Thermal Analysis of Rotary Regenerator from Changes in Mass Flow Rate

Guilherme Henrique da Cunha, Paulo Cesar Mioralli, Elson Avallone,
Paulo Henrique Palota, Murilo Secchieri de Carvalho

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

I. Introduction - Thermal analysis of typical rotary regenerators under the laminar flow regime is computationally performed from changes in mass flow rate of gas streams. High mass flow rates may imply good thermal exchange in the regenerator, however, they can result in high pressure drop which negatively impacts the pumping power cost. On the other hand, if the mass flow rate is considerably low, significant contamination between the gases can occur from the fluid carryover leakage. The ratio of residence time t_{res} of flow on each side of the equipment to the time t_0 required for a complete matrix rotation is calculated for the regenerators, representing the fluid carryover leakage. The total heat transfer in the regenerator and the pressure drop in each gas stream are also obtained for each simulated case. Conditions for acceptable fluid carryover leakage, suitable pressure drop and good heat transfer in the regenerator were assumed based on literature and practical observations. A mass flow rate range that associates these conditions was chosen as good operating situations for each simulated equipment.

II. Problem Description - The schematic diagram of the rotary regenerator is show in Fig. 1. The mass flow rate values were considered to be the same for both streams of each regenerator. 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. The total heat transfer is obtained using the Effectiveness-NTU method specific to rotary regenerators[1]. The fluid properties[2,3] are obtained at the average temperature of each gas stream. The matrix properties of the rotary regenerator are assumed constant. A computer program written in *C* programming language was developed for the simulation of rotary regenerator. Three typical sizes of regenerators were simulated: small, medium-sized and large. The condition $(t_{res}/t_0) \leq 0.015$ was used for acceptable fluid carryover leakage. The values of pressure drop up to 200, 350 and 600 Pa were considered as suitable[4] for the small, medium-sized and large regenerators, respectively.

