Cfd Investigation of Heat Transfer Characteristics of Solar Air Heater with Benzene Shaped Roughness

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Abstract

In this paper study of benzene shape solar air heater in rectangular solar system is consists of absorber plate. Geometry for the benzene shaped rectangular channel has completed collection of the parameters. The rate of heat transfer is maintained by values of benzene shaped roughness in different positions of gaps between the arm of benzene shape roughness (g = 2, 3.8, and 5.6) and constant gap between each benzene G = 45 mm, and relative gap position G/e = 10.7 where e = 4.2 mm is height of benzene type roughness. These are the parameters of roughness which worked on hydraulic diameter of rectangular (Dh = 46.15 mm) under Reynolds number in range of 4000, 7000, 10000, 13000, 16000, 19000, and 22000 and The maximum efficiency of solar model η_{max} = 1.515072 examined for g = 3.8 mm, P/e = 14, P = 58.8 mm and Re = 22,000.

Keywords:benzene shaped ribs, CFD, Turbulent flow, Heat transfer enhancement.

1.0 Introduction

In the present day of manufacturing, where alternate source of energy is mainfocus of the researchers. In this context, solar energy is emerging as a prime source ofalternate energy with several areas of applications like solar water heating, cooking, e-rickshaws, solar heating building etc as reported by various researchers(1)(2)(3).Main objective of the solar energy is to reduce or minimize theuse of commercial energy for making a good balance of global warming on earth environment(4). Solar thermal energy is emerging area of research for the researchers. In order to enhance thermal efficiency of renewable energy various research have been done in past few decays.

To improve the thermal efficiency, several research has been done in order to develop the technology.Solar air heater (SAH) is one of the important technology that collects energy from sun and also reduces global warming developed through fuels and other toxics sources of energy(5). The most of thesolar air heaters are design and planted for several area of applications like thermal industries, energy power systems, heating applications parts, air and solar energy system etc(1)(3)(4). Many researchers used passive methods to obtain maximum thermal performance of solar air heater. J.L. Bhagoria et al. developedan experiment setup of rectangular solar air heater. In his reseach work higher thermal transfer for Reynolds number 3000 – 18,000, wedge type rib roughness, angle of attack ϕ = 8°, 10°, 12°, and 15°, e/ D = 0.015 – 0.033, maximum heat transfer at 10° was observed(6). The results reveals that in rectangular solar air heater heat transfer of wedge type rib solar air heater is maximum 2.4 and 5.3 times of smooth channel. R.P. Saini et. al. investigated heat transfer coefficient of SAH with artificial roughness. In their researchwork, heat transfer rate increased under some conditions of permeates of relative height roughness e/D_h = 0.018 – 0.037, relative pitch roughness p/e = 8 – 12, Re = 2000 – 12,000 and observed higher Nusselt number 7.58 times of smooth absorber plate at p/e = 10, Re = 12000, and e/D_h = 0.0379(7). Dhananjay Guptaet. al. performedan experiment on SAH 2640 mm long with transverse rib roughness. Calculation of maximize nusselt numer with decrement in friction factors at channel aspect ratio = 6.8 to 11.5, p/e = 0.018 – 0.052 was done with the help of renolds number in the range of 3000 to 18000 (8). . Alok Chaube et al. examined heat transfer characteristics of artificial roughness mounted on smooth solar air heater. The paper presents the value of turbulence model like shear stress transport k-w with variations of Reynolds number in range of 3,000 to 20,000. The results found in 2D and 3D modeling analysis with different computational time(9). Atul Lanjewar et al. worked on heat transfer and friction characteristics of w-shape rib solar air heater and found maximum improvement of 2.36 and 2.01 times of Nusselt number and friction factor of w-shaped SAH respectively with smooth channel at 60°angle of attack of rib roughness(10). P. Ganesh Kumar et al. have been published a research article based on combined techniques of solar air and water energy. Incerese in Nusselt number and Reynolds number with decreased friction factors was reported in their research work (11). Moreover, research work has been carried out in smooth SAH to increase heat transfer coefficient using different artificial roughness by M. K.Sahu et al. (12). On other hand numerical investigation of thermal hydraulic performance of SAH with broken arc roughness was calculated by R.S. Gill et. al.(13)and found maximum thermal efficiency is 1.94 at relative gap position d/w = 0.65, Reynolds number of 16,000 and broken arc rib.

