Comparison of oscillating flow characteristics of a metallic and a nonmetallic regenerators at high frequencies

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The oscillating flow characteristics of two regenerators are studied carefully under constant temperature condition in this paper. They are identical in geometrical dimension, but packed with stainless steel wire screens and nylon screens, respectively. The results show that cycle-averaged pressure drop in oscillating flow is 1.2-2 times higher than that in steady flow for a stainless steel regenerator, which is close to experimental results in previous work, while the oscillating flow pressure drop in a nylon wire screen regenerator is larger than that in a stainless steel regenerator at the same mass flow rate, which is three to five times higher than that in steady flow.

INTRODUCTION

An accurate prediction of the pressure drop across a regenerator subjected to an oscillating flow is crucially important for the design of a regenerative refrigerator. In recent years, some works [1,2,3,4] have been performed on the oscillating flow pressure-drop in the regenerator packed with stainless steel wire-screens under different experimental conditions. Some useful correlation equations between the friction factor f and Reynolds number Re were obtained. These experimental results are beneficial to the analysis and optimum design of an oscillating flow regenerator.

Recently, high frequency Stirling-type nonmagnetic and nonmetallic pulse tube cryocoolers for cooling Superconducting Quantum Interference Devices (SQUIDs) have been developed in our laboratory. The main components of the refrigerator are made of nonmagnetic and nonmetallic materials. The refrigeration performances of the pulse tube cryocooler have been studied [5,6]. The oscillating flow characteristics of the nonmetallic regenerator packed with nonmetallic materials have not yet been studied at present. The present work is an attempt at closing this gap in the database.

EXPERIMENTS

Regenerator samples

Two samples of regenerators are tested to measure oscillating flow characteristics. The regenerator 1# is packed with the stainless steel wire screens, which are widely used as popular regenerator materials for cryocoolers. The regenerator tube is also stainless steel tube. For the regenerator 2#, the regenerator tube is made of glassfilled epoxy, and the regenerator matrix consists of a stack of nylon screens, which are the same as the materials in the reference [5]. To be compared, the geometric dimension of the two regenerators is same. The regenerator has an inner diameter of 11 mm, a wall thickness of 1.25 mm and a length of 70 mm. Table 1 shows the specification of the two regenerators as mentioned above.

Table 1 Properties of sample regenerators

Regenerator NO.	Wire screen materials	Number of packed screens	Mesh No.	Wire diameter (mm)	Pitch (mm)	Porosity	Hydraulic Diameter (mm)
1#	Stainless steel	853	400	0.03	0.0635	0.63	0.051
2#	Nylon	672	350	0.0426	0.0726	0.54	0.050

Experimental configurations and methods

An experimental apparatus is designed for the measurement of the dynamic pressures and velocities of the oscillating flow gas at the two ends of the regenerator. The schematic diagram of the experimental apparatus can be found in the author's other research paper [7] in this conference. The instantaneous velocities of the oscillating gas flow are obtained by using a hot wire anemometer (DANTEC, 55P11). Two differential pressure transducers are used for the pressure measurements at two sides of the test section. The two heat exchangers are provided at the two ends to maintain a constant temperature through the whole test section. A linear compressor is used to generate oscillating pressure and flow at various frequencies (30-60 Hz).

RESULTS AND DISCUSSIONS

Pressure drop characteristics

Figure 1 shows amplitudes of pressure drop across the two regenerators for different amplitudes of mass flow rate ($m1_{max}$) at the inlet-end of the test section. Figure 2 presents the phase difference between the pressure drop and the mass flow rate. 1# (st.st.) in these figures denotes the regenerator packed with the stainless steel wire screens. The different amplitudes of mass flow rate are achieved by adjusting the input electric power of the compressor. The experimental data is obtained in operating frequencies of 30 Hz and 40 Hz and the mean pressure of 2.0 MPa. It is clear from Figures 1,2 that the pressure drop amplitude and the phase difference is proportional to the amplitude of mass flow rate, and the frequency has little effect on the pressure drop amplitude and the phase difference, and pressure drop always lags the mass flow rate at the inlet end. The pressure drop and phase difference across the stainless steel regenerator and the nonmetallic regenerator have obvious difference. The pressure drop and phase difference across the regenerator 2# with Nylon wire screens are larger than that across the regenerator 1# with stainless steel