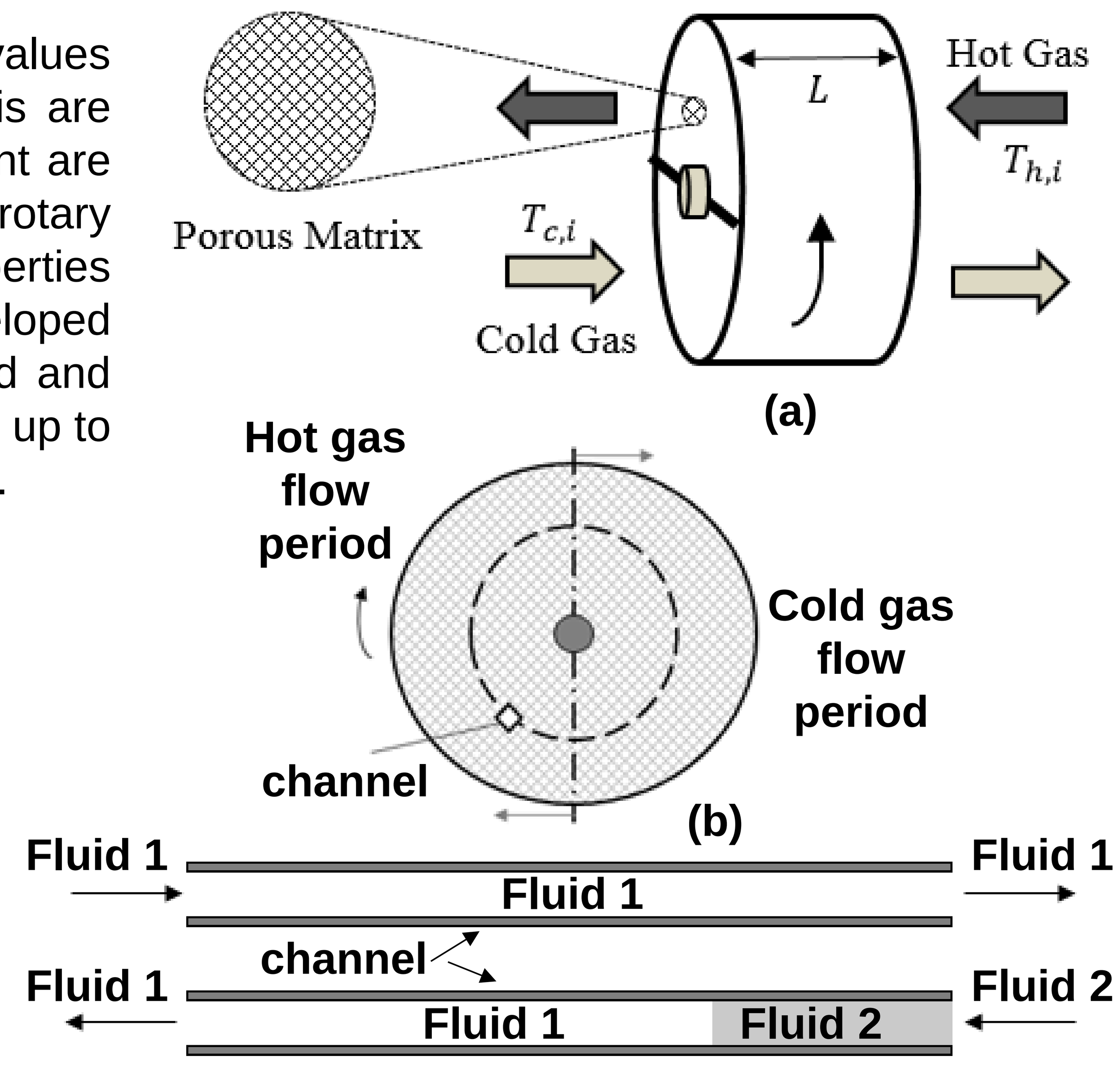

Figure 1. The schematic diagram of the rotary regenerator: (a) Operation; (b) Fluid carryover leakage.

III. Results and Discussion - The input data of the computer program developed for the simulations are listed in Table 1. Fig. 2 shows two results for each simulated regenerator. The first graph shows the total heat transfer as a function of the mass flow rate. The second graph shows two results simultaneously: the ratio (t_{res}/t_0) for both streams of the regenerator as a function of the mass flow rate (vertical bars) and also the pressure drop ΔP for both streams of the equipment as a function of the mass flow rate (continuous lines). Fig. 2 exhibits a similar behavior for the three typical rotary regenerators. The total heat transfer increases as the mass flow rate increases. The pressure drop increases linearly as the mass flow rate increases. The ratio (t_{res}/t_0) decreases as the mass flow rate increases. Based on the condition $(t_{res}/t_0) \leq 0.015$ for acceptable fluid carryover leakage and the limit pressure drop values considered as suitable for the simulated regenerators, a mass flow rate range was chosen, that provide: acceptable fluid carryover; suitable pressure drop, whose values approximate those observed in typical regenerators operating close to optimal conditions and; good heat transfer rate, whose value is limited to up to about 20% less than the maximum possible value considering laminar flow regime.

From the discussion above and the analysis of Fig. 2, the ranges $1.1 \leq \dot{m} \leq 1.8$ kg/s, $45 \leq \dot{m} \leq 70$ kg/s and $330 \leq \dot{m} \leq 430$ kg/s can be chosen as suitable for good heat transfer rate, pressure drop close to optimal operating conditions and acceptable fluid carryover leakage in the small, medium-sized and large rotary regenerator.

Table 1. Operating conditions: Input data for computer program of typical rotary regenerators.

Regenerator	Matrix porosity	Matrix length (m)	Matrix wall thickness (m)	Matrix diameter (m)	Matrix rotation (rpm)	Mass flow rate (kg/s)	Inlet Temperature (° C)	
							$T_{h,i}$	$T_{c,i}$
Small	0.83	0.2	0.00035	0.7	8	0.2 - 2.0	50	20
Medium-sized	0.90	1.5	0.00050	6.0	3	10 - 100	450	80
Large	0.90	3.5	0.00060	15.0	2	80 - 530	600	150

