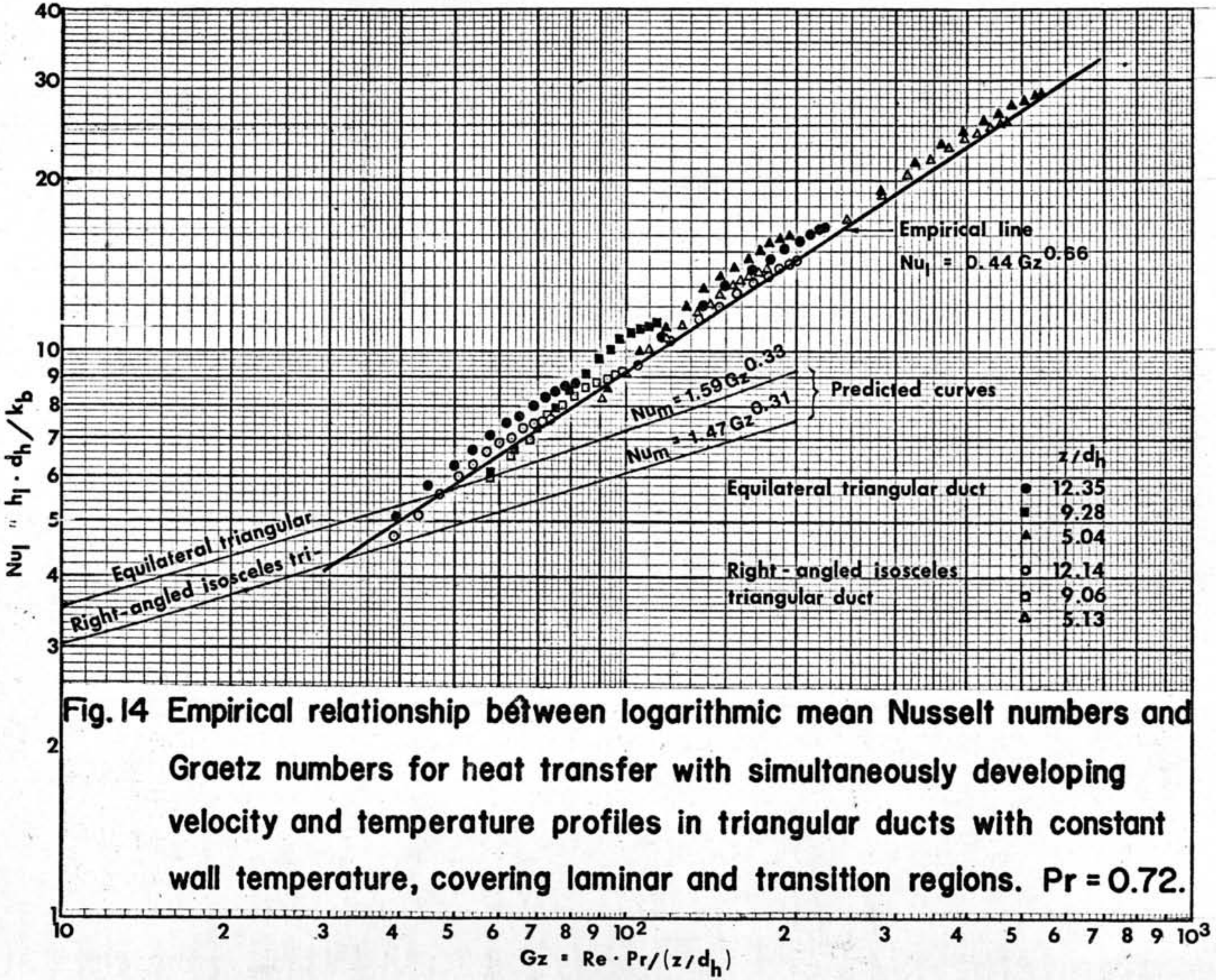

Fig. 14 Empirical relationship between logarithmic mean Nusselt numbers and Graetz numbers for heat transfer with simultaneously developing velocity and temperature profiles in triangular ducts with constant wall temperature, covering laminar and transition regions. Pr = 0.72.

drawn under the test results except for a few points which might assume to be experimental errors. To avoid over design of heat transfer equipment, the following empirical formula is recommended to be used for both cross sections instead of the numerical solutions

$$Nu_1 = 0.44 \ Gz^{0.66}$$

Such above relationship can be used as a lower limit in design with Graetz numbers varying from 30 to 550. For Graetz numbers under 30, the limiting value, obtained by theoretical analysis, is recommended to be used. In obtaining test data, however, the maximum possible errors were about 5 %. These errors should be taken into account when the empirical formula is used.

It has long been realized that laminar flow heat transfer is dependent on the duct geometry, flow inlet velocity profile, and the thermal boundary condition. These conditions are difficult to control in an experimental test programme, nevertheless the present work has effectively devoted to this task.

3.4 Suggestions for future work

(i) the present work can be extended to cover turbulent region;

(ii) very few experimental data exists for simultaneously developing velocity and temperature profiles in triangular ducts with constant heat input per unit length of the duct and more test results are still needed in order that an empirical formula may be established for the design of heat exchangers;

(iii) experimental data for laminar flow heat transfer with fully developed velocity profiles in triangular ducts with the thermal boundary conditions of constant wall temperature and constant heat input per unit length of the duct are also required;

(iv) it is of some interest to note that the numerical solutions obtained are not too satisfactory. Closer agreement between the experimental and analytical results may probably be obtained by employing a better numerical method and also taking into account the viscous and conduction terms in the z-direction. It will however be quite a task to do so.