INSTITUTO FEDERAL DE
EDUCAÇÃO, CIÊNCIA E TECNOLOGIA
SÃO PAULO
Campus Catanduva

Range of Porosity in Typical Regenerators for an Appropriate Balance Between Heat Exchange and Pressure Drop

Paulo Cesar Mioralli, Marcelo Augusto Botan da Silva, Elson Avallone, Paulo Henrique Palota, Pablo Sampaio Gomes Natividade

Federal Institute of Education, Science and Technology of São Paulo – IFSP Campus Catanduva-SP, Brazil

I. Introduction - Heat transfer analysis in a rotary regenerator is performed. The matrix porosity of the exchanger directly influences the amount of heat transfer between the circulating gases in the equipment and the matrix plates. Studies with analysis from the matrix porosity of the rotary regenerator[1-5] are less commonly found in the literature. From the pre-established flow rate values in the regenerator, the total heat transfer and the pressure drop are calculated for different matrix porosity values. The results show that there is a range of matrix porosity values in which there is a good relationship between the total heat transfer and the pressure drop in the equipment.

II. Theoretical Analysis and Procedure - The schematic diagram of the rotary regenerator is show in Fig. 1. Two gas streams are introduced counterflow-wise through the parallel ducts of regenerator. Cold gas is injected inside one duct and hot gas inside the other. The porous matrix, that stores energy, continuously rotates through these parallel ducts. The matrix receives heat from the hot gas on one side and transfers this energy to the cold gas on the other side. The matrix channels were assumed smooth. The fluid velocity was considered constant inside each channel.

The hydrodynamic and thermal analysis are performed for each gas stream. The pressure drop in the matrix ducts and the convective heat transfer coefficient are obtained from correlations for Darcy friction factor and Nusselt number. Correlations for smooth ducts with circular cross-sectional area were used based on the hydraulic diameter of matrix ducts for laminar flow regime. The correlations take into account hydrodynamically fully developed flow with thermal entrance length and constant wall temperature boundary condition. The total heat transfer is obtained using the Effectiveness-NTU method specific to rotary regenerators[1].

The fluid properties[2] are obtained at the average temperature of each gas stream. The matrix properties of the rotary regenerator are assumed constant. The AISI 1010 low alloy carbon steel and the 2024-T6 aluminum alloy materials are considered for the matrix in this work. The Table 1 shows the matrix properties used for the simulated regenerator cases, where c_m and ρ_m are the specific heat and the density of matrix, respectively. A computer program written in *C* programming language was developed for the simulation of rotary regenerator. The *Dev-C++* software was used for compilation and recording results. Three typical sizes of regenerators were simulated: small, medium-sized and large.