Based on the past experience of the researchers, solar air heaters (SAH) are the most frequent and least expensive solar energy collectors because of their simple design. This device uses solar sunlight to generate thermal energy. In addition to space heating and drying timber, solar air heaters can be used to cure industrial products and cure/dry concrete and clay building components. The absorber plate, the rear plate, and some kind of insulation are the basic three constituents of this particular solar air heater.Due to the intricacy of the flow pattern and computational restrictions, only a few CFD investigations have been done so far to evaluate the performance of solar air heaters. CFD applications are being utilized to carry out essential research in the field of solar air heaters, thanks to advancements in computer, hardware, and numerical methods. The choosing of a turbulence model is one of the most difficult aspects of designing a solar air heater using CFD. In a CFD simulation, selecting an appropriate turbulence model is not an easy option. In this study, the optimal turbulence model for the construction of a solar air heater is also investigated using CFD.

2.0 Experimental setup

The prime objective of the design model ofsolar air heater is to achieve the maximum percentage of heat transfer and demonstrate higher efficiency. In the present investigation Ansys model of solar air heater has been developed and simulated for higher efficiencywith maximum heat transfer. The first step of the designing phase is to calculate the parameters of smooth duct and draw the design in Ansys software. Figure 1 represents the design of rectangular channel section which was related to the parameters. To create a smooth rectangular channel for air flow duct has been designed with cross-sectional dimension of 2400 x 300 x 25 mm. during the experimental iterations,large number of variations was applied.Initially in the first step discrete benzene shape roughness with constant gap between each benzene was taken to start the experimentation. Other parametric changes withcenter section and pitch space of P = 42, 51.6, 58.8, and 67.2 mm are placed between roughness. Relative pitch roughness p/e = 10, 12, 14, and 16 where e = 4.2 mm height of roughness,and gap (g = 2, 3.8, and 5.6 mm) used to move fluid flow around surface and change laminar flow into turbulent flow for achieving the maximum heat transfer rate and thermal performance. The complete design model is analysis with *RNG* K-e standard model under situation of Reynolds number 4000-22000. *RNG k-e* model is solution function of viscous fluid particles and calculate the effect of all types of turbulence scale of fluid particles motions.