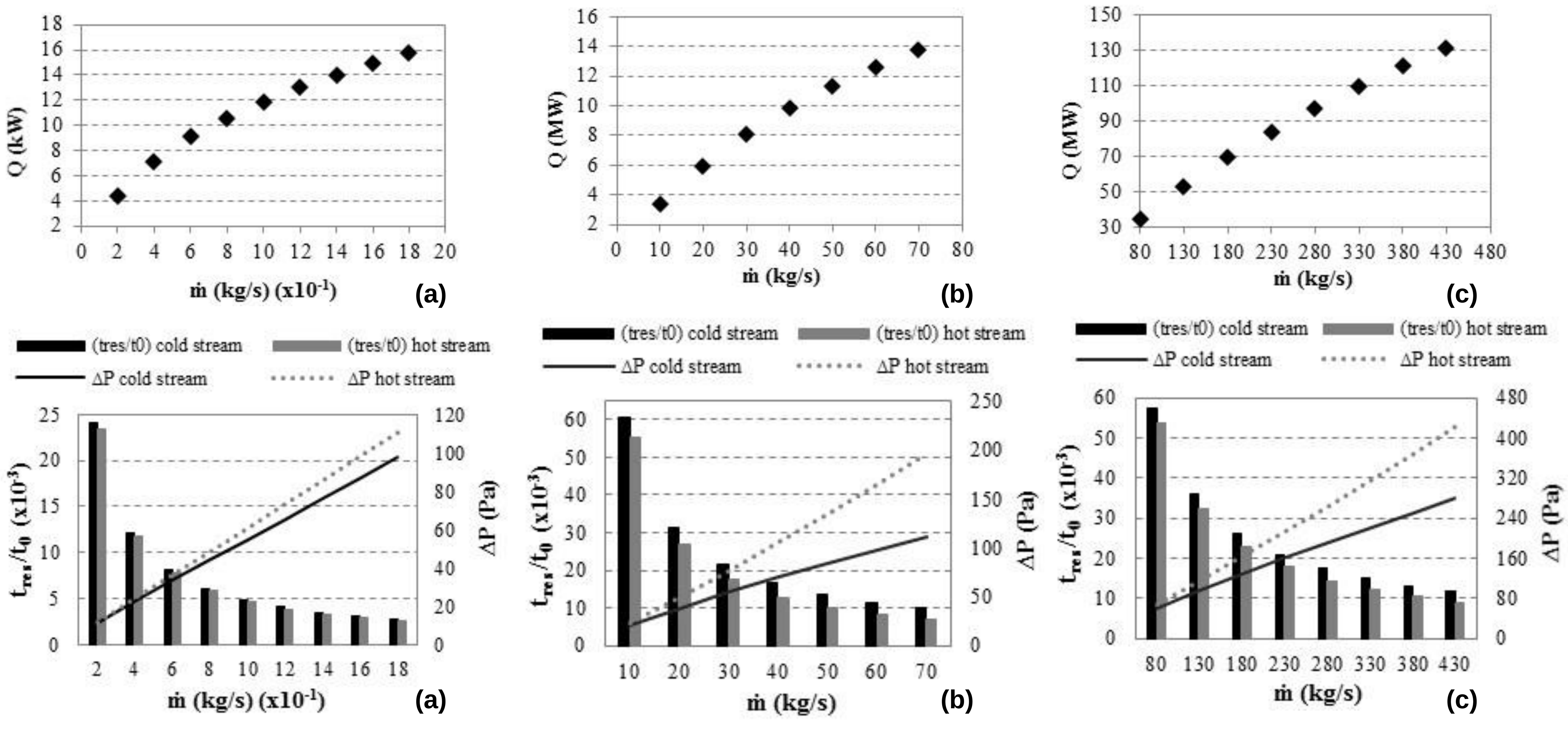

Figure 2. First graph: total heat transfer versus mass flow rate; Second graph: (t_{res}/t_0) and ΔP as a function of the mass flow rate. (a) small; (b) medium-sized; (c) large.

IV. Conclusion - A mass flow rate range was chosen for each simulated equipment. The mass flow rate ranges $1.1 \leq \dot{m} \leq 1.8$ kg/s, $45 \leq \dot{m} \leq 70$ kg/s and $330 \leq \dot{m} \leq 430$ kg/s were chosen for the small, medium-sized and large rotary regenerator, respectively. These ranges associate acceptable fluid carryover leakage, suitable pressure drop and good heat transfer. The limit values of the mass flow rate ranges chosen for the medium-sized and large regenerators were defined by the condition of maximum acceptable contamination (minimum limit) and by the suitable pressure drop (maximum limit). For the small regenerator, the minimum limit was defined by the heat transfer rate up to 20% lower when compared to the maximum value observed in this case. Similarly to the medium-sized and large regenerators, the satisfactory pressure drop also defined the maximum limit in the small equipment. The results can help to establish good operating conditions for rotary regenerators.

V. References

[1]Kays, W. M. & London, A. L. (1964). *Compact Heat Exchangers,* New York, USA: McGraw-Hill, 3rd.
[2]White, F. M. (1974). *Viscous Fluid Flow,* New York, USA: McGraw-Hill.
[3]Wark, K. (1983). *Thermodynamics,* New York, USA: McGraw-Hill, 4th. Based in NASA SP-273. U. S. Government Printing Office: Washington, 1971.
[4]Mioralli, P. C. (2005). *Thermal analysis of a rotary regenerator*. Master diss., Faculty of Mechanical Engineering, State University of Campinas, Brazil, 2005. (in Portuguese).