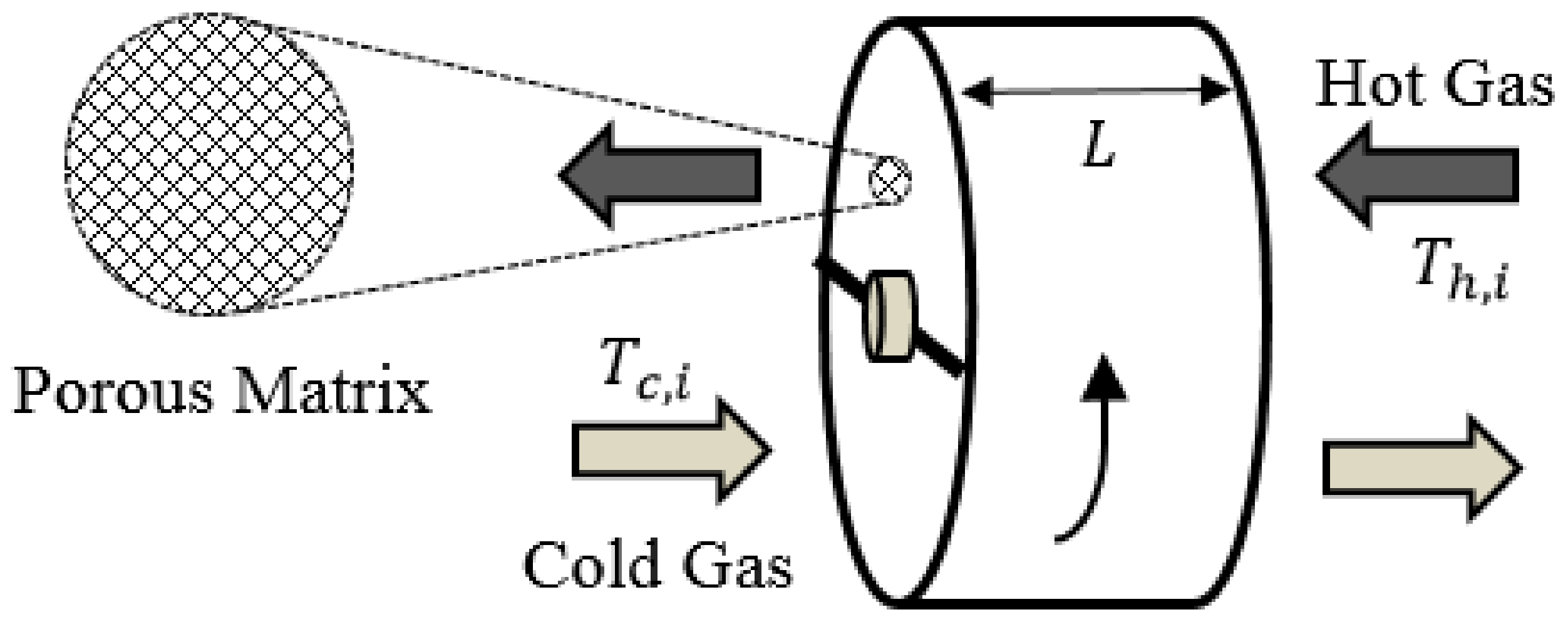


Figure 1. Rotary Regenerator.

Table 1. Matrix Properties.

	c_m (J/kg K)	ρ_m (kg/m^3)
2024-T6 Aluminum	875	2,770
AISI 1010 Steel	434	7,832

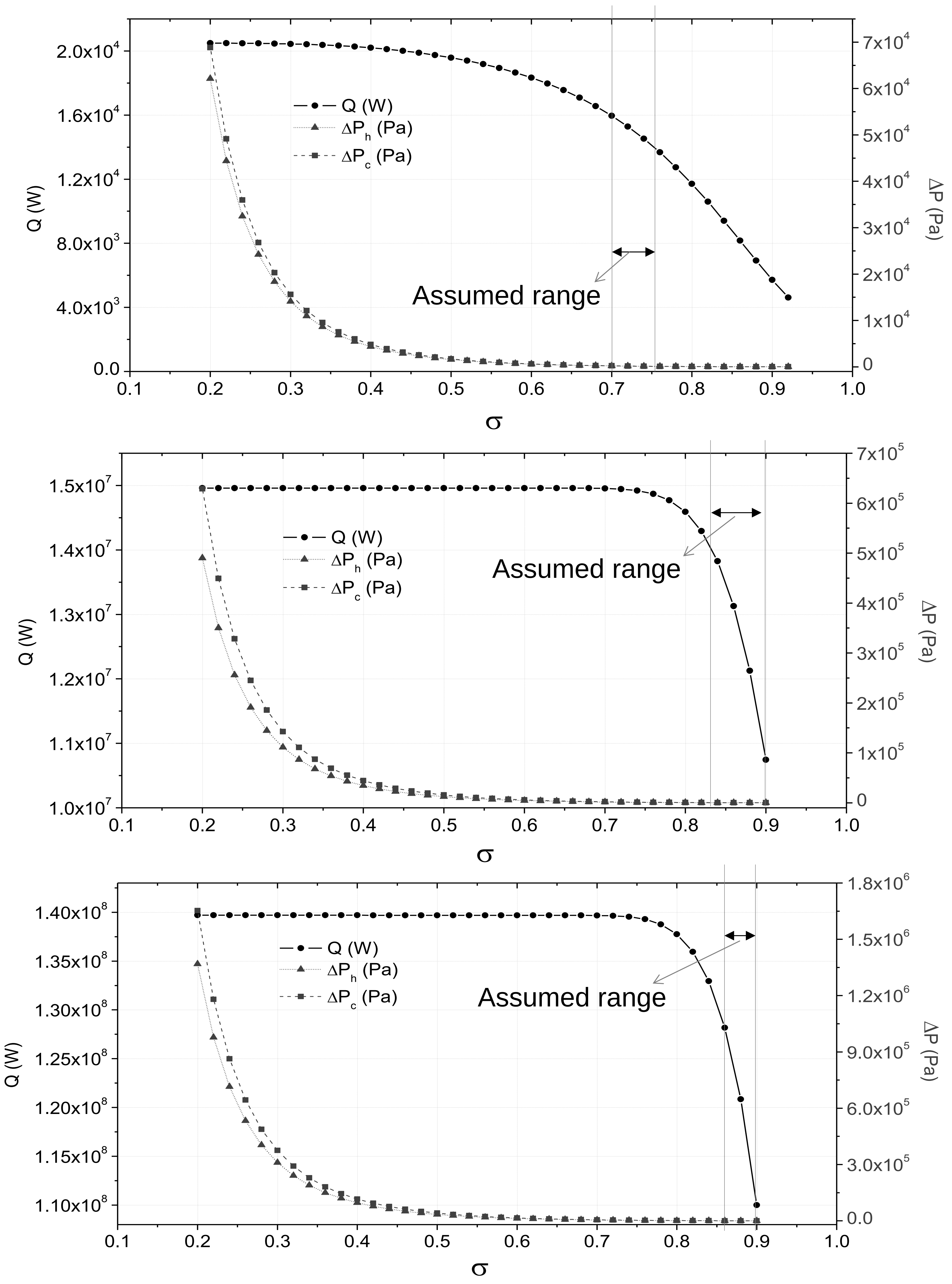
Table 2. Operational conditions: Input data for computer program of typical rotary regenerators.