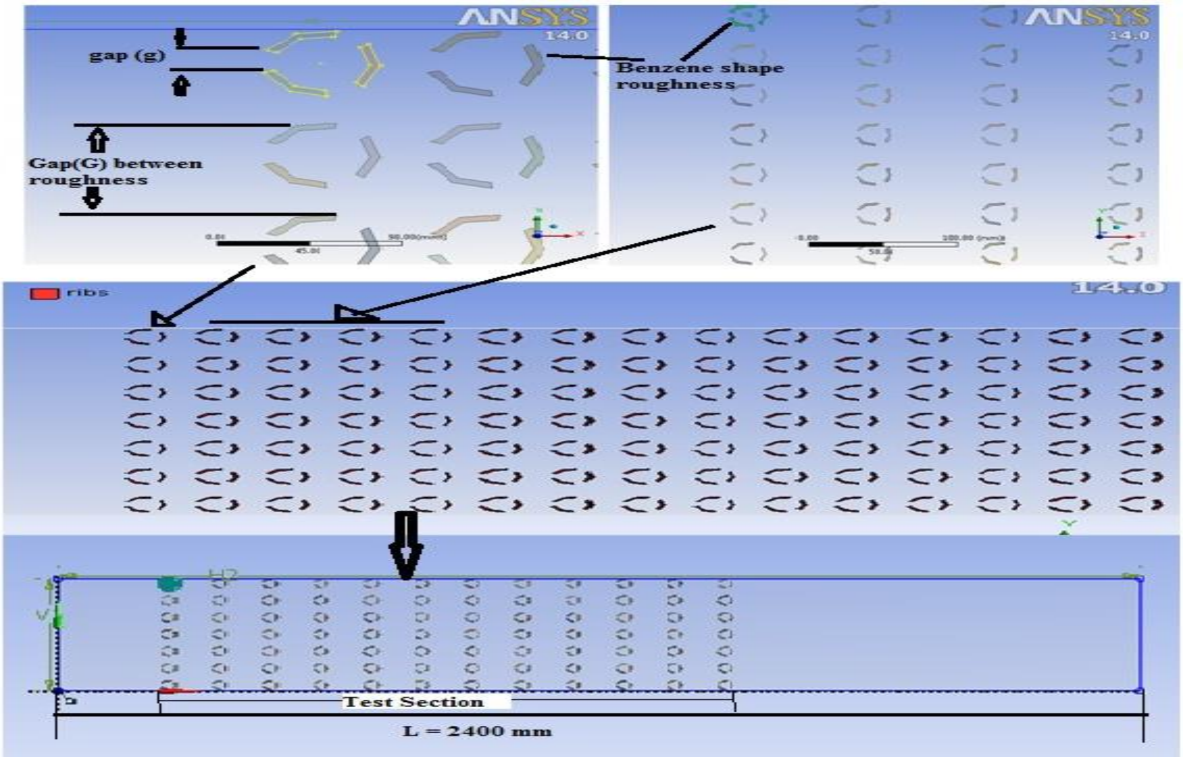

Figure 1: Geometry of the Rectangular Solar air heater with rib roughness.

2.1 *Mesh generation of the rectangular duct*

Meshing contains different types of grids which are the result ofvariousintersecting lines.The grids are calculated by numbering nodes and cells. For best heat transfer rate, we apply meshing method.Mesh generation enhances the smoothness of the model by refining the grain size which is based on changing of cells and nodes. The meshing of design model is observed at face sizing 0.003 m as shown in figure 2.

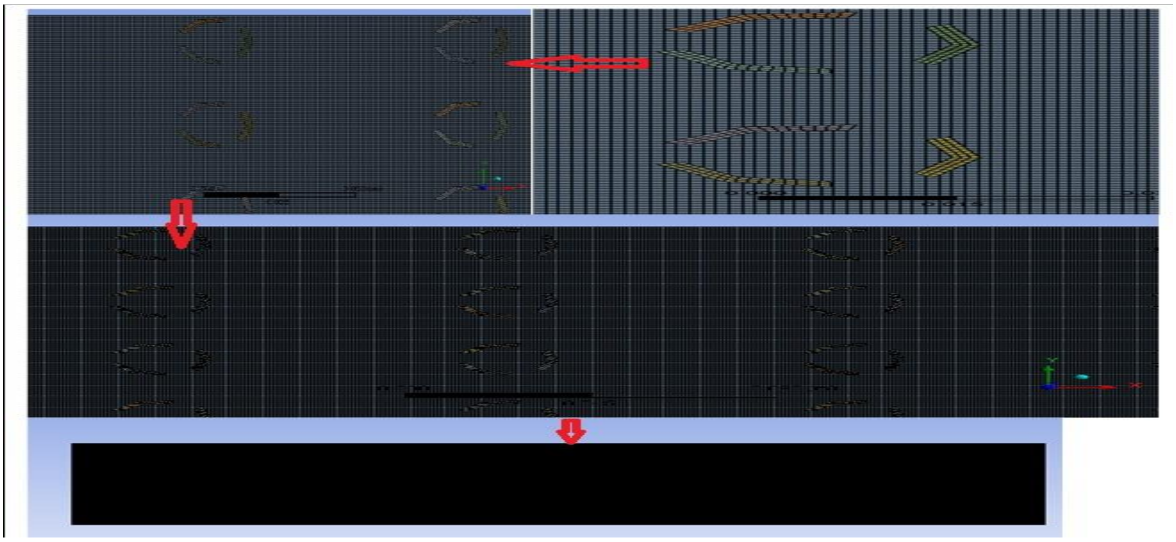

Figure 2 shows analyzed meshing of design Y-shaped model.

3.0 Data Reduction and calculations

The design of benzene shaped solar air heater has a motive to increase or improvement the thermal performance between the absorber duct and working fluid because we have already discussed about the thermal efficiency of solar air heater which was found low and many obstacles roughness used to improve the thermal efficiency. The results like heat transfer characteristics, friction factors coefficients, turbulent kinetic energy, pressure drop, temperature gradient, and conversion of energy are improved and investigated with the help of ANSYS FLUENT workbench. Firstly the results are determined from Smooth duct and then compared with the roughened solar air heater because the comparison explain rise amount of heat energy. These results depend upon the variation of the inserted parts benzene shaped rib roughness which was mounted on the smooth solar duct.

