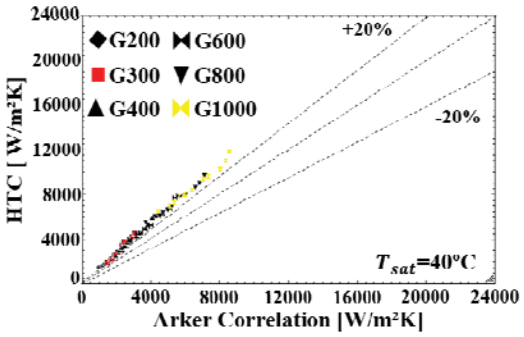
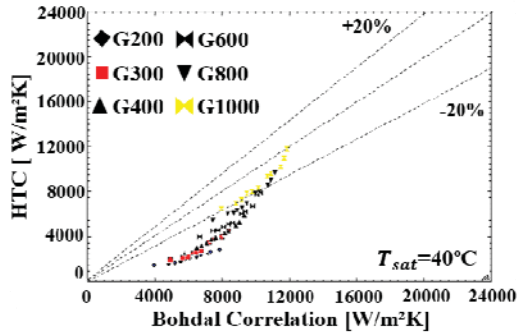
There are presented in Fig. 3 graphs showing the deviations from the correlations of Arkers and Rosson (1960), Bohdal et al., (2011), Cavallini and Zecchin (1974) and also the deviation presented by the use of the neural network compared to the experimental ones.

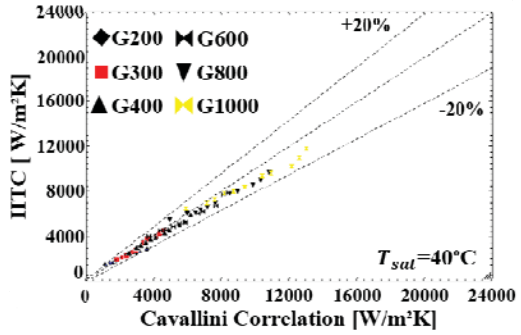
Among the correlations analyzed, the one that best fitted the experimental data was the Cavallini and Zecchin (1974) correlation. It has presented values of average relative deviation, absolute deviation, and accuracy equal to 5.42%, 7.81%, and 96.96% respectively. The MRD, MARD, and Accuracy values of the other correlations are shown in Tab. 4.



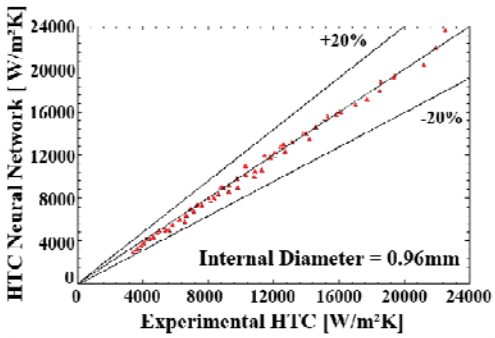
(a)



(b)



(c)



(d)

Figure 3. Graphical comparison between three correlations and the Neural Network based on the experimental data.

Table 4. MRD, MARD, and Accuracy of the correlations.

CORRELATIONS	MRD (%)	MARD (%)	ACCURACY (%)
REDE NEURAL	2,53	3,66	100
CAVALLINI	5,42	7,81	96,96
WANG	-0,15	0,17	56,06
KOYAMA	-0,24	0,26	33,33
BOHDAL	0,86	0,86	9,09
CHATO	0,36	0,36	9,09
HUANG	1,19	1,20	4,54
ARKER	-0,26	0,37	3,03
HARAGUSHI	1,28	1,28	1,51
PARK	-0,64	0,64	0
SHAH	-0,64	0,64	0

CONCLUSIONS

There are few experimental studies regarding the measurement of the heat transfer coefficient in condensation of the eco fluid R1234yf in smooth horizontal ducts. Among the published ones it can be mentioned the experimental data provided by Wang et al. (2012) and Yang and Nalbandian (2018). Both studied the heat transfer coefficient of R1234yf for different values of mass flux, saturation temperatures, and quality.

However, these authors studied the coefficient for ducts with an internal diameter of 4 mm, while Del Col et al. (2010) studied for the internal diameter of 0.96 mm. Both Wang et al. (2012) and Yang and Nalbandian (2018) presented a comparison between their experimental data with some models of prediction of the heat transfer coefficient. Del Col et al. (2010), on the other hand, did not present this comparison in his work.

Considering this context, this work analyzed the data provided by Del Col et al. (2010) comparatively with ten correlations of condensation heat transfer present in the literature and also with a Multilayer Perceptron neural network.

The use of the neural network serves as a reference considering that, being a computational technique and having reliable experimental data, the prediction model generated by it fits very well. However, the neural network needs to be used only in conditions similar to those which generated it, once it has great deviations when used outside this range.

Figure 3 has presented the deviations graphs of ± 20% between the experimental data and the correlations. It is observed that the accuracy presented by the neural network, as expected, is superior to all the other three indicated.

