

Comparative Analysis of Thermohydraulic Performance of Enhanced Viscous Oil and Oil Product Heaters

E M Khusnutdinova, I A Konakhina and A F Khamidullina

Kazan Federal University, 18 Kremlyovskaya street, Kazan, 420008, Russian Federation

rr-088@mail.ru

Abstract. This paper covers the analysis of positive and negative effects produced when enhanced helical hollow beams are installed into oil and oil product heaters if compared to the baseline designs. Special attention is given to the consideration of effect on the complex rheology of high-paraffin oils.

Performance indicators that show actual expenditures spent for fabrication and operation of new heat exchanging equipment are generic indicators of how such equipment, specifically oil heaters, are efficient in use. However, difficulties are usually faced in practice when it is required to estimate benefits, either positive or negative, of several competitive enhanced designs. For getting inputs, substantial material and power consumption, its in-place tests, comprehensive performance tests are required to produce a heat exchanger. Therefore, the decision-making stage demands for methods to adequately represent actual figures of thermo-hydrodynamic processes in heat exchangers and select most suitable options.

The heat-exchange efficiency evaluation methods used depend on a thermal resistance ratio of the fluids and can be uni- and bidirectional subject to relations of these measures. Unidirectional means when the rate of heat exchange in the surface heat exchangers is much less on one side of the medium than another one. The side with lower heat transfer coefficient should be taken into consideration. Such cases may include almost all heat exchangers-preheaters of viscous fluid being limiting factor, it means oil or oil products.

For evaluation of how the geometry of an enhancer influences the performance and efficiency of a heat exchanger, a method proposed by M.V. Kirpichyov can be applied [1]. It is based on the determination of the energy coefficient E_0 that shows relation between two types of energy – specific heat production $Q = \alpha \Delta t$, W/(m²), and specific energy consumptions to overcome hydraulic friction N_0 that are produced for an unit of heat-exchange surface in upgraded thermal elements when the basic design is compared with those of the below ratio, W/m²:

$$N_0 = \frac{G \Delta p}{(\rho F)} \quad (1)$$

where G is the fluid mass flow, kg/s; ρ is the fluid density, kg/m³; Δp is the hydraulic losses produced by the friction between the fluid flow and the surface, Pa/m; F is the heat exchange area for 1 m of thermal



element length, m².

Thus, a dimensionless energy coefficient can be calculated by the formula:

$$E_0 = \frac{\alpha \Delta t}{N_0} \quad (2)$$

where α is the coefficient of heat transfer from the surface towards the fluid flow, W/(m² K); Δt is variation of the inlet and outlet flow temperature averaged by the cross-section, K.

This method allows evaluation of how the enhanced surfaces of heat-exchangers-oil and oil product heaters are effective both at the design stage and during the commercial tests.

However, the Guckman criteria calculation should be performed to estimate effect of particular type of operating expenses for the entire performance of the heat exchanger. These criteria are used to measure the following:

- 1) Saving of heat energy (hot water or vapour) consumed for heating purpose;
- 2) Reduction in power consumption for carrying fluids through the heat elements;
- 3) Lowering specific amount of metal per unit of equipment due to decrease of heat exchange surface required.

Conditioning the competitive conditions of the options being discussed is an important factor to achieve an objective correlation. [1, 2, 3]. For this, three characterizations of heat exchange surface are used: heat flow Q , kW; wattage required to flush the coolant N , kW; heat exchange area F , m². Three dimensionless criteria of efficiency are applied to achieve comparative conditions of thermo-hydraulic processes going on the enhanced heat exchange surfaces of different configuration. These are:

- 1) Owing to heat flow K_q ;
- 2) Owing to energy used for flushing the coolant K_n ;
- 3) Owing to heat exchange area K_f .

Generally, the above criteria are described by the following ratios:

$$K_q = \frac{\alpha_e F_e \Delta t_e}{\alpha_0 F_0 \Delta t_0}; \quad (3)$$

$$K_n = \frac{G_e \Delta p_e \rho_0}{G_0 \Delta p_0 \rho_e}; \quad (4)$$

$$K_f = \frac{F_e}{F_0}, \quad (5)$$

where indices “0” and “e” stand for the type of heat exchange surface of the respective parameter, — baseline or enhanced; α is the heat transfer coefficient, kW/(m² K); Δt is the difference between the inlet and outlet flow temperatures averaged by the cross-section of a 1-m long heat element run, K; — related hydraulic losses, Pa; F is the heat exchange area, m², for 1 m of the element length; G is the mass flow of the coolant, kg/s; ρ is the fluid density, kg/m³.

Since the benefits of the enhancer may be obvious not within the entire range of the oil or oil product heater performance, the entire range is subject to calculation and the output will be visualized in charts and reduced to the analytical or criterial ratios: .

$$K_q = f(Re); \quad (6)$$

$$K_n = f(Re); \quad (7)$$

$$K_f = f(Re). \quad (8)$$

If screw-type enhancers are in use, the rate of heat transfer and hydraulic losses in the enhanced laminar flow passage matches the rate of heat exchange and hydraulic losses occurred in the turbulent flow of bare tube passage. Therefore, the analysis should consider all typical points of flow regime variations and select appropriate analytical or criterial equation. If the analysis is based on the charts, such kind of issues is usually not true, but the charts cannot be used for computations. Anyway, they are subject to conversion to either criterial or analytical equations.

Medium paraffin oil produced for the Yuzhno-Khylchuyuckoye oil field with 4.61% mass per cent of paraffin wax is considered as a simulation fluid to attack the above targets. The fluid rheology is described in [4].

The intensifying vortex generators consist of a twisted tape insert and helical round-shaped wall ledges. The vortex generators have the following data: $S/D = 2-10$; $d/D = 0.6-0.95$ (D = pipe ID, d = reduced diameter of pipe flow area with vortex generator, S = twisting step) [4]. The baseline model that is used for correlation of intensifying regimes is bare tube type.

The main benefit that contributes to heat and hydraulic characterization of enhancement flow passages is the reduction on hydraulic friction (internal flow) and wattage consumed to carry the fluid due to its pseudoplastic rheology. This benefit is measured at a level of 10-15% thanks to localized shear effect.

References

- [1] Nazmeyer Yu G and Konakhina I A 2001 *Organization of power technology complexes in petrochemical industry* (M.: MEI publishers) p 364
- [2] Konakhina I A, Khusnutdinova E M , Khamidullina G R and Khamidullina A F 2016 *IOP Conference series: Materials Science and Engineering* Vol 134 Is 1 **012019**
- [3] Nazmeyer Yu G and Konakhina I A 1993 *Enhancement of heat transfer in the flow of viscous fluid in helical pipes* (M.: Teploenergetika) pp 59-62
- [4] Nazmeyer Yu G 1996 *Hydrodynamics and heat exchange between vortex flows of rheologically complex fluids* (M.: Energoatomizdat) p 304