3.1 Mathematical data reduction used in SAH

In this section, Mathematical equations used to solve turbulence model based velocity of fluid which strikes upon mounted roughness. The given equations are general mathematical equations and used for enhancing results with variations of parameters by Ansys fluent tools.

Continuity equation $$\frac{\partial \rho}{\partial t} + \Delta(\rho \vec{v}) = S_m \quad (1)$$

$$\frac{\partial \rho}{\partial t} + \frac{\partial(\rho u_i)}{\partial x_i} = 0 \quad (2)$$

Momentum equations

$$\frac{\partial(\rho u_i)}{\partial t} + \frac{\partial(\rho u_i u_j)}{\partial x_j} = -\frac{\partial p}{\partial x_i} + \frac{\partial}{x_j}\left[\mu\left(\frac{\partial u_i}{\partial x_j} + \frac{\partial u_j}{\partial x_i} - \frac{2}{3}\delta i_{ij}\frac{du_l}{dx_l}\right)\right] + \frac{\partial(-\rho\overline{u_i' u_j'})}{\partial x_j} \quad (3)$$

and standard equation for k and ε

$$\frac{\partial(\rho k)}{\partial t} + \frac{\partial(\rho k u_i)}{\partial x_i} = \frac{\partial}{\partial x_j}\left[\left(\mu + \frac{\mu_t}{\sigma_k}\right)\frac{\partial k}{\partial x_j}\right] + G_k + G_b - \rho\epsilon - Y_M + S_k (4)$$

Energy equation

$$\frac{\partial(\rho\epsilon)}{\partial t}+\frac{\partial(\rho\epsilon u_i)}{\partial x_i}=\frac{\partial}{\partial x_j}\left[\left(\mu+\frac{\mu_t}{\sigma_\epsilon}\right)\frac{\partial\epsilon}{\partial x_j}\right]+C_{1\epsilon}\frac{\epsilon}{k}(G_k+C_{3\epsilon}G_b)-C_{2\epsilon}\rho\frac{\epsilon^2}{k}+S_\epsilon \quad (5)$$

where $\mu_t = \rho C_\mu \frac{k^2}{\epsilon}$, $C_{1\varepsilon}$ = 1.42, $C_{2\varepsilon}$ = 1.68 $C_{3\varepsilon}$ = 1.3 σ_k = 1.0, σ_ε = 1.2 and C_μ = 0.0845.

$Re = \frac{\rho v d}{\mu}$ for input velocity of fluid (6)

$Nu = \frac{hD}{k}$ and Nu = $0.023(Re)^{0.8}(Pr)^{0.4}$ for standard equation of dittus-boelter correlation (7)

$fr = 0.3164\ Re^{-0.25}$ blasius eq. for friction factor [18] (8)

3.2 Validation of dataof rectangular channel with Dittus-boelter equation

The figure 3 shows the validation of results of smooth channel and dittus – boelter equation and this equation is a standard equation of heat transfer rate from convection to conduction and also most valuable used for the transmission of working fluid from laminar to turbulent flow and extensively used for turbulent flow to maintain or define the effective design with perfect condition. Figure3 shows the comparison between the dittus-boelter equation and smooth rectangular duct. In figure 3 can see that heat transfer rate increased with increasing Reynolds number so heat transfer rate of depends upon Reynolds number.

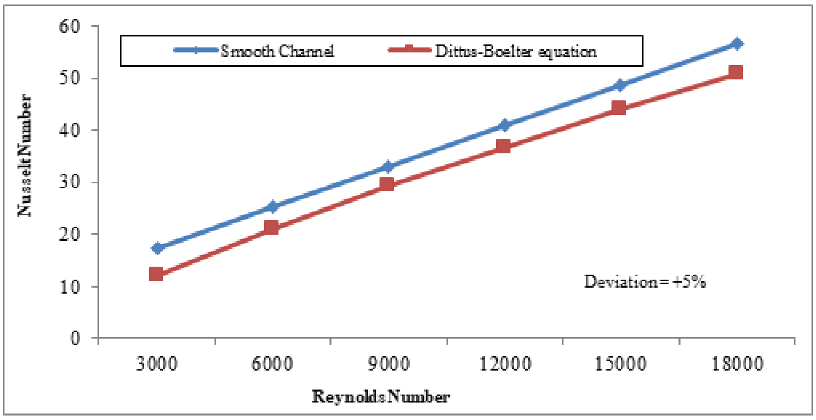

Figure 3. Variations in heat transfer rate of standard Dittus-Boelterequation and smooth channel.