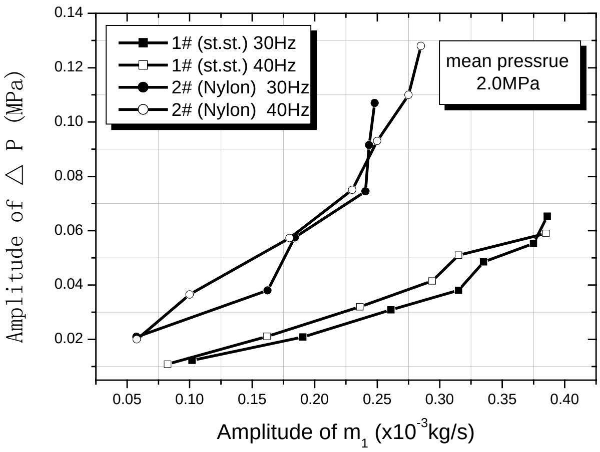

Figure 1 Pressure drop characteristics

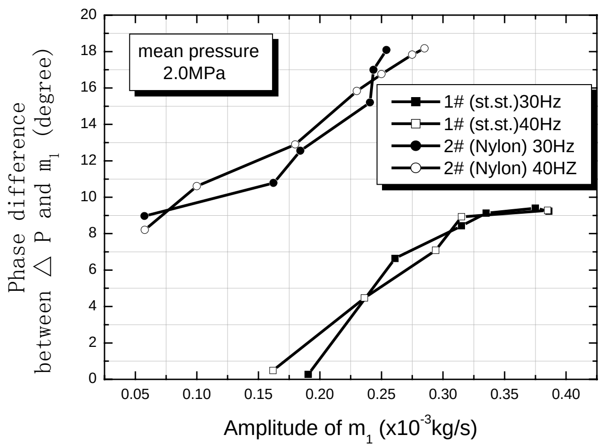

Figure 2 Phase shift characteristics

wire screens under the same mass flow rate. The results show that the oscillating flow pressure drop correlation equations and models about the stainless steel regenerator obtained in other works [1,2,3], are not applicable to the nonmetallic regenerator. The pressure drop characteristics in nonmetallic regenerator should be considered carefully.

<u>The comparison of the pressure drop under oscillating flow and steady flow</u>

We compared the oscillating flow pressure drop obtained from the experimental data with that from steady flow. The following correlation equation in steady flow is used for predicting the friction factor of a steady flow through a stack of woven screens [8]:

$$f_{st} = 33.6/\mathrm{Re}_l + 0.337 \qquad f_{st} = \Delta P_{st}/0.5\rho u^2 n \qquad u = u_0/\beta \tag{1}$$

where, ΔP_{st}: the steady flow pressure drop, u: the cross sectional mean flow velocity in the packed column, n: the number of screens, Re_l : Reynolds number defined as $\mathrm{Re}_f = l \cdot u / v$, l :mesh distance. Based on the experimental data, the cycle-averaged pressure drop of oscillating flow ($\Delta\overline{P}$) may be computed by the following equation:

$$\Delta\overline{P} = \frac{1}{N_i}\sum_{j=1}^{N_i}\sqrt{\Delta\tilde{P}_j^{\,2}} \tag{2}$$

with N_i being the total number of sampling intervals in one cycle and $\Delta\tilde{P}_j^{\,2}$ being the ensemble-averaged data at j^th^ interval. The compared results of pressure drop of oscillating flow and steady flow are shown in Figure 3. The ratio of cycle-averaged pressure drop to the steady flow pressure drop ($\Delta\overline{P}/\Delta P_{st}$) is also described in Figure 4. The results show that the oscillating flow pressure drop in a stainless steel regenerator is 1.2-2 times higher than that of the steady pressure drop at the same cross-sectional mean velocity. The consistent results have been obtained in other works [1,3], which ensured the reliability and creditability of our experimental results. It is found clearly that the oscillating flow pressure drop for a nonmetallic regenerator is three to five times higher than that of a steady flow at the same Reynolds number. The difference of the pressure drop and the phase shift between stainless steel regenerators and non-metallic regenerators subjected to oscillating flows is mainly determined from the