Regenerator	L (m)	e (m)	D (m)	n (rpm)	Inlet Temperature (° C)		Mass Flow Rate (kg/s)	
					$T_{h,i}$	$T_{c,i}$	$\dot{m}_{h,i}$	$\dot{m}_{c,i}$
Small	0.2	0.00035	0.7	8	50	20	0.68	0.76
Medium-sized	1.5	0.00050	6.0	3	450	80	39.00	62.00
Large	3.5	0.00060	15.0	2	600	150	292.50	411.30

III. Results and Discussion - The input data of the computer program developed for the simulations are listed in Table 2. Figs. 2, 3 and 4 show the total heat transfer and the pressure drop of both gas streams as a function of the matrix porosity for the small, medium-sized and large regenerator, respectively. It is observed that the pressure drop for both gas streams behaves similarly. There is a decrease in the pressure drop values as the porosity increases. For the three simulated cases, the range of porosity can be assumed for an appropriate balance between heat exchange and pressure drop in the regenerators ,considering the typical pressure drop values[3] for the tested regenerators and the decrease of heat transfer less than 40% when compared to their highest values (for $\sigma = 0.2$). In Fig. 2, the range $0.70 \leq \sigma \leq 0.76$ can be assumed, with the percentages of the decrease in heat transfer between 22% and 33% when compared to the highest value $Q \approx 20.5\ kW$ for $\sigma = 0.2$. In Fig. 3, the range $0.83 \leq \sigma \leq 0.90$ can be assumed. This range taking into account the decrease of heat transfer in the equipment less than 40% when compared to the heat transfer $(Q \approx 15\ MW)$ obtained for $\sigma = 0.2$. In Fig. 4, the range $0.86 \leq \sigma \leq 0.90$ can be assumed. This range taking into account the decrease of heat transfer in the equipment less than 40% when compared to the heat transfer $(Q \approx 0.14\ GW)$ obtained for $\sigma = 0.2$. The percentages of the decrease in the pressure drops values are greater than 99% for the assumed porosity range when compared to the highest porosity values for both streams with $\sigma = 0.2$ for the three tested cases.

A simultaneous analysis of Figs. 2, 3 and 4 shows that the assumed ranges of porosity values, for an appropriate balance between heat exchange and pressure drop, moves to the right on the abscissa axis as the dimensions and typical operational conditions of the rotary regenerators increase. It is also observed that the assumed porosity ranges for the three simulated cases of regenerator are relatively narrow.

IV. Conclusion - For each simulated typical regenerator, a range of porosity values for an appropriate balance between heat exchange and pressure drop was chosen. The results showed that the selected porosity ranges are narrow and moves to the right on the abscissa axis as the dimensions and typical operational conditions of the rotary regenerators increase. Nonetheless, the extent of porosity range may vary according to the desired limits for the heat transfer and the pressure drop of gas streams. Additionally, the obtained results can contribute to the definition of operational conditions of rotary regenerators in search of better performance.



Figures 2, 3 and 4. Heat transfer and pressure drop versus porosity for small, medium-sized and large regenerator, respectively.

V. References

[1] P. C. Mioralli, M. M. Ganzarolli, “Temperature Distribution in a Rotary Heat Exchanger”, Proceedings of COBEM, 2005, paper code 0356.
[2] P. C. Mioralli, M. M. Ganzarolli, “Influence of Porosity in a Rotary Regenerator Performance”, Proceedings of ENCIT, 2006, paper code CIT06-0549 (in Portuguese).
[3] P. C. Mioralli, M. M. Ganzarolli, “Optimal Porosity of a Rotary Regenerator with Fixed Pressure Drop”, Proceedings of ECOS, 2007, pp. 1307-1314.
[4] P. C. Mioralli, M. M. Ganzarolli, “Thermal Optimization of a Rotary Regenerator with Fixed Pressure Drop”, Proceedings of ENCIT, 2008, paper code 7-5302.
[5] P. C. Mioralli, M. M. Ganzarolli, “Thermal analysis of a rotary regenerator with fixed pressure drop or fixed pumping power”, Applied Thermal Engineering, vol. 52, 2013, pp. 187-197.
[6] W. M. Kays, A. L. London, “Compact Heat Exchangers”, McGraw-Hill, 3rd, New York, U.S.A, 1964.
[7] F. M. White, “Viscous Fluid Flow”, McGraw-Hill, New York, U.S.A, 1974.
[8] P. C. Mioralli, “Heat Transfer in a Rotary Regenerator with Fixed Pressure Drop”, Doctoral thesis, FEM/UNICAMP, Campinas-SP, Brazil, 2009 (in Portuguese).