4.0 Results and Discussion

4.1 Effects of Benzene shape roughness on SAH

Numerical analysis of Benzene shaped model is decrypted which has been calculated by using of Ansys software. There are lots of effects of mounted Benzene shaped rib on the smooth solar air heater due to number of variations in Benzene shaped rib roughness. The Benzene shape roughness divided into Reynolds number grew, the velocity grew for Re = 4000 - 22000 at pitch space P = 58.8 mm when the gap is taken between each arm of roughness used in the solar rectangular duct g = 3.8 mm and G = 45 mm respectively. The maximum velocity is obtained 16.68 m/s at maximum Reynolds number Re = 22000 at this velocity also obtained large circular zone of air that increased the heat energy as shown in figure 4.The effects of roughness on heat transfer rate are nominated as Nusselt numbers, Friction factors, and velocity variations on the wall.The velocity contour is used for find out the average velocity, discharge and mass flow rate around the whole solar air heater and shows a curve of constant value of air properties at any instant in time. In figure 5 the maximum result calculated by the Ansys because the gap (g = 3.8 mm) in the benzene shape roughness is more effective to circulate the air with high turbulent velocity. All valuable the data are validated to those of a flat channel. In figure 6. observed minimum friction results fr = 0.02945471, 0.041452325, and 0.039244565 for g = 2, 3.8, and 5.6 mm respectively for P/e = 16. These results are minimum at maximum value of Reynolds number (Re = 22000)

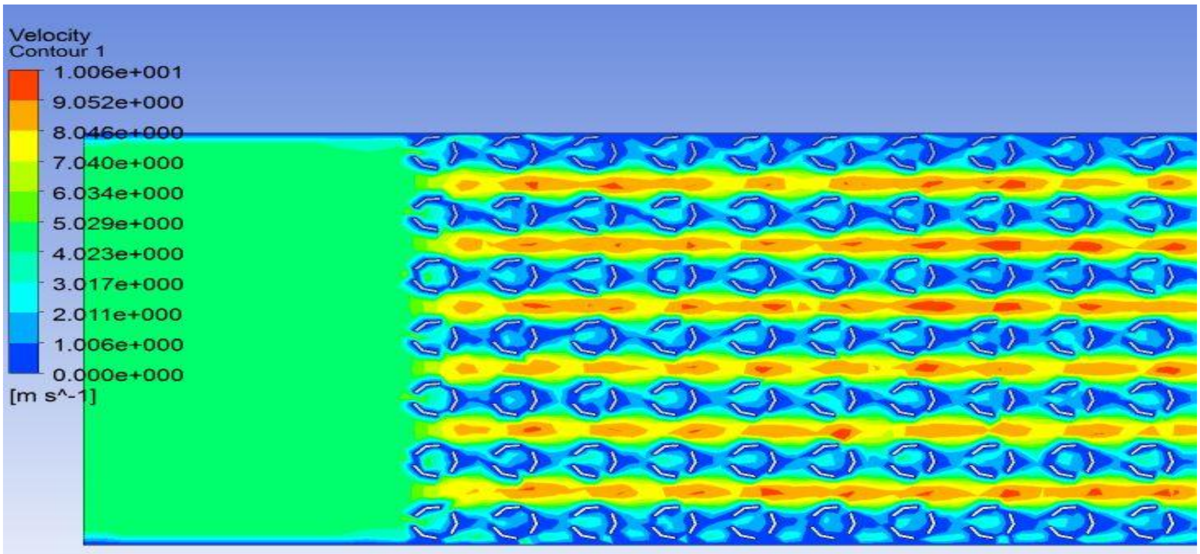

Figure 4 Increment in velocity of fluid at p = 58.8 mm.

