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HEAT TRANSFER IN A HETEROGENEOUS DRAG REDUCTION SYSTEM

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Abstract—Heat transfer measurements are reported on heterogeneous and homogeneous drag reduction systems. The heterogeneous drag reduction is caused by injecting concentrated polymer solution into turbulent pipe flow. The heat transfer reduction in heterogeneous drag reduction proves to be equal to the reduction of the radial momentum transfer. The experimental evidence suggests that it may be possible to achieve considerable drag reduction in supply lines to heat exchangers without diminishing the heat transfer.

NOMENCLATURE

- Re, Reynolds number based on the physical properties of the solvent;
- c, polymer concentration averaged over the tube cross section calculated from the rates of flow of water and concentrated polymer solution;
- Δp, pressure drop;
- h, heat transfer coefficient based on the logarithmic-mean temperature-difference;
- % drag reduction is calculated from $100 \times (\Delta p_N - \Delta p_{dr})/\Delta p_N$;
- % heat transfer reduction is calculated from $100 \times (h_N - h_{dr})/h_N$.

Subscripts

- N, (Newtonian) is used for the measurements with pure water;
- dr, is used for drag reduction measurements.

INTRODUCTION

CONTINUOUS injection of concentrated polymer solution into turbulent pipe flow provides an effective and convenient mean to obtain large degrees of drag reduction, both at very low concentration levels and at relatively low Reynolds numbers. This kind of drag reduction is caused by the presence of a long polymer thread which is formed during the injection process [1, 2]. We shall call this kind of drag reduction, heterogeneous drag reduction and drag reduction caused by a homogeneous polymer solution, homogeneous drag reduction. Experimental evidence is available (a detailed set of measurements will appear in the doctorate thesis of the first author [2]) that the thread or thread-like structure is still intact after a length equivalent to 1000 tube diameters.

Literature [3] reports that in homogeneous drag reduction momentum and heat transfer are affected in different ways. A possible explanation might be that in homogeneous drag reduction the heat transfer is affected by the changed nature of the transition layer due to both the change in momentum transfer and the presence of polymer molecules in the viscous zone and the transition layer. In our previous article [1] we made the assumption that the polymer thread will affect first of all the large eddies. This means that the polymer thread will influence both layers via the decreased (radial) momentum transfer only. Now, if the analogy between heat and momentum transfer applies in this situation, the heat transfer will decrease like the momentum transfer.

HEAT TRANSFER MEASUREMENTS

The experimental set-up consists of a tube-in-shell heat-exchanger equipped with copper-constantan thermocouples to measure the inlet and outlet water and steam temperatures as well as the temperatures on the outside wall of the tube (Fig. 1). Uniform heating is obtained by condensing low pressure steam. The tube is fabricated from copper and has an o.d. of 10 mm and an i.d. of 8 mm. The heat exchanging section of the tube is 1·04 m long. A small injection tube is soldered into the entrance section and two pressure taps are fitted just before and after the heat-exchanging section. Tap water is pumped once-through by a centrifugal pump from a supply vessel. Flow rates are measured in the supply line with a Fischer–Porter turbine flow meter, pressure drop measurements are made with a Texas Instruments servo precision pressure gauge. We supply the concentrated polymer solution from a constant discharge displacement pump.

Introductory measurements gave reasonable agreement between the measured heat transfer and the heat transfer calculated from the accepted correlations. The average value of the three measured wall temperatures was used in calculating the heat transfer coefficient based on the logarithmic-mean temperature-difference. We measured the heat transfer together with the pressure drop at two Reynolds numbers as a function of the polymer concentration (averaged over the tube cross section), by injecting a 5000 ppm Separan solution (Separan AP 30 is a polyacrylamide made by Dow) at various injection rates. The results are given in Fig. 2. Considering the inherent spread in heat transfer measurements, the results are very satisfactory. Within the experimental error the heat transfer reduces like the radial momentum transfer. We also made some heat transfer

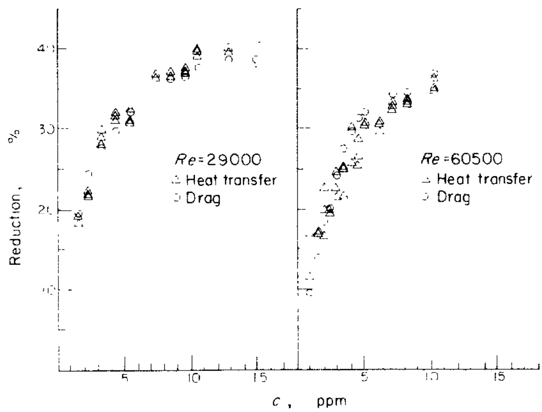

FIG. 2. Results from heat transfer and pressure drop measurements in a heterogeneous drag reduction system at two Reynolds numbers.