In sequence, the values of MRD, MARD, and Accuracy were presented in Tab. 4 for all ten correlations mentioned in Tab. 1. The correlation of Cavallini and Zecchin (1974) was the one that best suited, with MRD, MARD, and Accuracy values equal to 5.42 %, 7.81%, and 96.96% respectively. Moreover, it was just slightly inferior to the model proposed by the neural network technique, which presented the values of MRD, MARD, and Accuracy in 2.53%, 3.66%, and 100%.

REFERENCES

Akers, W. W., 1960, Condensation inside a horizontal tube, Chem. Eng., Vol. 56, pp. 145-149.

Bohdal, T., Charun, H., and Sikora, M, 2011, Comparative investigations of the condensation of R134a and R404A refrigerants in pipe minichannels, International Journal of Heat and Mass Transfer, Vol. 54, pp. 1963-1974.

Calm, J., 2008, The next generation of refrigerants – Historical review, considerations, and outlook, International Journal of Refrigeration, Vol. 31, No. 7, pp.1123-1133.

Cavallini, A., and Zecchin, R., 1974, A dimensionless correlation for heat transfer in forced convection condensation, in: *Fifth Int. Heat Transfer Conference*, Tokyo, Japan, pp. 309-313.

Del Col, D., Torresin, D., and Cavallini, A., 2010, Heat transfer and pressure drop during condensation of the low GWP refrigerant R1234yf, International Journal of Refrigeration, Vol. 33, No. 7, pp.1307-1318.

Dobson, M. K., and Chato, J. C., 1998, Condensation in smooth horizontal tubes, ASME Journal of Heat Transfer, Vol. 120, No 1, pp. 193-213.

E. UNION, 2006, Directive 2006/40/ec of the european parliament and of the council of 17 may 2006 relating to emissions from, Bruxelas.

Haraguchi, H., Koyama S., and Fujii, T., 1994, Condensation of Refrigerants HCFC22, HFC134a and HCFC123 in a Horizontal Smooth Tube : 2nd Report, Proposals of Empirical Expressions for Local Heat Transfer Coefficient, Transactions of the Japan Society of Mechanical Engineers Series B, Vol. 60, No. 574, pp. 2117-2124.

Huang, X., Ding, G., Hu, H., Zhu, Y., Peng, H., Gao, Y., and Deng, B., 2010, Influence of oil on flow condensation heat transfer of R410A inside 4.18 mm and 1.6 mm inner diameter horizontal smooth tubes, International Journal of Refrigeration, Vol. 33, No. 1, pp. 158-169.

Koyama, S., Kuwahara, K., Nakashita, K., and Yamamoto, K., 2003, An experimental study on condensation of refrigerant R134a in a multi-port extruded tube, International Journal of Refrigeration, Vol. 26, No. 4, pp. 425-432.

McLinden, M. O., Kazakov, A. F., Brown, S., and Domanski P. A., 2014, A thermodynamic analysis of refrigerants: Possibilities and tradeoffs for Low-GWP refrigerants, International Journal of Refrigeration, Vol. 38, pp. 80-92.

More, J. J., 1978, The Levenberg-Marquardt algorithm: Implementation and theory, Lecture Notes in Mathematics, Vol. 630.

Park, J. E., Vakili-Farahani, F., Consolini, L., and Thome, J. R., 2011, Experimental study on condensation heat transfer in vertical minichannels for new refrigerant R1234ze(E) versus R134a and R236fa, Experimental Thermal and Fluid Science, Vol. 35, No. 3, pp. 442-454.

Shah, M. M., 2016, A correlation for heat transfer during condensation in horizontal mini/micro channels, International Journal of Refrigeration, Vol. 64, pp. 187-202.

Tanaka, K., Higashi, Y., and Akasaka, R., 2010, Measurements of the Isobaric Specific Heat Capacity and Density for HFO-1234yf in the Liquid State, Journal of Chemical & Engineering Data, Vol. 55, No. 2, pp. 901-903.

UN Environment, 1987, Montreal Protocol on substances that Deplete the ozone Layer, in: *https://www.unenvironment.org/ozonaction/ who-we-are/about-montreal-protocol,* Montreal.

Wang, L., Dang, C., and Hihara, E., 2012, Experimental study on condensation heat transfer and pressure drop of low GWP refrigerant HFO1234yf in a horizontal tube, International Journal of Refrigeration, Vol. 35, No. 5, pp. 1418-1429.

Wang, W. W. W., Radcliff, T. D., and Christensen, R. N., 2002, A condensation heat transfer correlation for millimeter-scale tubing with flow regime transition, Experimental Thermal and Fluid Science, Vol. 26, No. 5, pp. 473-485.

Yang, C. Y., and Nalbandian, H., 2018, Condensation heat transfer and pressure drop of refrigerants HFO-1234yf and HFC-134a in small circular tube, International Journal of Heat and Mass Transfer, Vol. 127, pp. 218-227.