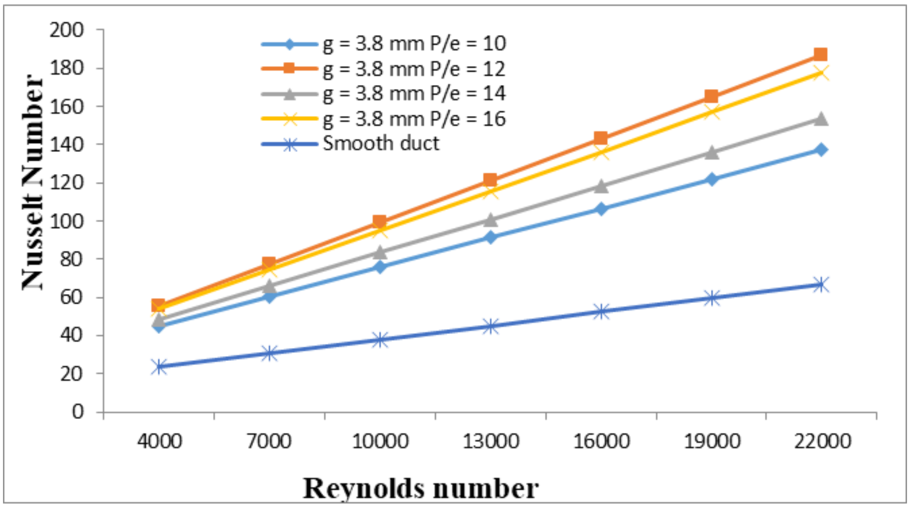

Fig. 5 explains Nusselts number increased with increasing Reynolds number at g = 3.8 mm.

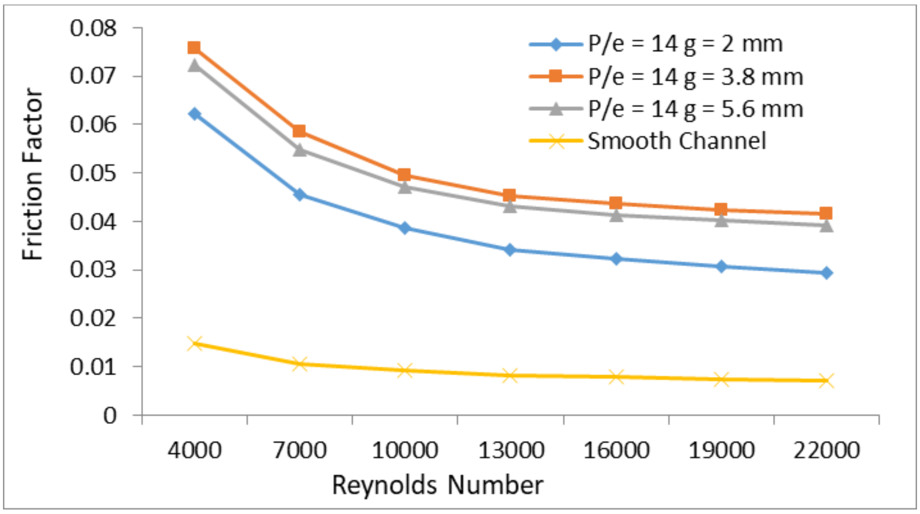

Fig. 6. A comparison between decrement of friction factors.

5.0 Conclusion

This chapter represents the conclusion of the new technique of Benzene shape roughened solar air heater. The complete solar model was designed and overall thermal efficiency was calculated by CFD analysis. This program specially worked for fluid related problems to make all values of design model easier. In the model, there are two roughness were used as Benzene shaped with gap and Benzene shaped without gap. The variations of roughness were specially used for increasing the life of solar air heater with heat transfer rate. All results are calculated with variations are angles of Benzene shaped.

According to CFD analysis, main results are examined as follows.

1. Nusselt numbershave higher increment as well as Friction factors decrement with increasing in Reynolds number Re, relative roughness pitch *P/e*,and gap of Benzene shaped rib roughness (*g*) mounted on smooth plate. The heat transfer of Benzene shaped with gap (*G*) is 4.7557 and 1.0548 times maximum of smooth channel and Benzene shaped without gap. When no gap (*G*) is taken in Benzene shape rib roughness, then maximum heat transfer rate is 4.50815 times of smooth rectangular plate.

2. The highest thermal performance was obtained *THPP* = 1.515072 and Benzene rib with gap (g = 3.8 mm) and Benzene shaped without gap respectively at Reynolds number *Re* = 22000, *P/e* = 14.