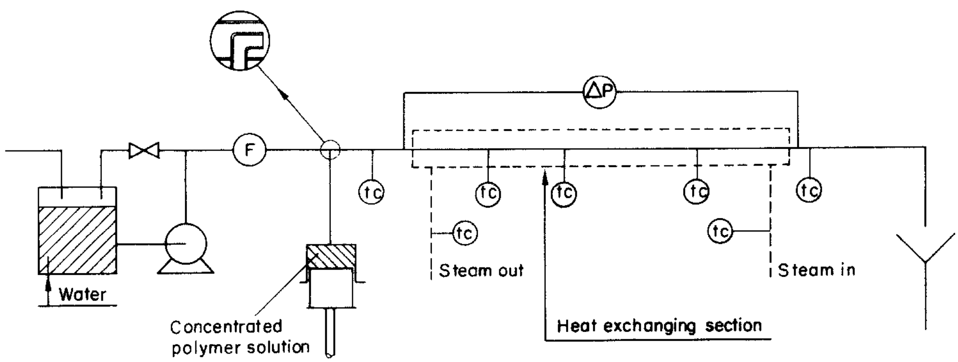

FIG. 1. Experimental set-up for heat transfer and pressure drop measurements on heterogeneous drag reduction.

measurements in homogeneous drag reduction. The results are given in Fig. 3. The heat transfer values tend to be a little lower than the drag reduction values.

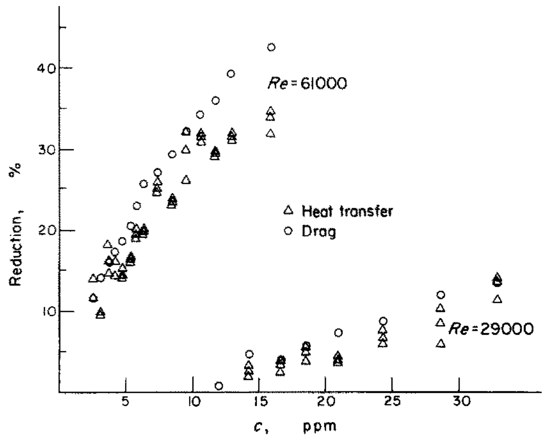

FIG. 3. Results from heat transfer and pressure drop measurements in a homogeneous drag reduction system at two Reynolds numbers.

DISCUSSION

Comparison of the homogeneous measurements with literature values is difficult since most of the reported measurements deal with much more concentrated solutions or with different kind of polymers than we used. However, in most of the reported measurements the reduction in heat transfer is larger than the drag reduction. The fact that the analogy between momentum and heat transfer in heterogeneous drag reduction appears to hold seems a strong indication of the correctness of our assumption that the boundary layer is influenced only via the decreased momentum transfer. However, extensive measurements are required to give conclusive evidence.

We have demonstrated [2] that transition of heterogeneous drag reduction into homogeneous drag reduction within one system is possible. Since at low Reynolds numbers the homogeneous drag reduction is negligible and, consequently, the heat transfer is unchanged, the injection technique may offer an interesting application in large heat transfer systems. If we take for example a heat transfer system consisting of a long supply line and a heat transfer system consisting of a long supply line and a heat transfer section, injection of concentrated polymer solution effectively reduces the pressure drop in the supply line; destroying the thread at the beginning of the heat transfer section can result into a non-drag reduction situation, which means non-reduced heat transfer.

ACKNOWLEDGEMENTS

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REFERENCES

1. J. VLEGGAAR and M. TELS, Drag reduction by polymer threads, *Chem. Engng Sci.* **28**, 965–968 (1973).
2. J. VLEGGAAR, Studies on drag reduction, Doctorate thesis University of Amsterdam, (January 1973).
3. G. K. PATTERSON *et al.*, *Ind. Engng Chem.* **61**, 22–30 (1969).

TRANSFERT THERMIQUE DANS UN SYSTEME HETEROGENE A REDUCTION DE TRAINEE

Résumé—On rapporte des mesures de transfert thermique sur des systèmes à réduction de trainée héterogènes et homogènes. La réduction de trainée hétérogène est due à l'injection dans l'écoulement turbulent en conduite d'une solution de polymère concentrée. La réduction du transfert thermique dans le cas d'une réduction de trainée hétérogène est égale à la réduction du transfert radial de quantité de mouvement. L'évidence expérimentale suggère qu'il serait possible d'obtenir une réduction considérable de trainée dans des canalisations des échangeurs de chaleur sans diminuer le transfert thermique.

WÄRMEÜBERGANG IN EINEM HETEROGENEN SYSTEM DER WIDERSTANDSVERMINDERUNG

Zusammenfassung—Es wird über Messungen des Wärmeübergangs an heterogenen und homogenen Systemen der Widerstandsverminderung berichtet. Die heterogene Widerstandsminderung wird durch Einspritzen einer konzentrierten Polymerlösung in eine turbulente Rohrströmung erreicht. Die Reduzierung des Wärmeübergangs bei heterogener Widerstandsminderung erweist sich genau so gross, wie die Reduzierung des radialen Impulsaustausches. Das Experiment ergibt die Möglichkeit, eine merkliche Widerstandsminderung in Zuführungsleitungen zu Wärmetauschern zu erreichen ohne Verminderung der übertragenen Wärme.

ПЕРЕНОС ТЕПЛА В ГЕТЕРОГЕННОЙ СИСТЕМЕ СНИЖЕНИЯ ЛОБОВОГО СОПРОТИВЛЕНИЯ

Аннотация—Сообщается о результатах исследования процесса переноса тепла в гетерогенных и гомогенных системах снижения лобового сопротивления. Гетерогенное снижение сопротивления достигается путем подачи концентрированного плоимерного раствора в турбулентный поток в трубе. Оказывается, что уменьшение переноса тепла при гетерогенном снижении сопротивления равно уменьшению радиального переноса количества движения. Экспериментальная проверка показала, что можно достичь значительного уменьшения сопротивления в подающих трубопроводах теплообменников, не снижая переноса тепла.