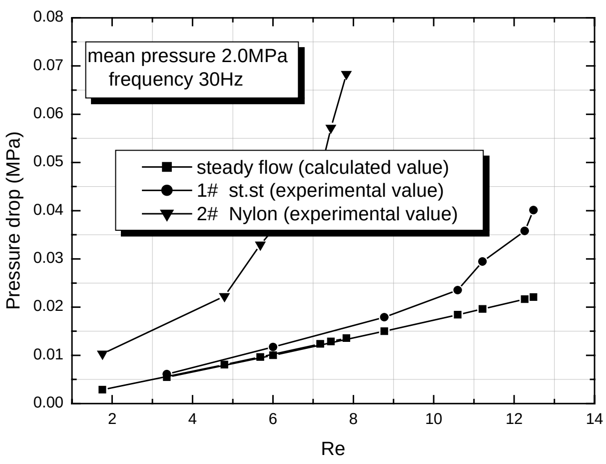

Figure 3 Comparison between the amplitude of the experimental pressure drop and the calculated value from the steady flow

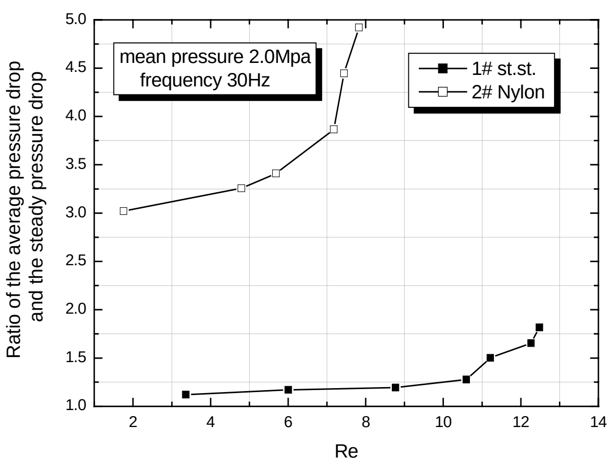

Figure 4 Ratio of the oscillating flow pressure drop to the steady flow pressure drop

characteristics of the wire screens. The effect mechanism of non-metallic wire screens on the oscillating flow characteristics is probably distinct from that of the stainless steel wire screens, which required to be considered carefully. The results in this paper should be useful for the optimum design of a non-metallic and non-magnetic pulse tube cooler.

CONCLUSIONS

An extensive set of experimental data has been collected to compare pressure drops for a metallic regenerator and a non-metallic regenerator at the same Reynolds number under high frequency oscillating flow. The experimental results of the metallic regenerator are identical in magnitude with conclusions obtained in previous works. However, averaged pressure drop in a nonmetallic regenerator packed with nylon wire screens is larger than that in a metallic regenerator packed with stainless steel wire screens at the same mass flow rate. The oscillating flow pressure drop in a nonmetallic regenerator is three to five times larger than that in a steady flow at the same Reynolds number.

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REFERENCES

1. Helvensteijn, B.P.M., Kashani, A. Spivak,A.L., et al., Pressure drop over regenerators in oscillating flow, CEC/ICMC 97, Portland, Oregon, USA (1997)
2. Zhao T S, Cheng, P. Oscillating pressure drops through a woven-screen packed column subjected to a cycle flow. Cryogenics (1996) 36 333-341
3. Yonglin Ju, Yan jiang and Yuan Zhou, Experimental study of the oscillating flow characteristics for a regenerator in a pulse tube cryocooler, Cryogenics (1998) 38 649-656
4. Sungryel Choi, Kwanwoo Nam, Sangkwon Jeong, Investigation on the pressure drop characteristics of cryocooler regenerators under oscillating flow and pulsating pressure conditions, Cryogenics (2004) 44 203-210
5. Dang, H.Z., Ju, Y.L., Liang, J.T., and Zhou Y., On the development of a non-metallic non-magnetic miniature pulse tube cooler, Cryocoolers 12 (2002) 799-804
6. Dang, H.Z., Ju, Y.L. and Zhou, Y, System design and measurement of a non-metallic non-magnetic miniature pulse tube cooler, Proceedings of ICEC 19 (2002) 423-426
7. Wang X-L., Zhao M-G., Cai J-H., Liang J-T., Zhou Y., Experimental analysis of the oscillating flow characteristics for high frequency regenerators, ICEC 20 (2004) (in press)
8. Miyabe, H，Takahashi S，Hamaguchi K. An approach to the design of stirling engine regenerator matrix using packs of wire gauzes, Proc.17th IECEC (1982) 1 1839-1844